Canadian CubeSat Project

Western University CubeSat

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1. Mission Description

The primary mission objective for Western University's CubeSat is HQP training and development, and educational outreach. The training and development with focus on multi-year undergraduate Capstone projects to design, build, and test a 2U CubeSat. The HQP training will leverage both in-house expertise and knowledge in space engineering and operations, as well as industry partner mentoring and workshops. The educational outreach component will take advantage of the Western University Centre for Planetary Science and Exploration (CPSX) well established outreach program.

1.1. Training Objectives

The short-term training goal of the project is to develop Western University's first nanosatellite and have it launched into orbit, and to contribute to the demonstration of Canada's highly qualified space scientists and engineers. The intent is to leverage the existing expertise of the Centre for Planetary Science and Exploration (CPSX) into increased contributions to space engineering by making manageable and incremental gains by means of a CubeSat development program. CPSX and its members have experience in training HQP in mission operations, analogue mission campaigns, planetary science and exploration. The long-term goal of the project is to develop applicable skills that will allow the HQP involved to be effective participants and leaders in the Canadian space community. The training and development will comprise of several components:

- Spacecraft engineering activities related to the design, manufacture, integration and testing of a CubeSat;
- Software development to facilitate remote access for users to the ground station that communicates with the CubeSat; and
- Mission planning and operations of a CubeSat.

1.2. Technical Objectives

The Western University CubeSat project proposes to flight demonstrate one of two novel imaging platforms. The primary payload will be a novel imaging instrument provided by Canadensys: a space-grade 360° imaging system that leverages deep-space ruggedized Canadian technology currently being developed for cislunar and lunar surface exploration. The capture of 360° images and video from the spacecraft will support both engineering and technology demonstration objectives, as well as having utility for Earth and climate observation. The payload has the potential to provide a first-in-Canada demonstration of immersion / VR-ready images from space, documenting the journey of the CubeSat.

The CubeSat mission will provide a valuable opportunity to gain orbital flight heritage for the Canadian immersive situational awareness system, which was designed for planetary surface exploration, as a test for its utility in orbital nanomissions in cislunar pace and around Mars, as well as prox ops, servicing and debris applications in Earth orbit.

The secondary technical objective is to extend the capabilities of the REALM platform to enable remote access to the CubeSat ground station. The intent is to further develop this platform to facilitate asynchronous educational activities for various age groups for public engagement and educational outreach.

1.3. Educational Outreach Objectives

CPSX has a history of public engagement and education outreach to wide-ranging audiences through its public talks, annual Space Day, summer Space Camp, and in-the-classroom outreach activities. This program will be further enhanced with in-class CubeSat demonstrations.

Furthermore, the Western University CubeSat project proposes to collaborate with Nunavut Arctic College to provide the CPSX Space Camp program to students in Nunavut, and to bring Nunavut Arctic College students to Western University for training and operations opportunities.

1.4. Objectives for Western University

The Western University CubeSat project will establish a path forward for space engineering education to complement the existing space science research and programs. The development of a ground station will serve as a legacy project for the Faculties of Engineering and Science. Future students may gain experiential learning opportunities in nanosatellite communication links, operations and data retrieval, while promoting cooperation with other universities through ground station resources sharing. The CubeSat development will facilitate a new avenue for CPSX to promote the space science and engineering capabilities of the university at regional, national and international levels. CPSX will be able to enhance its already established public engagement of education outreach program to promote STEM subjects and attract domestic undergraduate and graduate students to Western University's programs.

2. Benefits to Canada

2.1. Advancement of new Knowledge and Technology

As a result of the development and operation of the proposed CubeSat mission, the following advancements of new knowledge and technology are expected:

2.1.1. A technology demonstration of a novel imaging platform

The Western University CubeSat project proposes to flight demonstrate one of two novel imaging platforms. The primary payload will be a novel imaging instrument provided by Canadensys: a space-grade 360° imaging system that leverages deep-space ruggedized Canadian technology currently being developed for cislunar and lunar surface exploration. The capture of 360° images and video from the spacecraft will support both engineering and technology demonstration objectives, as well as having utility for Earth and climate observation. The payload has the potential to provide a first-in-Canada demonstration of immersion / VR-ready images from space, documenting the journey of the CubeSat.

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In the event the primary imaging platform is unavailable, Western University will provide a novel miniaturized multi-spectral imaging camera that is currently being developed for agriculture drones. The imager will be modified for operation on a 2U CubeSat platform for technology demonstration purposes.

Both these imaging platforms payloads in development will potentially provide significant new science data from the CubeSat mission. It also also builds a good ongoing collaboration with industry partner

2.1.2. Extend REALM to remote CubeSat Operations

The Research and Educational Activities using Laboratory Mechatronics (REALM) project was developed at Western University (under SHARCNET) in collaboration with IBM. At its core, REALM is an extensible platform for building remote experiment control. REALM was developed with a grant from CANARIE to enable remote access to laboratory equipment for educational and research purposes.

REALM is the most recent development of the Science Studio project, the first of which was to enable remote users to access the Canadian Light Source VESPERS beam line. The REALM platform enabled a robotic manipulator arm to be controlled using various teaching modes via a web browser in a classroom setting. It was able to be reconfigured with short turn around time to enable tele-operation of a mobile robot platform by a research group in Italy via a web browser.

The intent is to take the existing REALM platform code and repurpose it so that the CubeSat can be operated in a web browser by students in the classroom for outreach purposes, and by students at Nunavut Arctic College. This redevelopment will further demonstrate the capabilities of the REALM platform.

2.2. HQP Development and Training

The HQP trainees involved in the CubeSat project will gain knowledge and professional skills relevant to future Canadian space missions, and to marketplace employment requirements.

2.2.1. HQP involvement

The proposed activity shall include senior undergraduate student involvement by incorporating CubeSat subsystems as Capstone Design Projects. To attract the best students for future graduate studies, senior undergraduate students will be allowed the opportunity to contribute to the mission, thereby fostering interest and development of skills in space sciences and engineering. Additionally, the inclusion of graduate students within the scope of the project will allow HQP the opportunity to develop supervisory and mentor-ship skills through interaction with undergraduate students. It is envisioned to have students from Mechatronic Systems Engineering, Mechanical Engineering, Software Engineering, Electrical Engineering, and Computer Engineering programs make up the majority of the undergraduate HQP.

The proposed activity shall include undergraduate and graduate students, particularly form the variety of disciplines involved in the Collaborative Graduate Program in Planetary Science and Exploration participate in the CubeSat operations and educational outreach program.

2.2.2. Number of HQP in relation to budget

The budget accounts for the part-time involvement of **1 Postdoc HQP** Project Manager. Graduate student HQP receive financial support as part of the graduate studies acceptance and will not require an additional stipend from this budget. Graduate student HQP travel to workshops and conferences will be supported through this budget. Undergraduate student HQP travel to workshops and conferences will be supported through this budget. Additionally, the budget will support **12 undergraduate student HQP** on summer internships.

2.2.3. HQP involvement over all phases of the project, from beginning to end

Most of the technical development falls within the first two years. During each of the two years, all undergraduate HQP will receive hands-on experience in detailed design, assembly, integration and verification activities required of a nanosatellite mission. The first year will focus on preliminary design, This first year will involve **1 Postdoc HQP**, **3~~4~~ graduate student HQP**, and **25 undergraduate student HQP**.

The second year will focus on the detailed design. This second year will involve ~~the same~~a Postdoc and **3 graduate student HQP**, and a new group of **25 undergraduate student HQP**.

The third year will focus on the assembly, integration and verification, referenced to the detailed design. This ~~second~~ third year will involve ~~the same~~a Postdoc and **3 graduate student HQP**, and a new group of **25 undergraduate student HQP**.

In the operations year, the HQP will focus on satellite operations, data analysis, educational outreach, and publications. This year will involve a new group of at minimum **4 graduate student HQP**, plus additional undergraduate HQP depending on time of operations.~~.~~

The intention is to hold a high school level competition to involve at least **1 High School student** in workshops and operations, to assist in the delivery of the local outreach program, and promotion of space science and technology within their schools.

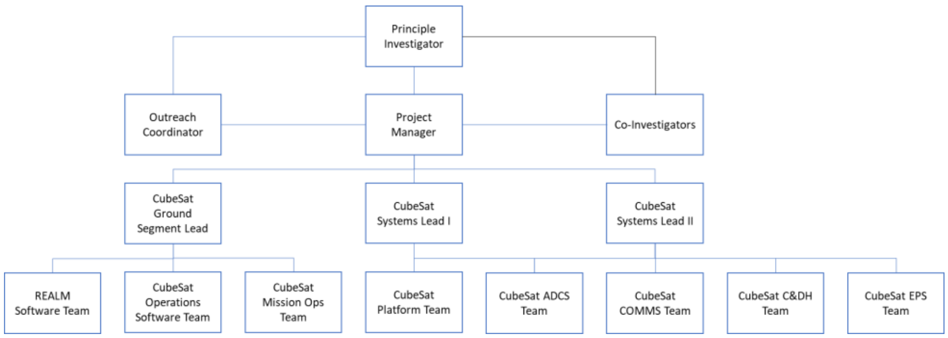
2.3. Expanding STEM Educational Outreach to Nunavut

The outreach plan involves expanding the STEM educational outreach to Nunavut. Western University will partner with Nunavut Arctic College to facilitate training of the CPSX classroom outreach program. Western will also hold two weeks of its Space Camp in Iqaluit to promote space science and education.

Additionally, 4 Nunavut Arctic College student HQP will come to Western University for its CubeSat workshop, and 4 Nunavut Arctic College student HQP will come to Western University to participate in mission operations.

3. Project Team

The assembled team consists of a Principle Investigator (PI), Co-Investigators, a project manager (PM), and educational outreach coordinator, the CubeSat development team, and the CubeSat Operations Team



3.1. Quality and Experience of the Team

3.1.1. Principle Investigator: Dr. Jayshri Sabarinathan

Dr. Sabarinathan is an Associate Professor and Associate Chair, Graduate of Electrical and Computer Engineering at Western University. She will be responsible for the overall success of the CubeSat mission. Dr. Sabarinathan will also provide the technical training and support for the CubeSat and ground station communications subsystems, and the electrical power subsystem. Her research interests are primarily in novel sensor development and instrumentation miniaturization. She has expertise and leads collaborative projects in bio-chemical sensor and hybrid micro-sensor design, miniature instrumentation and multi-spectral camera development. She currently holds OCE and NSERC CRD grants for building multispectral cameras for UAV based remote sensing. Her research work has also led to a patent for novel micro-sensor.

She is currently the instructor for engineering course on Antennas Communications involving students in link budget calculation and antenna design projects. Her past experience include involvement in SEDS student group activities and participating as a team member and instrument team lead in NASA-UMICH Get Away Special (GAS) project which flew on STS 89 and 88~~will be responsible for the overall success of the CubeSat mission. Dr. Sabarinathan will also provide the technical training and support for the CubeSat and ground station communications subsystems, and the electrical power subsystem.~~

3.1.2. Project Manager: Dr. Matthew Cross

Dr. Matthew Cross is a Postdoctoral Associate in Electrical and Computer Engineering at Western University. His research is focused on machine learning and rover mobility, including proximally detecting hazardous terrain conditions. As a NSERC-CREATE scholar he participated in CanMars analogue mission operations as science activity planner each year. During his master's program at Carleton University in Aerospace Engineering, he worked on the development of the Kapvik lunar rover prototype for the Canadian Space Agency. He previously worked at the European Space Agency as a spacecraft systems engineer for a lunar orbiter program. Dr. Cross will execute the project and manage the day-to-day activities of the project, and provide technical training and support for the CubeSat systems engineering.

