

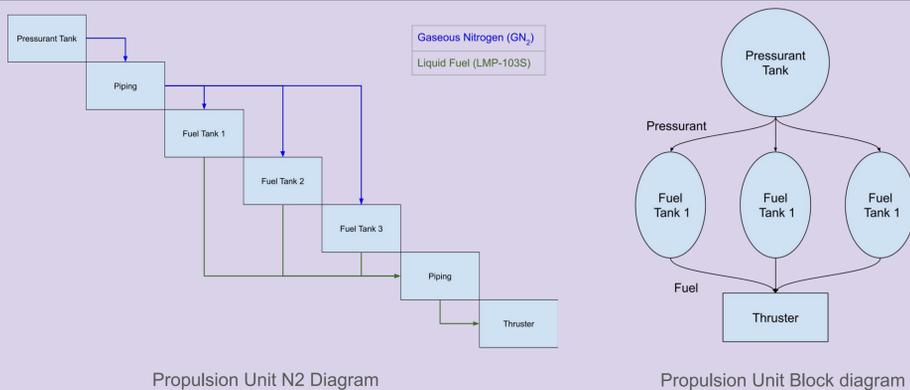


# Developing a Modular Cubesat Propulsion Unit

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## Abstract

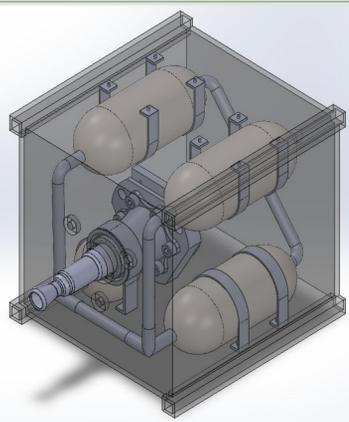
Miniaturized spacecraft such as CubeSats have revolutionized access to space for research, commercial, and exploration missions. However, propulsion continues to be a limiting factor for 1U CubeSats, constraining their ability to maneuver, maintain orbit, and comply with deorbiting requirements. This project addresses that gap by developing a fully self-contained propulsion unit that integrates thruster, fuel, pressurant storage, and structural housing into a modular package. The design is universally compatible with standard 1U CubeSat payloads and can be mounted without significant customization, enabling broader mission flexibility for academic and commercial purposes.



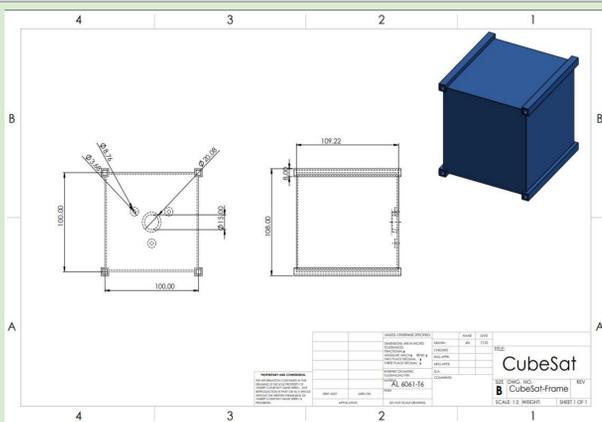
## System Design

The propulsion unit was designed from the inside out, starting with the thruster as the core component. Its orientation and mounting defined the structural layout and flow path. Surrounding the thruster are three cylindrical fuel tanks placed symmetrically to maximize internal volume while ensuring mass balancing and structural integrity. A single pressurant tank sits opposite of the thruster, enabling direct routing to the fuel tanks for uniform pressurization. All components are designed with Aluminum 6061 to simplify manufacturing while meeting all design specifications.

The system uses a blowdown feed architecture, where pressurized gaseous nitrogen flows from the pressurant tank into the fuel tanks, driving the propellant into the thruster. This reduces complexity in the design. Pipes are kept short, direct and anchored, minimizing pressure loss and vibration risk.



Full Propulsion Unit Assembly

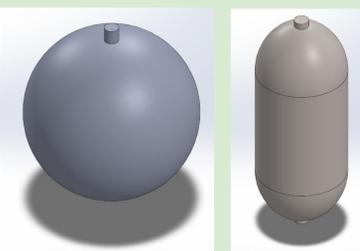


CubeSat Structure

## Tank Design

The propulsion system uses three fuel tanks and one pressurant tank. All are made using Aluminum 6061 with the fuel tanks designed for maximum volume and the pressurant tank designed to withstand higher pressures.

