Title: *In-Situ* Measurement of Material Degradation in Space
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UN Development Goals: Sustainable Cities and Communities, Industry Innovation and Infrastructure

1. Need

As space missions become more common, space debris has accumulated, and space situational awareness must become more capable to ensure mission safety. Tracking and cataloging debris is a crucial component and necessary to differentiate debris. Ground-based optical reflectance spectroscopy offers a cheaper method than current methods using satellites such as MDA's Sapphire to track debris, however existing temporal-resolved data has been insufficient [1] to model changing material spectra exposed to the space environment which has limited the efficacy of ground-based methods.

2. Mission Objectives

1. Measure reflectance spectra of three common spacecraft materials (triple junction solar panel, AZ-93 white paint, bare aluminum) periodically and transmit back to a ground station
2. Augment existing specular bidirectional reflectance distribution functions of spacecraft materials with collected data and compare against external measurements (i.e. NASA's LDEF missions)
3. Share models with SSA community to drive ground-based debris monitoring technologies

3. Key Performance Parameters

1. Monolithic payload used to maintain optical geometries and reduce failure modes
2. Independent optical assemblies for each sample offer redundancy in payload operation and shifts critical failure risks away from the peripheral optics which are most vulnerable
3. On-board lighting allows measurements in eclipse to reduce thermal noise and stray light, though solar-illumination capabilities are available as a backup
4. Recessed optics shields instrumentation from the space environment, and a reference beam allows correction for remaining degradation experienced across the optical assembly.
5. Space-qualified electrical power system and transceiver reduces risk of operational failure

4. Concept of Operations

The ground segment will consist primarily of data downlinks at 437 MHz using the AX-25 communications protocol to a ground station at Royal Military College (RMC), Kingston. Launch and deployment is assumed to use the NanoRacks CubeSat Deployer on the ISS with standard interface protocols to the P-Pod.

The space segment is divided into five modes, shown in Figure 1. Each mode is controlled by the on-board computer (OBC) via serial protocols. Data is triple-modular redundantly stored to correct for errors.

