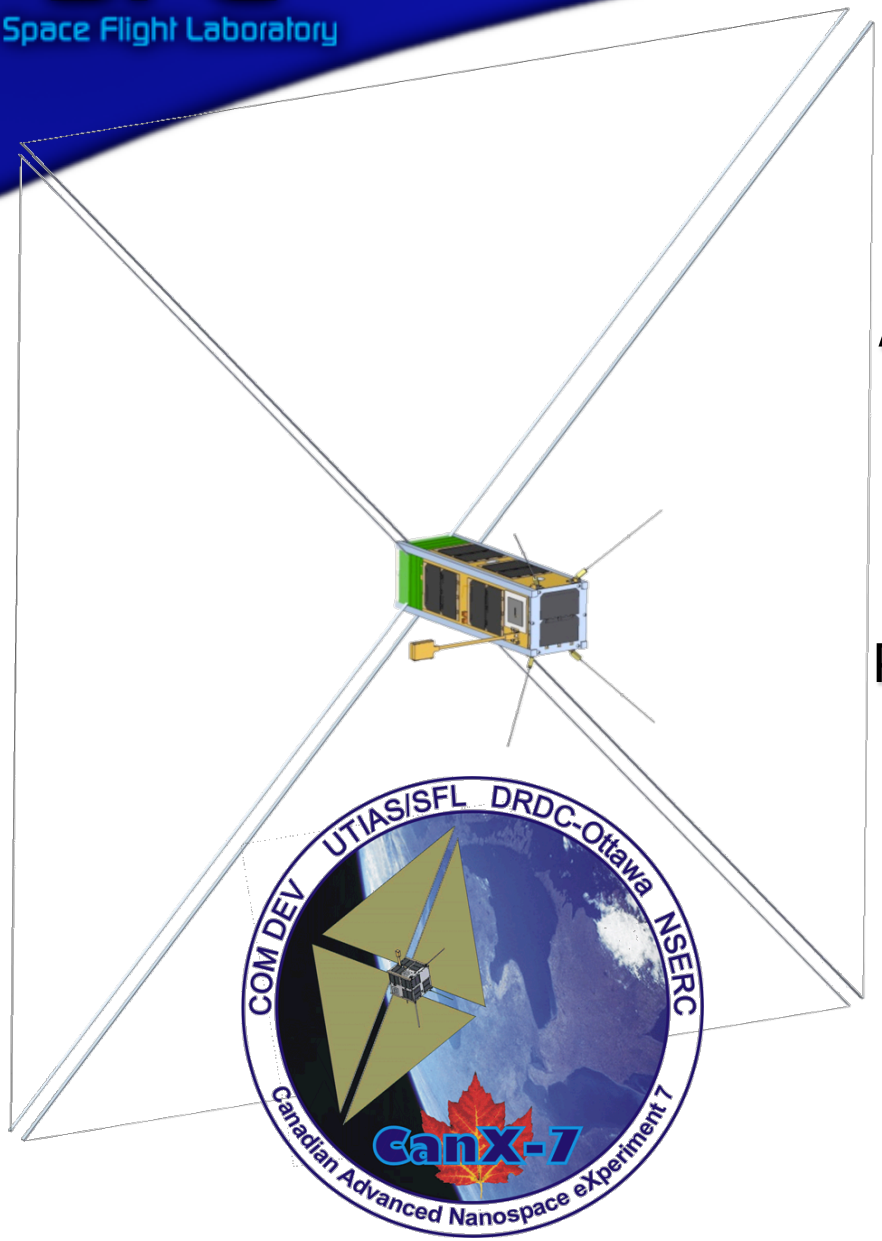
UTIAS SFL Space Flight Laboratory

Building Canada's Future In Space



The CanX-7 Drag Sail Mission

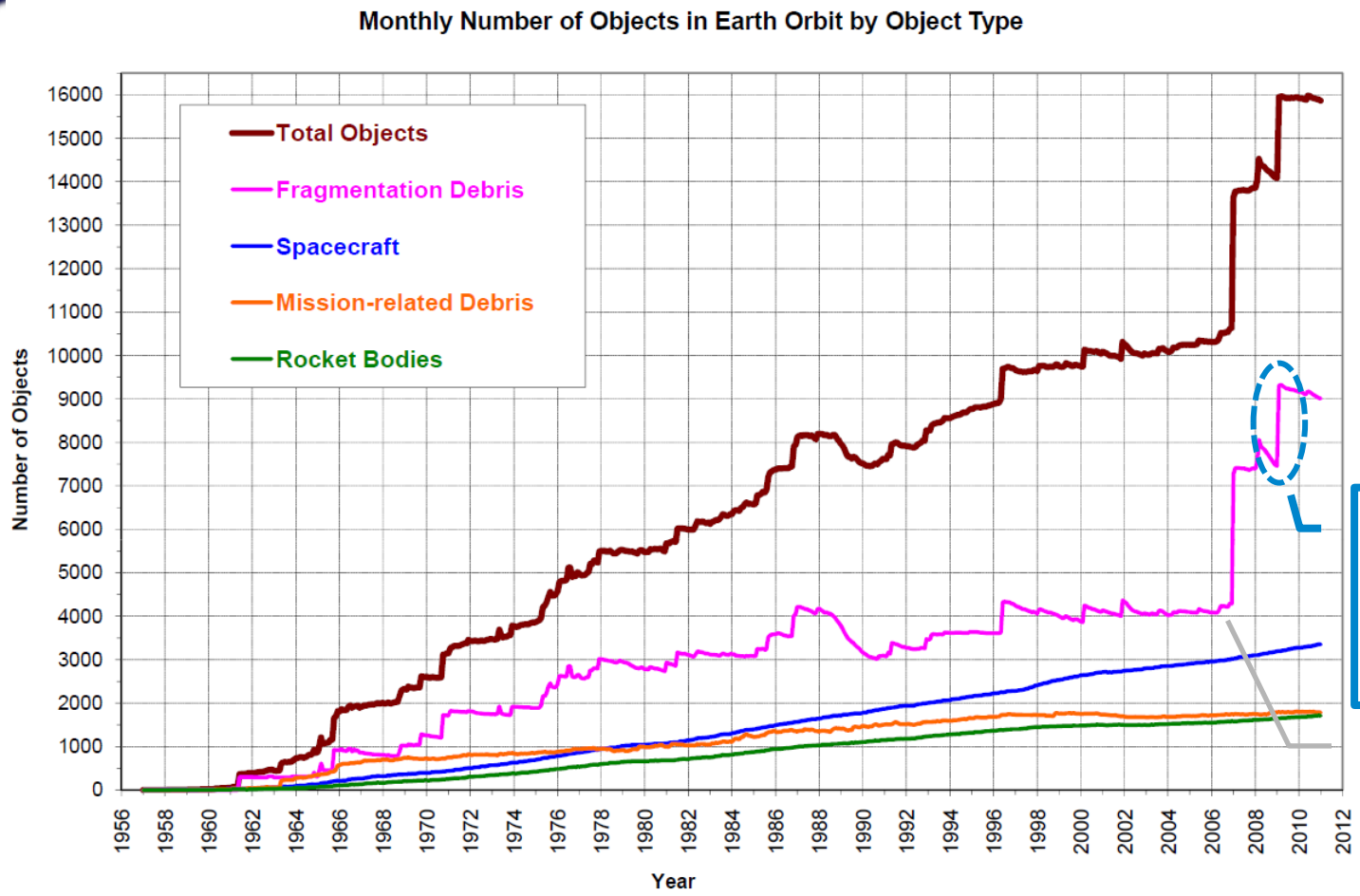
A cubesat for demonstrating a small-satellite compatible deorbiting device

Presented to the 2012 Summer CubeSat Developer's Workshop

Jesse Hiemstra, Barbara Shmuel, Fiona Singarayar, Vincent Tarantini, Brad Cotten, Bryan Johnston-Lemke, Grant Bonin, Dr. Robert E. Zee

August 2012

The Space Debris Problem



2009
Kosmos 2251 & Iridium 33 collision

Fengyun-1C antisatellite test

Source: Orbital Debris Quarterly News, vol. 361, no. 1802, 15-Jan-2011

The Problem for Small Satellites

- Inter-Agency Space Debris Coordination Committee (IADC) Space Debris Mitigation Guidelines (2007)
  - Two protected regions (LEO, GEO).
  - LEO guidelines: deorbit within 25 years from end of mission.

- Not the law (yet)…
  - Canadian Department of Foreign Affairs and International Trade (DFAIT), Industry Canada (IC) require debris plan as pre-requisite for communications licenses.
  - Significant issue for Canadian satellites, particularly small, responsive missions.

Deorbiting Devices for Small Satellites

- Propulsion systems
- (Active) solar sails
- Electrodynamic tethers
- Passive drag devices: Ribbons, balloons, **sails**

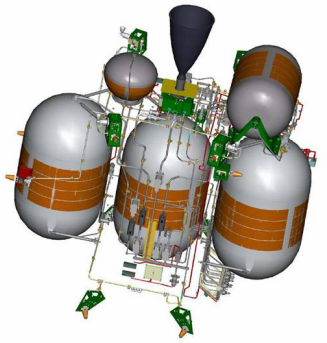


Image credit: http://cmsa.uah.edu/?projects&id=29

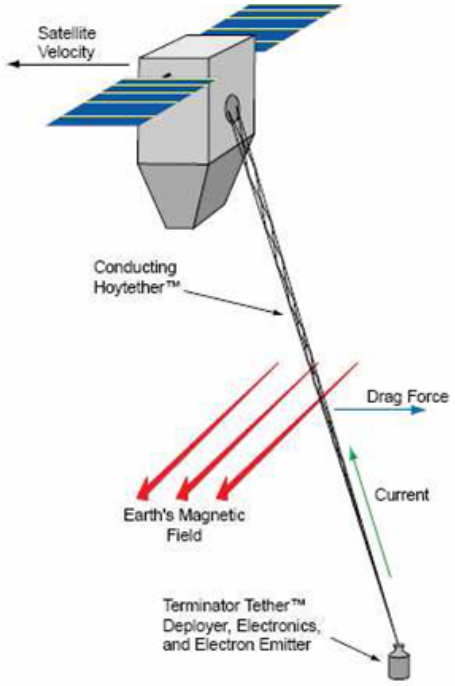


Image credit: http://www.tethers.com/papers/TTReno00.pdf

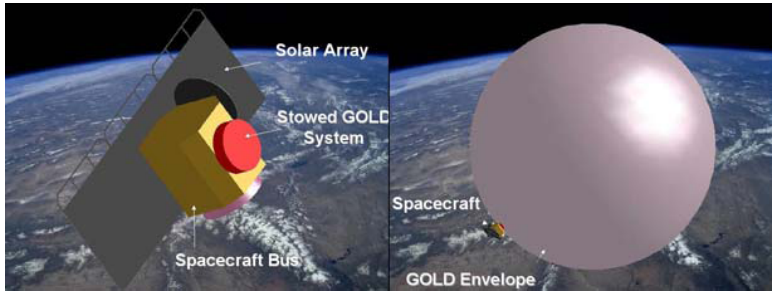


Image credit: http://www.gaerospace.com/projects/GOLD/index.html

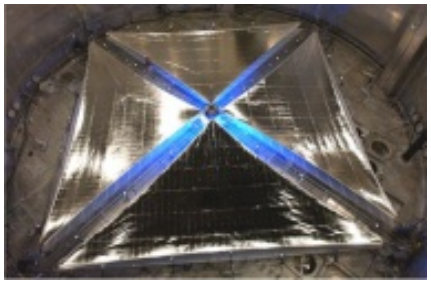


Image credit: http://www.nasa.gov/mission_pages/smallsats/nsd_bluesail.html

CanX-7 Mission Objectives

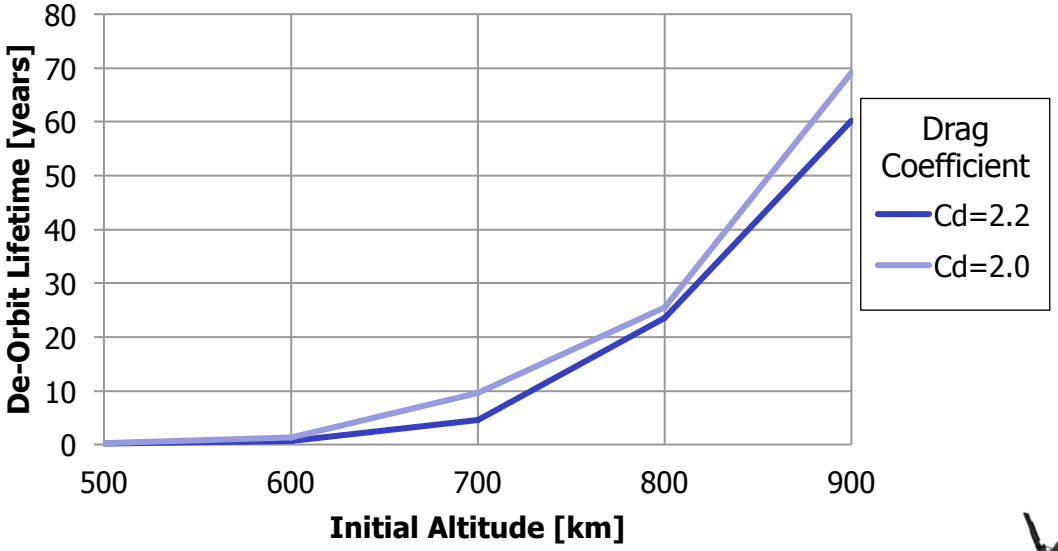
- Demonstrate a drag sail deorbiting device on a 3U as well as 20 cm edge-length platform, capable of being **adapted** to
  - passively deorbit a 15 kg reference spacecraft,
  - from an 800 km circular polar orbit,
  - within 25 years.
- Operate a secondary payload for 6 months, then deploy drag sail.

