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EXPERIENCE WITH THE MARITIME MONITORING AND MESSAGING MICROSATELLITE (M3MSAT)

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Abstract

The Maritime Monitoring and Messaging Microsatellite (M3MSat) is a technology demonstration mission that will contribute to solving the current difficulties of Canadian maritime surveillance faced by the Canadian Armed Forces (CAF). M3MSat is a joint project between the Canadian Space Agency (CSA), Defence Research and Development Canada (DRDC). M3MSat will be used to evaluate the ability to perform high performance space-based detection of ship transmitted Automated Information System (AIS) signals in dense shipping regions of the Earth. The microsatellite will also perform global maritime surveillance. Integration of the information gathered by the satellite into a recognized maritime picture will make it possible to identify and record marine traffic, determine the direction and speed of vessels, ensure that ships are travelling legally through Canadian waters, and help ensure safety of life at sea. This will ultimately serve to protect public security, national interests, and global operations by improving Intelligence, Surveillance and Reconnaissance (ISR) within Canada. In addition to the AIS data exploitation, the developmental experience with M3MSat will further increase DRDC's expertise in microsatellite system design and operations. This paper discusses the microspace philosophy adopted by DRDC in the development of M3MSat. It presents the lessons learned throughout the satellite development and provides recommendations on how those lessons could be integrated into the development of future CAF microsatellite systems. Most specifically, it addresses project management, requirements definition, standardization and operations. Based on the M3MSat experience, the paper highlights that it is possible to successfully manage a microsatellite project with more than one client organization, although this situation can easily result in a higher number of requirements and expansion of mission scope. It also underlines that striving to achieve bus standardization does not always bring cost savings. Finally, it establishes that streamlined operations can be adequate to achieve microsatellite operational readiness of a technology demonstrator.

1. INTRODUCTION

In the last few years, DRDC has focused most of its space efforts on microsatellites. M3MSat is the latest example. It is a technology demonstration microsatellite mission striving to explore space-based Automated Information System (AIS) technology that is believed to have outstanding potential to contribute to maritime security and hence directly support the Canadian Armed Forces (CAF). This paper highlights key aspects of the M3MSat satellite development where the *microspace* approach worked, as well as areas that could be improved upon in the future development of microsatellites for the Government of Canada. In order to frame the discussion, an outline of the M3MSat mission will be provided followed by a definition of the *microspace* philosophy. A discussion on several lessons learned will then ensue, focussing on the project management, requirements definition, standardization and operations. Finally, key recommendations will be presented.

2. BACKGROUND

Details on M3MSat and the *microspace* philosophy are provided below.

2.1 M3MSat

M3MSat is a technology demonstration mission that will contribute to solving the current difficulties of Canadian maritime surveillance faced by the CAF. It is a joint project between the Canadian Space Agency (CSA), Defence Research and Development Canada (DRDC) and is manufactured by COM DEV International Ltd. with support from the University of Toronto Institute for Aerospace Studies (UTIAS).

M3MSat will be used to evaluate the ability to perform high performance space-based detection of ship transmitted AIS signals. The AIS is a system to improve safety at sea through the broadcasting of signals in the very high frequency (VHF) bands. Since 2004, the International Maritime Organization (IMO) mandates all ships of 300 tons or more sailing in international waters, cargo ships of 500 tons or more not involved in international voyages and all passenger ships to carry an AIS transponder [1]. Ships fitted with an AIS transponder broadcast their positions, speed, heading, and other relevant information, which serve to inform neighbouring vessels and maritime authorities of ship traffic. The AIS signal was intended as a line-of-sight transmission capability and it has a nominal range of 40 nautical miles. It is therefore very useful to manage ship density in ports and other high traffic areas from the coasts. The AIS signal can also be detected from space. With the right spacecraft configuration, space-based AIS detection can allow for the identification of ships anywhere on the Earth surface, which has the potential to greatly increase the long-range maritime picture.

