CubeSat Technology Exploration Project - CubeSTEP

Additive Manufacturing in Creating a Universal Bus

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Introduction to CubeSTEP

Project Overview

- Student led, multi-disciplinary collaborative project between CPP and JPL
- JPL University Crowdsourcing initiative (JUCI)
- Started in Spring 2020

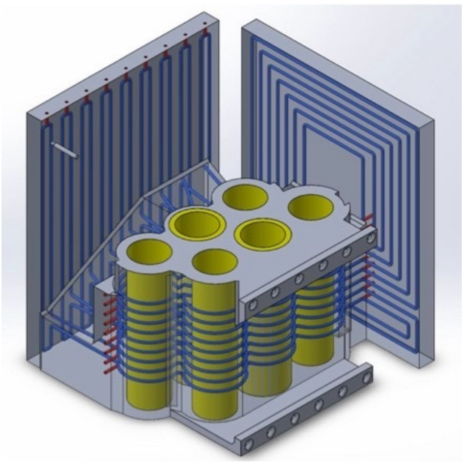
Project Objectives

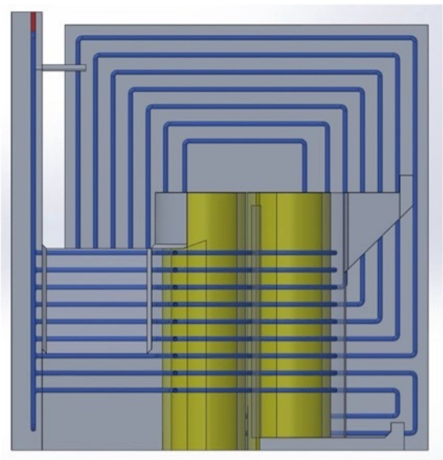
- Design and manufacture a universal CubeSat testbed for TRL maturation
- Utilize additive manufacturing to integrate customized structures and technology
- Design, develop and test an Oscillating Heat Pipe (OHP)

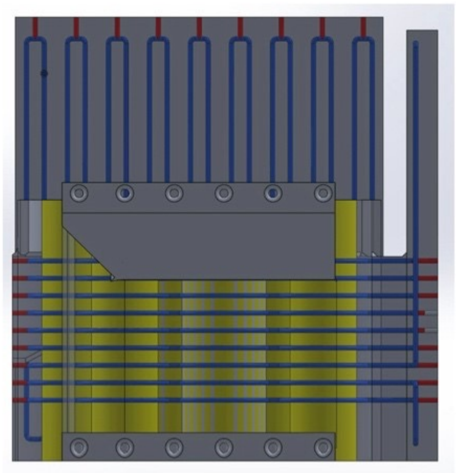
Universal Testbed

Purpose

- CubeSTEP's core objective is to create a universal testbed
- Standardized and Economic Platform
- Additive Manufacturing
  - Integration of complex geometries into bus structure







Universal Testbed

High Level Requirements - 1

Level 2 Requirements		
Req. ID	**Requirement**	**Rationale**
M-1.0	The CubeSat Bus shall be capable of operating while in Low Earth Orbit	To increase TRL we need to be able to test payloads in Earth orbit
F-1.0	The CubeSat Bus shall be equipped with a dedicated flight software system	The CubeSat needs dedicated software to receive and send tasks to other parts of the mission
H-1.0	The CubeSat Bus shall utilize Commercial Off The Shelf (COTS) components for all subsystems	COTS will be used to decrease cost and lead time associated with creating in-house components
S-1.0	The CubeSat Bus shall provide a structure for avionics and the payload	The structure will be used to house all CubeSat components and provide Bus-Payload integration
C-1.0	The CubeSat shall be able to communicate with the Ground Station while in Low Earth Orbit	The CubeSat will need a subsystem to send data and receive commands from the Ground Station

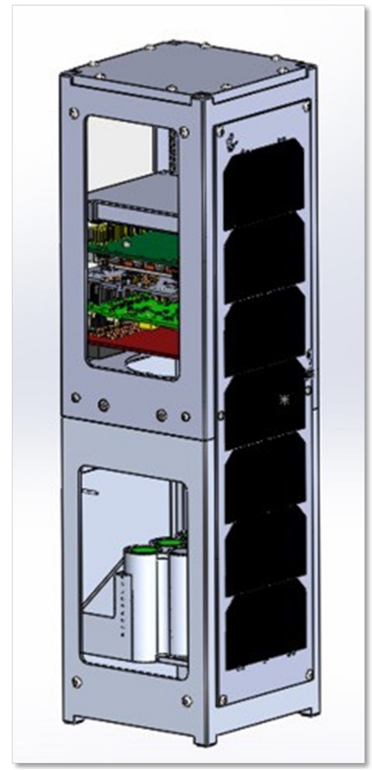
Universal Testbed

High Level Requirements - 2

Level 3 Requirements		
Req. ID	**Requirement**	**Rationale**
H-1.1	The CubeSat shall be able to compile, store, and manage payload data as well as commands from the Ground Station	The CubeSat needs to be able to process commands as well as collect data from testing and store that data until downlink
H-1.2	The CubeSat shall generate power using Solar Panels	Solar Panels are the cheapest and most available power generation option for CubeSats
H-1.3	The CubeSat shall have 3 axis stabilization	The CubeSat will need to know what its orientation is, how it is changing, and be able to control the orientation for power generation
H-1.4	The CubeSat shall be able to distribute its generated power to other components	Different components will have different voltage and power requirements, so the CubeSat needs to collect the power generated and distribute it accordingly
H-1.5	The CubeSat Bus shall be able to send data and receive commands from the Ground Station	The CubeSat will need to downlink data and receive commands from the ground

Challenges in Creating a Common Bus

- Interfaces
  - Mechanical
    - Secure the payload to the bus
  - Electrical
    - Feed wiring through the structure
  - Data
    - Varying component capabilities
    - Varying types of data collected and output
- Flight Software
  - Modularity



Impact of Additive Manufacturing

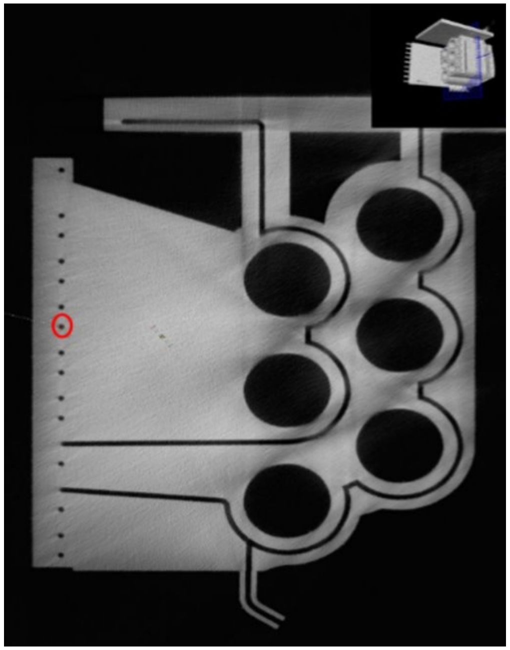
Design

- Design must be made with printer capabilities in mind
  - Print orientation
  - Support structures
  - Size of structure
  - Complex geometries
    - Difficult and costly to machine
    - Can be 3D printed

