CubeSats can serve multiple stakeholders too: use of the DESCENT mission to develop national and international collaboration

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Abstract

Deorbiting spacecraft using electrodynamic tethers (DESCENT) is a CubeSat mission that will showcase electrodynamic tether technology for deorbiting satellites from low earth orbit. The mission is funded by Canadian Space Agency (CSA) through the Flight for Advancement of Science and Technology (FAST) program, with in kind support from Honeywell. DESCENT comprises two 1U CubeSats which are connected by a 100m long tether. Charge collected in the tether crossing the Earth's magnetic field is expelled through a Spindt array, creating a Lorentz force (H. Wen, 2008) in the same direction as atmospheric drag. This increases orbital decay bringing the satellite down to burn up in the Earth's atmosphere.

DESCENT's bus is a combined effort of graduate researchers from York and Ryerson Universities located in Toronto, Canada. The mission supports four experiments – the primary payload from York is the electrodynamic tether and its deployment system. Secondary payloads come from the University of Sydney, Australia, looking at radiation dosage in Low Earth Orbit, and from another group within York looking at solar cells with an innovative coating that can potentially increase panel efficiency significantly. Finally, the mission is expected to provide a platform for University of Calgary to probe the coherent backscatter of radio waves by the F-region ionosphere at high latitudes with the orbiting tether using ground radars.

As such, DESCENT demonstrates the potential of a small mission for regional, national and international collaboration, promoting Canadian research and space capabilities and exposing Canada's next generation of HQPs to this community. The paper reviews the benefits and challenges of having various partners on a small satellite mission. It will discuss the coordination

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approach between the various sub-teams of the satellite. The paper will demonstrate the capacity of a small Canadian University-led satellite to support such a range of national and international activities and partnerships.

I. Introduction

The majority of big space missions include collaboration from partners within the Space industry. Different parts of the project are led with different sub-contractors and suppliers in the industry. With CubeSats gaining attention in the recent decade, the traditional space practices are being passed on to CubeSat development as well. CubeSats have been research projects for many university teams, have provided learning experiences for high school students and have acted as "proof of concept" mission platforms for many industrial investors. CubeSat developers have collaborated with launch providers to bring their satellites to space.

The domain and potential a CubeSat brings to the industry has increased over time. CubeSats are becoming quite capable small-sized satellites with multiple buses and payloads; with different organization focusing on various aspects of the CubeSat development process. DESCENT is one such Canadian CubeSat mission demonstrating collaboration within the space industry. It has different partners focusing on different areas of the mission. Researchers from York are working on the DESCENT systems design and system architecture, as well as the ground segment and operations; while researchers from Ryerson are working on the attitude stabilization system. The electrodynamic tether payload (EDT) is also being developed at York University, along with a payload from University of Sydney to look at the radiation dosage in Low Earth Orbit. York also has another research group mounting solar cells with an innovative coating to increase solar cell performance, and a group from the University of Calgary will probe the coherent backscatter of radio waves while the satellite with its deployed tether passes overhead. DESCENT is also a collaboration between government and industry partners, with the Canadian Space Agency supporting the mission and in-kind support from Honeywell.

II. Mission Overview

The DESCENT space segment consists of two 1U CubeSats attached with a 100m long tether. As the tether moves along the Earth's plasma, the tether collects electrons from the Earth's magnetic field and ejects them from an on-board Spindt array. This creates a Lorentz force (H. Wen, 2008) which slows the satellite down and brings it down to burn up in the Earth's atmosphere. The satellite will be launched from the International Space Station (ISS) by NanoRacks, a US company providing small satellites launch service from the ISS. Upon deployment, after the attitude stabilization is achieved, the two CubeSats will be commanded to separate. A ground station located at York University, Toronto, Canada will be responsible for communications to the spacecraft. The mission duration, along with the deorbiting process is expected to last six months.

The DESCENT mission focuses on studying dynamics of a bare Electro-Dynamic Tether. It will quantify the current generation capability of a 100m long EDT in Low Earth Orbit to validate its feasibility as a spacecraft deorbiting platform. This will not only improve the current state of tether propulsion technologies, but also help develop new tools for future space missions. The primary objectives of the mission are as follows:

1. Complete a deployment of a 100m long tape Electro-Dynamic Tether (EDT).
2. Demonstrate the ability of a bare tape EDT to collect electrons from ambient plasma.
3. Demonstrate the ability of a bare tape tether coupled with a Spindt Array to deorbit spacecraft in Low Earth Orbit.

The secondary objectives of the mission aim to further enhance our understanding of Electro-Dynamic Tethers. They also serve as a stepping stone for the development of future low-cost missions, utilizing pre-existing standards and commercially available inexpensive components. The secondary mission objectives are as follows:

1. Measure the electric potential bias of the EDT with respect to the ambient plasma to better characterize its deorbiting capabilities.
2. Observe deorbiting efficiency of an EDT system using a Spindt Array.
3. Demonstrate low cost command and data handling using a Raspberry Pi Zero TM module and inter-CubeSat wireless communications using an Xbee module.

