OSPREY VAPORSAT

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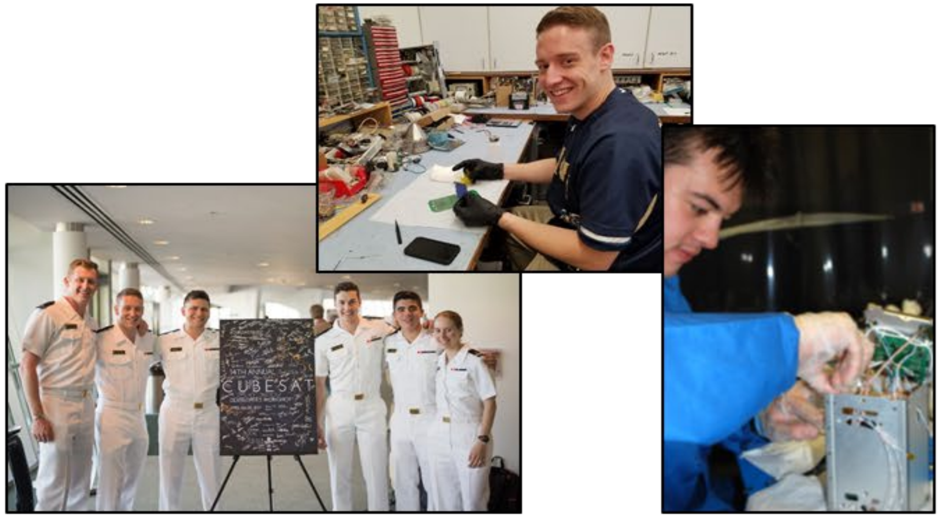
United States Naval Academy

22 April 2024

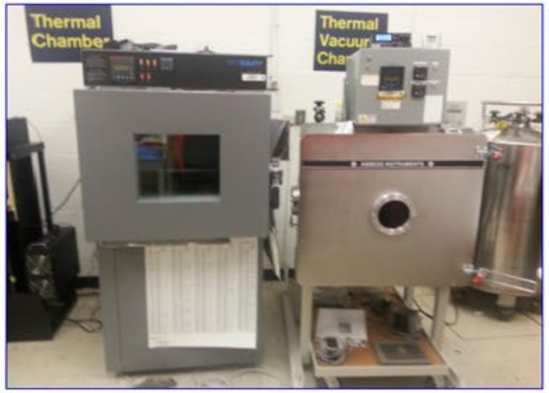
Naval Academy Small Satellite Program (NASSP)

The foundation of our space systems curriculum for the Astro Track students

- Provides midshipmen full-range of hands-on space system development experiences
  - Satellite design
  - Bus and payload development, integration, and testing
  - Mission operation
- Guides students through regulatory and validation procedures
- Educates future naval officers
- Research for future space technologies



Shaker



Thermal and Thermal Vacuum Chambers

Solar Simulator

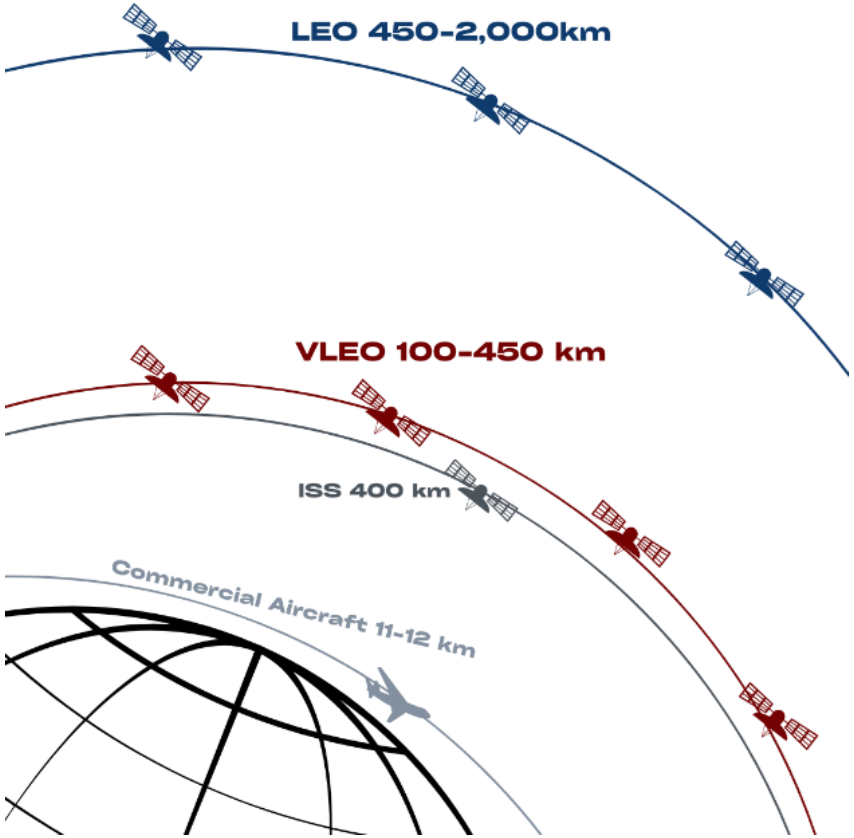
Missions:

- Sapphire
- PCSat
- PCSat-2 (ISS)
- ANDE
- MidSTAR
- RAFT/MARScom
- PSAT
- DRAGONsat
- USS Langley
- BRICSat
- QIKCOM-1 (hosted)
- QIKCOM-2 (hosted)
- BRICSat-2
- PSAT-2
- RSat

Agenda

- Background
  - Motivation/Rationale
  - Problem Statement
  - Key Features
  - Our Solution
- Mission Overview
- Overview of OSPREY
- Design details
- Conclusion

- Very Low Earth Orbit (VLEO) is typically defined as the 100-450km orbit range
- VLEO advantages
  - Self-cleaning orbits
  - Shorter communication distance
  - Closer to Earth for sensors and cameras, improved resolutions and apertures
  - Space in LEO is increasingly becoming congested
  - Many entities are interested in research that can only be conducted in VLEO



Background: Problem Statement

- Orbit lifetime in VLEO is incredibly brief due to significant drag forces, on order of several days
  - Currently challenging to design for VLEO missions due to exorbitant costs of adding conventional propulsion systems
  - The power budget is also a major concern for conventional in-orbit propulsion systems

- VLEO presents unique challenges as well as enormous potential for future development
  - More research into the VLEO altitude range has yet to be conducted, specifically the Ionosphere

Credit: ESA GOCE

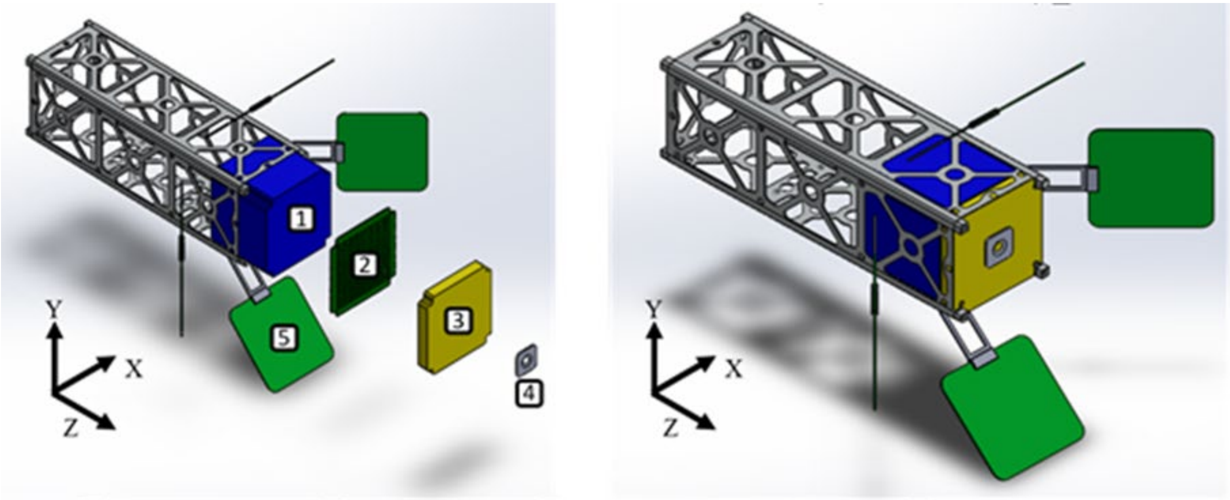
Background: Key Features

To address the previous problems, several key features are needed:

- Minimal electrical power requirements
- Commercially available materials
- Scalable form-factor
- Simple thermal control
- Passive propulsion system

Background: Our Solution

- OSPREY VAPORSAT is designed to use commercially available, off the shelf materials to make a thruster that extends the on-orbit lifetime for CubeSats to 10-20 days per 1U tank size at a 250 km altitude orbit.
- Methanol propellant will be used due to its desirable chemical properties and relatively low cost
- Passive heating from the space environment will keep the methanol in a liquid state
- An ePTFE barrier will ensure liquid fluid is not lost but allow the vapor pressure to escape and produce thrust through a optimized nozzle design



1 Propellant Reservoir 2 Phase Separator 3 Expansion Chamber 4 Nozzle 5 Attitude Stabilizer

Mission Overview

Stage 1: Separation

Rocket separation and satellite initialization handled by NASB.