3.1.3. Co-Investigator: Dr. Ken A. McIsaac

Dr. Ken A. McIsaac is Associate Professor and Chair of Electrical and Computer Engineering at Western University. His research focuses mainly on using techniques from computer vision to enable autonomous decision making in robotic systems. Dr. McIsaac's research covers a wide range of application domains, from systems with direct industrial relevance in waste collection and agriculture, to robotic systems that enable autonomous exploration of space and planetary systems. Dr. McIsaac will provide the technical training and support for the CubeSat onboard command and data handling (C&DH) subsystem, and operations software.

3.1.4. Co-Investigator: Dr. Matt Bourassa

Dr. Matthew Bourassa is a Research Engineer for the Department of Earth Science at Western and is responsible for developing technologies for field geologists and planetary rovers. He is currently working on creating a roadmap for planetary instrument development to plan the priority technologies that future space missions (ground or orbital) will require. He participated in the CanMars 2016 mission as the Daily Planner, which involves creating the daily and long-term plans for rover operations, as well as a member of the field team for the second part of the mission. During his PhD, he worked at CSA for two years and as a junior engineer through the Research Affiliate Program. Dr. Bourassa will provide technical training and support for the CubeSat attitude determination and control (ADCS) subsystems. Dr. Bourassa will also serve as backup Project Manager

3.1.5. Co-Investigator: Dr. Gordon Osinski

Dr. Gordon Osinski is an Associate Professor and the NSERC/MDA/CSA/CEMI Industrial Research Chair in Earth and Space Exploration in the Departments of Earth Sciences and Physics and Astronomy at the University of Western Ontario, Canada. He is a Co-I on the PanCam instrument on the 2020 ExoMars mission to Mars and he led the successful CanMars Mars Sample Return analogue missions with the Canadian Space Agency in 2015 and 2016. He is passionate about outreach and science communication and recently received the 2017 Faculty of Science Outreach Award for this work. Dr. Osinski is the Director of the Centre for Planetary Science and Exploration (http://cpsx.uwo.ca) at Western, the Principal Investigator of the Canadian Lunar Research Network (http://clrn.uwo.ca), and the founder and Chair of the Planetary Sciences Division of the Geological Association of Canada (http://uwo.ca/earth/GACPSD/). He is a member of several advisory committees, including the Space Advisory Board of the Government of Canada and the Planetary Exploration Consultation Committee of the Canadian Space Agency. Dr. Osinski will provide support for the CubeSat mission operations and act as the primary liaison with the Nunavut Arctic College.

3.1.6. Co-Investigator: Dr. Livio L. Tornabene

Dr. Tornabene is SETI Research Scientist and an Adjunct Research Professor at Western University. Dr. Tornabene has 16 years of experience with planetary missions, and maintains involvement, as a science team member with the High Resolution Imaging Science Experiment (HiRISE) on the 2006 Mars Reconnaissance Orbiter, and is also involved, more recently, as Co-Investigator on the Colour and Stereo Surface Imaging System (CaSSIS) on the ExoMars 2016 Trace Gas Orbiter. Dr. Tornabene will provide technical training and support for the CubeSat mission operations.

3.1.7. Co-Investigator: Dr. Nadeem Ghafoor

Dr. Nadeem Ghafoor is the Vice President of Space Exploration at Canadensys Aerospace, a Toronto-based space systems and services company focused on accessible space, where he leads the space exploration and space education business areas for government and commercial space applications. Dr. Ghafoor is the project lead across a wide range of space projects at Canadensys, with particular emphasis on game-changing technologies that enable smaller, faster and more affordable missions that can survive for longer durations in deep space and planetary environments, in an effort to unlock the space frontier and accelerate the pace of national and commercial development. He previously spent 9 years at a large Canadian space robotics company managing new exploration initiatives and prior to this worked for 5 years in the UK space industry supporting the development of 5 different microsatellite missions. Dr. Ghafoor is a firm advocate for cooperation and collaboration across the space sector, and a longstanding proponent of space education and its potential to engage and inspire.

Dr. Ghafoor is currently leading the development of several projects involving CSA support in the area of nano-class technologies and subsystems, ruggedized for deep space. Included in this is a wide angle immersion-ready 360 imager that is already being developed for two space exploration flight programs, and is baselined to simultaneously support science, technology demonstration and outreach / engagement objectives aboard the York U cubesat.

3.1.8. Educational Outreach Coordinator: Dr. Parshati Patel

Dr. Patel has been involved in public education and outreach for the past 8 years through a variety of roles at various scales. She is currently the CPSX Outreach Program Coordinator. She coordinates all CPSX outreach and education activities, including Space Camp and the Centre's bi-weekly public podcast, Western Worlds. Dr. Patel will provide support in the delivery of outreach programs.

3.1.9. Collaborator: Mary Ellen Thomas

Ms. Thomas is the Senior Research Officer at the Nunavut Research Institute, Nunavut Arctic College. Ms. Thomas will assist with facilitating the outreach component in Nunavut, and with facilitating the Nunavut Arctic College student participation.

3.1.10. Collaborator: Dr. Tom Dzamba

Dr. Tom Dzamba will provide Systems Support for the proposed development. Tom is the lead Vision and Optical Systems engineer at Canadensys, where he is currently leading the development of the NISA Optical Imaging System and supporting the development of the vision system for the 2015-2017 Deep Space Nano Core STDP. Previously, Tom was a key team member in the development and production of both the ST-16, and ST-16RT Sinclair Interplanetary star trackers - two commercially successful camera-based guidance sensors for small satellites. Tom's experience includes systems engineering of small satellite vision systems, development of calibration and test procedures for various optical sensors, and development of flight software for fine-pointing guidance sensors utilizing C++/Python/Matlab. Tom holds a Doctorate in Aerospace Engineering, a Masters of Applied Science, and a Bachelor of Engineering, all from Ryerson University. Following his graduate studies, Tom was MITACS Elevate post-doctoral fellow for two years while working with Sinclair Interplanetary.

3.1.11. Collaborator: Mr. Luke Stras

Mr. Luke Stras is the Electrical Systems Lead at Canadensys, coordinating all electronics activities. Luke Stras is the lead engineer for the Deep Space Nano-Core Low Temperature Nano-class Electronics CSA STDP development. Mr. Stras will be the lead engineer for all work that involves design, integration, and test of electronics, and will provide senior support and supervision for software-related tasks. Mr. Stras has worked on Canadian small spacecraft missions since 2001, and has performed systems engineering and detailed design on a number of Canadian micro and nano-satellite missions, including: Microvariability and Oscillations of Stars (MOST), CanX-1, two privately-funded space station prototypes, FalconSat-3 and FalconSat-5, the Bright Target Explorer (BRITE) missions, AISSat-1 through 3, Maritime Monitoring and Messaging Microsatellite (M3MSat), NORSAT-1 and 2, CanX-4 and 5, CanX-7, the Nanosatellite for Earth Monitoring Observation - Aerosol Monitoring (NEMO-AM), Nanosatellite for Earth Monitoring - High Definition (NEMO-HD), and the Kapvik micro-rover. His work spanned the design, assembly, integration, and test for various subsystems including: software, power, command and data handling, and focal plane development.

4. CubeSat Development and Operating Plan

4.1. CubeSat Concept

The Western University CubeSat will be a 2U form factor with a novel imaging payload, coarse attitude determination and control, body-mounted solar panels with rechargeable batteries for a power system, a communications system to facilitate commanding and telemetry with the ground station, onboard sensors to measure temperature of the faces, and an onboard computer to control process all commands to operate.

Western University will install its own ground station equipment to interface with its Mission Control room, that is currently used for HiRISE and CaSSIS planning, and has been used for running planetary exploration analogue campaigns. The CubeSat will then be operated primarily out of Mission Control.

4.2. CubeSat Development Timeline Justification

The focus of the CubeSat development is on undergraduate HQP and capacity building. The undergraduate HQP will be involved in the CubeSat project as part of their Capstone design project course. The CubeSat development will best fit into the academic schedule by spacing the Preliminary Design, Detailed Design, and AIT phases across three separate academic years.

During each of the three academic years, senior undergraduate students will form small groups to work on subsystems of the CubeSat. For example, Mechanical Engineering Students will perform the design, analysis and manufacturing of the CubeSat structure; Mechatronic Systems Engineering Students will perform the design, analysis and assembly of the attitude determination and control system, etc.

This plan to have Capstone design projects as the focus of the CubeSat Development Plan spread out over three years will increase the number of undergraduate HQP trainees while minimizing scheduling risk by affording summer term months to additional development time if needed.

The summer terms will be supported by undergraduate summer research HQP, and graduate student HQP. The first summer term will be spent on the Phase A Definition Phase; the second summer term will be spent closing out any RIDs from the PDR, ground station software development and outreach activities. The third summer term will be spent closing out any RIDs from the CDR, ground station software development and outreach activities. These summer months will also facilitate participation with classroom outreach activities and Space Camp without diverting from core development time.

4.3. 2U CubeSat Justification

The proposed CubeSat development calls for a 2U form factor. The intent is to, in additional to the training and outreach component, use the CubeSat for technology demonstration of an imaging payload provided by Canadensys, which will require the additional volume to house, and area for solar panels. Should this primary payload no longer be available, a novel miniaturized multi-spectral imaging camera being developed by Western Researchers for agricultural drones will be modified for spaceflight demonstration; this multi-spectral imaging camera will also require the internal volume afforded by the 2U form factor.

4.4. CubeSat Development

Each of the Capstone design groups will comprise of 3-4 senior undergraduate students, and will be supported by a graduate student HQP, and one of management team members (PI, Co-I, or PM). As the Capstone project is a required component of the undergraduate program, students will be working on the project as part of the core-curricular as opposed to extra-curricular activities.

The intention is to have the flight version of the CubeSat developed and assembled in the third Capstone year. However, the intention is to have pre-flight models developed to satisfy design and build requirements of the Capstone course. This will have the added benefit of having some components, such as a 2U structure will panels, sensors, and actuators available to be assembled into a demonstration unit that can be taken into classrooms.

Most of the CubeSat will be developed at Western University. The university provides standard engineering tools for the initial design of the CubeSat, including licences to engineering design and analysis software such as SolidWorks and Matlab.

As hardware begins to be built or acquired, university laboratory space will be utilized for electronics handling and testing, and manufacturing. Clean room space is also available on campus; however, it is envisioned to utilize facilities at MDA prior to vibration testing and final delivery to CSA; budget has been allocated for vibration testing.

A breakdown of the CubeSat development is provided in Section 7 Project Management Plan. The team that will lead the CubeSat development and operations, and HQP training, is provided in Section 3 Project Team.

4.5. CubeSat Operations

The plan is to operate the CubeSat out of the Mission Control Room at Western University. The ground station will be based on Western University property in London, Ontario. London's latitude in comparison to ISS will provide on average 2710 seconds of contact per day. If logistics permit, Western University could provide ground station access to teams from higher latitudes and less favourable communications windows.