Impact of Additive Manufacturing

Manufacturing

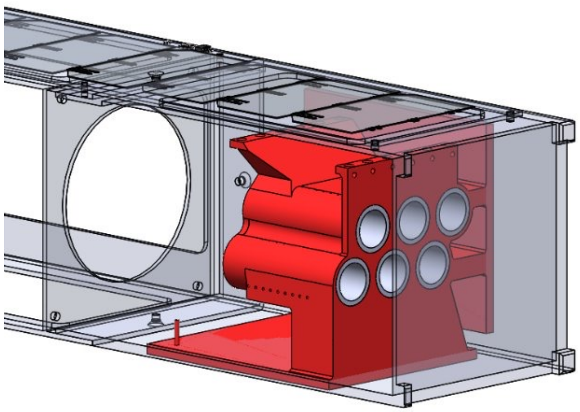
- Common materials are aluminum alloys
- Powder Bed Fusion
  - Fine layer of metal powder spread across preheated metal substrate
  - A layer of powder fully melted by laser energy across printing bed
  - Scanned according to predefined slice pattern
  - Process repeats
- Post Processing
  - Powder Removal
  - Surface Finishing
  - Heat Treatment



Impact of Additive Manufacturing

Integration

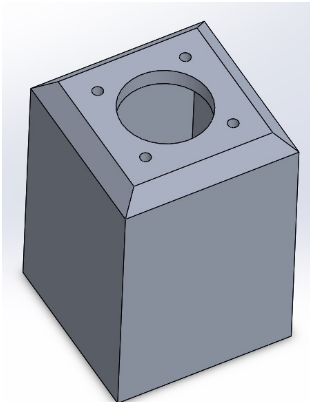
- Additive manufacturing can allow for payloads to be integrated into the structure itself
  - Payload and structure both 3d printed
  - Allows for OHP walls to be exposed to space environment, acting as a heat sink

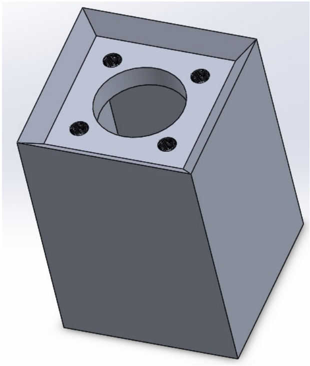


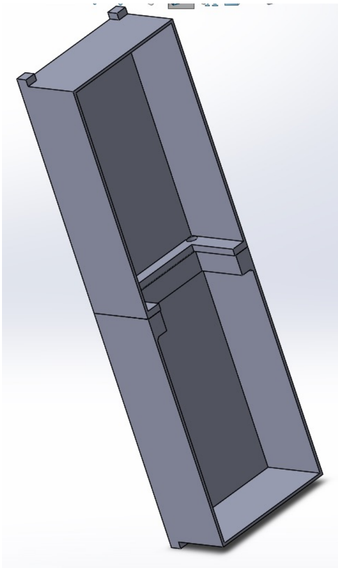
Bus Interfaces

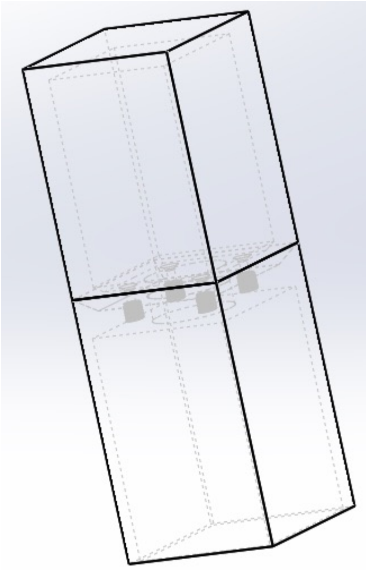
Mechanical

- Four key-locking inserts (ex. Keenserts) bonded into the bottom z-face of the OHP half of the bus. Suitable Allen-head fasteners used to attach other half of bus
- Key locking insert placement 3d printed into additively manufactured structure





