SMALL IS BEAUTIFUL

REPORT FROM THE 1ST CANADIAN NANOSATELLITE WORKSHOP (CNW 2012)

April 23rd, 2012
Hôtel Fairmont le Château Frontenac
Québec City, Québec

Image Credit: COM DEV

Date of Report: June 13, 2012

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EXECUTIVE SUMMARY

In the current environment of fiscal challenges, small is beautiful. The last century saw the transformation of computers from expensive monstrosities the size of rooms into the small, low-cost and commonplace electronic devices of today. A similar progression is now taking place in satellite technology. Microsatellite and nanosatellite missions offer a compelling alternative to large space projects, with the capability to support Canadian commercial, governmental, scientific, and academic applications in a responsive and cost-effective manner.

Recognizing the significant potential of small space technologies, the First Canadian Nanosatellite Workshop (CNW 2012) was held on April 23, 2012 at the Hôtel Fairmont le Château Frontenac in Québec City, in conjunction with the Canadian Aeronautics and Space Institute (CASI) ASTRO 2012 Conference at the same venue. CNW 2012 was a platform to showcase and exchange innovative research on nanosatellite-based science and engineering among academia, government and industry groups within Canada and abroad. The objectives of the workshop were to provide a networking opportunity for the nanosatellite community, update and exchange information on current and planned nanosatellite activities, inform the community of research opportunities inside and outside Canada, identify and establish new collaborative opportunities, and promote interest in nanosatellite activities within the Canadian space community

This report summarizes the discussions of the CNW 2012 participants. Section 2 describes the plenary sessions, which covered government roles in nanosatellite research, current and planned Canadian nanosatellite missions, industrial activities and international opportunities. The responses of the workshop participants to specific questions addressing key concerns and issues are documented in Section 3. Finally, the principal findings and recommendations of the workshop, which are detailed in Section 4, can be summarized as follows:

- Nanosatellites and microsatellites have demonstrated a capability to serve operational needs in a cost-effective and responsive manner
- Government agencies and funding organizations should explore ways to pool their resources together in order to create a fiscally achievable support program for Canadian nanosatellite development
- Current Canadian funding programs should provide incentives for nanosatellite programs to seek and engage with international programs as a means of maximizing the leveraging of Canadian funds
- A Canadian program analogous to the U.S. National Science Foundation's Cubesat program should be considered
- The Canadian community should coordinate its efforts with the goal of designing, building, launching and operating a series of nanosatellite missions

The challenge ahead is to formulate a coherent national strategy that will create a sustainable and fiscally achievable national nanosatellite program that will drive innovation, train the next generation of highly qualified personnel and produce tangible socioeconomic benefits for Canadians. It is the profound hope of the CNW 2012 participants that their discussions and the resulting findings and conclusions will form the basis of a positive first step towards helping Canada realize big benefits from small space technologies.

SOMMAIRE EXÉCUTIF

Dans le contexte financier actuel, on voit petit. Au cours du siècle dernier, nous avons vu les ordinateurs passer d'engins monstrueux coûtant un prix exorbitant et occupant l'espace d'une pièce entière aux petits appareils peu coûteux qui sont aujourd'hui si courants. Une transformation semblable se produit actuellement dans le monde des technologies des satellites. En effet, les petites missions nanosatellitaires et microsatellitaires offrent une solution de remplacement intéressante aux grands projets spatiaux traditionnels, puisqu'elles donnent la possibilité de faire fonctionner des applications canadiennes des domaines universitaire, scientifique, gouvernemental et commercial de manière fiable et rentable.

Le 23 avril 2012, le premier atelier canadien sur les nanosatellites (CNW 2012) a eu lieu à l'Hôtel Fairmont Le Château Frontenac, à Québec, de même que la Conférence ASTRO de l'Institut aéronautique et spatial du Canada (IASC), afin de discuter du potentiel immense des petites technologies spatiales. Le CNW 2012 était un événement lors duquel des groupes universitaires, gouvernementaux et industriels canadiens et étrangers présentaient leurs recherches scientifiques innovatrices dans le domaine des technologies nanosatellitaires. Cet atelier se voulait une excellente occasion pour les participants de se créer un réseau de contacts, de se renseigner mutuellement sur les activités nanosatellitaires actuelles et futures, de prendre connaissance des projets de recherche ayant cours à l'intérieur et à l'extérieur du Canada, d'établir de nouvelles possibilités de travail collaboratif et de susciter l'intérêt de la communauté spatiale canadienne.

Dans le présent rapport, nous résumons les discussions des participants lors du CNW 2012. Dans la section 3, nous donnons un compte rendu des séances plénières, durant lesquelles on a discuté des rôles du gouvernement dans la recherche sur les nanosatellites, des missions nanosatellitaires actuelles et prévues du Canada ainsi que des activités industrielles et des projets internationaux dans ce domaine. Les réponses qu'ont données les participants à des questions précises concernant certains enjeux importants sont présentées dans la section 4. Enfin, dans la section 5, nous présentons les principales conclusions et recommandations issues de l'atelier dont voici le résumé :

- La preuve a été faite que les nanosatellites et les microsatellites peuvent combler certains besoins de façon fiable et peu coûteuse.
- Les agences gouvernementales et les organismes de financement devraient explorer différentes façons de rassembler leurs ressources dans le but de créer un programme financièrement réalisable pour soutenir le développement des nanosatellites canadiens.
- Les programmes canadiens de financement actuels devraient prendre des mesures pour inciter les chercheurs en technologies nanosatellitaires pour les inciter à participer aux programmes internationaux, ce qui contribuerait à maximiser l'utilisation des fonds canadiens.
- On devrait envisager de mettre sur pied un programme canadien comparable au programme du Cubesat de la Fondation nationale des sciences des É.-U.
- La communauté canadienne devrait coordonner ses efforts afin de lancer une série de missions nanosatellitaires.

La prochaine étape sera de formuler une stratégie nationale cohérente qui nous permettra de mettre sur pied un programme nanosatellitaire durable et financièrement réalisable qui encouragera l'innovation, formera du personnel hautement qualifié et générera des retombées socioéconomiques tangibles au bénéfice des Canadiens. Les participants du CNW 2012 souhaitent ardemment que leurs discussions et les conclusions et recommandations qui en découlent fourniront les éléments nécessaires pour que le Canada puisse devenir un acteur important dans le monde des petites technologies spatiales et en récolter les bénéfices.

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PREFACE

This report is based on the materials collected during the First Canadian Nanosatellite Workshop held on April 23, 2012, Québec City. The first part summarizes the views from industry, academia and government presenters. The second part tabulates the participants' responses to a questionnaire pertaining to the various aspects of nanosatellite development in Canada. Taken together, the authors develop a series of recommendations that forms the basis of the Canadian Nanosatellite Strategy.

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1. INTRODUCTION

Satellite technology is undergoing a revolution that is in many ways similar to that experienced by the computer industry late in the last century. Where once computers were expensive monstrosities the size of rooms that could only be afforded and utilized by governments, the military and large corporations, today's computing devices are so small, inexpensive and commonplace that everyone can realize the benefits of the technology.

An analogous progression in satellite technology is illustrated in Figure 1, from NASA's huge billion-dollar Hubble Space Telescope to the MOST (Microvariability and Oscillations of STars, otherwise known as Canada's "Humble" Space Telescope) microsatellite and the Canadian BRITE (BRIght Target Explorer) nanosatellite, the latter pair totalling only a few million dollars including launch costs. While smaller and much less expensive, the Canadian MOST and BRITE are designed to conduct world-class astronomical observations that are as cutting-edge and exciting (though not as far reaching) as the data collected by their much larger American cousin. While Canada has successfully designed and launched satellites of all sizes, as summarized in Figure 2 the smaller microsat-, nanosat- and cubesat-type platforms promise to provide responsive and cost-effective space solutions for Canadian academia, industry and government in unprecedented ways – just as the engineers who worked on the early room-sized mainframe computers could not have imagined the multitudes of practical applications enabled by the low-cost laptops, tablets and handhelds of today.