Figure 1, displays stages of the DESCENT CubeSat lifecycle

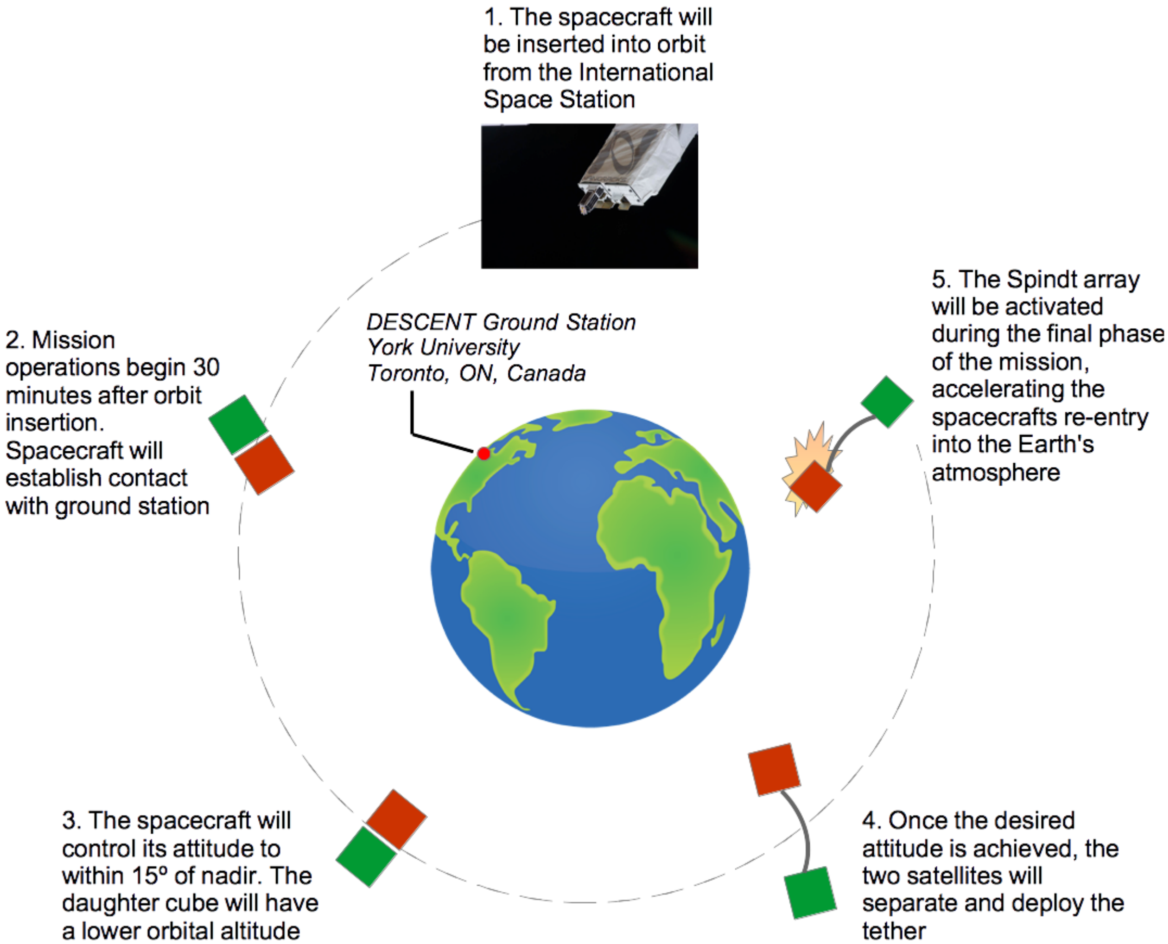

Figure 1: DESCENT Lifecycle (NanoRacks, LLC)

III. System Architecture

For the ease of communication between group members the two – 1U CubeSat are referred to as “Mother” CubeSat and “Daughter” CubeSat. The daughter cube will carry the primary payload, the electrodynamic tether and will be attached to the mother cube via the tether. Prior to tether deployment, the two CubeSats are held in close proximity using a filament that will be broken using burn wire. The separation of the two cubes is ensured using a spring. Upon stabilization of orbit, a command will be sent to burn the wire, and the compressed spring will provide the force to separate the cubes and deploy the tether. The daughter cube contains all the required commandable functionality for the satellite. It holds on board a GomSpace UHF/VHF transceiver for ground communications and houses a ClydeSpace On Board Computer (OBC). The daughter cube also hosts a NovAtel OEM615 GPS receiver to serve as a secondary module for orbit information, which is not mission critical, but may provide more precise orbit information than available from USSTRATCOM during tether deployment and activation. Pre-deployment, a wire interconnect between the cubes allows the mother OBCs (two cold redundant Raspberry Pis) to communicate with the daughter. A communication link between the two CubeSats will be established using an Xbee link after the separation.

Whilst not critical for the primary mission, the mother CubeSat does carry two of the secondary payloads – the solar cell experiment from a second group at York and a PCB from the University of Sydney used for looking at radiation dosage in LEO. Both cubes will be using a Clyde Space EPS and a 20Wh battery along with Clyde Space solar panels pre- integrated with sun sensors and magnetorquers mounted on the side walls of the CubeSats. Figure 2, displays the functional diagram for the mission.

