Canadian Space Agency Agence spatiale canadienne

Evaluation of the Near Earth Object Surveillance Satellite (NEOSSat) Project

For the period from February 2005 to December 2013

Project # 13/14 02-02

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Abbreviations Used in the Report

CCD	Charge-coupled device
CSA	Canadian Space Agency
DND	Department of National Defence
DRDC	Defence Research and Development Canada
ESA	European Space Agency
GEO	Geosynchronous Earth Orbits
HEOSS	High Earth Orbit Space Surveillance
HQPs	Highly Qualified Persons
IP	Intellectual Property
JPO	Joint Project Office
MEO	Medium Earth Orbits
MPS	Mission Planning System
MOC	Missions Operations Centre
MOU	Memorandum of Understanding
NASA	National Aeronautics and Space Administration
NESS	Near Earth Space Surveillance
NORAD	North American Aerospace Defence Command
PAA	Program Alignment Architecture
PHA	Potentially Hazardous Asteroids
PWGSC	Public Works and Government Services Canada
ROE	Read Out Electronics
RFP	Request for Proposals
SAIC	Science Applications International Corporation
WISE	Wide-field Infrared Survey Explorer

Executive Summary

Background

The Near Earth Object Surveillance Satellite (NEOSSat) project began in February 2005 with the signing of a Memorandum of Understanding (MOU) between the Canadian Space Agency (CSA) and the Department of National Defence (DND), establishing NEOSSat as a collaboration combining two projects: DND's space surveillance mission HEOSS (High Earth Orbit Space Surveillance) and the CSA's asteroid finding project NESS (Near Earth Space Surveillance). The two missions share the same passive optical sensor payload integrated into a multi-mission microsatellite bus. Each mission, however, is directed and managed by a different science team.

Following a competitive process, the NEOSSat development contract, encompassing Phases B, C and D, was awarded to Dynacon in July 2007. In 2008 Dynacon sold its satellite business to Microsat Systems Canada Inc. (MSCI), and MSCI continued the project as a subcontractor to Dynacon. After lengthy delays, NEOSSat was launched in February 2013 by Antrix Corporation, an India-based launch provider.

The scope of the NEOSSat mission includes:

- Development of an affordable multi-mission bus for future CSA and/or DND missions, i.e., the design of the satellite platform allows the same bus to be used for several future microsatellite missions;
- Discovery of new asteroids and comets and monitoring their trajectories; and
- Development of technology and expertise for monitoring satellites and space debris in medium Earth orbits (MEO) and geosynchronous Earth orbits (GEO).

The focus of this evaluation was on the CSA components of NEOSSat, i.e., the development of a multi-mission bus and the discovery and monitoring of new asteroids and comets and monitoring their trajectories. The evaluation covers the entire history of NEOSSat, from the CSA's signing of its two contracts in 2005 to the end of December 2013.

Relevance/Need

A sound rationale for NEOSSat-type satellite missions exists. Support for Government of Canada investment in the development of new satellites is articulated in the Aerospace Review (November 2012) and in the Space Policy Framework (February 2014). NEOSSat was planned and designed to be the world's first space-based asteroid detection system, and the first stand-alone space-based surveillance of space system. The assessment, prediction, and mitigation of events caused by asteroids that could potentially cross the Earth's orbit will benefit not only Canada but other nations.

The NEOSSat mission reflects societal needs for the identification of potentially hazardous asteroids, contributing to the knowledge base with respect to asteroids and contributing to the knowledge base on potentially hazardous space objects and debris. Because of the nature of the NEOSSat mission, i.e., the acquisition and distribution of data on potentially hazardous asteroids and comets and the identification and tracking of space debris, this type of satellite project would not be undertaken by the private sector and therefore government investment was necessary.

The NEOSSat project is well aligned with federal priorities in terms of promoting excellence and encouraging partnerships. The NEOSSat project science team, led by Dr. Hildebrand of the University of Calgary, has a dozen internationally distributed planetary scientists active in asteroid research. NEOSSat gives Canadian scientists leverage in collaborating with the world's leading space agencies, including the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and the Japanese Space Agency.

Performance

Implementation Compared to Plan

The NEOSSat project was implemented in accordance with the activities in the original plan. However, the mission encountered significant delays totalling 41 months, primarily as a result of a lack of capacity on the part of the prime contractor. This lack of capacity meant that the CSA and DND were faced with a choice of cancelling the project or taking a calculated risk and continuing to work with the contractor. Continuing the work required the CSA and DND to play a bigger role in the project by providing technical assistance and mentoring to the contractor. Without the technical capacity within the CSA and DND, it is unlikely that the NEOSSat project would have been completed successfully.

Recommendation 1: There is a need for the CSA to establish a process to address risk factors in cases where deficiencies are observed regarding the financial, technical and/or project management of contractor performance during contract execution.

Recommendation 2: In order to mitigate potential risks related to contractor capacity, there is a need for the CSA to continue to maintain technical capacity, either internally or available on an as needed basis, to effectively manage projects and to step in and undertake the more technical aspects of a project if a contractor is unable to do so. If the prime contractor does lose capacity then the CSA should ensure it has a way to deal with that risk.

While the mission experienced significant delays, this is not unusual for satellite missions, as such projects involve the integration of many complex, often untested, technologies.

Production of Outputs

NEOSSat successfully employed a standard multi-mission microsatellite bus architecture based on several subsystem design envelopes used in previous microsatellite missions. Expansion capabilities have been incorporated into the design so that the hardware can be used in future missions. The microsatellite design provides a stable platform that can accommodate many payload/instrument types.

The main issue with NEOSSat is that although images have been acquired, the image quality does not at present meet the imagery requirements of the scientific aspects of the mission. NEOSSat is only taking engineering images and not scientific images. In December 2013, the science teams developed a post-processing technique that removes the pattern on short duration exposure images, and imagery can be used for some mission objectives. A stable focus is needed in the imager in order to yield images of a scientific quality, due to the very low levels of light that are reflected off asteroids. Whether the intended production of 288 images per day can ever be achieved is a matter of concern. Because of the issues with the imager, commissioning of the satellite will be delayed, as will the CSA's acceptance of the delivered spacecraft.

The ground segment is working, and final integration system testing is being undertaken.

Achievement of Immediate Outcomes

There is evidence that the NEOSSat project has helped build capacity within industry, government and academia. The project also served as a training ground for young scientists; smaller, less risky satellite projects like NEOSSat are ideal for this objective. Within the CSA, expertise has been maintained and, in fact, CSA staff played a mentoring role with respect to MSCI. NEOSSat is part of the long-term development of capacity in both industry and the CSA in the field of small satellite bus technologies. Canada now boasts several companies, including MSCI, COM DEV, Magellan, and Utias, which all have demonstrated capabilities in the manufacture of microsatellites and nanosatellites.

A few interviewees noted that the space technology industry is generally protectionist, with most countries with a space industry tending to purchase from within the country. The space industry is seen as strategic by many countries and thus there are barriers to free trade in the international market.

The NEOSSat science team, led by the University of Calgary, includes internationally recognized planetary scientists in asteroid research, who will use NEOSSat data to continue their research on small bodies within the near-Earth portion of the solar system. It is expected that NEOSSat will assist Canadian universities and the CSA to gain leverage in collaborative efforts with other space agencies internationally.

Lessons learned as a result of the NEOSSat mission have already been applied within the CSA, for example, in the Sapphire satellite mission led by Defence Research and Development Canada (DRDC). They are providing CSA engineers and project managers with value-added improvements in the way microsatellite projects are managed, which will benefit future CSA missions.

It was clearly recognized that it is premature to assess whether NEOSSat will contribute to an increased portion of Aten-class asteroids being detected and catalogued, as science images are not yet available.

Achievement of Intermediate Outcomes

The majority of key informants expressed the view that NEOSSat has and will help the Canadian space industry develop export potential. Multi-mission generic bus technology will continue to be in demand in the international space industry. In particular, global interest in nano- and microsatellites is increasing rapidly.

In terms of spinoffs from the NEOSSat mission, in January 2013, MSCI announced its intention to build an 84 satellite system in low-Earth orbit, consisting of 78 satellites in six polar orbital planes with a spare in each orbit. The bus for the constellation is based on a standardized architecture used in both NEOSSat and MOST, which should help MSCI in ramping up production. In addition, several of the other contractors involved in NEOSSat have gone on to work on other microsatellite projects.

NEOSSat did help establish several partnerships within industry, the government and in space science. For example, NEOSSat was the first joint microsatellite project between the CSA and DRDC. In particular, joint project management experience was gained through the establishment of a joint project management office.

Recommendation 3: The CSA, in collaboration with other federal partners and industry, should define a strategic direction to establish "niche" capacities and capabilities within the Canadian space industry that can exploit trends and opportunities in the international space marketplace. This would align with the Space Policy Framework and the Aerospace Review, providing firms in the Canadian space sector with direction on anticipated work and facilitating planning and capacity development, allowing the industry and academia to better respond to the needs of the CSA and other federal departments.

It is premature to assess NEOSSat's contribution to an increased science knowledge base concerning asteroids and comets.

The management structures for NEOSSat were well developed and understood by both the CSA and DRDC. Although there is a sense among interviewees that the management structure for the project was onerous, the hands-on management structure was necessary given the lack of capacity and experience on the part of the prime contractor.

Unintended outcomes

The successful partnership formed by the CSA and DRDC is an excellent example of a federal government goal of encouraging inter-departmental partnerships. While the differing cultures of each organization did present some challenges, overall there is a sense that the partnership was more positive and beneficial than had been anticipated.

There is some concern on the part of the science team at the University of Calgary that its partnerships with other researchers internationally may be negatively affected should the quality of NEOSSat data imagery not improve.

Efficiency and Economy

There is evidence that NEOSSat's outputs could not have been produced at a lower cost. As a fixed-price contract, the project was perceived to have been underfunded by as much as 50% from the outset. The contract costs have not increased (i.e., no additional funding was provided to MSCI), and the CSA has not overspent on its risk allocation budget. Much of the overspending vis-à-vis internal costs stems from the lack of capacity and experience on the part of MSCI and the need for DND and the CSA to provide the missing technical capacity.

The onerous reporting requirements resulted in added time and therefore cost on the part of MSCI and the CSA. The CSA has since implemented a more risk-based approach for other projects. But, again, the onerous reporting and oversight may have been necessary given the lack of capacity and expertise on the part of the prime contractor.

1 Introduction

In the early 2000s the Canadian Space Agency (CSA) and the Department of National Defence (DND) had been independently exploring the utility of microsatellites.[1] The effectiveness of microsatellites had been demonstrated by the success of the Microvariability and Oscillation of STars (MOST) astronomy microsatellite launched in 2003. At the time, the CSA was undertaking an initiative to develop a Canadian multi-mission microsatellite bus under the Small Sat/Micro Sat Working Group, which included DND participation in the process. In parallel, the CSA had funded a study which determined that a space-based sensor would be useful to discover and track near-Earth objects (NEOs). Meanwhile DND was collaborating with US government agencies in sponsoring the design for a functional satellite tracking microsatellite based on MOST, which led to the High Earth Orbit Space Surveillance (HEOSS) project.

The NEOSSat project began in February 2005 with the signing of a Memorandum of Understanding (MOU) between the CSA and DND, establishing NEOSSat as a collaboration combining two projects: DND's space surveillance mission HEOSS and the CSA's asteroid finding project NESS (Near Earth Space Surveillance).

Upon completing separate Phase A contracts for the development of the spacecraft bus (contracted to Dynacon) and payload concepts (contracted to the University of British Columbia) in 2005, the CSA and DND decided that the NEOSSat project should combine the two projects. Following a competitive process, Dynacon was awarded the overall Phase B/C/D of NEOSSat development contract in July 2007. In 2008, Dynacon sold its satellite business to Microsat Systems Canada Inc. (MSCI), and MSCI continued the project as a subcontractor to Dynacon. After lengthy delays, NEOSSat was launched in February 2013 by Antrix Corporation, an India-based launch provider.

The scope of the NEOSSat mission includes:

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- Discovery of new asteroids and comets and monitoring their trajectories; and
- Development of technology and expertise for monitoring satellites and space debris in medium Earth orbits (MEO) and geosynchronous Earth orbits (GEO).

The evaluation of the NEOSSat project for the Canadian Space Agency (CSA) was conducted on behalf of the CSA Audit and Evaluation Directorate by Kelly Sears Consulting Group in collaboration with Beechwood Consulting and Research Inc., BBMD Consulting Inc., and Hickling Arthurs Low Corp. The evaluation is a requirement of the CSA five-year evaluation plan and was conducted in accordance with the Treasury Board of Canada Secretariat's *Policy on Evaluation* (2009). According to the CSA Evaluation

[1] A microsatellite is defined as having a size of less than one metre on a side and a mass of less than 100 kg.

Plan, the evaluation is to be completed by March 31, 2014. The evaluation was conducted by Kelly Sears between July 2013 and February 2014.

The evaluation covers the entire history of NEOSSat, from the CSA's signing of its two contracts in 2005 to the end of December 2013.

This report presents the findings and recommendations resulting from the evaluation. A description of the project, including its context, resources allocated, governance and logic model, is described in Chapter 2. We outline the evaluation approach and methodology in Chapter 3; findings for the relevance and performance issues are presented in Chapter 4; and overall conclusions and recommendations are provided in Chapter 5.

2 Background

This chapter provides a brief profile of the NEOSSat project as well as the logic model focused on the CSA aspects of the project. Components of the project which pertain exclusively to DND have not been included in the profile and logic model because the evaluation focused solely on the CSA's investment in NEOSSat.

2.1 Program Profile

The Near Earth Object Surveillance Satellite (NEOSSat), launched on February 25, 2013, is the world's first space telescope dedicated to detecting and tracking asteroids, satellites and space debris. The satellite is a joint project of the CSA and DND. The joint project incorporates two complementary missions:

- DND's space surveillance mission (High Earth Orbit Space Surveillance – HEOSS).
- The CSA's asteroid finding mission (Near Earth Space Surveillance – NESS).

The two missions share the same passive optical sensor payload integrated into a multi-mission microsatellite bus. Each mission is directed and managed by a different science team.

The CSA's focus for NEOSSat (i.e., the NESS mission) is in scanning the inner solar system to pinpoint Aten and Atira class asteroids that may some day pass close to and/or impact Earth, while DND's focus (i.e., the HEOSS mission) is on searching for satellites and space debris as part of Canada's commitment to keeping orbital space safe for all space activities.