The CubeSat will be operated by HQP trainees under the guidance of Dr. Tornabene. The intent will be to have a core group of HQP trainees run the day-to-day operations. Additional operational opportunities will be provided to students from Nunavut Arctic College and local high school students.

The CubeSat operations will feature a first-in-Canada demonstration of immersion / VR-ready images from space to document the journey of a CubeSat through Earth orbit for all of Canada.

With the REALM development to enable remote access to the ground station, the intent is to have access to the ground station in the classrooms, or Space Camp, to demonstrate CubeSat operations with students and to enable students to upload commands. Members of public can view the CubeSat operations in the Mission Control room during public nights.

4.6. CubeSat Operations in Mission Control Room

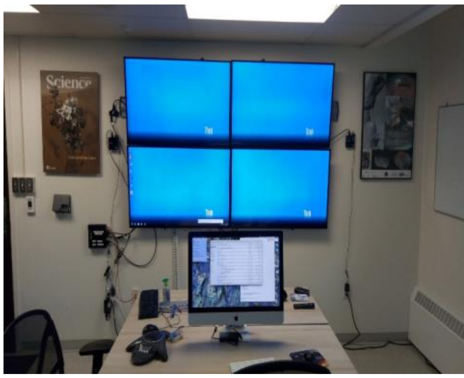


Image: Mission Control main control centre.

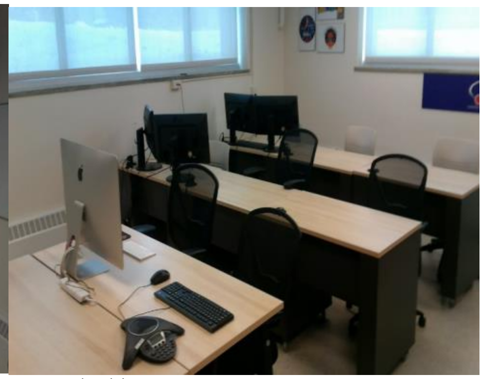


Image: Support PC and mobile stations.

The Centre for Planetary Science and Exploration (CPSX) at Western University's mission control (housed in the newly renovated Physics and Astronomy building) provides a well-equipped and state-of-the-art facility that seats 11 individuals, and is specifically available in support of, or planning for, mission operations for planetary/analogue missions, and remote telescopic observations led by core-faculty members of CPSX. The facility hosts a variety of state-of-the-art equipment, including a main PC for running the 4 wall mounted TVs and support PCs, Polycom Soundstation HD voice speakerphone, and white board.

5. Training Plan

5.1. Training Team

The Principle Investigator (PI), co-investigators, project manager, and mentors will form a training team to provide the necessary training to the HQP. The methods of the training activities are as follows:

- The training team shall require the HQP to provide both oral and written progress reports monthly; feedback on the quality of the reports will be provided to ensure continual improvement in quality and pertinence to be in line with academic, industrial and government expectations and standards.
- The training team shall inform the HQP of upcoming relevant conferences and journal article submission deadlines and to encourage the submission of papers, articles, and presentations to facilitate the development of technical communication skills.
- The training team shall, on a rotating basis, observe the HQP-led weekly meetings; encourage HQP to present findings and results to demonstrate and enhance their self-confidence and technical competence; provide feedback on the professionalism, communication style, relevance, and diligence to ensure continual improvement in the leadership skills of the HQP.
- The training team shall, when possible, allow HQP to sit in and participate in meetings in which the training team member meets with a outside collaborator; i.e. an industrial partner, government agent etc.
- The training team shall, on a rotating basis, provide a seminar on their experiences in project leadership, industrial interaction, spacecraft AIV activities, spacecraft operations, and other relevant topics in line with the project schedule.

- The training team shall, when possible, provide specialized hands-on technical training for applicable project work. When a specialized skill is required to be developed on the part of the HQP that does not fall under the expertise of an existing member of the training team, the training team shall recommend an external consultant to provide the training.

5.2. Skills Development

5.2.1. Project Management Skills

As a result of the CubeSat project, HQP trainees will develop the following project management skills: Project planning and task scheduling; Resource (fiscal and manpower) acquisition, allocation and utilization; Documentation generation and project status updates to applicable partners; Risk identification and mitigation; Interaction with scientists to drive mission payload requirements definition; Ensuring ethical practices and conformation to university, provincial and federal regulations and policies; Project leadership and interpersonal skills; and Mission planning.

5.2.2. Systems Engineering Skills

As a result of the CubeSat project, HQP trainees will develop the following systems engineering skills: Requirements definition and tracking; Operations definition; Subsystem design; Subsystem interface definition and control; Subsystem assembly, integration and verification; Spacecraft / ground station communication and operations; Lower-cost solutions space systems design and analysis; Best practices and lessons learned

5.2.3. Technical Skills

As a result of the CubeSat project, HQP trainees will develop the following technical skills: Spacecraft thermal modeling, analysis, and control design; Spacecraft structural modeling, analysis, and manufacturing; Spacecraft vibration testing; MatLab and/or LabView based data processing techniques; Spacecraft power budgeting; Spacecraft electrical power system design and analysis; Solar panel assembly; Amateur radio licensing; Spacecraft frequency registration; Link budget design; Antenna pattern design; Spacecraft software development and implementation; Spacecraft avionics design and analysis; Mission orbit analysis utilizing Satellite Toolkit (STK); Sensor and actuator design and analysis; Attitude control law design; Ground station implementation; On-going satellite operations and ground station maintenance.

5.2.4. Communication Skills

As a result of the CubeSat project, HQP trainees will develop the following communication skills: Scientific and technological conference and journal publications; Conference participation; Promotion of the CubeSat to the university and partners; Promotion of the benefits of space science, engineering and education to Canadians; and Promotion of space science, engineering, and education to encourage youth to pursue science and technology.

5.2.5. Team Work and Leadership Skills

As a result of the CubeSat project, HQP trainees will develop the following team work and leadership skills: Fostering positive team work environment; Adapting to changing program conditions; Fostering confidence of project members through positive reinforcement, constructive feedback, merit recognition, and regular team activities; Small-team self-management; Establishing regular project meetings with agenda and action items; Collaboration with outside partners; and Mentoring students participating in project.

5.3. Workshops and Training

Western University and CPSX will leverage its heritage in offering space education short courses by developing a CubeSat short course over the summer as part of the training plan. The CubeSat workshop will be targeted to Western University and Arctic College students, however students from across Canada will be eligible to participate. A plan of topics to be covered over a week-long short is as follows: Overview and roadmap of CubeSat missions and technologies; Planetary Missions utilizing CubeSats; CubeSat Assembly, Integration and Testing; Orbital Analysis with Satellite Tool Kit; CubeSat Attitude Determination and Control; CubeSat Communications with Earth; CubeSat Structural Modeling and Testing; CubeSat Thermal Modeling, Control and Testing; CubeSat Power Systems; CubeSat Onboard Command and Data Handling; and CubeSat Operations. Is envisioned to have both university members and guest speakers from industry deliver the content for this program. Canadensys and MDA have committed to being industry supporters for our CubeSat workshop.

For example, a training workshop on attitude determination an control will be development by Co-I Dr. Bourassa as part of this CubeSat short course. Part of development process for the CubeSat will require training the students in the areas of orbit analysis, and attitude determination and control. To train the HQP, a series of lessons will be put together to ensure that HQP on the CubeSat team has a base level of understanding of orbital mechanics and satellite dynamics. These lessons will focus on the introduction to orbits and the two-body problem, satellite observations, as well as attitude dynamics and pointing. Subsequently, the sub-teams that require more advanced knowledge in these fields will complete additional sets of lessons as required. The focus of these lessons would include orbital coordinate systems, orbital determination, attitude coordinates systems, and attitude determination and control.

Additional workshops will be developed from the existing knowledge base at Western. For example, PM Dr. Cross is developing a Space Mission Design course for the Professional Space Studies Masters Program, and content from that course will be repurposed and focused on requirements management. Dr. Sabarinathan teaches an existing course in RF Communications which includes developing link budgets, and this will be condensed to provide a workshop for students who aren’t otherwise enrolled in the course.

5.4. Additional HQP Development and Training Resources

The Centre for Planetary Science and Exploration has established a weekly research forum which encourages graduate students to present their current work to faculty and students. Participation in the forum is encouraged and required for students enrolled in the collaborative graduate program. Students also present their work at the annual Space Day, and are strongly encouraged to participate in conferences and publish work in journals.

The intention will be for HQP trainees to present their CubeSat development work at the Research Forum, to participate and present at the annual Space Day. When appropriate, HQP trainees will submit publications for peer review whenever possible and to present that work at relevant conferences.

Canadensys has committed to mentoring undergraduate and graduate students in the areas of mission planning, payload assembly, integration and testing, and collaborative research.

5.5. Facilitating Gender Balance in Trainee Population

The Western University CubeSat project will be open to students of all gender identities. The current leadership team has three women in prominent and visible positions, including the PI. Two of the three proposed Graduate Student HQP trainees are women with experience in space related projects and communications. CPSX outreach and Space Academy are delivered with a gender balanced team of mostly science students to promote women in STEM subjects. At present, there are interested undergraduate women for the first year of the CubeSat development. The intention is to utilize the leadership team, graduate student HQP trainees, and outreach team to promote the CubeSat project internally to encourage women to participate and have gender parity by the third year of development. Western also hosts the very popular GoEng Girl and GoCode Girl activities every year for Grade 7-11 girls which includes active participation from university students and faculty members. In addition to the outreach plan described in the next section, The CubeSat project team would participate in hands-on activities and information sessions during these days to inform girls about opportunities in space science and engineering.

6. Outreach Plan

The public education and outreach program at the Centre for Planetary Science and Exploration (CPSX) at Western University has seen steady growth in development and expansion of the program with focus on planetary science and space exploration. The vision for CPSX is "To strengthen and grow the Canadian space community through inspiring and training the next generation of scientists and engineers." The outreach program shares this vision and is guided by the following objectives: i) offer educational re-sources to teachers and educators, ii) encourage and inspire students to consider career opportunities in science by engaging them in activities related to planetary science and space exploration, iii) raise awareness and general interest of the public in science through planetary science and space exploration events, and iv) train graduate students in teaching and outreach practices.

The current program offered can be divided into three broad categories: i) training, ii) public event and activities, and iii) school visits and academic programs.

Training activities are one of the most critical activities of the program. The training category encompasses three major groups which fall into the following areas: Teacher training, Graduate student training and Conference attendance. Teacher training provides educators with the knowledge and resources in planetary science and space exploration. Graduate student training prepares them with communication, presentation and teaching skills. Conference attendance allows to stay up-to-date with teacher needs and outreach activity programming as well as build network and foster collaborations with local and national organizations.

The public events and activities focus on emphasizing on research conducted within CPSX as well as Canada in planetary science and space exploration to the public. This is subdivided in public events and field outreach. Public events include regular or yearly programming (such as CPSX Space Camp and Western Worlds podcast) as well as one-time events (such as Analogue Mission public night). The field outreach allows to inform local communities about the research being conducted in the area and to increase the visibility of science in the community.

The academic activities, based on the Ontario science curriculum, have been developed with the support of local school board and educators. Three types of programs are being offered in school visits:

i) Activity based, ii) Inquiry based, and iii) Workshop based. Inquiry based programs are designed to follow the inquiry learning model putting participants in charge of their own learning. Activity based programs have two components: presentation and hands-on activity. Several different inquiry based labs and hands-on activities have been combined into themed workshops. This programming is the most popular amongst all the programming in CPSX.