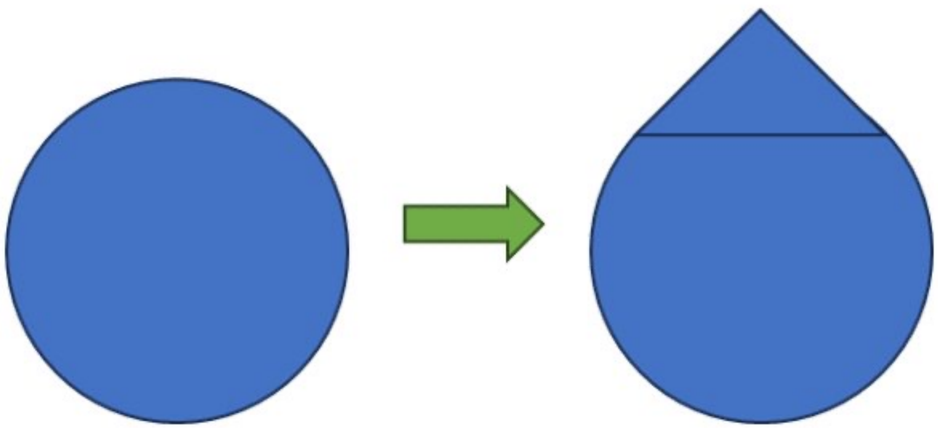




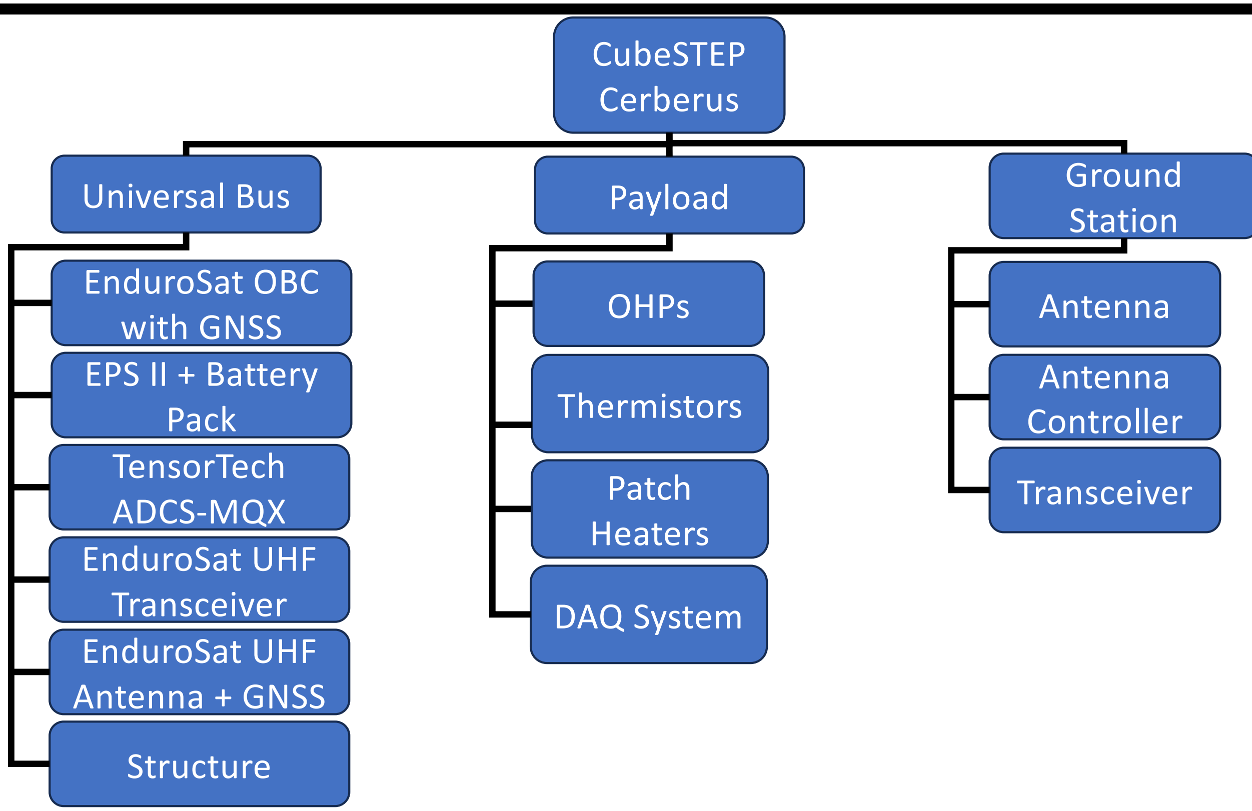
3D Design

Impact of AM in CubeSTEP

- Flat plate OHPs will be printed vertically
- Overhangs greater than 45° avoided
- Support structure inside thermal reservoir
- OHP channel diameter and turn radius determined by printer capabilities



System Level Design



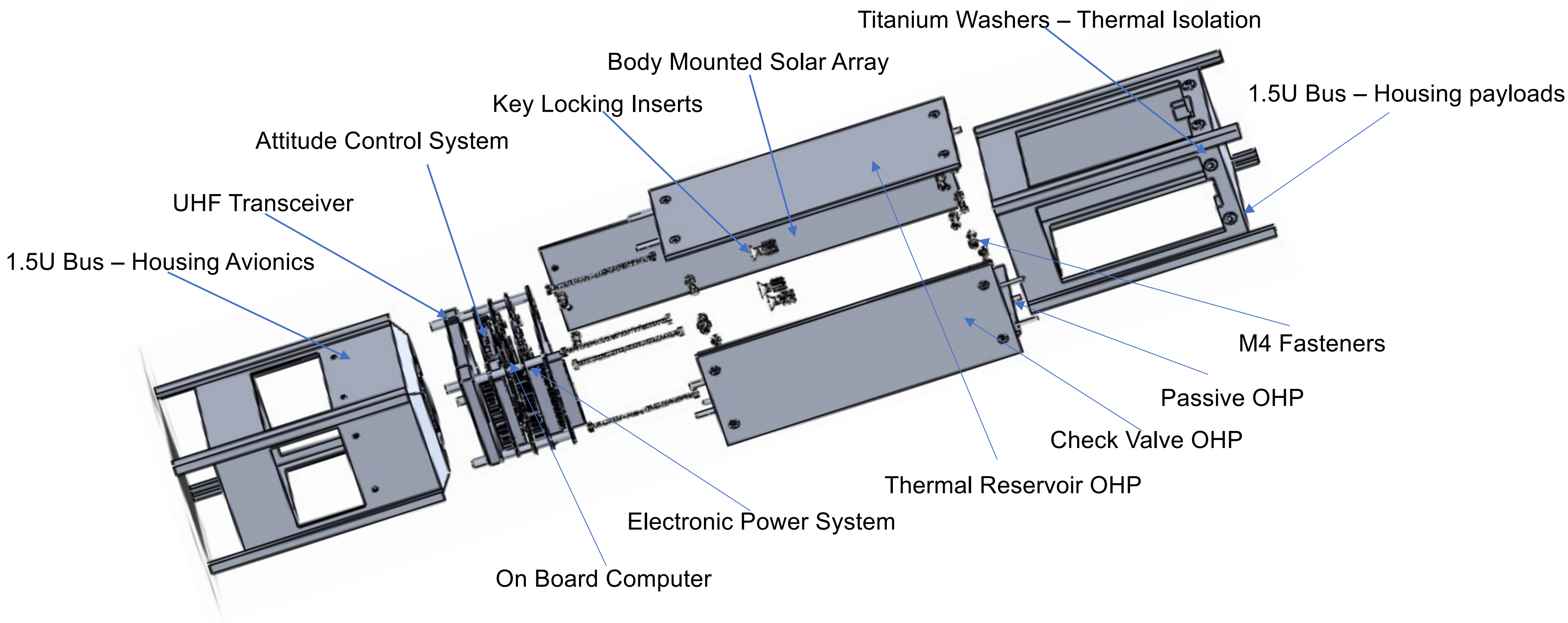
Bus Capability

Selected Boards

- EnduroSat
  - Average Available Power: 10 W
  - Battery Capacity: 42 Wh (4S)
  - Power Buses: 3V3, 5V, 12V, RAW (12-16.8V)
  - C&DH: Arm Cortex M7 with 2 MB Flash; Up to 480 MHz; 1x MicroSD card slot
  - Telemetry Data Rate: Up to 100 kbps
  - Payload Data Rate: Up to 125 Mbps
  - Data Interfaces: 4x RS-422/485; 2x I^2C; 2x UART; 8x GPIO; 1x CAN; Ethernet
- TensorTech ADCS-MTQ
  - Pointing Accuracy: 5 deg @ Sunlight
  - Torque: < 0.01 mNm
  - Slew Rate: 1 deg/s

Bus Structure

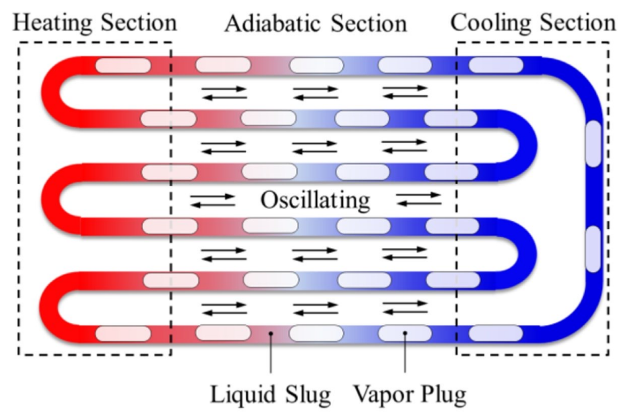
Current Design

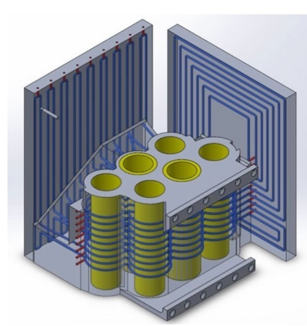


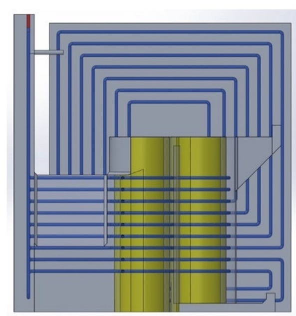
Payload Concept

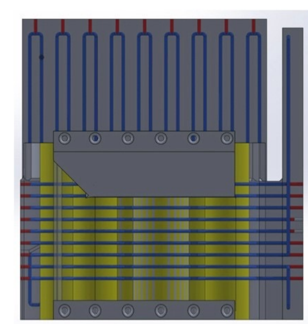
Oscillating Heat Pipe Integrated Battery Case

