PAssive Thermal Coating Observatory Operating in Low earth orbit (PATCOOL)

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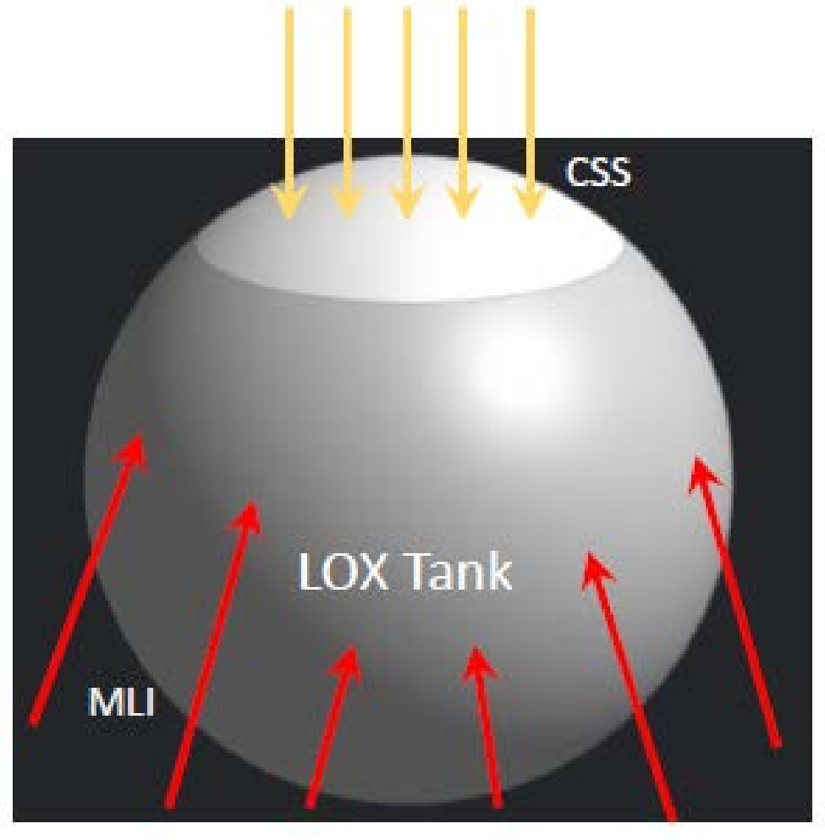
Overview

Surfaces that reflect one wavelength of thermal radiation while absorbing another, known as selective surfaces, have been researched extensively since the 1960s. C. H. Liebert and R. R. Hibbard demonstrated that an ideal cryogenic selective surface can theoretically attain a temperature of 40 K at a distance of 1 AU from the Sun. If applied as a coating, the cryogenic selective surface could allow for novel passive thermal in-space capabilities such as long-term cryogenic propellant storage.

The ADvanced Autonomous MUltiple Spacecraft (ADAMUS) Laboratory at the University of Florida (UF) is currently developing a CubeSat, the PAssive Thermal Coating Observatory Operating in Low-earth orbit (PATCOOL), to serve as a platform to characterize the performance of experimental selective surface samples in a low-Earth orbit (LEO) environment. To characterize the experimental selective surface's performance on orbit, two small metallic samples coated with the experimental surface shall be prepared as well as two samples coated with the current state of the art in passive thermal coating technology. The temperature of these four samples will then be recorded over the mission duration of at least 72 hours and compared to assess the ability of the selective surface to achieve and maintain low temperatures in comparison to the current state of the art.

Concept to Application



Concept for implementing cryogenic selective surface (CSS) for long-term on-orbit LOX storage

PATCOOL CubeSat CAD model and prototype

Mission Requirements and Timeline

Highest Level Requirements
CubeSat ejects from deployer
Ground systems make contact with CubeSat
CubeSat shields the samples from direct heating from the Earth, and minimizes heat transfer from the CubeSat itself to the samples
CubeSat includes enough temperature sensors to record temperature readings from each sample, the sample housing component, and a component in the lower-section of the CubeSat
CubeSat has a minimum operational life of 72 hours
CubeSat shall be capable of transmitting all collected data back to Earth