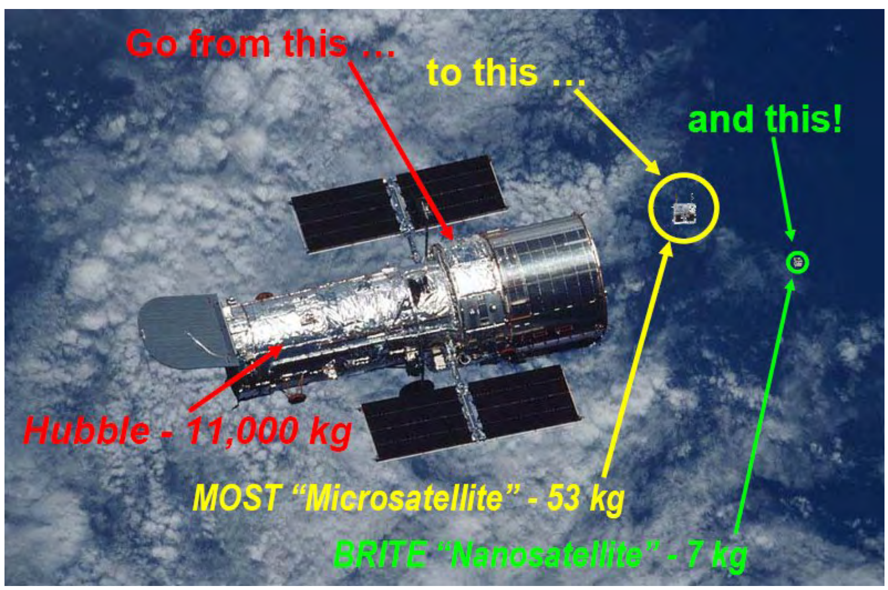

Figure 1 Progression from large expensive satellites to smaller cost-effective microsatellites and nanosatellites *(Image credit: UTIAS/SFL)*

It was in this context that the First Canadian Nanosatellite Workshop (CNW 2012) was held on April 23, 2012 at the Hôtel Fairmont le Château Frontenac in Québec City, in conjunction with the Canadian Aeronautics and Space Institute (CASI) ASTRO Conference at the same venue. The CNW was a direct response to a recommendation from the Workshop on Suborbital Platforms and Nanosatellites hosted by the Canadian Space Agency (CSA) in April 2010, which proposed the establishment of an annual Canadian forum on nanosatellite activities.

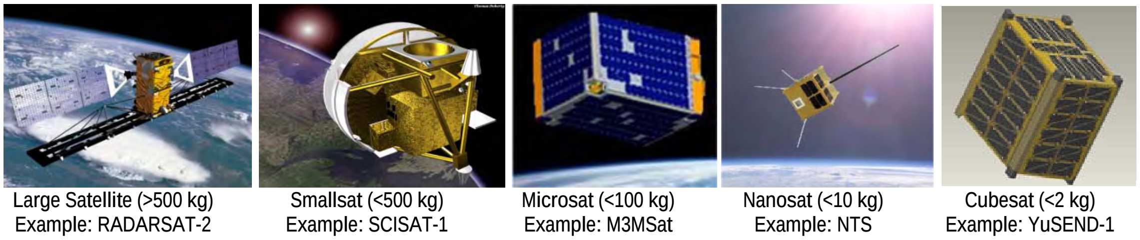

Figure 2 Examples of Canadian satellites of all major size categories from large satellite to cubesat (*Image credits: Canadian Space Agency, Bristol Aerospace, COM DEV, York University*)

CNW 2012 was a platform to showcase and exchange innovative research on nanosatellite-based science and engineering among academia, government and industry groups within Canada and abroad. The workshop had the following objectives:

- To provide a networking opportunity for the nanosatellite community
- To update and exchange information on current and planned nanosatellite activities
- To inform the community of research opportunities inside and outside Canada
- To identify and establish new collaborative opportunities
- To promote interest in nanosatellite activities within the Canadian space community

As this was the first workshop held exclusively for the Canadian nanosatellite community, it was difficult not to note the growing research community whose focus was primarily on the engineering and science enabled through nanosatellite development. There were over seventy participants from universities, industries, government agencies and international participants. Lists of the workshop chairs, organizing committee, moderators and participants are provided in Appendix C.

2. OVERVIEW OF WORKSHOP PROGRAM

The workshop was initiated by Professors Regina Lee and Sunil Bisnath of York University. The program was developed in conjunction with an organizing committee with members from academia, industry, government agencies and non-profit organizations. The main workshop program for CNW 2012 consisted of four plenary sessions:

1) Government Roles in Nanosatellite Research – moderated by Sunil Bisnath (York University)
2) Canadian Nanosatellite Missions – moderated by Freddy Pranajaya (UTIAS/SFL)
3) Industry Activities – moderated by Larry Reeves (Geocentrix)
4) International Opportunities – moderated by Regina Lee (York University) and Patrick Gavigan (Defence Research and Development Canada Ottawa)

2.1 Government Roles in Nanosatellite Research

The roles of government in nanosatellite research include being an enabler, supporter, user or early adopter of new space technologies. David Kendall of the CSA briefed the workshop on the FAST (Flights for the Advancement of Science and Technology) program, which aims to provide grants for activities requiring access to space and sub-orbital flights, or ground-based facilities, or field sites on Earth in order to train highly qualified personnel (HQP), while conducting science investigations or performing technology demonstrations, simulations or validations. Gary Geling of Defence Research and Development Canada (DRDC) explained the defence perspective on nanosatellite research, namely, that it is an excellent generator of new ideas for future defence missions, it helps reduce future mission risk, and it contributes to national innovation. DRDC has supported UTIAS/SFL CanX-2, CanX-4 and CanX-5 nanosatellite missions, and it is now supporting CanX-7 development. Pierre Bourassa of of the Natural Sciences and Engineering Research Council of Canada NSERC) explained that with the growing globalization and partnership trends, the race is really on for innovation. Inter-country partnerships within the European Union (EU) are also raising the competitive bar. Likewise, emerging countries are moving from the role of aid receivers to that of true partners in innovation. NSERC has identified a number of existing and potential funding mechanisms that could be used by the Canadian nanosatellite community including the NSERC partnership programs such as Collaborative Research and Development (CRD), Strategic Network grant and Engage programs. While an increasing number of government organizations are recognizing nanosatellites as potentially effective solutions for applications such as asset monitoring, security and resource management, there remains a lack of reliable long-term funding and a coherent national strategy to sustain nanosatellite research.

2.2 Canadian Nanosatellite Missions

Numerous Canadian universities, with or without space engineering programs, have initiated programs for nanosatellite missions. The Space Flight Laboratory (SFL) at the University of Toronto Institute for Aerospace Studies (UTIAS) has been playing a key role in the development of nanosatellite missions in Canada. SFL has also identified itself as a leader in providing products and services, including the brokering of launch opportunities, to both the Canadian and international nanosatellite communities. It is currently operating three nanosatellites and supporting one microsatellite, and has twelve nanosatellite missions under various stages of development. SFL's list of international clients include Austria, Poland, Norway, Slovenia and Australia. York University has an active research program in support of nanosatellite missions in partnership with COM DEV, DRDC and other research groups. Ryerson University has established active engineering and scientific research programs in the area of nanosatellite mission development. Many Canadian university nanosatellite mission programs have been catalyzed by the Canadian Satellite Design Challenge (CSDC), a program in which undergraduate and graduate student teams design and build an operational nanosatellite based on commercially available off-the-shelf components. A total of twelve universities are actively participating in the program this year. The ultimate goal of the CSDC is to launch the winning nanosatellite into orbit to conduct scientific research.