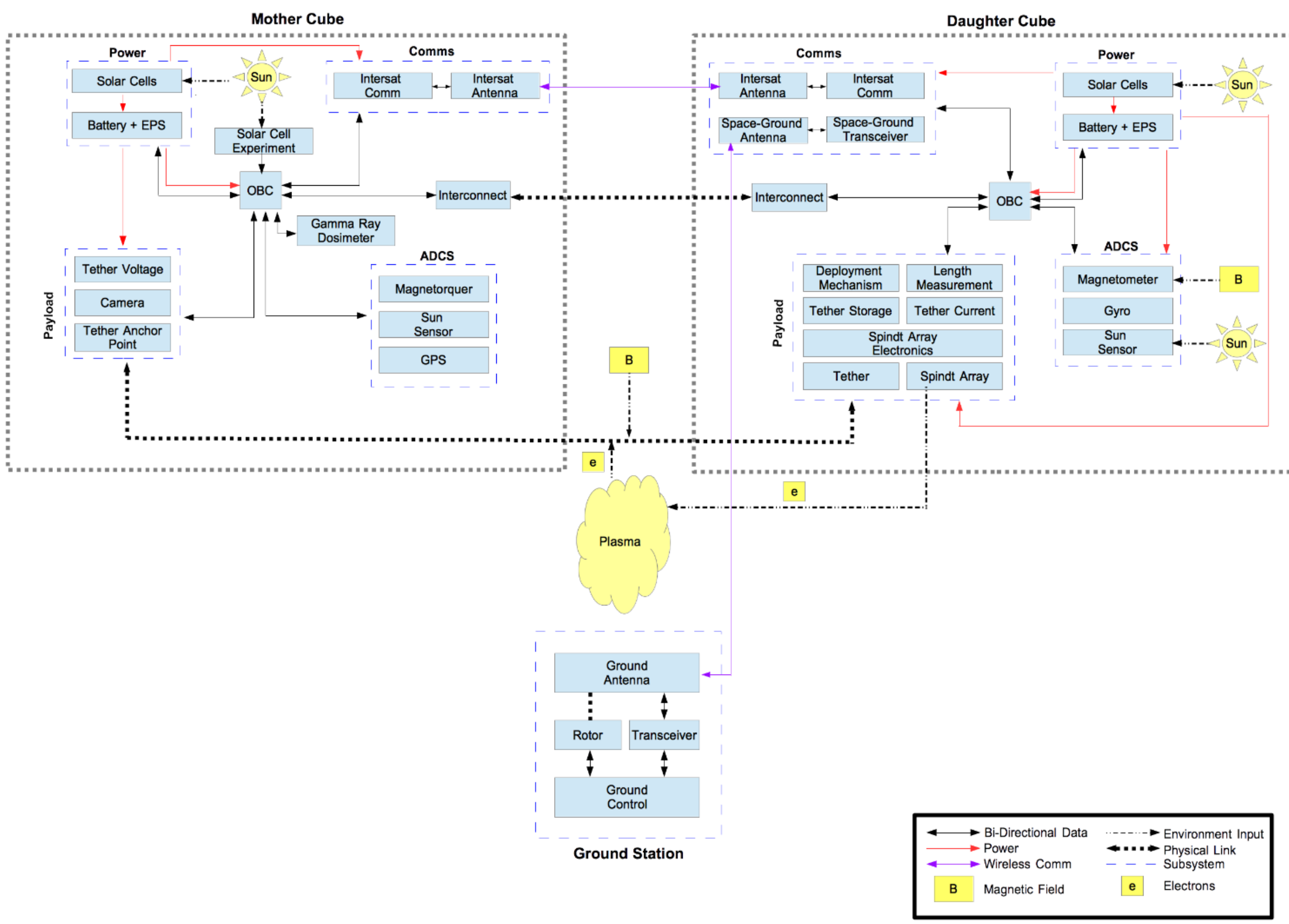

Figure 2: Mission Functional Diagram

IV. Software Architecture

Bright Ascension software compatible with the Clyde Space OBC was purchased for on board operations. The primary software uses the framework provided by Bright Ascension. The software is developed for the OBC for the daughter satellite and the Raspberry pi on board the mother satellite individually, although as much commonality between the two systems has been provided. The software will support ADCS functionality, telecommands and telemetry of subsystem and payload buses, data handling, storage, housekeeping and time tagged commands. The software is broken into three layers. The platform support package (PSP), the framework layer and the application layer. The application layer supports all the components; with implemented actions and parameters for each subsystem of the spacecraft. The framework layer details the drivers, protocol handlers, libraries and system services for the components implemented in the application layer. Finally, the PSP helps in linking the hardware components to the software on the spacecraft. The Bright Ascension architecture and development environment allow the developer to have identical application layer code, but by selecting the relevant framework and PSP layers at configuration and compile time, the same code base supports multiple systems architectures.

The application layer can be further broken into hardware specific components for the spacecraft and the task which each component is equipped with. These tasks may include automation, data pool, data store etc. for all or some components in the hardware specify layer.