Subsystem Requirements			
COTS ADCS	Power	Communication	Controller and C&DH
CubeSat shall be detumbled to below 0.01 rad/s within 24 hours of deployment	Through solar power generation and battery capacity, CubeSat shall provide sufficient power for each expected mission mode power requirement	CubeSat shall make contact with the Iridium Satellite Constellation within 3 hours of being deployed into orbit	Controller shall have sufficient data capacity to store all collected data between downlink instances
CubeSat shall maintain sample zenith-pointing to within 20 degrees	Battery shall have enough capacity to provide power for each mission mode during eclipse periods	Information from Earth may be sent to the CubeSat during operation	Controller shall have the ability to receive and execute commands from Earth
CubeSat shall maintain sun projection vector to within ±15 degrees of CubeSat edge equipped with 3U solar panels	Solar panels shall generate enough power such that immediately after deployment and during detumbling, CubeSat can generate net positive power	All scientific data and telemetry collected during mission duration can be transferred to Earth	Controller shall be able to command all other CubeSat subsystems

System Requirements Review
March 2019 – June 2019

Preliminary Design Review
June 2019 – October 2019

Critical Design Review
October 2019 – March 2020

Fabrication & Flight Qualification Testing
March 2020 – December 2020

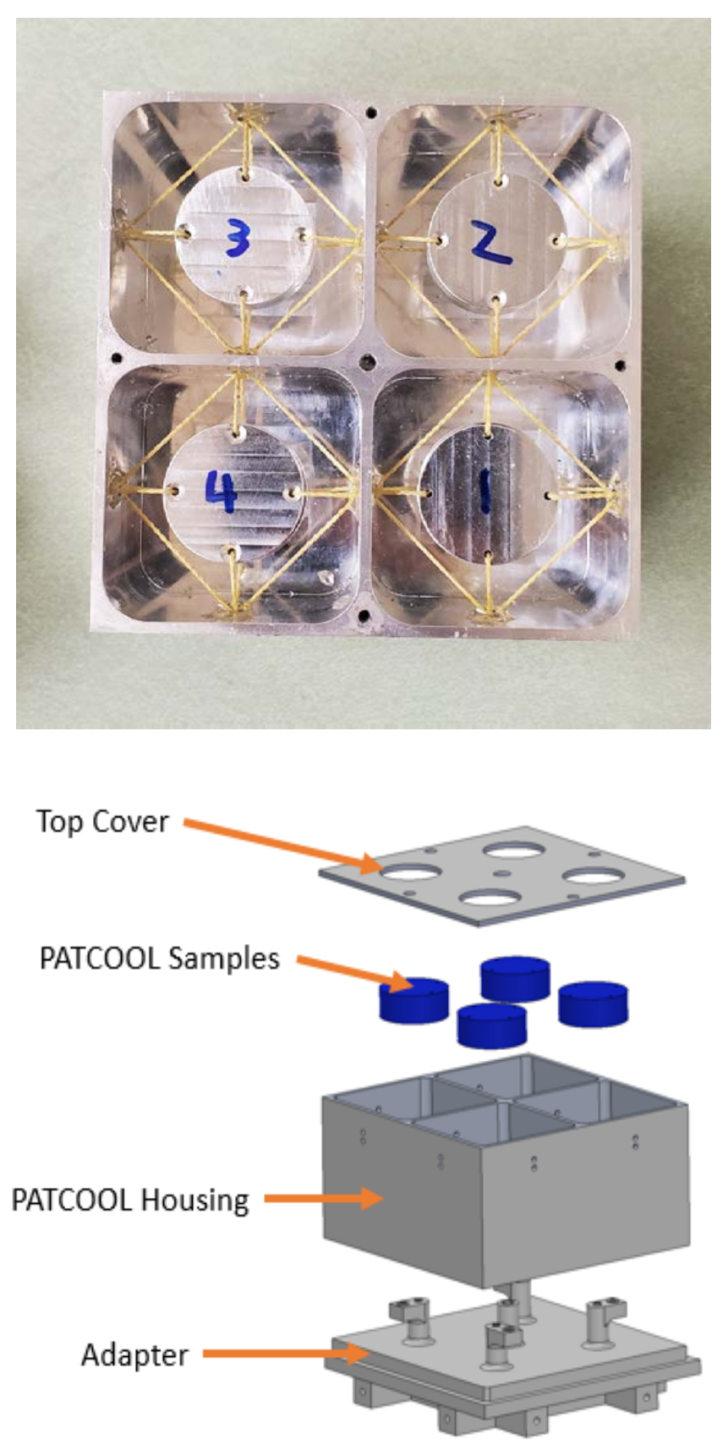
Integration for Flight & Storage
December 2020 – June 2021