Specification	Fuel Tank (x3)	Pressurant Tank
Outer Diameter	40mm	40mm
Height	84mm	44mm
Wall Thickness	1.0mm	1.0mm
Volume per tank	6.95 cm <sup>3</sup>	2.882 cm <sup>3</sup>
Mass per tank	18.78 grams	7.78 grams



Pressurant Tank

Fuel Tank

## Thruster Selection

### What is our thruster?

The thruster is an **ECAPS 1N green monopropellant engine** designed to fit within the volume and power limits of a 1U Cubesat frame. It uses **LMP-103S**, a safe, high performance propellant that provides reliable thrust with minimal system complexity.

### Why did we choose it?

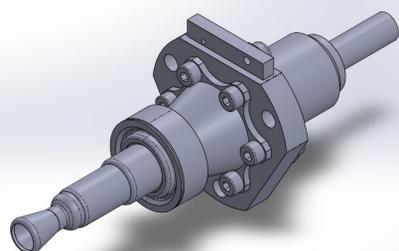
- Flight proven and commercially available (>25 satellites)
- Works with a simple pressure-fed system (no moving parts)
- Uses a non-toxic monopropellant for safe, efficient handling
- Provides sufficient thrust and impulse

### How does it work?

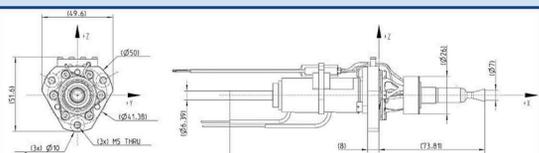
- The thruster works by pushing nitrogen-pressurized LMP-103S through a heated catalyst bed, which breaks it down into hot gases. These gases expand through a nozzle to generate thrust. Using a monopropellant eliminates the need for a complex ignition or oxidizer system.

## Bradford ECAPS's 1N HPGP Thruster Specifications

Propellant	LMP-103S
Propellant Density	1242 kg/m <sup>3</sup>
Propellant Temperature	5 to 60
Burst Pressure	>86 bar (1247 psi)
Thrust Class	1 N
Operating Pressure	5.5-22 Bar
Thrust Range	0.25 - 1 N
Nozzle Expansion Ratio	100:1
Typical Steady State ISP (vacuum)	208-224 s
Propellant Throughput	24kg
Total Impulse, Ns	50000 Ns
Number of Pulses	>60000
Pulse Length	10ms to 60 minutes



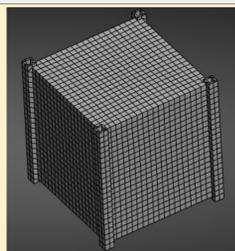
Thruster Isometric view



Thruster Schematic

## Finite Element Analysis

To analyze the CubeSat, the frame underwent Finite Element Analysis (FEA) with three distinct tests: static structural analysis, modal analysis, and random vibration analysis. These simulations were designed to evaluate the CubeSat's performance under launch and operational conditions.



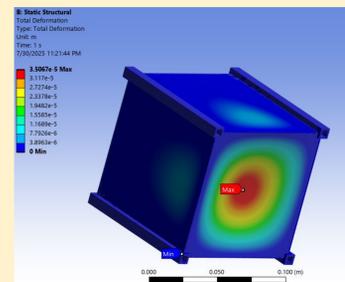
Mesh

### Boundary Conditions

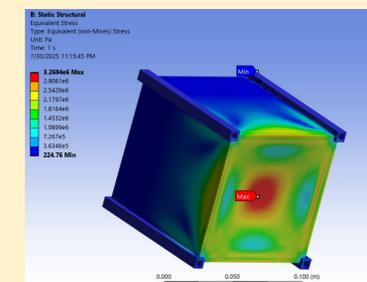
1. Floor of Constraint: The side of the CubeSat that faces the ground should be fully constrained. This will simulate the floor of the 1U CubeSat during launch.
2. Top of Constraint: The CubeSat facing the sky should be constrained in all directions other than the vertical direction (+z-direction for our model).

### Static Structure Analysis

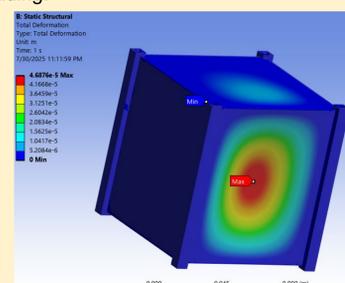
A static structural analysis was performed to evaluate the Cubesat's ability to withstand quasi-static launch loads. Separate cases were tested for axial and lateral load inputs based on standard rideshare requirements.