Stage 2: Passive ADCS and drag chute deployment

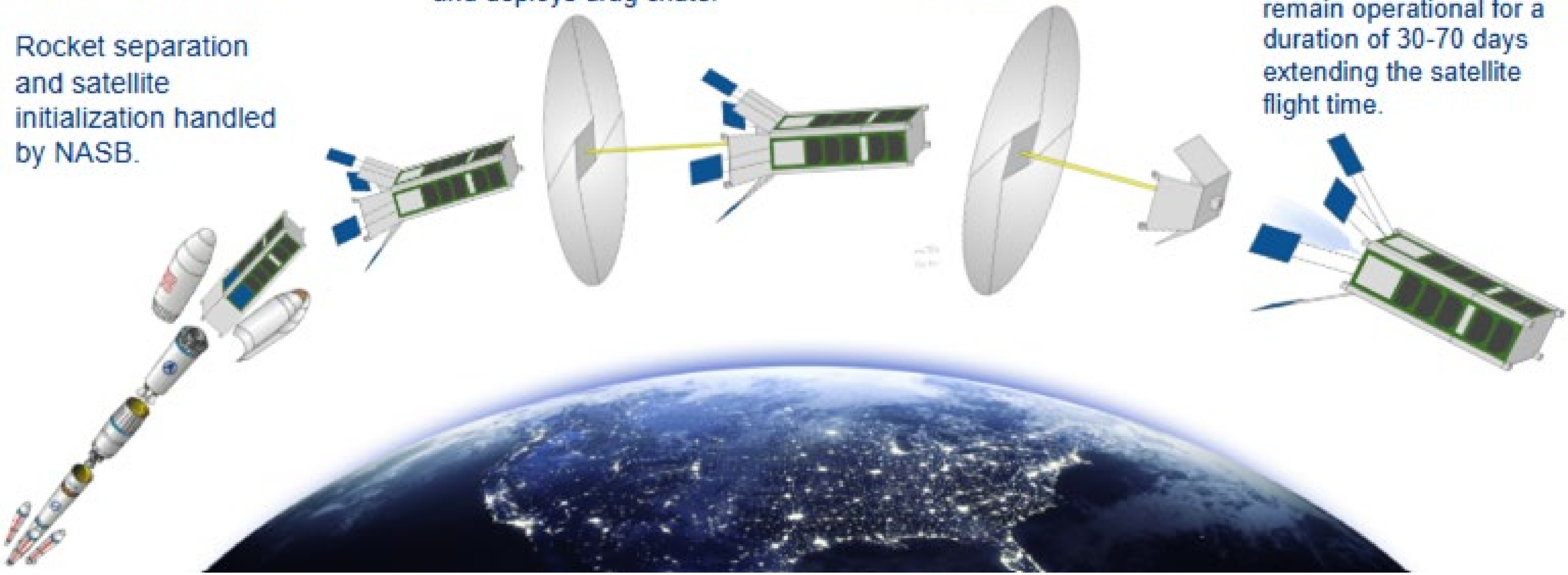
30 minutes after release, a command from NASB deploys the aeroflaps into their flight configuration and deploys drag chute.

Stage 3: Nozzle activation

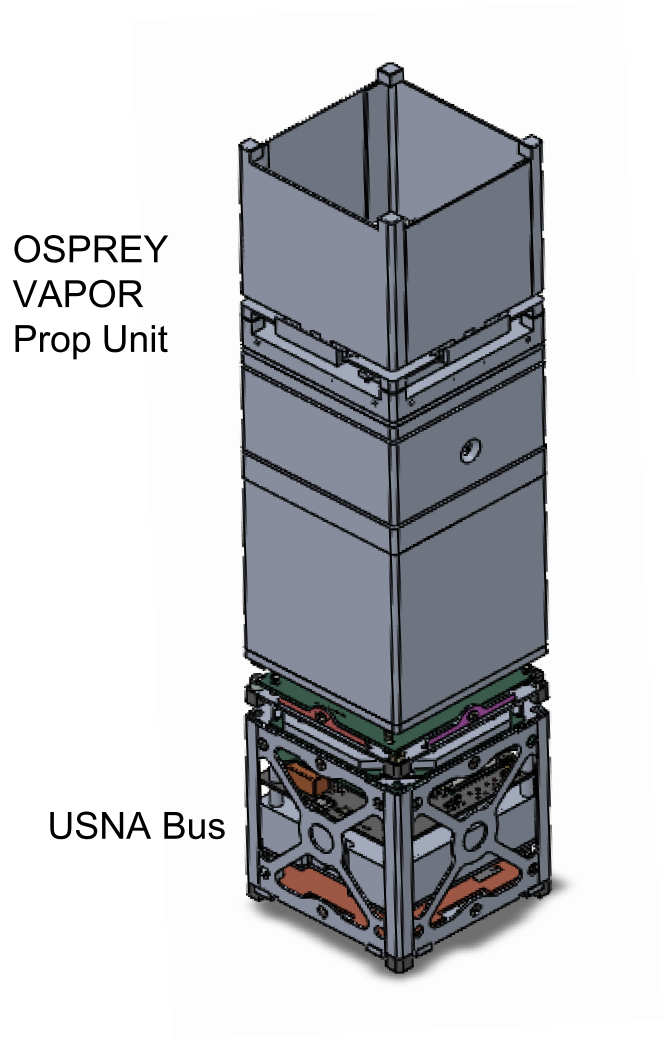
Once the spacecraft reaches 250 km altitude, a command from NASB releases the chute and opens the nozzle plug to begin thrust.

Stage 4: Sustained Flight

Propulsion system will remain operational for a duration of 30-70 days extending the satellite flight time.



General Specifications



Tank Mass → 1.7 kg

NASB Mass → 1 kg

Drag Chute Module Mass → 0.44 kg

Propellant Mass → 0.96 kg

Battery and Connection Parts → 0.3 kg

Total Mass → 4.4 kg

Actuation mechanism power → < 3.5 W

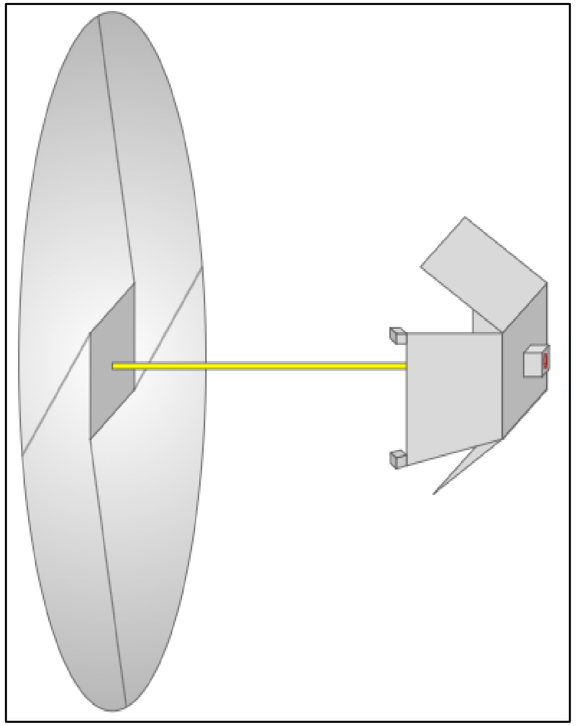
4U Form Factor

Initial altitude	Days to descend	Average thrust	Total Impulse	Powered flight time
250 km	0 days	166 μN	487.1 Ns	33 days
400 km	8 days	139 μN	471.1 Ns	39 days
450 km	21 days	74.47 μN	454.7 Ns	70 days