Telemetry & On-Orbit Data Collection
June 2021 – December 2021

Extended Mission Operations
December 2021 – June 2022

Inside the Satellite

Payload

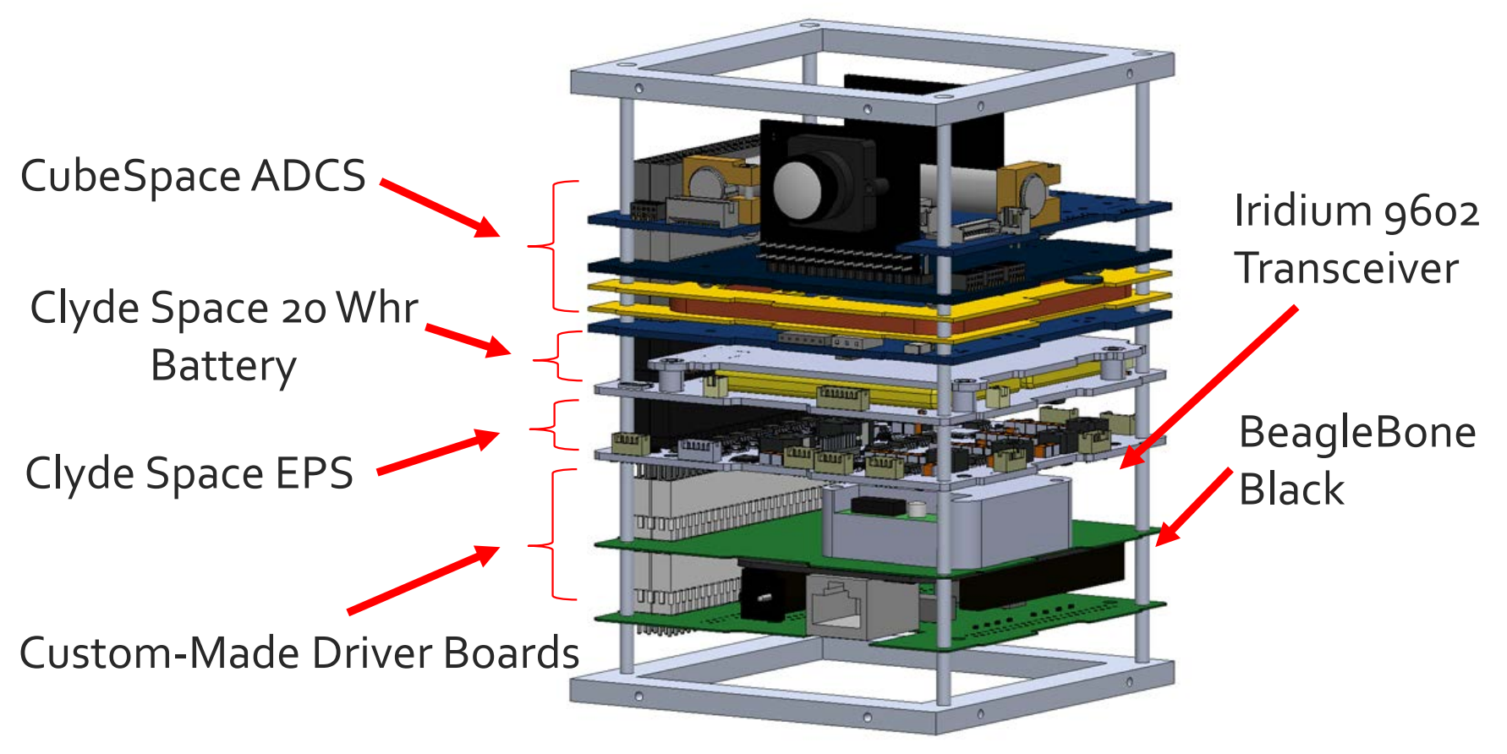


Uncoated PATCOOL payload prototype (top) and labeled PATCOOL components (bottom)

