CAPACITY BUILDING THROUGH ACADEMIC / INDUSTRIAL COOPERATION IN SPACE SYSTEMS RESEARCH

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Abstract

This year marks the 60th anniversary of Canada's space program. The first launch of the Black Brant Sounding Rocket took place on September 5th, 1959. As Canada's space program has matured, however, we have seen a growing reluctance to truly advance the boundaries of space technology. This reluctance stems from risk aversion, brought about by the scarcity of Canadian mission opportunities and the high costs associated with the need for high-reliability missions (i.e., there are few mission opportunities, so missions need to be high-reliability, which drives up costs and further decreases mission opportunities). With fewer and fewer made-in-Canada mission opportunities, the country risks losing the valuable space capacity that has been established over decades of pioneering work in space science, engineering, and operations. In a concerted effort to strengthen (and not just maintain) Canada's space capacity, the University of Manitoba and Magellan Aerospace have established a three-pronged research collaboration that: a) Establishes shared facilities for collaborative research; b) Executes leading-edge research into space systems control, manufacturing, and environmental protection; and c) Engages with the undergraduate and graduate engineering student community at the University of Manitoba to inspire and train the next generation of space engineers and scientists. This paper outlines the key pillars of this industrial / academic partnership and discusses how it will grow to support Canada's space capacity development program.

Introduction

Canada has a long history of innovation in space research and commercialization. From the Black Brant Sounding Rockets to space robotics, space geology and remote sensing spacecraft such as the RADARSat Constellation Mission (RCM), Canada has shown strong leadership in virtually every area of space technology development[6]. However, in order to remain at the forefront of the space industry, Canada must find new ways to integrate burgeoning technologies into space missions, while simultaneously maintaining and growing capacity.

Capacity maintenance is a key challenge facing the Canadian space industry. The annual funding for the Canadian Space Agency typically funds only a small number of large programs with relatively long timelines. The result is a capacity demand that goes in cycles. At times when large numbers of engineers, scientists and technicians are required to support Canadian space programs, it can be difficult to find appropriate skillsets. Conversely, when lulls in Canadian space programs occur, it is difficult to find work for the specially-trained labour, which leads to layoffs and a loss of capacity. While a continuous supply of on-going large space programs would solve this problem, one needs to be realistic about the capabilities of a Canadian Space Agency with historically modest budgets.

A more realistic solution to the problem of space capacity maintenance and expansion is to supplement the large space programs with on-going research and development. Continuous investment in research and development not only employs existing capacity, but it also arms the industry with new technologies specifically aimed at future programs. The ongoing research serves to advance the state-of-the-art and prepare staff for the challenges associated with upcoming missions.

However, while it used to be commonplace to find dedicated industrial research and development laboratories nestled within the walls of engineering companies, that practice has waned recently. Companies has found it difficult to justify the overhead costs associated with a dedicated R&D staff that mostly works on internally-funded projects. Company management tends to prefer "billable hours" over other work because it improves the company's financial performance in the near term. As such, R&D efforts are often limited to specifically funded projects with limited scope and limited flexibility to explore potentially valuable research areas.