2.3 Industry Activities

Traditionally, nanosatellites have been viewed primarily as an educational tool to instruct students in the design and build of spacecraft. In recent years, Canadian industry has begun to employ nanosatellites as responsive, flexible and cost-effective platforms for a number of applications, such as COM DEV's NTS mission (Figure 3). These include proving new mission concepts, de-risking or providing qualifying flight heritage for new products, developing specific niche or "blue sky" technologies, or augmenting or "gap filling" existing operational constellations. For instance, the company Xiphos developed a Q-series of microprocessor cards that have high processing power, low form factor and low power consumption. This product is gradually penetrating the nanosatellite markets. The company MSCI is actively developing the COMMStellation© project, a constellation of nanosatellites or microsatellites providing the internet service at low cost to anywhere in the world.

In summary, nanosatellites provide Canadian industry unique platforms for the development of commercial systems, providing responsive and cost-effective platforms for validating mission concepts and gaining flight heritage and qualification. They also provide a means to address the launcher availability problem when looking at the rapid deployment of commercial systems.

Figure 3 Monitoring maritime traffic using NTS with each dot representing an AIS signal from a ship (*Image credit: COM DEV*)

2.4 International Opportunities

International collaboration is a hallmark of the Canadian space program and the nation's nanosatellite efforts are no exception. There are opportunities for Canada to build relationships with other nations beyond its traditional partnership with the United States, particularly in Europe and Asia. At CNW 2012, participants were briefed on three representative international opportunities by speakers from Würzburg University in Germany, Surrey Satellite Technology Ltd. in the United Kingdom and the Korea Advanced

Institute of Science and Technology (KAIST). There are many other international organizations that have either worked with Canadians in the past or are currently seeking partnership on nanosatellite projects including the Indian Space Research Organization (ISRO), the Indian Institute of Technology (IIT) Madras and Boston University. The European Space Agency's QB50 program is an example of an international effort to launch and operate nanosatellites for the purpose of Earth observation.

3. SUMMARY OF PARTICIPANT FEEDBACK

With such a large and varied audience, the workshop organizers had a great opportunity to capture views on nanosatellites so that a national nanosatellite strategy could be formulated. Following the plenary sessions described in Section 2, over forty of the workshop participants completed questionnaires that addressed the following questions:

1) What science or technology missions do you think could be enabled by nanosatellite platforms? With these proposed missions, what are the enabling technologies that need to be developed?

2) How can Canada develop the enabling technology/technologies mentioned in Question #1?

3) Are there any nanosatellite missions currently being pursued outside Canada that you believe should be pursued in this country?

4) One challenge for the utility of nanosatellites is to convince decision makers that they can be used for operational needs. Here, "operational needs" is defined as the capability to provide high quality data at a high frequency that can support needs of civilian or military organizations such as telecommunications, surveillance, etc. Do you believe nanosatellite can support operational needs?

5) Are there any opportunities related to nanosatellites (funding, partnership, collaboration, etc.) inside or outside Canada that you are aware of and would like to share with other participants?

6) In your opinion, which link is the strongest in Canadian nanosatellite R&D and which one is the weakest? What strategy should we pursue to strengthen links?

7) Rank Canada in aspects of nanosatellite R&D and your prediction in the next five years.

8) What is the estimated schedule and cost for a nanosatellite project?

9) Do you think this kind of workshop will be necessary in the future? Please explain your choice.

A summary of these responses to each question is captured below. The responses of the questionnaire provide valuable guidance in setting the Canadian nanosatellite strategy.

3.1 Proposed Missions and Enabling Technologies

A number of potential science or technology missions were identified by the workshop participants. These potential missions and the associated enabling technologies that would need to be developed are summarized in Table 1. It should be pointed out that some of these mission ideas, such as large baseline interferometry and the effects of radiation on micro-organisms, are extremely novel and have not yet been attempted anywhere on a nanoastellite platform. If implemented successfully, they could potentially revolutionize the future of space missions. All of these novel ideas require enabling technologies that need to be developed and demonstrated in space. This could explain why almost one thrid of the respondents indicate that they would like to work on a technology demonstration mission (see Figure 4).

Table 1 Potential missions and enabling technologies

Category	Mission Description	Enabling Technologies
Atmospheric Sciences	GNSS radio occultation GNSS reflectometry Other passive RF remote sensing	Single frequency techniques for atmospheric and ionospheric retrievals. Improved GPS carrier phase ambiguity resolution techniques. High-performance, compact and low cost GNSS receivers and on-board processors.
	Greenhouse gas (CO_2, CH_4) monitoring Aerosol monitoring	Compact and efficient infrared sensors. Space-based multi-wavelength pico-second lidars.
Earth Observation	High revisit rate optical imaging	Compact and efficient optical sensors.
	General optical imaging General thermal imaging	Accurate and low power/cost components (e.g. ACS, CMOS, OBC, propulsion). Small and efficient infrared sensors.
	Earthquake prediction	Multi-frequency antennas, miniaturized interferometric SAR.
Astronomy	General space astronomy	Compact ACS and propulsion.
	Large-baseline interferometry Terrestrial planet finding	Micro-thrusters, non-linear controllers. Commercially hardened embedded systems, vacuum-rated actuators.
	Charged particle detection General space weather	Compact and low-cost sensors. Radiation shielding.
Technology Demonstration	General technology demonstrations	High-performance radiation tolerant computers. Flexible and cost-effective plug-and-play components. Autonomous and cost-effective ground segments. Direct “in the field” tasking of nanosatellites on-orbit.
	Radiation effects testing	Radiation-tolerant COTS components.
	Formation flying	Precise relative navigation and collision avoidance. Compact ACS actuators and sensors.
	Solar sails	Membrane fabrication. Sail deployment dynamics and mechanisms.
	MEMS technology demonstration	High-performance radiation tolerant computers. Flexible and cost-effective plug-and-play components.
Other	Latency tolerant communications Low data rate communications Store and forward communications	Antennas and software defined radios.
	AIS Other asset tracking solutions	Antennas and software defined radios.
	Radiation effects on microorganisms General space life science	Compact habitats for microbial life. Fluorescence imagers.
	Microgravity science platform	Microfluidic science payloads.

It was recognized that one of the strengths of nanosatellites is the potential to provide more responsive and cost-effective mission solutions due to more flexible quality assurance and product assurance requirements. There was also recognition of a clear, market-driven push to develop operationally-based small/micro/nano satellite-based solutions, and the trend is international. The workshop participants felt this needs to be seriously explored, as it can really benefit Canada's niche with respect to balancing budget and technical excellence. In addition, the workshop participants believe there need to be more missions that engage the public. Canadians support space science and technology in general, but the more they are engaged at the non-scientific level, the more they will come to understand, appreciate and support space.