Since its inception, many activities have been developed and conducted by CPSX in various settings. CPSX offers teacher training workshops through various avenues such as conferences. These workshops allow teachers to participate in the hands-on activities, which are based on the curriculum, as well as receive educational resources to be used in classrooms. Last year, 45 teachers participated in the workshop hosted by CPSX at Science Teachers' Association of Ontario (STAO) conference. Graduate students have lead numerous workshops in classrooms as well as attended and presented in conferences such as STAO, and Royal Astronomical Society of Canada (RASC)- Annual General Meeting.

Public events & activities. CPSX organizes and hosts various public events throughout the year, including Asteroid Day, International Observe the Moon Night, Science Literacy Week. Since 2012, CPSX has been producing bi-weekly space science and technology themed podcast, called 'Western Worlds', meant for the public. Six seasons have aired of the podcast and currently in production phase of the seventh season. In 2016, CPSX launched a space science and technology themed summer camp (called CPSX Space Camp) for children 9 to 14 years of age. 50 campers participated in the pilot program. CPSX expanded the summer camps to 8 weeks in 2017, accommodating 200 campers and introduced two themes for the camp.

CPSX currently offers total of nine activities and workshops as part of the program. This includes seven single period presentations, which can be combined with six hands-on activities and two multi-period inquiry based labs. Topics include: Impact Cratering, Rocks from Space, Mining Space, Hazards and Challenges of Space Exploration, Planetary Landscapes and Mapping, The Moon etc. All the materials are available on the website for the educators to use (cpsx.uwo.ca/outreach).

There are several future activities in planning. This includes the development of more inquiry based labs, several single period activities and presentations, offering more teacher training workshops, hosting more public events as well as collaborating and partnering with other departments within the university as well as other organization. In addition, Interactive Mapping of Mars (iMars), a digitally enhanced learning activity, is in its final phase and will be ready to launch soon. iMars is an online activity where participants plan and design a rover mission to Mars based on the mission goal. CPSX's Impact Earth project is in its early phase of development. This project will combine several components such as hands-on activity, inquiry-based lab, citizen science project and teaching kits. Using the experience from the Analogue mission, CPSX is currently developing activity to simulate analogue mission using Lego kits. A pilot workshop using the Lego kits was held during the CanMars Analogue Mission Public Night.

The program has seen considerable growth in the past years. In the year 2014-2015, 1923 participants were reached through 26 events. In the year 2015-2016, the program reached 5783 participants through 42 events. The number of events organized as well as the number of people reached has gone up significantly from the year before. Between September 2016 and December 2016, 18 events were conducted reaching 2869 students, teachers and members of public.

Feedback from teachers, participants and graduate students is crucial in assessing the success of the program. The participants of the program are asked to fill out pre-activity and post-activity feedback forms, while the teachers are requested to fill out the feedback form after each event, thus instantly receiving feedback for all the events.

6.1. CubeSat education and outreach plan

Over the past 5 years, the CPSX has established itself as a national leader in Space STEM outreach and awareness. The proposed CubeSat program will enable CPSX to take these outreach activities to the next level by literally "Launching Western into Space". Using the existing CPSX outreach activities as a foundation, a public outreach and education plan for this CubeSat initiative has been developed. Activities are planned throughout the development, building, and launch of the CubeSat. These activities are grouped around the 3 themes of the CPSX outreach program outlined above; namely, academic programs, public outreach events, and training opportunities. As noted above, these activities will not only be delivered in classrooms in the Thames Valley District School Board and the London District Catholic School Board, but also in communities in Nunavut through our partnership with the Arctic College, and also nationally through the publication of free content on the CPSX website.

6.1.1. Academic programs

We will expand on the existing offerings of CPSX and develop hands-on inquiry-based activities on CubeSats that will be linked directly to the Ontario Curriculum. Students will explore the traditional approaches to satellite design with large, heavy platforms, and then the new approaches using CubeSats. Comprehending the difference in scale will be facilitated with the development of a demonstration unit of the CubeSat that will be taken into classrooms to show the different spacecraft components and their function. Students will also build their own CubeSat using cardboard templates designed to mimic the exact specifications of the Western CubeSat. Students will compete in teams to develop ideas for science questions that their CubeSats can address.

Commented [Oz1]: Get some text from Parshati

During the operation of the CubeSat, further activities will be offered. Students will be able to view the status of the CubeSat, including orientation, temperature, power. Students will be able to send a command to the CubeSat to engage a magnetorquer to spin the spacecraft. The students can then view the resultant changes in spacecraft status. For more advanced students, we will provide the state of the spacecraft and have them predict the change in status for a given magnetorquer command. Based on the current spacecraft state, students will predict the pointing direction of the camera to determine what it will image. Similarly, based on the current spacecraft state, they will be able to determine how the spacecraft will need to rotate to image the Earth. In this way, students will gain a unique hands-on and immersive experience in spacecraft operations.

6.1.2. Public outreach events

A new section of the CPSX website will be specifically developed for this initiative. A window on the front page will show the most recent status of the CubeSat. This will encourage the public to frequent the CPSX website for upcoming events and current news. The CubeSat development and operations will be featured at all public events run by CPSX throughout the various phases of this project. The CubeSat design, development, testing and integration will be made public on the CPSX Facebook and Twitter accounts, and will be featured on the Western Worlds podcast. CPSX has existing connections to regional media, including CBC London, The Weather Network, and SpaceQ for disseminating current space related activities and news at Western University; these connections will be leveraged to promote the development and operations of the CubeSat as an education and outreach tool. CPSX will also provide a booth at various conferences, including Lunar and Planetary Science Conference and the International Astronautical Congress, that will include information on the CubeSat.

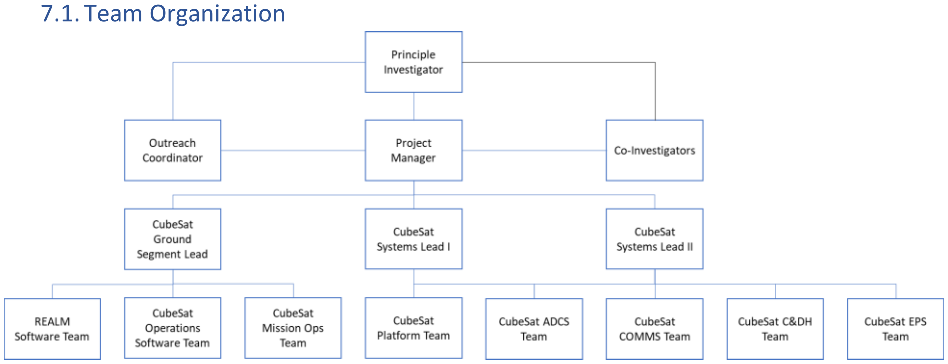
6.1.3. Training opportunities

Through the involvement of the Faculty of Education in CPSX, teacher trainees will assist in the development of new CubeSat targeted classroom lessons.~~....~~ We will also disseminate the resources noted in section 6.1.1. to teachers through a new Annual Summer Educators Institute that CPSX is developing in partnership with the Faculty of Education. Modeling on the former CSA Educators Conference, this summer institute will bring together teachers from across the country and provide them with the resources and background to take these CubeSat activities into their classrooms. Another venue for engaging teachers is the Science Teachers' Association of Ontario (STAO) conference, which CPSX attends annually. We will develop a workshop and resources for a booth related to this CubeSat mission.

The training activities, which have primarily to date been focused on graduate students, will be expanded to the undergraduate participants in this CubeSat program. These students will be tutored in science communication and will play an integral role in the Facebook and Twitter social media campaigns that will showcase the CubeSat design, development, testing and integration. The students will also be interviewed for a series of Western Worlds podcasts through the different phases of this mission. These HQP will also be provided the opportunity to present at conferences.

7. Project Management Plan

7.1. Team Organization



Role	Details
Principal Investigator Dr.Jayshri Sabarinathan	• Overall team management (WBS 1100). • Define the objectives of the mission and the mission architecture to achieve the mission objectives • Assemble the HQP team and supervise the development and training of the HQP • Act as the primary point of contact (POC) for CSA

	• Inform CSA on any problem or difficulty that has an impact on the institution CubeSat development project schedule • Manage the CubeSat as a project that respects the milestones and schedule • Provide quarterly reports to CSA regarding the status of the project including any issues or concerns that need attention • Designate, and support, a PM for the execution of the project and the management of the project resources • Support HQP development according to the training plan • Attend progress/safety review meetings with CSA and launch provider technical authorities and report any issue that impacts on the schedule • Obtain the satellite operation licence prior to the delivery of the CubeSat to the launch provider • Provide technical training and support for the CubeSat and ground station communications subsystems, and the electrical power subsystem
Project Manager Dr. Matthew Cross	• Maintain a document specifying the mission requirements and goals • Prepare a project schedule and ensure that it is reasonably adhered to • Carryout the day-to-day coordination and execution of the project • Review group progress and ensure that deliverables will be met • Carryout the day-to-day management and allocation of the project resources • Carryout the day-to-day supervision of the CubeSat development team • Report to the PI any problem or difficulty that arises in the execution of the project • Provide weekly progress reports to the PI regarding the status of the project and adherence to project schedule, including any issues or concerns that require attention • Ensure that any required resources are provided (workspace, software, etc.) • Ensure that room bookings and announcements are made for full-team meetings • Invite speakers and advisors to team meetings as required • Provide technical training and support for the CubeSat systems engineering.
Co-Investigator Dr. Matthew Bourassa	Dr. Bourassa will also serve as backup Project Manager • Support the PI in carrying out their responsibilities • Assist in the development and training of HQP • Attend progress/safety review meetings with CSA and launch provider technical authorities on behave of the PI if they are unable to attend • Provide technical training and support for the CubeSat attitude determination and control (ADCS) subsystems.
Co-Investigator Dr. Ken McIsaac	• Support the PI in carrying out their responsibilities • Assist in the development and training of HQP • Attend progress/safety review meetings with CSA and launch provider technical authorities on behave of the PI if they are unable to attend • Provide technical training and support for the CubeSat onboard command and data handling (C&DH) subsystem, and operations software.
Co-Investigator Dr. Gordon Osinski	• Support the PI in carrying out their responsibilities • Assist in the development and training of HQP • Attend progress/safety review meetings with CSA and launch provider technical authorities on behave of the PI if they are unable to attend
Co-Investigator Dr. Livio Tornabene	• Support the PI in carrying out their responsibilities • Assist in the development and training of HQP • Provide technical training and support for the CubeSat mission operations

Co-Investigator Dr. Nadeem Ghafoor	• Support the PI in carrying out their responsibilities • Facilitate the collaboration between the Western CubeSat group and the Canadensys payload group
Educational Outreach Coordinator Dr. Parshati Patel	• Execute the Outreach Plan
Collaborator Ms. Mary Ellen Thomas	• Facilitate collaboration between Western University and Nunavut Arctic College for educational outreach
Collaborator Dr. Tom Dzamba	• Provide optical systems expertise
Collaborator Mr. Luke Stras	• Provide electrical systems expertise
CubeSat System and Ground Segment Team Leads ~~Graduate Student HQP: Kelsey Doerksen, Andrea Zagar, HQP3~~	Each of the subsystem team leads is responsible for the success of their subsystem. They are responsible for: • Scheduling and preparing an agenda for weekly group meetings • Preparing and maintaining a schedule and list of deliverables • Ensuring that any required documents/presentations are prepared • Communication and cooperation with other groups • Manage the mass, power, data, and volume budgets • Coordinate with the systems and operations teams as required
CubeSat Platform Team ~~Undergraduate Student HQP: Danlei Chen, Nicholas Van Osch, Derek Webb~~	The platform subsystem team is responsible for the development of their subsystem. The team is responsible for: • Designs and builds the structure of the satellite including the mounting for all components, fulfilling compliance with design requirements, including launch vibration. • Performs structural analysis. • Conducts the steady-state and transient thermal analysis of both the internal and external structure to ensure component thermal operating requirements are met. • Integration of payloads
CubeSat Electrical Power System Team ~~Undergraduate Student HQP: Christopher Booth, HQP2, HQP3~~	The platform subsystem team is responsible for the development of their subsystem. The team is responsible for: • Develops the power subsystem, including solar cells, rechargeable batteries and power regulators. • Manages the power budget.
CubeSat Communications Team ~~Undergraduate Student HQP: Nadav Bloch, Sam Bender, HQP3~~	The platform subsystem team is responsible for the development of their subsystem. The team is responsible for: • Develops the communication system including any necessary antennas, transceivers, amplifiers, and modulation/encoding techniques. • Manages the link budget.
CubeSat Command and Data Handling Team	The platform subsystem team is responsible for the development of their subsystem. The team is responsible for: • Develops the command and data handling architecture, selects hardware components, designs the circuit board layout and programs the microprocessor. • Manages the data budget.