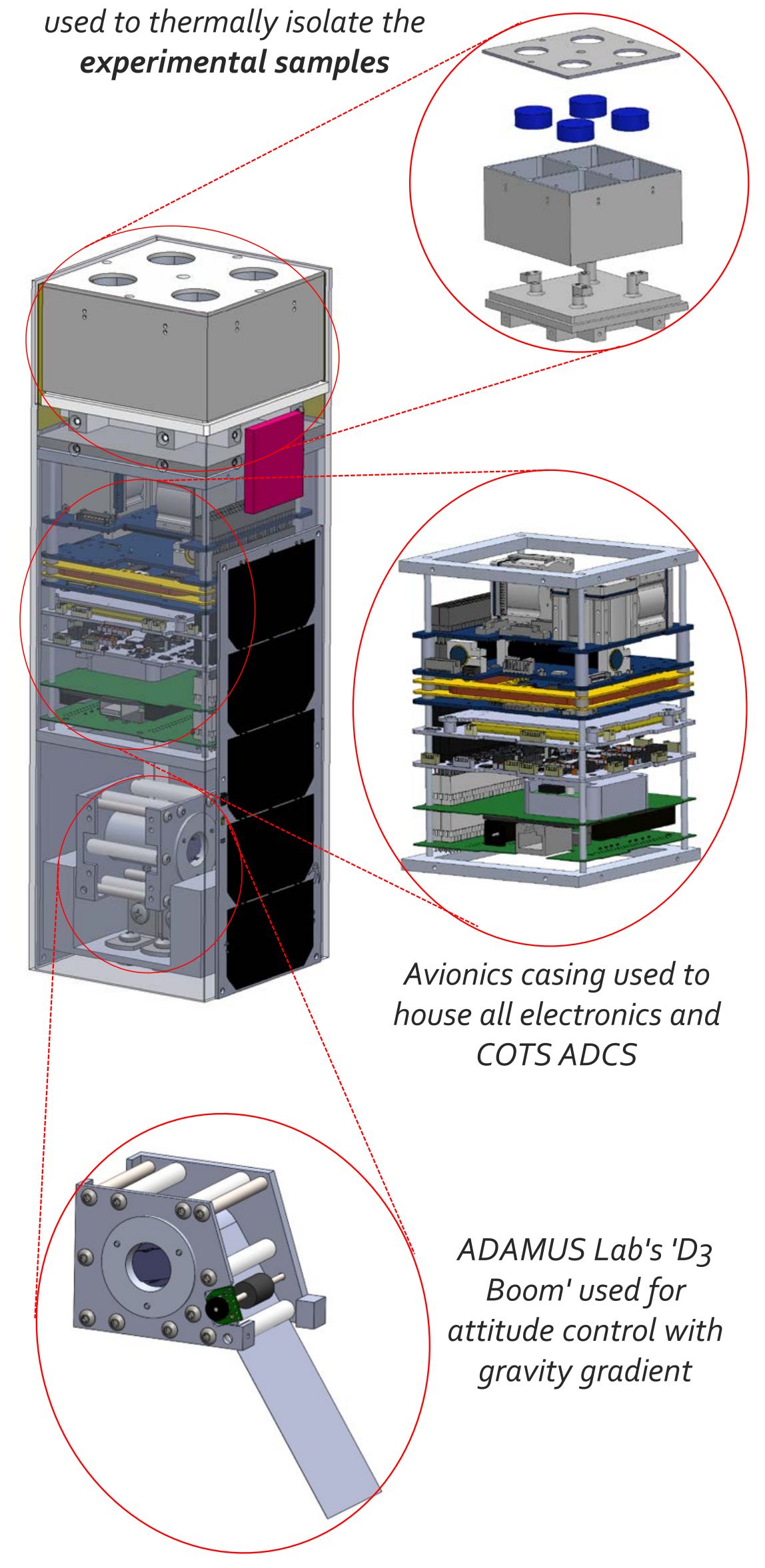
The primary payload is comprised of an aluminum housing containing four small aluminum samples. The outside of the sample housing is painted in AZ-93, which allows the aluminum housing to radiate heat to deep pace more effectively. The samples are held to the housing with Kevlar string. Within the aluminum disks lies a thermistor to periodically measure the temperature of each sample during the mission. Two of the aluminum disks are coated in an experimental cryogenic selective surface coating and the other two thermal samples are coated with AZ-93 white thermal paint. An adapter made of Ultem serves as the interface between the PATCOOL housing and the CubeSat structure. Mounted atop the housing structure is a top cover which is also coated in AZ-93.