V. Communication and Ground Architecture

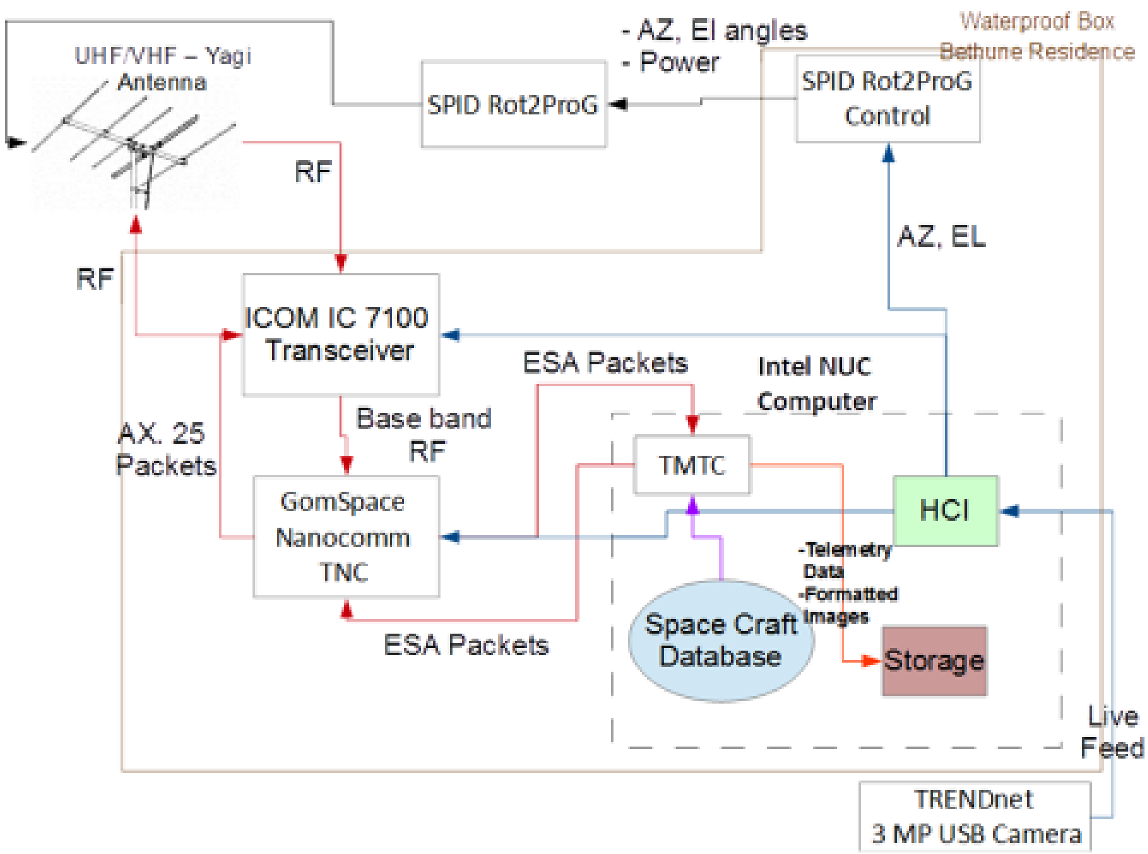

Figure 3: Ground Station Architecture

Figure 3 displays the architecture for the York University ground station. The ground station consists of a CushCraft UHF/VHF Yagi antenna for communication to satellite in the amateur band. The antenna, TNC, transceiver and the ground station operating computer will be placed in a waterproof box and mounted on a York University building roof. The ground architecture uses the Ham Radio deluxe software along with Bright Ascension's TMTC tool for communicating telecommands from the computer to the daughter on board computer. An "end-to-end" test of the ground commands will be tested with the ground architecture as a part of the systems test of the spacecraft.

The space to ground link has on board the daughter satellite a GomSpace NanoCom AX100 transceiver, which will communicate in the amateur radio frequencies (435-437 MHz). The uplink rate will be 4800 bps, while the downlink is estimated to be 19200 bps.

VI. Operations

Upon orbit insertion of the two – 1U CubeSats from the NanoRacks deployers mounted on the ISS in early 2019, the CubeSats will power on, but will not trigger any active components for the first 30 minutes (NanoRacks, LLC, 2013). This means that the satellite will not transmit any information nor enable any antenna or other deployment mechanisms. This is a requirement of the launch provider to ensure that the satellite operations do not interfere with the operations of the ISS.

After the first 30 minutes, the spacecraft will allow the transmitter to be turned on, on detection of an uplink, and a set of first housekeeping telemetry and system tests will be performed. Following this, the attitude control system will be commissioned. Once a stable attitude has been achieved the system will perform secondary payload test and the deployment mechanism will be turned on. Finally, the Spindt array will be activated and current flowing through the tether will be measured.

VII. Teams and Sub-Teams working on DESCENT

As previously mentioned, the DESCENT mission is a collaboration of York and other universities and industry partners. Following is an outline of the groups involved in the mission.

A. York University DESCENT team

a. Mission Prime and Bus

Team Descent at York University has overall responsibility for the DESCENT mission, as well as all bus systems apart from the attitude control software and some attitude control hardware.

b. Tether

Team Descent is leading the design and architecture of the tether including the custom stowage unit for holding the tether pre – deployment. The tether is a 100m long aluminum tape, which is 4mm wide and 35μm thick. The tether will move across the ambient plasma in the LEO, and a voltage of 10V has been predicted to be produced at the anode (the part of the tether which joins the mother satellite). To prevent a build-up of charge from the tether being distributed to the daughter satellite and affecting daughter systems, the tether will be insulated where it encounters the daughter cube. On the daughter satellite, the tether is “connected” to the ambient plasma potential which will generate a positive charge along the length of the tether.

The custom stowage unit is made to store the folded tether and the associated tether length measurement system and tether braking mechanism. The storage is fixed to the daughter satellite by the four thread holes in the corners seen in figure 4: these pass through the daughter stack screws. The 100m long tether is folded in a ‘Zig-Zag’ fashion and is fixed at the bottom of the tether storage box by the tether fix mechanism. The braking mechanism is similar to the one used on a past tether mission, the T-s mission (Y. Chen, 2013), however the spring has been replaced by a threaded rod which pushes against the tether to provide a friction force. A LED and a photodiode are also placed on the end where the tether exits the stowage box. The LED and the photodiode sensor together will aid in providing length measurements for the tether.