Design Details

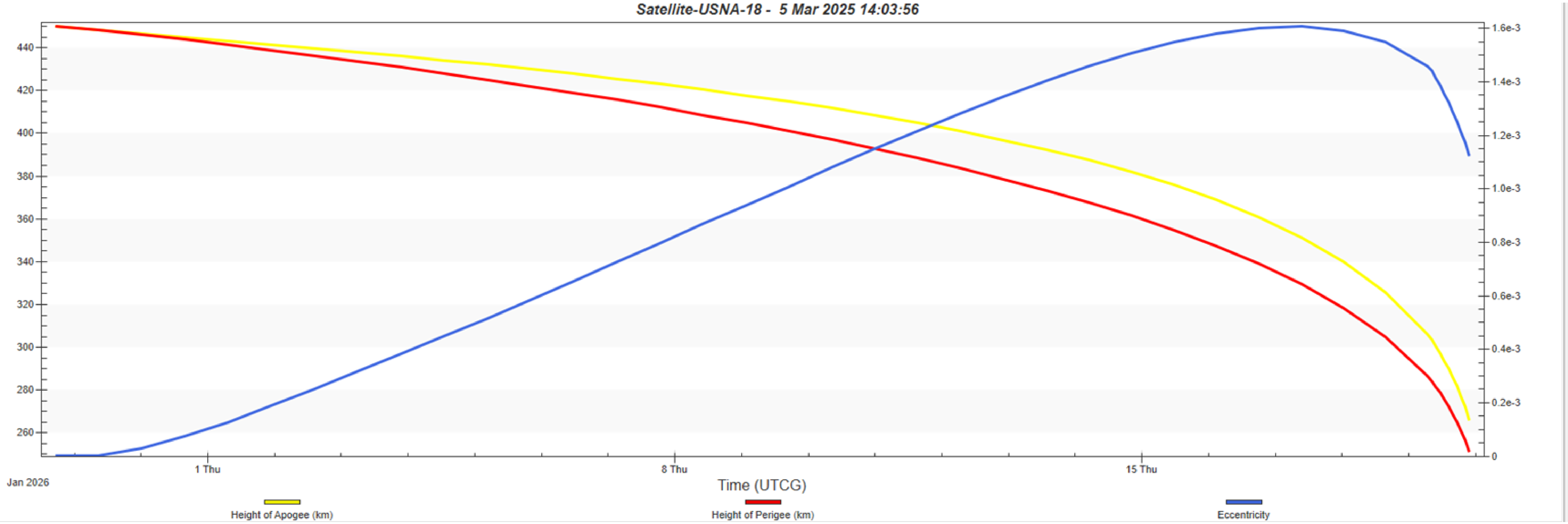
Design: Chute Module

- 1 m^2 ultra-lightweight drag chute
- “Jack-in-the-box” form factor for ease of deployment
- 6V motor mechanism will extend chute behind spacecraft



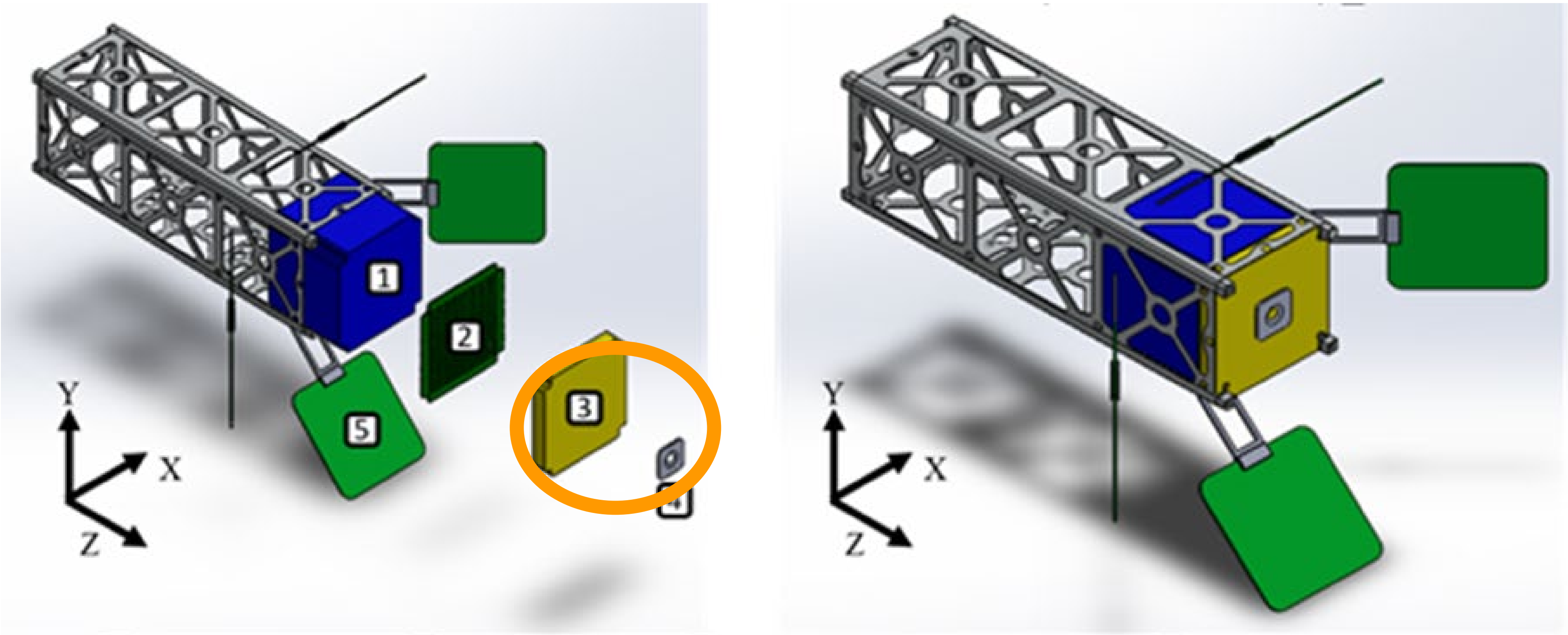
Deployed Drag Chute Model and Prototype

Design: Chute Operation



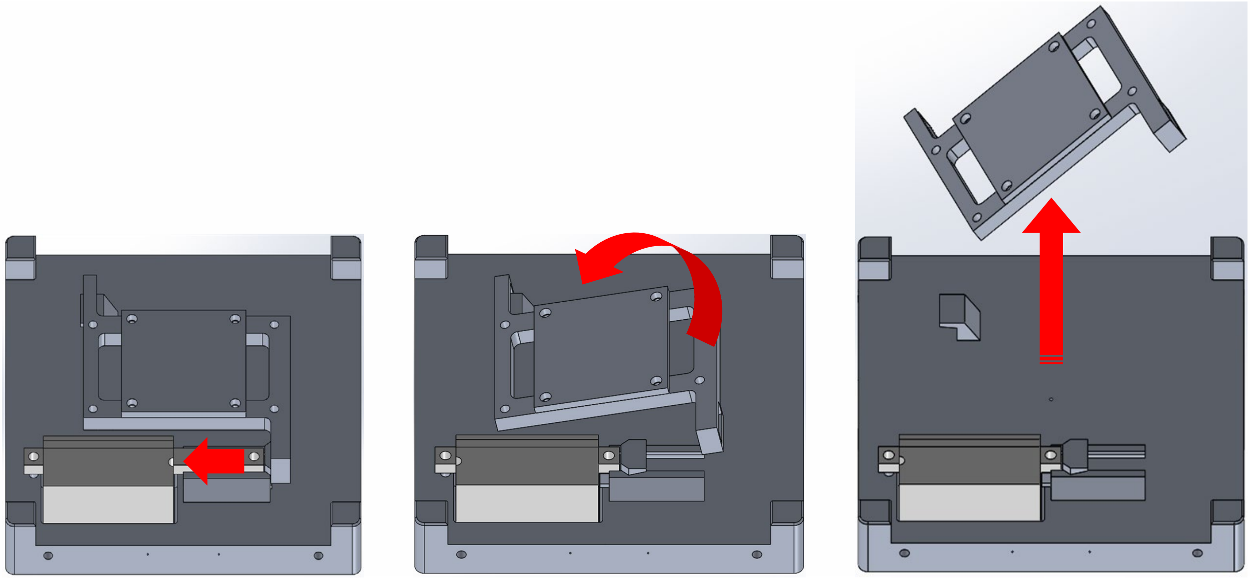
- Orbital decay from 450 to 250 km altitude for a 5 kg satellite with a 1m^2 drag chute is projected to take 21 days.
- Modeled using STK.