NEOSSat's specific scientific goals related to the NESS mission are:

- To discover new near-Earth asteroids by searching the sky along the ecliptic plane as close to the Sun as its microsatellite custom baffle design allows (to within 45° of the Sun). This search will focus on two groups of asteroids; one called Aten-class (asteroids with orbits mostly within the Earth's orbit) and, in particular, Atira-class (asteroids whose entire orbit is within Earth's orbit).
- To conduct follow-up tracking of any near-Earth asteroids discovered by NEOSSat and other search programs.
- To assess potentially hazardous asteroids (PHAs) by better defining their orbital parameters.
- To monitor comets when they come close to the Sun, and to check suspected comets for out-gassing activity.
- To provide ground-based asteroid radar-imaging programs with accurate targeting locations.

NEOSSat also has a technological goal to reduce overall mission costs with a multi-mission microsatellite bus that maximizes the commonality between bus components.

2.2 Governance, Roles and Responsibilities

NEOSSat involved the establishment of a Joint Project Office (JPO) to facilitate teamwork, and share work progress reviews and decision making. A Supporting Arrangement agreement was signed in February 2005 with the purpose of developing and operating NEOSSat as a collaborative project between the CSA and DND. The Supporting Arrangement provides that the CSA and DND contribute funds to the project for activities carried out under Phases B, C and D. Procurement and related management and administration were managed by PWGSC on behalf of the CSA.

The satellite and data resulting from this mission are co-owned by the CSA and DRDC. Ownership vests in accordance to the proportional amounts paid by each partner.

The NEOSSat project is managed through the JPO with a project manager provided by each partner. The CSA project manager is the overall Project Manager and the DRDC project manager is the Deputy Project Manager.

Communication within the team is conducted as follows.

- Regular CSA-DRDC project team meetings and weekly teleconferences.
- Regular updates provided to the Space Program Project Status Board. The CSA also has participated in DRDC Senior Review Board quarterly reviews in Ottawa during Phases B, C and D.
- Weekly project progress reports submitted by the Project Manager to the Project Leader or delegate until 2012. Monthly dashboards submitted after 2012 to the President of the CSA and Executive Committee.
- Weekly Director progress reviews since 2011.
- Early in the project, monthly project status meetings were held with the Project Leader in preparation for the monthly VP Science, Technology and Programs review meetings. After the CSA reorganization in 2007, these VP meetings were eliminated and the monthly DG Space Programs (March 31, 2010) and DG Space Utilization project reviews became the forum for regular progress reviews for both the CSA and DRDC.

The microsatellite Telemetry Tracking and Control (TT&C) service and operations during the NEOSSat project are provided by the CSA and conducted out of the CSA headquarters in St-Hubert.

Once NEOSSat becomes fully operational, data requests will be received and processed at the Mission Planning System (MPS), and satellite acquired data will be distributed to the NESS and HEOSS Principal Investigators. Access to NESS and HEOSS data will be under the sole authority of the CSA and DRDC, respectively. The analysis and dissemination of the scientific results of the project will be the responsibility of the two Principal Investigators and their science teams.

2.3 Resource Allocation

The estimated cost of the NEOSSat project is approximately $25M over all of its phases. The satellite was launched in February 2013 and is still in Phase D, i.e., it is not fully operational as of January 2014. Once it becomes fully operational, an operating budget of $1.4M per year over two years has been allocated.

Based on experience with other satellites such as MOST, CSA mission managers expect NEOSSat to continue to be operational well beyond two years. However, neither the CSA nor DRDC has provided for ongoing funding of the operations of the NEOSSat after the two-year operational window initially estimated. Ongoing operation of NEOSSat will require users of the data to provide the necessary funds to continue operating the satellite. A summary of estimated costs by phase is presented in Table 2.1.

Table 2.1: Estimated Cost, Phases A though E

Phase	Total Cost ($)	CSA ($)	DRDC ($)
A (Requirements definition and concept design)	1,580,025	475,569	1,104,456
B and C (Project Design)	7,011,351	2,849,180	4,162,171
D (Implementation)	13,539,501	7,043,870	6,495,631
Sub-total: B, C and D	20,550,852	9,893,050	10,657,802
E – Operations	2,800,000	2,601,958	199,800
Total	**24,952,635**	**12,970,577**	**11,982,058**

As of January 2014, the CSA had spent $13,986,530 on NEOSSat, representing an over expenditure relative to the project budget. The project is on-budget with respect to its risk allocation budget of $1.63 million (having spent $1.58 million as of January 2014). NEOSSat is also on budget with respect to the contract work having spent $9.42 million out of a $9.89 million budget. The area where the CSA has overspent is on internal expenses. To date the CSA has spent $2.99 million on internal costs related to NEOSSat. Table 2.2 summarizes the financial and human resources (FTEs) for the NEOSSat mission for the CSA.

Table 2.2: CSA Human and Financial Resources for NEOSSat – 2007-08 to 2013-14[1]

	2007-08	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14
Forecast budget ($)	1,982,000	4,483,000	2,552,000	1,978,000	5,071,000	3,456,000	3,785,108	1,036,302
Actual expenditures ($)	130,548	2,126,727	785,724	2,143,800	686,112	696,498	2,663,200	185,483
Forecast CSA internal costs (Operations, administration)[2]	257,000	181,000	302,000	1,130,000	404,000	856,000	351,000	157,000
Actual CSA internal costs (Operations, administration)[3]	130,363	327,452	349,091	458,760	523,384	492,648	641,110	68,629
Amount of risk funding allocated ($)	283,000	334,000	355,000	353,000	1,149,000	-	1,099,000	357,000
Amount of risk funding spent ($)				173,000	157,000	108,000	835,000	304,000
Forecast FTEs (#)	2.26	1.56	2.55	9.36	3.28	6.82	2.74	1.2
Actual FTEs (#)[4]	1.12	2.70	2.78	3.18	3.35	3.38	2.98	0.5

Source: CSA Financial data, January 2014.

[1] Totals for Forecast amounts cannot be summed because resources are reallocated annually as needed based on project needs.

[2] Forecast does not represent all costs because the CSA financial system does not track forecast expenditures in a way that information specific to NEOSSat can easily be extracted. The amounts listed include salaries without including travel and other costs. However salaries reflect 90% of internal costs.

[3] Actual internal costs included salaries, travel, and inter-ministerial costs (e.g., accommodation costs). Costs associated with subcontracts are not reflected. Forecast internal costs underestimate internal costs relative to actual costs because more cost components are included in actual costs in the above table.

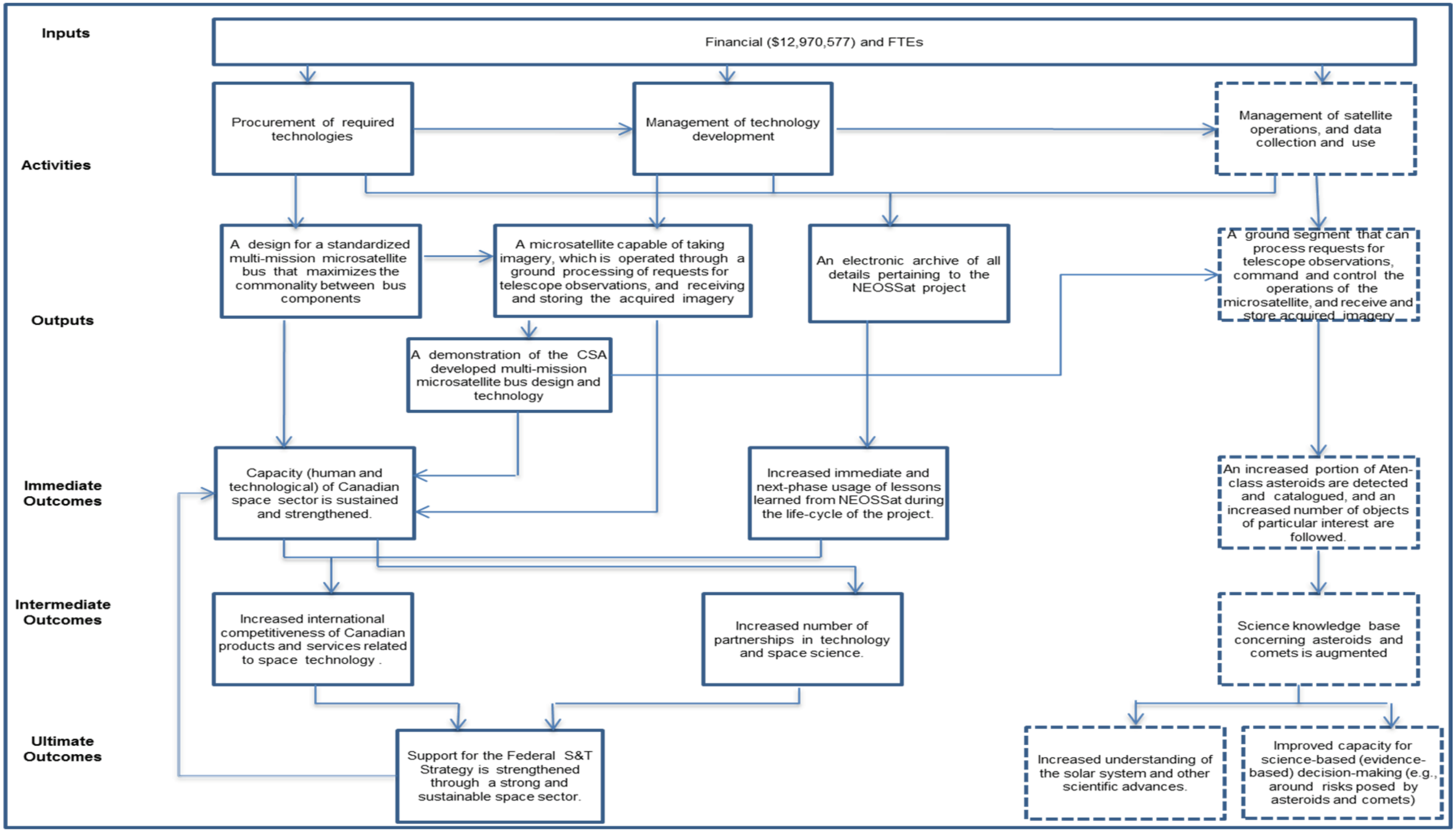
2.4 Prior Evaluation of the Program

No prior evaluations of the NEOSSat project have been undertaken.

2.5 Program Theory

Figure 2.1 depicts the logic model for the NEOSSat project developed by the evaluation team. The elements on the far right flowing from Phase E (Satellite Operations) have not yet been fully implemented and are depicted in dashed boxes. Phase E comprises the scientific objectives of the project, while Phases B, C and D focus on the technological objectives. The logic model elements are described in Appendix A.

Figure 2.1: NEOSSat Logic Model



Note: Dashed boxes are elements flowing from Phase E (Satellite Operations) have not yet been fully implemented.

3 Evaluation Approach and Methods

3.1 Approach and Methods

3.1.1 Approach

In the parlance of evaluation research methodology, the design chosen for the NEOSSat evaluation was a basic "post-test only non-experimental design," whereby the evaluation team observed the status of the NEOSSat project at one point in time, several months after launch of the satellite which took place in February 2013. As discussed later in this section, the timing of the evaluation meant that it was premature to fully assess the project's achievement of its intermediate and longer-term outcomes. In effect, the evaluation was similar to a mid-term evaluation, in that it assessed the performance of the project in producing each of the intended outputs and conducted a preliminary assessment of its success in achieving its outcomes.

The methodological approach and level of effort for this evaluation were determined using a risk-based approach. The NEOSSat project is of a relatively low materiality ($25 million overall with approximately $13 million attributable to the CSA) and the satellite has been launched so the project is nearing completion. Given the project is nearing completion, the recommendations are intended as lessons learned for improving management of similar projects at the CSA in the future. Taking into consideration the level of risk, the evaluation used interviews and a document and file review as data sources. These are described in the sections below.

The evaluation team worked closely with an Evaluation Consultative Group (ECG). Members of the ECG included CSA managers and staff involved in the implementation of NEOSSat as well as representatives from the Audit and Evaluation Directorate within the CSA. The ECG provided input and feedback on key deliverables for the evaluation, including project workplan; Evaluation Plan; interview guides; presentation of preliminary findings; and the final report. The ECG also provided names of individuals to be interviewed.

3.1.2 Data Sources

3.1.2.1 Document Review

A review of existing documentation that relates to the NEOSSat mission was undertaken to help address all evaluation issues of relevance, effectiveness, efficiency, and economy. A number of documents were provided by the Project Authority and other members of the ECG and these documents were reviewed as part of the process of developing the work plan, Logic Model, Project Profile, Evaluation Matrix and Evaluation Plan. Additional documents were identified by the research team through an internet search. All documents were reviewed systematically, using a template based on the evaluation matrix, during the data collection phase of the evaluation.

Although no challenges were encountered during the document review, it must be noted that a number of documents received were marked as confidential and could not be quoted. Although this provided important context to the evaluation team in interpreting the findings, the information contained in the documents could not, in many cases, be used in the report. This challenge was mitigated through the use of other documents and interviews.

A list of documents reviewed is included in Appendix B.

3.1.2.2 Key Informant Interviews

Key informant interviews served as an important source of qualitative information for this evaluation. Interviews were conducted with interviewees representing the CSA, MSCI, DRDC, and the University of Calgary using tailored interview guides. The interviewees were identified by members of the ECG and represented individuals who had been directly involved in the NEOSSat project. Interviews were conducted both by telephone and in-person. Interview guides used for the evaluation are included in Appendix C.

A key limitation in the interview findings is the relatively small number of interviewees. Reasons for this include the nature of the subject being evaluated, i.e., a project as opposed to a program and the recent launch of NEOSSat which meant that there were no users of the data flowing from NEOSSat as yet.[2] The interviewees represent a variety of perspectives and included individuals with no vested interest in the NEOSSat project thus affording an objective perspective on NEOSSat.

With respect to analysis, the relatively small number of interviewees (n=11) and the specific roles and responsibilities of each interviewee means that reporting interview findings using counts of interviewees (i.e., how many said what) is neither relevant nor appropriate due to issues of confidentiality.

3.2 Purpose and Scope

The CSA Audit and Evaluation Directorate required the conduct of an evaluation of the NEOSSat Project as per the CSA's five-year departmental evaluation plan and in accordance with the Treasury Board of Canada Secretariat's Policy on Evaluation (2009).

The evaluation was designed to address the relevance of the NEOSSat project and the performance of the satellite in achieving the project outcomes.