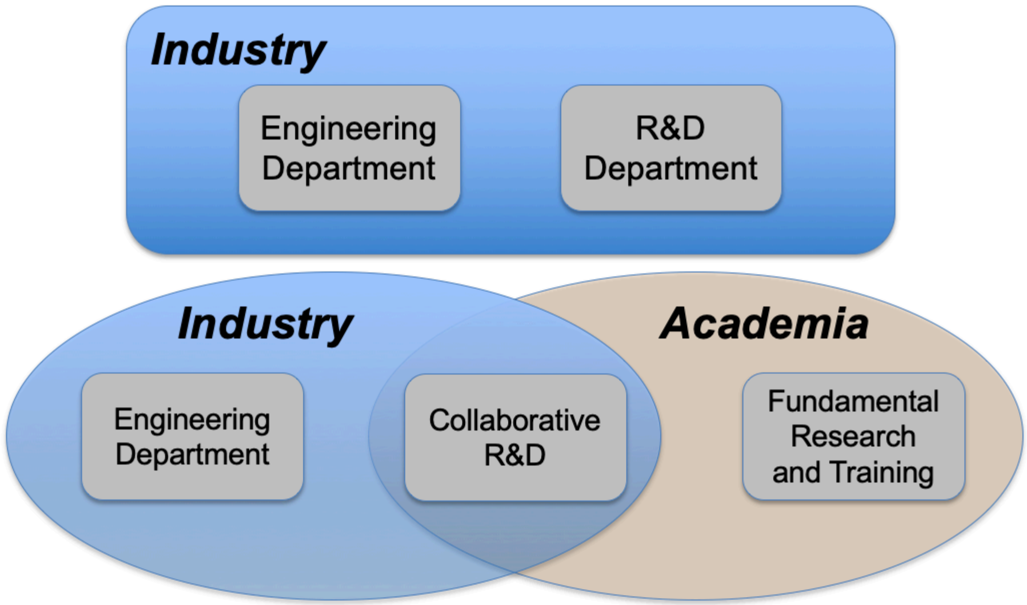

Figure 1: Classical (top) and modern (bottom) models of industrial research and development.

A more modern approach to engineering research is to form partnerships between industry and academia. While industry focusses on product development and commercialization, academia tends to focus on fundamental research, discovery and training. The intersection between industry and academia is a rich area of collaborative research, commercialization and Highly Qualified Personnel (HQP) training. Further, with industry viewing the academic partner as an extension of their R&D staff, they are able to more efficiently deploy staff to the most pressing (and profitable) projects, while continuing to explore new areas that hold potential for future missions or projects. Within academia, professors and researchers leverage the collaboration to ensure their research is topical and timely while simultaneously working closely with industry to identify likely areas for commercialization and future research spinoffs.

From a capacity perspective, partnerships between industry and academia help to smooth out the peaks and valleys of industrial project funding by funding on-going research with minimal costs due to the inexpensive nature of academic-based research staff. This relationship enables industry to staff directly from a pool of known and experienced graduate researchers at the University in response to peaks in demand. It also prevents a loss of capacity between programs since industrial teams can staff more efficiently and redeploy staff at any time to work on the on-going research being led by the academic team.

This paper describes the key pillars of the partnership forged between the University of Manitoba and Magellan Aerospace to develop / commercialize new space technologies, train HQP and build capacity in the Canadian space industry. We achieve these goals through:

- Collaborative research
- Cooperative teaching
- Shared facilities
- Active mentorship

STARLab

In 2018, the University of Manitoba and Magellan Aerospace partnered with the Natural Sciences and Engineering Research Council (NSERC) to establish the NSERC / Magellan Aerospace Industrial Research Chair in Satellite Engineering[5]. This five-year renewable appointment (held by Dr. Philip Ferguson) aims to break down the barriers that currently prevent new technology integration into the space sector. Throughout this research program, we address three key aspects of space systems design. Firstly, we are developing resilient spacecraft control systems by investigating safe, self-configuring and adaptive control strategies for satellites that can reduce development time by eliminating the need for simulation, characterization or calibration prior to launch. Second, we are developing develop robust and scalable "cloud-based" solutions that leverage orbital knowledge of existing space objects to help with controlling satellite position and orientation in orbit. Third, we are investigatoing smart technologies for harsh environments by designing miniature attitude sensing and control technologies to be embedded into multi-function structural spacecraft panels that provide protection from launch vibration, space radiation and small space particles.

The chair program also led to the establishment of the University of Manitoba Space Technology and Advanced Research Laboratory (STARLab). The STARLab provides a large shared facility that supports collaborative research, development, validation and testing of a wide variety of space technologies ranging from space structures, communications, guidance, navigation and control.

Figure 2: STARLab Logo

One of the key benefits of the collaborative research program is the agility our partnership provides. Students from the STARLab and engineers from Magellan are constantly communicating and sharing results (on at least a weekly basis). This tight partnership ensures that research topics evolve with the needs of industry, providing the best possible return on our research investment. The partnership also puts students and engineers in direct contact, that sets up future employment relationships for Magellan to exploit in support of large space programs.