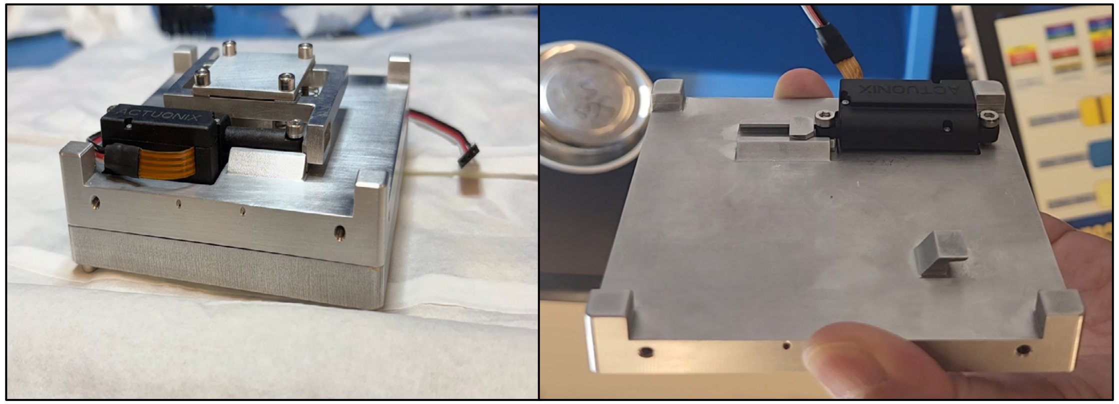
Design: Nozzle Deployment



1 Propellant Reservoir 2 Phase Separator 3 Expansion Chamber 4 Nozzle 5 Attitude Stabilizer

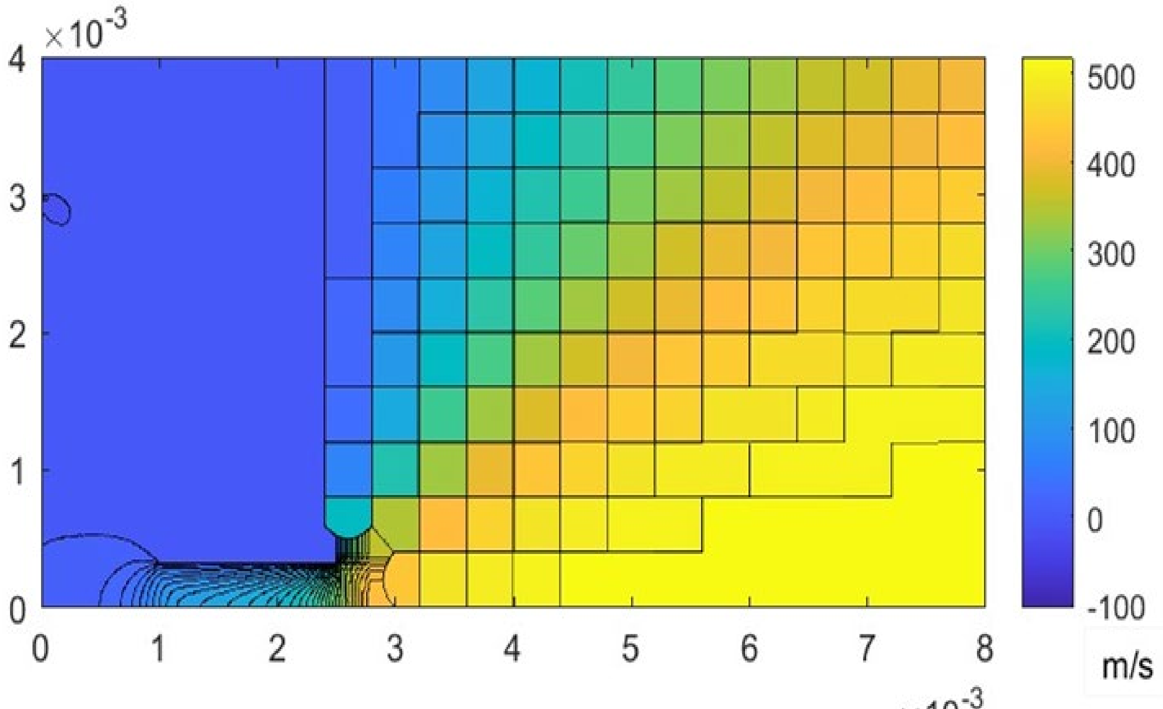
- Nozzle sealed with O-ring and a clamp connection to chute module
- Micro linear servo will detach connection to jettison chute module when 250 km altitude has been achieved
  - Nozzle cap will be released with the drag chute module jettison