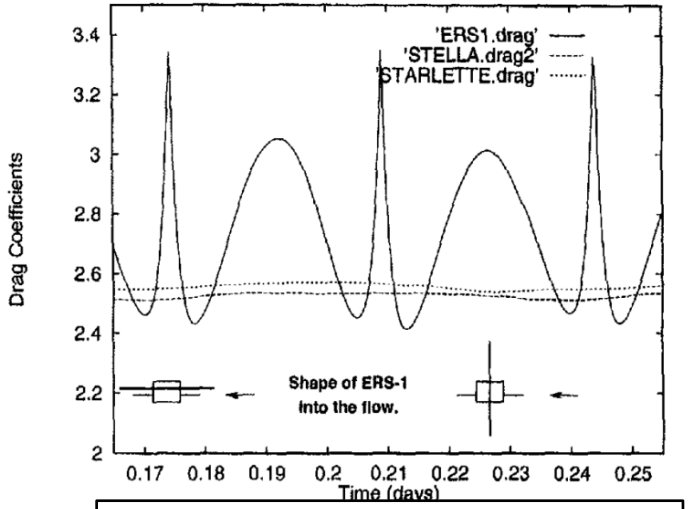
Lifetime Analysis Method

- What is the deorbit lifetime?
- Using the Satellite Tool Kit (STK) software lifetime tool, determine the deorbit lifetime of a spacecraft with a fixed drag coefficient and constant ram area.

Lifetime Analysis Method

- Selected drag coefficient appears conservative.





Predicted de-orbit lifetime for a 15 kg satellite with area $A = 2.0\ \mathrm{m}^2$.

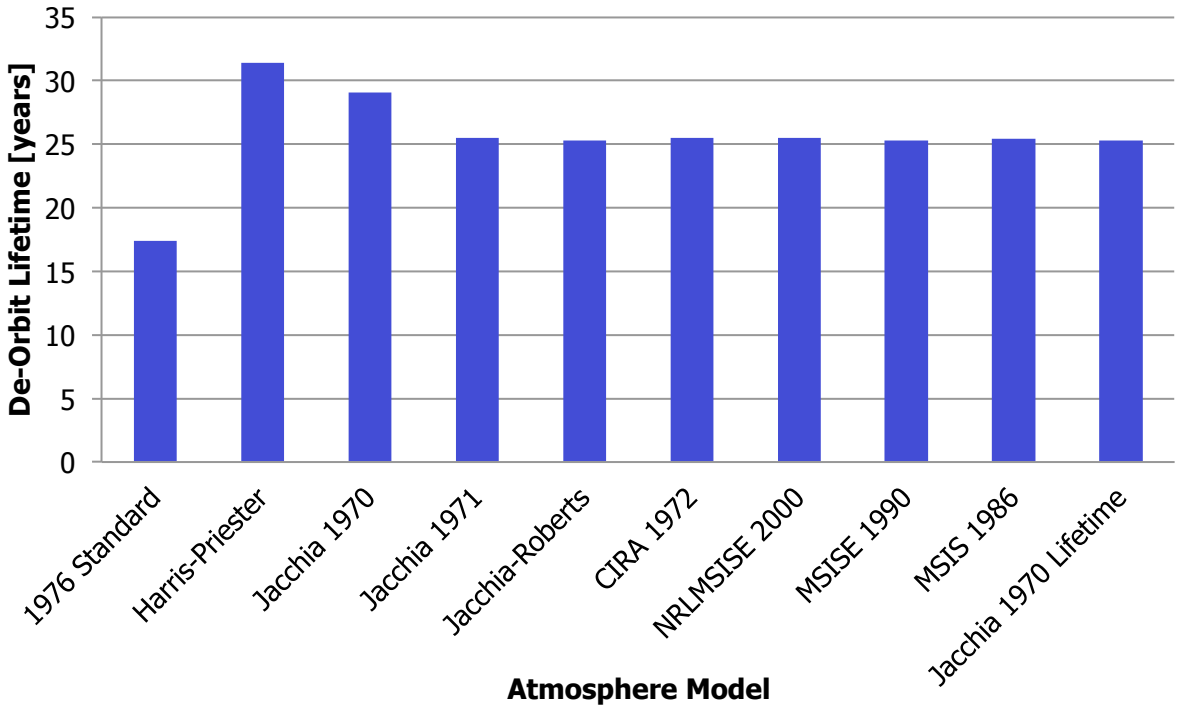
ERS-1 Satellite. (http://ilrs.gsfc.nasa.gov/satellite_missions/list_of_satellites/ers1_general.html)

Solved-for drag coefficients of ERS1, STELLA, and STARLETTE, around one orbit.
(I. K. Harrison and G. G. Swinerd, "A free molecule aerodynamic investigation using multiple satellite analysis," Planetary Space Science, vol. 44, no. 2, pp. 171-180, 1996.)

Lifetime Analysis Method

- Results using most atmospheric models agree, but…

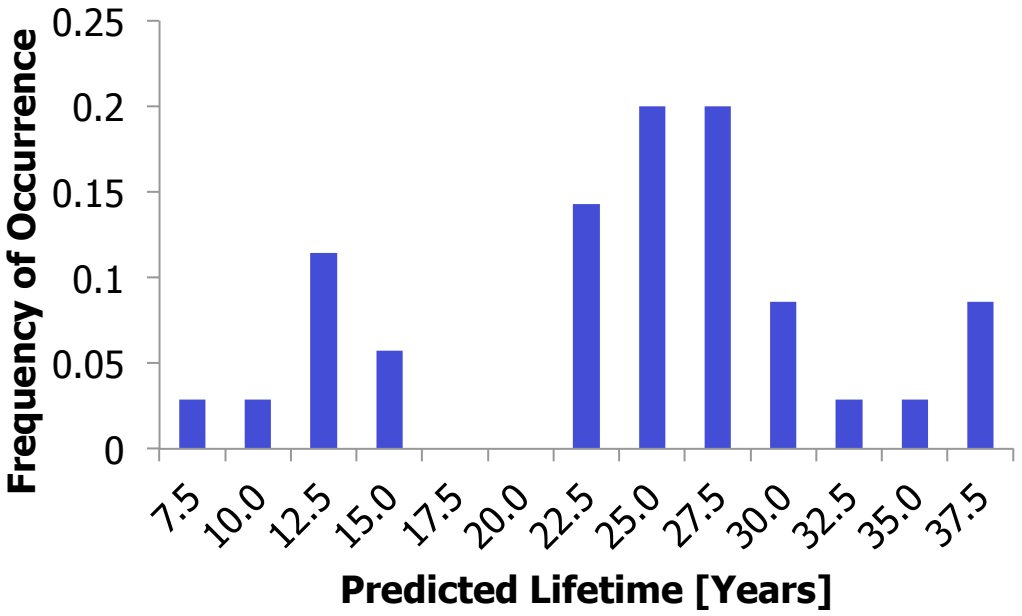
Predicted de-orbit lifetimes using common atmospheric models.
(Ballistic coefficient $C_D/B = 3.75\ \mathrm{kg/m^2}$.)



Lifetime Analysis Method

- Solar activity affects atmospheric density, and solar cycle variation is difficult to predict.

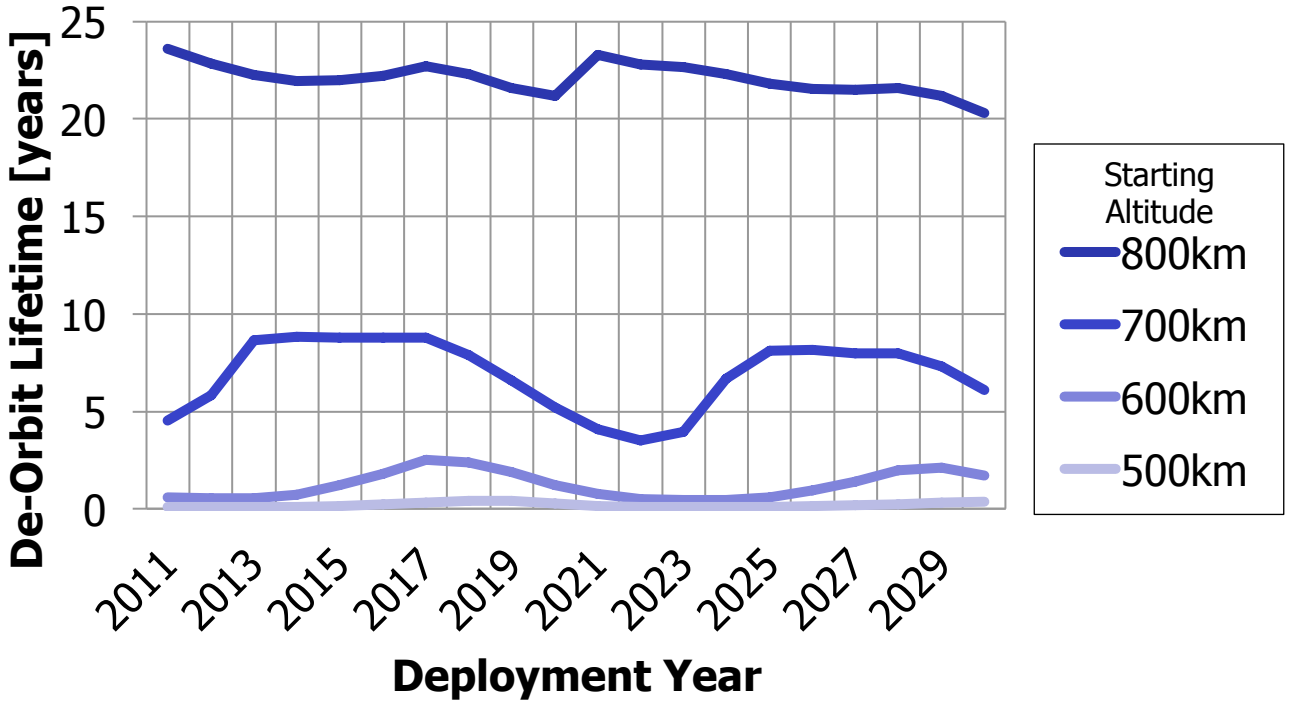
Histogram showing distribution of de-orbit lifetimes from 800 km using NRLMSISE-2000 atmospheric model for various predictions of solar activity.
(Ballistic coefficient $C_B = 3.75\ \mathrm{kg/m^2}$.)



Lifetime Analysis Method

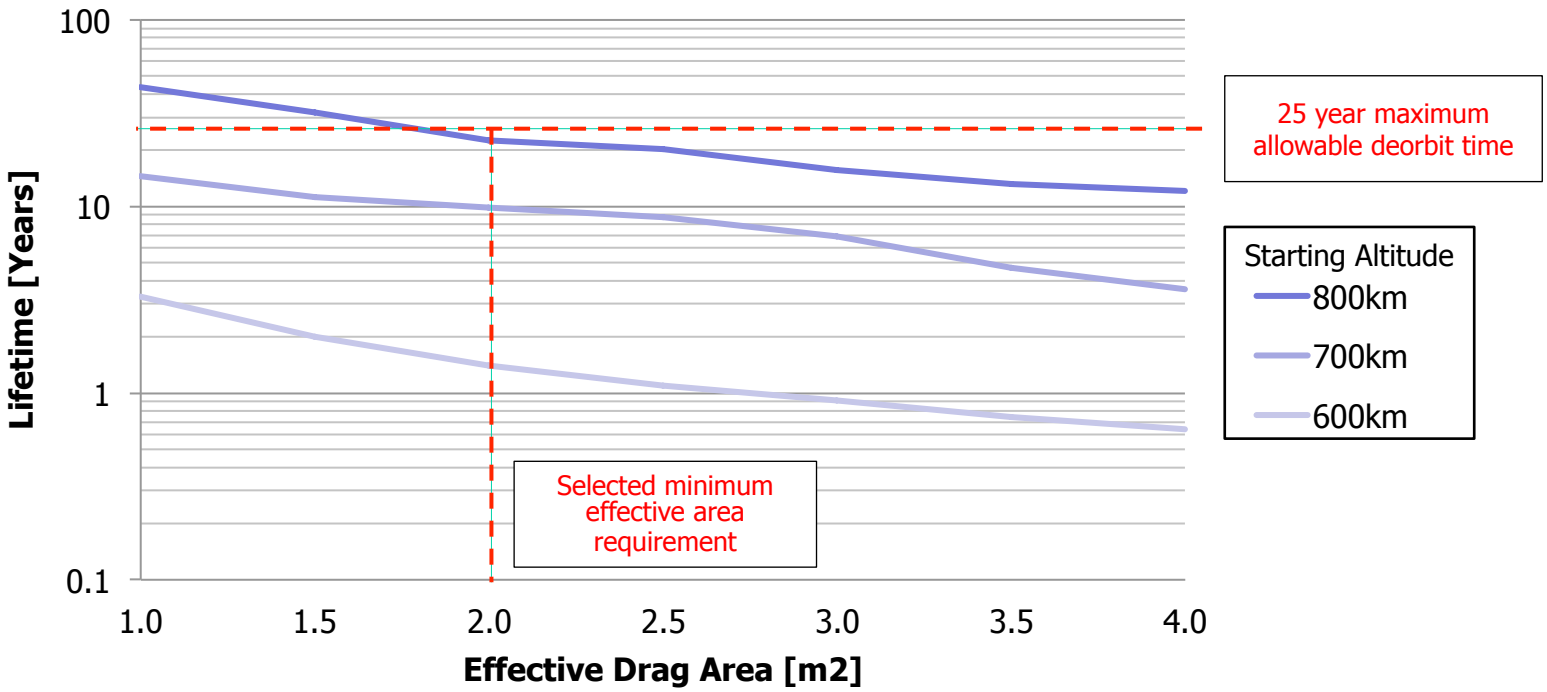
- Deployment date affects deorbit life.