Weighing less than 100 kilograms and about one meter-cube in size, M3MSat will be detecting AIS signals from an orbit between 500 and 600 kilometres. Integration of the information gathered by the satellite into a recognized maritime picture will make it possible to identify and record marine traffic, determine the direction and speed of vessels ensure that ships are travelling legally through Canadian waters, and help ensure safety of life at sea. This will ultimately serve to protect public security, national interests, and global operations by improving ISR within Canada.

In addition to the primary AIS mission, M3MSat has two other secondary payloads led by the CSA: a Low Data Rate Service (LDRS) instruments to demonstrate the transmission of messages from the ground and back, and a Dielectric Deep Charge Monitor (DDCM) sensor, which will assess the level of electrostatic charge accumulation in the spacecraft non-conductive surfaces [2]. Figure 1 illustrates the M3MSat configuration. The M3MSat launch is scheduled for late 2015.

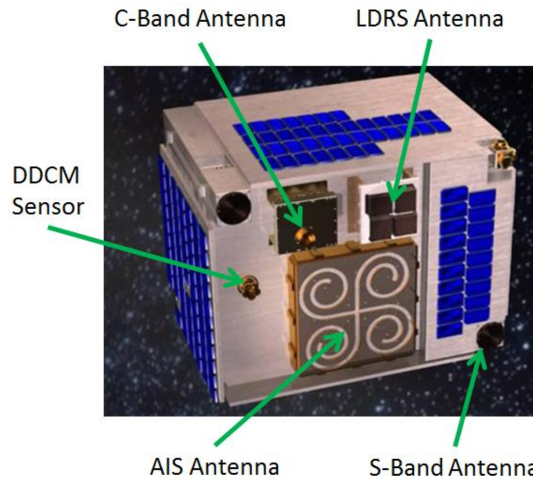

Figure 1. M3MSat Spacecraft

2.2 *MICROSPACE*

DRDC's involvement in space systems is focused on the microsatellites and smaller spacecraft development of technology demonstrators that have the potential to provide a military advantage to the CAF. Microsatellites systems are smaller in sizes (10-100 kilograms) compared to traditional operational spacecraft, and therefore offer the promise of being less costly due to a reduced amount of components and less mass to launch in space. It still costs on average at least US$10,000-20,000 per kilogram to launch in Low Earth Orbit [3], but it can also be a lot more expensive depending on the launch provider. It is also expected that smaller spacecraft will have a narrower mission focus (ideally *one payload, one mission, one customer*) and that their development will require smaller technical and management teams, as well as have a reduced design and development timeline compared to larger systems. The strategy and paradigm behind microsatellite development is sometime referred as the *microspace* philosophy [4].

By nature, a technology demonstrator exists to establish whether a specific technology, approach or concept is viable and/or validate performance parameters. Technology demonstration projects are expected to tolerate a higher level of risk, as they are not proven concepts and despite detailed analysis could fail to yield the expected results. A failure to achieve project objectives due to a hardware or software malfunctions or to other variables not anticipated serves to inform the client that this approach did not work and that alternatives need to be explored. Therefore although the technology demonstration mission might not achieve all of its objectives, it will still serve to determine whether the approach taken is feasible or not. M3MSat is a technology demonstrator developed with the *microspace* philosophy in mind.

3.LESSONS LEARNED

Throughout the M3MSat development, DRDC aimed at applying the *microspace* philosophy. Several relevant lessons learned will be discussed below.

3.1 Management

The *microspace* approach calls for small management teams. It is expected that a microsatellite will offer a limited capability and therefore be less complex and easier to manage. The level of management required is also directly related to the number of customers. Ideally, microsatellite should have only one customer. M3MSat is a joint project between DRDC and the CSA. Although DRDC is the primary customer for the AIS payload, there are two other CSA payloads: the LDRS instruments and the DDCM sensor. The fact that there are multiple payloads and more than one entity involved add an extra burden as all need to be consulted on any decisions taken. In the case of M3MSat, it was understood by all parties that the AIS mission was primary. Furthermore, the integration of the secondary payloads was non-invasive and did not interfere significantly with the main AIS mission; hence it greatly alleviated the potential for conflicting situation due to trade-offs, as there were very few to be made.