Cooperative Teaching

Engineering pedagogy is an evolving topic with a series of unique challenges. On the one hand, industry requires young engineers to graduate with a deep understanding of the basics of engineering and engineering science. Topics ranging from linear algebra to simple structures, partial differential equations to fluid mechanics, solid body dynamics and control to thermodynamics and everything in between are the fundamental building blocks of all engineering curricula that must be taught from first principles. However, on the other hand, there are the "soft skills", such as leadership and product design that industry expects out of engineers, but is rarely taught in a formal way. Kumar and Hsiao discuss these such soft skills in [1], suggesting a "Problem-Based Learning" (PBL) methodology. Training through team-based problem solving very closely mimics the scenarios in which industry operates every day and thus prepares students for everyday engineering solutions. Similarly, Dym et al discuss the benefits of "Project- Based Learning" in [2] to instil fundamental design skills into graduating engineering students.

Fundamentally, the purpose of an engineering education is to prepare students for careers in engineering industry by training students on specific skill-sets. Building upon the basic fundamentals listed above, it is clear that courses focused on in-class PBL in team settings, prepare students the best for the kinds of industrial challenges that await them post-graduation. Therefore, a key aspect of the University of Manitoba / Magellan Aerospace partnership revolves around HQP training, in part through collaborative teaching.

The space industry revolves around requirements management through classical systems engineering. Requirements are the language of a space systems engineer. Well thought-out and phrased requirements with logical decomposition and verification will set the stage for a successful project in technical, budgetary and schedule performance. In most industrial settings, the need for better systems engineering training has been the most prominent request. Pohl covers the fundamentals of systems engineering in [3].

In keeping with the PBL approach, an important aspect of systems engineering training is to put it to the test in real-world design scenarios. To this end, the University of Manitoba and Magellan Aerospace have developed a graduate course on space systems engineering. This course provides graduate students with an industrially-relevant exposure to classical systems engineering, taught from the perspective of space systems engineering. Jointly taught by the Faculty of Engineering and engineering staff from Magellan Aerospace, students learn how to clearly define and execute a complex, multi-disciplinary satellite engineering project through formal requirements definition and a statement of work. The course is centered on a large group project, relevant to Magellan Aerospace. As the course progresses, students learn (at a high level) the various aspects of space systems engineering, including:

- Space systems requirements management and verification
- Spacecraft power subsystems
- Spacecraft structural design
- Space to ground communications
- Spacecraft attitude and orbit control
- Spacecraft thermal control
- Flight software
- Spacecraft computer systems
- Spacecraft assembly, integration and test planning
- Spacecraft launch operations
- Spacecraft on-orbit commissioning
- Spacecraft operations and design for human factors
- Spacecraft de-orbit and decommissioning
- Contract negotiations
- Customer interactions
- Technical writing
- Technical presentations

The course culminates with student groups conducting a Preliminary Design Review (PDR) of their project to a team of space systems engineers and managers at Magellan Aerospace, Winnipeg.

The kind of training provided by this graduate course goes far beyond the typical academic lecture-based courses most students are used to. The direct interaction between engineers and students ensures that the student project work closely follows industrial design practices. The interaction also provides Magellan employees with direct access to students, providing insight into the types of students getting ready to enter the job market. In some ways, this course serves as an extended job interview for Magellan to scout out new candidates for future engineering positions.

Classroom to Cleanroom

The University of Manitoba has made large investments in aerospace research, reflecting the strong industrial presence of this sector in the Winnipeg area. In 2014, the University partnered with Magellan Aerospace and Western Economic Diversification Canada to construct the Magellan Aerospace / University of Manitoba Advanced Satellite Integration Facility (ASIF), located at Magellan. This facility is jointly owned and operated by the University and Magellan and has been designed to meet both contractual and research requirements of both organizations. The ASIF is a 6,000 square-foot ISO Class 8 cleanroom with large floor areas and support infrastructure to accommodate up to three projects simultaneously. The ASIF is the only one of its kind in Western Canada. Undergraduate and graduate researchers, as well as other University personnel engaged in satellite research have access to this facility for a minimum of 500 hours per year.