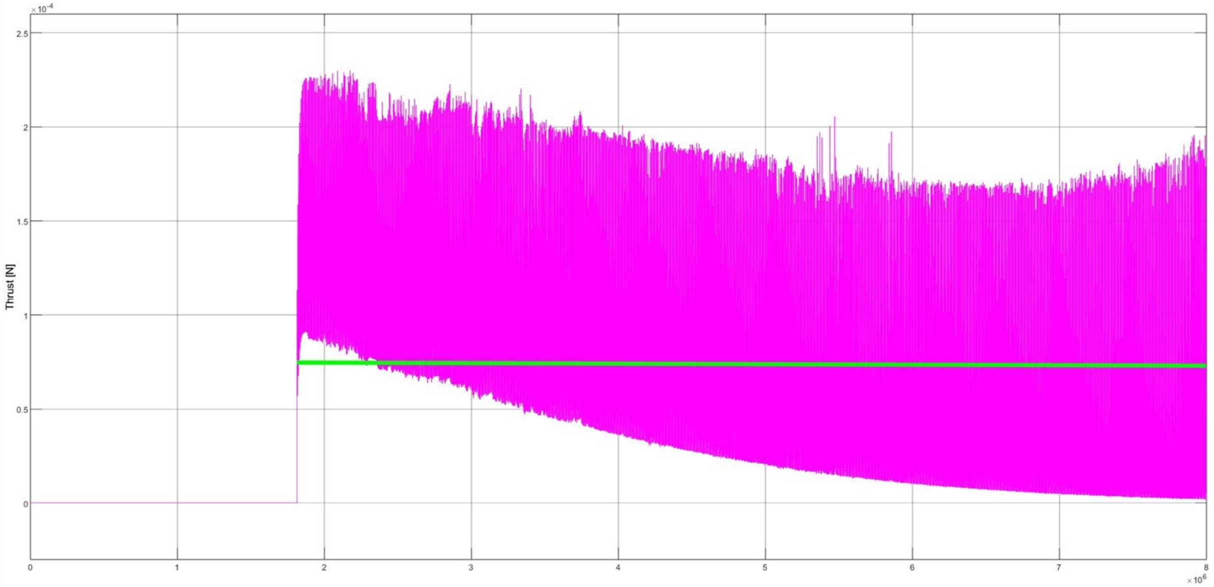


Before Nozzle Actuation *After Nozzle Actuation*

Design: Thrust Generation



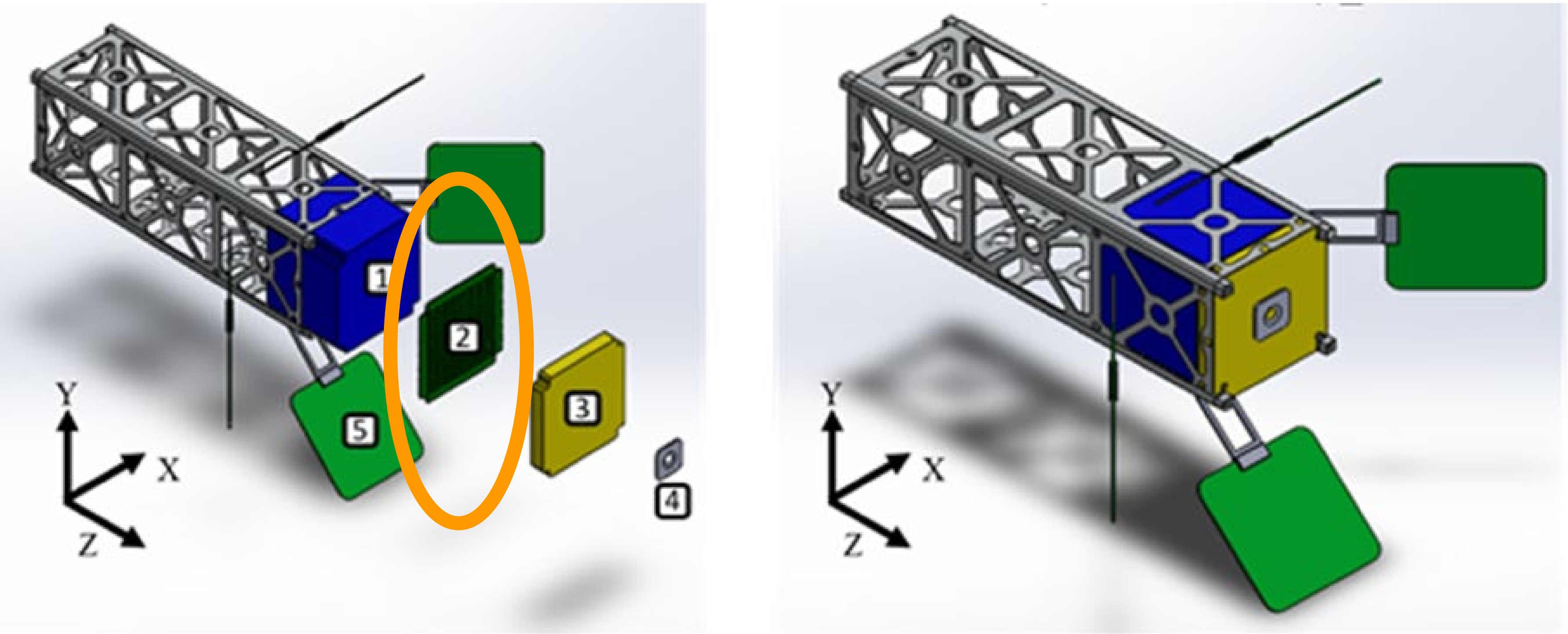
DSMC Exit Velocity Simulation



Thrust Generated over Mission Lifetime

- Both Sparta DSMC and Simulink used to simulate methanol flow
- Average mass flow rate from Simulink model: 155 μg/s
- Average exit velocity from Simulink model: 232 m/s
- Average exit velocity from DSMC model: 270 m/s

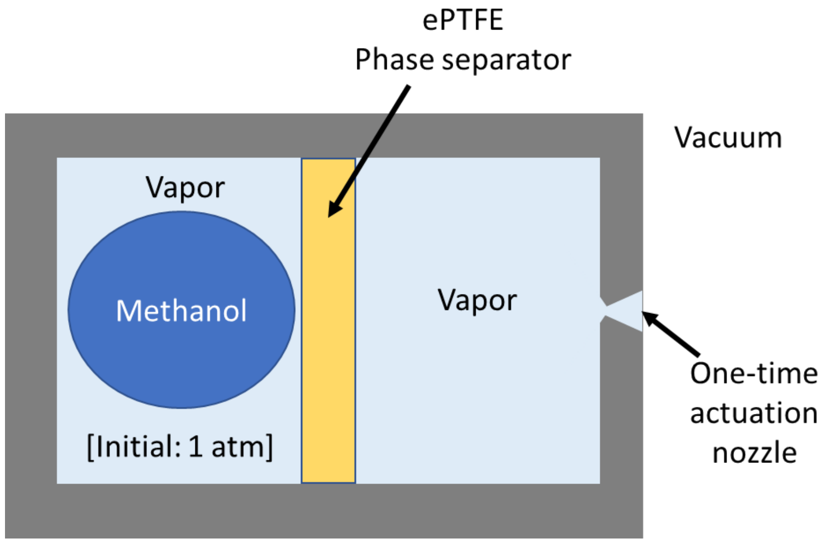
Design: Propellant Phase Separator

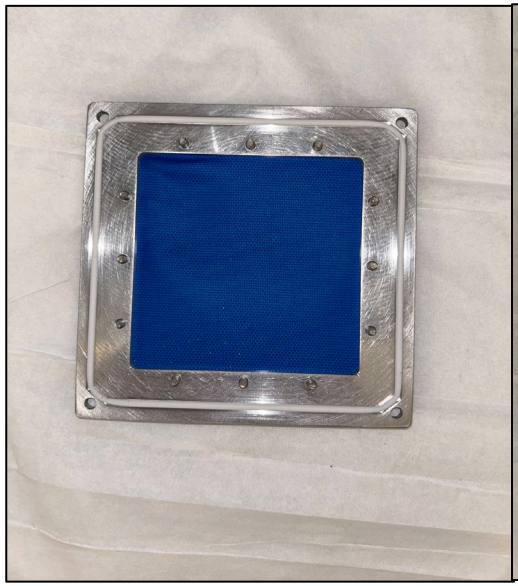


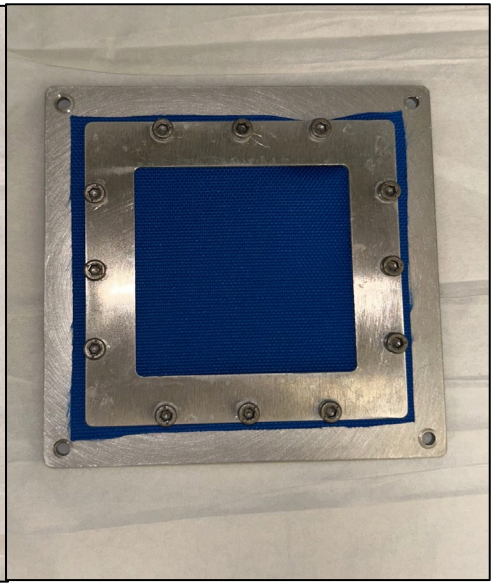
1 Propellant Reservoir 2 Phase Separator 3 Expansion Chamber 4 Nozzle 5 Attitude Stabilizer

Design: Propellant Phase Separator

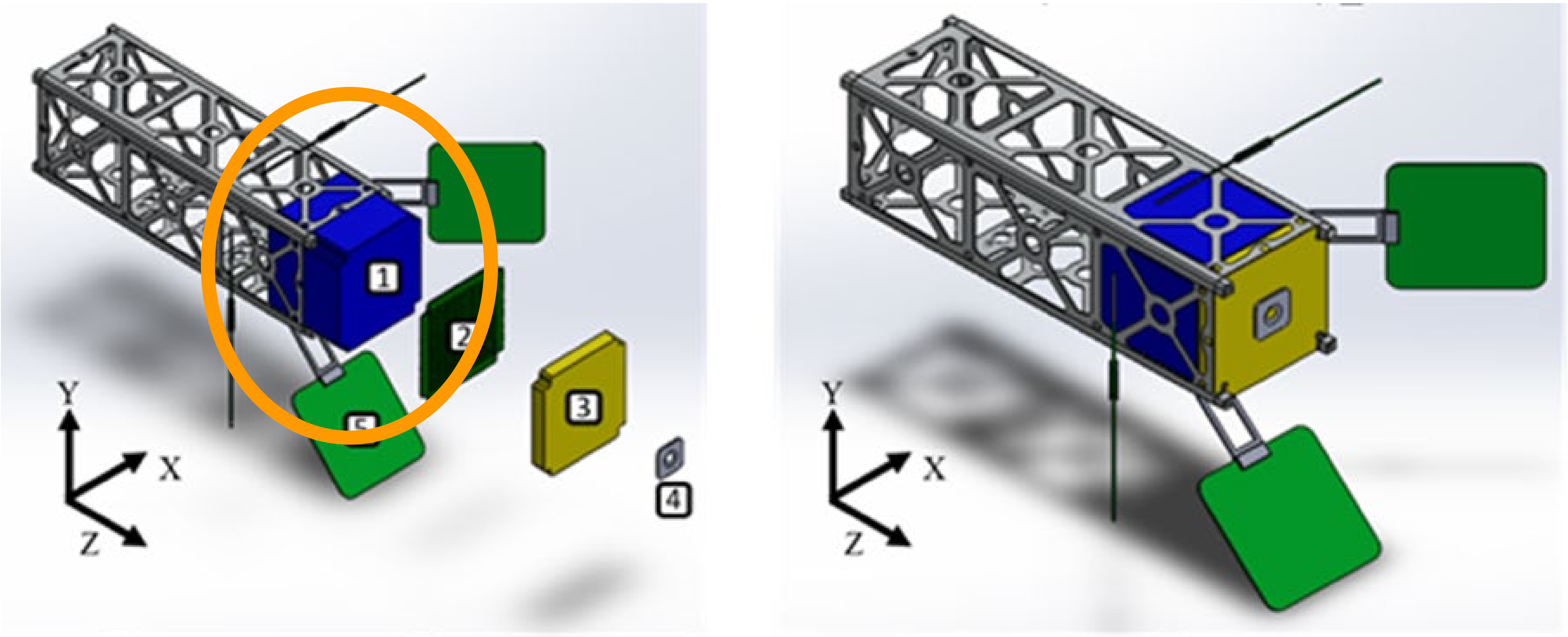
- Liquid propellant tank and nozzle vapor chamber separated by semipermeable membrane
- Expanded Polytetrafluoroethylene (ePTFE) membrane
- Permeable to vapor, not liquid
- Capable of holding high pressure differentials without rupture
- 35 cm^2 surface area
- Vapor mass flow >7×10^{-7} kg/s