- Single loop OHP filled with liquid 'slugs' and vapor 'plugs'
- Phase change facilitates higher heat transfer and mitigates thermal runaway
- Regulates battery temperature with high discharge rate
- Addresses critical thermal management challenges and enables higher-power missions



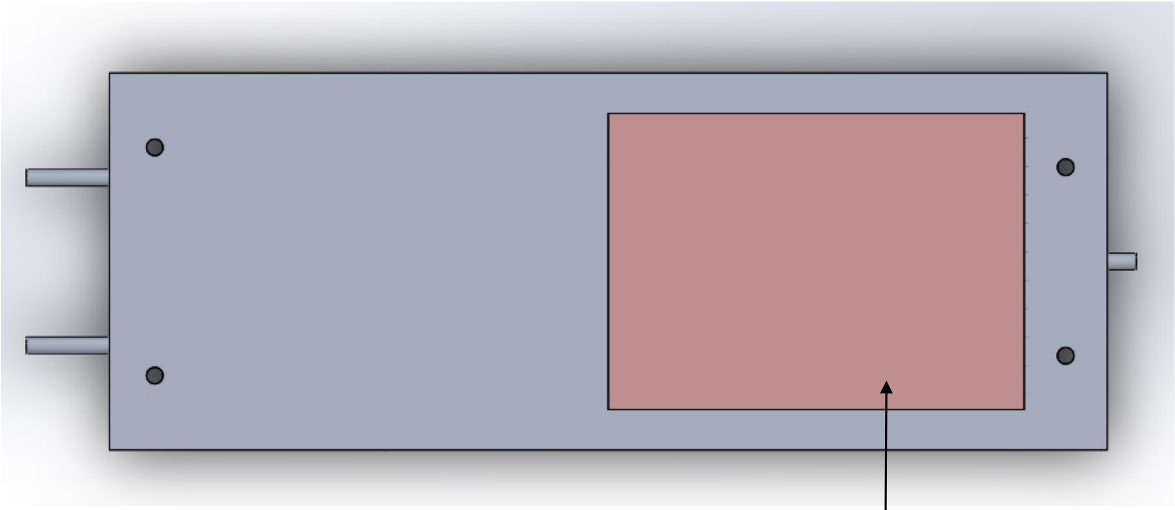






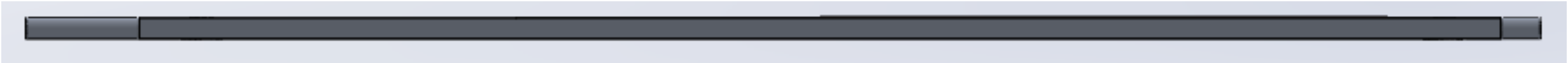
CubeSTEP Cerberus

Passive OHP



Top View

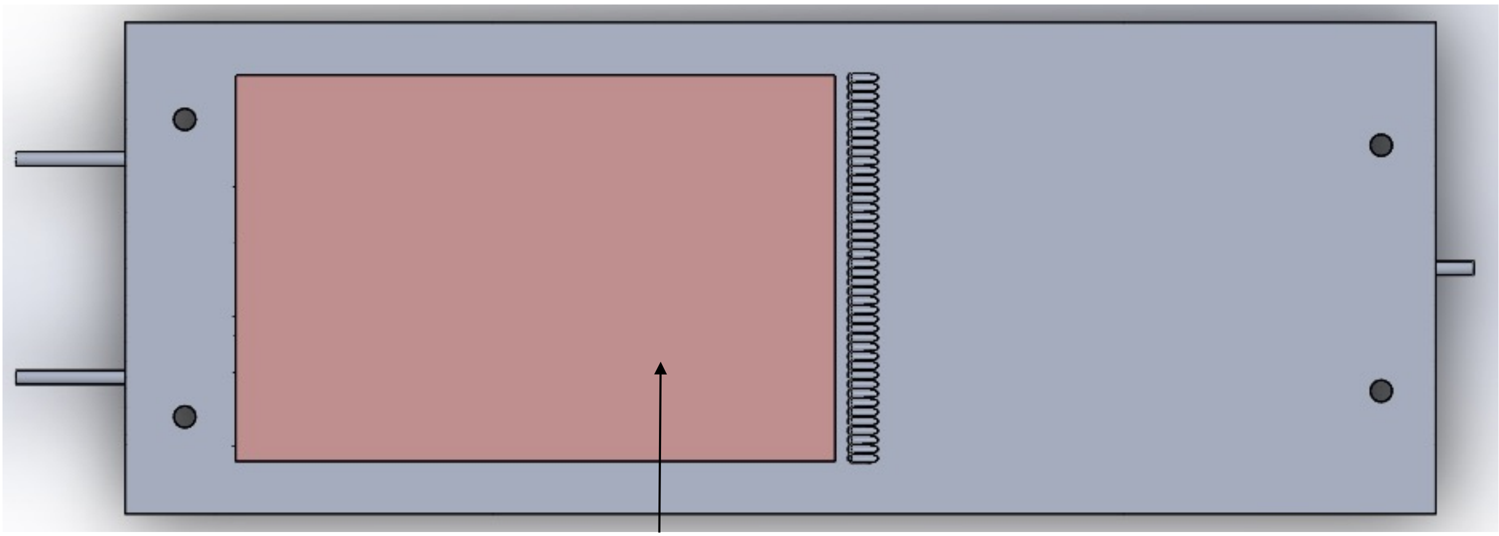
Patch Heater Placement



Side View

CubeSTEP Cerberus

Check Valve OHP



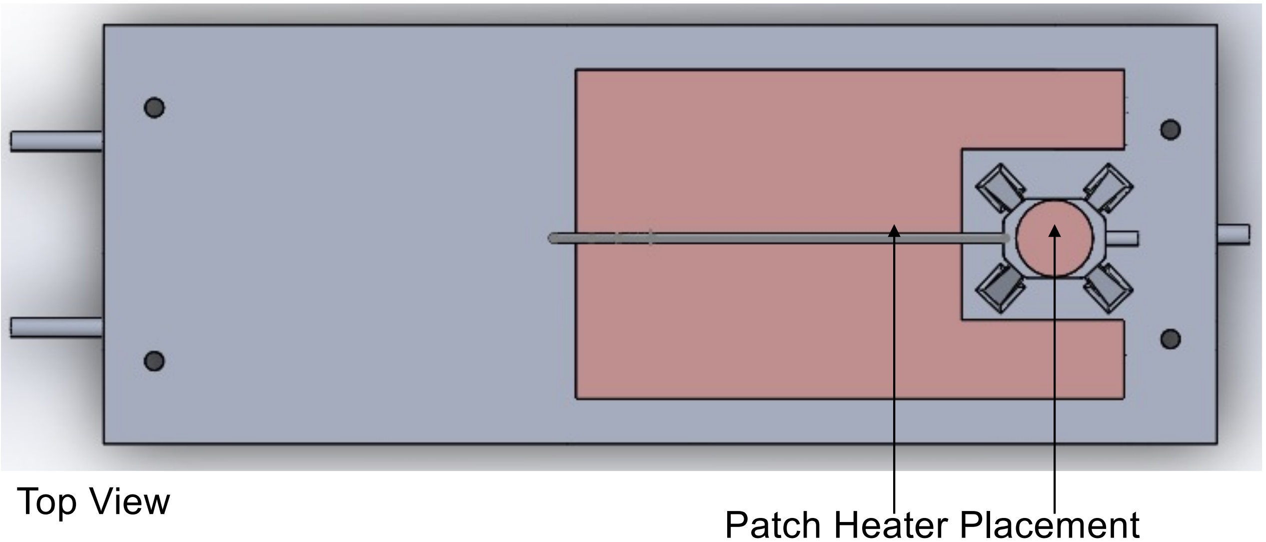
Top View

Patch Heater Placement

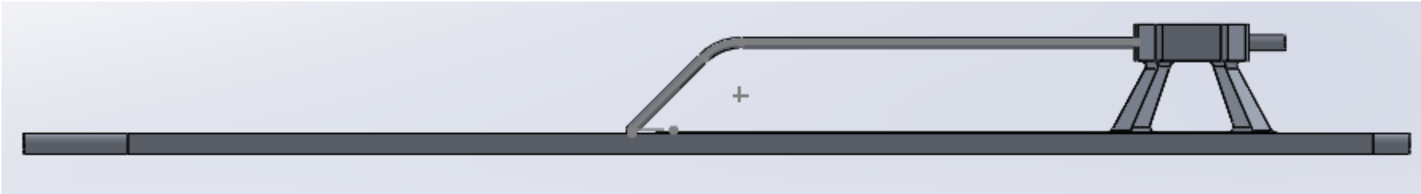
Side View

CubeSTEP Cerberus

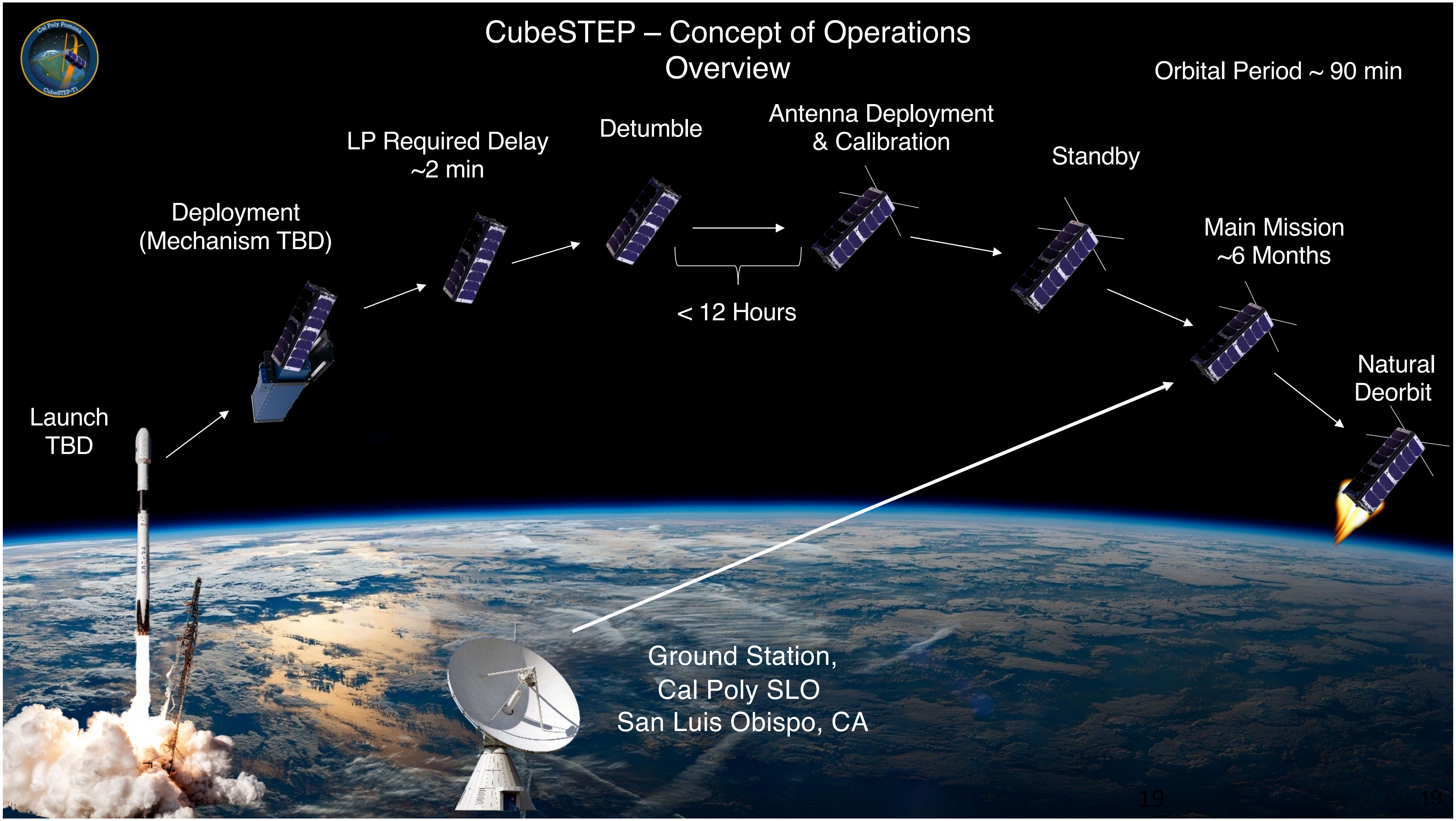
Thermal Reservoir OHP

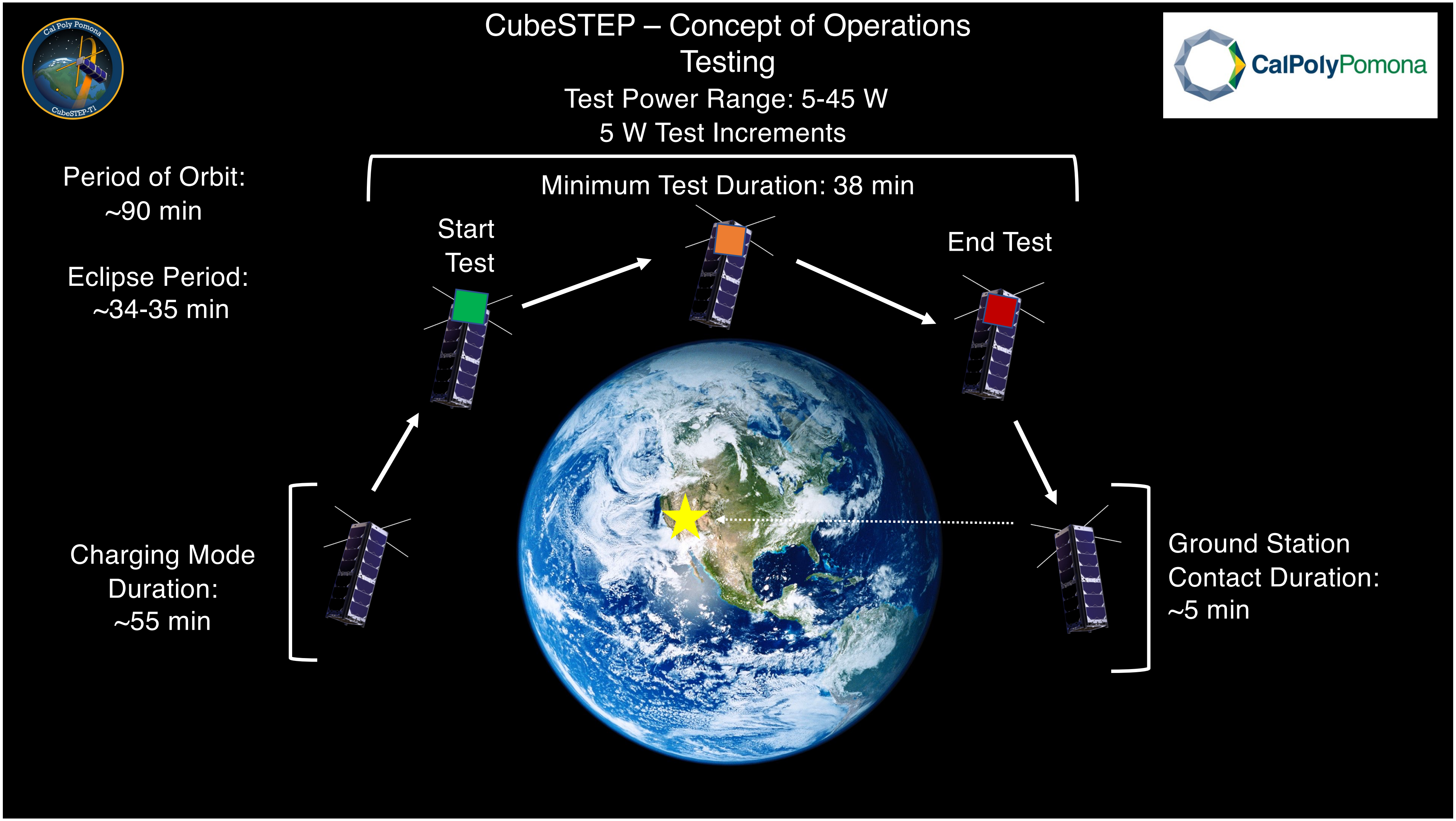


Top View



Side View


CubeSTEP – Concept of Operations Overview
Orbital Period ~ 90 min
Launch TBD