3.3 Evaluation Issues

The evaluation focuses on the five core issues identified in the Treasury Board of Canada Secretariat's Directive on the Evaluation Function (2009), which includes issues of relevance (continuing need, alignment with federal government priorities, alignment with federal roles and responsibilities) and

[2] At present, users are only seeing engineering test data for review purposes and not operational mission data.

performance (achievement of expected outcomes, demonstration of efficiency and economy). The Evaluation Matrix, outlining the evaluation issues and questions, indicators and data sources is presented in Appendix D. The specific questions addressed by the evaluation are listed below.

Relevance

1. Is there a continued need for the CSA to be involved in a microsatellite project such as NEOSSat?
2. Is the NEOSSat project aligned with federal government priorities?
3. Is the NEOSSat project consistent with federal roles and responsibilities?

Performance

4. To what extent have NEOSSat activities been implemented as intended?
5. To what extent has NEOSSat produced its expected outputs?
6. To what extent has NEOSSat achieved its immediate outcomes?
7. To what extent has NEOSSat achieved its intermediate outcomes?
8. Is the NEOSSat project design appropriate for achieving expected results?
9. Have there been any unintended (positive or negative) outcomes?
10. Is the project undertaking activities and producing outputs in the most efficient manner?
11. Is the project achieving its intended outcomes in the most economical manner?

3.4 Limitations

The main limitations and risks faced by the evaluation along with the mitigation strategies are summarized in the following table:

Table 3.1 Limitations to the Evaluation and Mitigation

Limitations/Risks	Mitigation Strategy
Absence of baseline data – Because a performance measurement strategy had never been developed or implemented, no baseline data was available on many of the outcomes.	This is a problem common to many federal government evaluation studies. This issue mainly concerned assessing the impacts of NEOSSat maintaining the core manufacturing capabilities of the Canadian satellite communications industry. The evaluation gathered primarily qualitative evidence from key informants on this issue. Interviews were undertaken with the prime contractor as well as several subcontractors in order to obtain a variety of perspectives.
Difficulties in measuring outcomes – Since the NEOSSat satellite was launched very recently, it has not been in operation long enough for many of the intended outcomes to have been achieved.	The evaluation was able to assess whether most of the intended outputs had been achieved and most of the immediate outcomes. Some evidence was collected on the intermediate and longer-term outcomes. A full summative evaluation is scheduled in the future, at which time a more fulsome assessment of the outcomes will be conducted.
Attribution of outcomes to the NEOSSat project – The NEOSSat project is one of many satellite missions/space	Attribution was not an issue for NEOSSat's immediate outcomes. As noted above, due to the timing of the

Limitations/Risks	Mitigation Strategy
projects being undertaken in Canada. Thus the assessment of attribution of change relative to some of the intended NEOSSat project outcomes was expected to be difficult to attribute solely to the project.	evaluation, it was premature to fully assess the intermediate and longer-term outcomes. Where findings are presented, the report is careful not to attribute change solely to NEOSSat.
The subject matter is highly technical – There was a risk that the evaluation team might not understand some of the evidence collected (e.g., interviews of technical specialists) or develop incorrect findings.	The evaluation team included consultants with science/engineering backgrounds and in-depth experience in evaluating space programs and projects. The evaluation team also worked very closely with CSA personnel to ensure the team gained a clear understanding of NEOSSat's activities, outputs and outcomes.
Corporate memory at DND and DRDC – DND/DRDC staff generally turn over every two years as part of their posting cycle. As a result it was difficult to contact some individuals who had been involved over the entire ten-year time history of NEOSSat.	The evaluation team sought to fill gaps in information from the perspective of DRDC by interviewing multiple individuals from the agency and in some cases tracking down individuals from DND who were no longer involved in NEOSSat. We note that the evaluation was focused on the CSA's involvement, however DRDC is a key partner in the NEOSSat project and thus representatives were interviewed in order to produce a credible evaluation.

4 Results

This chapter presents evaluation findings related to the relevance and performance of the NEOSSat project.

4.1 Relevance

The issue of relevance concerns whether or not a program continues to serve a demonstrable need, is responsive to the needs of Canadians and is an appropriate activity for the Government of Canada. Given that NEOSSat is a one-time project, and not an ongoing program, the analysis took the perspective of examining the relevance of projects / missions similar to NEOSSat, i.e., projects that support the development of advanced systems intended to maintain Canadian space manufacturing capabilities and contribute to scientific knowledge and information of importance to Canada.

4.1.1 Continued Need for the Program

A sound rationale for NEOSSat-type missions exists. This rationale is reflected in the objectives of satellite missions that serve both societal and scientific needs. The limited commercial application of missions such as NEOSSat means that there is a need for government funding in order to garner these societal and scientific benefits.

The Aerospace Review report published in November 2012 provides a solid rationale for the Government of Canada's investment in the development of new satellites.[3] The report explains that space is becoming ever more essential to modern economies and national security. Satellites are playing growing roles in fields as diverse as precision agriculture, resource extraction, meteorology and climatology, environmental monitoring, the delivery of education and health services, emergency response, border surveillance, the operation of civil and military drones, and the rapid deployment of armed forces.

NEOSSat is the world's first space-based asteroid detection system, and the first stand-alone space-based surveillance of space system. The assessment, prediction, and mitigation of events caused by asteroids that could potentially cross the Earth's orbit will benefit not only Canada but also other nations. This knowledge will be a valuable tool to help manage Earth-orbiting assets (e.g., communication satellites, the International Space Station) as well as exploration spacecrafts for the purposes of transportation and in-situ Moon and Mars missions.

For NESS, the objectives of the mission are to discover near-Earth asteroids, track and explore targeted asteroids, and provide ground-based imaging with accurate targeting locations. These objectives are still or perhaps more relevant today given the asteroid impact in Russia in February 2013.[4] The science

[3] Reaching Higher: Canada's Interests and Future in Space, Aerospace Review, V.2, November 2012.
[4] The Chelyabinsk meteor was a near-Earth asteroid that entered the Earth's atmosphere over Russia on Feb. 15, 2013.

objective of NESS is seen as contributing to increasing Canada's international reputation in space science and has helped open doors to collaboration with other space agencies such as Japan and Germany.

For HEOSS, the primary objective is to raise awareness and identify and track space objects and space debris. This responds to the request by the North American Aerospace Defense Command (NORAD) to not only provide qualified personnel but also contribute to the data available in tracking space objects and debris. The project also responds to the need to ensure the avoidance of collisions between space objects and debris with existing satellites as well as with the International Space Station and other in-orbit space assets. NEOSSat is seen as playing an important role, along with the DND-sponsored Sapphire satellite launched in February 2013, in helping Canada contribute to the defence of space assets. The need for tracking of space objects and space debris is noted in Canada's newly released Space Policy Framework which states that the "...sheer number of objects in orbit makes the global communications infrastructure more vulnerable to the escalating risk of satellite collision."

The societal benefits that accrue from the NEOSSat project are the identification of potentially hazardous asteroids (allowing for emergency planning preparedness), contribution to the knowledge base with respect to asteroids (and potentially providing insights on the origins of the universe) and the contribution to the knowledge base on potentially hazardous space objects and debris (avoiding potential collisions between space-based assets).

Several key informants also expressed the opinion that this type of project, focused solely on the acquisition and distribution of data on potentially hazardous asteroids and comets and the identification and tracking of space debris, is not the type of project that would be undertaken by the private sector as there is limited commercial application. Government funding support is therefore a necessity.

4.1.2 Alignment with Federal Priorities

The CSA objectives of NEOSSat – increased competitiveness of the Canadian space sector, increased partnerships, and increased scientific research on asteroids – are aligned with the recently released Space Policy Framework and the broader federal government S&T priorities set out in the Federal S&T Strategy.

The NEOSSat project is well aligned with federal priorities in terms of promoting excellence and encouraging partnerships. The NEOSSat project science team, led by Dr. Hildebrand of the University of Calgary, has a dozen internationally distributed planetary scientists active in asteroid research, including scientific collaborators from the University of British Columbia, the Planetary Science Institute, the University of Arizona, the University of Western Ontario, the National Aeronautics and Space Administration (NASA), and Science Applications International Corporation (SAIC).[5] NEOSSat gives Canadian scientists leverage in collaborating with NASA, European Space Agency (ESA), and the Japanese Space Agency. New earth-space technologies, including NEOSSat, are a focus of the University of Calgary in becoming one of Canada's top-five research institutions by 2016.

[5] NEOSSat: Canada's sentinel in the skies, CSA, Feb. 25, 2013.

NEOSSat is also aligned with federal economic priorities as reflected in Canada's Economic Action Plan. Canada's space industry is a sophisticated research and innovation leader, turning investments in knowledge into a global advantage in several niche areas, including robotics and satellite communications. The Canadian Space Program is creating new opportunities for industry and scientists as well as long-term social and economic benefits for all Canadians.[6]

The Space Policy Framework highlights five guiding principles which will inform Canada's space activities. These include putting Canadian sovereignty, security and prosperity first; supporting and utilizing the domestic space industry; fostering partnerships; focusing on excellence; and developing capacity. The NEOSSat mission reflects the principles outlined in the Space Policy Framework through its focus on building Canadian space technological and management capacity particularly where Canadian firms have developed expertise, supporting excellence in space research, and developing partnerships with key space agencies in the U.S., Europe and Japan as well as academia.

NEOSSat is also well aligned with CSA priorities. The CSA has three priority areas: (i) provide space data, information and services; (ii) foster knowledge and innovation through space exploration; and (iii) sustain and enhance future Canadian space capacity. NEOSSat supports all of these priorities. The project also supports the CSA's Program Alignment Architecture (PAA), more specifically the following Sub-Sub Programs: Satellite Operations, Data Handling, Exploration Missions and Technology and Space Astronomy Missions.

4.1.3 Alignment with Federal Roles and Responsibilities

NEOSSat-type missions, including financial and other support for them, are aligned and consistent with federal jurisdiction, roles and responsibilities. The CSA has the legal mandate to support the Canadian space industry and is recognized as the government's lead space organization. As noted in the *Canadian Space Agency Act* (last amended March 16, 2012), the Agency may exercise its powers, and perform its duties and functions, in relation to all matters concerning space over which Parliament has jurisdiction and that are not by or pursuant to law assigned to any other department, board or agency of the Government of Canada.

The type of research being undertaken by NEOSSat has limited or no commercial value and therefore needs government funding to reap the benefits for Canadians in terms of increased public safety and other benefits accruing from the mission. R&D is needed in order to allow firms to develop and test the technologies before the market for these products is fully developed. This is being done in other countries and it is seen as important for the federal government to support Canadian companies and thus ensure a level playing field for Canadian firms in the space sector.

[6] Canada's Economic Action Plan 2013.

4.2 Performance

This section addresses the evaluation questions related to performance, including the implementation of activities, the production of outputs, the achievement of outcomes, and economy and efficiency. The ultimate outcomes are not addressed because, based on discussions with the Evaluation Consultative Group and the early stage of the NEOSSat project, it was decided that it would be premature to expect measurable progress on the ultimate outcomes.

4.2.1 Implementation of Activities

Based on interview findings and the document review, the NEOSSat project was implemented in accordance with the activities in the initial plan; however, the project encountered significant delays totalling 41 months, due to a number of factors. There were very divergent opinions expressed as to the reasons why these delays have occurred.

The majority of interviewees representing the CSA indicated that the primary reason for the delays was that the contractor[7] did not have the necessary capacity, either technically or operationally, to undertake this project. According to the Dynacon proposal for NEOSSat, the Utias Space Flight Laboratory (University of Toronto) was supposed to be a major subcontractor to Dynacon similar to its role on MOST. Although the NEOSSat contract was awarded to Dynacon on this basis, Dynacon-MSCI never concluded a contract with Utias. The lack of capacity on the part of Dynacon-MSCI was compounded by the departure of a few key individuals from Dynacon shortly after the contract was finalized in 2007, as well as significant turnover within MSCI during the course of the project (a large number of individuals were replaced over the course of the project, including the chief engineer, power engineer, quality assurance engineer, and software configuration management). MSCI had to recruit replacement staff which was challenging and the company did not always succeed in a timely fashion.

Another source of significant delay was the federal government approval, authorities and contracting processes. Once Dynacon-MSCI was awarded the contract, it reportedly took PWGSC twelve months to issue a contract following completion of Phase A. It then took the CSA an additional four months after Phase B to get the approvals and authorities to implement the project.

Delays beyond the control of MSCI also stemmed from the difficult financial situation experienced by Routes AstroEngineering part way through its subcontract with MSCI. Routes went out of business and some of its assets were subsequently acquired by another firm in 2010, including the intellectual property (IP) for which MSCI had paid. MSCI was forced to replicate the systems developed by Routes. That caused a one year delay. The CSA was also forced to recover some parts for NEOSSat from Routes, which caused an additional delay of a few months.

[7] Dynacon was selected as the primary contractor in 2007. In 2008 the satellite business was sold to MSCI and MSCI de-facto became a Prime Contractor. When the proposal from Dynacon was reviewed by the CSA and PWGSC and the contract awarded to the company, Dynacon was deemed to be fully compliant with the requirements and having the capacity and experience to undertake the NEOSSat project successfully.

Finally there were delays in the launch of the satellite by Antrix, an Indian launch services provider. On the positive side, the launch delays provided MSCI with needed additional time to complete the spacecraft. As it was, the satellite was launched somewhat prematurely. The computer programs were not ready and, post launch, work continues on "fine pointing" the software module, required for taking precise images of orbiting objects and asteroids.

The majority of partner interviewees (DRDC and MSCI) and those on the science team identified that an important challenge in implementing NEOSSat was the very different risk cultures that exist within the CSA and DRDC. The CSA has a particular approach to how they work - they undertake space projects focused on high reliability and high quality control. The CSA's history is seen as being rooted in manned space and so they are very risk averse. DRDC has less emphasis on this when working in the microspace environment and thus is viewed as being more risk tolerant compared to the CSA. The low level of tolerance for risk at the CSA serves to increase costs and timelines. One interviewee noted that the CSA's approach to NEOSSat was somewhat contradictory to the intent of "faster, generic and much lower cost."

The NEOSSat project experienced delays totaling 41 months. According to CSA representatives, it is not unusual and, in fact, it is common for space technology projects to experience delays due to the technical nature of the projects. Space projects involve the integration of many complex, often untested, technologies and this frequently results in delays as testing reveals problems that must be resolved prior to launch. It is also common to experience launch delays when the satellite is not part of the primary payload, which was the case for NEOSSat. The delay caused by the prime contractor's lack of technical and operational capacity was, however, unusual and pointed to weaknesses in the contracting process which the CSA has recognized in its assessment of lessons learned from the NEOSSat project.