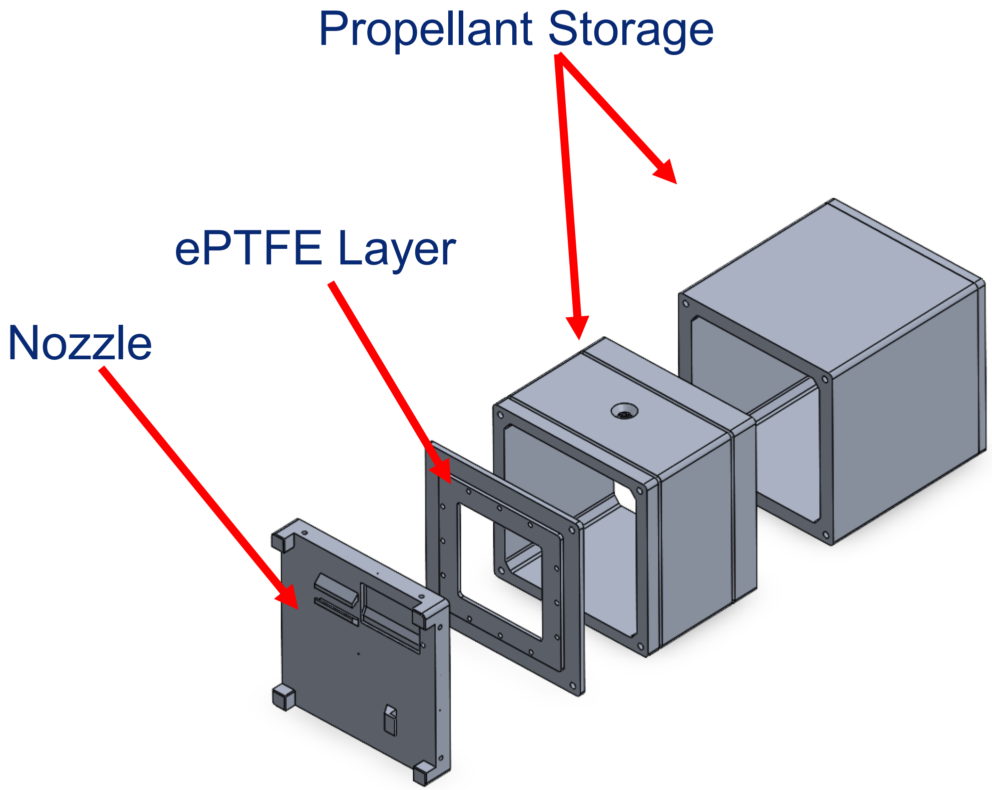


Design: Propellant Tank



1 Propellant Reservoir 2 Phase Separator 3 Expansion Chamber 4 Nozzle 5 Attitude Stabilizer

- Features
  - Modular, two chamber design.
  - Separation of the vapor and liquid using ePTFE.
  - Use of the CubeSat structure to incorporate the propellant tank.
- Material
  - 6061 Aluminum is the primary material.
  - 3M Scotch Weld 2216 to seal ePTFE.
  - O-Ring to create the seal between the aluminum parts.



Design: Tank

- Physical tank assembly requires 218mm M3 threaded rods
- Multiple phases of testing in vacuum chamber to verify seal function