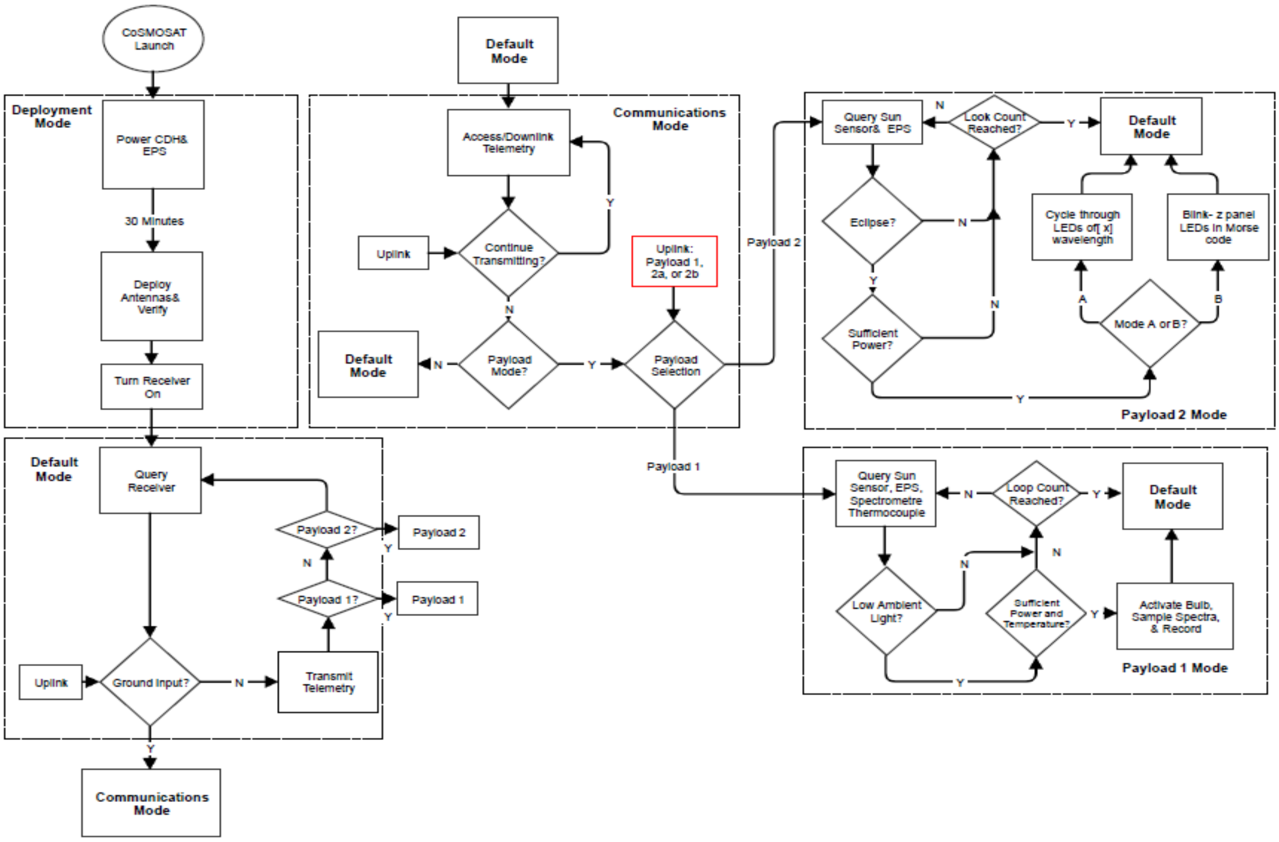

Figure 1: Space-segment overview showing the five modes of operation: deployment, default, communications, payload 1 (this report), and payload 2 (not discussed).

5. Space Segment Description

The satellite uses an AvaSpec-Mini CMOS spectrometer to measure the specular reflection spectra of each material at 60° from the normal to allow a large exposure angle while still matching common ground experiment setups (Figure 2). The proposed structure is 10 x 10 x 30 cm (3U) and weights 4 kg (Figure 3). ANSYS simulations predict a fundamental frequency of 149 Hz and < 0.005 mm deformation during launch.

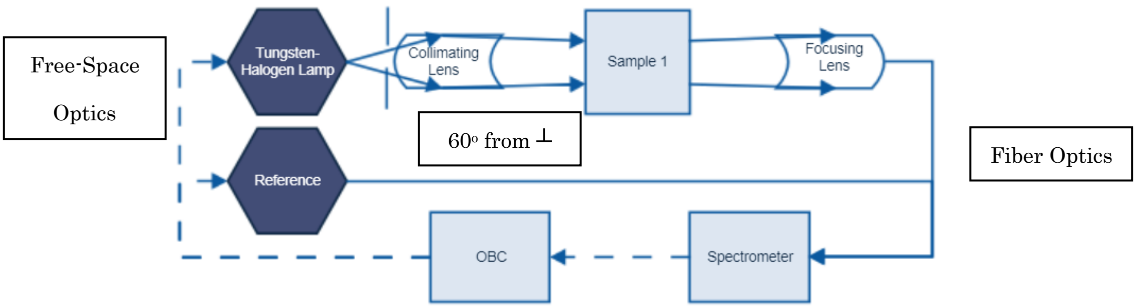

Figure 2: Block diagram of one optical assembly to observe a sample.

The on-board Nano Avionics antenna and radio (NA-RFS-G1-R2 and NA-UHF-G0-R0) transmit at 9600 baud to match the Yagi-Uda antenna ground station. 810 kB of data is expected during downlink, with a 0.9 dBm margin down and 15.6 dBm up which includes polarization, atmosphere, path, TX/RX, and sensitivity losses.

The payload is attitude-independent and only passive control using neodymium magnets and HuMu80 hysteresis rods are needed to detumble and orient the satellite for communications. Attitude determination using sun sensors and magnetometers is used for confirmation during measurements.