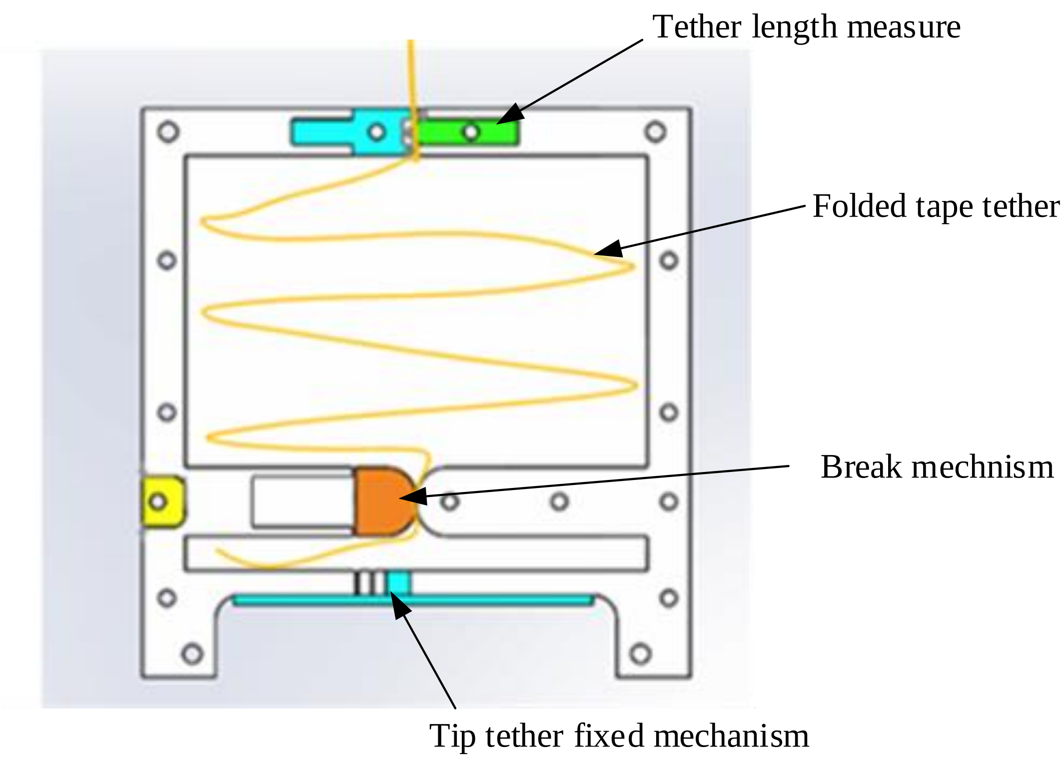

Figure 4: Tether Stowage Box

c. Spindt Array

The Spindt array is attached to the nadir face on the daughter cube. The Spindt array is made up of a Spindt pin array as well as a mesh grid. A small single cell battery helps in generating sufficient potential for electrons collected by the tether back into the ambient plasma. Figure 5 showcases the Spindt array mounted on the daughter satellite.

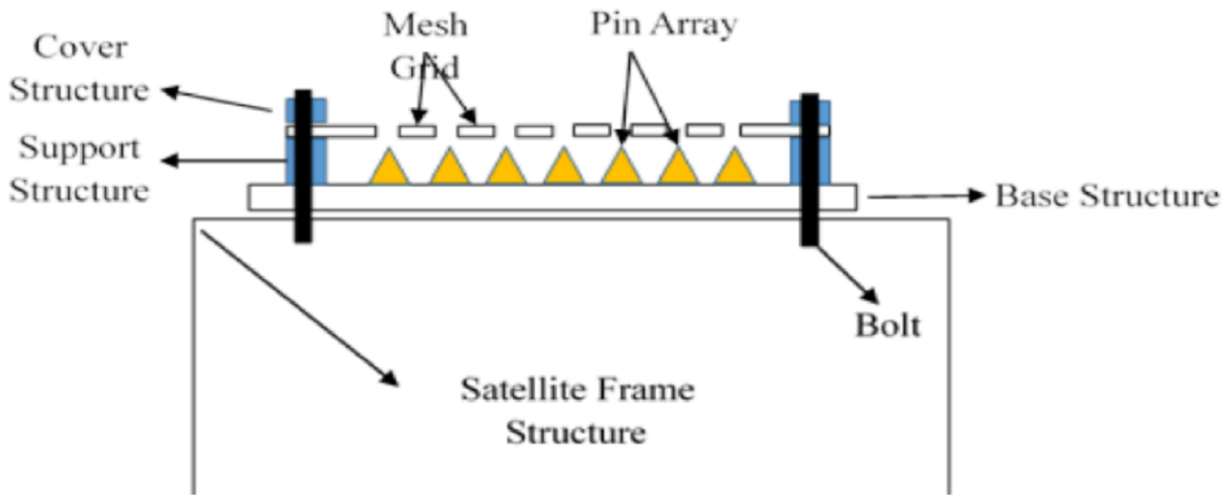

Figure 5: Spindt Pin Array and Mesh Grid

d. CubeSat Separation Mechanism

Mother and daughter satellite will be held together by thread wrapped in Dyneema burn wire before separation (A. Thurn). A spring is sandwiched between the two cubes. Upon receiving a command from ground the Dyneema wire will burn and the spring will create the initial force for separation. After 80m of the tether deployment the braking mechanism will help in slowing down the process. There are some 20 m of the original tether length behind the braking mechanism. Figure 6 displays the CubeSat separation mechanism.