~~Undergraduate Student HQP: Claire Lizotte, HQP2, HQP3~~	
CubeSat Attitude Determination and Control Team ~~Undergraduate Student HQP: Jordan Principe, Jeffrey Fitzpatrick, Ryan Alizadeh~~	The ADCS subsystem team is responsible for the development of their subsystem. The team is responsible for: • Develops the ADC subsystem for coarse pointing of the CubeSat
CubeSat Operations Software Team	The Operations Software team is responsible for the development of their subsystem. The team is responsible for: • Development of ground segment software to upload time-tagged commands to the CubeSat and receive telemetry and housekeeping data from the CubeSat • Facilitate integration with the REALM software
CubeSat REALM Software Team	The REALM Software team is responsible for the development of their subsystem. The team is responsible for: • Development of the REALM platform to enable remote access to the • Facilitate integration with the REALM software

7.2. Work Breakdown Structure

Project:	**Western University CubeSat**		
Work Package Title:	Management	**WBS Ref:**	1100
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	7 May 2018 30 Apr 2022 (End of Mission)	**Accountable Manager:**	Sabarinathan
Estimated Effort:	5 hours per month	**Resources:**	Cross, Bourassa, Osinski, McIsaac
Objectives:			
• Plan and manage "Western University CubeSat" contract. Oversight to ensure successful completion of the contract			
Inputs:			
• Contract starts • Gantt chart • Work breakdown structure			
Tasks			
• Coordinate the work of Co-Is, PM, and all HQP trainees • Manage action items adopted during the project • Prepare meetings and deliverables • Prepare monthly progress reports to CSA • Monitor task progression, logistics, and budget			
Outputs and Deliverables			
• Monthly progress reports to CSA • Updated project control document with milestones and cost estimates • Milestone meeting minutes • Final End of Mission Report to CSA			

Project:	**Western University CubeSat**		
Work Package Title:	**Mission Concept Review**	**WBS Ref:**	1110
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	3 Aug 2018 31 Aug 2018	**Accountable Manager:**	Sabarinathan
Estimated Effort:	48 hours per month	**Resources:**	Cross, Bourassa, Osinski, McIsaac, HQP Trainees
Objectives:			
• Successfully pass Mission Concept Review			
Inputs:			
• Requirements Documents • Mission Operations Concept • Preliminary mission analysis and system design budgets			
Tasks			
• Prepare review deliverables • Participate in review • Perform review close-out requirements			
Outputs and Deliverables			
• Phase A close-out; commence Phase B			

Project:	**Western University CubeSat**		
Work Package Title:	**Preliminary Design Review**	**WBS Ref:**	1120
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Apr 2019 30 Aug 2019	**Accountable Manager:**	Sabarinathan
Estimated Effort:	32 hours per month	**Resources:**	Cross, Bourassa, Osinski, McIsaac, HQP Trainees
Objectives:			
• Successfully pass Preliminary Design Review			
Inputs:			
• System design definition documents • Preliminary ICDs and ground segment definition			
Tasks			
• Prepare review deliverables • Participate in review • Perform review close-out requirements			
Outputs and Deliverables			
• Phase B close-out; prepare for Phase C			

Project:	**Western University CubeSat**		
Work Package Title:	**Critical Design Review**	**WBS Ref:**	1130
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Apr 2020 30 Aug 2020	**Accountable Manager:**	Sabarinathan
Estimated Effort:	55 hours per month	**Resources:**	Cross, Bourassa, Osinski, McIsaac, HQP Trainees
Objectives:			
• Successfully pass Critical Design Review			
Inputs:			
• System detailed design documents • Ground Segment definition			

Tasks	
• Prepare review deliverables • Participate in review • Perform review close-out requirements	
Outputs and Deliverables	
• Phase C close-out; prepare for Phase D	

Project:	**Western University CubeSat**		
Work Package Title:	**Flight Readiness Reviews**	**WBS Ref:**	1140
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Apr 2021 30 Apr 2021	**Accountable Manager:**	Sabarinathan
Estimated Effort:	55 hours per month	**Resources:**	Cross, Bourassa, Osinski, McIsaac, HQP Trainees
Objectives:			
• Successfully pass Vibration Testing Review and Flight Readiness Review			
Inputs:			
• Assembled CubeSat • Testing Documents			
Tasks			
• Vibration test CubeSat • Prepare review deliverables • Participate in reviews • Perform review close-out requirements			
Outputs and Deliverables			
• CubeSat • Phase D close-out; prepare for launch and operations			

Project:	**Western University CubeSat**		
Work Package Title:	Operating Frequencies	**WBS Ref:**	1200
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	7 May 2018 31 Aug 2018	**Accountable Manager:**	Bourassa
Estimated Effort:	6 hours per month	**Resources:**	
Objectives:			
• Operating Frequencies			
Inputs:			
• Mission Requirements • Mission Operations Report • Mission Analysis Report			
Tasks			
• Review ITU regulations and assignment procedures to select a design frequency range. • Acquire necessary licences and submit necessary registration to facilitate communication between ground station and CubeSat.			
Outputs and Deliverables			
• Operating Frequencies			

Project:	Western University CubeSat		
Work Package Title:	Educational Outreach	WBS Ref:	1300
Sheet:	1 of 1	WP Est. Value:	
Schedule Start: Schedule End:	1 May 2018 30 Apr 2022 (End of Mission)	Accountable Manager:	Patel
Estimated Effort:	20 hours per month	Resources:	
Objectives:			
• Implementation of the Outreach Plan			
Inputs:			
• CubeSat development progress • CPSX educational resources			
Tasks			
• Feature the CubeSat project on Western Worlds podcast • Promote CubeSat project during CPSX public nights and Space Day • Incorporate CubeSat lessons into classroom activities • Incorporate CubeSat lessons into Space Camp • Incorporate CubeSat operations into classroom and / or Space Camp			
Outputs and Deliverables			
• Educational outreach			

Project:	Western University CubeSat		
Work Package Title:	Define Requirements	WBS Ref:	2100
Sheet:	1 of 1	WP Est. Value:	
Schedule Start: Schedule End:	7 May 2018 3 Aug 2018	Accountable Manager:	Cross
Estimated Effort:	30 hours per month	Resources:	Bourassa, HQP Trainees
Objectives:			
• Define design requirements for the CubeSat			
Inputs:			
• Gantt chart • Work breakdown structure • NASA Systems Engineering Handbook			
Tasks			
• Define mission requirements • Define system requirements • Define subsystem-level requirements			
Outputs and Deliverables			
• Mission Requirements Document • System Requirements Document • Subsystem Requirements Documents • Requirements Traceability Matrix • Preliminary Mass Budget • Preliminary Power Budget			

Project:	**Western University CubeSat**		
Work Package Title:	Mission Operations Concept	**WBS Ref:**	2200
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	7 May 2018 3 Aug 2018	**Accountable Manager:**	Cross
Estimated Effort:	30 hours per month	**Resources:**	Tornabene, Bourassa, HQP Trainees
Objectives:			
• Define CubeSat mission operations			
Inputs:			
• Gantt chart • Work breakdown structure • NASA Systems Engineering Handbook • Mission Requirements • Ground station operation • Outreach plan			
Tasks			
• Define mission operations scheme including satellite operating modes, ground station development and operation, satellite lifecycle, outreach plan, etc.			
Outputs and Deliverables			
• Mission Operations Report			

Project:	**Western University CubeSat**		
Work Package Title:	Mission Analysis	**WBS Ref:**	2300
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	7 May 2018 31 Mar 2019	**Accountable Manager:**	Bourassa
Estimated Effort:	13 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Conduct mission analysis for CubeSat deployed from ISS			
Inputs:			
• Mission Requirements • Mission Operations Report			
Tasks			
• Perform a mission analysis given the orbital parameters provided by CSA and assuming ground station located in London, ON. • Include such information as illuminated / eclipse times, ground station coverage, etc for various potential deployment times from ISS			
Outputs and Deliverables			
• Mission Analysis Report			

Project:	**Western University CubeSat**		
Work Package Title:	Interface Control Documents	**WBS Ref:**	2400
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2018 31 Mar 2020	**Accountable Manager:**	Cross
Estimated Effort:	10 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Define mechanical, power, data interfaces between subsystem components			
Inputs:			
• NASA Systems Engineering Handbook • Mission Requirements			

• System Requirements • Subsystem Requirements • Subsystem Interface Documents • Design Definition Documents
Tasks
• Develop / select an interface standard and control scheme. Employ a method of tracking interfaces between all components and describe in the Interface Control Document for mechanical, electrical and data interfaces
Outputs and Deliverables
• Subsystem Interface Control Documents

Project:	**Western University CubeSat**		
Work Package Title:	CubeSat System AIT Implementation	**WBS Ref:**	2500
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Jan 2021 30 Mar 2021	**Accountable Manager:**	Cross
Estimated Effort:	40 hours per month	**Resources:**	Bourassa, HQP Trainees
Objectives:			
• Implement the CubeSat System AIT			
Inputs:			
• NASA Systems Engineering Handbook • Subsystem AIT Plans			
Tasks			
• Develop a plan for, and implement the assembly, integration and verification testing of the CubeSat System			
Outputs and Deliverables			
• CubeSat System AIT Implementation Plan			

Project:	**Western University CubeSat**		
Work Package Title:	CubeSat User Manual	**WBS Ref:**	2600
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2020 30 Mar 2021	**Accountable Manager:**	Cross
Estimated Effort:	10 hours per month	**Resources:**	Bourassa, HQP Trainees
Objectives:			
• Define how to operate the CubeSat and write user manual for operations team			
Inputs:			
• NASA Systems Engineering Handbook • Mission Requirements • System Requirements • Subsystem Requirements • Design Definition Documents • Mission Operations Report			
Tasks			
• Develop an operations manual that describes how to operate the CubeSat using the ground station interface. Describes functionality and limitations to sensors and actuators. Describes conditions and procedures for different operating conditions			
Outputs and Deliverables			
• CubeSat User Manual			