4.2.2 Achievement of Expected Outputs and Outcomes

This section addresses the extent to which the expected outputs and outcomes for the NEOSSat project have been achieved.

4.2.2.1 Production of Expected Outputs

4.2.2.1.1 Design for a Standardized Multi-Mission Microsatellite Bus

MSCI's use of commercial-grade components in a standard multi-mission microsatellite bus architecture capitalized on the technology developed for the MOST microsatellite but the NEOSSat bus was not simply a follow-on design of the MOST bus.[8] The guiding philosophy for the design of the NEOSSat system was to employ proven microsatellite designs as a starting point, making adaptations to these in order to meet the core science objectives of NEOSSat.

[8] www.mscinc.ca/missions.

The resulting design allows the mission to be achieved while re-using structural, power, on-board computing, telemetry and command and ground station subsystem design envelopes from previous successful microsatellite missions. For example, NEOSSat utilizes a Maksutov Cassegrain telescope which shares design lineage with the MOST mission but is amplified and optimized for imaging by the addition of field flattening optics. A sun safety shutter was also added to reduce risk of damage to the charge-coupled device (CCD) array, should the bore sight be pointed toward the sun.

As the multi-mission microsatellite bus design has developed through NEOSSat, 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 input/output interfaces as well as modular components to ensure a significant level of re-usability while reducing non-recurring engineering. The microsatellite design provides a platform suitable for many payload/instrument types.

The development of the multi-mission bus has contributed to innovation and increased knowledge. From an operational perspective, the multi-mission bus should prove beneficial to the integration of differing payloads within the same spacecraft, reducing overall costs and shortening the life cycle of mission development.

4.2.2.1.2 Electronic Archive Pertaining to the NEOSSat Project

A project management system was established and maintained for NEOSSat. Project documentation is filed in accordance with the project classification template developed by project management, consistent with applicable CSA standards and applicable internal procedures. A document tree was established for the project, defining “official” documents (including e-mail) that are forwarded to the CSA Corporate Filing System on a regular basis. Upon project closeout, the Corporate Filing System will make a list of all project documents for archiving.[9]

The NEOSSat Statement of Work specified that the electronic archive is intended to “capture the details of the program in an informal manner so as to minimize the cost of documentation without the loss of detailed information.” The Statement of Work specifies that the archive is to be delivered on an external USB drive.

All interviewees indicated that this is an ongoing process and has been in place since the inception of the project.

4.2.2.1.3 Microsatellite Capable of Taking Imagery

During ground testing of the NEOSSat imagery instrument, the instrument underwent several adjustments to improve image quality to acceptable levels. Ground testing of the spacecraft engineering model continued until mid-January 2013, at which point the CSA and DRDC decided to launch the

[9] Joint Implementation Plan 16 March 2007.

spacecraft hardware with plans for software uploads to further develop and refine performance to meet specifications.

In December 2013, a post processing technique developed by the science teams improved the quality of the images without fine pointing of the spacecraft such that short exposure duration images are considered acceptable for mission purposes. Work on eliminating noise and improving image acquisition continues. With the inclusion of fine pointing, further evaluation of the post processing technique will be done.

As of January 2014, the CSA and MSCI have a team working on two planned solutions. Whether the intended production of 288 images per day can be achieved is a matter of concern to a number of interviewees. Because of the issues with the imager, commissioning of the satellite was drawn out and compliance with all performance criteria of the delivered spacecraft is pending. Interviewees indicate that, because of the very low levels of light that are reflected off asteroids, fine pointing of the spacecraft is needed for a stable focus in order to produce images of a scientific quality.

4.2.2.1.4 Ground Segment that Can Process Requests and Receive and Store Imagery

The ground segment is working, and final integration system testing is being undertaken. Telemetry, tracking and control (TT&C) service and operations during the NEOSSat mission are provided by the Missions Operations Centre (MOC) established at the CSA's headquarters. NEOSSat data requests are being received and processed at the Mission Planning System in Ottawa. Once images of scientific quality are available, they will be distributed to the NESS and HEOSS Principal Investigators for analysis and dissemination to their science teams.

4.2.2.1.5 Demonstration of the Multi-Mission Microsatellite Bus Design and Technology

The commissioning (process by which the satellite is tested to verify it functions according to its design specifications) of the spacecraft is in progress and, therefore, while it is too early to assess whether this output has been fully achieved, it was noted by some interviewees that the basic functions (solar panels, batteries, radios, on-board computer) on the spacecraft are functional.

4.2.2.2 Achievement of Immediate Outcomes

This section presents evaluation findings related to the achievement of immediate outcomes.

4.2.2.2.1 Sustained and/or Strengthened Capacity of the Canadian Space Sector

There is general agreement among interviewees that capacity has been built within industry, government and academia as a result of NEOSSat. Within MSCI, the project supported the strengthening of MSCI expertise with six staff involved directly and ten support personnel who also developed additional capability over the period of the project. There has been the creation of jobs for Highly Qualified Persons (HQPs) as well as the maintenance of expertise within the CSA as a result of being involved in NEOSSat. NEOSSat is part of the longer-term development in capacity in both industry and the CSA in the microsatellite bus technology.

The level of participation of the prime contractor and subcontractors in the project has increased the level of capacity of the Canadian space industry in the development and manufacturing of small satellites in an ever-increasing international marketplace.

Despite the overall view that NEOSSat has had a positive impact on capacity, there is a concern that the impact on capacity was not as significant as it could have been. One interviewee argued that, because the prime contractor, in order to protect its competitive advantage, did not collaborate/subcontract to the extent that it should have, capacity development suffered.

The NEOSSat science team, led by the University of Calgary, includes internationally recognized planetary scientists active in asteroid research who expect to use NEOSSat data to continue research on small bodies within the near-Earth portion of the solar system. It is expected that NEOSSat will assist Canadian universities and the CSA in gaining leverage in collaborative efforts with NASA, the European Space Agency and the Japanese Space Agency.

NEOSSat also served as a much-needed training ground for young scientists. As some interviewees pointed out, there is a need for young scientists to work on smaller, less risky projects such as NEOSSat in order to gain experience prior to working on larger, more complex projects. Furthermore, one interviewee noted that there are currently too few of these smaller projects and this will impact future space science capacity.

Numerous firms were involved in building NEOSSat – MSCI, Spectral Applied Research, and GlobVision – representing a significant number of players who have had the opportunity to build space hardware and thus capacity in the industry. Although NEOSSat may not necessarily have resulted in new entrants as prime contractors, the project has opened the door for new entrants as subcontractors. There has also been the building of physical infrastructure as a result of NEOSSat such as the clean room built by MSCI at its facility. This infrastructure, which was funded by MSCI, will be used for other projects undertaken by the firm.

Interviewees noted that there are other microsatellite programs that benefited from the NEOSSat experience, such as M3MSat and Sapphire (which was launched at almost the same time as NEOSSat). As a result, interviewees argued that industrial capabilities in microsatellites are being strengthened in Canada within companies such as COM DEV, Magellan, MSCI, and Utias, which have all now manufactured microsatellites as well as nanosatellites.[10]

[10] Microsatellites are defined as weighing between 10 and 100 kilograms while nanosatellites weigh between 1 and 10 kilograms.

4.2.2.2.2 Lessons Learned Used

The majority of interviewees indicated that lessons have been collected throughout NEOSSat and have already been used within the CSA. Lessons learned are providing CSA engineers and project managers with value-added improvements in the way microsatellite projects are initiated, executed and controlled, which will benefit future CSA microsatellite projects in terms of cost, schedule, risk and quality. Certain skills are embedded in all space missions (e.g., configuration engineers, product assurance) and some interviewees noted a clear lack in these areas during NEOSSat on the part of both the contractor and the CSA. The lack of configuration management was identified as a key weakness at MSCI. In response to this, the CSA provided mentoring and assistance to MSCI staff on product structuring and the linking of all technical documents to form an integrated baseline. For subsequent projects, some CSA representatives would like to ensure that these areas are adequately staffed at both the CSA and the contractor.

Lessons from NEOSSat are already being applied within DND. The experience of NEOSSat, particularly in the Critical Design Review and Preliminary Design Review phases, were directly translated and used in the Sapphire satellite and, according to DRDC representatives, had a direct positive impact on Sapphire. They noted that findings and technology from NEOSSat will be used in other upcoming projects at DRDC.

According to DRDC representatives, DRDC undertakes a detailed “lessons learned” review after full commissioning of spacecraft and payloads. According to some DRDC interviewees, in the case of NEOSSat, given the newness of the relationship with the CSA and the choice of a new contractor, it may have been beneficial to implement, from the start, a process to capture data and lessons learned throughout the project phases. These interviewees stated that the capture of lessons learned was not as good as they would have expected.

Within the CSA, the group involved in NEOSSat has been consulting with those developing the RFPs for the next small satellite projects. In particular, some of the contracting issues experienced in NEOSSat have been identified and will be mitigated in upcoming RFPs. However, it was also noted that each mission is unique and so it is impossible to expect that past experience will provide solutions to all issues.

4.2.2.2.3 An Increased Portion of Aten-Class Asteroids Detected and Catalogued

It was clearly recognized that it is premature to assess whether NEOSSat will contribute to an increased portion of Aten-class asteroids being detected and catalogued as science images are not yet available. The detection of Aten-class asteroids is a considerable technical challenge. As explained by one interviewee, Aten-class asteroids fly between the Earth and the sun and occasionally cross the orbit of the Earth. These asteroids are particularly dangerous because they can’t be seen from the Earth due to the scattered light in the atmosphere. The only way to find them is through the use of a satellite such as NEOSSat which can look for objects between the Earth and the Sun. The instruments on NEOSSat are not intended to compete with the large telescopes in scanning for all asteroids but rather to identify these Aten-class asteroids that cannot be seen otherwise.

It was noted by one interviewee that there is currently another satellite in orbit, Wide Field Infrared Survey Explorer (WISE), that was repurposed in the fall of 2013 by NASA to detect near-Earth asteroids, including Aten-class. This may mean that NEOSSat, even if it becomes fully operational and takes the number of images hoped for (288 per day), may still not be the first to detect and catalogue 50% of Aten-class asteroids as intended; however, it could detect a significant proportion.

4.2.2.3 Achievement of Intermediate Outcomes

4.2.2.3.1 Competitiveness (i.e., capacity and capability) of Canadian space products and services

The majority of interviewees expressed the opinion that NEOSSat has and will help the Canadian space industry develop export potential. In particular, the need for multi-mission generic buses will continue to be in demand in the international space industry.

However, a few interviewees noted that the space technology industry is generally protectionist, with most countries with a space industry tending to purchase from within the country. The space industry is seen as strategic by many countries and thus there are barriers to free trade in international markets.

4.2.2.3.2 Market potential for microsatellites

Global interest in nano and microsatellites (under 100 kg) is increasing. Nano/microsatellite launch demand has grown by an average of 5 percent per year since 2000, with an expected 20-25 percent growth per year over the next 7 years. [11]

Nano/microsatellite development continues to be led by the civil sector, but the defence/intelligence community is showing increased interest and involvement. Applications for nano/microsatellites are diversifying, with increased use in the future for science, Earth observation, and reconnaissance missions.

4.2.2.3.3 Spinoffs from NEOSSat Technology

The newest and maybe the most ambitious entrant into the commercial satellite market is COMMStellation. MSCI announced in January 2013 its intention to build an 84-satellite system in LEO orbit, dubbed “Backhaul to the Future.” The constellation will consist of 78 satellites in six polar orbital planes with a spare in each orbit.

Although MSCI is not a volume producer of microsatellites, it is the largest global manufacturer of re-action wheels for other microsatellite prime contractors and sells dozens per year, and thus it does have experience in volume manufacturing. The bus for the constellation is based on a standardized architecture used for both MOST and NEOSSat, which should also help in ramping up production.[12] MSCI is looking for service providers who want to improve service to their customers, technology partners

[11] Nano/Microsatellite Market Assessment, February 2013, Spaceworks Enterprises Inc.

[12] Satellite Executive Briefing, Vol. 4 No. 3 March 2011, Satellite Markets and Research Magazine.

who can bring complementary technologies to the COMMStellation initiative, and military or industrial leaders who are looking for strategic communications to and from remote areas.[13]

Another example contributing to Canada's competitiveness in the manufacture and use of microsatellites includes is the M3MSat satellite for maritime monitoring, designed and built by COM DEV International (planned launch May 2014).

4.2.2.3.4 Partnerships in Technology and Space Science

Partnerships were established between industry companies (e.g., MSCI and Spectral Applied Research) as well as within government (the CSA and DRDC) and academia (science team at University of Calgary including scientists from Japan, the US, and the EU). Interviewees noted that the scientific partnerships will continue to evolve and the extent to which they are successful will depend on the quality of the imagery obtained from NEOSSat.

The NEOSSat project is the first joint microsatellite project between DRDC and the CSA, helping establish the foundations for efficient and sustainable microsatellite development in an intra-governmental collaborative environment. Joint project management experience was gained through the JPO (Joint Project Office) set up by DRDC and the CSA to manage the NEOSSat design, construction and launch phases (see Section 4.2.2.4 for more detail on management structure).

The Mission Planning System (MPS) for the tasking, collection and distribution of the payload data, once data downloading is operational, will be located in DRDC; both the NESS and HEOSS science teams will use the MPS.

4.2.2.3.5 Impact on Knowledge Base Concerning Asteroids and Comets

It is premature at this stage to assess NEOSSat's contribution to an increased science knowledge base concerning asteroids and comets, as the quality of the imagery is not sufficient at this time to allow for the data capture at a resolution required to achieve this outcome.

4.2.2.4 Appropriateness of Design of Management Structures

Based on findings from the document review and key informant interviews, the management structures for NEOSSat were well developed and clearly understood by the CSA and DRDC. However, there was some disagreement among those interviewed on whether the design for the management of NEOSSat was appropriate for ensuring the success of the project. Overall the management of the NEOSSat project was seen as onerous by many. However, the lack of capacity and experience on the part of the contractor was an important factor in the level of oversight and input into the project on the part of the CSA. The increased oversight in terms of accountability and reporting imposed on MSCI was linked to the perceived risk level as well as increased accountability requirements placed on federal departments

[13] MSCI press release, January 19, 2011.

and agencies by the central agency, Treasury Board. The mentoring and technical input provided to the contractor by the CSA and DRDC, reflecting a very “hands-on” management structure, was necessary to the success of the project.