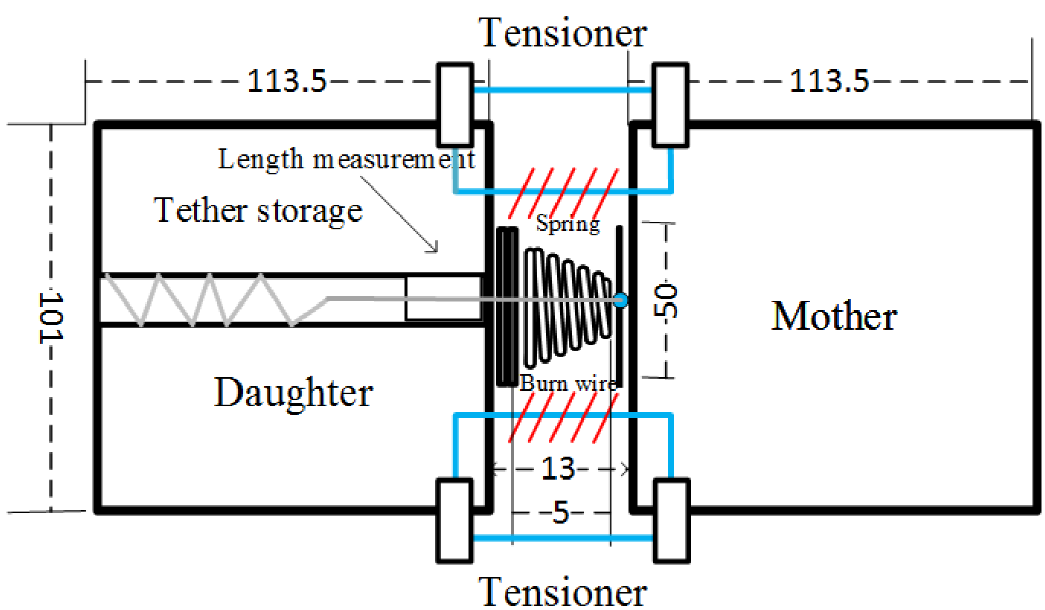

Figure 6: CubeSat Separation Mechanism

B. York University Nanosatellite Laboratory

a. Solar panel cover experiment and zenith deck sun sensor

The Solar Panel Payload (SPP, Figure 7) is comprised of a 1-U (10cm x 10cm) sized panel with 8 individual cells, a thermometer, custom-designed digital sun sensor as well as circuitry for in-situ monitoring of solar-cell performance. Four of the 8 individual cells will deploy conventional cover glass as a protective layer, and four cells will employ SWAS-enhanced cover glass. A high number of cells is desirable to ensure accuracy in the final measurements; since the precision measurement capabilities of the current monitoring circuit are expected to be constrained by the volume, mass and power requirements of the Nano-satellite platform. A sun sensor is included in the circuit to provide a reference of the direction and intensity of the sun-vector, a crucial component for evaluating the performance of the SWAS-enhanced solar cells with respect to the incident angle of the sun. Through sufficient ground testing and by utilizing a high number of solar cells, it is expected that this payload will be able to quantify the effect of SWAS-enhancement on-orbit and raise the TRL of the SWAS technology.

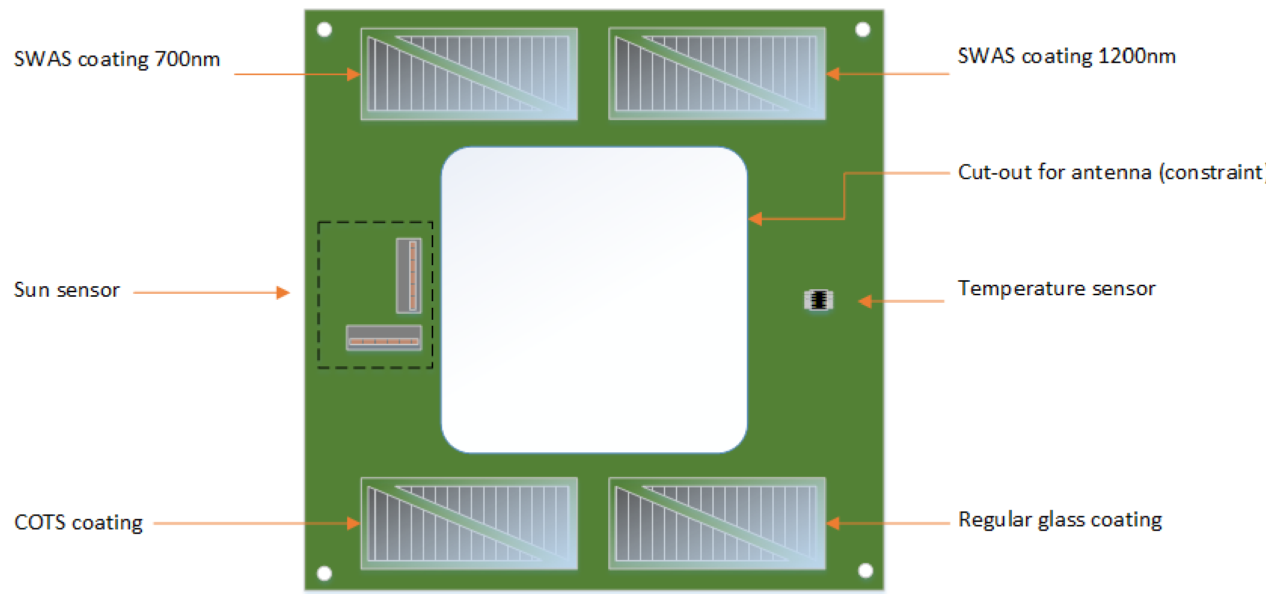

Figure 7: Solar Panel Payload

C. Ryerson University

a. Attitude control software and dedicated PCB

Ryerson is responsible for the attitude determination and control system (ADCS) of the mission. The attitude determination and control will be used prior to deployment. Post-deployment, the attitude determination will continue to operate to provide attitude of the system but the tether dynamics are expected to be greater than the attitude control could address, therefore no control is planned for post-deployment. The ADCS relies on sun sensors integrated with the solar panels and solar panel voltage, as well as magnetorquer coils integrated into the panels. It also makes use of a 3-axis magnetometer and 3-axis gyroscope integrated into the ClydeSpace OBC. Ryerson have designed additional components to be integrated into a mission-specific PCB for each cube that include ADCs for photo diodes integrated on the nadir and zenith decks of the mother and daughter cube and H-bridges for controlling the torque coils on the solar panels and dedicated z-axis coils.

D. Honeywell

a. Industrial collaborator

Honeywell's COM DEV facility in Cambridge, Ontario is providing mission review and system test facility support for the DESCENT mission. Honeywell has been supporting the EDT technology development in York University over a number of years, through early simulation and prototyping through to this first flight trial.

E. Canadian Space Agency

a. Support funding, technical review and expertise

The DESCENT CubeSat mission has been funded by the Canadian Space Agency (CSA) through its FAST grant mechanism. CSA is helping the team with mission gate reviews and other technical support for the team.

F. University of Calgary

a. Coherent Backscatter experiment

The EDT will be used during ground measurement of coherent backscatter (CBS) of electromagnetic waves from the F-region of ionosphere. The University of Calgary will measure backscatter from a region of sky, and compare it with the backscatter with the satellite overhead, to attempt detection of the CubeSat through this technique. This is the least intrusive experiment, requiring no flight hardware, and no ground hardware specific to the mission.

G. University of Sydney

a. Sydney University Gamma Ray dosimeter

A space flight compatible gamma ray dosimeter, Sydney University Gamma Ray (SUGAR) dosimeter has been developed to measure the radiation dosage in the LEO. The performance has been verified during recent High-Altitude-Balloon (HAB) conducted by School of Aerospace, Mechanical and Mechatronics Engineering of the University of Sydney, Australia. The dosimeter has also been tested for the space environment, having undergone random vibration testing in the range from 0 Hz to 1000 Hz and thermal vacuum testing in the range from -20 C to +50 C and 10^{-5} mBar.