Project:	**Western University CubeSat**		
Work Package Title:	CubeSat Operations	**WBS Ref:**	2700
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 May 2021 30 Apr 2022	**Accountable Manager:**	Tornabene
Estimated Effort:	80 hours per month	**Resources:**	Cross, Bourassa, HQP Trainees
Objectives:			
• Operate the CubeSat to support educational outreach and training			
Inputs:			
• Ground station • CubeSat User Manual			
Tasks			
• Perform the day-to-day operations of the CubeSat to ensure that it functions through end of life. • Support the Educational Outreach objectives in classrooms and Space Camp			
Outputs and Deliverables			
•			

Project:	**Western University CubeSat**		
Work Package Title:	Platform Definition	**WBS Ref:**	3110
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	7 May 2018 31 Mar 2018	**Accountable Manager:**	Cross
Estimated Effort:	35 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform detailed design definition of the CubeSat platform			
Inputs:			
• System Requirements • Subsystem Requirements			
Tasks			
• Literature review or technology survey to determine the most appropriate selection • Interface Definition • Model structure to satisfy the given requirements • Configure hardware to accommodation all subsystem units into structure • Perform FEA and thermal analysis of spacecraft throughout development. • Select thermal control methods such as hardware elements and surface coatings • The selection shall be documented and the parameters such as operating temperature range, power requirements, interface requirements, etc. shall be detailed • Define interfaces			
Outputs and Deliverables			
• Platform justification and design definition documents • Preliminary platform design specification • Preliminary platform AIT Plan • Interface Control Documents			

Project:	**Western University CubeSat**		
Work Package Title:	Platform Detailed Design	**WBS Ref:**	3120
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2019 30 Mar 2020	**Accountable Manager:**	Cross
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform detailed design of the CubeSat platform			
Inputs:			
• System Requirements • Subsystem Requirements • Interface Control Documents • ADCS subsystem justification and design definition documents • Preliminary ADCS design specification			
Tasks			
• Configure hardware to accommodation all subsystem units into structure including harness • Perform FEA and thermal analysis of spacecraft throughout development • Develop the thermal management system and software for integration with the on-board computer • Development manufacturing plan for CubeSat Structure • Development vibration and AIT plans			
Outputs and Deliverables			
• Platform justification and design definition documents • Platform design specification • Platform AIT Plan • Platform vibration test plan			

Project:	**Western University CubeSat**		
Work Package Title:	Platform AIT	**WBS Ref:**	3130
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2020 31 Dec 2020	**Accountable Manager:**	Cross
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform assembly, integration and verification testing of the CubeSat platform			
Inputs:			
• Interface Control Documents • Platform justification and design definition documents • Platform design specification • Platform AIT Plan			
Tasks			
• Assemble, integrate and verification test the CubeSat platform • Prepare CubeSat for vibration testing			
Outputs and Deliverables			
• Platform subsystem			

Project:	**Western University CubeSat**		
Work Package Title:	ADCS Definition	**WBS Ref:**	3210
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2018 31 Mar 2019	**Accountable Manager:**	Bourassa
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform detailed design definition of the CubeSat ADCS system			
Inputs:			
• System Requirements • Subsystem Requirements			
Tasks			
• Literature review or technology survey to determine the most appropriate selection • Characterize appropriate attitude control actuators to satisfy the given requirements • Characterize appropriate attitude determination sensors to satisfy the given requirements. • Characterize appropriate attitude control law algorithms • The selection shall be documented and the parameters such as operating temperature range, power requirements, interface requirements, etc. shall be detailed • Interface Definition			
Outputs and Deliverables			
• ADCS subsystem justification and design definition documents • Preliminary ADCS design specification • Preliminary ADCS AIT Plan • Interface Control Documents			

Project:	**Western University CubeSat**		
Work Package Title:	ADCS Detailed Design	**WBS Ref:**	3220
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2019 30 Mar 2020	**Accountable Manager:**	Bourassa
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform detailed design of the CubeSat ADCS system			
Inputs:			
• System Requirements • Subsystem Requirements • Interface Control Documents • ADCS subsystem justification and design definition documents • Preliminary ADCS design specification			
Tasks			
• Sensor selection and acquisition or development plan • Actuator selection and acquisition or development plan • Write control software to read sensor values and actuator actuators			
Outputs and Deliverables			
• ADCS subsystem justification and design definition documents • ADCS design specification • ADCS AIT Plan			

Project:	**Western University CubeSat**		
Work Package Title:	ADCS AIT	**WBS Ref:**	3230
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2020 31 Dec 2020	**Accountable Manager:**	Bourassa
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform assembly, integration and verification testing of the CubeSat ADCS subsystem			
Inputs:			
• Interface Control Documents • ADCS subsystem justification and design definition documents • ADCS design specification • ADCS AIT Plan			
Tasks			
• Assemble, integrate and verification test the ADCS subsystem			
Outputs and Deliverables			
• ADCS subsystem			

Project:	**Western University CubeSat**		
Work Package Title:	COMM Definition	**WBS Ref:**	3310
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	7 May 2018 31 Mar 2018	**Accountable Manager:**	Sabarinathan
Estimated Effort:	35 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform detailed design definition of the CubeSat COMM system			
Inputs:			
• System Requirements • Subsystem Requirements			
Tasks			
• Literature review or technology survey to determine the most appropriate selection • Produce a link budget given the results of the Mission Analysis Report and detailed requirements. Note the required transmit and receive antenna gains • Given the selected operating frequency and required gain, select communication system hardware. • Develop the software required to support the communications protocol. This includes design for each mode of operation, including beacon operation and authentication procedures • The selection shall be documented and the parameters such as operating temperature range, power requirements, interface requirements, etc. shall be detailed • Interface Definition			
Outputs and Deliverables			
• COMM subsystem justification and design definition documents • Preliminary COMM design specification • Preliminary COMM AIT Plan • Interface Control Documents • Link Budget			

Project:	**Western University CubeSat**		
Work Package Title:	COMM Detailed Design	**WBS Ref:**	3320
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2019 30 Mar 2020	**Accountable Manager:**	Sabarinathan
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform detailed design of the CubeSat COMM system			
Inputs:			
• System Requirements • Subsystem Requirements • Interface Control Documents • COMM subsystem justification and design definition documents • Preliminary COMM design specification			
Tasks			
• Given the selected operating frequency and required gain, select communication system hardware. • Develop the software required to support the communications protocol. This includes design for each mode of operation, including beacon operation and authentication procedures • Develop assembly, integration and verification testing plan for hardware and software			
Outputs and Deliverables			
• COMM subsystem justification and design definition documents • COMM design specification • COMM AIT Plan			

Project:	**Western University CubeSat**		
Work Package Title:	COMM AIT	**WBS Ref:**	3330
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2020 31 Dec 2020	**Accountable Manager:**	Sabarinathan
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform assembly, integration and verification testing of the CubeSat COMM subsystem			
Inputs:			
• Interface Control Documents • COMM subsystem justification and design definition documents • COMM design specification • COMM AIT Plan			
Tasks			
• Assemble, integrate and verification test the COMM subsystem			
Outputs and Deliverables			
• COMM subsystem			

Project:	**Western University CubeSat**		
Work Package Title:	C&DH Definition	**WBS Ref:**	3410
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2018 31 Mar 2019	**Accountable Manager:**	McIsaac
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform detailed design definition of the CubeSat C&DH system			

Inputs:
• System Requirements • Subsystem Requirements
Tasks
• Literature review or technology survey to determine the most appropriate selection • Define an on-board computer system. • Define a data budget shall be created to ensure sufficient storage and processing power is selected. • Define a system architecture for data/command dissemination to all other subsystems. • Define any required software that is not included in another subsystem's scope. This includes scheduling operations, data handling, etc. • The selection shall be documented and the parameters such as operating temperature range, power requirements, interface requirements, etc. shall be detailed • Interface Definition
Outputs and Deliverables
• C&DH subsystem justification and design definition documents • Preliminary C&DH design specification • Preliminary C&DH AIT Plan • Interface Control Documents

Project:	**Western University CubeSat**		
Work Package Title:	C&DH Detailed Design	**WBS Ref:**	3420
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2019 30 Mar 2020	**Accountable Manager:**	McIsaac
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform detailed design of the CubeSat C&DH system			
Inputs:			
• System Requirements • Subsystem Requirements • Interface Control Documents • C&DH subsystem justification and design definition documents • Preliminary C&DH design specification			
Tasks			
• Develop an on-board computer system. • Develop a data budget shall be created to ensure sufficient storage and processing power is selected. • Develop a system architecture for data/command dissemination to all other subsystems. • Develop any required software that is not included in another subsystem's scope. This includes scheduling operations, data handling, etc. • Develop assembly, integration and verification testing plan for hardware and software			
Outputs and Deliverables			
• C&DH subsystem justification and design definition documents • C&DH design specification • C&DH AIT Plan			

Project:	**Western University CubeSat**		
Work Package Title:	C&DH AIT	**WBS Ref:**	3430
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2020 31 Dec 2020	**Accountable Manager:**	McIsaac
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform assembly, integration and verification testing of the CubeSat C&DH subsystem			
Inputs:			
• Interface Control Documents • C&DH subsystem justification and design definition documents • C&DH design specification • C&DH AIT Plan			
Tasks			
• Assemble, integrate and verification test the C&DH subsystem • CubeSat software integration verification testing			
Outputs and Deliverables			
• C&DH subsystem			

Project:	**Western University CubeSat**		
Work Package Title:	EPS Definition	**WBS Ref:**	3510
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	7 May 2018 31 Mar 2018	**Accountable Manager:**	Sabarinathan
Estimated Effort:	35 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform detailed design definition of the CubeSat EPS system			
Inputs:			
• System Requirements • Subsystem Requirements • Mission Analysis Report			
Tasks			
• Literature review or technology survey to determine the most appropriate selection • Given the mission analysis and operations reports, develop a power budget for use by all other subsystems • Define power generation system • Define power storage system • Define power management and distribution system • The selection shall be documented and the parameters such as operating temperature range, power requirements, interface requirements, etc. shall be detailed • Interface Definition			
Outputs and Deliverables			
• EPS subsystem justification and design definition documents • Power Budget • Preliminary EPS design specification • Preliminary EPS AIT Plan • Interface Control Documents			

Project:	**Western University CubeSat**		
Work Package Title:	EPS Detailed Design	**WBS Ref:**	3520
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2019 30 Mar 2020	**Accountable Manager:**	Sabarinathan
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform detailed design of the CubeSat EPS system			
Inputs:			
• System Requirements • Subsystem Requirements • Interface Control Documents • EPS subsystem justification and design definition documents • Preliminary EPS design specification • Preliminary EPS AIT Plan			
Tasks			
• Develop a power generation system • Develop a power storage system • Develop a power management and distribution system including a power harness and cabling • Develop assembly, integration and verification testing plan for hardware and software			
Outputs and Deliverables			
• EPS subsystem justification and design definition documents • EPS design specification • EPS AIT Plan			

Project:	**Western University CubeSat**		
Work Package Title:	EPS AIT	**WBS Ref:**	3530
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2020 31 Dec 2020	**Accountable Manager:**	Sabarinathan
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform assembly, integration and verification testing of the CubeSat EPS subsystem			
Inputs:			
• Interface Control Documents • EPS subsystem justification and design definition documents • EPS design specification • EPS AIT Plan			
Tasks			
• Assemble, integrate and verification test the EPS subsystem			
Outputs and Deliverables			
• EPS subsystem			

