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OPERATIONAL USE OF SMALL SATELLITES FOR THE CANADIAN ARMED FORCES

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The boundary between research and militarily operational space systems can be somewhat blurry and there are barriers that inhibit transitions from one to the other. Examples of these barriers include issues related to reliability, security and business models. This paper will discuss this boundary and the accompanying barriers from the point of view of small space systems. This paper uses experiences from the development of Canada's Near-Earth Object Surveillance Satellite (NEOSSat) and Maritime Monitoring and Messaging Micro-Satellite (M3MSat) microsatellites to inform this discussion.

1 Introduction

With the increasing prevalence of small spacecraft technologies there is an associated push to use small satellites, microsatellites and nanosatellites for operational purposes. Defence Research and Development Canada (DRDC) has supported the development of microsatellite and nanosatellite technologies in Canada with a view toward helping enable low cost space systems for the Canadian Armed Forces (CAF). For example, DRDC has helped develop and test new technologies by providing financial support to the Canadian Advanced Nanospace eXperiment (CanX) program at the University of Toronto Institute for Aerospace Studies - Space Flight Laboratory (UTIAS-SFL), including the CanX-2, CanX-4&5 and CanX-7 missions. In addition DRDC, in partnership with the Canadian Space Agency (CSA), is a main customer for the Maritime Monitoring and Messaging Micro-Satellite (M3MSat) and Near-Earth Object Surveillance Satellite (NEOSSat) missions.

The involvement of the Department of National Defence (DND) with small space systems is not limited to the Research and Development (R&D) sphere. Data from COM DEV's Nanosatellite Tracking Ships (NTS) spacecraft was sold to the Government and used as part of security operations for the Vancouver Olympics, and the SAPPHIRE satellite is providing operational space surveillance data to the United States (US) Space Surveillance Network (SSN).

The low price point and shorter development times promised by the microspace philosophy are attractive for future missions, but key issues remain to be addressed before small space systems can be embraced for operational missions. Among these issues is the necessity for operational accreditation of systems before they can be used by the military. This accreditation includes requirements such as security, reliability, performance, mission length, compatibility with coalition partners, export controls, and disposal plans.

Other issues involve understanding how best to perform space operations for the CAF, a topic which must include military doctrine. Examples of some questions that need to be addressed involve the difference between tactical and strategic assets and the use of data from privately owned and/or operated sources as opposed to government owned assets. Some of these concerns can ultimately force development schedules and greatly drive costs.

DRDC has confronted many of these issues during the planning and development of the NEOSSat and M3MSat missions. Insights from these and other related projects will be discussed.

2 Background

This section overviews several key topics of this paper. First, two different approaches to space systems development, Canada's military space arena, military spacecraft design philosophy, as well as small and microsatellite approaches are discussed in Sections 2.1, Section 2.2, and Section 2.3. The differences between strategic and tactical style mission is discussed in Section 2.4. In addition, a summary of some recent Canadian space missions is provided in Section 2.5. An operational context is provided in Section 2.6 followed by a discussion about personnel related issues in Section 2.7. Finally, the R&D context is provided in Section 2.8.

2.1 Military Space in Canada

Typical space capabilities for the CAF include Intelligence, Surveillance and Reconnaissance (ISR), Positioning Navigation and Timing (PNT), Space Situational Awareness (SSA), and Satellite Communication (SATCOM). With respect to procurement of space capabilities, Canada's DND and the CAF focus less on the specific system being procured and more on the capability sought to fill the need that has been identified. In effect, with respect to military space, DND does not necessarily seek to procure specific satellites or specific satellite bus types, nor do they seek large satellites over small satellites. Instead, they are interested in supplying capability to the CAF. For example, if the DND identifies a 15 year capability gap in a certain area they may seek to fill this gap with a single 15 year satellite mission, multiple shorter satellite missions, a satellite constellation, procure data/ services on the international market, or some other option depending on the results of an Option Analysis (OA). Capability gaps may include contribution to an existing operational system in use within the CAF or larger capability that is operated by one of Canada's international partners or may be a new capability area for the CAF. Often, these projects are seen as large scale capital procurements to establish strategic capabilities. For example, DND has partnered with the US for the Wideband Global SATCOM (WGS) constellation on Advanced Extremely High Frequency (AEHF) [1, 2, 3]. The CAF now also contributes to the US SSN with SAPPHIRE, an example of Canada contributing to an existing military capability operated by an international partner [4, 5]. More details on these specific satellite systems will be provided in Section 2.5.

