BeaverCube: Coastal Imaging with VIS/LWIR CubeSats

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Agenda:

● Mission Overview
● Concept of Operations
● Subsystems
● Path Forward
● Acknowledgements

*Image credit: P. do Vale Pereira (MIT)*
Mission Overview
Mission Objectives

● Cloud top and ocean infrared data yield important insights
  ○ Scientific study of Earth’s climate and weather
  ○ Large satellite platforms are expensive and offer limited observation frequency and locations

● This mission seeks to
  ○ Prove use of CubeSat platform to gather measurements using relatively low-cost cameras
  ○ Demonstrate operation of Accion’s Tiled Ionic Liquid Electrospray (TILE) propulsion technology for orbital maneuvering
  ○ Serve as an educational exercise for students

● Future missions:
  ○ Constellations to expand measurement frequency/coverage

Visual+IR data post hurricane Florence [1]

Accion TILE Electrospray Thruster[2]
Main Mission Objectives

BeaverCube shall:
- Successfully capture a minimum of **20 infrared and 10 visual images** of the Earth;
- Measure **ocean color as well as sea surface and cloud top temperature**;
- Downlink scientific data (space-to-Earth) and uplink (Earth-to-space) commands to the **MIT UHF ground station**
- Operate for at least **90 days**;
- Perform **orbital altitude** changes.
Conops: Launch and Initialization

BeaverCube:
- Altitude: ~405 km
- Inclination: 51.6 degrees

Image credit: A. Frey and T. Wells (MIT)
ConOps: Operations

Image Collection

GlobalStar Beaconing

GPS

Uplink
Uplink Frequency: 450 MHz

BeaverCube

Downlink
Downlink Frequency: 401.5 MHz

MIT UHF Ground Station

Propulsive Maneuvers

End of Life

Image credit: A. Frey and T. Wells (MIT)
High Level CAD

Image credit: P. do Vale Pereira (MIT)
BeaverCube CAD

Primary Antenna (forward)

GPS Antenna

Imaging Payload

Solar Panels

Propulsion (aft)

Image credit: M. Campbell and T. Tran (MIT)
Structures - CAD

- 2 mm thick solar panels
- 2.5 mm tall bolt heads
- 19 mm allowable protrusion

| Center of Mass [mm] (With respect to the geometric center) |
|------------------|------------------|
| X                | -0.17            |
| Y                | +0.63            |
| Z                | -14.94           |

Image credit: M. Campbell, J. Coray and T. Tran (MIT)
Command & Data Handling
Hardware - C&DH BFC Render

Image credit: C. Lindsay, E. Sit, B. John (MIT)
Approach - Payload
Payload - Science Motivation

• Deliver high resolution imagery in an area of importance for ocean warming and commercial fisheries.
  – Cape Hatteras
  – New England

• The targeted sites are co-located with important research infrastructure, particularly the Ocean Observatories Initiative Pioneer Array

• The region is also subject to damaging storms from both tropical and extra-tropical systems

Image and Content Credit: S. Baber, A. Miller (MIT) and JHU APL

• The above image, generated using MetOp, (EUMETSAT series), GOES, Meteosat, and Suomi NPP, shows the temperature anomaly in degrees celsius between 1985 to 2012.
Payload: Science Motivation

**Sea Surface Temperature (SST)** is an indicator for temperature anomalies in the ocean and can be used to forecast storms and climate change trends.

**BeaverCube** payload is equipped with two **thermal IR cameras** and a **visual camera** to detect high spatial and temporal resolution images to measure both SST and ocean color.

**Ocean Color** is used to measure phytoplankton concentration in a region and can indicate the biological productivity of the region. It can also be used to track Colored Dissolved Organic Matter (CDOM), and can be used to track surface current patterns.

The data from **BeaverCube** will help **WHOI** develop higher resolution models of regional ocean processes. These models could help with **weather forecasts** and help predict migration patterns of marine life and help the **local fishing industry**.
Payload- Overview

**Goal:** Measure ocean color and sea surface temperature

**Hardware:**

- 2 IR Cameras
  - 11.5-12.5 um (M16 band)
  - 7.5-13.5um (Entire IR band)
- 1 Visual camera
  - 400-700 nm (Visual Spectrum)

**Parameters Measured:**

- **Sea Surface Temperature (SST)** - an indicator for temperature anomalies, weather patterns, and climate change
- **Ocean Color** - indicates the biological productivity of the region

*Image and Content Credit: S. Austin, M. Garcia, T. Tran, M. Campbell, J. Coray (MIT)*
Payload- Phases Overview

**Ground Station Pass (MIT):**
- Uplink target information
- Downlink science and calibration images

**Imaging:**
- Cameras take calibration and science images
  - Involves timed camera power on and power off

**Post-Processing:**
- Calculate the gain factor from calibration buoy images
  - Apply to science images
Payload: Vicarious Calibration for IR and VIS Cameras

Predict when BeaverCube will directly overpass a buoy.