Project:	**Western University CubeSat**		
Work Package Title:	Ground Station Definition	**WBS Ref:**	3610
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2018 31 Mar 2020	**Accountable Manager:**	Sabarinathan
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Develop the ground station for Western University			

Inputs:
• Mission Analysis Report • Operating frequencies
Tasks
• Given the selected operating frequency and required gain, select and acquire ground station hardware.
Outputs and Deliverables
• Space to Ground Interface Control Documents • Ground station hardware • User Manual

Project:	**Western University CubeSat**		
Work Package Title:	Operations Software	**WBS Ref:**	3620
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2018 31 Mar 2020	**Accountable Manager:**	McIsaac
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform detailed design of the CubeSat EPS system			
Inputs:			
• Ground station hardware • Mission Operations Report			
Tasks			
• Develop the software required to support the communications protocol from the ground station. This includes design for each mode of operation, including beacon operation and authentication procedures			
Outputs and Deliverables			
• Ground station operations software • User Manual			

Project:	**Western University CubeSat**		
Work Package Title:	REALM Interface Development	**WBS Ref:**	3630
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 Sep 2018 31 Mar 2020	**Accountable Manager:**	McIsaac
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform assembly, integration and verification testing of the CubeSat EPS subsystem			
Inputs:			
• Ground station hardware • Mission Operations Report • Operations Software • Outreach Plan			
Tasks			
• Develop the software from the existing REALM platform codebase to enable remote access to the ground station to send commands and receive telemetry			
Outputs and Deliverables			
• REALM Ground Station Interface			

Project:	**Western University CubeSat**		
Work Package Title:	Ground Station System Integration	**WBS Ref:**	3640
Sheet:	1 of 1	**WP Est. Value:**	
Schedule Start: **Schedule End:**	1 May 2020 31 Aug 2020	**Accountable Manager:**	McIsaac
Estimated Effort:	40 hours per month	**Resources:**	HQP Trainees
Objectives:			
• Perform assembly, integration and verification testing of the Ground Station system			
Inputs:			
• Ground station hardware • Mission Operations Report • Operations Software • Outreach Plan • REALM Ground Station Interface			
Tasks			
• Integrate and test software interoperability. Ensure that all command and data handling functions are operational.			
Outputs and Deliverables			
• Remotely accessible CubeSat operations platform			

7.3. Milestones and Deliverables

Project Stage	Phase / Milestone	Deliverables and Actions (WBS Ref)	Timeline
CubeSat Project Grant Awarded			1 May 2018
	Kick-off Meeting (KOM)	WBS 1100 Meeting Agenda (1-week prior) Meeting Presentation (1-week prior) Meeting Minutes (1 week after)	7 May 2018
Mission Definition	A	WBS 1100; WBS 1200; WBS 2100; WBS 2200; WBS 2300; WBS 3110; WBS 3310; WBS 3510	4 Months
	Mission Concept Review (MCR)	WBS 1110 Meeting Agenda (1-week prior) Meeting Presentation (1-week prior) Meeting Minutes (1 week after) Mission Operations Report Requirements Document	KOM + 4 Months
Preliminary Design	B	WBS 1100; WBS 2300; WBS 2400; WBS 3110; WBS 3210; WBS 3310; WBS 3410; WBS 3510; WBS 3610; WBS 3620; WBS 3630; Preliminary Design Justification, Design Definition, Design Specification, and Interface Control Documents Mission Analysis Report	8 Months
	Preliminary Design Review (PDR)	WBS 1120 Meeting Agenda (1-week prior) Meeting Presentation (1-week prior) Meeting Minutes (1 week after)	KOM + 12 Months
Detailed Design	C	WBS 1100; WBS 1300; WBS 2400; WBS 2500; WBS 3120; WBS 3220; WBS 3320; WBS 3420; WBS 3520; WBS 3610; WBS 3620;	12 Months

		WBS 3630	
	Critical Design Review (CDR)	WBS 1130 Design Specification Documents Design Definition Documents Interface Control Documents AIT Planning Documents Meeting Agenda (1-week prior) Meeting Presentation (1-week prior) Meeting Minutes (1 week after)	KOM + 24 Months
AIT	D	WBS 1100; WBS 1300; WBS 2600; WBS 3130; WBS 3230; WBS 3330; WBS 3430; WBS 3530; WBS 3640	11 Months
	Vibration Testing	WBS 1140 CubeSat	KOM + 35 Months
	Vibration Testing Review	WBS 1140	
	Flight Readiness Review (FRR)	Meeting Agenda (1-week prior) Meeting Presentation (1-week prior) Meeting Minutes (1 week after)	KOM + 36 Months
Operations	E	WBS 1100; WBS 1300; WBS 2700	
Decommission / End of Mission	F	WBS 1100 Final Report to CSA	KOM + 48 Months

7.4. Project Schedule

	Name	Start	End	Duration (Days)	Duration (Months)	Associated WBS Refs	Resources	Work (hours)
1	**Management**	**01-May-18**	**30-Apr-22**	**1460**	**48**			**228**
	Assemble and manage ongoing enrollment of the HQP trainee team	01-May-18	30-Apr-22	1460		1100	JS	20
	Coordinate the work of Co-Is and PM	01-May-18	30-Apr-22	1460		1100	JS	50
	Manage action items adopted during the project	01-May-18	30-Apr-22	1460		1100	JS	50
	Prepare meetings and deliverables	01-May-18	30-Apr-22	1460		1100	JS	50
	Monitor task progression, logistics and budget	01-May-18	30-Apr-22	1460		1100	JS	50
	Kick-Off Meeting (KOM)	07-May-18	07-May-18	0		1100	JS, MC, MB, GO, KM	8
2	**Phase A Mission Definition**	**01-May-18**	**31-Aug-18**	**122**	**4**			**612**
	Operating Frequencies	07-May-18	31-Aug-18	116		1200	MB	24
	Define Requirements	07-May-18	03-Aug-18	88		2100	MC, MB, GS1, GS2, GS3, UGS1, UGS1, UGS3	90
	Mission Operations Concept	07-May-18	03-Aug-18	88		2200	MC, MB, GS1, GS2, GS3, LT, UGS1, UGS1, UGS3	90

	Preliminary Mission Analysis	07-May-18	03-Aug-18	88		2300	MB, GS2, UGS1, UGS1, UGS3	90
	Preliminary Mass Budget	07-May-18	03-Aug-18	88		3110	MC, GS2, UGS1, UGS1, UGS3	90
	Preliminary Link Budget	07-May-18	03-Aug-18	88		3310	JS, GS1, UGS1, UGS1, UGS3	90
	Preliminary Power Budget	07-May-18	03-Aug-18	88		3510	MC, GS3, UGS1, UGS1, UGS3	90
	Deliverable Preparation	03-Aug-18	17-Aug-18	14		1110	JS, MC, MB, GS1, GS2, GS3, UGS1, UGS1, UGS3	24
	Mission Concept Review (MCR)	24-Aug-18	24-Aug-18	0		1110	JS, MC, MB, GS1, GS2, GS3, UGS1, UGS1, UGS3	8
	Review Close Out	24-Aug-18	31-Aug-18	7		1110	JS, MC	16
3	**Phase B Preliminary Design**	**01-Sep-18**	**30-Apr-19**	**241**	**8**			**2396**
	Mission Analysis	01-Sep-18	31-Mar-19	211		2300	MB, GS2, ADCS	49
	Platform Definition	01-Sep-18	31-Mar-19	211		3110	MC, GS2, PLAT	280
	ADCS Definition	01-Sep-18	31-Mar-19	211		3210	MB, GS2, ADCS	280
	COMM Definition	01-Sep-18	31-Mar-19	211		3310	JS, MC, GS3, COMM	280
	C&DH Definition	01-Sep-18	31-Mar-19	211		3410	KM, MC, GS3, CDH	280
	EPS Definition	01-Sep-18	31-Mar-19	211		3510	JS, MC, GS3, EPS	280
	Preliminary Interface Control Definition	01-Sep-18	31-Mar-19	211		2400	MC, GS1, GS2, GS3	70
	Preliminary Ground Station Definition	01-Sep-18	31-Mar-19	211		3610	JS, GS1, OPS	280
	Preliminary Operations Software Definition	01-Sep-18	31-Mar-19	211		3620	KM, GS1, OPS	280
	Preliminary REALM Interface Definition	01-Sep-18	31-Mar-19	211		3630	KM, GS1, REALM	280
	Deliverable Preparation	01-Apr-19	16-Apr-19	15		1120	JS, MC, MB, GS1, GS2, GS3	24
	Preliminary Design Review (PDR)	23-Apr-19	23-Apr-19	0		1120	ALL	8
	Review Close Out	23-Apr-19	30-Apr-19	7		1120	JS, MC	5
4	**Phase C1 Preliminary Detailed Design**	**01-May-19**	**31-Aug-19**	**122**	**4**			**1200**
	Educational Outreach	01-May-19	31-Aug-19	122		1300	PP, GO, UGS1, UGS1, UGS3	240
	Close out PDR RIDs	01-May-19	31-Aug-19	122		1120	JS, MC, MB, GS2, GS3, UGS1, UGS1, UGS3	120
	Ground Station Definition	01-May-19	31-Aug-19	122		3610	JS, GS1, UG1	280
	Operations Software Definition	01-May-19	31-Aug-19	122		3620	KM, GS1, UG2	280
	REALM Interface Definition	01-May-19	31-Aug-19	122		3630	KM, GS1, UG3	280
5	**Phase C2 Detailed Design**	**01-Sep-19**	**30-Apr-20**	**242**	**8**			**2347**
	Interface Control Definition	01-Sep-19	31-Mar-20	212		2400	MC, GS1, GS2, GS3	70
	Platform Detailed Design	01-Sep-19	31-Mar-20	212		3120	MC, GS2, PLAT	280
	ADCS Detailed Design	01-Sep-19	31-Mar-20	212		3220	MB, GS2, ADCS	280
	COMM Detailed Design	01-Sep-19	31-Mar-20	212		3320	JS, MC, GS3, COMM	280