The JPO created by the CSA and DRDC was established to facilitate teamwork, and share work progress reviews and decision making, with a project manager provided by each partner. A Supporting Arrangement was signed in February 2005 with the purpose of developing and operating NEOSSat as a collaborative project between the two agencies. As noted earlier, the CSA project manager is the overall mission Project Manager and the DRDC project manager is the Deputy Project Manager. The project was managed in accordance with the CSA Project Approval and Management Framework approved by Treasury Board.

Procurement management and administration were handled by PWGSC. PWGSC provided an officer to assist the CSA team in managing the procurement process and negotiating the contracts on behalf of the Crown, monitoring costs and timelines, negotiating changes resulting from reviews, and approving payments.

The satellite and data resulting from this mission are co-owned by the CSA and DRDC with ownership reflecting the proportional amount paid by each partner.

The lack of capacity on the part of the prime contractor had a significant impact on the way the NEOSSat project was managed. As noted previously, many interviewees did not consider the prime contractor to have the necessary capacity and experience to successfully undertake NEOSSat. Some interviewees from DRDC and the CSA stated that the contract with the prime contractor should have been cancelled as soon as the lack of capacity on the part of the prime contractor became evident. Cancelling the project would, according to interviewees involved in the decision making, have risked the loss of much of the work already completed. It is evident based on interview findings that the CSA and DRDC took a calculated risk in continuing the project with MSCI as the prime contractor.

The decision to continue with MSCI as the prime contractor had important implications for both the CSA and DRDC. Both departments took on the role of mentor and provided back-up capacity for MSCI, i.e., CSA and DRDC staff took a much more active role in the technical aspects of NEOSSat than is normally the case for a contract of this kind. The CSA and DRDC became more active in mentoring, follow-up and verification and, in some cases, suggesting solutions to MSCI. However, the CSA and DRDC had to tread carefully because they could not be seen as providing direction to the industrial team (i.e., MSCI). One interviewee noted that the alternative for the CSA would have been to let MSCI “sink or swim,” which would not have benefited the CSA, DND or MSCI. The CSA had little choice but to play a role in building capacity by mentoring the industrial team.

The reporting requirements imposed on federal departments and agencies were reported by some interviewees to have increased during the course of NEOSSat and thus had an impact on the design of the management approach to the project. Federal government requirements have evolved to be more stringent and, in the view of many interviewees, onerous and this impacted the management of

NEOSSat by requiring the prime contractor to provide detailed reports to meet the CSA's accountability requirements to the federal government. This resulted in more time and increased costs to the contractor as well as to the CSA.

4.2.2.5 Unintended Outcomes

There were relatively few unintended outcomes identified by interviewees. On the positive side, interviewees representing both the CSA and DRDC feel that the working relationship between the CSA and DRDC has evolved further as a result of NEOSSat. NEOSSat was the first joint initiative that involved co-funding and co-management through the establishment of a Joint Project Office. In addition, the satellite is co-owned by the two agencies. This type of partnership through which both departments benefit reflects the federal government's goal of encouraging joint inter-departmental initiatives. Although interviewees noted challenges with respect to the differing cultures within the departments (as discussed earlier), overall there is a sense that the relationship has been more positive and beneficial than anticipated. The collaboration has not ended with NEOSSat, as the two organizations are currently collaborating on other projects such as M3MSat.

On the negative side, there was a greater than anticipated demand for CSA internal resources as a result of the lack of sufficient capacity and expertise on the part of MSCI. The decision on the part of the CSA and DRDC to proceed with the NEOSSat project with MSCI despite the evident challenges meant a higher level of hands-on involvement and a notable amount of mentoring of the contractor on the part of both the CSA and DRDC. This affected other CSA projects from which CSA staff were drawn in order to support NEOSSat as well as the budget for NEOSSat because a higher than anticipated amount was spent on internal expenses.

Again on the negative side, issues with the quality of the imagery from NEOSSat have affected the progress of research for which NEOSSat data is required. In anticipation of data from NEOSSat, the science team at the University of Calgary has developed partnerships with other researchers internationally and the lack of data from NEOSSat has frustrated researchers at the University of Calgary and its research partners. There is a fear on the part of the University of Calgary that the lack of data from NEOSSat will jeopardize these partnerships.

4.2.3 Demonstration of Efficiency and Economy

The TBS Directive on the Evaluation Function defines the demonstration of efficiency and economy as the "assessment of resource utilization in relation to the production of outputs and progress towards expected outcomes." In general, the analysis of efficiency requires assessing relationships between inputs and outputs and/or outcomes, and the assessment of economy concerns the extent to which best use is made of resource inputs to achieve intended outcomes.

In practical terms, the key efficiency and economy questions of relevance to the NEOSSat project were identified in the evaluation methodology design report as the following:

- Was the budget for NEOSSat appropriate/economical given the intended outputs to be produced and the mission's outcomes?
- Did the project proceed in an efficient fashion?
- How did the actual expenditures on NEOSSat compare to the original budget?

No documentary evidence was provided by the CSA on the efficiency and economy issues, i.e., no previous assessments of the above sorts of questions were provided to the evaluation team.

The majority of those interviewed indicated that NEOSSat's outputs could not have been produced at a lower cost. As a fixed price contract, it was identified that the project was underfunded from the outset, both for the funding agreement and the level of effort required within the CSA. Interviewees who estimated the extent of underfunding consistently estimated that NEOSSat was underfunded by approximately 50%. This estimate could not be verified by the evaluation team.

According to CSA representatives, internal (operational costs) incurred by the CSA in managing the NEOSSat project were much higher than anticipated. The CSA spent significant resources on assisting MSCI in completing NEOSSat. The CSA brought in a tiger team prior to the launch of NEOSSat in order to get the satellite ready for launch in time. In addition, a CSA staff member spent six weeks in India to oversee MSCI in readying the satellite for launch. The financial data provided by the CSA reflects the fact that higher than anticipated internal costs were incurred by the CSA.

Some interviewees representing industry and DRDC noted that the CSA did not always appear to be managing NEOSSat efficiently or cost effectively. Interviewees noted that it was often the case that CSA representatives far outnumbered industry or DRDC representatives at meetings. There is a general sense among these interviewees that the large numbers of CSA staff at meetings was unnecessary and inefficient. However, one CSA representative noted that the small number of industry representatives reflected the inadequate resources on the part of the contractor. DRDC representatives also noted that the CSA tended to revisit decisions and this created inefficiencies particularly at meetings between the CSA and DRDC.

As previously noted, there is general agreement among interviewees that the reporting requirements imposed on MSCI were heavy, particularly relative to the small size of the project. However it was also noted that MSCI kept the length and detail in the reports to a minimum. The reporting requirements are seen by some interviewees as having resulted in unnecessary time and cost (and thus inefficiency) on the part of both MSCI which had to produce the reports, and the CSA which had to review and archive the reports. A representative from the CSA noted that the agency has implemented a more risk-based approach to reporting, although this came too late for NEOSSat. However, the reporting requirements and oversight must be balanced against the calculated risk taken by both the CSA and DRDC in continuing to work with MSCI despite the lack of capacity and expertise to successfully complete the project.

The increased costs reflected an increase in the launch capital funding to allow for the consideration, selection and finalization of the launch agreement; an increase in funding to the CSA and DND for technical support of the Missions Operations Centre ground segment development to permit delivery of an upgraded ground terminal and the development of operations procedures; funding to DND for professional services to acquire the Mission Planning System; a increase in the risk allocation; funding for satellite testing at David Florida Laboratories; and increased labour costs due to delays and underestimation of technical support requirements.

Perhaps an obvious finding pertaining to operational efficiency is that NEOSSat's outputs were produced several years later than planned (41 months later, to be precise), and thus the achievement of most of the outcomes is also being delayed. In addition, the costs of producing NEOSSat's outputs will have been larger than expected due to the delays. While the amount of the contract has not changed, internal project management costs have been greater than budgeted with a total of $2,991,437 spent as of January 2014.

The financial data for NEOSSat provided by the CSA indicates that the CSA has in fact overspent on internal resources allocated to NEOSSat. The contract costs have not increased (i.e., no additional funding was provided to MSCI), and the CSA has not overspent on the risk allocation budget. Much of the overspending vis-à-vis internal costs stems from the lack of capacity and experience on the part of MSCI and the need for DND and the CSA to provide the missing technical capacity. The CSA and DND implicitly committed themselves to providing assistance when deciding to continue with MSCI as the contractor. From an economy perspective, the CSA and DND choose to spend internal resources to assist the contractor rather than loose what resources had already been spent on NEOSSat.

From a total cost perspective, if there is agreement that the NEOSSat project was underfunded, i.e., the contract with MSCI should have been valued at more than $9.42 million, then the increased use of internal resources on the part of the CSA and DND simply reflects a more accurate cost of NEOSSat, i.e., what the contract should have been valued at.

5 Conclusions and Recommendations

This section summarizes the conclusions of the evaluation study with respect to each evaluation question and presents the study recommendations.

5.1 Relevance/Need

A sound rationale for NEOSSat-type satellite missions exists. The Aerospace Review report issued in November 2012 supports Government of Canada investment in the development of new satellites. Satellites are playing increasingly important roles in a wide variety of fields. NEOSSat was planned and designed to be the world's first space-based asteroid detection system, and the first stand-alone space-based surveillance of space system.[14] The assessment, prediction, and mitigation of events caused by asteroids that could potentially cross the Earth's orbit will benefit not only Canada but other nations.

The societal benefits that will accrue from the NEOSSat project are the identification of potentially hazardous asteroids (allowing for emergency planning preparedness), contribution to the knowledge base with respect to asteroids (and potentially providing insights on the origins of the universe) and the contribution to the knowledge base on potentially hazardous space objects and debris (avoiding potential collisions between space-based assets).

Because of the nature of the NEOSSat mission, i.e., the acquisition and distribution of data on potentially hazardous asteroids and comets and the identification and tracking of space debris, this type of satellite project would not be undertaken by the private sector and therefore government investment was necessary. The need for tracking of objects in orbit is echoed by the newly released Space Policy Framework which notes that the number of objects in orbit makes the global communication infrastructure more vulnerable to the escalating risk of satellite collision.

The NEOSSat project is well aligned with federal priorities In terms of promoting excellence and encouraging partnerships. For example, near Earth-space technologies, including NEOSSat, are a focus of the University of Calgary's goal to become one of Canada's top-five research institutions by 2016. The NEOSSat project science team, led by Dr. Hildebrand of the University of Calgary, has a dozen internationally distributed planetary scientists active in asteroid research. NEOSSat gives Canadian scientists leverage in collaborating with the world's leading space agencies, including NASA, ESA, and the Japanese Space Agency.

The Space Policy Framework highlights five guiding principles which will inform Canada's space activities. These include putting Canadian sovereignty, security and prosperity first; supporting and utilizing the domestic space industry; fostering partnerships; focusing on excellence; and developing capacity. The NEOSSat mission reflects the principles outlined in the Space Policy Framework through its focus on building Canadian space technological and management capacity particularly where Canadian firms have

[14] Project Brief for Effective Project Approval, August 17, 2009

developed expertise, supporting excellence in space research, and developing partnerships with key space agencies in the U.S., Europe and Japan as well as academia.

5.2 Performance

5.2.1 Implementation Compared to Plan

The NEOSSat project was implemented in accordance with the activities in the original plan. However, the mission encountered significant delays totalling 41 months. The primary reason identified for the delays is that the prime contractor (originally Dynacon, followed by MSCI) was viewed as not having the necessary capacity, either technically or operationally, to undertake this project. This lack of capacity was exacerbated by the departure of key individuals shortly after the contract was finalized in 2007, together with significant turnover in the subsequent years. The lack of capacity on the part of the contractor meant that the CSA and DND were faced with a choice of cancelling the project or taking a calculated risk and continuing work with the contractor. Continuing work with the contractor required the CSA and DND to play a bigger role in the project by providing technical assistance and mentoring to the contractor. Without the technical capacity within the CSA and DND, it is unlikely that the NEOSSat project would have been completed successfully.

Recommendation 1: There is a need for the CSA to establish a process to address risk factors in cases where deficiencies are observed regarding the financial, technical and/or project management of contractor performance during contract execution.

Recommendation 2: In order to mitigate potential risks related to contractor capacity, there is a need for the CSA to continue to maintain technical capacity, either internally or available on an as needed basis, to effectively manage projects and to step in and undertake the more technical aspects of a project if a contractor is unable to do so. If the prime contractor does lose capacity then the CSA should ensure it has a way to deal with that risk.

Another source of the delays was the prolonged contracting process handled by PWGSC; the CSA also took an additional four months after Phase B to get the internal system requirements in place. Another factor was the loss of one of MSCI's subcontractors (Routes AstroEngineering) during the transition from Phase B to Phase C, along with the IP, which meant that MSCI had to replicate the systems developed by Routes. Finally, there were launch delays experienced by Antrix, the India-based launched provider.

On the positive side, the launch delays provided MSCI with much-needed additional time to complete the satellite. Nonetheless, the satellite was launched somewhat prematurely. The on-board computer software was not ready, and as of January 2014, work continues on "fine pointing" the software module, which is necessary for taking precise images of orbiting objects. In addition aspects of the imager with other spacecraft systems could not be tested until after launch.

While the mission experienced significant delays, this is not unusual for satellite missions, as such projects involve the integration of many complex, often untested, technologies.

5.2.2 Production of Outputs

NEOSSat successfully employed a standard multi-mission microsatellite bus architecture based on several subsystem design envelopes used in previous microsatellite missions. Expansion capabilities have been incorporated into the design so that the hardware can be used in future missions. The microsatellite design provides a stable platform that can accommodate many payload/instrument types.

The main issue with NEOSSat is that although images have been acquired, the image quality does not at present meet the imagery requirements of the scientific aspects of the mission. NEOSSat is only taking engineering images and not scientific images. In December 2013, the science teams developed a post-processing technique that removes the pattern on short duration exposure images and imagery can be used for some mission objectives. A stable focus is needed in the imager in order to yield images of a scientific quality, due to the very low levels of light that are reflected off asteroids. Whether the intended production of 288 images per day can ever be achieved is a matter of concern. Because of the issues with the imager, commissioning of the satellite will be delayed, as will the CSA's acceptance of the delivered spacecraft.

The ground segment is working and final integration system testing is being undertaken.