The different mandates of each organization can also increase the management complexity. In the case of M3MSat, CSA is an organization, which has for mandate “to promote the peaceful use and development of space, to advance the knowledge of space through science and to ensure that space science and technology provide social and economic benefits for Canadians” [5]. DRDC’s mission on the other hand is: “to provide a strategic knowledge and technology advantage to support defence and security operations at home and abroad with knowledge and technology; provides S&T to forecast, cost, and deliver future readiness levels to meet operational requirements; and, generates knowledge and technology for a robust, connected and multi-jurisdictional security and intelligence environment [6]. Both organizations’ respective mandates do not conflict with each other. In fact, they are quite complementary with the main differences being that DRDC has a single operational client in the CAF and it is focused on defence and security. Moreover, each organization brings a set of experience and expertise that can benefit the development of any projects. In the case of CSA, its representatives brought a wealth of knowledge in spacecraft systems design and satellite operations expertise, which greatly benefitted and complemented the more operational-focused DRDC team.

Building on their partnership with the Near-Earth Object Surveillance Satellite (NEOSSat), also a DRDC-CSA joint microsatellite project, the relationship throughout the M3MSat development worked very well despite being two distinct customer organizations involved in the project. A dedicated small team in each respective organizations, understanding of each other’s mandate and regular communications through meetings, tele-conference calls, visits and emails greatly mitigated the complexity of two customers for a single microsatellite.

3.2 Requirements Definition

As mentioned earlier, ideally a microsatellite will have a narrow mission focus. In the case of M3MSat, although there were two secondary payloads (LDRS and DDCM), it was understood by the management team that the primary mission objective was to deliver space-based AIS data. Based on this agreed objective, the mission requirements were predominantly focused on this goal. The requirements were also influenced by the different background of each organization. DRDC is focused on developing and demonstrating new technologies to serve the CAF operational community. CSA has had years of experience in the development and operations of larger space systems, especially with the Radarsat satellites. Through this legacy, they have acquired extensive experience on operational space systems and have developed detailed standards and standard operating procedures (SOPs). Hence, many procedural and technical requirements outside those specifically related to the performance of the AIS payload and data management requirements were led by the CSA. Although they made the platform more robust which has led to high confidence in the spacecraft performance once in orbit, some of these extra requirements may not have been necessary for a technology demonstration mission.

The potential operationalization of M3MSat, in which the spacecraft would be used to directly support daily CAF operations and space-based AIS commercial activities as opposed to being a R&D effort, also influenced the requirements definition. It has driven more stringent requirements to support better spacecraft performance and a longer term mission. For example, although the mission only calls for the use of one AIS payload, there are two AIS payloads onboard M3MSat which can be used interchangeably. The addition of a second AIS payload does increase the size and mass of the spacecraft as well as its complexity.

3.3 System Standardization

It was required that M3MSat use a generic bus design using the CSA-defined multi-mission microsatellite bus (MMMB) specifications [7]. The MMMB initiative provides a common set of specifications for microsatellite bus design with a goal to reduce non-recurring expenses across a range of microsatellite missions. By using generic subsystems and electronic ground support equipment, it is expected that it will standardize the government microsatellite missions and hence increase efficiency and reduce cost by enabling the use of common protocols and ground infrastructure to support the mission. NEOSSat, also a joint project between DRDC and CSA and which was launched in February 2014, was the first microsatellite to use the MMMB. M3MSat is the second spacecraft to use the same approach.