2.2 Military Spacecraft Design Philosophy

Historically, military space systems are ``large and very expensive spacecraft with long operational life and, unfortunately, an equally long development cycle'' [6]. These systems are designed to be highly reliable, leading to long development cycles and risk aversion. Although there is a push within the US, for example, to move away from the large and aggregated systems, historical practices are still present [7].

2.3 Small Satellites and Microspace

The microspace philosophy pushes spacecraft designers to develop low cost spacecraft within tightly integrated teams and relatively short time frames. Organisations following this approach often use Commercial Off The Shelf (COTS) components and a *build early and test often* mentality. They also tend to focus on low overhead and are light on documentation when possible. This approach has yielded a number of small spacecraft buss classifications, as defined in Table 1. Several organizations market small satellites based on the concept of building *off the shelf* small satellite missions, for example Surrey Satellite Technology Ltd (SSTL) and UTIAS-SFL. [6, 8, 9]

Satellite Class	Mass Range
MiniSatellite	100 to 500 kg
MicroSatellite	10 to 100 kg
NanoSatellite	1 to 10 kg
PicoSatellite	0.1 to 1 kg

Table 1: Small Satellite Class Definitions [6].

2.4 Strategic vs. Tactical Missions

Operational space missions in Canada are typically viewed as *strategic* in nature. The term *strategic*, from the term *strategy*, is defined as ``relating to the gaining of overall or long-term military advantage'' [10]. These space systems are often controlled from a command center, have their data analyzed by specialists who provide the results of the data to strategic decision makers. This can then lead to orders being sent to forces in the field, or can inform government policy. These types of projects have rigid Standard Operating Procedures (SOPs) and Concept of Operations (CONOPS) and have management offices to oversee their life cycle and operations. By contrast, emerging space technologies are beginning to allow for space systems to be viewed as tactical systems which are used in the field. *Tactical operations* are defined as ``military operations conducted on the battlefield, generally in direct contact with the enemy'' [11]. By contrast to the more traditional strategic style systems, these systems advertise relatively lower costs and represent the *good enough solution* for military needs. They tend to be focused more on direct tasking and use of these assets from the field. Although there is no specific policy that addresses use space assets in a tactical manner, historical activities, attitudes and vestigial practices have prevailed.

2.5 Selected Canadian Missions with CAF Involvement

A list of select missions with CAF involvement is provided in Table 2. The examples in the table include spacecraft developed using a variety of mechanisms. Some are research activities funded to academic institutions by the government. Others are government owned and operated satellites for operational use. These missions will be used as examples for this paper.

2.6 Operational Context

From the perspective of the CAF, operational space systems are systems which provide the CAF capabilities that

Mission	Description
CanX-2, CanX-4&5, and CanX-7	Government sponsored nanosatellite technology demonstrations at UTIAS-SFL. [12, 13, 14]
NEOSSat	SSA and asteroid detection research satellite. Government owned and operated. [15, 16]
M3MSat	AIS detection research satellite. Government owned and operated. Data sharing agreement with exactEarth. [17]
NTS	Technology demonstration of AIS signal detection from space. Developed for COM DEV by UTIAS-SFL. Some data sold to CAF for support to operations during 2010 Olympics. [18]
SAPPHIRE	Operational SSA spacecraft for CAF. Owned by government, contractor operated. [4, 5]
RADARSAT-1	Decommissioned operational spacecraft for ISR. Government owned and contractor operated. [1]
RADARSAT-2	Privately owned spacecraft for ISR. Government prepaid for imagery through development funding. [19, 20]
RCM	Three operational spacecraft for ISR currently under development. Government owned and operated. [21]
Commercial services	The Canadian Government manages a set of standing offers with private companies for various remote sensing and geospatial data used by the CAF. [22]

Table 2: Select Canadian Space Missions with CAF Involvement.

are used in their operations. These systems must be reliable and available for use when called upon by military commanders. These capabilities form part of the broader military system. As such, reliability and security are crucial and these systems have strictly managed CONOPS and SOPs. They must also be designed to work in concert with existing systems in use within the CAF.