Predicted de-orbit lifetime as a function of deployment date.
(Ballistic coefficient $C_b = 3.75\ \mathrm{kg/m^2}$.)



Lifetime Analysis Results

- Effective ram area requirement is set at 2.0 m^2.



Attitude Analysis Method

- What size of sail is needed to achieve a given effective area?
- Conversely, what is the effective area of a given spacecraft and sail?

Attitude Analysis Method

- Furthermore, the deorbit device must work over a range of orbits and spacecraft configurations.
  - Inclination restricted to 80° -100° (i.e., polar / sun-synchronous).
  - Local Time of Ascending Node (LTAN) free.
  - Altitude free.
  - Magnetic dipole moment restricted.

Attitude Analysis Method

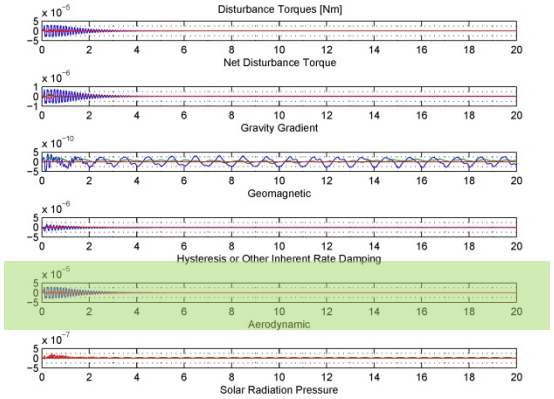
→ Parametric Study: Simulate the attitude dynamics, while…

- Holding altitude constant
- Varying other orbital parameters
- Varying the atmospheric density through a range equivalent to one solar cycle
- Varying the magnetic configuration (dipole moment magnitude and direction)

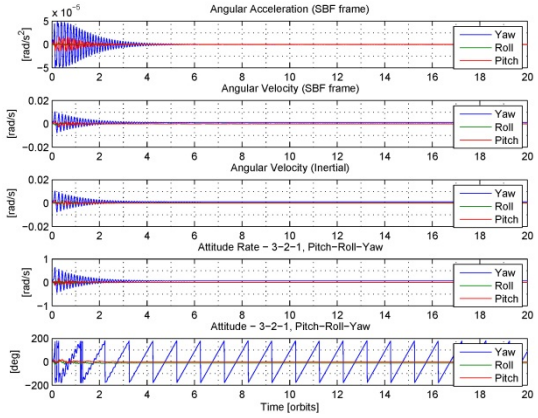
… Then determine the resulting effective area.

Preliminary Attitude Analysis Results (example)

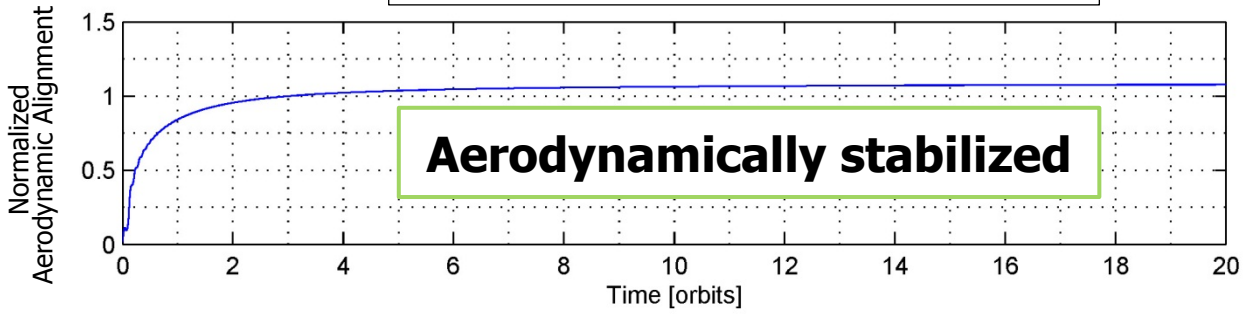
Input: Disturbance torques

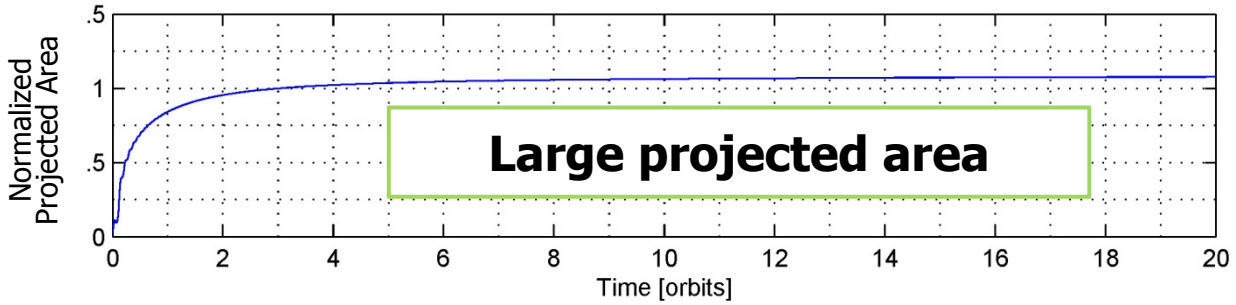


Output: Spacecraft attitude



Result: Figures of merit





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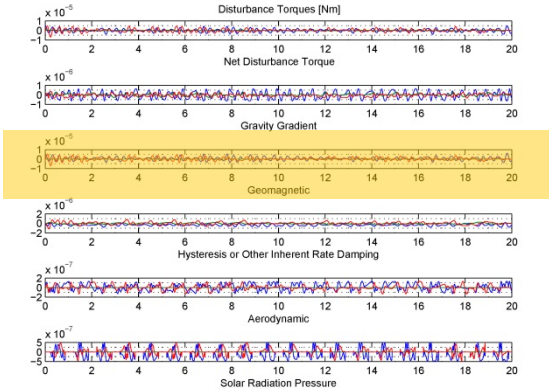
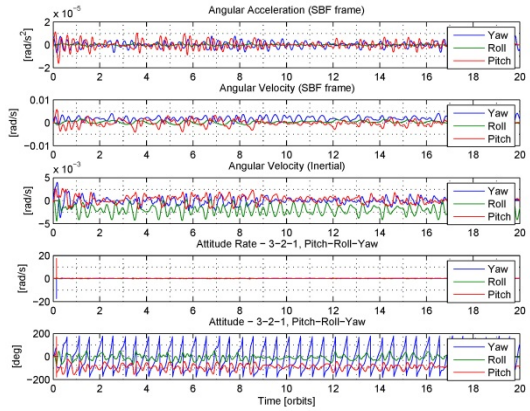


Output: Spacecraft attitude



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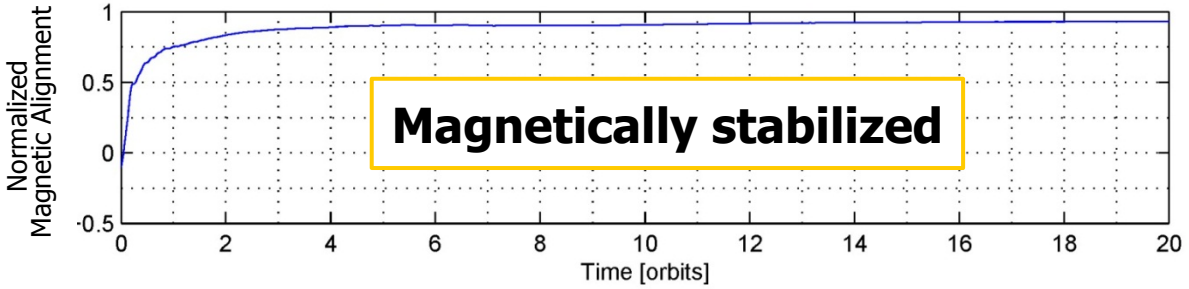

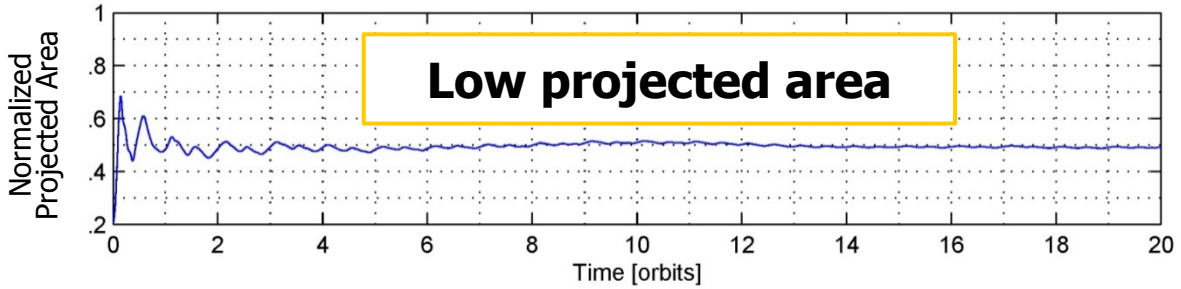

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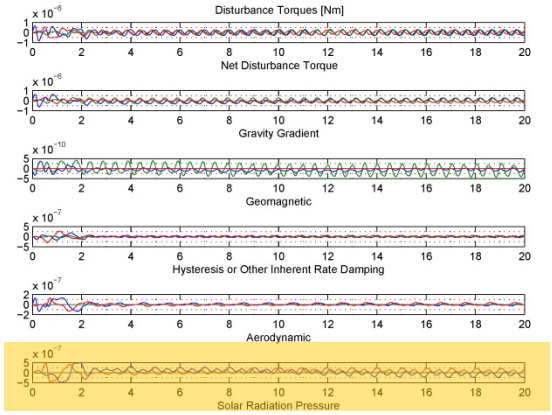

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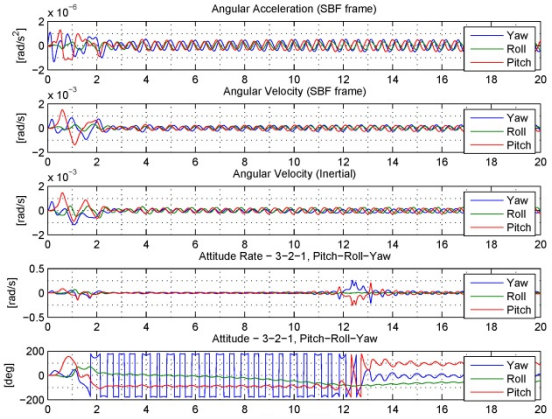
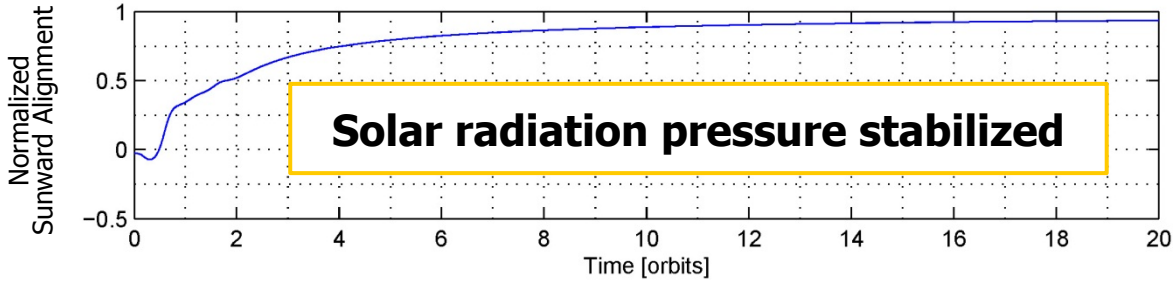
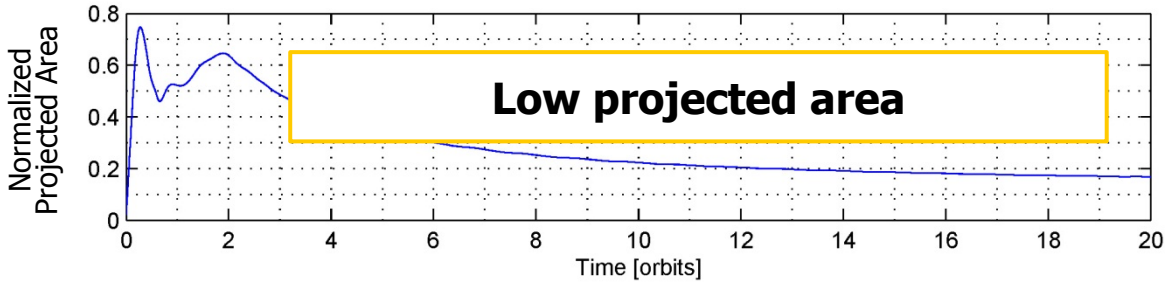