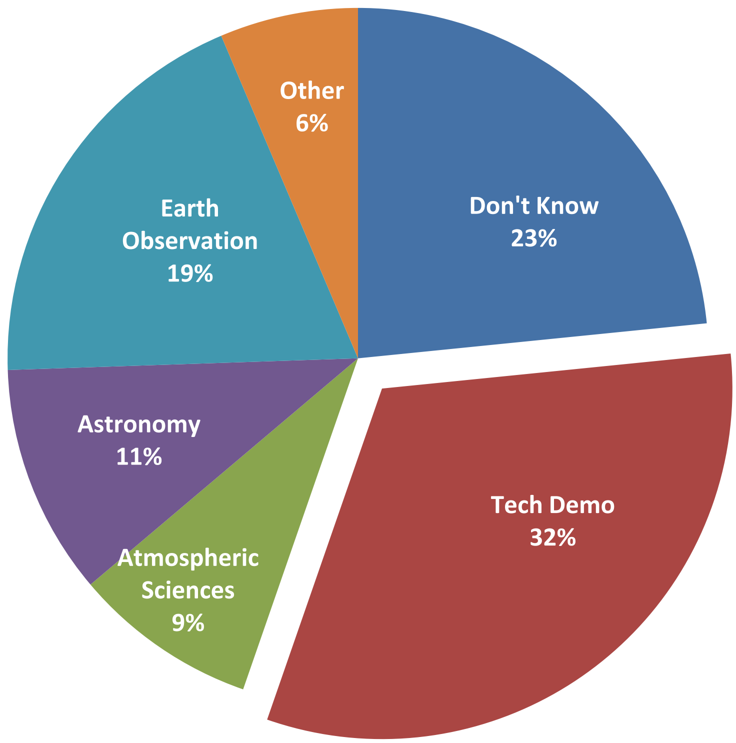

Figure 4 Responses of workshop participants on future potential nanosatellite mission categories

3.2 Development of Enabling Technologies

The workshop participants made a number of suggestions on how Canada could develop the enabling technologies mentioned in Section 3.1. These are summarized as follows:

- Develop a roadmap of missions and technologies of interest to the CSA and then release AOs related to these in order to spur development through competition
- Create a grants program with target technologies in mind, in which academics or companies would bid to develop the specified technologies

- Expand the CSA Space Technologies Development Program (STDP) and Department of National Defence (DND) Technology Demonstration Program (TDP) funding programs
- Provide launch opportunities on a regular basis
- Offer competitions to spur development and innovation
- Increase collaboration and implement combined funding programs among government research agencies (CSA, NRC, CRC, etc.), academia and industry
- Implement systematic, on-going, long-term funding programs for both academia and industry
- Leverage student research and incentivize industry to conduct R&D work with academia
- Invest in more hands-on education for future space engineers and scientists
- Fund more Phase 0 studies and "see where it goes"

As nanosatellites are still an emerging satellite platform, it is reasonable for the community to expect government agencies to take a leadership role. According to the participant feedback, in the short-term, government agencies could support the development of nanosatellites by creating a mission and technology roadmap and by coordinating and/or combining funding from various agencies. As demonstrated by the Nanosatellite Tracking Ships (NTS) mission, industry can find a way to execute self-funded nanosatellite missions with little or no government investment. However, an appropriate level of strategic government support would nevertheless be desirable in most cases.

3.3 International Nanosatellite Missions

There are a number of nanosatellite missions currently being pursued outside Canada that the workshop participants believe should be pursued in similar forms in this country. These are summarized in Table 2.

Table 2 Notable international nanosatellite missions

Mission	Justification
QB50 NSF Cubesat Science Missions	Need more collaborative, coordinated, nation-wide research opportunities to enhance engineering capability and support science community.
COSMIC GNSS-RO Microsatellite Constellation	COSMIC is nearing end-of-life and a follow-on is uncertain. Potential for Canada to step in to play a niche role and serve needs of Environment Canada. Meteorological datasets of great importance in Canada and globally.
TDS-1 (U.K.)	Cost-effective platform for technology demonstration.
Solar Sailing	Technology still has room for development, which Canada can contribute. Enabler for future deep space missions.
Nanosat Network (Germany)	Application of networking technology in space would open many doors.
MIT Planet Transits Astronomy Project	Could collaborate with MIT and/or develop our own capabilities in this area. Quest for life outside the Solar System is a very visible, highly popular area of science.
Prisma (Sweden)	Demonstrate autonomous formation flying.
STRaND-1 (SSTL)	Innovative attempt to break new ground in space hardware by testing useful COTS technologies in space.

Note that some of these missions include the involvement of government agencies such as the European Space Agency (ESA), the U.S. National Science Foundation (NSF) and the U.K. Space Agency. For the American NSF Cubesat Science missions, not only is NSF contributing funding, but the National Aeronautics and Space Adminhisration (NASA) is also providing expertise in assisting the universities in the development of the nanosatellite platforms and payloads. This is a model that should be explored in Canada.

3.4 Nanosatellites in Support of Operational Needs

Traditionally, nanosatellites have been mostly used as a means for students to receive hands-on flight experience in a cost-effective and low-risk manner. However, many of the workshop participants thought that there are few obstacles that would prevent a nanosatellite from supporting operational needs other than the fact that they have not been much utilized in this manner to date.

"Operational needs" are defined as the capability to provide quality data at a high frequency in a manner that can support the requirements of civilian or military organizations in applications such as telecommunications and surveillance. As shown in Figure 5, two-thirds of the workshop participants think that nanosatellites could support operational needs, as long as requirements are reasonable and tailored to the capabilities of smaller spacecraft.

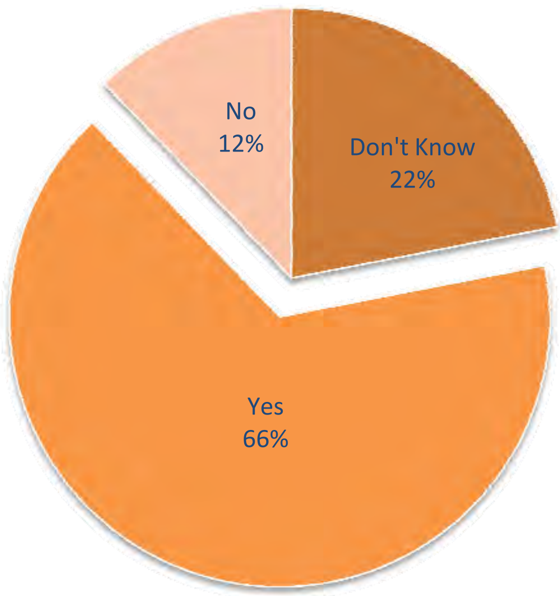

Figure 5 Participants' responses to the question of nanosatellites supporting operational needs

While currently not as capable as large satellites, it is expected that the utility of nanosatellites will increase with the advancement of technology. It was recognized that while nanosatellites are not a "silver bullet", they do have an operational role to play alongside their larger counterparts. Whether nanosatellites are suitable for operational needs depends on the user requirements and the specific payload. If the operations are over a short timeframe and involve a payload that a nanosatellite could accommodate then the model is viable. The potential for rapid turnaround times for nanosatellites could allow them to fill niches not easily accomplished by larger spacecraft.

Nanosatellites could also accomplish some missions that would be more expensive with conventional satellites, for example to fly in swarms or networks in order to increase repetition and reduce revisit times. While a single nanosatellite may not suffice for some missions, a group of nanosatellites could still be more responsive and cost-effective than a single larger conventional satellite. Clusters of nanosatellites could be built *en masse* and held either as on-orbit spares or be available for responsive replenishment through periodic launches. Economies of scale could allow for more numerous assets on-orbit, which would lead to much more robust operational systems. To enable such future infrastructure, assembly, integration and test (AIT) processes and capabilities would have to be improved.

To better support operational needs, nanosatellite reliability must be increased, otherwise nanosatellites will be relegated to "one shot" short life missions better suited for academia, technology demonstration or pre-operational missions. Fortunately, commercial technology has advanced to the point that many COTS components are extremely reliable, are small enough to be able to fit onto nanosatellite platforms and have the capability to provide high quality operational data. In certain types of applications, higher quality data can be obtained by correlating multiple sources of lower quality data.

Some examples of current and planned operational nanosatellites were cited including NTS and NEMO-AM (Nanosatellite for Earth Monitoring and Observation – Aerosol Monitoring). As discussed in Section 3.1, a number of potential applications for future operational nanosatellite missions were identified by the workshop participants including wildlife beacon monitoring, Earth observation, astronomy, space situational awareness, latency tolerant or low bandwidth communications, and meteorology.

For example, the COSMIC mission is a constellation of six small satellites that collect hundreds of GNSS radio occultation observations per day. The resulting information, which includes atmospheric temperature, pressure and humidity as functions of height, is currently being used by Environment Canada and other national meteorological agencies, thereby improving weather prediction. Unfortunately, two of the COSMIC satellites have already suffered on-orbit sub-system failures, and the remaining satellite are nearing the end of their operational lives. A constellation of nanosatellites could augment and eventually replace the COSMIC system in a responsive and cost-effective manner.