Table 1 Attributes of PIN diode of SUGAR dosimeter

Criterion	**Test results**
Mass including PCB (Figure 1a)	9.6 g
Footprint (Figure 1b)	4.5 cm2 (28 mm 16 mm)
Operating voltage	3.5V
Current drain	2.9 mA
Power consumption (Figure 1a)	1.5 mW

60 Co-Gamma Response	5.8(counts.min-1/µSvh^{-1}) ±1.5%
Temperature sensitivity	(270–333K), stable within±2 %
Vibration immunity (Balloon Flight)	Remain intact at 2.8G
Microwave (RF) immunity	Guaranteed

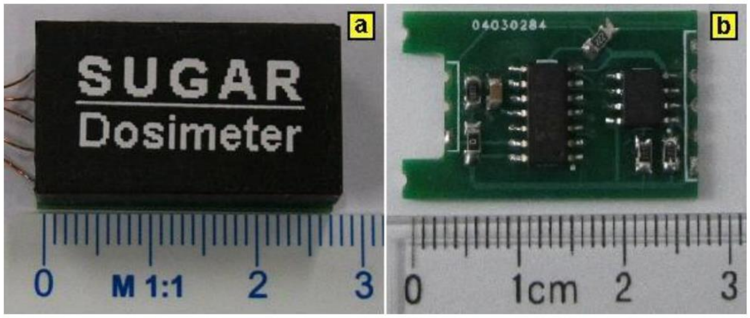

Figure 8: 10 (a) Showing the dosimeter assembled on the PCB (b) The PCB with the SMD components

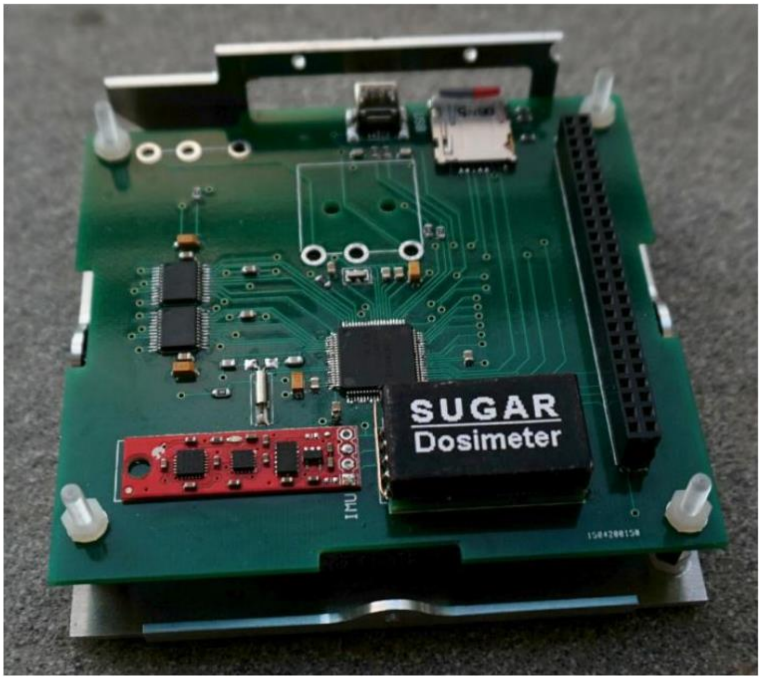

Figure 9: SUGAR dosimeter mounted on the CubeSat

VIII. Descent timeline

The DESCENT mission started in March 2016. It is due for launch in early 2019. The initial mission proposal included the involvement of the York and Ryerson DESCENT teams, the Calgary experiment and the partnership of Honeywell and CSA. After the mission was first proposed, the York Nanosatellite laboratory payload, and the Sydney dosimeter were added. Figure 10 displays the timeline for the mission, along with integration from different teams along the mission timeline.

