CubeSat Proximity Operations Demonstration (CPOD) Mission Update

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Small Satellite Conference
Logan, Utah
August 11th, 2015
Company Overview

• **Founded in 2011**
  – Co-founders blend academia and commercial experience

• **30+ employees**
  – Eclectic leadership experienced in Traditional and New Space
  – Cradle of “Young Veterans” involved in developing, testing, operating and launching next-generation NanoSatellites

• **Locations**
  – Headquarter in Irvine, CA
    • 8,700 ft² facility to support Vehicle Systems Group
  – San Luis Obispo, CA
    • Offices and lab hosting the Launch Services Group
  – International subsidiary in Torino, Italy
CPOD ConOps Overview - Designed to Maximize Mission Success Probability

1. Mission Operations Center
2. Launch
3. Release together from 6U dispenser
4. a. Initial SOH Checkout
   b. Separate and Continue Checkout
   c. Orbit Maneuvering to Initial Proximity Distance (Walking Safety Ellipse)
5. CubeSat A performs RPO relative to CubeSat B
6. Decreased Range RPO & Docking Scenarios
7. Residual Ops
8. Disposal

Main RPO Experiment Phases
Mission-Planning / Pre-Launch
CPOD Rendezvous and Docking ConOps

△GPS via ISL

<table>
<thead>
<tr>
<th>ISL Ranging</th>
<th>NFOV Bearings</th>
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Rbar

Inject into Walking Safety Ellipse

5.1 Initiate Safety Ellipse

5.2 Drift km’s during checkout

Vbar

Stabilize into Safety Ellipse about CubeSatB

5.3

Reduce Size Safety Ellipses & NFOV checkout

NFOV Ranging

5.4

Docking Ranging

IR1 B & R

IR2 B & R

Docking Bearings

Docking Ranging

Approach to WP1

Approach to WP2

Transfer to V-bar

Transfer to InPlane NMC

Reduced Size NMC

Docking Sensor checkout

NFOV Bearings & Ranging

Approach & Dock

7.6

7.5

7.4

7.3

7.2

7.1

6.3

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CPOD Vehicle Configuration
-External Isometric Views

- Thermal Radiators
- GPS Patch
- S-Band Patch
- Separation Devices
- Docking Mechanism
- Solar Panel Arrays with MPPTs
- Star Trackers
- UHF Antennas
- Thermal Radiator
CPOD Vehicle Configuration
-Internal Arrangement and Packaging

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GPS Receiver
Battery Module
S-Band Transmitter
UHF Radio
Cold Gas Thrusters (8)
Inertial Reference Module (IRM)
Battery Module
Endeavour Bus
Propulsion Module
RPOD Module
# CPOD Performance Summary

<table>
<thead>
<tr>
<th>Capability</th>
<th>Specification</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Power Generated</td>
<td>17W</td>
<td>Polar Sun-Sync Orbit Average</td>
</tr>
<tr>
<td>Average Load</td>
<td>15W</td>
<td>Fully Active</td>
</tr>
<tr>
<td>Pointing Accuracy</td>
<td>0.2 degrees (three sigma)</td>
<td>Inclusive of knowledge &amp; control error</td>
</tr>
<tr>
<td>Mission Data Downlink</td>
<td>~60MB / day</td>
<td>UHF TTC S-Band Downlink</td>
</tr>
<tr>
<td>Delta-V</td>
<td>~25 m/s</td>
<td>Cold Gas</td>
</tr>
<tr>
<td>Total Mass</td>
<td>5.5kg</td>
<td>Wet Mass</td>
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CPOD Environmental Testing

- **Early component and subsystem environmental testing used to reduce risk of issues at system level**
  - Risk reduction environmental testing completed on low TRL components (RWA, battery module, star camera, and IMU show on right)
  - Modules used to enable testing complex sub-systems before full vehicle integration (IRM, RPOD, etc.)

- **Lessons Learned**
  - Thermal test before thermal vacuum testing
  - Design for repeated assembly and disassembly of complex modules
  - Feature rich test interfaces are invaluable when attempting to understand issues without deintegration
  - Testing with non flight like surface finishes may hide surface roughness issues
CPOD Integrated Flat-Satellites

**Accomplishments to date**
- EDU avionics bring-up complete with 100% of subsystems functionally verified
- Integration risk reduced by interfacing to flight representative subsystems early in the program
- Complex low-level bus protocols functionally verified with flight data rates and electrical connectivity

**Lessons Learned**
- Several concurrent partial flatsats are needed for complex missions
- Flatsat configuration important to consider when designing tightly integrated systems (i.e. can it even be built as a flatsat)
CPOD Hardware in the Loop (HITL) Testing

• **Complex distributed ADCS/GNC system necessitated real time hardware in the loop testing**
  – Sensors and actuators simulated in real time with flight like dynamics
  – Autocoded truth and flight code enable rapid iteration and commonality between software only simulation and HITL testing

• **HITL platform fully operational**
  – Closed loop propulsive maneuvers demonstrated

• **Lessons Learned**
  – HITL testing is possible for CubeSat class missions
  – HITL interfaces should be included in system and EGSE design from initial conception
CPOD Air Table Testing (Video)
CPOD Development Status

- EDU vehicle assembled and fully qualification tested
- Flight vehicles fully assembled and undergoing final environmental testing
- Manifested on US launch scheduled for late 2016
- Pursuing follow on missions to transition from technology demonstration to operational missions
Questions?