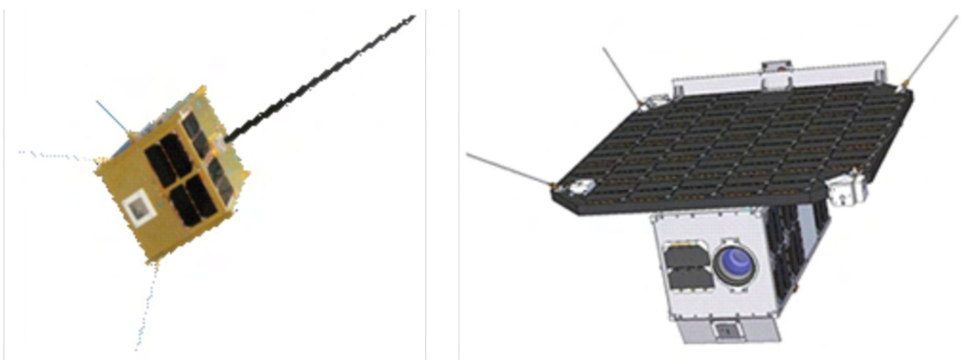

Figure 6 Examples of Canadian-developed operational nanosatellites, NTS (left) and NEMO-AM (right) *(Image credits: COM DEV, UTIAS/SFL)*

3.5 Funding, Partnership and Collaboration Opportunities

The workshop participants shared with each other potential opportunities related to funding, partnership and collaboration both inside and outside of Canada. Funding opportunities within Canada were generally well understood. MITACS[1] is currently looking for strategic projects in the satellite and aerospace fields, with their Accelerate program expanding to support internships at non-profit research centres such as government laboratories with industry partnership and collaboration. Other potential Canadian funding opportunities include CSA FAST (Flights for the Advancement of Science and Technology), NSERC CRD (Collaborative Research and Development) and DRDC TIF (Technology Investment Fund). Potential non-

[1] MITACS stands for Mathematics, Information Technology and Complex Systems is a national not-for-profit research organization

traditional funding sources, such as Canada's pension funds and venture capital, were also mentioned. Obviously, a strong business case would need to be built in order to attract private capital investment.

An example of successful domestic scientific collaboration on a nanosatellite mission is BRITE (BRIght Target Explorer). Domestic partnership includes UTIAS/SFL, Université de Montréal, the University of British Columbia and extensively involves both students and postdoctoral researchers. On the international scale, the partnership involves researchers from Austria, Poland, UK, Germany, etc. Austria and Poland have committed funds to purchase 4 BRITE satellites from UTIAS/SFL. CSA also contributes funds to two BRITE satellites. That means an initial constellation of 6 BRITE satellites will have government support from three countries. The team remains open to anyone who is interested in the science. Another recent catalyst for developing domestic partnerships in academia is the Canadian Satellite Design Challenge (CSDC), which is an initiative to encourage university students to design a nanosatellite mission for which the first prize is a launch.

Opportunities for partnership and collaboration outside of Canada include the QB50 project, which will be an international network of fifty nanosatellites in low-Earth orbit that will conduct atmospheric research. The major funding for the project comes from the European Space Agency (ESA). There are also major nanosatellite initiatives at the ESA, the Massachusetts Institute of Technology (MIT) and the University of Tokyo. There is a range of potential international funding, particularly for student nanosatellite work. For instance, the Bavaria-Québec Cooperation may be open to receiving satellite project proposals. Not only should Canadian federal agencies review whether they can combine their funding programs, they should also investigate whether their programs can be leveraged with foreign funding mechanisms.

3.6 Linkages

Workshop participants were provided with the illustration of six different links in Figure 7 and were asked to rank the strongest and weakest in Canadian nanosatellite R&D, and also to suggest strategies to strengthen these links.

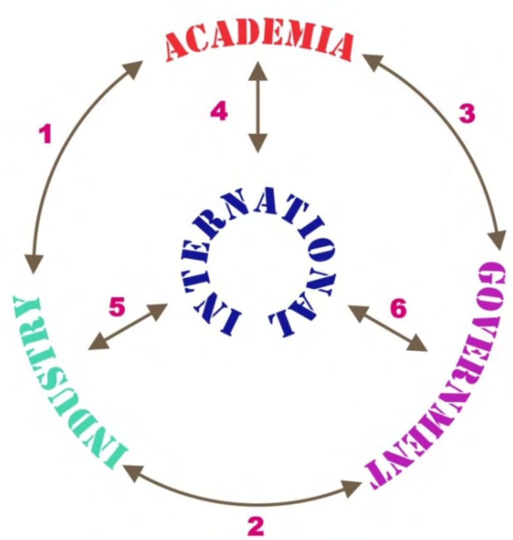

Figure 7 Possible inter-relationships among academia, industry, government and international

Among the domestic partners, industry, and government, almost a third of the participants think that industry and academia have the strongest link (Figure 8). The academia and government link is perceived to be strong by 17% of the participants, but only 11% believe that government and industry have a strong link.

The link with the international partner is much weaker except the link between academia and the international partners.

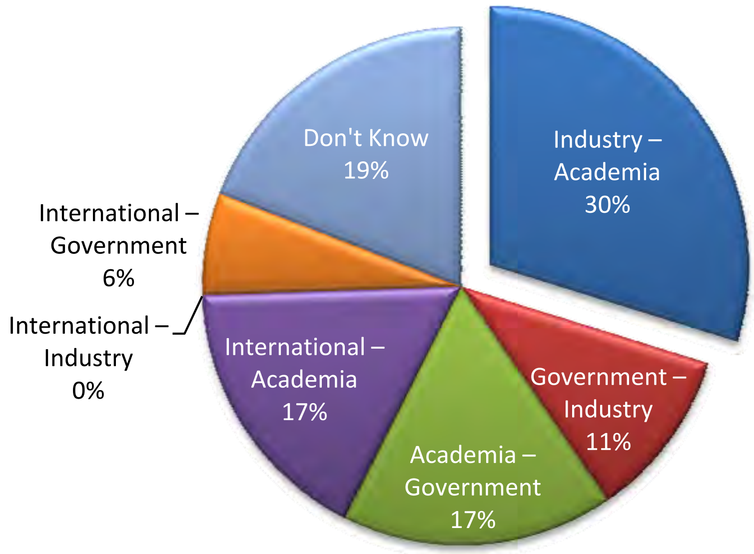

Figure 8 Participants' view on the strongest links among the partners

To strengthen the links, the workshop participants made the following strategy suggestions:

- Hold more Canadian Nanosatellite Workshops
- Increase the use of public-academic-private partnerships where appropriate
- Promote international cooperation beyond Canada's traditional partners, for example Australia, Brazil and Israel are good candidates
- Streamline government oversight of space projects to focus on results rather than process
- Support industrial R&D in developing technologies that are useable for worldwide markets, as Canada is falling behind the United States, Europe and Japan
- Place an emphasis on fostering partnerships and programs rather than specific standalone projects
- Promote opportunities for co-op terms, masters and doctorate projects and contracts for recently graduated students
- Establish further competitions similar to the Canadian Satellite Design Challenge (CSDC)
- MITACS should focus on the three primary domestic linkages of academia-industry, academia-government and government-industry
- Government is too focused on bureaucracy and red tape, and decision making processes related to funding should be streamlined in order to minimize applicant wait time
- Government should take a more active role in linking industry with academia, as opposed to simply providing funding to academia and then leaving them to find industrial partners on their own
- A Canadian vision of what we want to do in space is needed to give guidance as to what we should pursue, and then we can look for ways that nanosatellites can play in meeting that vision

One underlying message of these suggestions is that the government can take a leadership role in streamlining the process of its programs and promoting partnerships both inside and outside Canada with the academia, industry as well as with international partners.