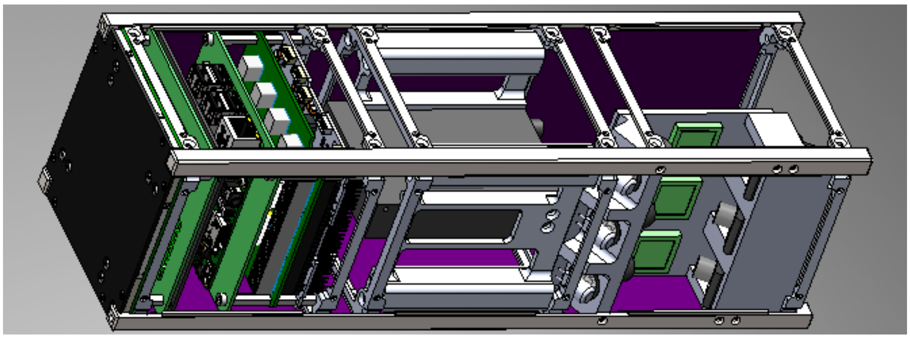

Figure 3: CAD model of the satellite with external panels removed, showing the EPS, OBC, and transceiver (left unit), spectrometer and magnet mounts (middle), and primary payload (right). Wiring is omitted.

Solar panels are mounted on each side and power is stored/managed by a Clyde Space 25-02452 EPS. Normal operation uses 7.51 W·h/orbit at an average power of 4.87 W, resulting in a 33% depth of discharge (DOD). During payload operation, a peak usage of 18.0 W·h at 11.7 W results in an expected 78% DOD.

6. Orbit/Constellation Description

It is assumed the satellite will be deployed from the ISS and will follow the ISS orbit, however any non-sun-synchronous low-earth orbit is acceptable. Based on in-house simulations of Earth's magnet field, the satellite's magnets are positioned to align the +z face towards nadir over Kingston, ON.

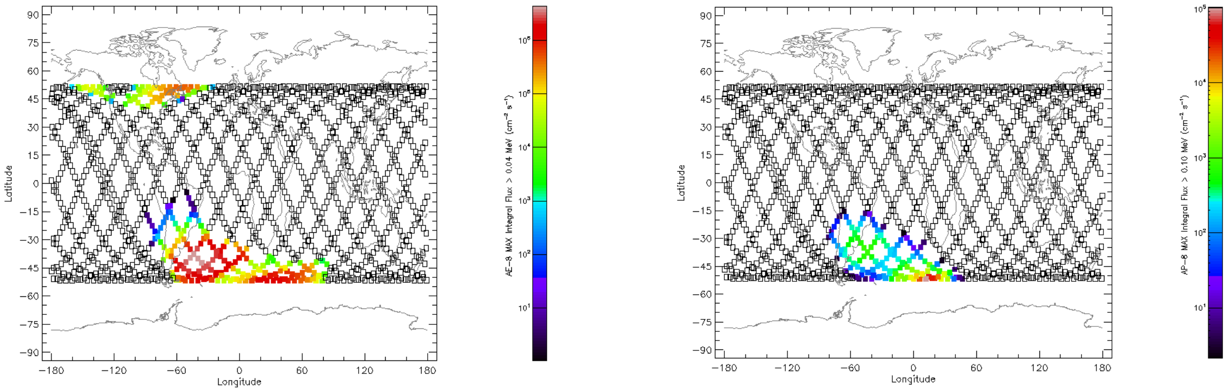

Figure 4: Maximum electron (left) and proton (right) fluxes expected in ISS flight path over July 2018 using the AE-8 and AP-8 models in SPENVIS respectively. Fluxes range from 10 to 10^5 cm^{-2} s^{-1} in images.