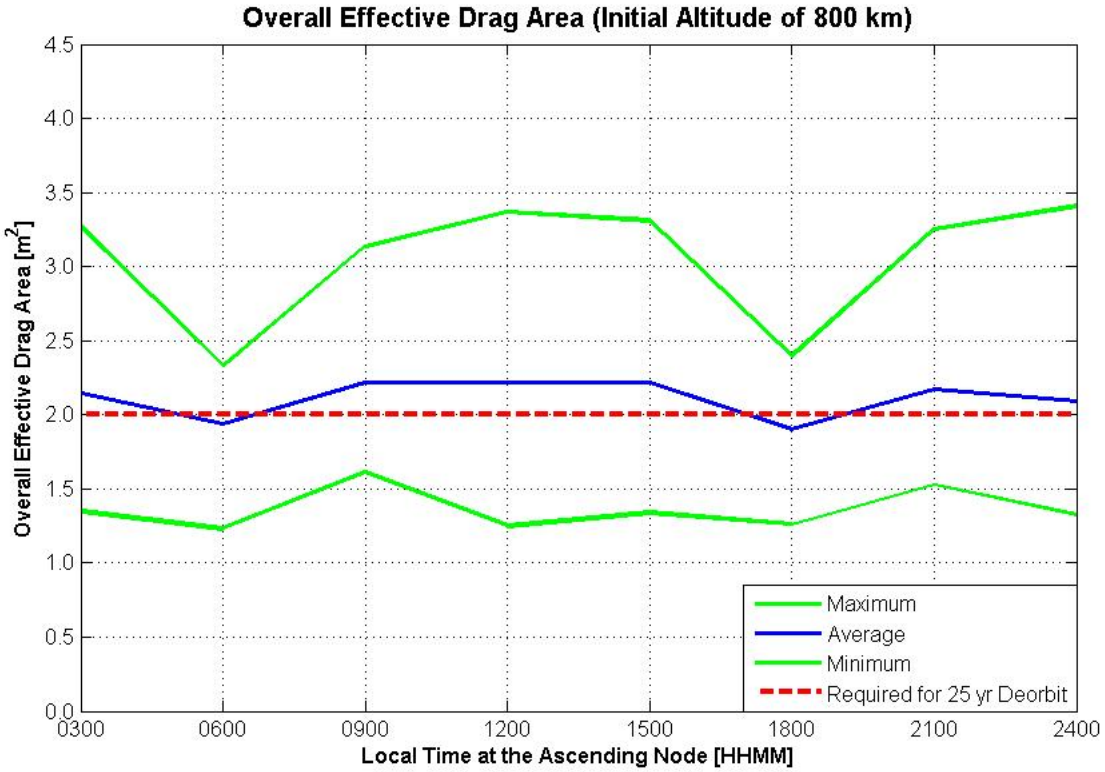
Result: Figures of merit





Preliminary Deorbit Analysis Results

Figure of Merit: Effective Area
Specifically: Dwell-time-weighted average settled projected area, throughout the atmospheric density range equivalent to a whole solar cycle



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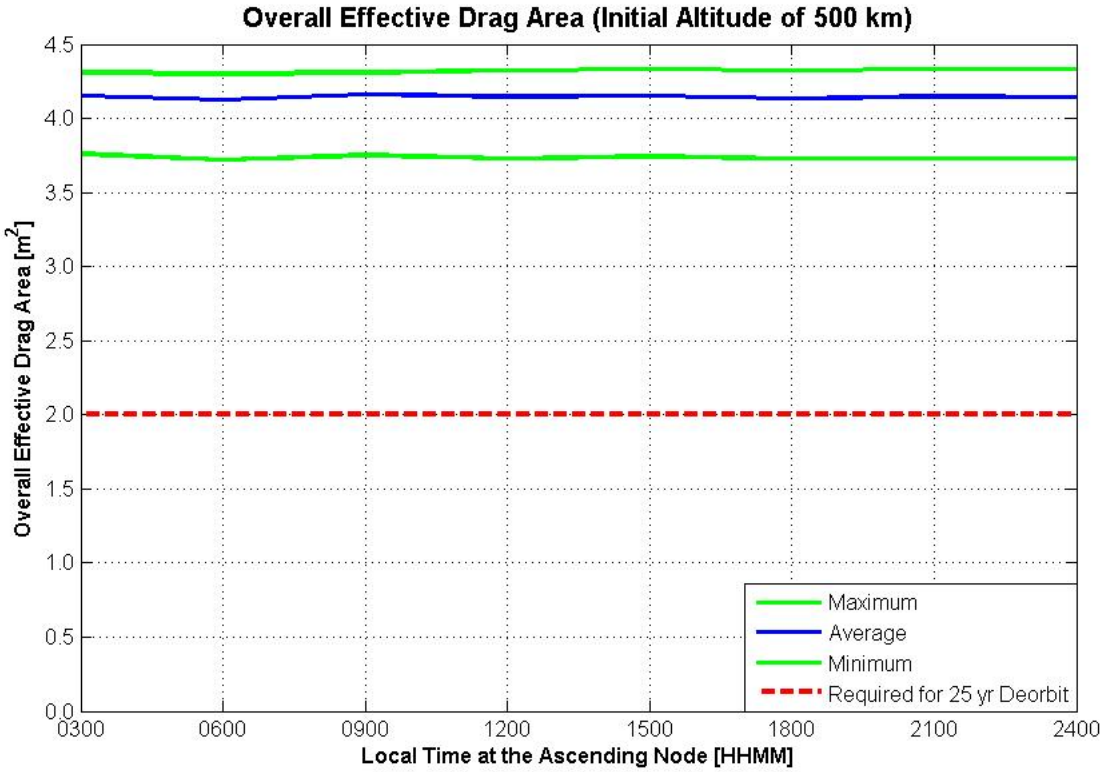
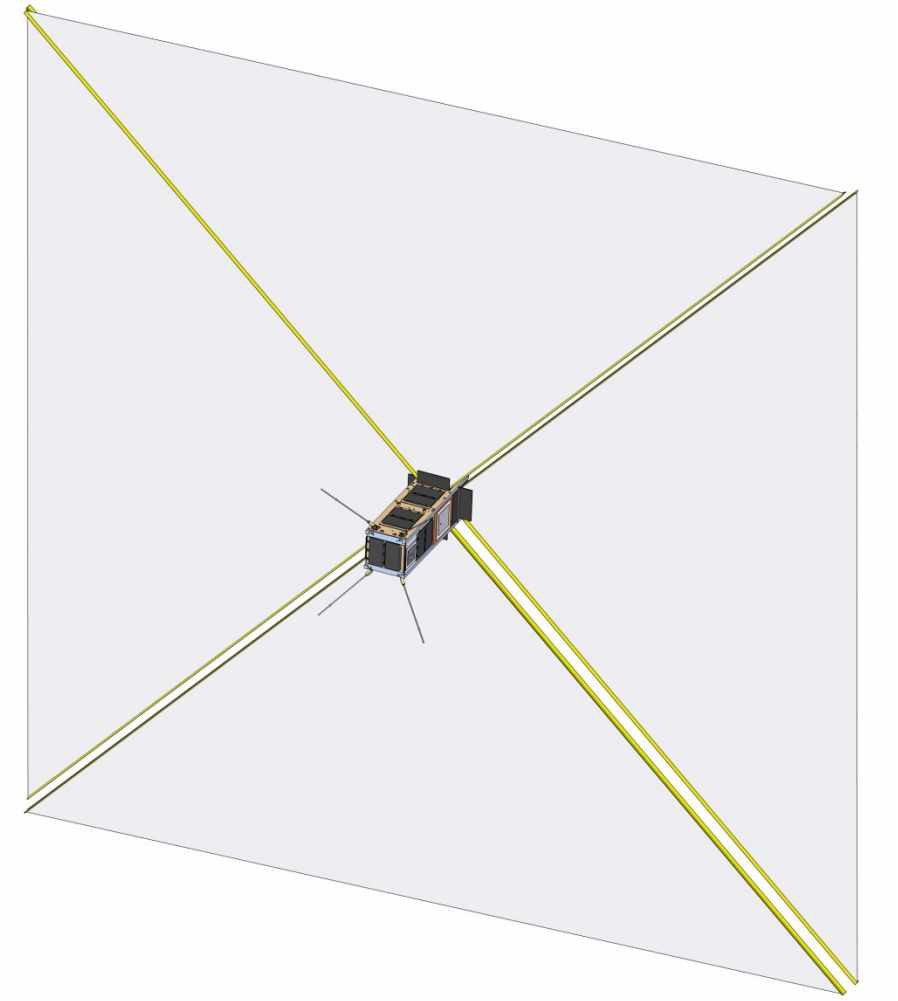


Preliminary Deorbit Analysis Results

- Sail area requirement set at 4.0 m^2 to achieve 2.0 m^2 effective area for most 800 km starting orbits.

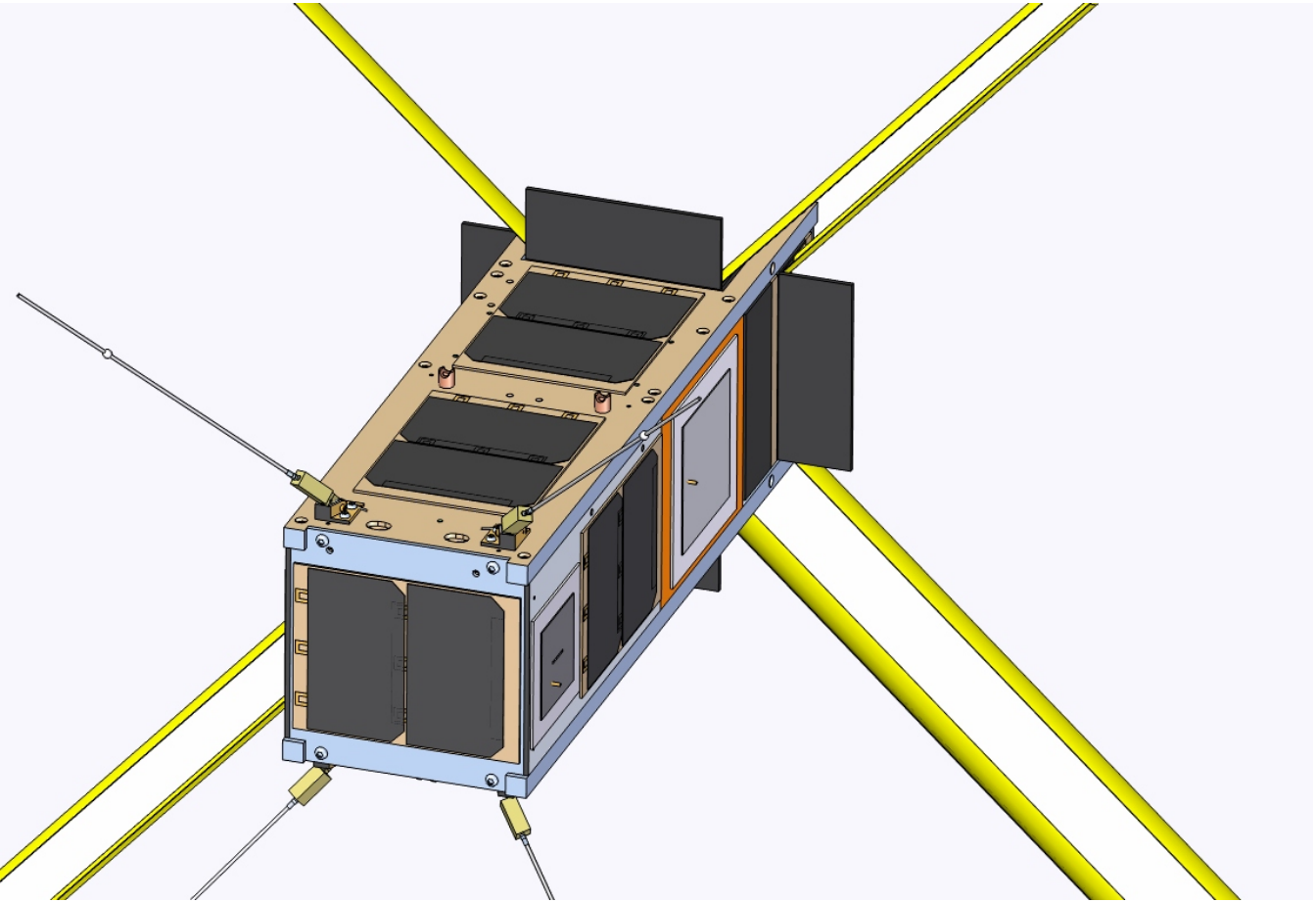
CanX-7 Spacecraft



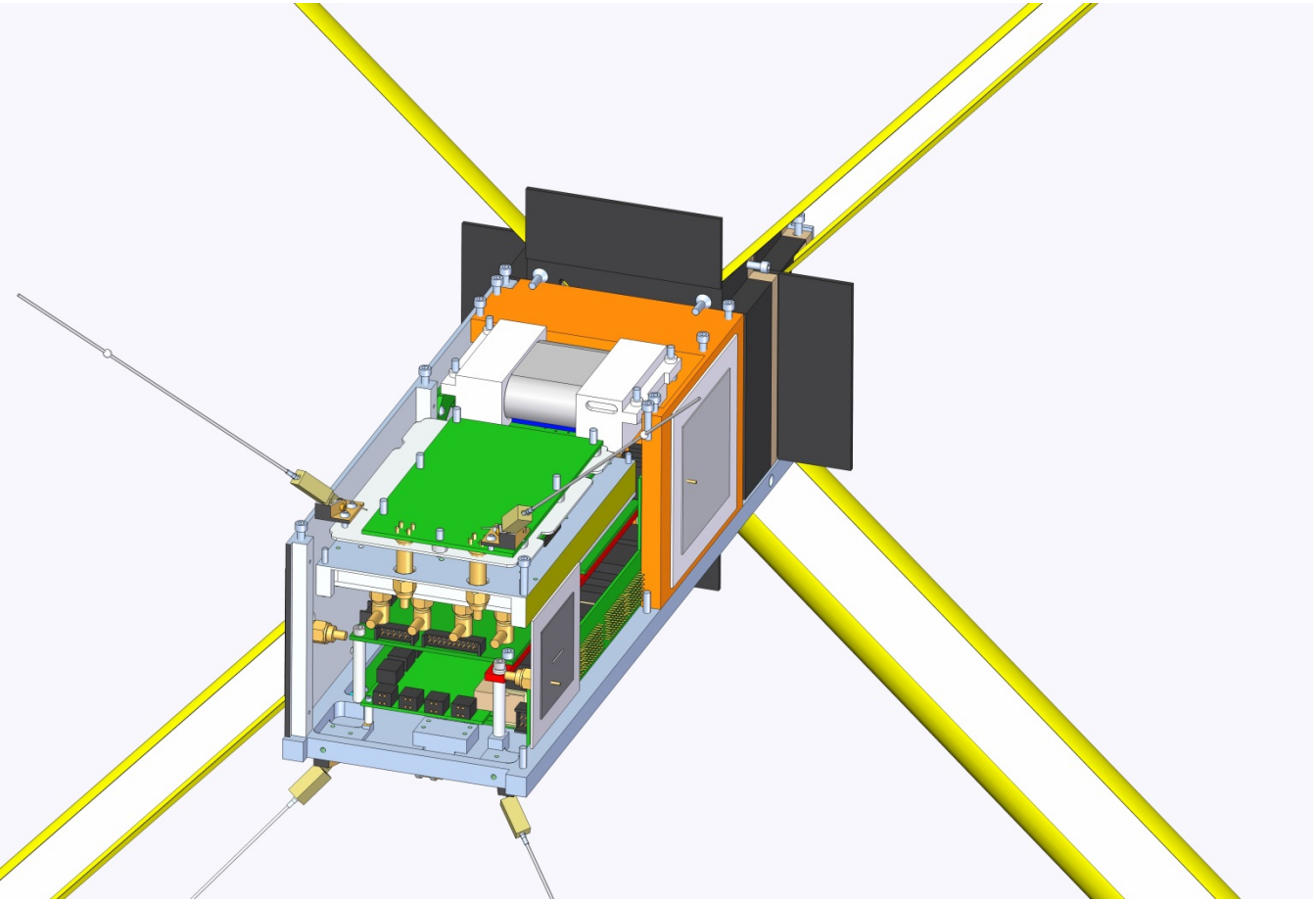
Basic Spacecraft Functional Requirements

- Accommodate primary payload: Deorbit system.
- Conform to limitations imposed on sail area, magnetic dipole moment, etc. determined from deorbit analysis.
- Accommodate secondary payload, including specific provisions for attitude control.
- Survive and operate in the space environment (leads to power, communications, command & data handling, and thermal requirements).