Deployment (Mechanism TBD)
LP Required Delay ~2 min
Detumble
Antenna Deployment & Calibration
< 12 Hours
Standby
Main Mission ~6 Months
Natural Deorbit
Ground Station, Cal Poly SLO San Luis Obispo, CA


CubeSTEP – Concept of Operations
Testing
Test Power Range: 5-45 W
5 W Test Increments
Cal Poly Pomona
CubeSTEP-TI
CalPolyPomona
Period of Orbit:
~90 min
Eclipse Period:
~34-35 min
Minimum Test Duration: 38 min
Start
Test
End Test
Charging Mode
Duration:
~55 min
Ground Station
Contact Duration:
~5 min

Conclusion

- Additive manufacturing is a critical tool in designing a universal testbed
  - Enables the design of complex geometries
  - Diverse technologies can be integrated directly into bus structure
- Challenges to be overcome:
  - Mechanical, Electrical, & Data Interfaces
  - Modular Flight Software

Next Steps

2024 Spring — Design & PDR

The team focuses on designing the new OHPs, as well as changes to the COTS components and structure. A PDR level review is conducted

2024 Summer — Manufacturing & CDR

The new OHPs will be printed, and a CDR level review will be conducted

2024 Fall — OHP & Structure Testing

The passive, check valve, and thermal reservoir OHPs will be tested in a vacuum chamber on campus. The structure will undergo vibrations and EMI testing

2025 Spring — Integration & Final Reports

The structure, OHPs, and COTS will be integrated. Flight safety report will be completed

2025 Fall — Launch

CubeSTEP will have our first launch, data from the OHPs will be monitored for the main mission duration of 6 months

2026 Spring — Return To Battery Case

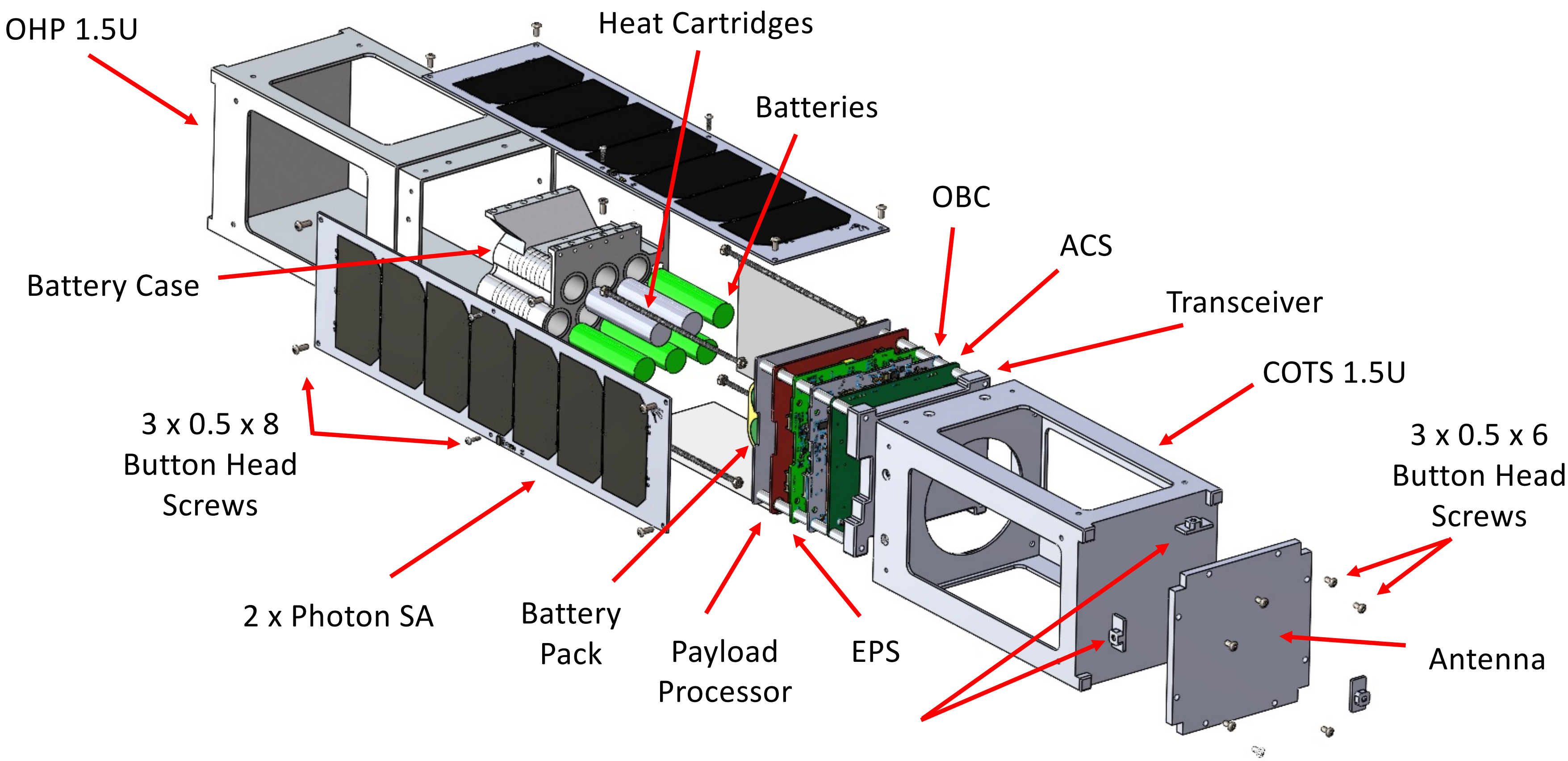
CubeSTEP will return focus back to the battery case, optimizing it based off information learned from the in-flight performance of the flat plate OHPs