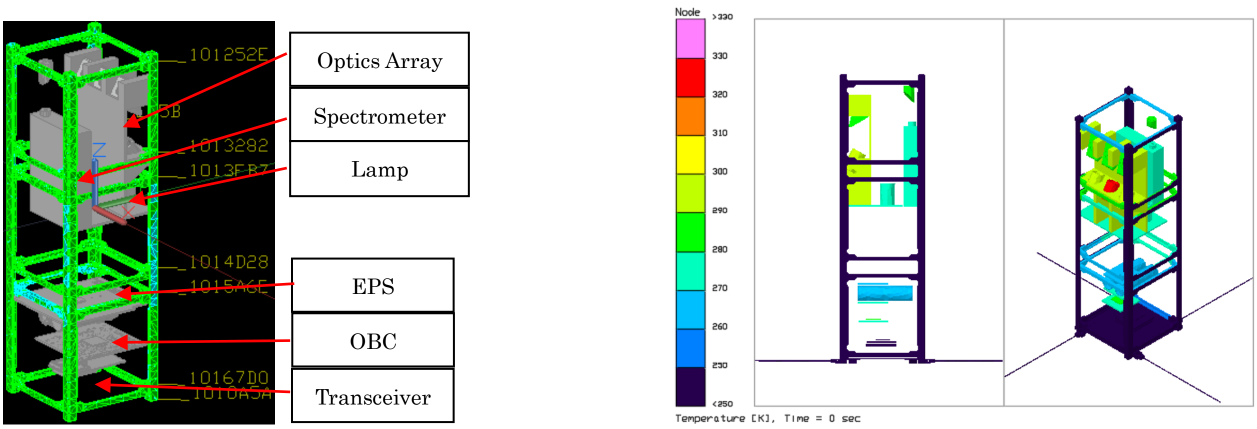

Figure 5: Payload operation thermal simulation using Thermal Desktop. Critical components are >280 K

Thermal models of the orbit path (Figure 5) were developed to ensure acceptable conditions for operation, with hot and cold cases used for thermal testing at RMC. *Figure* 4 shows the expected radiation fluxes encountered by the satellite and used for radiation testing of critical systems at TRIUMF in Sept. 2017.

7. Implementation Plan

This project was developed by the Queen's Space Engineering Team (QSET) – a group of undergraduate and graduate students from Queen's University and RMC which has worked on projects in the space industry for over 10 years. The satellite was constructed over a two-year period, with the timeline shown in Figure 6. Facilities at both institutions were used for manufacture, assembly, and testing, with a ground station available for use at RMC during flight. Through the Canadian Satellite Design Challenge (CSDC), radiation, vibration, and thermal-vacuum tests were also performed at TRIUMF and the David-Florida laboratory.

Qualification testing and launch would be managed in partnership with the CSDC committee through the Canadian Space Agency. Deployment is expected to be from the NanoRacks CubeSat Deployer on the ISS.