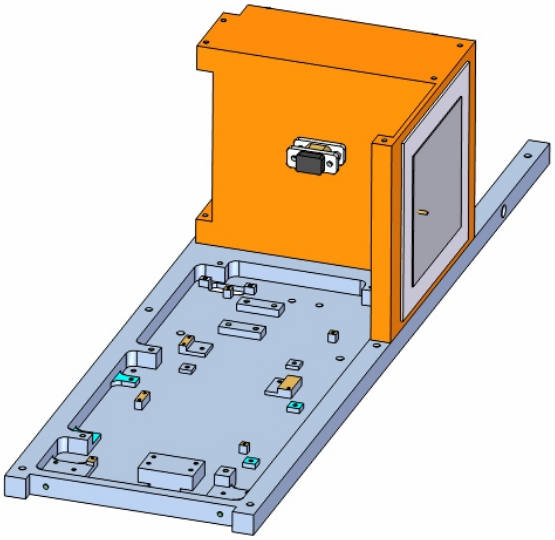
CanX-7 Spacecraft



CanX-7 Spacecraft

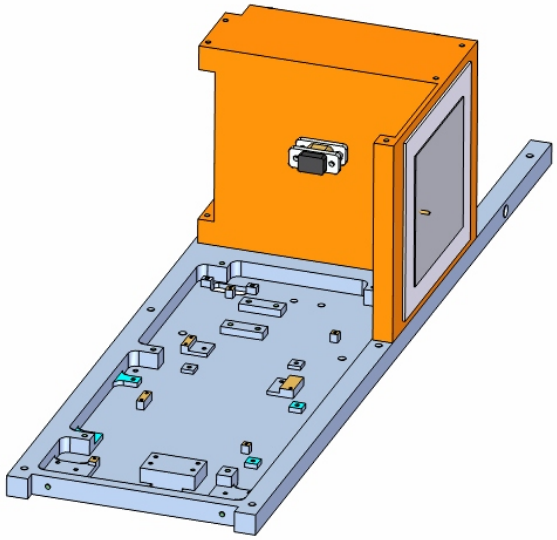


Secondary Payload



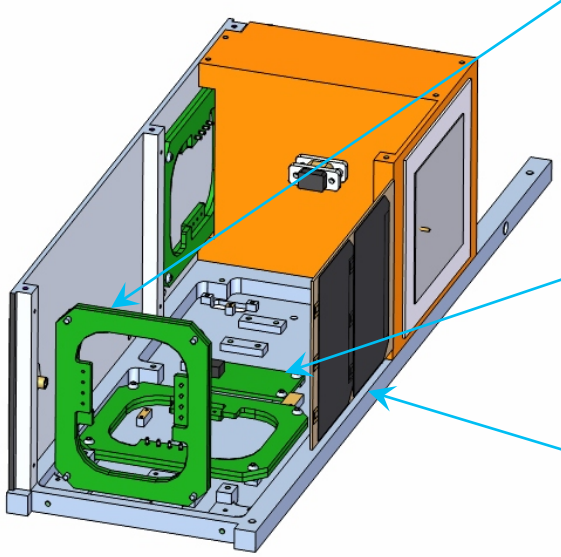
- COM DEV Automatic Dependent Surveillance Broadcast (ADS-B) receiver
- ADS-B GPS position broadcasts are more accurate than radar. Widespread adoption by 2020.

Secondary Payload



- Like radar, ADS-B range is limited by line-of sight.
- Orbital receivers can enable tracking of aircraft over oceans, eliminating the need for slotting aircraft into routes along waypoints.

Attitude Control System

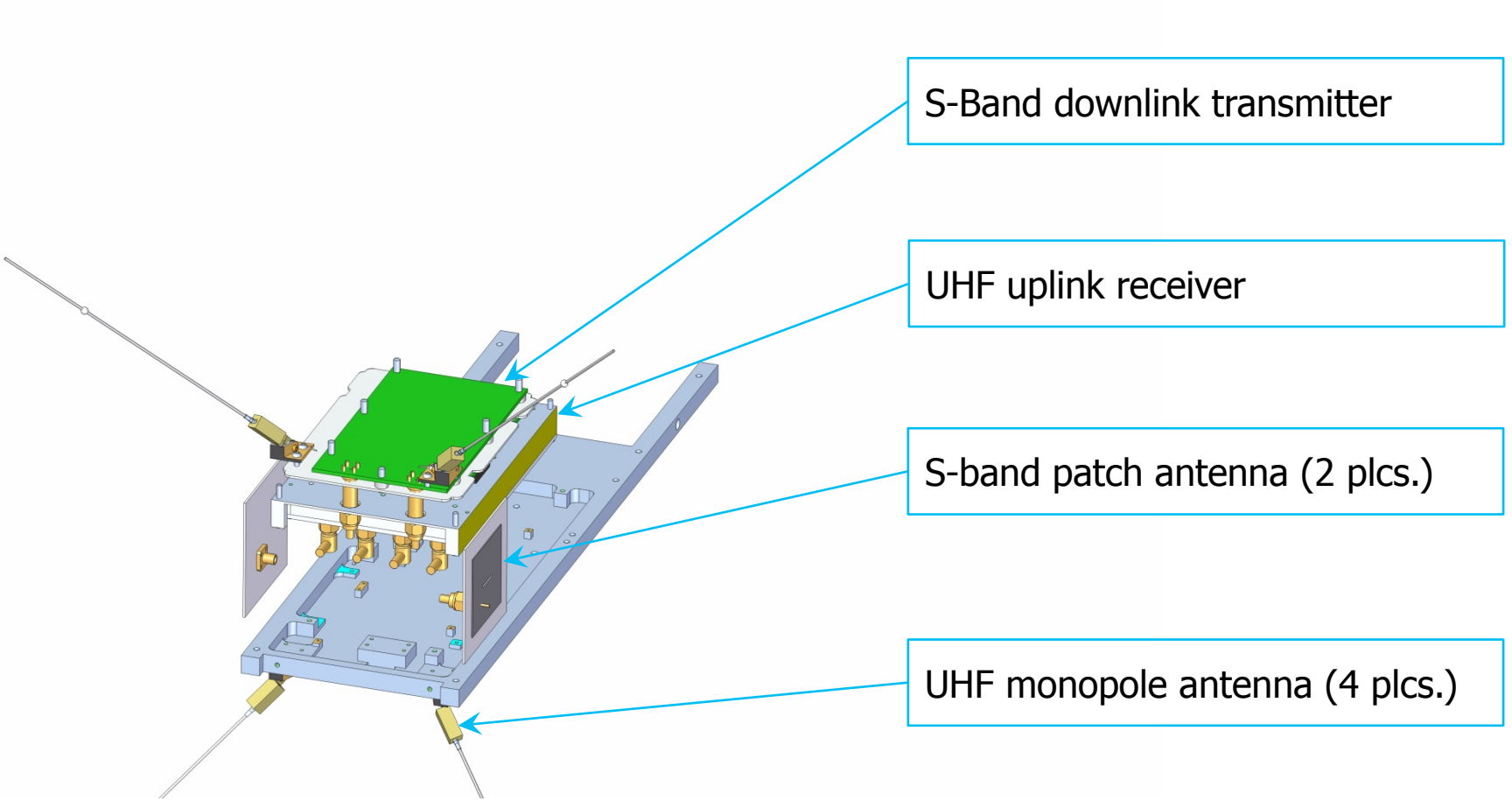


Magnetorquer (3 plcs.)

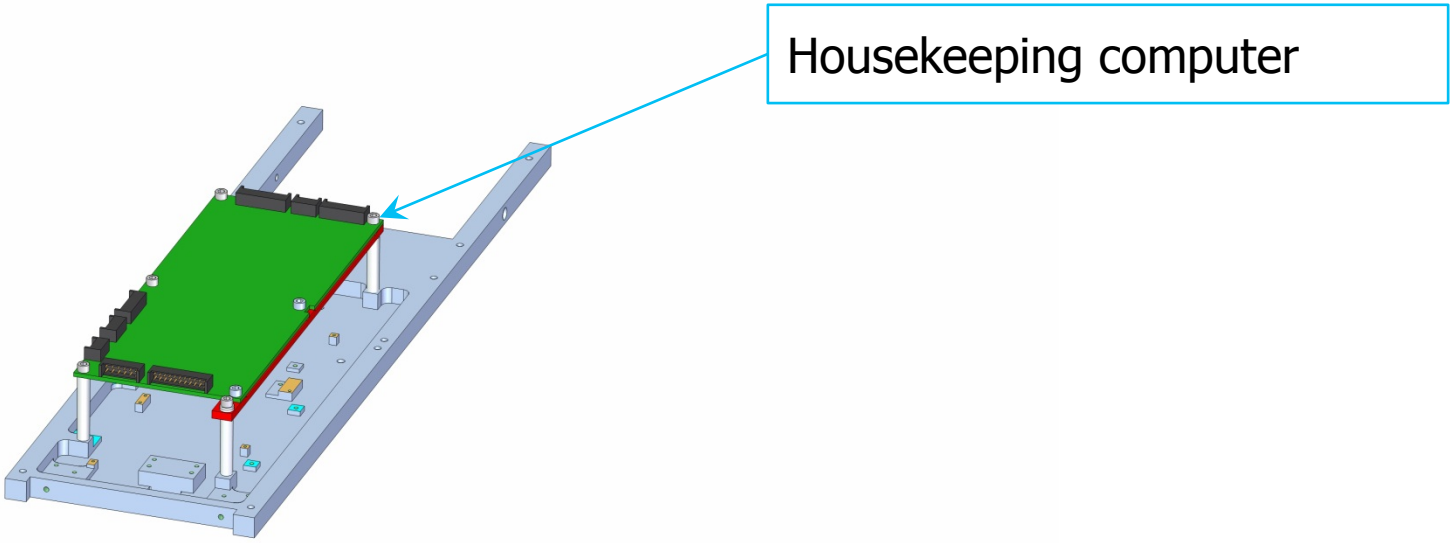
3-Axis magnetometer

Solar cell pairs (typ.) used as coarse sun sensor

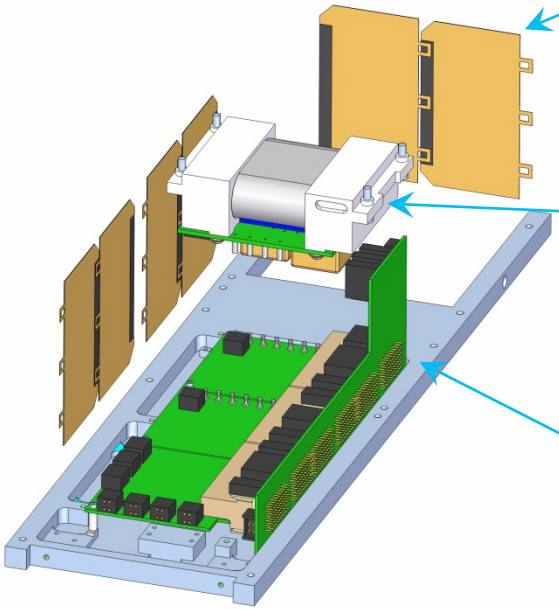
Communications System



Command and Data Handling System



Power System



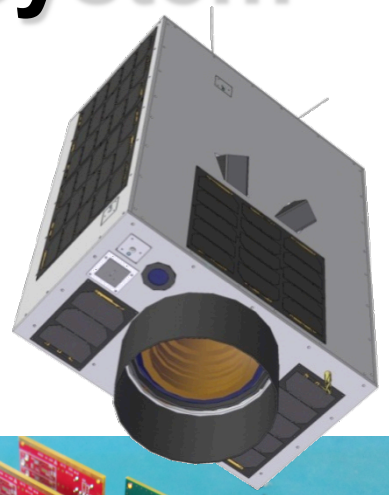
Solar cell pairs (Typ.)