2.7 Personnel

Personnel training is a key factor determining how these systems are implemented. For example, military personnel are typically posted to new positions every few years creating a relatively high turnover environment. As such, corporate memory with respect to the control of individual highly complex satellites can be difficult to maintain, especially as there is no specific space occupation within the CAF. Hence the CAF tends to not operate spacecraft themselves. For example, with the SAPPHIRE spacecraft, operations of the satellite are performed by a contractor and the data is delivered to the CAF [4, 5]. As a result, CAF personnel do not need to be trained on the operations of the specific spacecraft.

As previously mentioned, the CAF does not have a career occupation that is tied to the space domain or the operation of space assets. As a result, space related positions in the CAF are filled by officers and NCM from a variety of technical fields. Examples of these occupations include Aerospace Control Officers (AECs), Aerospace Engineer Officers (AEREs), Communications and Electronics Engineer Officers (CELEs), Aircraft Combat Systems Officers (ACSOs) and Aerospace Control Operators (AC OPs). These personnel are typically drawn from the Royal Canadian Air Force (RCAF) although some are from other occupations within the Canadian Army and the Royal Canadian Navy (RCN). As CAF members are typically posted to new position every few years, when a member is assigned to a space related position they are likely to be posted to an unrelated activity in their next position. Combining these two factors leads to a work force that does not necessarily have the experience or technical depth for performing in house spacecraft operations or spacecraft systems engineering activities, despite the fact that the CAF does employ highly technically competent soldiers. Simply put, without a military occupations dedicated to space related operations it is difficult to generate a workforce with sufficient technical depth for in house space operations.

2.8 Research and Development Context

R&D fills an important role in space systems by integrating and critically evaluating evolving knowledge into new space platforms and techniques. Spacecraft developed for

R&D purposes are in many ways very different from those developed for operational use by the CAF. R&D projects are typically established in order to increase the Technology Readiness Level (TRL) of a specific technology, perhaps for future use to the CAF. Spacecraft developed for R&D missions are best considered as prototypes. For example, TopSat, developed by the United Kingdom (UK), was an ISR prototype satellite designed for technology demonstration to evaluate suitability for national procurement and not for operational use [23]. From this perspective, operational availability and interoperability with other CAF systems are not necessarily requirements for such spacecraft. These missions are potentially a lead up study or demonstrations to risk mitigate a potential capital project. Operational certification is outside of scope.

3 Military Doctrine and Canadian Space Policy

DND has not published an approved space policy since 1998, nor is there specific up to date strategy and doctrine for the CAF in space, although draft documents have been prepared. Key to Canada's defence activities in space is the partnership with the US and the maintenance of that relationship. Historically, Canada has not developed satellites for sole use of the military; traditionally these are joint projects with a *whole of government* focus. SAPPHIRE was the first and is currently the only operational Canadian military satellite that was developed only for DND [4, 5]. Canada does have a space policy framework that outlines Canada's activities in the space sector. CAF space involvement is aligned to the ``whole of government" approach. The policy framework identifies five key areas for Canada's focus in space. They include: ``Canadian Interests First", ``Positioning the Private Sector at the Forefront of Space Activities", ``Progress Through Partnerships", ``Excellence in Key Capabilities", and ``Inspiring Canadians". [24, 25, 26]

When considering the key areas identified in the policy framework within the context of the procurement of space systems and space capabilities in Canada, the policy pushes toward space systems for operational use in highly important and strategic areas. It also encourages for partnerships between organisations, and by extension, countries. Furthermore, it pushes for cutting edge work to be performed in the private sector.

As activities in space are seen as highly strategic for the Government of Canada, and by extension the CAF, and due to the factors previously outlined in this paper, the trend is for the CAF to plan missions that are highly strategic as opposed to tactical missions. This is not only based on their very high cost but also on the role that space capabilities play for Canada. This does not necessarily mean that this requires the procurement of spacecraft to be owned and operated by the Government of Canada.

The main goal is not on procuring satellites or flying space missions, the goal is on gaining access to space capabilities for the forces. This can therefore mean the establishment of a data license agreement with service providers or purchasing capacity from a foreign partner. This is discussed in more detail in Section 4.