Avionics

Commercially available avionics are used in the PATCOOL satellite except for two custom-made driver boards: one to contain the thermistor circuit and mount the transceiver, and the other to contain the BeagleBone Black processor and control the D3 device.



3U CubeSat Design



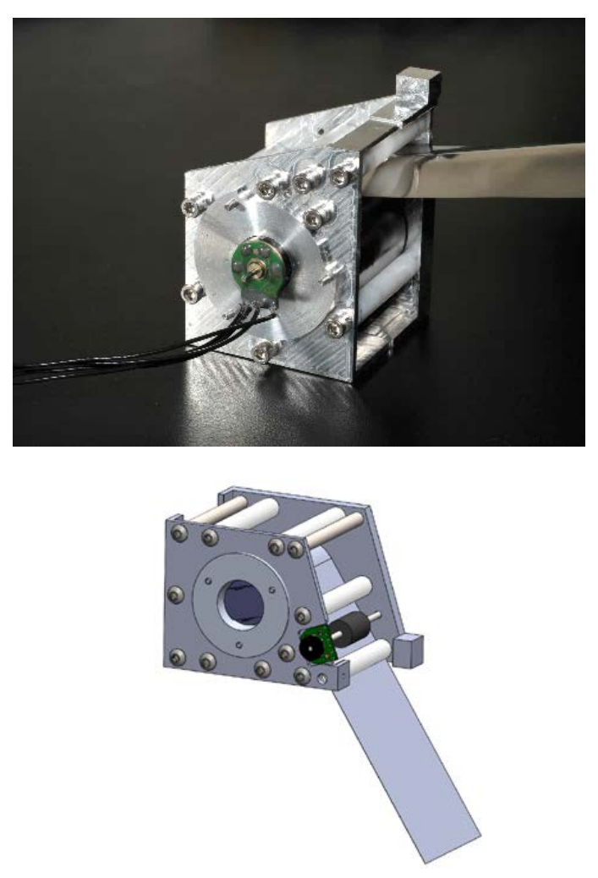
Expanded view of payload housing used to thermally isolate the ***experimental samples***