Figure 3: Jointly-owned University of Manitoba / Magellan Aerospace ASIF

The ASIF and associated vibration and thermal vacuum testing facilities provides critical facilities to support the STARLab research. Within the ASIF, students learn a variety of skillsets including:

- Space-grade soldering
- Wire harnessing
- Mechanical assembly
- Space hardware handling
- Electrostatic discharge best practices
- Foreign Object Debris (FOD) training
- Instrumentation design
- Polymeric application
- Environmental test design
- Data collection and management

HQP exposed to real space engineering processes such as those outlined above gain a unique training experience that establishes a strong technical and research footing. This experience is key to space capacity building since these students enter the workforce upon graduation with an industrially-relevant skillset, ready to make an immediate impact to whatever space project they are assigned to.

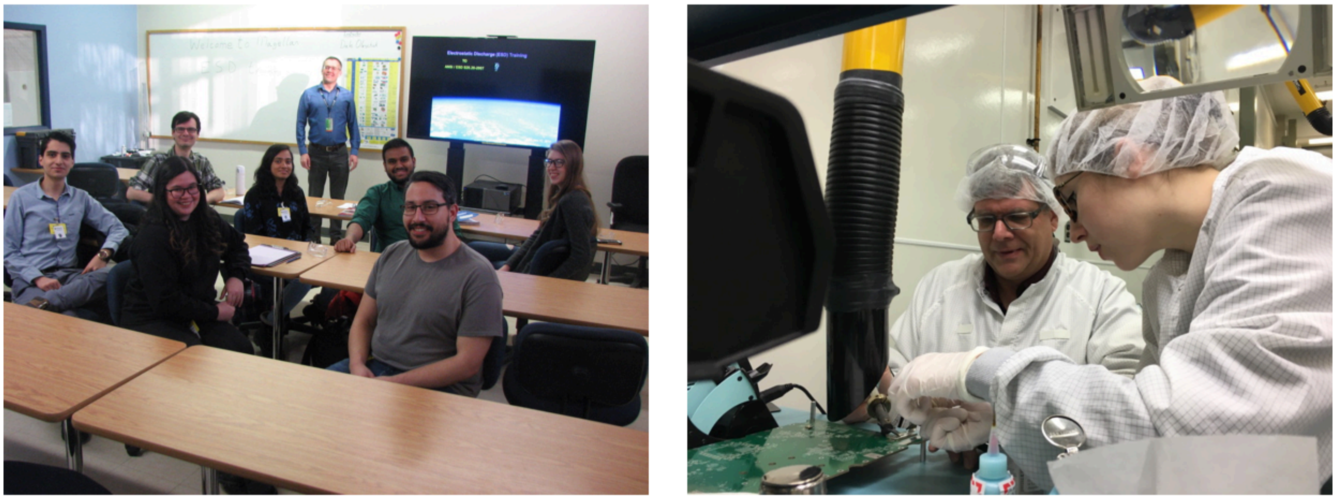

Figure 4: Students obtaining classroom electrostatic discharge (left) and practical soldering (right) training at Magellan Aerospace.

Collaborative Projects

Kinsner et al discuss the benefits of industry / academia collaboration in the context of a satellite design project with industrial advisors in [4]. To this end, the partnership between the University of Manitoba and Magellan Aerospace also provides valuable design mentorship from Magellan's engineering staff to the University students in support of a wide variety of research projects. One such project is the ManitobaSat-1 project, funded by the Canadian Space Agency as part of the Canadian CubeSat Program.

ManitobaSat-1 is a 3U sized CubeSat mission under development by STARLab at the University of Manitoba in collaboration with York University, the University of Winnipeg, the Interlake School Division and Magellan Aerospace[7]. The mission's primary purpose is to expose students to real spacecraft design, assembly, test and operations while providing important and relevant science data. The scientific mission studies how various materials commonly found on asteroids and meteorites change during exposure to space radiation and solar illumination in space. The scientific data will be used by NASA in conjunction with the OSIRIS-Rex mission to understand the origin and history of deep-space objects.