4 Schedule, Cost and Risk

This section outlines several schedule, cost, and risk drivers for space projects. It explores these from the perspective of government owned and operated space missions, government owned and contractor operated missions, industry owned and operated with a data license to the government or space services and data being provided by an international partner. Each of these methods presents alternatives with respect to cost, risk and schedule. These models can be used for operational and for R&D missions as well.

4.1 Government Owned and Operated

One approach is for the Government to own and operate spacecraft itself. An advantage with this approach is that the government maintains full control of the mission. A disadvantage is that the government also owns all the risk associated with the project and self-insures the space asset once the spacecraft is delivered. This can include maintenance of the asset and the ground station, training of staff and operators. Should maintenance or other issues arise the government would need to adapt and mitigate these issues. Risk aversion from this paradigm may in turn drive requirements for spacecraft reliability. As timelines for government procurements and activities can have long turnaround times, this can increase mission risk. The RADARSAT-1 project, an operational mission, followed this model [1]. From an R&D perspective, the M3MSat and NEOSSat missions also follow this model [15, 16, 17].

4.2 Government Owned and Contractor Operated

A method of mitigating the risks presented by having the Government perform operations itself could be to contract out the operations of its spacecraft to private companies. This permits access to skilled personnel for operations and development. An advantage of this approach is that the government maintains ownership and control of the spacecraft and how it is operated, however they can isolate themselves from the risks related to personnel and maintenance. Life Cycle Maintenance Management (LCMM) of the ground segment architecture and asset is controlled with in service support contracts. These risks can be delegated to the in service support contractor through contract clauses. Canada's first operational military satellite, SAPPHIRE, follows this model [4, 5].

4.3 Privately Owned and Operated, Data Licensed to Government

Another approach is for the government to purchase access to space based capabilities from a commercial supplier. In this scenario, the government does not necessarily need to concern itself with how the company has engineered the space system or how the system is operated. The government can simplify its interest in the space system to the data it generates or service it provides. This method encapsulates schedule, development and operational risk to the private company. This company will typically insure this space asset and associated resources. Ultimately, from the government's perspective this arrangement becomes a subscription service for space based data or services. In this scenario, the government has less control over what it can do with the data or data service, and is bound by the terms of its contract with the service provider. This can present an issue if the government selects to share its data or use of the space system with another partner as the company may see this partner as a potential customer. From the government's perspective, having a simple contractual arrangement for procuring this data in a timely manner is key. One mechanism is to have a standing offer with various data suppliers, where the contractual agreements are negotiated with potential data vendors in advance [22]. The advantage of this approach is the relative simplicity of contracting only for services from commercial providers; however the government ultimately does not have control of the spacecraft itself.

Examples of such subscription service engagements for the Government of Canada include the standing offers that are maintained with private companies for various remote sensing and geospatial data used by the CAF [22]. A unique case of the use of data procured from a privately owned and operated spacecraft is a credit model. Using this model, the government pre pays for data to offset the development cost of the spacecraft in exchange for data credits once the spacecraft is operational. This method is used with the RADARSAT-2. [19, 20]

4.4 International Partnership

Similar to the method of contracting for space data or services from private industry, space capabilities can also be procured from international partners. In this case, there is dependence on the part of the governments on each other, however this can also be a useful means for ensuring coalition interoperability of systems and can also provide access to space capabilities that are not domestically available to Canada on its own. An example of this is the use of the US Global Positioning System (GPS) to provide PNT capabilities to the CAF. As a partner with the US for GPS, and as a partner in the broader COSPAS-SARSAT organization, Canada's DND is contributing Medium Earth Orbit Search and Rescue (MEOSAR) repeaters for the next generation of GPS satellites [27]. An advantage of this approach is that it allows the government to capitalize on space systems developed by other countries; however there is a dependence on another country's government.

5 Operational Accreditation

This section discusses the complexities of having a system accredited for use by the CAF. These issues include security, reliability, performance, mission length, mission partners and national law and policy.