Avionics casing used to house all electronics and COTS ADCS

ADAMUS Lab's 'D3 Boom' used for attitude control with gravity gradient

Drag De-Orbit Device

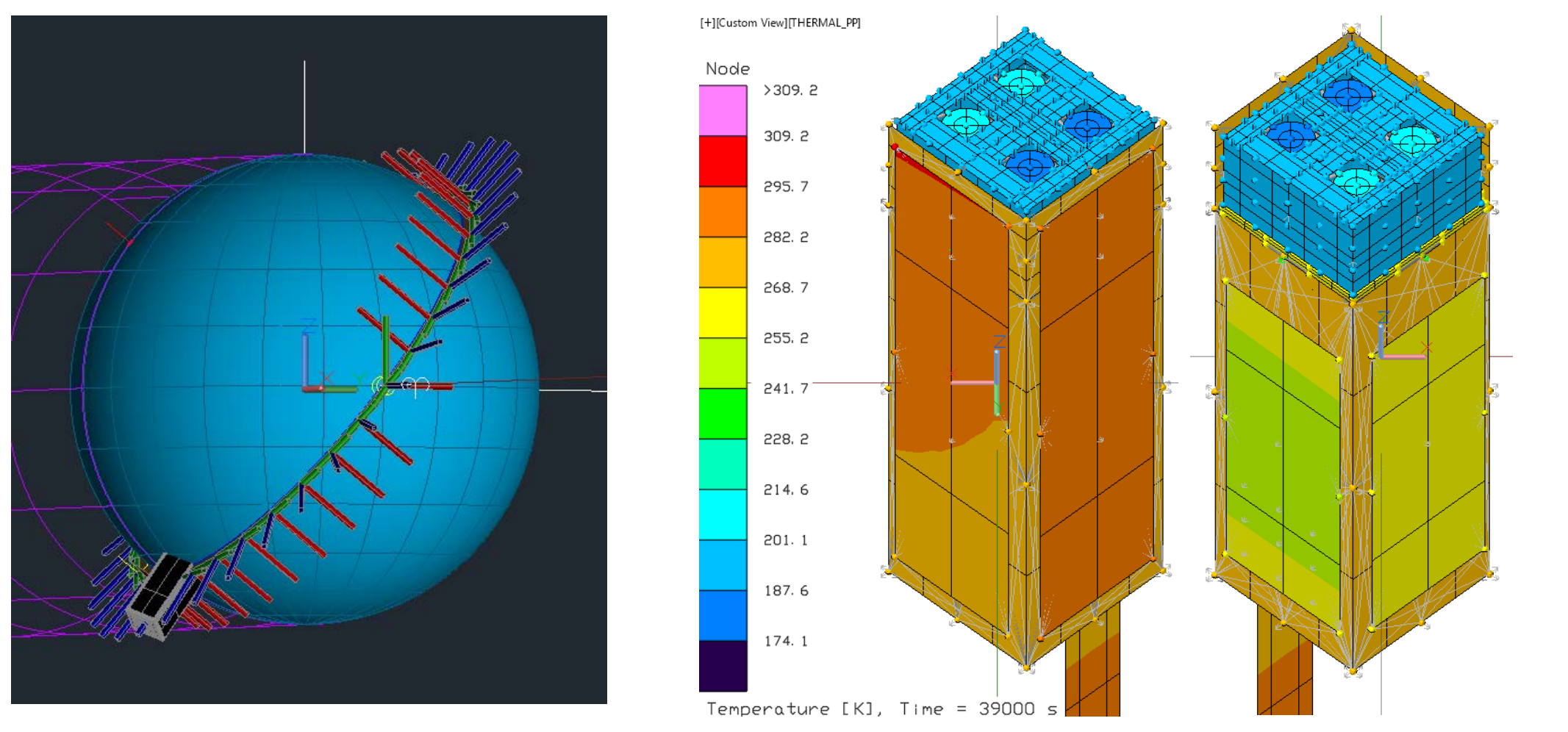
As part of a separate project, a drag de-orbit device (D3) was developed and integrated into the satellite with a tip mass added. This tip mass is positioned at the bottom of the CubeSat and is attached to a retractable tape-spring boom, providing gravity-gradient stabilization.



D3 prototype and CAD model

Thermal Analysis

A comprehensive thermal analysis was performed using Thermal Desktop to simulate the anticipated orbital-thermal case. An ISS orbit was imported to Thermal Desktop to define the orbital-thermal environment the CubeSat would encounter. A simulation was then performed to assess the temperature response within the thermal samples and the CubeSat sample housing component over the anticipated duration of the PATCOOL mission of 72 hours, or 259,200 seconds. From the simulations, it is demonstrated that the temperature of the samples coated with the experimental selective surface reach the lowest temperature out of the entire CubeSat system at 166.1 K, and the CubeSat housing component and white-painted samples achieve higher temperatures of 199.6 K and 212.2 K respectively.



Orbital-thermal analysis performed using Thermal Desktop

Vibration Testing

To simulate the launch environment, the CubeSat prototype (minus avionics and solar panels) was taken to NASA Ames Research Center and subjected to random vibrations at 9.47 times the force of gravity. The satellite was secured in a PPOD launcher, which was attached to a vibration table via aluminum base plate. The launcher was then subjected to vibration frequencies from 20 to 2000 Hz for two minutes on each axis (*x*, *y*, and *z*), which simulates the worst-case environment for a satellite. Between each axis of vibration testing, a sine sweep test was conducted to detect the resonance frequencies of the satellite. Then, the satellite was removed from the launcher, inspected for damage, and re-inserted into the launcher.

CubeSat prototype fitting inside a PPOD launcher atop the vibration table