5.2.3 Achievement of Immediate Outcomes

Key informants agreed that the NEOSSat project has helped build capacity within industry, government and academia. For MSCI, the prime contractor, the project has strengthened the company's expertise, as a large number of staff have been directly and indirectly involved. Jobs have been created for HQPs. The project also served as a training ground for young scientists; smaller, less risky satellite projects like NEOSSat are ideal for this objective. Within the CSA, expertise has been maintained and in fact CSA staff played a mentoring role with respect to MSCI. In summary, NEOSSat is part of the long-term development of capacity in both industry and the CSA in the field of small satellite bus technologies. Canada now boasts several companies, including MSCI, COM DEV, Magellan, and Utias, which all have demonstrated capabilities in the manufacture of microsatellites and nanosatellites.

The only negative comment is that the prime contractor is viewed as having not collaborated/subcontracted to the extent that was expected, thus limiting the extent of capacity development throughout the industry.

A few interviewees noted that the space technology industry is generally protectionist, with most countries with a space industry tending to purchase from within the country. The space industry is seen as strategic by many countries and thus there are barriers to free trade in the international market.

The NEOSSat science team, led by the University of Calgary, includes internationally recognized planetary scientists in asteroid research, who will use NEOSSat data to continue their research on small bodies within the near-Earth portion of the solar system. It is expected that NEOSSat will assist Canadian universities and the CSA to gain leverage in collaborative efforts with other space agencies internationally.

Lessons learned have been captured throughout the history of the NEOSSat mission and have already been applied within the CSA, for example, in the Sapphire satellite mission led by DRDC. They are providing CSA engineers and project managers with value-added improvements in the way microsatellite projects are managed, which will benefit future CSA missions. However, some key informants noted that certain skills (e.g., configuration engineers, product assurance) were not incorporated into the NEOSSat project on the part of both the prime contractor and the CSA. Also, some interviewees stated that the capture of lessons learned could have been better handled.

It was clearly recognized that it is premature to assess whether NEOSSat will contribute to an increased portion of Aten-class asteroids being detected and catalogued, as science images are not yet available.

5.2.4 Achievement of Intermediate Outcomes

The majority of key informants expressed the view that NEOSSat has and will help the Canadian space industry develop export potential. Multi-mission generic bus technology will continue to be in demand in the international space industry. In particular, global interest in nano- and microsatellites is increasing rapidly.

In terms of spinoffs from the NEOSSat mission, in January 2013, MSCI announced its intention to build an 84 satellite system in low-Earth orbit, consisting of 78 satellites in six polar orbital planes with a spare in each orbit. The bus for the constellation is based on a standardized architecture used in both NEOSSat and MOST, which should help MSCI in ramping up production. In addition, several of the other contractors involved in NEOSSat have gone on to work on other microsatellite projects.

NEOSSat did help establish several partnerships within industry, the government and in space science. For example, NEOSSat was the first joint microsatellite project between the CSA and DRDC. In particular, joint project management experience was gained through the establishment of a joint project management office.

Recommendation 3: The CSA, in collaboration with other federal partners and industry, should define a strategic direction to establish "niche" capacities and capabilities within the Canadian space industry that can exploit trends and opportunities in the international space marketplace. This would align with the Space Policy Framework and the Aerospace Review, providing firms in the Canadian space sector with direction on anticipated work and facilitating planning and capacity development, allowing the industry and academia to better respond to the needs of the CSA and other federal departments.

It is premature to assess NEOSSat's contribution to an increased science knowledge base concerning asteroids and comets.

While the management structures for NEOSSat were well developed and understood by both the CSA and DRDC, many interviewees stated that the management of the project was onerous. However, the very hands-on management structure was necessary given the lack of capacity and experience on the part of the prime contractor. The onerous reporting requirements resulted in additional time and costs incurred by both the prime contractor and the CSA.

5.2.4.1 *Unintended outcomes*

The successful partnership formed by the CSA and DRDC is an excellent example of a federal government goal of encouraging inter-departmental partnerships. While the differing cultures of each organization did present some challenges, overall there is a sense that the partnership was more positive and beneficial than had been anticipated.

There is some concern on the part of the science team at the University of Calgary that its partnerships with other researchers internationally may be negatively affected should the quality of NEOSSat data imagery not improve.

5.2.5 Efficiency and Economy

The majority of key informants stated that NEOSSat's outputs could not have been produced at a lower cost. As a fixed-price contract, the project was perceived to have been underfunded by as much as 50% from the outset.

According to CSA representatives, internal costs incurred by the CSA in managing the project were much higher than planned. The agency invested significant resources in assisting MSCI completing the project. For example, the CSA brought in a "tiger team" prior to launch in order to prepare the satellite for launch.

Some interviewees commented that the CSA did not always appear to be managing the mission efficiently; for example, CSA representatives typically outnumbered those from industry and from DRDC at the many meetings that occurred. DRDC representatives also noted that the CSA tended to revisit decisions.

As noted earlier, the project's onerous reporting requirements also resulted in added time and therefore cost on the part of MSCI and the CSA. The CSA noted that the agency has since implemented a more risk-based approach for other projects. But, again, the onerous reporting and oversight may have been necessary given the lack of capacity and expertise on the part of the prime contractor.

The financial data for NEOSSat provided by the CSA indicates that the CSA has in fact overspent on internal resources allocated to NEOSSat. The contract costs have not increased (i.e., no additional funding was provided to MSCI), and the CSA has not overspent on the risk allocation budget. Much of the overspending vis-à-vis internal costs stems from the lack of capacity and experience on the part of MSCI and the need for DND and the CSA to provide the missing technical capacity. The CSA and DND implicitly committed themselves to providing assistance when deciding to continue with MSCI as the contractor. From an economy perspective, the CSA and DND choose to spend internal resources to assist the contractor rather than loose what resources had already been spent on NEOSSat.

From a total cost perspective, if there is agreement that the NEOSSat project was underfunded, i.e., the contract with MSCI should have been valued at more than $9.42 million, then the increased use of internal resources on the part of the CSA and DND simply reflects a more accurate cost of NEOSSat, i.e., what the contract should have been valued at.

Management Response and Action Plan

	RESPONSIBILITY ORGANIZATION / FUNCTION	MANAGEMENT RESPONSE	DETAILS OF ACTION PLAN	SCHEDULE
RECOMMENDATION # 1				
Recommendation 1: There is a need for the CSA to establish a process to address risk factors in cases where deficiencies are observed regarding the financial, technical and/or project management of contractor performance during contract execution.	Programs and Integrated Planning Directorate / Director General	Agree	The new methodology for project management will include a process regarding the continuous monitoring of contractors' financial, technical and project management performance.	March 2015
RECOMMENDATION # 2				
Recommendation 2: In order to mitigate potential risks related to contractor capacity, there is a need for the CSA to continue to maintain technical capacity, either internally or available on an as needed basis, to effectively manage projects and to step in and undertake the more technical aspects of a project if a contractor is unable to do so. If the prime contractor does lose capacity then the CSA should ensure it has a way to deal with that risk.	(1) Engineering Development/ Manager (2) Procurement and Contract Administration/ Manager (3) Programs and Integrated Planning Directorate/ Director General	Agree	(1) Identify the key technical expertise and provide input to the CSA HR Strategic Plan. (2) Extend standing offers for engineering services using existing contract options and tools. (3) Provide "Guidelines for Project Intervention" based on a governance decision making protocol to provide internal and external capacity when a need to mitigate deficiencies is encountered.	(1) March 2015 (2) March 2015 (3) December 2014
RECOMMENDATION # 3				
Recommendation 3: The CSA, in collaboration with other federal partners and industry, should define a strategic direction to establish "niche" capacities and capabilities within the Canadian space industry that can exploit trends	Programs and Integrated Planning Directorate / Director General Policy/ Director General	Agree	• Complete the CSA Space Strategy and make it publically available for industry and academia to plan in the long term. • The CSA will lead an Annual Space Conference with all Canadian key stakeholders. The first one	March 2015 Ongoing

	RESPONSIBILITY ORGANIZATION / FUNCTION	MANAGEMENT RESPONSE	DETAILS OF ACTION PLAN	SCHEDULE
and opportunities in the international space marketplace. This would align with the Space Policy Framework and the Aerospace Review, providing firms in the Canadian space sector with direction on anticipated work and facilitating planning and capacity development, allowing the industry and academia to better respond to the needs of the CSA and other federal departments.			is on Feb 25, 2014, at the CSA.	

Appendices

Appendix A: Logic Model and Narrative

Figure A-1 depicts the logic model for the NEOSSat mission. The elements on the far right flowing from Phase E (Satellite Operations) have not yet been fully implemented and are depicted in dashed boxes. Phase E comprises the scientific objectives of the project, while Phases B, C and D focus on the technological objectives related to the NEOSSat project. The logic model includes the elements described below.

Inputs: The NEOSSat mission inputs include FTEs (16.38 as of fiscal year 2012-13) and a total estimated budget of $12,970,577.

Activities: There are three main activities undertaken by the CSA for the NEOSSat mission. The activities of NEOSSat will be implemented sequentially however there will be extensive overlap.

- The Procurement of the required technologies includes the development of technical requirements and concept design, issuance of the request for proposal and management of the contract including monitoring the evolution of costs and timelines negotiating changes resulting from reviews and approving payments. Procurement and management of the resulting contracts are accomplished by means of the CSA's contracting infrastructure.
- Management of the development of the technology includes working in collaboration with the contractors tasked with developing the technologies.
- The management of satellite operations and data collection and use is the ground segment of the NEOSSat mission and involves operating the satellite and processing requests for telescopic observations and receiving and storing of the acquired imagery. The management of data collection and use includes the analysis and dissemination of the scientific results.

Outputs: There are five outputs identified in the logic model which result from the NEOSSat mission activities:

- A design for a standardized multi-mission microsatellite bus that maximizes the commonality between bus components. This is the key technological objective of the NEOSSat mission. This is the key output resulting from activities related to Phases A, B and C of the NEOSSat mission. The design will allow for the building of the microsatellite, which will occur in Phase D;
- An electronic archive of all details pertaining to the NEOSSat project. The electronic archive is the result of all activities related to NEOSSat and is a key deliverable for the contractor. It is expected to be a source of lessons learned and best practices which may be transferred to other CSA or DRDC missions. The electronic archive contains evolving baseline data in an orderly structure based on the NEOSSat system's item hierarchy. The structure and linking of the data is critical to its usefulness. The electronic archive contains:
  - the project requirements, the financial budget, project schedule and risk assessment right from Phase A;
  - the resulting design produced in Phases B and C;

  - the manufacturing, assembly, integration and test results of Phase D;
  - the commissioning data from Phase E and whether the system is meeting mission requirements; and
  - all change approvals to requirements and the forecasted impacts on cost, schedule and risk. Change data would provide the basis for performance measurement and the ability to monitor the evolution in the project's requirements, cost and schedule baselines.

- A microsatellite capable of taking imagery, which is operated through a ground processing of requests for telescope observations, and receiving and storing the acquired imagery. This is one of the two outputs resulting activities related to Phase D of the NEOSSat mission. The building of the satellite will allow for the demonstration of the microsatellite to occur towards the end of Phase D;
- A demonstration of the CSA-developed multi-mission microsatellite bus design and technology. This output will occur at launch of the NEOSSat satellite and will link to the ground segment operations which will occur during Phase E; and
- A ground segment that can process requests for telescope observations, command and control the operations of the microsatellite, and receive and store acquired imagery. This is the key output resulting from activities related to Phase E of the NEOSSat mission.

Immediate Outcomes: There are three immediate outcomes resulting directly from the outputs delivered by the NEOSSat mission.

- Capacity (human and technological) of the Canadian space sector is sustained and strengthened within the CSA itself and as a result of contracts between the CSA and the space sector (including both industry and universities). The increased capacity will flow from contracts related to outputs related to the design and demonstration of a standardized multi-mission microsatellite bus and the microsatellite capable of taking imagery.
- Increased immediate and next-phase usage of lessons learned from NEOSSat during the life-cycle of the project. This outcome flows from the electronic archive of details pertaining to the NEOSSat project.
- An increased proportion (i.e., 50%) of Aten-class asteroids are detected and catalogued and an increased number of objects of particular interest are followed. This is the key science objective of the NEOSSat mission for the CSA. This outcome flows from the ground segment that can process requests for telescope observations, command and control the operations of the microsatellite, and receive and store acquired imagery.

Intermediate Outcomes: There are three intermediate outcomes resulting from the immediate outcomes.

- Increased international competitiveness of Canadian products and services related to space technology as a result of strengthened human and technological capacity. The improved capture and analysis of lessons learned will also contribute directly to the increased competiveness of Canadian products and services in this area since this will allow the CSA, DRDC and contractors to benefit from the lessons learned from NEOSSat and thus improving cost-effectiveness.

- Increased number of partnerships in technology and space science. This will flow from the increased human and technological capacity of the Canadian space sector making the CSA and Canadian industry and academia more appealing partners.
- Science knowledge base concerning asteroids and comets is augmented. This outcome will flow from the identification cataloguing and tracking of Aten-class asteroids.