3.7 Aspects of Nanosatellite R&D

The workshop participants were asked to rank Canada (in terms of quarterly percentile), compared to the World, in aspects of nanosatellite R&D and to give a prediction for the next five years. These results are summarized in Table 3.

Table 3 Canadian rankings in aspects of nanosatellite R&D

R&D Aspect	Currently*					In 5 Years*				
	1st	2nd	3rd	4th	Don't Know	1st	2nd	3rd	4th	Don't Know
Innovation	11	8	5	0	17	10	10	2	1	18
Industrial Capability	3	13	6	1	18	5	13	4	0	19
Education	10	9	6	2	14	11	10	4	1	15
Expertise in Industry	4	13	7	0	17	7	12	4	0	18
Expertise in Academia	14	9	4	1	13	14	10	2	0	15
Development Infrastructure	3	12	10	1	15	7	15	3	0	16
Government Support	1	10	8	6	16	2	9	9	4	17
Public Support	3	5	8	10	15	3	7	5	10	16
International Recognition	7	7	10	2	15	7	10	6	1	17

**In terms of quarterly percentile. For instance, 1st implies top 25%, 2nd implies 26%–50%*

There are some important findings that can be inferred from the data:

1. A significant number of participants believe that in terms of innovation, education and expertise in academia, Canada ranks in the top quarterly percentile, and that this ranking can be maintained in the next five years.
2. However, the nanosatellite industry is perceived as the best only in the second quarterly percentile, with the standing remaining unchanged for the next five years.
3. Many participants felt that government and public support is at best in the second quarterly percentile, and there are a significant number of respondents think that public support is at the fourth quarterly percentile. This standing would likely remain the same in the next five years.
4. In terms of international recognition, Canada's ranking is perceived to be in the 3rd quarterly percentile, i.e., the country is not perceived as a trailblazer in nanosatellite development.

The key message is that Canadian academia is generally perceived as top notched in terms of nanosatellite innovation and education, but it is not currently matched by an appropriate level of support from the government and industry. This is a key point to consider in defining a national nanosatellite strategy. In terms of research, the participants were asked to rank the level of challenge being encountered. These results are summarized in Table 4.

Table 4 Rating of other research aspects of nanosatellite R&D

Research Aspect	10 – Very Challenging; 5 – Neutral 0 – Not an Issue											
	10	9	8	7	6	5	4	3	2	1	0	Don't Know
Support from your organization	1	2	1	2	0	4	2	2	2	3	11	11
Support from outside your organization	2	1	3	1	1	11	3	4	1	1	0	13
Access to specialized facility (e.g. TVAC)	0	1	0	2	2	2	2	3	2	5	4	18
Access to expertise inside your organization	2	2	1	1	1	1	2	3	5	5	8	10
Access to expertise outside your organization	1	3	0	1	3	8	1	3	6	3	0	12
Creating the team	1	2	2	1	4	7	2	0	3	3	1	15
Launch opportunities	6	2	4	2	2	6	2	0	1	0	1	15

Key findings from the responses are as follows:

1. Most participants do not perceive getting support and access to expertise within their organizations as an issue.
2. The majority also have not encountered problems in accessing specialized facilities.
3. Getting support from outside of their organizations or creating a team has proven to be challenging for a majority of the respondents.
4. As expected, the vast majority of participants feel that obtaining launch opportunities is challenging, and more than 15% of the respondents indicated it was "Very Challenging."

3.8 Funding and Schedule

The participants were asked if they were given an opportunity to develop a nanosatellite, what would be the cost and schedule be, as well as what nanosatellite format they would develop. Here are the key findings:

1. From Figure 9, one can observe that 34% responded that it will take six months to a year for Phase 0-A, and almost half the respondents believed that Phase B-D could be completed in one to two years. Only a very small number of respondents believed that Phase 0-A would take more than one year and that Phase B-D will require more than two years.
2. In terms of cost, Figure 10 shows that 29% believed \$50K-\$100K is the optimal cost for Phase 0-A studies and an equal number of respondents chose \$1M-\$2M as the cost for Phase B-D. Only 10% of respondents believed that a nanosatellite could be completed for less than \$1M and another 12% recommended a budget of over \$2M. Therefore nanosatellites are still extremely cost effective in comparison to traditional large space projects that can cost hundreds of millions of dollars.

These responses agree reasonably well with the U.S. National Science Foundation (NSF) funded nanosatellite projects (Appendix B) in which up to six missions are funded with an award of less than \$2M each and a duration of less than three years.

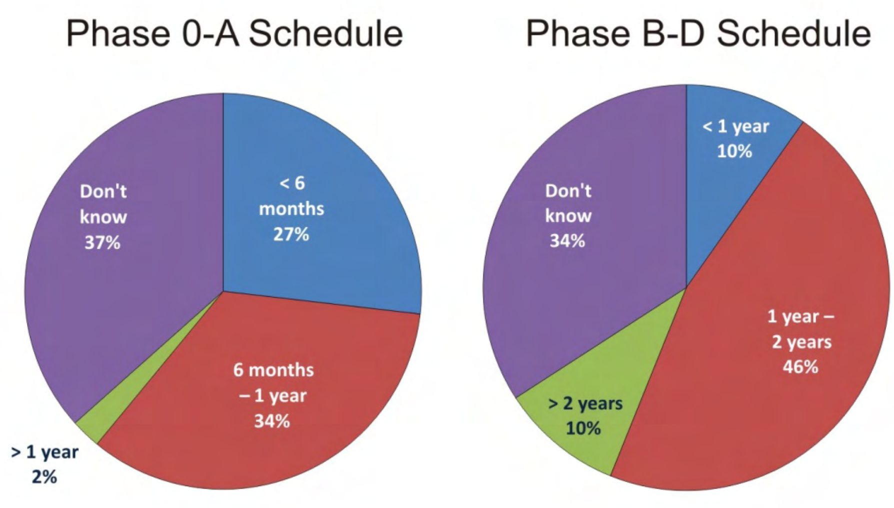

Figure 9 Participants' response to the estimated schedule for a nanosatellite development

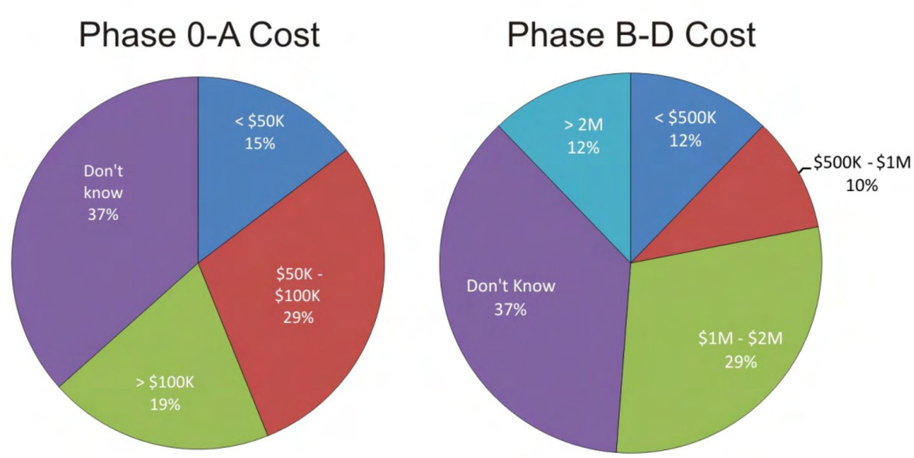

Figure 10 Participants' response to the estimated cost for a nanosatellite development

When asked about the estimated mass of their next nanosatellite development, only 3% believed that they would develop a nanosatellite for less than 1 kg and in fact 39% responded that it would be more than 3 kg. In terms of volume, less than 10% chose 1U or 2U as the preferred format, 20% chose 3U and another 26% preferred a non-standard format (Figure 11). Recall that cubesats were first proposed in 2000 with a mass of 1 kg and dimensions of 10×10×10 cm. This is what is commonly known as 1U format. Soon, many researchers and engineers recognized that the constraints of mass and volume prohibited the development of breakthrough missions, and hence the 1U progressed into the development of the 2U (2 kg and 10×10×20 cm) and eventually the 3U format. A comparison of cubesat formats is illustrated in Figure 12 .