As M3MSat was the second microsatellite to use the MMMB, it was expected that savings in time and cost could be accomplished. Although the M3MSat bus will undoubtedly help COM DEV to obtain flight heritage on their MMMB design for future government missions with a MMMB requirement, this common microsatellite bus approach also added complexity to the M3MSat development. For example, the spacecraft communications protocol mandated was more complex than would have been necessary to support the AIS mission and the operations of a microsatellite. The protocol implemented was the NASA developed Integrated Test and Operations System (ITOS) [8], which is a comprehensive command and telemetry solutions offering many functionalities not required for M3MSat. Using a similar approach as the UTIAS Generic Nanosatellite Bus control system would have been sufficient and reduce the complexity of the operations [9]. Furthermore, the MMMB specifications called for an Actuator Deployment Terminal (ADT), a system that can be used to deploy equipment from the spacecraft after launch (such as solar panels). This system was not required for M3MSat, although it had to be included in the design to conform to the MMMB specifications.

Comparing NEOSSat and M3MSat, it was learned that using common bus specifications for technology demonstration missions did not yield as much efficiency as expected. Although both used the MMMB design, they each required different mission planning systems due to the dissimilar missions, simulators and ground station requirements. Imposing MMMB specifications for different types of missions can also lead to more complex systems. In a technology demonstration environment such as at DRDC, this increases project complexity as it adds another set of requirements that needs to be met. Without such a constraint, a company could design a spacecraft strictly to fulfil the current mission using the *microspace* philosophy. Moving forward, the trade-off between imposing MMMB requirements and allowing the spacecraft builder to create a more streamlined design should be closely evaluated with regards to technology demonstrators supporting the CAF.

3.4 Operations

Following the *microspace* approach, it is expected that the operations segment will be less complex than for large space missions. Consequently, DRDC as the primary operator looked at a streamlined operations team and ground segment implementation for M3MSat.

3.4.1 Team

The DRDC M3MSat team consists of a small team of operators and engineers, and the required hardware and software to operate the spacecraft. The operational training included theory and hands-on practice on the flatsat (set of flight hardware interconnected to validate spacecraft functionality and bus performance) at DRDC. All members of the operational team were trained on all systems to increase efficiency. This cross-training was supplemented by support from CSA subject matter experts. Training schedules with all required personnel were developed and implemented to ensure operational readiness.

3.4.2 Ground segment

The DRDC ground segment in support of M3MSat is comprised of a ground station and a Mission Operations Centre (MOC). The ground station includes a 9.1meter S-band antenna for Telemetry, Tracking and Command (TT&C), a 4.6meter C-band antenna for AIS data download and antenna controllers. The mission planning software, data management system and spacecraft ground terminal are part of the MOC. Figure 2 displays the ground segment architecture. Although redundancy is present for key systems, adopting the *microspace* philosophy meant that the ground segment is not as robust as a full operational system could be with multiple levels of back-ups available for each system. Through careful risk mitigation, the system was designed to support the operations of space R&D activities and it has been demonstrated to be ready operationally through regular interactions with the M3MSat flatsat.

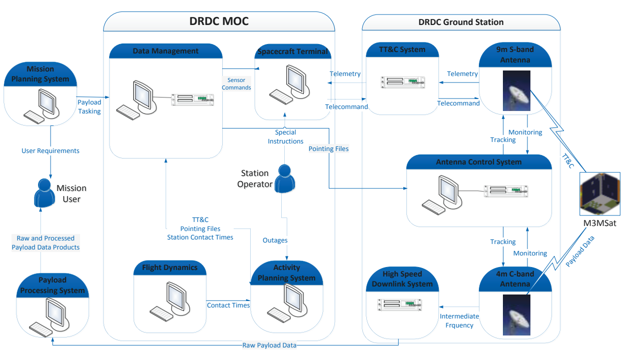

Figure 2. M3MSat Ground Segment Architecture

3.4.3 Documentation

Adopting a *microspace* approach allowed DRDC to reduce the amount of documentation required for M3MSat. Although all space mission aspects (bus, payloads, communications links, spacecraft integration and test, ground segment, operations, launch, end-of life, etc.) need to be considered even for smaller spacecraft, the level of details required can be diminished with simpler systems and missions. In the case of M3MSat, a technology demonstration project, DRDC's details on the ground segment and operations were combined into the same document, hence reducing the overall amount of documentation.