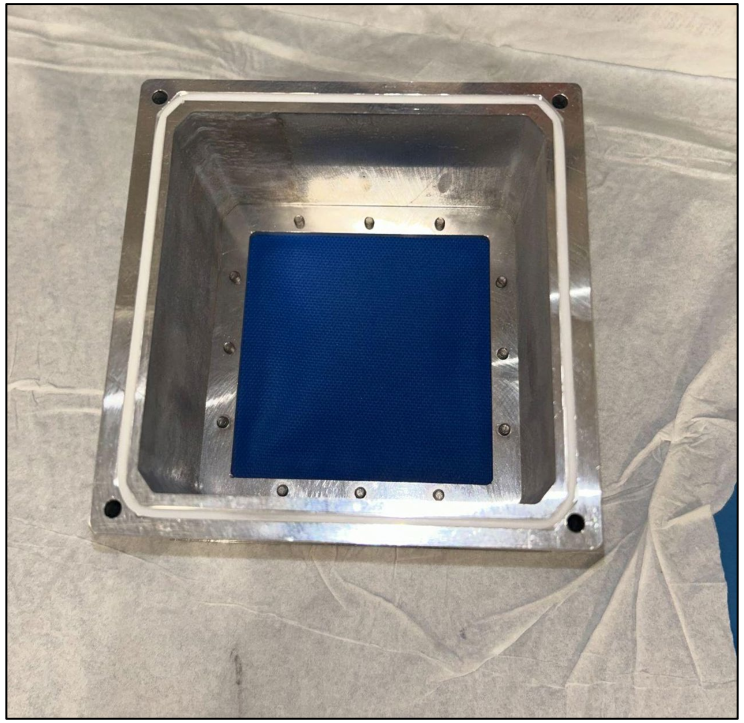


Figure: ePTFE Bracket Inside Tank

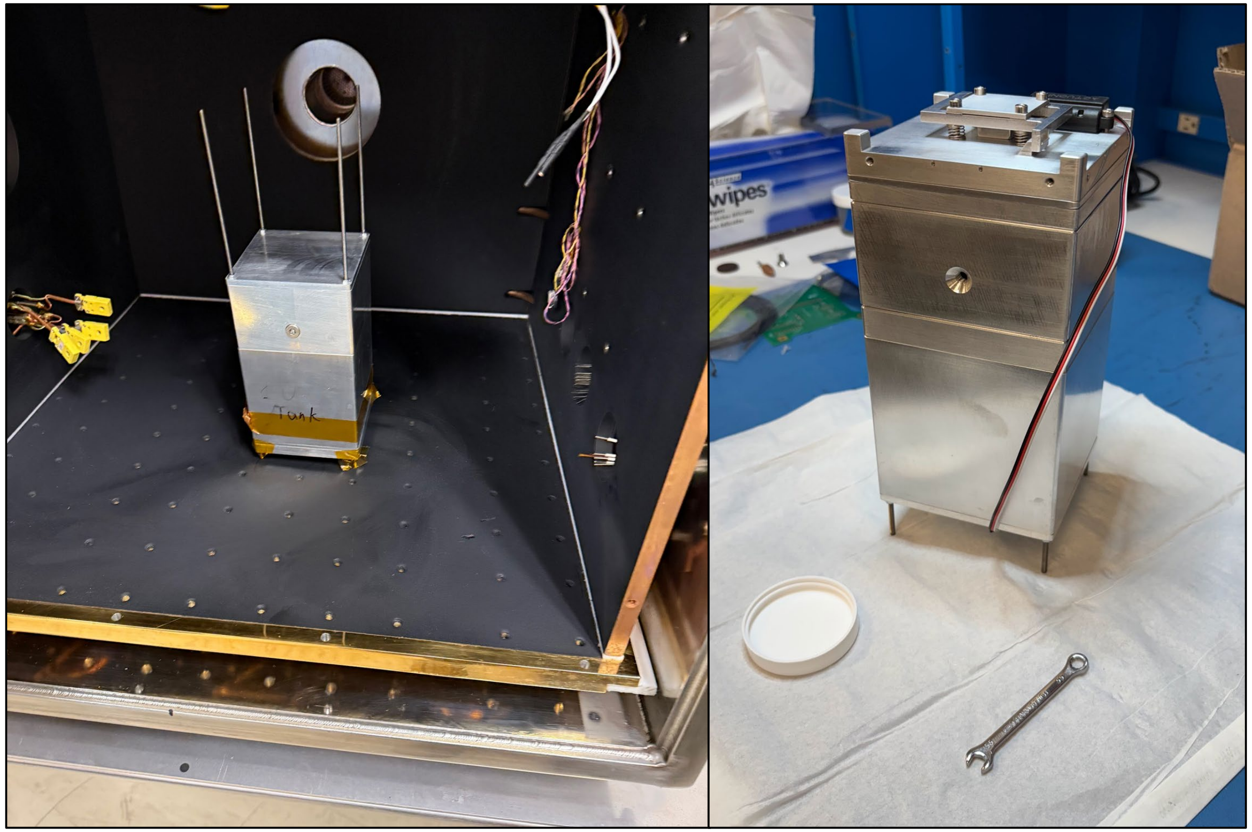
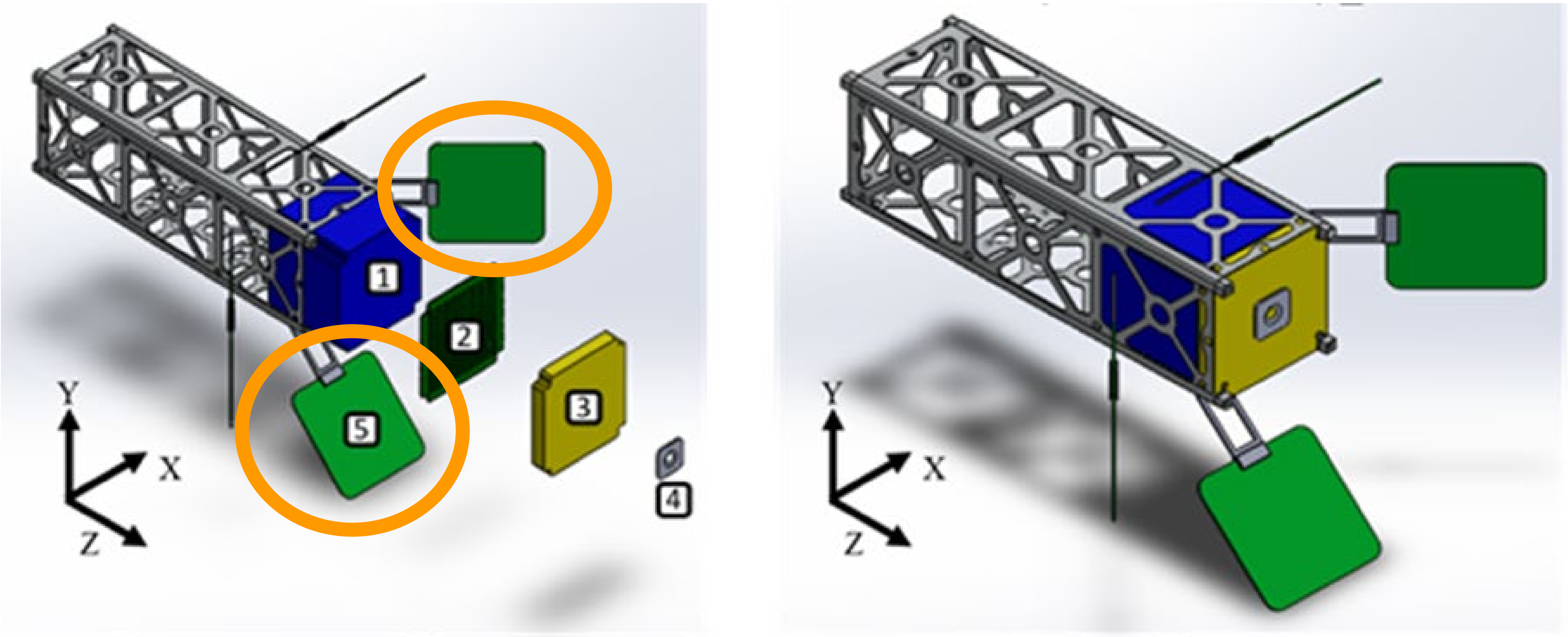


Figure: Full Tank Assembly

Design: Attitude Control



[1] Propellant Reservoir [2] Phase Separator [3] Expansion Chamber [4] Nozzle [5] Attitude Stabilizer

Design: Attitude Dynamics and Control

- ADCS will deploy 4 7.4x5.8 cm FR4 panels in a shuttlecock configuration
- Panels will be stored on the side of the spacecraft to minimize storage
- To act passively the panels will utilize the drag to orient the spacecraft being held to the spacecraft by nitinol wire
- Burn resistor will burn wire to initiate ADCS deployment
  - two burn resistors for redundancy

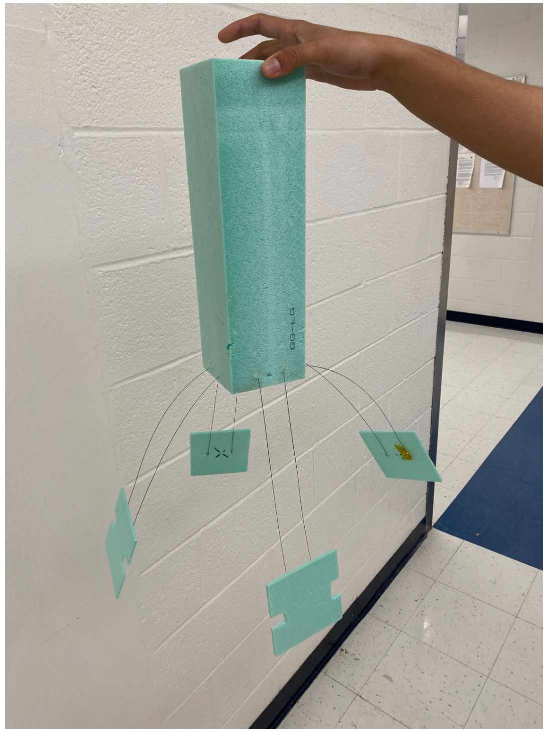


Figure: Full Foam Mockup

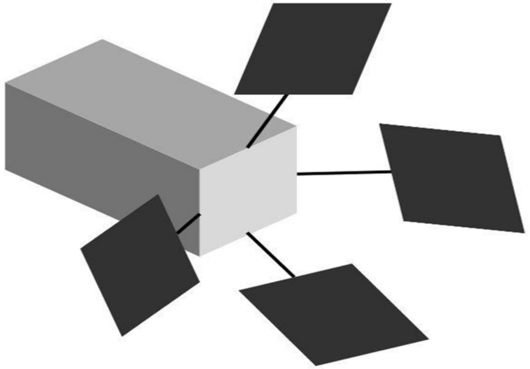


Figure: Fully deployed panels

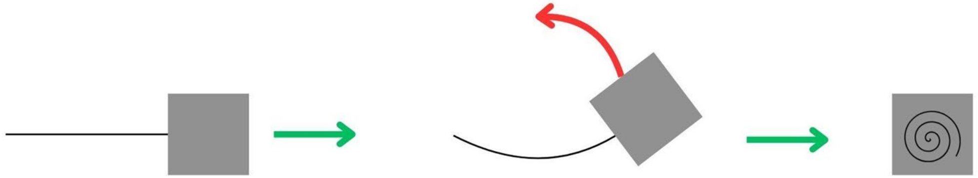


Figure: Panel storage for launch

Design: Attitude Dynamics and Control Cont.