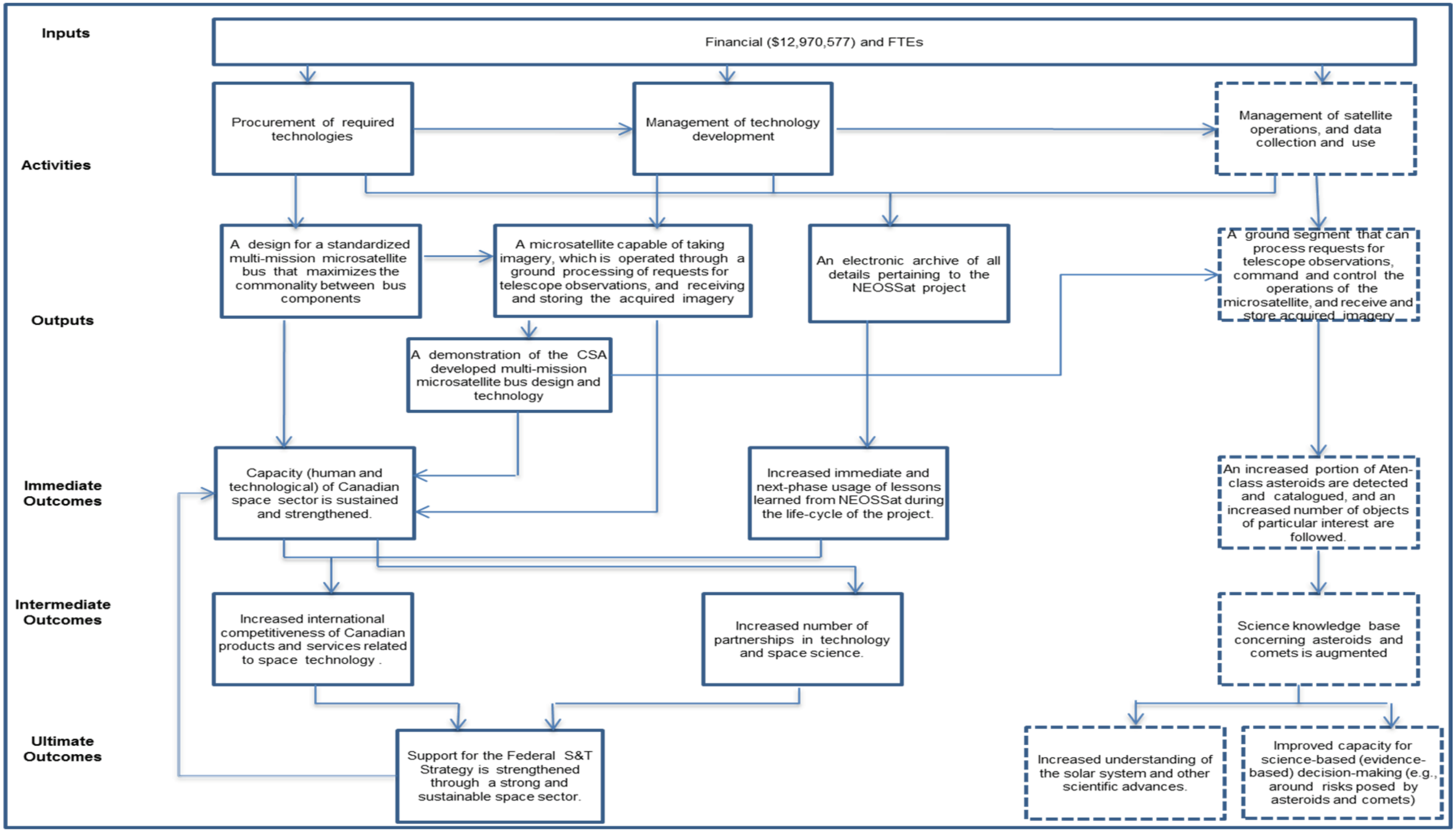
Ultimate Outcomes: There are three ultimate outcomes resulting from the NEOSSat mission:

- Support for the Federal S&T Strategy is strengthened through a strong and sustainable space sector as a result of increased international competitiveness and the increased number of partnerships. This outcome is achieved by contributing to all three pillars of the S&T Strategy:
  - Entrepreneurial advantage, through the contribution to private sector involvement and the potential commercialization of the design and technology developed;
  - Knowledge advantage, through the development of a unique micro bus multi-mission platform; and
  - People advantage, through the sustained and strengthened capacity of the Canadian space sector.

Support for the Federal S&T Strategy will in turn further strengthen and sustain the Canadian space sector.

- Increased understanding of the solar system and other scientific advances. This outcome flows from the increased science knowledge related to Aten and Astiras-asteroids.
- Improved capacity for science-based (evidence-based) decision making in areas related to risks posed by asteroids and comets. This outcome will flow from the increase in knowledge base about asteroids. The knowledge about asteroids and comets will facilitate more informed decision making based on science.

Figure A-1: NEOSSat Logic Model



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Appendix C: Interview Guides

Evaluation of the NEOSSat Project -- Interview Guide – Interviews within the Canadian Space Agency

A. Background

Thank you for agreeing to be interviewed as part of the Evaluation of the Near Earth Object Surveillance Satellite (NEOSSat) project. The Canadian Space Agency has engaged a team of outside evaluation specialists to conduct this independent evaluation.

The objectives of the NEOSSat project are to:

- Develop an affordable multi-mission bus that can be used for future CSA and/or DND missions.
- Discover new asteroids and comets and monitor their trajectories.
- Develop technology and expertise for monitoring satellites and debris in medium Earth orbits (MEO) and geosynchronous Earth orbits (GEO).

The total estimated cost of the NEOSSat mission is $25 million, of which the CSA is contributing $13 million and Department of National Defence (DND) $12 million.

The objectives of the evaluation study are to assess the continued relevance of the objectives of the NEOSSat project and its performance in achieving those objectives. The study is focusing on the CSA's investment in the project (and not DND's).

The evaluation involves a number of data collection activities, including interviews within the CSA and with several partners, members of the science team and potential users of data that will be generated by NEOSSat.

Your views will be kept confidential by the evaluation team, and only aggregated results will be included in the evaluation report. Once approved, the final evaluation report will be made public by the CSA in accordance with Treasury Board policy.

Your interview is expected to last up to one hour.

B. Questions

Please review the following questions in advance of your interview. If you have no opinion on a particular question, feel free to skip it.

1) **Relevance.** One of the original objectives of the NEOSSat mission was to develop an affordable microsatellite technology that could be used for future CSA and DND microsatellite missions. In your view, is this objective still relevant today? What gaps would exist if the NEOSSat mission had not been developed?

2) **Needs addressed.** What scientific and societal needs does the NEOSSat mission address? Is there any overlap between the needs addressed by NEOSSat and other projects or missions?

3) **Alignment with government priorities**. How do the overall objectives of the NEOSSat mission (stated above) currently fit with the CSA and broader federal government priorities such as the Federal S&T Strategy, job creation, etc.? Are there any documents you can point to that would help demonstrate this alignment?

4) **Government funding of space R&D.** Is the level of funding a barrier to the conduct of space-related R&D? Do you believe it is appropriate for the federal government to stimulate R&D in the space industry by directly funding R&D?

5) **Implementation.** To what extent has the NEOSSat project been implemented as initially planned? What, if any, challenges have been encountered? How were these challenges addressed?

6) **Outputs.** Has NEOSSat produced – or likely to produce – the following outputs:

    a) A design for a standardized multi-mission microsatellite bus that maximizes the commonality reusability between bus components across missions?

    b) An electronic archive of all details (i.e., design, engineering, test data) pertaining to the NEOSSat project?

    c) A microsatellite capable of taking imagery, which is operated through ground processing of requests for telescope observations?

    d) A ground segment that can process requests for telescope observations, command and control the operations of the microsatellite, and receive and store acquired imagery?

    e) A demonstration of the CSA-developed multi-mission microsatellite bus design and technology?

7) **Immediate outcomes.** Has NEOSSat achieved – or likely to achieve – the following short-term outcomes:

    a) Contribute to sustained and/or strengthened capacity of the Canadian space sector (including government, academia and industry)? For example: creation of jobs for highly qualified personnel; building of new infrastructure; or development of new product designs with product potential.

    b) Lessons learned via NEOSSat have been used and will be incorporated into subsequent missions?

    c) Contribute to an increased portion of Aten-class asteroids being detected and catalogued? How likely is it that NEOSSat will contribute to an increase in the number of objects of particular interest followed? (Note: the goal is to detect 50% of Aten-class asteroids.)

8) **Intermediate outcomes.** Is NEOSSat likely to achieve the following intermediate outcomes:

a) Help position Canadian companies for export opportunities? For example, what is the current market potential for a microsatellite such as NEOSSat? Have there been any spinoffs or technology transfer from NEOSSat technology?

b) Contribute to an increase in the number of partnerships in technology and space science?

c) Contribute to the science knowledge base concerning asteroids and comets? For example, are you aware of any conference presentations and publications in peer-reviewed journals related to NEOSSat that have been made?

9) **Ultimate outcomes.** Finally, is NEOSSat likely to achieve its longer-term outcomes:

a) Contribute to increased support for the federal S&T strategy, e.g., a strong and sustainable space sector?

b) Contribute to an increased understanding of the solar system and other scientific advances?

c) Contribute to an improved capacity for science-based decision making (e.g., around the risks posed by asteroids and comets)?

10) **Design.** Is the NEOSSat project design appropriate for ensuring the mission is successful?

11) **Unintended impacts.** To your knowledge, have there been any unintended impacts from the NEOSSat project (either positive or negative)?

12) Economy and efficiency:

a) Could NEOSSat's outputs have been produced at a lower cost? How appropriate were the amounts of financial and human resources allocated to NEOSSat?

b) Could the project's activities been carried out in a more efficient manner?

c) Might there have been entirely different ways of achieving the intended outcomes at a lower cost?

13) **Other comments.** Finally, do you have any other comments regarding NEOSSat that have not been covered above?

Evaluation of the NEOSSat Project -- Interview Guide – Interviews with Canadian Space Agency Partners

A. Background

Thank you for agreeing to be interviewed as part of the Evaluation of the Near Earth Object Surveillance Satellite (NEOSSat) project. The Canadian Space Agency has engaged a team of outside evaluation specialists to conduct this independent evaluation.

The objectives of the NEOSSat project are to:

- Develop an affordable multi-mission bus that can be used for future CSA and/or DND missions.
- Discover new asteroids and comets and monitor their trajectories.
- Develop technology and expertise for monitoring satellites and debris in medium Earth orbits (MEO) and geosynchronous Earth orbits (GEO).

The total estimated cost of the NEOSSat mission is $25 million, of which the CSA is contributing $13 million and Department of National Defence (DND) $12 million.

The objectives of the evaluation study are to assess the continued relevance of the objectives of the NEOSSat project and its performance in achieving those objectives. The study is focusing on the CSA's investment in the project (and not DND's).

The evaluation involves a number of data collection activities, including interviews within the CSA and with several partners, members of the science team and potential users of data that will be generated by NEOSSat.

Your views will be kept confidential by the evaluation team, and only aggregated results will be included in the evaluation report. Once approved, the final evaluation report will be made public by the CSA in accordance with Treasury Board policy.

Your interview is expected to last up to one hour.

B. Questions

Please review the following questions in advance of your interview. If you have no opinion on a particular question, feel free to skip it.

1) **Relevance.** One of the original objectives of the NEOSSat mission was to develop an affordable microsatellite technology that could be used for future CSA and DND microsatellite missions. In your view, is this objective still relevant today? What gaps would exist if the NEOSSat mission had not been developed?

2) **Needs addressed.** What scientific and societal needs does the NEOSSat mission address? Is there any overlap between the needs addressed by NEOSSat and other projects or missions?

3) **Government funding of space R&D.** Is the level of funding a barrier to the conduct of space-related R&D? Do you believe it is appropriate for the federal government to stimulate R&D in the space industry by directly funding R&D?

4) **Implementation.** To what extent has the NEOSSat project been implemented as initially planned? What, if any, challenges have been encountered? How were these challenges addressed?

5) **Immediate outcomes.** Has NEOSSat achieved – or likely to achieve – the following short-term outcomes:

   a) Contribute to sustained and/or strengthened capacity of the Canadian space sector (including government, academia and industry)? For example: creation of jobs for highly qualified personnel; building of new infrastructure; or development of new product designs with product potential.

   b) Lessons learned via NEOSSat have been used and will be incorporated into subsequent missions?

   c) Contribute to an increased portion of Aten-class asteroids being detected and catalogued? How likely is it that NEOSSat will contribute to an increase in the number of objects of particular interest followed? (Note: the goal is to detect 50% of Aten-class asteroids.)

6) **Intermediate outcomes.** Is NEOSSat likely to achieve the following intermediate outcomes:

   a) Help position Canadian companies for export opportunities? For example, what is the current market potential for a microsatellite such as NEOSSat? Have there been any spinoffs or technology transfer from NEOSSat technology?

   b) Contribute to an increase in the number of partnerships in technology and space science?

   c) Contribute to the science knowledge base concerning asteroids and comets? For example, are you aware of any conference presentations and publications in peer-reviewed journals related to NEOSSat that have been made?

7) **Ultimate outcomes.** Finally, is NEOSSat likely to achieve its longer-term outcomes:

   a) Contribute to increased support for the federal S&T strategy, e.g., a strong and sustainable space sector?

   b) Contribute to an increased understanding of the solar system and other scientific advances?

   c) Contribute to an improved capacity for science-based decision making (e.g., around the risks posed by asteroids and comets)?

8) **Design.** Is the NEOSSat project design appropriate for ensuring the mission is successful?

9) **Unintended impacts.** To your knowledge, have there been any unintended impacts from the NEOSSat project (either positive or negative)?

10) Economy and efficiency:

a) Could NEOSSat's outputs have been produced at a lower cost? How appropriate were the amounts of financial and human resources allocated to NEOSSat?

b) Could the project's activities been carried out in a more efficient manner?

c) Might there have been entirely different ways of achieving the intended outcomes at a lower cost?

11) **Other comments.** Finally, do you have any other comments regarding NEOSSat that have not been covered above?

Evaluation of the NEOSSat Project -- Interview Guide – Interviews with Science Team

A. Background

Thank you for agreeing to be interviewed as part of the Evaluation of the Near Earth Object Surveillance Satellite (NEOSSat) project. The Canadian Space Agency has engaged a team of outside evaluation specialists to conduct this independent evaluation.

The objectives of the NEOSSat project are to:

- Develop an affordable multi-mission bus that can be used for future CSA and/or DND missions.
- Discover new asteroids and comets and monitor their trajectories.
- Develop technology and expertise for monitoring satellites and debris in medium Earth orbits (MEO) and geosynchronous Earth orbits (GEO).

The total estimated cost of the NEOSSat mission is $25 million, of which the CSA is contributing $13 million and Department of National Defence (DND) $12 million.

The objectives of the evaluation study are to assess the continued relevance of the objectives of the NEOSSat project and its performance in achieving those objectives. The study is focusing on the CSA's investment in the project (and not DND's).

The evaluation involves a number of data collection activities, including interviews within the CSA and with several partners, members of the science team and potential users of data that will be generated by NEOSSat.

Your views will be kept confidential by the evaluation team, and only aggregated results will be included in the evaluation report. Once approved, the final evaluation report will be made public by the CSA in accordance with Treasury Board policy.

Your interview is expected to last up to one hour.

B. Questions

Please review the following questions in advance of your interview. If you have no opinion on a particular question, feel free to skip it.

1) **Needs addressed.** What scientific and societal needs does the NEOSSat mission address? Is there any overlap between the needs addressed by NEOSSat and other projects or missions?

2) **Government funding of space R&D.** Is the level of funding a barrier to the conduct of space-related R&D? Do you believe it is appropriate for the federal government to stimulate R&D in the space industry by directly funding R&D?

3) **Implementation.** To what extent has the NEOSSat project been implemented as initially planned? What, if any, challenges have been encountered? How were these challenges addressed?