DRDC's approach to M3MSat operations remained focus on *microspace* and the validity of the approach was demonstrated through a successful Operational Readiness Review held in February 2014.

4. RECOMMENDATIONS

DRDC, in conjunction with CSA, strove to apply the *microspace* philosophy to the development of M3MSat. Some aspects worked very well, others could be improved upon. Key recommendations are as follow:

1. Although one entity is best to manage microsatellites, it can be successfully accomplished by two organizations with complementary mandate (such as DRDC and CSA). Through a joint management office with few representatives backed up by small dedicated teams understanding each other's mandate, and regular communications over pre-established channels, it is possible to effectively manage a microsatellite mission. It is expected that with the current governmental fiscal realities, joint management structures will continue to exist. Despite being less costly than larger spacecraft, microsatellite missions still costs millions of dollars (for example, both NEOSSat and M3MSat cost more than $10 millions). They allow for burden sharing of the mission costs as well as the leveraging of expertise in each organization. It is recommended that collaborative opportunities continue be explored when entities concerned have similar or complementary mandates and a common interest in the microsatellite technology proposed.

2. Requirements definition is an area where having more than one customer can impact spacecraft development. This is either caused by the two organizations having different focus (operational asset versus technology demonstration for example) or if there is more than one payload, which can lead to divergent requirements to meet each mission objectives. Both of these situations could cause an increase in the number of requirements, which most likely would drive the costs upwards, either through a required

increased complexity and/or mass of the spacecraft. It is therefore recommended that if there is more than one customer for a microsatellite mission, a primary payload be identified (such as the AIS receiver on M3MSat). Care should be taken such that in the case of technology demonstration microsatellites, operationalization of the asset is not considered as a main requirement driver. Operationalization can lead to additional requirements on the platform that are not necessary for demonstration of the technology. It is recommended to scope future technology demonstration microsatellite missions to a defined set of research objectives to allow for a reduced list of requirements, relax the robustness and resiliency needed with the intent to shorten the development timeline to ensure the technology demonstration remain relevant, and lead to a lower cost mission.

3. In the case of microsatellites, utilizing standardized bus specifications does not in itself render the platform easier to design and built and it does not guarantee significant cost-savings. It most likely would if it was for a similar mission built by the same company; however, the promise of non-recurrent cost-savings is not realized when it is for two different types of missions developed by two separate contractors. Therefore it should not be assumed that if one mission worked well, using a similar bus design will make the development easier for future spacecraft, unless it is for a similar mission by the same company. In the case of microsatellites abiding to the *microspace* philosophy, it could be that customizing the whole system specifically for the primary mission might be more effective as all sub-systems would be designed to meet only one set of requirements. It is recommended that the option of using a standardized bus (such as the MMMB) be evaluated against the option of building a customized system to ensure that the most efficient way forward be selected.

4. Microsatellite operations can be developed following the *microspace* approach. Although M3MSat has not yet been launched, it has been demonstrated with DRDC that a small cross-trained team of operators and engineers with a minimum level of prior operational knowledge can successfully prepare for microsatellite operations. Theoretical preparation followed by frequent hands-on training and support by subject matter experts is a successful recipe. Although not yet proven with the M3MSat spacecraft, the DRDC ground segment systems have demonstrated their operational readiness with the flatsat usage. It is recommended that a similar approach be adopted for future R&D microsatellites.

5. CONCLUSION

The *microspace* philosophy offers many advantages. DRDC attempted to follow this approach throughout the development of M3MSat. Many aspects of the *microspace* philosophy were adopted and were successful, but there were also many lessons learned, which should be applied to future microsatellite missions. The recommendations presented are intended to inform operators, engineers, project managers and decision makers on key considerations to be addressed for future microsatellite R&D missions.

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