Today, even the 3U is considered too limiting for some applications and the nanosatellite community is considering avenues of future growth.

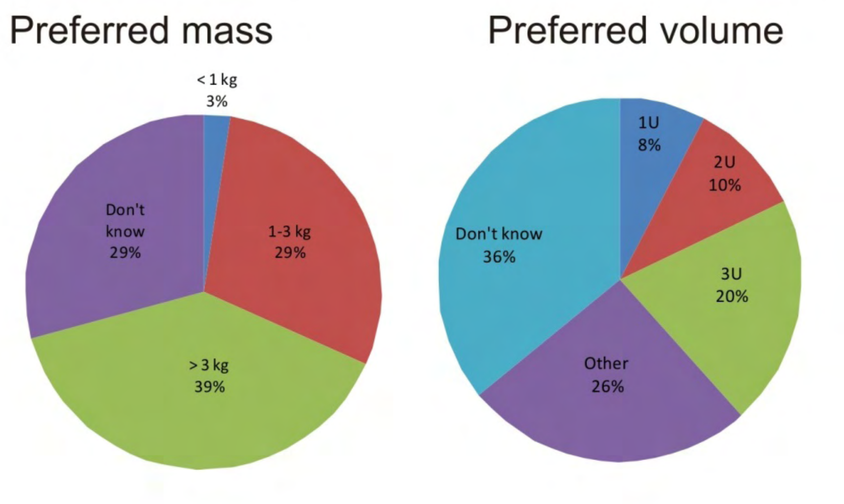

Figure 11 Preferred mass and volume of the next nanosatellite project

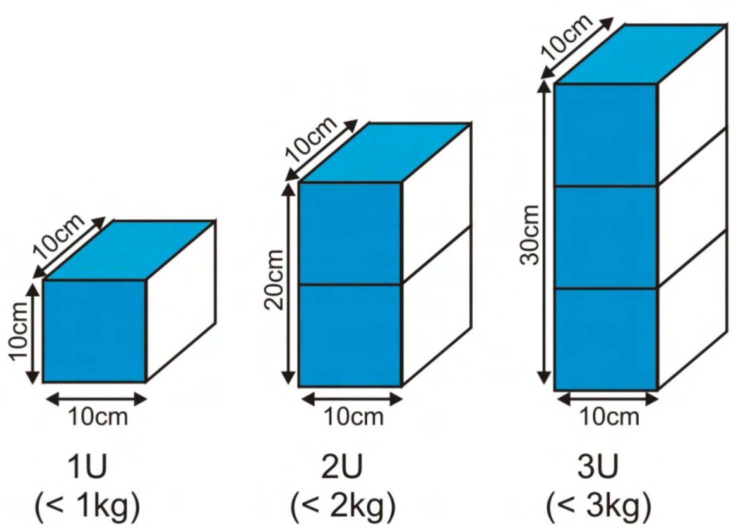

Figure 12 Standard Cubesat formats 1U, 2U and 3U

In terms of schedule, cost, mass and format, the response from the Canadian participants is consistent with international trends in the development of nanosatellites. This should be taken into consideration in the development of a national strategy.

3.9 Future Canadian Nanosatellite Workshops (CNW)

An overwhelming majority (over 80%) of participants thought this kind of workshop is necessary in the future in order to keep the momentum going. Compared to telecommunications satellites, nanosatellites are in their infancy. Workshops such as the CNW provide great opportunities for nurturing the growth of nanosatellite activities in the country. CNW provides the forum to disseminate news and information, exchange experiences and best practices, and increase awareness of what is going on in the field both domestically and internationally. By bringing together interested parties, a forum was created for networking and information exchange, as well as for creating opportunities for cooperation. Communication and networking is critical to partnerships, which are essential for projects and progress.

Suggestions for future workshops include holding a job fair or other networking events targeted at students and recent graduates. More decision makers should also be invited, particularly those from outside of Canada. There was also a request to have more scientists involved. Recalling that the concept of the BRITE constellation was first proposed by an informal conversation between an astronomy professor with an engineer from UTIAS/SFL, it is evident that interactions between engineers and scientists will stimulate innovative ideas for nanosatellites.

4. FINDINGS AND RECOMMENDATIONS

In the Canadian Space Agency's 2010 Workshop on Sub-Orbital Platforms and Nanosatellites, almost eighty participants self-identified as having a primary interest in nanosatellites. The first Canadian Nanosatellite Workshop (CNW) involved over seventy participants from academia, industry and government agencies. This consistency proves that nanosatellites remain of great interest to the nation's growing and diversified community of scientists, engineers and decision-makers. The challenge ahead is to formulate a coherent strategy to create a nanosatellite program that will spur innovation, train the next generation highly qualified personnel (HQP) and produce tangible socioeconomic benefits for Canadians.

Based on the discussions of the workshop participants, the principal findings and recommendations are:

1. In the current environment of fiscal challenges, small nanosatellite and microsatellite missions offer a compelling alternative to the large space projects of the past, with the capability to support Canadian academic, scientific, governmental and commercial applications in a responsive and cost-effective manner.
2. Through missions like NTS, it has been demonstrated that nanosatellites and microsatellites can serve operational needs in a cost-effective and responsive manner. Government agencies should take a leadership role in furthering the development of nanosatelllites and microsatellites by providing a roadmap of potential missions that would support the needs of the Federal and provincial governments as well as stimulate innovation and training in academia and industry.
3. Constructive competition should be encouraged. This could be based on the model of the Canadian Satellite Design Challenge (CSDC) in which twelve university teams are currently competing for a single launch opportunity. In an analogous manner, government agencies could support multiple Phase 0-A studies and then down select one or two promising missions for further development. Cost and socioeconomic benefit (essentially, return on investment) should be two of the major selection criteria.
4. Workshop participants estimated that a typical nanosatellite project should cost on the order of \$1M to \$2M including launch. This is consistent with the level of funding provided by the U.S. National Science Foundation (NSF) for American nanosatellite projects. The workshop participants recognized the challenges of the current fiscal environment and as such recommend that government agencies and funding organizations explore ways to pool their resources together in order to maximize the leverage. For instance, resources from the CSA (in-kind or cash) and DRDC (in-kind or cash) coupled with resources from NSERC and MITACS could create a sizable support program for nanosatellite development.
5. The current funding programs within Canada (NSERC, CSA, MITACS, DND) that are suitable for nanosatellite research do not offer incentives for international partnership. To encourage and promote international partnerships, incentives such as matching fund programs or partnership workshop grants should be implemented to allow Canadian researchers to engage with international programs. This would also maximize the leverage of Canadian funds, which is an important consideration given the fiscal challenges of today.
6. In order to sustain and advance nanosatellite research, a coordinated effort within the Canadian nanosatellite community to design, build, launch and operate a series of Canadian-built nanosatellites should be considered. QB50 is a good examples of such a coordinated mission concept in which multiple participants with complementary capabilities could collaborate on a nanosatellite or microsatellite mission of mutual benefit.
7. The annual NSF CubeSat program is a good example of a cost-effective and sustainable long-term funding model in which scientists and engineers can establish joint research program to develop a

nanosatellite mission from conception to operation. An analogous program should be considered for Canada.