Capture calibration image.

Relate bulk water temperature to water skin temperature measured by BeaverCube at the buoy site. (IR only)

Identify the pixel area corresponding to buoy with IMU data and flight path simulation.

Calculate gain value for the image.

*Image and Content Credit: Alex Miller and S. Baber (MIT)*
Payload- IR/VIS Cross Calibration with satellites

- **Predict** coincident events
- **Correct** data for atmosphere, viewing angle, clouds
- **Calculate** brightness temperature for both BeaverCube and crosscal target
- **Designate** cross cal satellite as “ground truth”

Image and Content Credit: S. Baber and A. Miller (MIT)
Calibration Target Modeling: Satellites

Image Credit: S. Baber and A. Miller (MIT)
Payload - Balloon Launch with Thermal and NoIR Cameras

Image Credit: S. Baber, M. Garcia, K. Clark (MIT)
Payload - Balloon Launch with Thermal and Visible Imaging Cameras

Raspberry Pi NoIR Camera Module V2 - 8MP

Boson Thermal Imaging Camera

Image Credit: S. Baber
Approach - Propulsion
Propulsion: Design to Meet Requirements, Electrospray

- Ionic liquid propellant in fuel reservoir
- Emitter chip with many emitter tips
- Voltage applied between emitter chip and extractor grid (1 - 2kV)

Adapted from http://www.mollahasan.com/
Propulsion: Design to Meet Requirements, Electrospray

- Electric force overcomes surface tension
- Ions evaporated from tips
- Ions accelerated in electric field between tip and extractor producing thrust

Adapted from http://www.mollahasan.com/
Propulsion: Design to Meet Requirements, Accion

System Design
- Propellant: Ionic Liquid
- Size: 0.5U
- Mass: 0.5 kg
- Number of Thrusters: 4

System Capabilities
- Thrust: 50 μN per .5U unit
- $I_{SP}$: 1800s
- Acceleration: 12.5 μm/s^2
- Torque: 5E-7 Nm

Image Credit: Accion Systems and M. Schroeder (MIT)
Propulsion: Translational Maneuvers

- Demonstrate electrospray capability through orbit raising maneuvers
- For safety:
  - Propagate until at safe and approved altitude below ISS
  - Wait until primary imaging science mission downlinks images successfully
  - Maneuvering will be approved by NASA and CSpOC before initiation
  - Can be attempted multiple times until detectable maneuver is made

Image Credit: M. Schoeder (MIT)
Propulsion: Translational Maneuvers

- Maneuvers will be detected using GPS measurements.
- GPS altitude readings from before and after maneuvers will be downlinked with propulsion system telemetry data after each firing.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Thrust</td>
<td>50 μN</td>
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<tr>
<td>Burn Time</td>
<td>3.5 hours</td>
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<tr>
<td>Acceleration</td>
<td>12.5 μm/s^s</td>
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<tr>
<td>Altitude Change</td>
<td>280.6 m</td>
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Status & Next Steps
BeaverCube Status

Week of June 29th, 2020

Hardware:
- All Engineering Model COTS components have been ordered, waiting on delivery of NSL BlackBox
- Thermal, CnDH, GPS, and OpenLST Rev1 boards have been received and tested
- Payload structure Rev1 complete
- Rev1 rails ordered, preliminary fit checks completed
- Propulsion system ready for integration

Software:
- Payload, comms drivers complete;
- Writing power scripts

Image Credit: T. Tran, M. Garcia, C. Lindsay, E. Sit, A. Choi
Systems: Schedule Milestones

● May 2020:
  ○ Fit check of main components
  ○ TRR
  ○ Mass Mockup Vibration Test

● August 2020:
  ○ Space Vehicle Integration
  ○ Thermal Vacuum Test
  ○ Vibration Test Report Completion

● September 2020:
  ○ Handover to Launch Service Provider

● Late 2020:
  ○ Launch
Thank you for listening!

For questions, contact:
beavercube-staff@mit.edu

Image credit: P. do Vale Pereira (MIT)