- MATLAB Simulation Data:
  - max drag experienced by satellite with shuttlecock configuration is approximately 157 μN
  - With the hysteresis damping and shuttlecock structure, the spacecraft will adequately stabilize in the pitch and yaw directions within 1 hour of launch vehicle deployment

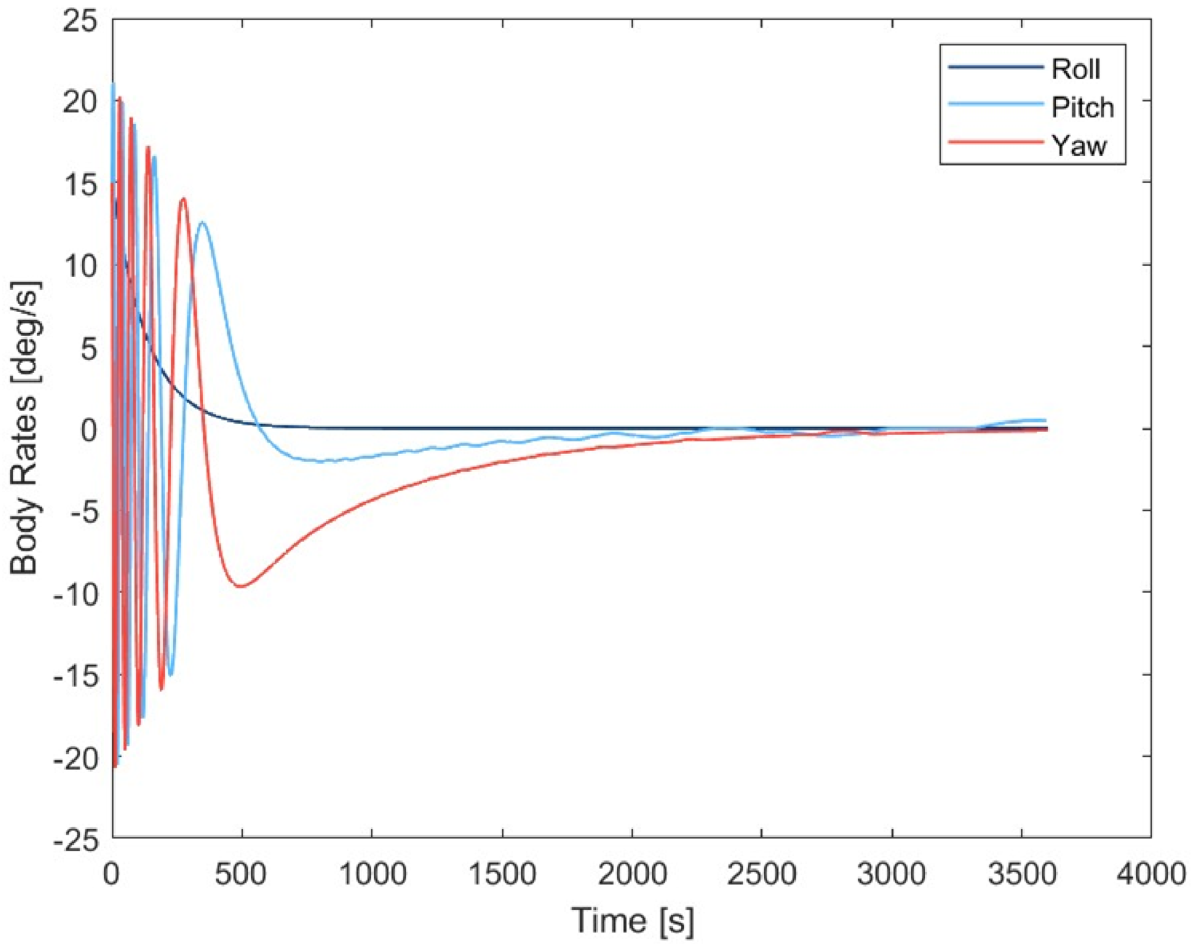
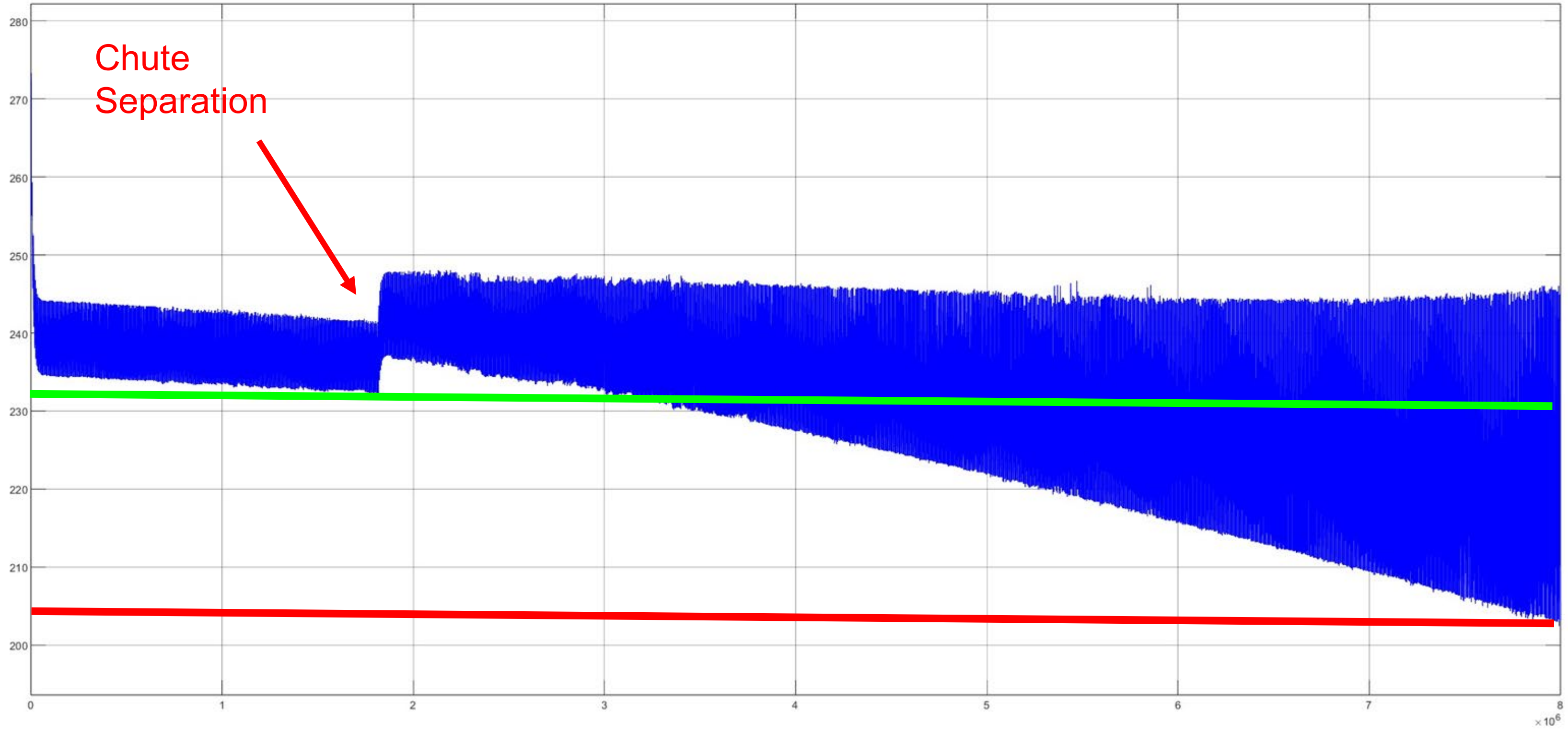


Figure: Angular velocity in each body axis of spacecraft over 1 hour timespan

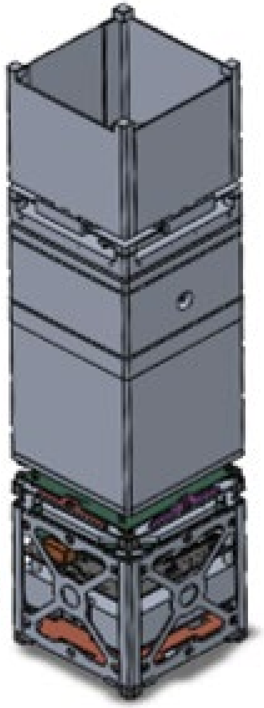
- 232 K average temperature (green)
- 203 K minimum temperature (red)
  - 16% higher than freezing point of methanol
- 70 days of fuel from 450 km initial altitude



Average temperatures stays well above minimum required temperature

Conclusion

- Passive “backpack” design for aerodynamic stabilization and drag makeup shown to be feasible within reasonable size constraints.
- Analysis conducted was assuming worst-case conditions and achieved pointing error of ± 20° → ± 1° with minimal damping.
- Orbit extension of 10-20 days could be achieved with approx. 1U of tank volume at 250 km altitude



Benefits

- No contribution to orbital debris
  - Only stays in orbit if functional
- Closer to target: smaller aperture
- Closer to ground station: improved link margin
- Closer to upper atmosphere: better data for earth science research
- Reduced launch cost

Thank you.
Questions?