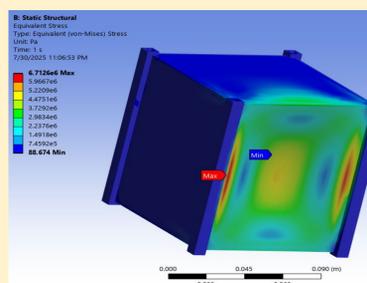
Total deformation of Cubesat when axial load is applied. Load factor of 10g is applied to the center of top region. Deformation is small and localized near the force application point, which is consistent for a Cubesat under axial loading.



Stress of Cubesat when axial load factor of 10g is applied. This demonstrates low stress and that Cubesat can withstand axial accelerations of common rockets.



Lateral load of 17g is applied. Deformation pattern is symmetric and smooth, which showcases stable model behavior.

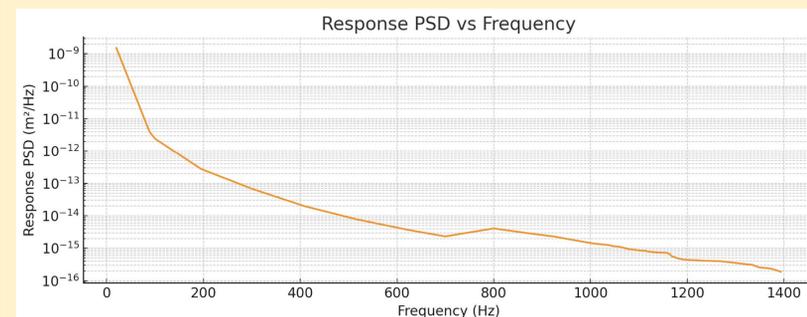


Stress distribution of lateral load factor of 17g. Stresses are demonstrated to be below yield strength of Aluminum 6061.

## Modal Analysis

A modal analysis was performed to determine the natural frequencies of the CubeSat assembly. The first six mode frequencies are shown below and all exceed the 100 Hz minimum typically required for CubeSat launch environments:

**Conclusion:** First mode is well above the standard threshold, confirming the structure is dynamically rigid.



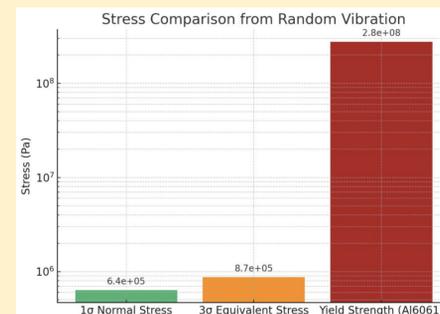
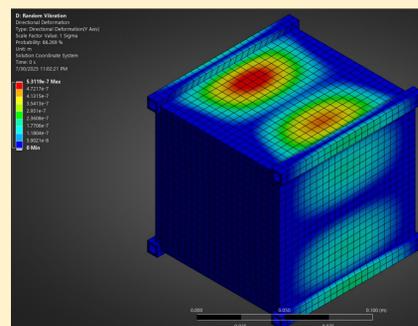
Mode	Frequency (Hz)
1	1004.8
2	1081.5
3	1136.3
4	1166.3
5	1166.6
6	1393.4

## Random Vibration Analysis

A random vibration analysis was conducted using a Power Spectral Density (PSD) input in the X-direction. The response was evaluated across all significant mode shapes derived from the modal analysis.

- **Peak RMS Displacement:** 228.7 μm at 54.66 Hz
- **Maximum Equivalent Stress:** 872.5 kPa
- **Material Yield Strength (Al6061):** ~276 MPa
- **Safety Margin:** > 300×

The structural stresses remained well within allowable limits under 3σ conditions, confirming that the design is robust under launch-induced random vibrations.



## Conclusion and Future Work

Compact propulsion systems enable CubeSats to perform advanced maneuvers such as orbit changes, station keeping, and controlled deorbiting, all while preserving valuable volume for mission payloads. We designed a fully integrated propulsion unit for 1U CubeSats that consolidates thermal, structural, and fluidic functions into a single, compact system. With a standardized, modular architecture, our design enhances mission adaptability and significantly reduces integration time. The system fits entirely within a 1U form factor, weighs only 441.83 grams, and is fully compatible with CubeSat electrical and structural interfaces making it an ideal solution for scalable, mission-ready deployments.

Upcoming work includes metal additive manufacturing, environmental testing, hot-fire validation, and full integration onto a flight-ready CubeSat platform. These efforts will support system-level qualification and generate key performance data for in-orbit use. Future iterations will also explore adapting the design for gimbaled propulsion to enhance attitude control and maneuverability, broadening its application across diverse CubeSat mission profiles, including constellation management and deep space navigation.