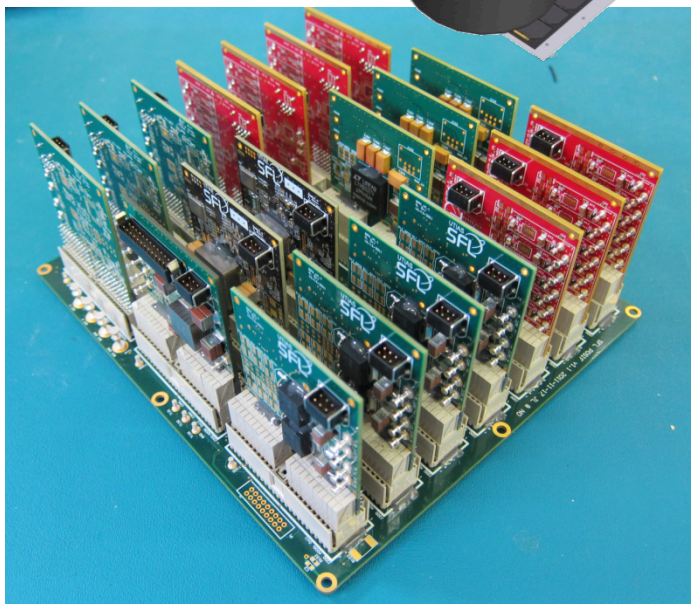
Battery and regulator

Power system electronics

Modular Power System

- 1-1000 W Throughput
- Deployed on Canadian Space Agency's Mars Exploration Science terrestrial rover (MESR).
- Planned for use on NEMO-HD microsatellite
- First planned spaceflight will be on CanX-7



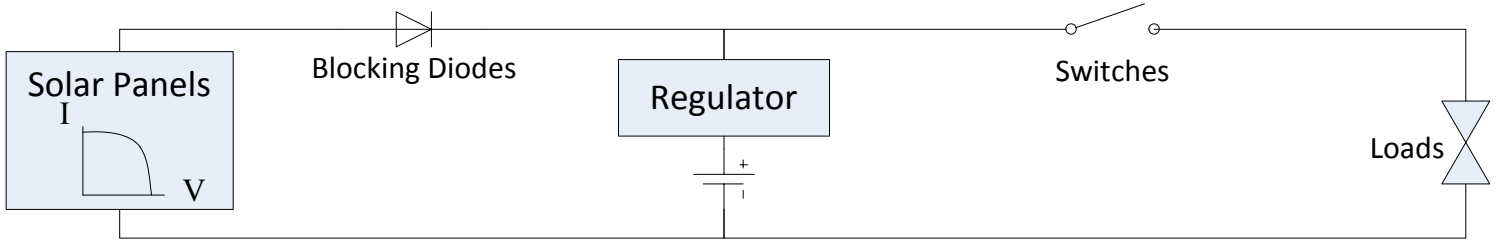


Modular Power System

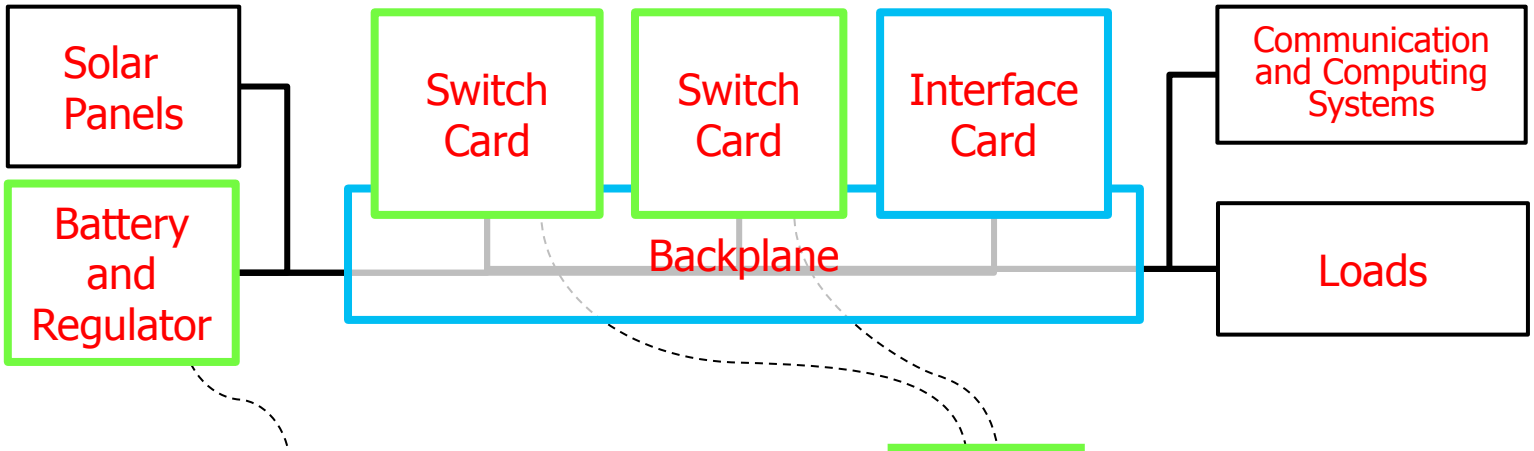
- For a new spacecraft design…
  - Select power system components as needed.
  - Test in-development hardware (payloads, new systems) using *already-built* power system components.
  - Construct a power system from existing designs and hardware, with less custom hardware.