Thank you!

Appendix

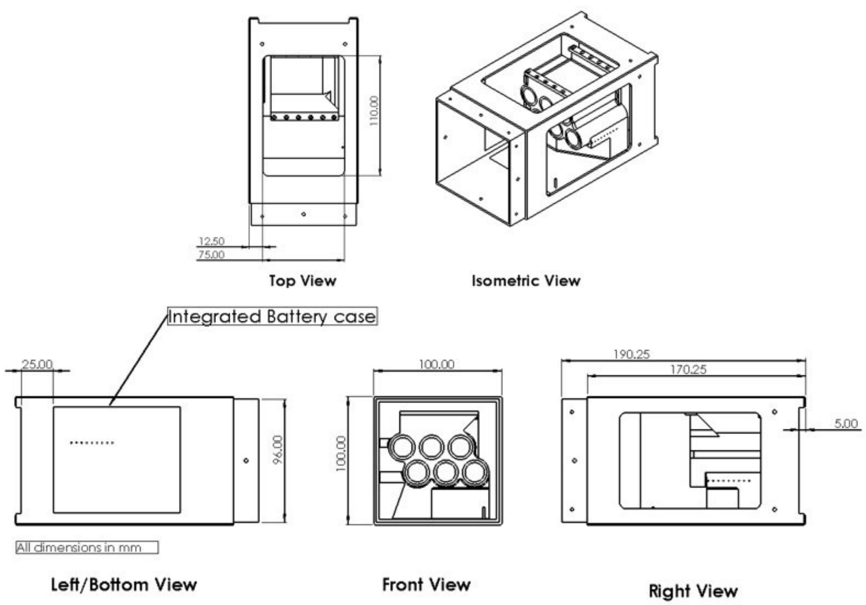
Structures

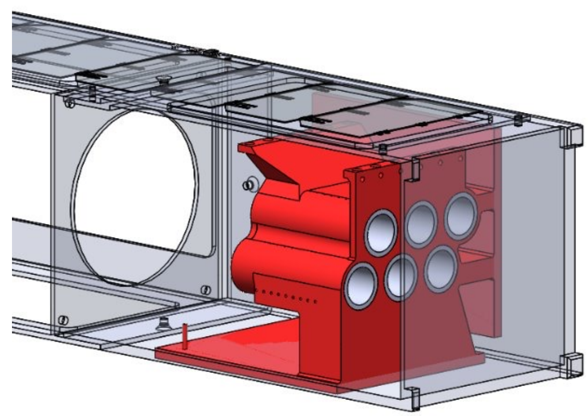
Exploded View of 3U CubeSat



AM - OHP Integration

OHP Battery Case Embedded in Structure





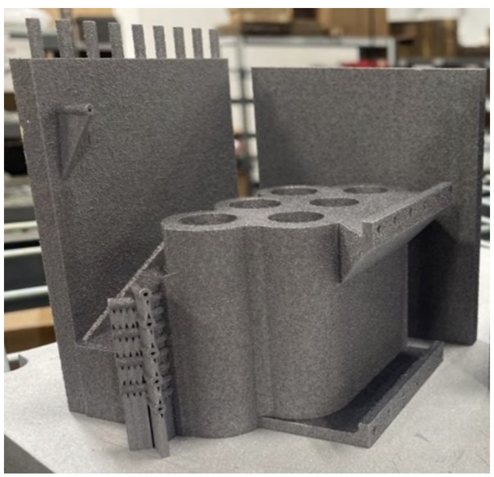
OHP –Battery Case Embedded Into Structure