A sustainable Canadian nanostellite program can be created with a very modest investment. Figure 13 illustrates one possible funding scenario that requires an initial investment of only $350K in Year 1, with the funding level gradually increaseing to $2.55M in Year 5 and beyond. In this scenario, it is assumed there will be sufficient budget for multiple Phase 0-A studies on the order of $350K each. At their completion, one to two missions would be selected with a total budget of $3M amortized over three years. Such a funding scenario for a nanosatellite program would still be much more cost-effective than the large space projects of the past, which could cost on the order of hundreds of millions of dollars. In the present age of fiscal austerity, small is beautiful.

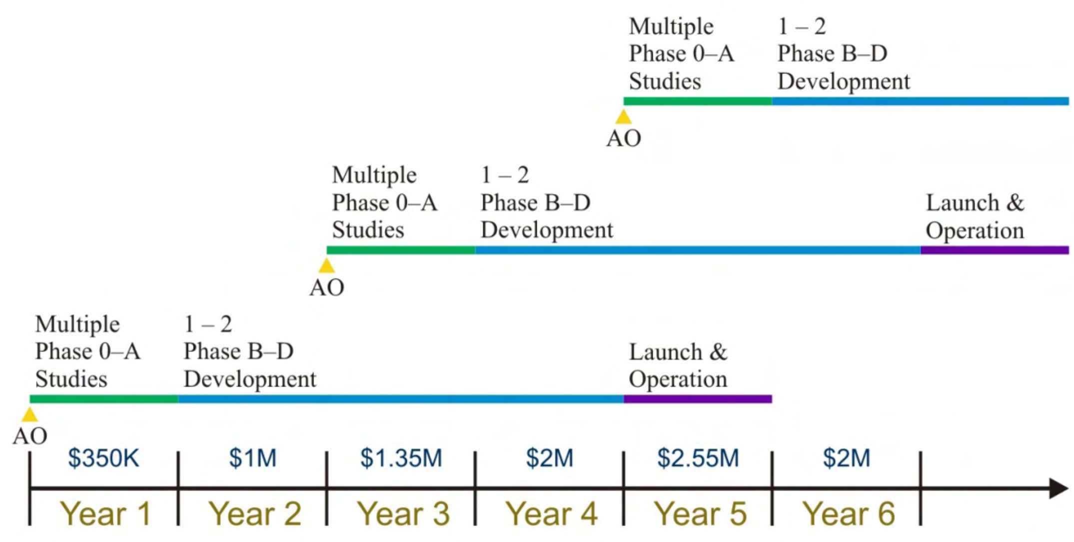

Figure 13 A proposed nanosatellite program budget and schedule

5. CONCLUDING REMARKS

Canadian academia and industry has been active in nanosatellite and microsatellite activities and the interest continues to grow. However, in the absence of a coherent national nanosatellite strategy, development activities are not always been well coordinated or supported. As such, it is recommended that government agencies should take a leadership by creating a roadmap and coordinating all the relevant support programs. Best practices should be adopted from successful foreign organizations such as the U.S. National Science Foundation (NSF) and the European Space Agency (ESA), provide good reference models for Canada to develop a sustainable nanosatellite program. The successful implementation of such a program is particularly important in the current fiscal downturn. Small nanosatellite and microsatellite missions offer a compelling alternative to the large space projects of the past, with the capability to support Canadian academic, scientific, governmental and commercial needs, driving innovation and providing tangible socioeconomic benefits for Canadians in a responsive and cost-effective manner. To reiterate the philosophy embodied by the title of this report, small is indeed beautiful.

Figure 14 CNW 2012 workshop participants *(Image credit: Azam Shaghaghi)*

APPENDIX A: ACRONYMS AND ABBREVIATIONS

AIS	Automatic Identification System (maritime)
AIT	Assembly, Integration, and Test
BRITE	BRIght Target Explorer (a constellation of astronomy nanosatellites)
CNW	Canadian Nanosatellite Workshop
CRD	Collaborative Research and Development
CSA	Canadian Space Agency
CSDC	Canadian Satellite Design Challenge
DND	Department of National Defence
DRDC	Defence Research and Development Canada
ESA	European Space Agency
EU	European Union
FAST	Flights for the Advancement of Science and Technology
GENSO	Global Educational Network for Satellite Operations
GNSS	Global Navigation Satellite System
HQP	Highly Qualified Personnel
IIT	Indian Institute of Technology
KAIST	Korea Advanced Institute of Science and Technology
LEO	Low-Earth Orbit
MITACS	Mathematics, Information Technology and Complex Systems is a national not-for-profit research organization
MOST	*Microvariability and Oscillations of STars*
NASA	National Aeronautics and Space Administration
NEMO-AM	Nanosatellite for Earth Monitoring and Observation – Aerosol Monitoring
NSERC	Natural Sciences and Engineering Research Council
NSF	National Science Foundation (US)
NTS	Nanosatellite for the Tracking of Ships
STDP	Space Technologies Development Program
STK	Satellite Tool Kit
STRaND	Surrey Training, Research and Nanosatellite Development (UK)
TDP	Technology Development Program
TDS-1	TechDemo Satellite-1 (UK)
TIF	Technology Investment Fund
TRL	Technology Readiness Level
TVAC	Thermal Vacuum Chamber
UTIAS/SFL	University of Toronto Institute of Aerospace Studies Space Flight Laboratory

APPENDIX B: U.S. NSF SUPPORTED NANOSATELLITE PROJECTS

The U.S. NSF Division of Atmospheric and Geospace Sciences has funded a series of nanosatellite developments. Below is a summary of the support:

Project Acronym	Organization	Fund (K USD)	Duration
DICE	Utah State University	1,200	3 Years
REPTile	University of Colorado	835	3 Years
CINEMA	UC Berkeley	960	3 Years
RAX	University of Michigan	1,050	3 Years
Firefly	Siena College, NASA GSFC	930	4 Years
FIREBIRD	Boston University, Montana State University	1,200	3 Years

- DICE stands for Dynamic Ionosphere Cubesat Experiment aims at the measurement of ionospheric plasma densities and to measure DC and AC electric field. Other partners include Embry-Riddle University and Clemson University.
- REPTile stands for Relativistic Electron and Proton Telescope integrated little experiment. It aims to measure directional differential flux of energetic protons and electrons.
- CINEMA stands for Cubesat for Ions, Neutrals, Electron and Magnetic Fields. Partners also include NASA Ames, Inter American University of Puerto Rico, Johns Hopkins University, Kyung-Hee University, Korea and Imperial College, UK.
- RAX stands for Radio Aurora Explorer. Two have been launched so far: one in 2010 and the second one in 2012.
- Firefly aims to determine whether Terrestrial Gamma Ray Flashes are triggered by lightning. NASA GSFC personnel provides hands-on training to students throughout the project.
- FIREBIRD stands for Focused Investigations of Relativistic Electron Burst Intensity, Range and Dynamics. It aims to study the spatial scale size and energy dependence of electron microbursts in the Van Allen radiation belts. A set of two Cubesats will be built by the two university teams.

APPENDIX C: ORGANIZING COMMITTEE AND PARTICIPANTS

Workshop Chairs

Sunil Bisnath	York University
Regina Lee	York University

Organizing Committee Members

Eric Edwards	Xiphos Technologies
Patrick Gavigan	Defence Research and Development Canada - Ottawa
Geoff Languedoc	Canadian Aeronautics and Space Institute
Freddy Pranajaya	UTIAS/SFL
Alfred Ng	Canadian Space Agency
Larry Reeves	Geocentrix

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Florent Bouguin	ABB-Bomem
Matthew Bourassa	Carleton University
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Brendan Cade	University of Manitoba
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Jeffrey Cain*	COM DEV
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Edward Cloutis	University of Winnipeg
Luchino Cohen	Canadian Space Agency
Allen Conrad	IMP Group Ltd.
Steve David	Carleton University
Anton de Ruiter	Carleton University
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Gary Geling*	Defence Research and Development Canada
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Tom Haylock	University of Waterloo

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