5.1 Security, Reliability, and Performance

Before the DND will procure any system, it must be confirmed to comply with security, reliability and performance requirements. This can apply to both operational and R&D systems, although whenever a new system is to be used operationally, or interfaces with an operational system the level of scrutiny increases. Security requirements are determined through a Threat Risk Assessment (TRA): a process used to generate a report outlining specific threats, assessed vulnerabilities of the system, calculation of risks, and a set of recommendations to be implemented [28]. This assessment must also consider the impact on existing capabilities. For example, the increasing risks due to collisions with space debris as well as the risk of satellite interference must be assessed [29, 30]. Ultimately, the military must be convinced that the systems will be available and functional when called upon. The system must be responsive to the tempo of operations and not the other way around. Data availability and assurance of service are key to CAF operations.

Naturally the CAF is only interested in data sources that provide an augmented capability to their existing capabilities. Performance requirements must therefore be based upon broader mission objectives from within the CAF and not based on notional performance estimates based on what can be delivered by technology. A militarily useful system does not necessarily require the latest *state of the art* if the mission objectives can be satisfied with solutions already available on the aerospace market. The military can be agnostic of the specific type of technology used to satisfy requirements, whether it is a particular satellite bus, sensor system or partnership with an external partner.

The process of performing these assessments can be highly laborious and time intensive. This leads to a natural tendency to seek to accredit long duration missions as opposed to many smaller missions. This can ensure the worthiness of the effort to pursue this process.

5.2 Mission Length

Generally space activities are seen from a highly strategic lens from which the CAF is seeking to procure long term capabilities. This may partially stem from the complexities of procuring space systems, where a procurement project office may be established, treasury board submissions drafted and approved in order to procure a space system. As the engineering effort is usually completed by contractors the internal effort within the government can be separated between the acquisition and LCMM costs. As procurement within the government is a complex and long duration process, the trend has been to procure longer duration missions for operational missions as opposed to shorter missions which are more typical of R&D missions. Through this approach, few procurement activities are required in order to fill a long term capability gap. In addition, as mentioned in Section 5.1, the long duration of the TRA process adds to the effort required to establish new missions.

5.3 Mission Partners

CAF operations are typically in partnership with a broader coalition of allied nations. For example, Canada's operations with North American Aerospace Defense Command (NORAD) and North Atlantic Treaty Organization (NATO). Such partnerships are typically military to military. As a result, key to operational accreditation may also include accreditation within the context of a system being used with allied systems. For example, the SAPPHIRE satellite is an accredited contributing sensor to the US Joint Space Operations Center (JSpOC). As such, accreditation includes a need to set up Information Technology (IT) linkages between different organizations. In fact, the accreditation process is very much an IT driven process, focused partly on the maintenance of the integrity of existing operational networks. Accreditation of projects with international partnerships typically requires complimentary accreditation activities within each of the partner organisations, which add time and cost to the project. Partnering with other academia and industry can also present similar challenges as any linkages with these partners would also require accreditation.

5.4 National Law and Policy Regulations

As with any space system developed in Canada, several policy and legal factors are involved. For example, Canadian export controls as well as compliance with Canada's space debris mitigation policies and spectrum licensing must be respected. Access to space is another issue as Canada does not possess a domestic space launch capability. This forces Canada to partner with another state to access launch capabilities.

6 Transition from Research to Operational

Unlike space projects designed for operational purposes, R&D based projects are often established in order to progress the state of the art in a particular field of interest, increase the TRL of a specific technology, or demonstrate the feasibility of new techniques. To this end, research organisations such as DRDC are not positioned for addressing operational accreditation or certification requirements intended for adoption of a system by the CAF as LCMM processes are not integrated or required in the DRDC project management structure. Research systems carry with them an increased level of risk that is unattractive to the CAF for operational systems. As such, operational accreditation of research systems is not typical, as the processes outlined in this paper can act as large barriers that scientific teams are not positioned to overcome.

Understanding that research missions are not intended for operational use, this does not exempt them from all of the challenges associated with implementing a space project in Canada. These projects still require a TRA and do need to be sufficiently reliable in order to perform their scientific missions. That said, they do not necessarily have to work within the context of existing CAF systems and can be developed as standalone systems. As these are not intended as operational systems, down time is permissible, depending on the research problem being investigated. They also do not need to deal with tempo of operations. Ultimately, simplicity is key as they may be controlled by a very small team. From this perspective, small short term missions are attractive options for these types of projects. These contrasts are outlined in Table 3. As the fundamental goals of operational and R&D space projects are not in alignment, transition of a project, or space asset, from one type to another is generally complex. A transition of this type would also mean a transfer from an R&D organisation to an operational organisation.