Design and Manufacturing

Payload

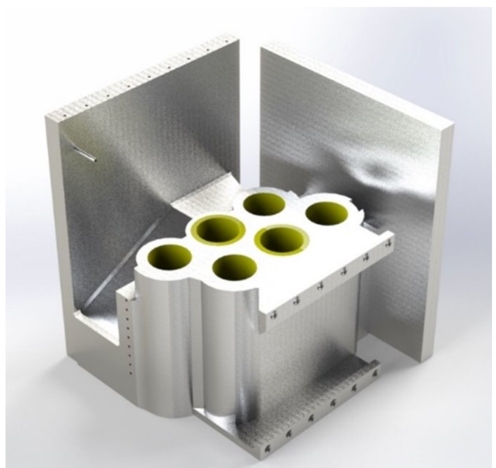
Design

Optimal geometry
utilizing minimal material
ANSYS & nTopology



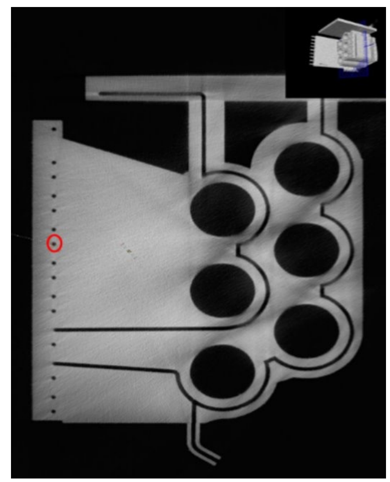
Fabrication

Powder Bed Fusion
AlSi10Mg
Achieve complex geometry



Post Processing

Post printing CT Scan
Powder Detection
Powder removal



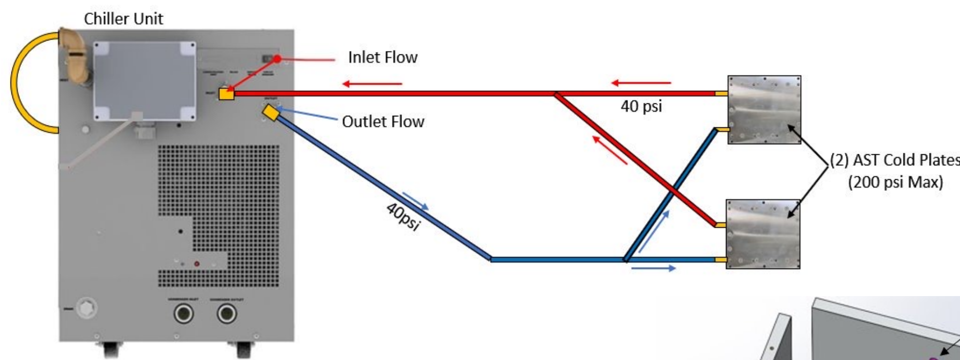
Post Processing

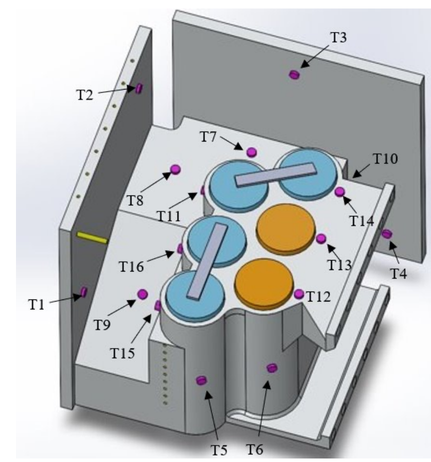
Remove drain port & weld
Charge valve & fill R134a
Leak test

Ground Testing

Chiller Testing

- Objective:
  - Characterize & test functionality of charged vs. uncharged battery case
- Method:
  - Tested OHP filled to 49.7% with R134a and empty
  - Used Chiller with cold plates to simulated space environment
  - Tested at 45° orientation
  - Tested at 25° C
  - Tested at 40 PSI

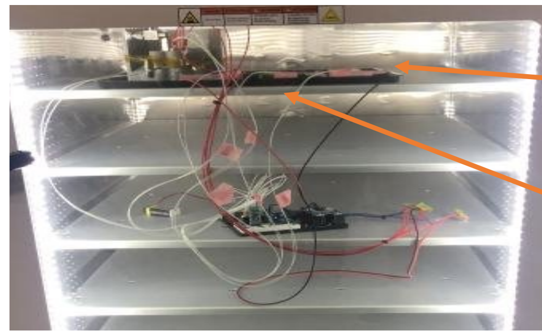


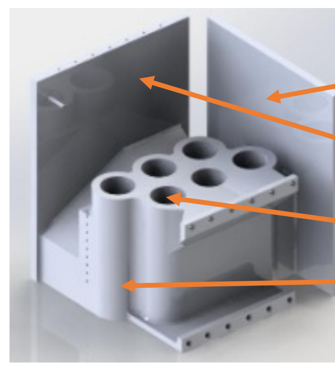


Ground Testing

Vacuum Testing

- Objective:
  - Determine proper OHP thermal load under radiative cooling environment
  - Characterize OHP under extreme heat loads
  - Characterize & optimize battery configuration
    - Used heat cartridges to simulate extreme battery temperatures
- Method:
  - OHP with thermal cartridges inside, hooked up to lithium-ion batteries, placed in vacuum chamber
  - Vary duty cycle of thermal cartridges
  - Record temperature data at 6 points on OHP, batteries and thermal cartridges using thermistors

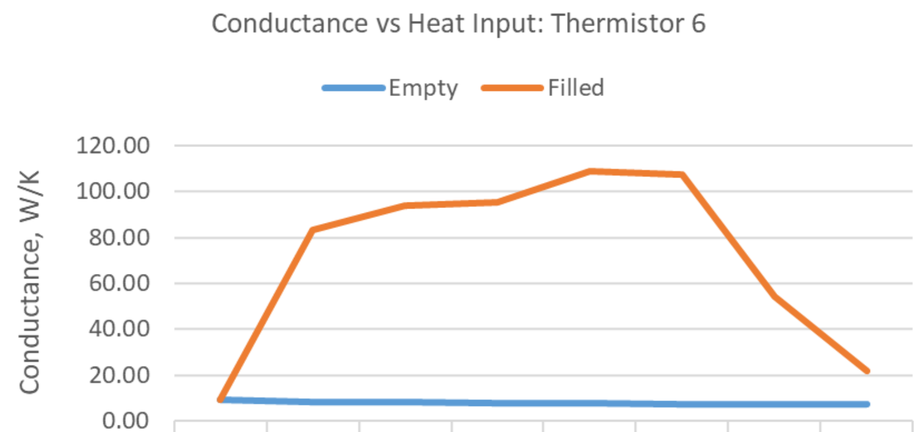




Performance

Chiller Test Results

- Chiller Test Results
  - 14.5x peak increase in conductivity
  - Matched expectations of JPL technologist
  - Demonstrated dry-out as expected

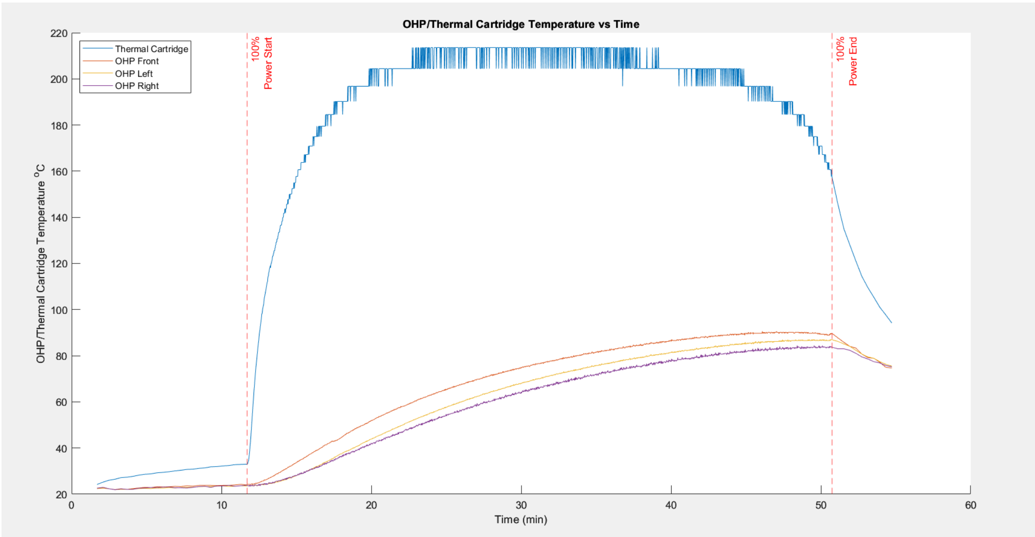


	5	10	15	20	25	30	45	60
Empty	9.09	8.20	7.98	7.69	7.65	7.39	7.33	7.28
Filled	9.26	83.3	93.7	95.2	109	107	54.2	22.0

Performance

Vacuum Test Results

- Vacuum Testing
  - Battery output determined to be optimized in a series configuration
  - OHP effectively mitigates thermal runaway
    - Heat cartridges reached up to 213°C while battery case averaged ~87°C
    - Average battery temperature in series was ~60°C



System Level Design