Modular Power System

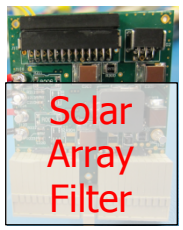
System Architecture

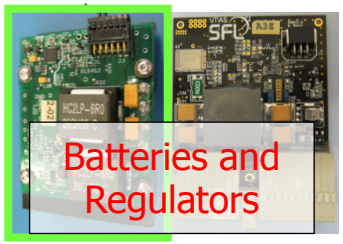


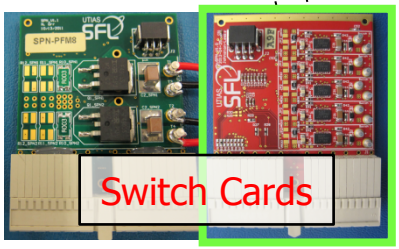
CanX-7 Hardware

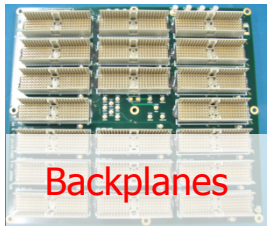


Stock Units

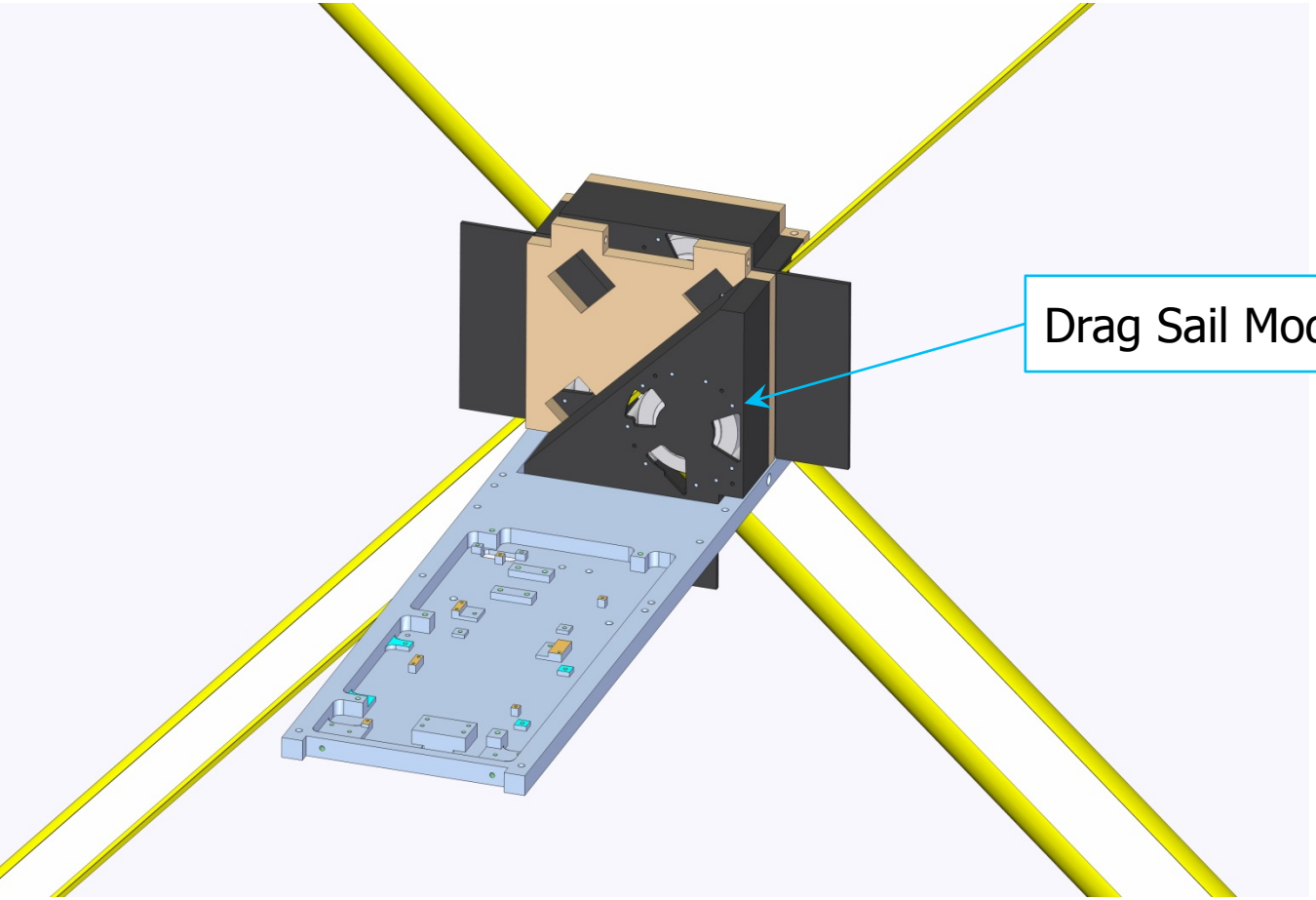




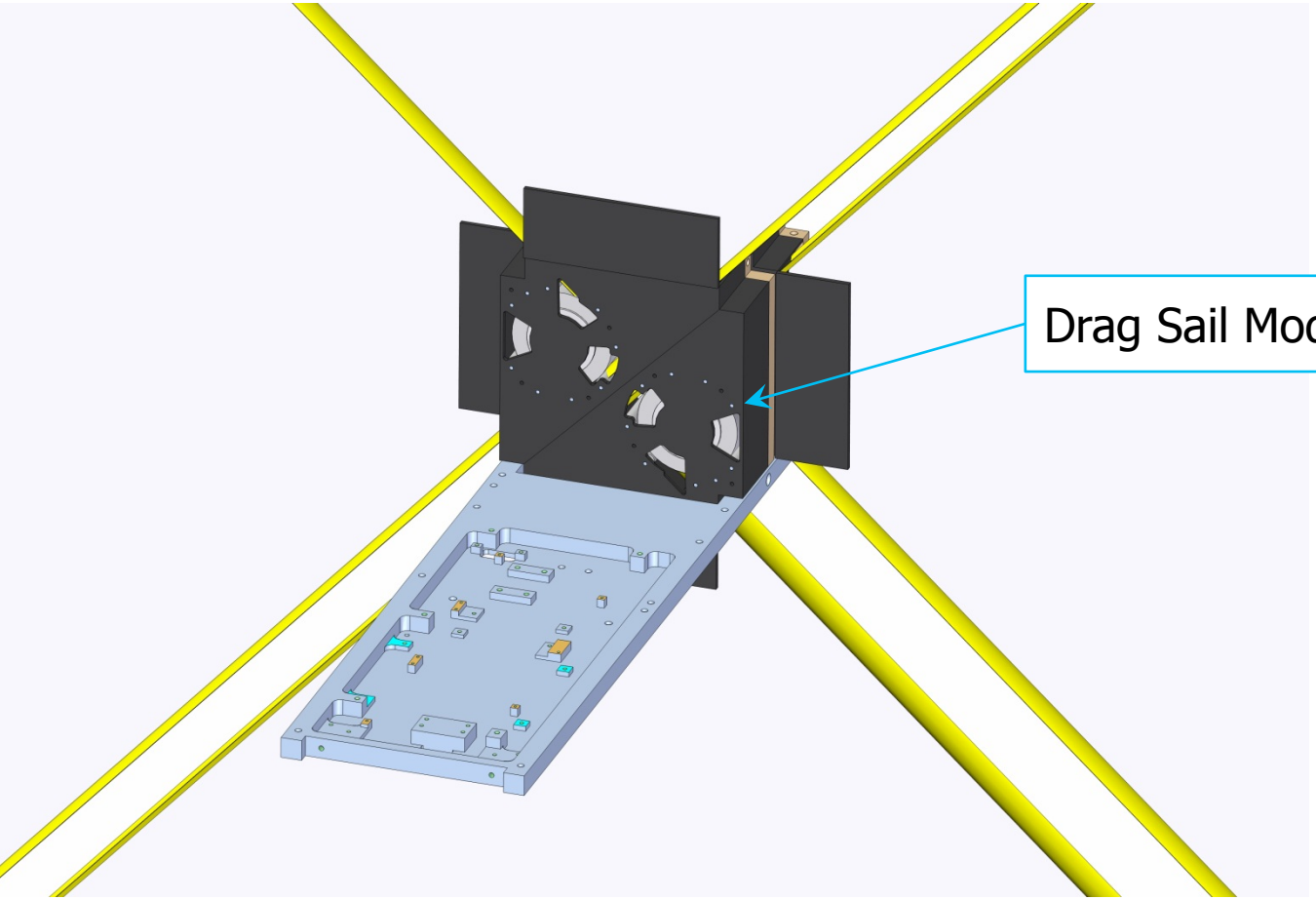




Deorbit System



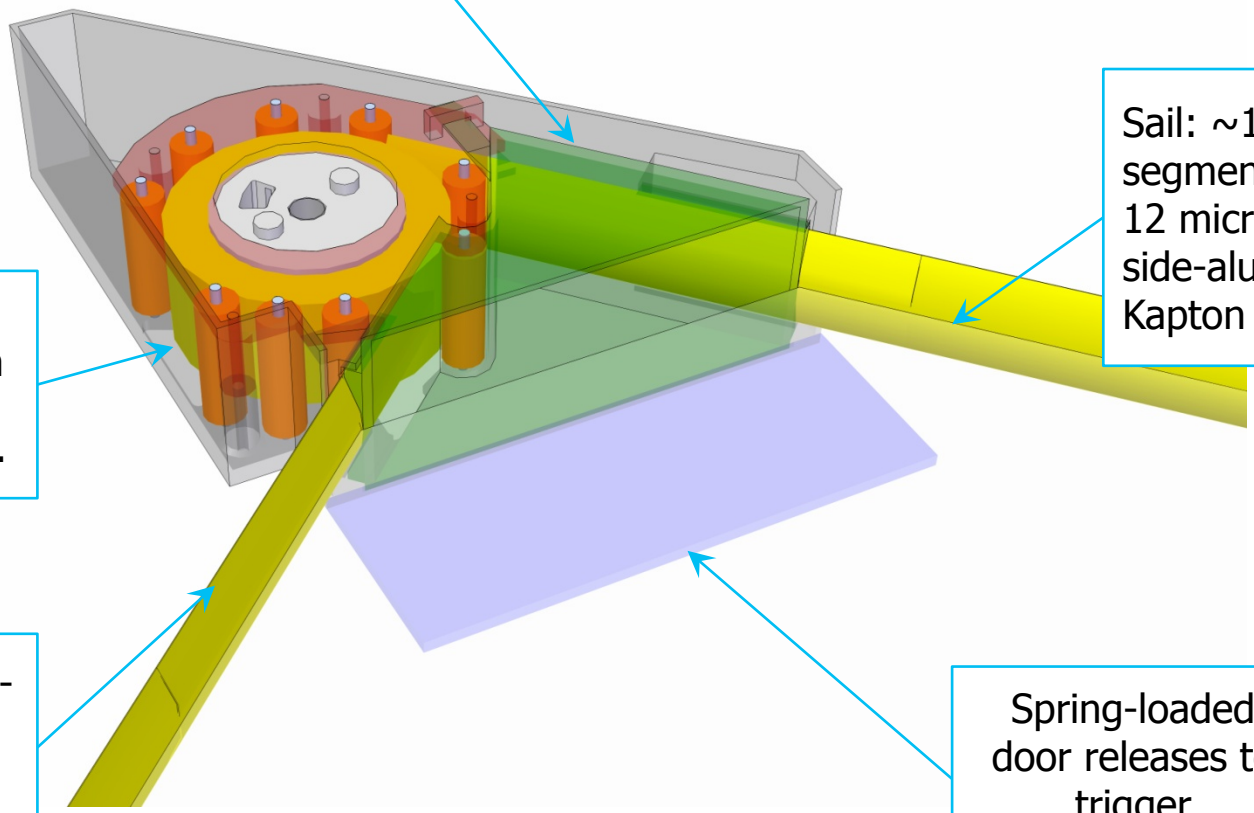
Deorbit System



Deorbit System Functional Requirements

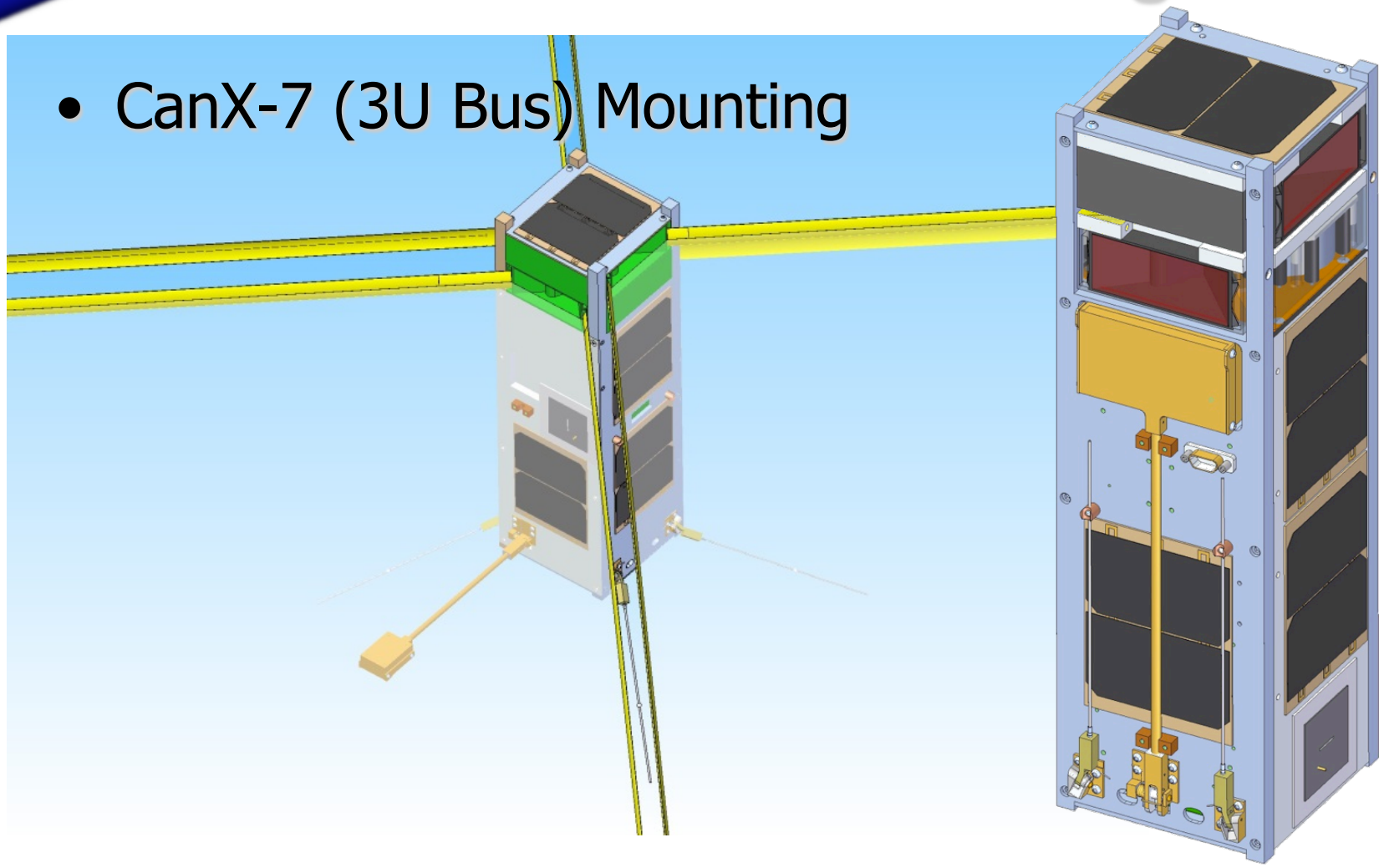
- Compatible with 3U and Space Flight Laboratory's (UTIAS-SFL) Generic Nanosatellite Bus (GNB) spacecraft
- Modular, bolt-on solution
- Scalable by the addition of modules
- Capable of repeated deployment (for testing)