4) **Outputs.** Has NEOSSat produced – or likely to produce – the following outputs:

   a) A design for a standardized multi-mission microsatellite bus that maximizes the commonality reusability between bus components across missions?

   b) An electronic archive of all details (i.e., design, engineering, test data) pertaining to the NEOSSat project?

   c) A microsatellite capable of taking imagery, which is operated through ground processing of requests for telescope observations?

   d) A demonstration of the CSA-developed multi-mission microsatellite bus design and technology?

5) **Immediate outcomes.** Has NEOSSat achieved – or likely to achieve – the following short-term outcomes:

   a) Contribute to sustained and/or strengthened capacity of the Canadian space sector (including government, academia and industry)? For example: creation of jobs for highly qualified personnel; building of new infrastructure; or development of new product designs with product potential.

   b) Contribute to an increased portion of Aten-class asteroids being detected and catalogued? How likely is it that NEOSSat will contribute to an increase in the number of objects of particular interest followed? (Note: the goal is to detect 50% of Aten-class asteroids.)

6) **Intermediate outcomes.** Is NEOSSat likely to achieve the following intermediate outcomes:

   a) Contribute to an increase in the number of partnerships in technology and space science?

   b) Contribute to the science knowledge base concerning asteroids and comets? For example, are you aware of any conference presentations and publications in peer-reviewed journals related to NEOSSat that have been made?

7) **Ultimate outcomes.** Finally, is NEOSSat likely to achieve its longer-term outcomes:

   a) Contribute to increased support for the federal S&T strategy, e.g., a strong and sustainable space sector?

   b) Contribute to an increased understanding of the solar system and other scientific advances?

   c) Contribute to an improved capacity for science-based decision making (e.g., around the risks posed by asteroids and comets)?

8) **Design.** Is the NEOSSat project design appropriate for ensuring the mission is successful?

9) **Unintended impacts.** To your knowledge, have there been any unintended impacts from the NEOSSat project (either positive or negative)?

10) **Economy and efficiency:**

a) Could NEOSSat's outputs have been produced at a lower cost? How appropriate were the amounts of financial and human resources allocated to NEOSSat?

b) Could the project's activities been carried out in a more efficient manner?

c) Might there have been entirely different ways of achieving the intended outcomes at a lower cost?

11) **Other comments.** Finally, do you have any other comments regarding NEOSSat that have not been covered above?

Appendix D: Evaluation Matrix

Relevance *Does the program remain consistent with and contribute to the federal government priorities and address actual needs?*		
Question	***Indicators***	***Sources/Methods***
1. Is there a continued need for the CSA to be involved in a microsatellite project such as NEOSSat?	1.1 Assessment/demonstration of ongoing societal and scientific needs for the NEOSSat mission or future missions such as NEOSSat.	› Document review (e.g., Treasury Board Submissions, Project Brief for Effective Project Approval) Dr. Hildebrand initial discussion paper (~2001) › Key informant interviews: ¤ CSA managers and staff.
2. Is the NEOSSat project aligned with federal government priorities?	2.1 NEOSSat aligns with the 2007 Federal S&T Strategy and other federal priorities, including job creation.	› Document review (e.g., Federal S&T Strategy, Departmental Performance Report, Report on Plans and Priorities) › Key informant interviews: ¤ CSA managers and staff.
	2.2 NEOSSat's objectives are aligned with current CSA priorities.	› Document review (CSA Report on Plans and Priorities, CSA Departmental Performance Report, current Program Activity Architecture, Project Brief for Effective Project Approval). › Key informant Interviews: ¤ CSA managers and staff.
3. Is the NEOSSat project consistent with federal roles and responsibilities?	3.1 NEOSSat falls under federal government jurisdiction.	› Document review (e.g., the CSA Act, 1990, Treasury Board Submission).
	3.2 Evidence of a need for the federal government to fill R&D gaps in the space sector (i.e., evidence of a funding barrier in space-related R&D).	› Document review (e.g., Treasury Board Submission, Aerospace Review Report Volumes 1&2). › Key informant interviews: ¤ CSA managers and staff. ¤ Partners. ¤ Science team.

<table>
<tr><th colspan="3">Performance
Has the program achieved its intended outcomes? Are the most appropriate, efficient and economic means being used to achieve outcomes?</th></tr>
<tr><th>Question</th><th>Indicators</th><th>Sources/Methods</th></tr>
<tr><td rowspan="3">4. To what extent have DIRECTION, VERIFICATION AND EVALUATION NEOSSat activities been implemented as intended?</td><td>4.1 Extent to which NEOSSat activities have been implemented as originally planned.</td><td>› Document review (e.g., activity tracking, review, progress and approval documents at/during each project phase).
› Key informant interviews:
¤ CSA managers and staff.
¤ Partners.
¤ Science team.</td></tr>
<tr><td>4.2 Challenges encountered in implementing NEOSSat activities and implications for success of NEOSSat.</td><td>› Document review (e.g., activity tracking, review, progress and approval documents at/during each project phase).
› Key informant interviews:
¤ CSA managers and staff.
¤ Partners.
¤ Science team.</td></tr>
<tr><td>4.3 Extent to which challenges were mitigated.</td><td>› Document review (e.g., activity tracking, review, progress and approval documents at/during each project phase).
› Key informant interviews:
¤ CSA managers and staff.
¤ Partners.
¤ Science team.</td></tr>
<tr><td colspan="3">5. To what extent has NEOSSat produced its expected outputs?</td></tr>
<tr><td rowspan="2">5a. A design for a standardized multi-mission microsatellite bus that maximizes the reusability of bus components across missions</td><td>5a.1 Extent to which NEOSSat maximizes the reusability of bus components across missions.</td><td>› Document review (e.g., activity tracking, review, progress and approval documents at/during each project phase).
› Key informant interviews:
¤ CSA managers and staff.
¤ Partners.</td></tr>
<tr><td>5a.2 Extent to which the NEOSSat bus will serve as a source of lessons</td><td>› Document review (e.g., activity tracking, review,</td></tr>
</table>

Performance		
Has the program achieved its intended outcomes? Are the most appropriate, efficient and economic means being used to achieve outcomes?		
Question	***Indicators***	***Sources/Methods***
	learned to provide adjustments to future mission activities that increase value for money.	progress and approval documents at/during each project phase) › Key informant interviews: ¤ CSA managers and staff. ¤ Partners.
5b. An electronic archive of all details (i.e., design, engineering, test data) pertaining to the NEOSSat project [Note: pertains to Phases B, C and D].	5b.1 Existence of an archive of details *(i.e., design, engineering, test data)* pertaining to the NEOSSat project.	› Document review (e.g., activity tracking, review, progress and approval documents at/during each project phase). › Key informant interviews: ¤ CSA managers and staff. ¤ Partners.
5c. A microsatellite capable of taking imagery, which is operated through ground processing of requests for telescope observations [Note: pertains to Phase E).	5c.1 NEOSSat is capable of taking imagery.	› Document review (e.g., activity tracking, review, progress and approval documents at/during each project phase). › Key informant interviews: ¤ CSA managers and staff. ¤ Partners. ¤ Science team. ¤ Users of NEOSSat data. › Quality standards of the US Space Surveillance Networks.
5d. A ground segment that can process requests for telescope observations, command and control the operations of the microsatellite, and receive and store acquired imagery	5d.1 Existence of a ground segment that can process requests for telescope observations, command and control the operations of the microsatellite, and receive and store the acquired imagery.	› Document review (e.g., activity tracking, review, progress and approval documents at/during each project phase) › Key informant interviews: ¤ CSA managers and staff ¤ Science team ¤ Users of NEOSSat data.
5e. A demonstration of the CSA-developed multi-mission microsatellite bus design and technology	5e.1 Success of the NEOSSat project in demonstrating and launching a multi-mission microsatellite	› Document review (e.g., activity tracking, review, progress and approval documents at/during each project phase).

Performance		
Has the program achieved its intended outcomes? Are the most appropriate, efficient and economic means being used to achieve outcomes?		
Question	***Indicators***	***Sources/Methods***
	design and technology.	› Key informant interviews ¤ CSA managers and staff ¤ Partners ¤ Science team.
6. To what extent has NEOSSat achieved its immediate outcomes?		
6a. Extent to which NEOSSat contributed to sustained and/or strengthened capacity of the Canadian space sector?	6a.1 Extent to which NEOSSat contributed to sustained and/or strengthened capacity of the Canadian space sector (industrial, academic, CSA internally).	› Document review. › Key informant interviews ¤ CSA managers and staff ¤ Partners ¤ Science team.
	6a.2 # of FTEs in NEOSSat (industrial, academic, CSA internally).	› Key informant interviews: ¤ CSA managers and staff ¤ Partners ¤ Science team.
6b. To what extent did NEOSSat result in increased immediate and next-phase usage of lessons learned from NEOSSat during the life cycle of the project?	6b.1 Extent to which lessons learned were captured and analyzed.	› Document review. › Key informant interviews: ¤ CSA managers and staff
	6b.2 Extent to which lessons learned are shared.	› Document review. › Key informant interviews: ¤ CSA managers and staff.
	6b.3 Evidence of mechanisms or “triggers” for effective use of lessons learned from NEOSSat.	› Document review. › Key informant interviews: ¤ CSA managers and staff.
	6b.4 Evidence that lessons learned have been (or are likely to be) used in subsequent missions).	› Document review. › Key informant interviews: ¤ CSA managers and staff.
6c. To what is NEOSSat likely to contribute to an increased portion of Aten-class asteroids being detected and catalogued, and objects of particular interest being followed?	6c.1 Extent to which NEOSSat technology is likely to detect and catalogue 50% of Aten-class asteroids.	› Key informant interviews: ¤ CSA managers and staff. ¤ Science team. › Document review.
	6c.2 Likelihood that 50% of Aten-class asteroids will be detected and	› Key informant interviews: ¤ CSA managers and staff.

Performance		
Has the program achieved its intended outcomes? Are the most appropriate, efficient and economic means being used to achieve outcomes?		
Question	**Indicators**	**Sources/Methods**
	their trajectories followed/tracked as a result of NEOSSat.	¤ Science team. ¤ Document review.
7. To what extent has NEOSSat achieved its intermediate outcomes?		
7a. To what extent has NEOSSat facilitated and/or contributed to the competitiveness (i.e., capacity and capability) of Canadian space products and services related to space technology?	7a.1 Extent to which NEOSSat has (or is likely to) contributed to the competitiveness of Canadian products and services.	› Key informant interviews: ¤ CSA managers and staff. ¤ Partners.
	7a.2 Examples of how NEOSSat has contributed to the competitiveness of Canadian products and services.	› Key informant interviews: ¤ CSA managers and staff. ¤ Partners.
	7a.3 Current market potential for a microsatellite such as NEOSSat.	› Document review. › Key informant interviews. ¤ CSA managers and staff. ¤ Partners. ¤ NASA. ¤ Japanese Space Agency (JAXA). ¤ Euro Space Agency.
	7a.4 Spinoffs from NEOSSat technology.	› Key informant interviews: ¤ CSA managers and staff. ¤ Partners.
	7a.5 Extent to which NEOSSat has positioned Canadian companies for export opportunities.	› Key informant interviews ¤ CSA managers and staff. ¤ Partners.
7b. To what extent has the NEOSSat project contributed to an increase in the number of partnerships in technology and space science?	7b.1 Extent to which NEOSSat has contributed to inter-departmental, national and international partnerships.	› Document review. › Key informant interviews: ¤ CSA managers and staff. ¤ Partners. ¤ Science teams. › Case study.

Performance *Has the program achieved its intended outcomes? Are the most appropriate, efficient and economic means being used to achieve outcomes?*		
Question	***Indicators***	***Sources/Methods***
	7b.2 Level of satisfaction with partnerships.	› Key Informant Interviews ¤ CSA managers and staff ¤ Partners ¤ Science teams ¤ ESA and NASA › Case study › Document review: ¤ 2001 MOU CSA/DND. ¤ 2005 Supporting Arrangement.
7c. To what extent did NEOSSat contribute to an increased science knowledge base concerning asteroids and comets?	7c.1 Extent to which NEOSSat has the potential to contribute to the knowledge base related to asteroids and comets.	› Document review. › Key informant interviews: ¤ CSA managers and staff. ¤ Science team. ¤ Users of NEOSSat data. ¤ US Space Surveillance Network.
8. Is the NEOSSat project design appropriate for achieving expected results?	8.1 Clearly defined and understood governance structure, including program processes, roles, responsibilities and accountabilities.	› Document review. › Key informant interviews: ¤ CSA managers and staff. ¤ Partners. ¤ Science team.
	8.2 NEOSSat resources/capacity commensurate with expected program results.	› Document review. › Key informant interviews: ¤ CSA managers and staff.
	8.3 Appropriateness of NEOSSat activities, processes and governance structures.	› Key informant interviews: ¤ CSA managers and staff. ¤ Partners. ¤ Science team.
9. Have there been any unintended (positive or negative) outcomes?	9.1 Presence/absence of unintended outcomes.	› Document review.
10. Is the project undertaking activities and producing outputs in the most efficient manner? › How could the efficiency of the project's	10.1 Actual versus planned expenditures.	› Financial analysis.
	10.2 Cost of producing NEOSSat outputs has been minimized	› Key informant interviews: ¤ CSA managers and staff.

Performance *Has the program achieved its intended outcomes? Are the most appropriate, efficient and economic means being used to achieve outcomes?*		
Question	***Indicators***	***Sources/Methods***
activities be improved? › Are there alternative, more efficient, ways of delivering the project?	relative to the technical requirements (i.e., costs have been as low as possible).	¤ Partners. ¤ Science team.
	10.3 Possible improvements to the efficiency of NEOSSat activities.	› Key informant interviews: ¤ CSA managers and staff. ¤ Partners. ¤ Science team.
	10.4 Possible alternatives, more efficient, ways of delivering program activities and outputs.	› Key informant interviews: ¤ CSA managers and staff. ¤ Partners. ¤ Science team.
11. Is the project achieving its intended outcomes in the most economical manner?	11.1 Extent to which NEOSSat's intended outcomes have been achieved at the least possible program cost.	› Financial analysis. › Case study.
	11.2 Extent to which good value is being obtained with respect to the use of public funds.	› Key informant interviews: ¤ CSA managers and staff. ¤ Partners. ¤ Science team. ¤ Users of NEOSSat data. › Case study.
	11.3 Extent to which the NEOSSat mission was effectively performed at lower cost relative to larger conventional platforms.	› Key informant interviews: ¤ CSA managers and staff. ¤ Partners.
	11.4 Evidence of/views on whether there are alternative means through which to achieve the same expected outcomes at a lower-cost	› Key Informants Interviews: ¤ CSA managers and staff. ¤ Partners. › Case study.