The operational side can inform research teams' lessons learned and operational requirements that need further study or development. In turn, the R&D groups can derisk technologies and capabilities to enable new operational developments. R&D feeds evolving knowledge into future operational capabilities.

7 Conclusion

This paper has explored the process of procuring space capabilities for the CAF for operations as well as for an R&D perspective. Typically, the CAF seeks to procure capabilities to fill long term strategic capability gaps. As

Category	Operational	R&D
Mission intent	Safeguarding life and property.	Technology investigation, important to be first demonstration of new technology.
Expectation of reliability	High reliability.	Expected to not have 100% reliability due to uniqueness of new technology.
System integrity and security	Security requirements are rigorous. Higher benchmark due to integration with operational systems.	Rigour can be reduced if the system does not integrate with operational systems.
System lifetime	Longer operational lifetime. For example, 5-7 years for SAPPHIRE.	Mission length is generally short. For example, 1-2 years for NEOSSat and M3MSat plans.
Sustainment maintenance and operations	Operations cell and LCMM on call.	R&D staff focused on evolving knowledge and research questions, not LCMM.

Table 3: Contrast of Operational and R&D Mission Parameters.

such, these systems must be found to be robust to the operational context, sufficiently secure, and have sufficient performance. Typically, these projects are established for long term use under strict SOPs and rigid CONOPS. By contrast, research projects are not established to procure systems to fill operational gaps, they are intended to increase the TRL of a technology, demonstrate its effectiveness, and help build leading and innovative Canadian industry. Regardless of the mission intent, Canadian law and policy, for example with respect to export controls, debris mitigation, must still be followed, however these projects may not need to consider how the assets will be operated and staffed in the long term. As such, for R&D projects short term tactical style missions can be more attractive options. This can allow the research team to focus more on the R&D as opposed to operations and maintenance related activities.

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A Biography

Mr. Gavigan is a Defence Scientist in the Space Systems and Operations Group at DRDC. He is responsible for applied research in nano, micro and small satellite space systems development with a research emphasis on small space systems integration. He has a bachelor's degree in computer systems engineering from Carleton University, a master's degree in aerospace engineering from the University of Toronto and completed the 2014 Space Studies Program at the International Space University.

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C List of Acronyms

AC OP Aerospace Control Operator

ACSO Aircraft Combat Systems Officer

AEC Aerospace Control Officer

AEHF Advanced Extremely High Frequency

AERE Aerospace Engineer Officer

AIS Automatic Identification System

CAF Canadian Armed Forces

CanX Canadian Advanced Nanospace eXperiment

CELE Communications and Electronics Engineer Officer

CONOPS Concept of Operations

COTS Commercial Off The Shelf

CSA Canadian Space Agency

DND Department of National Defence

DRDC Defence Research and Development Canada

GPS Global Positioning System

ISR Intelligence, Surveillance and Reconnaissance

IT Information Technology

JSpOC Joint Space Operations Center

LCMM Life Cycle Maintenance Management

M3MSat Maritime Monitoring and Messaging Micro-Satellite

MEOSAR Medium Earth Orbit Search and Rescue

NATO North Atlantic Treaty Organization

NCM Non Commissioned Member

NEOSSat Near-Earth Object Surveillance Satellite

NORAD North American Aerospace Defense Command

NTS Nanosatellite Tracking Ships

OA Option Analysis

PNT Positioning Navigation and Timing

RCAF Royal Canadian Air Force

RCM RADARSAT Constellation Mission

RCN Royal Canadian Navy

R&D Research and Development

SATCOM Satellite Communication

SOP Standard Operating Procedure

SSA Space Situational Awareness

SSN Space Surveillance Network

SSTL Surrey Satellite Technology Ltd

TRA Threat Risk Assessment

TRL Technology Readiness Level

UK United Kingdom

US United States

UTIAS-SFL University of Toronto Institute for Aerospace Studies - Space Flight Laboratory

WGS Wideband Global SATCOM