Sail Overview



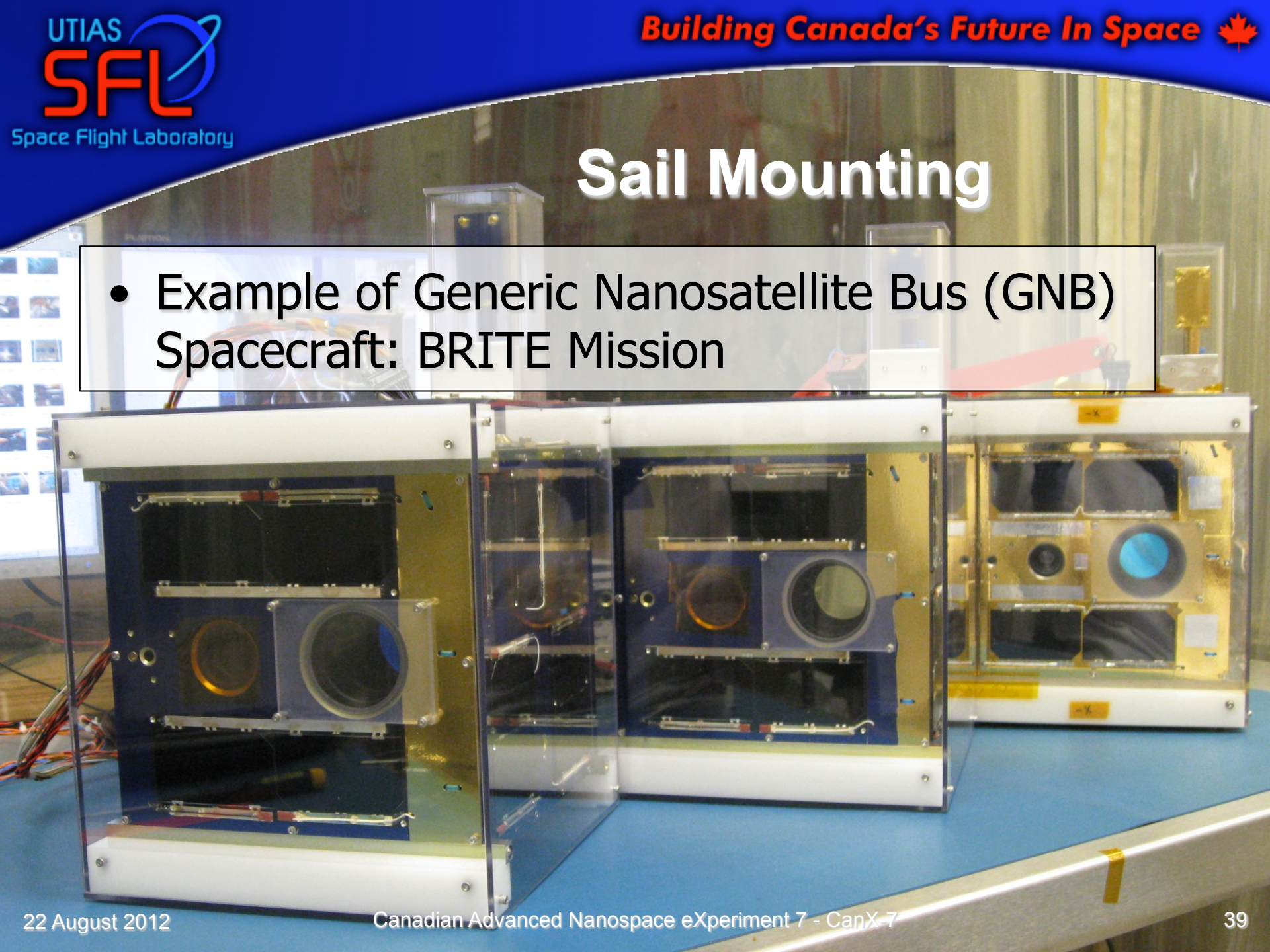
Sail Mounting

- CanX-7 (3U Bus) Mounting



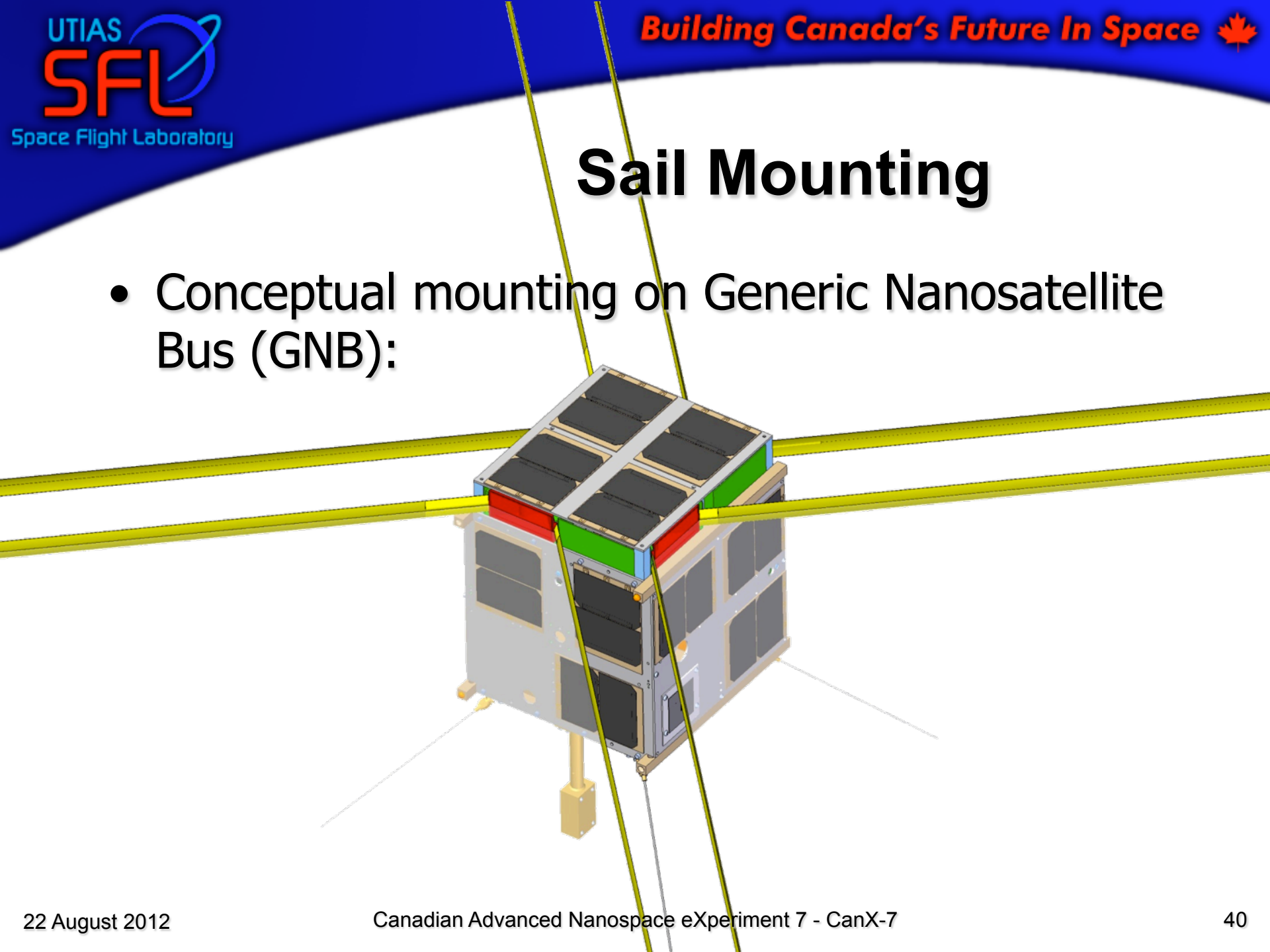
Sail Mounting

- Example of Generic Nanosatellite Bus (GNB) Spacecraft: BRITE Mission



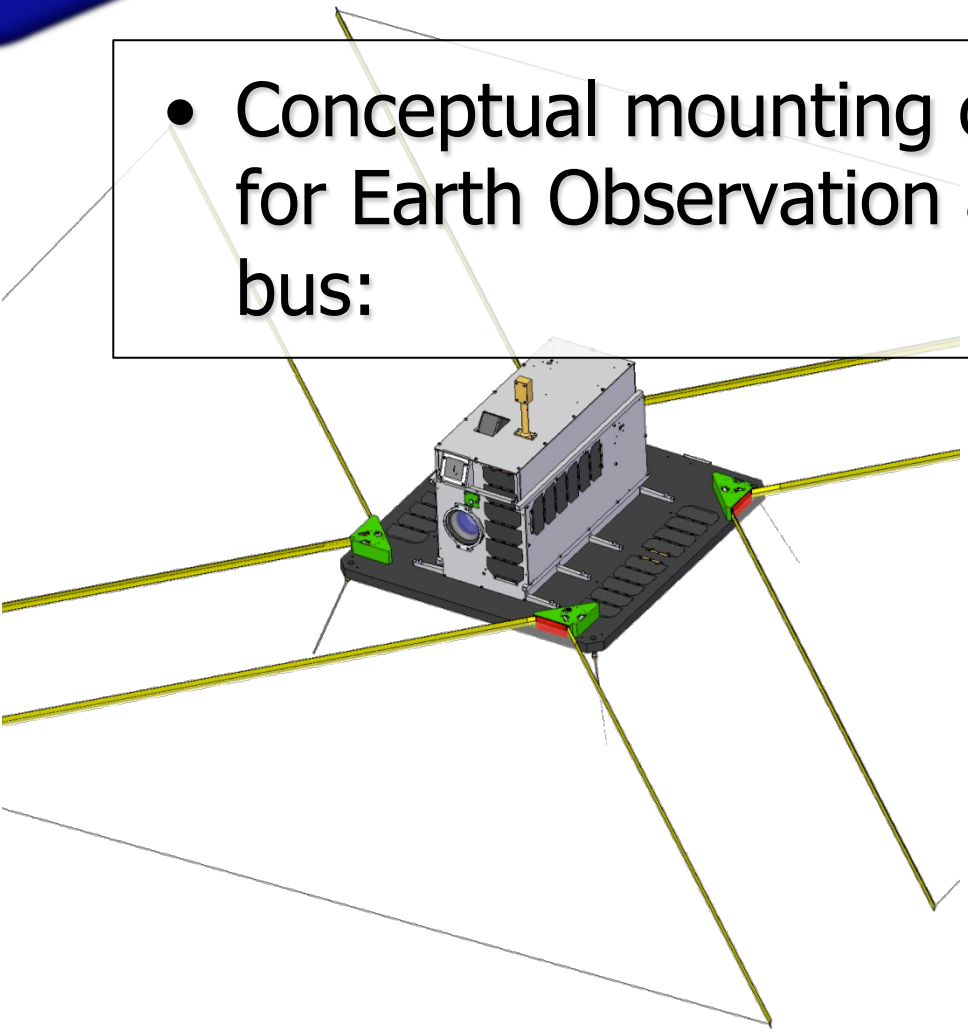
Sail Mounting

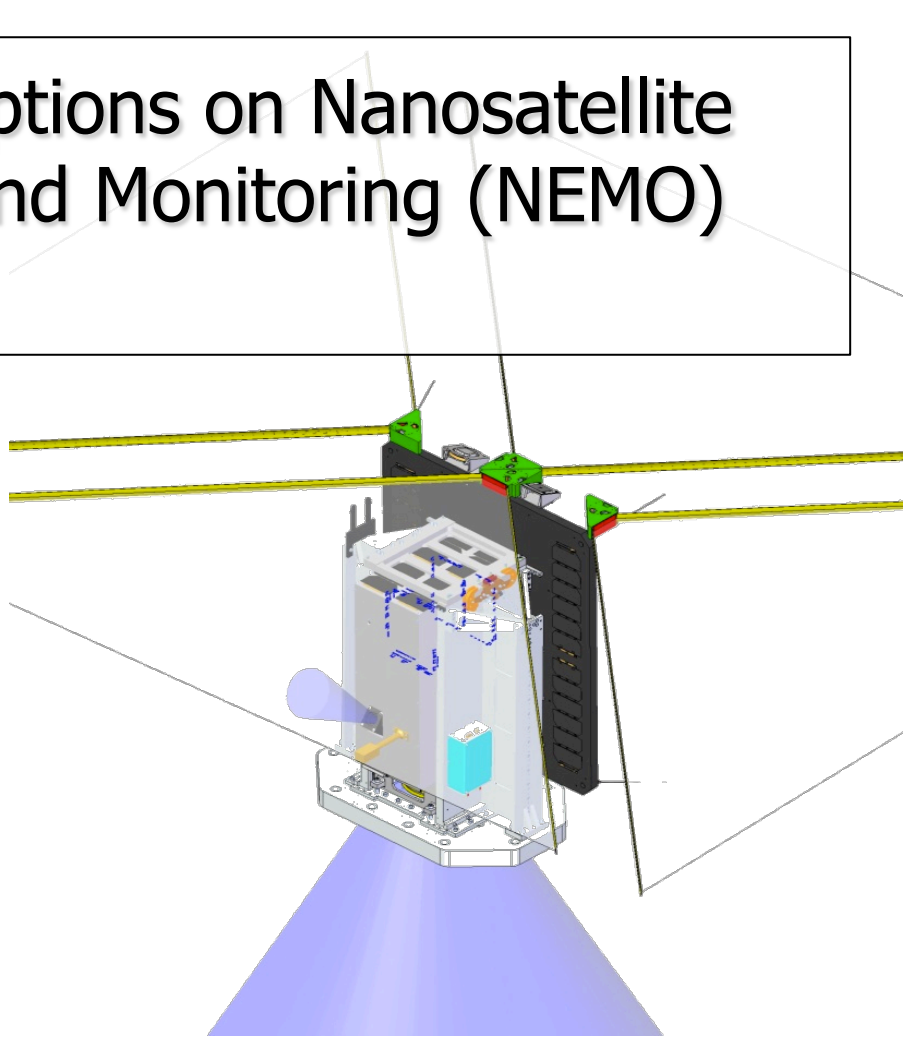
- Conceptual mounting on Generic Nanosatellite Bus (GNB):



Sail Mounting

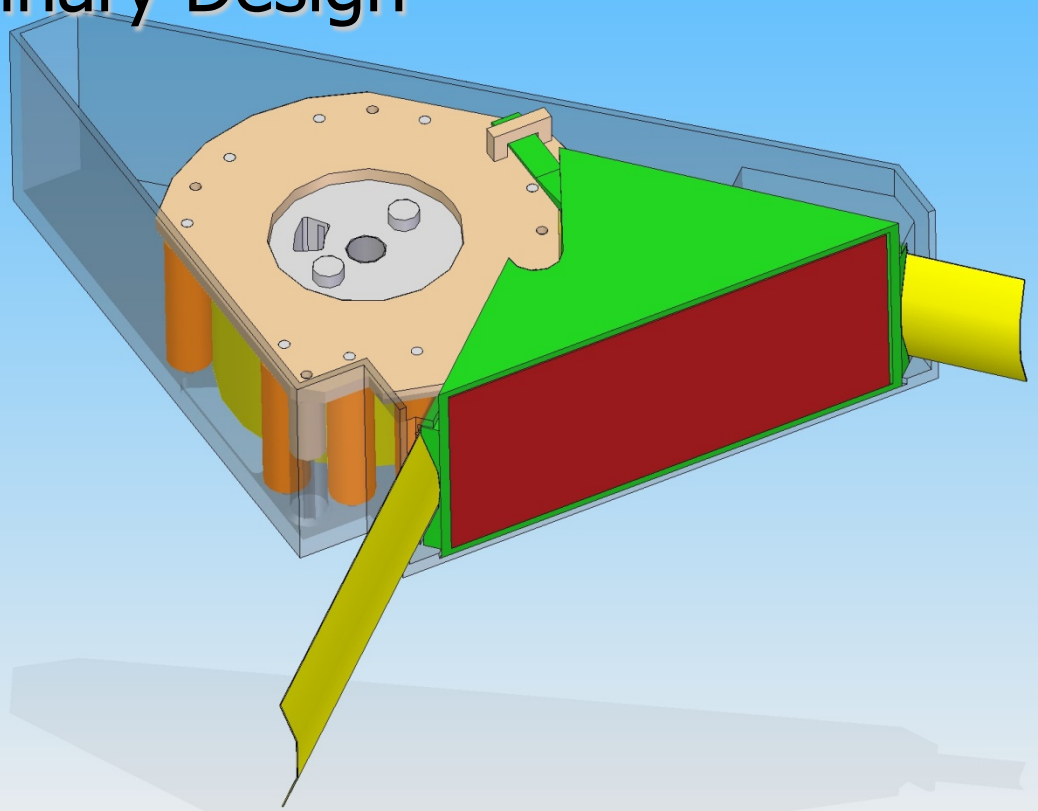
- Conceptual mounting options on Nanosatellite for Earth Observation and Monitoring (NEMO) bus:





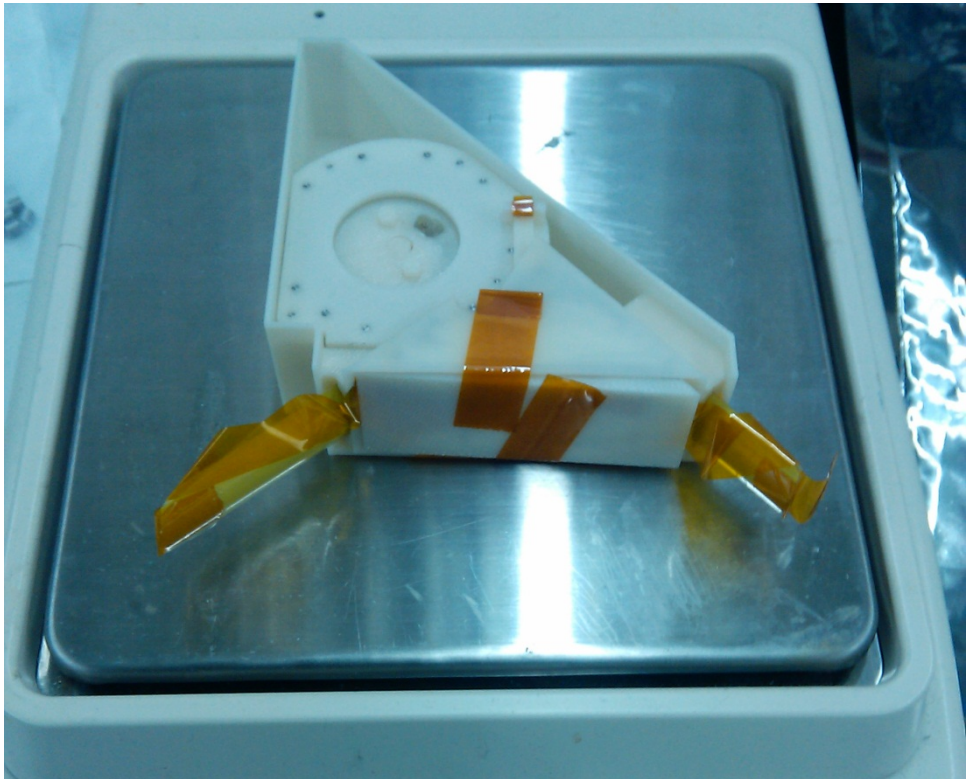
Mechanical Design

- Preliminary Design



Mechanical Design

- Third Generation Prototype



Mechanical Design

- Prototype Deployment Testing

Mechanical Design

- Prototype Deployment Testing

CanX-7 Review

- Modular deorbit device – Currently in detailed design phase.
- ADS-B secondary payload – Potentially one of the first demonstrations on-orbit.
- Modular power system – First planned spaceflight for this new system.

Acknowledgements and Questions

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