	C&DH Detailed Design	01-Sep-19	31-Mar-20	212		3420	KM, MC, GS3, CDH	280
	EPS Detailed Design	01-Sep-19	31-Mar-20	212		3520	JS, MC, GS3, EPS	280
	Ground Station Definition	01-Sep-19	31-Mar-20	212		3610	JS, GS1, OPS	280
	Operations Software Definition	01-Sep-19	31-Mar-20	212		3620	KM, GS1, OPS	280
	REALM Interface Definition	01-Sep-19	31-Mar-20	212		3630	KM, GS1, REALM	280
	Deliverable Preparation	01-Apr-20	16-Apr-20	15		1130	JS, MC, MB	24
	Critical Design Review (CDR)	23-Apr-20	23-Apr-20	0		1130	ALL	8
	Review Close Out	23-Apr-20	30-Apr-20	7		1130	JS, MC	5
6	**Phase D1 Preliminary AIT**	**01-May-20**	**31-Aug-20**	**122**	**4**			**640**
	Educational Outreach	01-May-20	31-Aug-20	122		1300	PP, GO, UGS1, UGS1, UGS3	240
	Close out CDR RIDs	01-May-20	31-Aug-20	122		1130	JS, MC, MB, GS2, GS3, UGS1, UGS1, UGS3	240
	Ground Station System Integration	01-May-20	31-Aug-20	122		3640	JS, KM, MC, MB, GS1, UGS1, UGS1, UGS3	160
6	**Phase D2 AIT**	**01-Sep-20**	**30-Apr-21**	**241**	**8**			**1045**
	Platform AIT	01-Sep-20	31-Dec-20	121		3130	MC, GS2, PLAT	160
	ADCS AIT	01-Sep-20	31-Dec-20	121		3230	MB, GS2, ADCS	160
	COMM AIT	01-Sep-20	31-Dec-20	121		3330	JS, MC, GS3, COMM	160
	C&DH AIT	01-Sep-20	31-Dec-20	121		3430	KM, MC, GS3, CDH	160
	EPS AIT	01-Sep-20	31-Dec-20	121		3530	JS, MC, GS3, EPS	160
	CubeSat System AIT	01-Jan-21	30-Mar-21	88		2500	MC, MB, GS2, GS3, PLAT, ADCS, COMM, CDH, EPS	120
	Write CubeSat User Manual	01-Sep-20	30-Mar-21	210		2600	MC, MB, GS1, GS2, GS3	70
	Vibration Testing	01-Apr-21	08-Apr-21	7		1140	MC, MB, GS2, PLAT	20
	Vibration Testing Review	09-Apr-21	16-Apr-21	7		1140	JS, MC	20
	Deliverable Preparation	01-Apr-21	16-Apr-21	15		1140	JS, MC, MB	2
	Flight Readiness Review (FRR)	23-Apr-21	23-Apr-21	0		1140	ALL	8
	Review Close Out	23-Apr-21	30-Apr-21	7		1140	JS, MC	5
7	**Phase E Operations**	**01-May-21**	**30-Apr-22**	**364**	**12**			**1680**
	CubeSat Educational Outreach	01-May-21	30-Apr-22	364		1300	PP	720
	Daily CubeSat monitoring and operations	01-May-21	30-Apr-22	364		2700	LT, MC, MB, GS1, GS2, GS3	960
8	**Phase F Decommissioning / End of Mission**	**30-Apr-22**	**30-Apr-22**	**0**	**0**			
	Final Report to CSA	30-Apr-22	30-Apr-22	0		1100	JS	8

7.5. Risk Assessment and Mitigation

Given the experience of the assembled team, we consider this to be a low-risk project. However, certain risks are intrinsic to this type of work.

Risk	Likelihood	Impact	Mitigation

Managerial issues	Low	Delay in work to be completed	Members of the project leadership team are tenured faculty or staff members of Western University. As such they are unlikely to leave their positions. The research associates are students and/or postdoctoral fellows specifically engaged for this research. It is uncommon in our experience for research trainees to abandon unfinished projects. The project leadership team has experience advising and training HQP, and in managing large projects.
Personnel issues and delays in hiring	Low	Delay in work to be completed	Members of the project leadership team are tenured faculty or staff members of Western University and are already in place. Potential undergraduate and graduate HQP have already been identified.
Financial issues	Low	Delay in work to be completed	The financial risks associated with the proposal are minimal. All matching funding required for this research to be conducted is secured.
Undergraduate HQP scheduling	Low	Delay in work to be completed	Undergraduate HQP will be following their Capstone design project milestones for this project. As their work on the CubeSat will be part of their degree program their time spent will be academically dedicated.
Environmental Risk	Low	HQP Safety and CubeSat re-entry hazards	The environmental risk associated with this project is viewed to be minimal. The design, analysis and technical development work will be conducted on site at Western University following university policies and guidelines. No chemical propellants are to be used that might leak during integration and launch. No volatile materials will be used in the CubeSat that might cause contamination upon atmospheric re-entry. No planetary protection needs to be considered as there is no biological experiment to be conducted. Risk to personnel is also considered negligible as there is no risk presented that is in addition to normal attendance to the university. All team members are to abide by Western University's published safety regulations for working in laboratory space and elsewhere on campus.
Failure of Western Engineering to provide technical support	Low	Delay in work to be completed	University Machine Services has a proven track record of more than twenty years of successful collaboration with Western researchers. UMS personnel will be involved with students at all phases of the design process to ensure that the selected design is manufacturable using standard tools and processes. All design documents will be prepared in accordance with relevant industrial standards. If it becomes necessary, a secondary service provider can be found in the Southwestern Ontario industrial sector.
Not provided roof access on campus for ground station antenna	Moderate	Additional networking requirements	The greatest risk associated with the ground station itself is securing roof access for mounting antenna on campus to readily connect to the Mission Control Room. A less desirable option is to place the antenna at university property off the main campus, such as at the Elginfield Observatory, which houses astronomy equipment and has a high-speed network connection to the main campus.
REALM Platform Redevelopment	Moderate	Reduced outreach capability	The REALM platform for remote access has been developed and demonstrated in different use cases. It is envisioned to repurpose the platform to enable remote access to the ground

			station from classrooms. This redevelopment will depend on undergraduate and graduate software engineering students, whereas the original REALM platform development benefited from IBM support.
CubeSat Component Development	Moderate	Delay in work to be completed	The CubeSat proposal does not include undergraduate HQP development of any new component that has not been previously demonstrated. Some unit components with flight heritage, such as solar cells, will be purchased off-the-shelf. The greatest source of technical risk will be software development. It will not be financially feasible to outsource the operations software; therefore, early software development and planning is required to ensure stable functionality of the nanosatellite operations software. The CubeSat mission operations do not require hard real-time control and therefore soft real time, or non-real time software can be developed.

8. Budget

8.1. Project Budget Breakdown

	YEAR 1	YEAR 2	YEAR 3	Total
Licenses and permits fees	2500	0	0	2500
Access fees to laboratories or special facilities	0	0	0	0
Registration fees (for events in direct support of a public engagement plan)	250	2000	2000	4250
Data Acquisition	0	0	0	0
Acquisition or rental of laboratory equipment	0	0	0	0
Materials and supplies	33824	66176	0	100000
Consultant services	0	2500	5000	7500
Bursaries	9000	9000	9000	27000
Salaries and benefits	10000	10000	10000	30000
Travel, including transportation, accommodations and meals	545	3000	3000	6545
Nunavut Related Travel	6631	19412	19412	45455
Acquisition, development and printing of materials	250	250	250	750
Cost related to obtaining security clearance	0	0	0	0
Publication and communication services and materials	750	523	750	2023
Translation services	0	250	250	500
Marketing and printing services	250	250	250	750
				0
Subtotal: Direct Costs	64000	113361	49912	227273
Direct costs ineligible for Overhead Calculation	0	0	0	0
Net Direct cost eligible for Overhead Calculation	64000	113361	49912	227273
Indirect (Overhead) Costs (10%)	6400	11336	4991	22727
TOTAL	70400	124697	54903	**250000**

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~~8.122.~~8.2. Nunavut Travel Plan

The additional $50,000 for travel for the benefit of participation with Nunavut is as follows:

Initial meeting (**$6631.12**):

- Two faculty or staff members of Western University will travel to Nunavut Arctic College in Iqaluit for an initial meeting and workshop.
- Travel between London, Ontario and Iqaluit requires an overnight in Ottawa on the northward journey.
    - Return airfare London-Ottawa: $289
    - Return checked luggage fee: $56.50
    - Return airfare Ottawa-Iqaluit: $1564
    - Overnight in Ottawa: $143
- Local stay in Iqaluit (3 nights):
    - Daily meals and incidentals (Treasury Board): $155.60
    - Nightly hotel accommodations: $265.42

Summer Space Camp Program (**$15,942.20**):

- Western University and CPSX will travel to Iqaluit to run their week-long Space Camp program for one week, for two summers
- Two Western University graduate student HQP trainees will execute the Space Camp program in coordination with Nunavut Arctic College
- Travel between London, Ontario and Iqaluit requires an overnight in Ottawa on the northward journey. In additional, excess luggage will be required to carry supplies to and from Iqaluit
    - Return airfare London-Ottawa: $289
    - Return airfare Ottawa-Iqaluit: $1564
    - Return checked luggage fee, 5 pieces over two HQP trainees: $830.70
    - Overnight in Ottawa: $143
- Graduate Student HQP trainees will take advantage of Nunavut Research Institute accommodations during their stay, which is $148 per month, for stays longer than 3 nights.
- For 7 days, daily meals and incidentals as per Treasury Board: $155.60

Workshop Attendance at Western (**$24,229.0**)

- Four students from Nunavut Arctic College will travel from Iqaluit to London, Ontario for two separate workshops (eight students in total); the CubeSat short course, and for CubeSat operations
- Travel between London, Ontario and Iqaluit requires an overnight in Ottawa on the northward journey.
    - Return airfare London-Ottawa: $289
    - Return checked luggage fee: $56.50
    - Return airfare Ottawa-Iqaluit: $1564
    - Overnight in Ottawa: $143

- Western University Residences offers overnight accommodations during the summer, and provides a nightly rate for a 4-person suite: $164
- Daily meals and incidentals of $98.45 per person per day, as per Treasury Board, for seven days

Total travel related costs before overhead: $45,454.52

10% Overhead: $4545.45

Total travel costs for participation with Nunavut: **$49,999.97**

~~8.123.~~8.3. In Kind Contributions

Canadensys will provide a space-grade 360° imaging system that leverage deep-space ruggedized Canadian technology currently being developed for cislunar and lunar surface exploration for technology demonstration. Canadensys will also provide support in the areas of mission planning, payload assembly, integration and testing, and collaborative research, in additional to technical support in the area of electrical system and optical system expertise. Canadensys will also provide mentorship support to undergraduate and graduate students at Western University. Canadensys will also provide expert support for the proposed CubeSat workshop.

MDA will provide, as mutually deemed beneficial, their expertise of an engineer or scientist to present at the proposed CubeSat workshop either in person or via teleconference.

MDA may also provide discounted access to testing facilities, namely vibration testing, however those discussions remain ongoing.

The CubeSat project includes graduate student HQP as members of the team, however it is anticipated to utilize existing graduate students through nominal funding mechanisms. Domestic graduate students in Western Engineering are provided, at minimum, a stipend of $13,000 per year plus the value of tuition (approximately $8000).

Undergraduate student HQP trainees enrolled in the Capstone project course will receive limited funding to support breadboarding and prototyping, and 3D printing.

~~8.124.~~8.4. University Resources

The team will be comprised of Western University students and staff that have access to licences to engineering design and analysis software, including SolidWorks and Matlab.

University students have access to funds and bursaries for travel to conferences, which will be pursued in addition to the amounts allocated in this budget.

The Mission Control Room housed in Physicals and Astronomy Building will be used for the mission operations.

University Machine Services (UMS) is an ancillary service located in the Thompson Engineering Building at Western University. It helps in instruction, research, and industry through the design and manufacture of specialized components and equipment.

The Electronics Shop provides some of the following services: consultation for electrical and electronic design, equipment selection, safety standards, etc; custom analog and digital design and fabrication; software design; fabrication or modification of equipment; equipment repair; and procurement and sales of electronic parts and supplies.

Research grade cleanroom facilities and specialized integrated circuit design and measurements are also available at Western as needed for some components integration for graduate students and research undergraduate students involved in the project

~~New engineering building to support student capstone projects~~