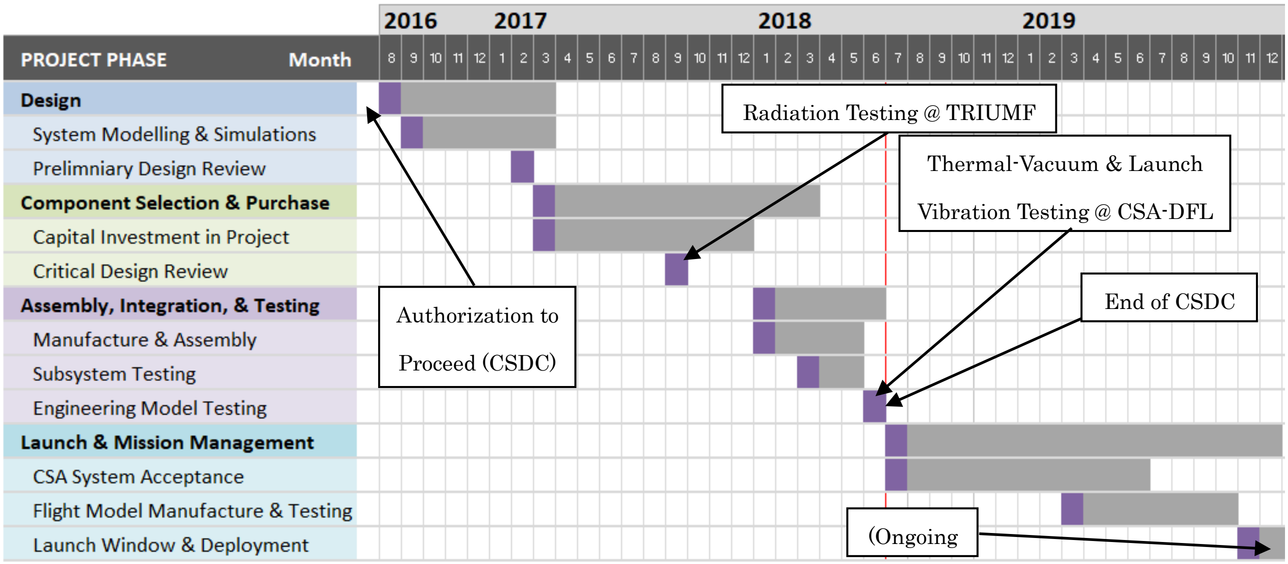

Figure 6: High-level Gantt chart of project development schedule, starting from authority to proceed

Major risks in the project have stemmed from the nature of the team and capabilities of its members:

1. As an open-access team, there is significant uncertainty in meeting project deadlines. Incentives are placed to reward dedicated members which has been successful over the 10-years of operation.
2. As a student team, QSET sees annual turnover resulting in loss of capabilities. To mitigate this, a public wiki (http://qsat.wikidot.com/) is used to document work and speed up member training.
    - Mentorship culture promotes knowledge sharing between experienced and new members
3. QSET has limited funding, facilities, and equipment to those available at the university. Existing industry relationships were leveraged (see http://qset.ca/), and other partners were approached.
    - Space-qualified components are non-redundant
    - Facility availability and lead times increase uncertainty in project timeline
4. Lack of experience working with space-qualified hardware resulted in the OBC and EPS

development as the critical path.

- High risk for damaging sensitive and irreplaceable hardware during testing

5. Primary usage of commercial-off-the-shelf (COTS) equipment increases risk in space environment

- Tests provided by the CSDC increase confidence in some COTS components

A cost estimate of the total life cycle is shown in Table 1. No disposal is necessary (re-entry burnout).

Table 1: Actual costs and estimates of complete satellite lifecycle in Canadian dollars.

Item	Subtotal ($)	Comments
Design & Development		
Modelling Software	0	(Actual) Solidworks, ANSYS, SPENVIS, Thermal Desktop, and KiCAD EAD available as student licenses or open source
Assembly, Integration & Testing		
Capital + Overhead	15,680	Actual
Manufacture	4,330	Actual
Space-Qualify COTS Components	20,000	Estimate as additional 100% of current cost
Labor + Facilities	0	(Actual) University-supplies facilities and student volunteers
Testing + Overhead	2,200	(Actual) Radiation, thermal-vacuum, and vibration testing provided by CSDC, incl. accommodations and transport
Launch & Operations		
ISS Deployment	85,000	Estimate for NanoRacks P-Pod system [2]
Payload Insurance	200,000	Estimate [3]
Launch	45,000	Estimate [3]
Ground Station	0	(Actual) Provided by RMC
TOTAL	**$426,000**	+15% Contingency

References

[1] NanoRacks, "Space Station Cubesat Deployment Services," n.d.. [Online]. Available: http://nanoracks.com/wp-content/uploads/Cubesat-Services.pdf. [Accessed 12 05 2018].

[2] J. B. J. S. D. W. Anders Kose Nervold, "A Pathway to Small Satellite Market Growth," *Advances in Aerospace Science and Technology,* vol. 1, no. 1, p. 7, 2016.

[3] G. A. W. K. A. Donald Bédard, "Laboratory Characterization of Homogeneous Spacecraft Materials," *JOURNAL OF SPACECRAFT AND ROCKETS,* vol. 52, no. 4, pp. 1038 - 1056, 2015.