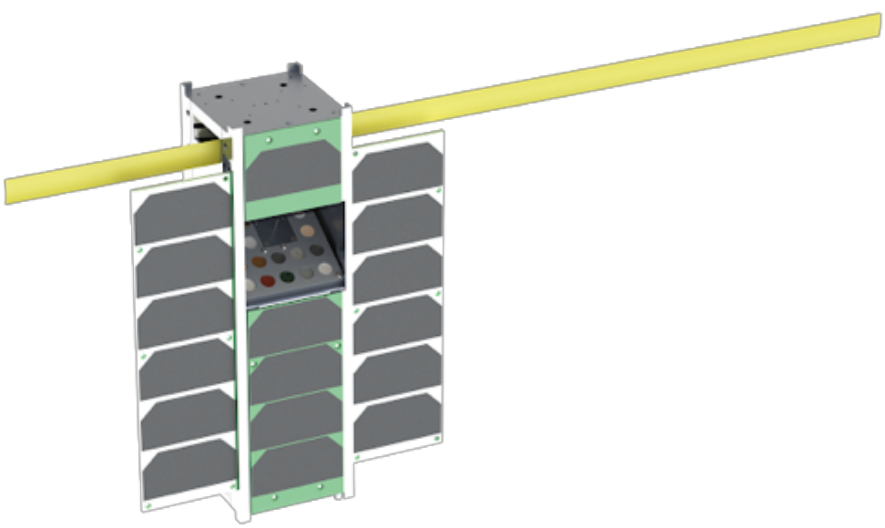

Figure 5: Rendering of ManitobaSat-1

The project involves HQP from multiple disciplines and with different educational levels ranging from undergraduate students to post-doctoral fellows, and led by seasoned researchers. Elementary school students are also involved in the payload design (in particular, to design a gnomon for the payload tray).

The project exercises various scientific disciplines (*e.g.,* geology, chemistry, physics, biology) as well as various engineering disciplines (*e.g.,* mechanical, electrical, thermal, optical), which interact closely to ensure that the project goals are met and that robust scientific results are obtained. In total 18 HQP from five different institutions and two different provinces are being trained across five different education levels.

By exploiting the partnership between the University of Manitoba and Magellan Aerospace, this project provides a rich training environment with knowledge transfer between different disciplines, multi-disciplinary research teams and a rich training environment with mentoring across different education levels and disciplines. The spacecraft will be assembled, integrated and tested in the ASIF. HQP will benefit from a unique training framework that immerses students into an active industrial setting. Engineers, technicians and inspectors from Magellan Aerospace assist the students through all phases of the satellite design, manufacturing, test and operations phases.

HQP from the ManitobaSat-1 program receive training that positions them well for direct entry into the space industry, or to continue a path of innovation and research at a post-secondary institution for more advanced degrees. All of the co-investigators and collaborators run active space research groups in Canada, with strong ties to other Canadian and international space research groups. The experience that these HQP obtain puts them in high demand for space industrial or space research teams coast to coast.

Conclusion

The Canadian Space industry is only as strong as the people that drive it forward. Thus, developing, maintaining and expanding our capacity for space science and engineering is paramount to Canada's future in space. This paper presented the steps the University of Manitoba and Magellan Aerospace have taken to establish space capacity in Canada. These steps include the development of a collaborative research program, cooperative teaching, shared facilities and an active engineering mentorship program. By exploiting the synergies between industry and academia, the University of Manitoba and Magellan have laid the groundwork for a strong, sustainable and experienced space capacity for Canada. The HQP that form this capacity have a unique set of industrially-relevant skills that make them immediately employable into the space industry upon graduation. Further, these partnerships strengthen industry by enabling more efficient staffing as well as an opportunity to remain as the forefront of space technology research.

Acknowledgements

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