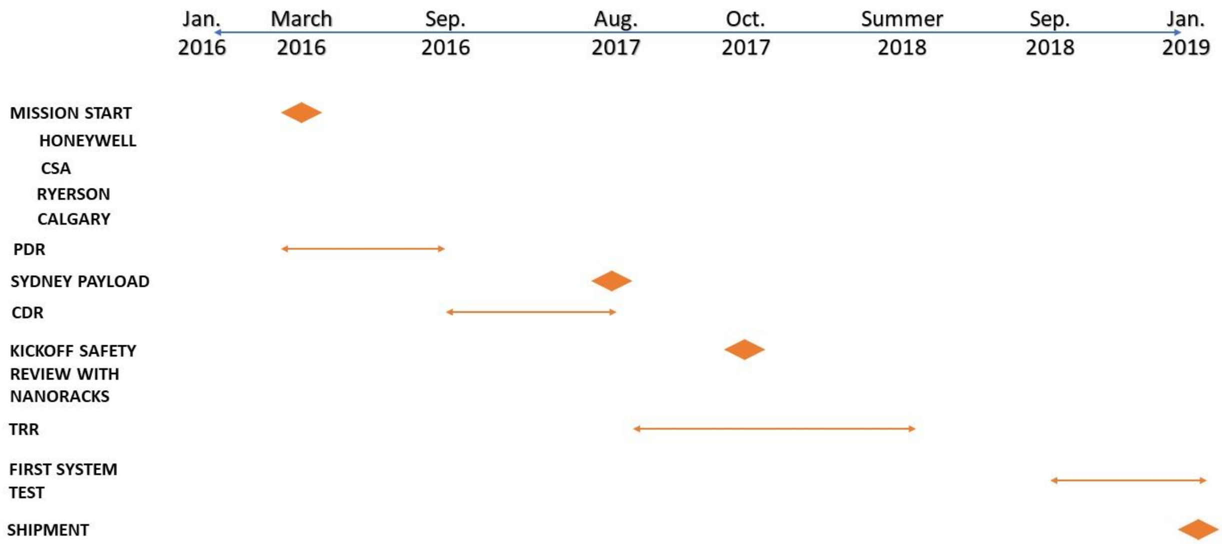

Figure 10: DESCENT Timeline

IX. CubeSat collaboration lessons learned

The DESCENT mission is demonstrating how CubeSat missions can provide broad possibilities for local, national and international collaboration, even in a small platform. The collaborations on this mission have given the core university teams a wide range of experiences, and have provided flight opportunities for a few payloads. The primary goal of DESCENT, to provide a flight trial for the electrodynamic tether, gives industry a low-cost opportunity for a low-TRL proof-of-concept. It also provides an excellent opportunity for training future space engineers. The potential of Nanosatellite missions to promote University-Industry collaboration and proof-of concept, and international collaboration, fits well in a Canadian context.

To manage collaboration on this mission, JIRA has been used to perform task management with team members. An extension to JIRA, Bitbucket, was purchased to manage code repositories. JIRA allowed team members to monitor and assign tasks to members, while Bitbucket allowed tracking changes in the code. JIRA also allowed management of the development plan and bug tracking for the mission. Figure 11 displays the software break down using the bitbucket software.

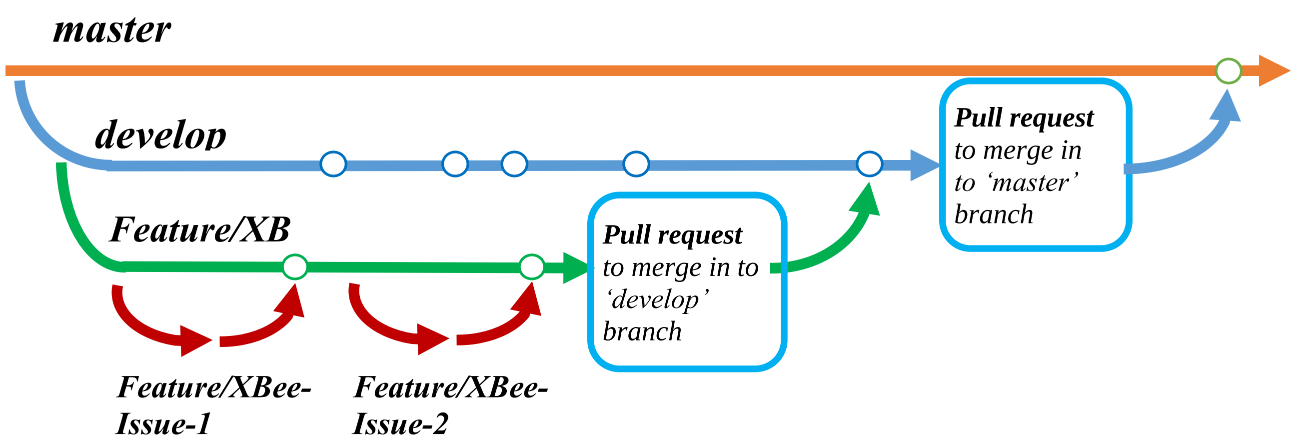

Figure 11: Bitbucket Management Framework

To monitor the progress of the team, regular meetings have been organized. Calgary operations are only performed after the mission launch; therefore, they have not been involved during the mission planning process. University of Sydney has communicated with York and sent a pre-assembled PCB based on the dimensions, and power lines and outlets provided to them. They have also provided York with a test sequence to assure correct integration into the mother satellite. York and Ryerson DESCENT teams meet every month to share the progress and work on the mission together, with individual teams meeting every week to insure mission status and coordinate the mission system and operations.

Beyond the current collaborations, the team is seeking further collaboration for the operations phase, to provide a longer contact time for the satellite amongst other benefits. Having international collaboration provides the greatest potential increase in access time. The key to multiple operator coordination is to have real-time data sharing between stations to ensure correct downlink of information and to make sure there are no repeats. Commercial collaboration tools such as Slack are being investigated to support such real-time data sharing.

X. Conclusion

The DESCENT satellite mission is providing a novel approach to providing a proof-of-concept for a new electrodynamic tether technology. The mission has also been able to support a wide range of collaborations from national and international partners. Such collaborations are well suited to University space opportunities and for growing Canadian space capabilities. Using external commercial management tools has made such collaboration easier to manage, and has created an easier platform for work allocation. As the DESCENT mission prepares for launch in early 2019, it is hoped further collaborations may be possible. It is hoped the DESCENT mission experience will provide some useful lessons on how to run future successful international collaborations using a CubeSat platform.

XI. Acknowledgements

The mission is supported by Canadian Space Agency (CSA) and Honeywell.

XII. References

A. Thurn, S. H. (n.d.). A Nichrome Burn Wire Release Mechanism for CubeSats. *41st Aerospace Mechanisms Symposium.* 2012.

GomSpace. (2016). *AX100 Datasheet.* Retrieved from https://gomspace.com/UserFiles/Subsystems/datasheet/gs-ds-nanocom-ax100-33.pdf

H. Wen, D. P. (2008). Advances in dynamics and control of tethered satellite systems. *Acta Mechanica Sinica*, no. 24, pp. 229-241.

NanoRacks, LLC. (2013, December 10). *NanoRacks Platform Documents.* Retrieved from http://nanoracks.com/wp-content/uploads/NanoRacks-CubeSat-Interface-Control-Document-CubeSat-Guide.pdf.

NanoRacks, LLC. (n.d.). *NanoRacks Images.* Retrieved from http://nanoracks.com/wpcontent/uploads/NanoRacks_CubeSat_Deployment.jpg

Y. Chen, R. H. (2013). History of the Tether Concept and Tether Missions: A Review. *International Scholarly Research Notices Astronomy and Astrophysics*.