CubeSat Proximity Operations Demonstration (CPOD) Vehicle Avionics and Design

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VP, Space Vehicles
# CPOD: Big Capability in a Small Package

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<tr>
<th><strong>Communications</strong></th>
<th>Directional Simplex S-band to Ground (2.2Ghz)</th>
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<tr>
<td></td>
<td>Directional Half-Duplex Inter-Satellite Link (ISL) (2.4Ghz)</td>
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<tr>
<td></td>
<td>Omni-Directional Half-Duplex UHF (400Mhz)</td>
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<tr>
<td><strong>ADCS</strong></td>
<td>3-Axis Multi-Objective Pointing with Momentum Dumping</td>
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<td></td>
<td>Contingency Coarse Pointing Mode</td>
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<td></td>
<td>Ground Tracking, Inertial Pointing, LVLH, Sun</td>
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<tr>
<td><strong>Navigation</strong></td>
<td>GPS L1 for Position and Velocity</td>
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<tr>
<td></td>
<td>Relative Bearing and Distance Determination (Optical, RF)</td>
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<td></td>
<td>Relative Attitude Determination (Optical)</td>
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<td>On-Board Navigation Solutions and Delta-V for Manuevers</td>
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<tr>
<td><strong>EPS</strong></td>
<td>Sufficient Peak Power, and Energy Storage</td>
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<td>Distributed Power Interfaces to Subsystems</td>
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<td>Docking Mechanism (Electro-Magnet)</td>
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<td><strong>Mechanical</strong></td>
<td>Deployables (UHF Antenna, Solar Panels, Vehicle Separation)</td>
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<td><strong>C&amp;DH</strong></td>
<td>Vehicle Monitoring and Control</td>
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<td>Fault Management</td>
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<td>Inter-Processor Communication</td>
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Space Vehicle Architecture

EPS
- Health & State Sensors
- Heater
- Power Sequencing

COMM
- S-BAND (downlink)
- UHF
- GPS
- Inter-Satellite link (Comm / Ranging)

RPO
- Wide Field Visible Imager
- Infrared Imager
- Docking Sensor
- Relative Position Estimation Processor (Imaging Processor)
- Maneuver Planning Processor (GN&C)
- Docking Mechanism
- Optical Target Aid

ADCS
- State Estimation & Control Processor
- 3-axis IMU
- Star Trackers w/ dedicated processing
- 3-axis Reaction Wheel Set
- 3-axis Sun Sensor Set
- 3-axis Magnetometer Set
- 3-axis Mag. Torquer Set
- 8-thruster Cold Gas

CONTRIBUTIONS
- Tyvak Nano-Satellite Systems
- Applied Defense Solutions
- Tyvak (Prev. 406 Aerospace)
- VACCO
CPOD Configuration

- Navigation Solutions, GPS, Docking Mechanism
- Cold Gas Propulsion
- C&DH, ADCS
- EPS
- UHF S-Band
- Side Panel Backplane Interface, Patch Antennas, and Charge Controllers

- 4x Radios
- 6x Antennas
- 5x Linux Computers
- 3x Microcontrollers
- 4x Deployables
- 6x Imagers

Tyvak Nano-Satellite Systems Inc.
Endeavor Vehicle: C&DH and ADCS 1/2U Solution

- **C&DH Linux Processor**
  - Arm9 @ 400Mhz
- **ADCS Linux Processor**
  - Arm Cortex-A8 @ 800Mhz
- **Reaction Wheels (x3)**
  - 10mn-m-s; 3mN-m; 10000 RPM Max
- **Star Trackers (x2) and IMU**
  - Pitch/Yaw/Roll 10/10/80” 1σ
- **Magnetorquers (x3)**
  - 0.1 A-m^2 in all axis

*Baffles Not Shown*
EPS – Battery Module and Solar Panels

• **Battery Module Features**
  – 11.1V Unregulated System
  – Greater than 80 watt power output capability
  – Greater than 40 watt power input (charge) capability
  – Temperature & power sensor telemetry
  – Fail-safe battery heater controller
  – Dual deployment switch power output inhibit

• **Solar Panels**
  – Supports 3 to 5 cell strings
  – Maximum Peak Power Tracking on Panels
  – Deployable Configurations Available
  – Thermal radiators
  – Panels customized for the mission
RF Communications

- **GPS Patch Antenna**
  - L1 Band, Two Phased Elements

- **Inter-Satellite Link**
  - 250kbps, RF Ranging @ 2.4Ghz

- **UHF Half-Duplex Radio**
  - 9.6kbps GMSK @ 400Mhz

- **S-Band Transmitter**
  - 1Mbps BPSK @ 2.2Ghz

- **Deployable UHF Antenna**
  - Omni-directional

- **S-Band Patch Antenna**
  - Two Switched Elements
## CPOD Performance Summary

<table>
<thead>
<tr>
<th>Capability</th>
<th>Specification</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Average Power Generated</td>
<td>~17W to 30W OAP</td>
<td>Polar Sun-Sync</td>
</tr>
<tr>
<td>Average Load</td>
<td>~15W</td>
<td>Fully Active</td>
</tr>
<tr>
<td>Pointing Accuracy</td>
<td>&lt;0.15 degrees</td>
<td>Star Trackers available under all mission scenarios</td>
</tr>
<tr>
<td>Mission Data Downlink</td>
<td>~60MB / day</td>
<td>UHF and S-Band</td>
</tr>
<tr>
<td>Delta-V</td>
<td>~30 m/s</td>
<td>Cold Gas</td>
</tr>
<tr>
<td>Total Mass</td>
<td>5.990kg</td>
<td>Wet Mass (13% Margin)</td>
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Component and Subsystem 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 subsystems 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
# Vehicle Level Avionics Testing

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<tr>
<th>Test</th>
<th>Description</th>
<th>Status</th>
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<tr>
<td>Self RF Compatibility</td>
<td>Verify all radios operate to specification under all vehicle operational scenarios</td>
<td>Passed</td>
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<tr>
<td>Anechoic Chamber Testing</td>
<td>Perform anechoic chamber test of S-Band, ISL, and UHF Antennas</td>
<td>Passed</td>
</tr>
<tr>
<td>GPS Lock</td>
<td>Check that vehicle achieves GPS lock under all operating modes</td>
<td>Passed</td>
</tr>
<tr>
<td>Hardware In The Loop</td>
<td>Guidance, Navigation and Control simulations driving flight-like actuators</td>
<td>Passed</td>
</tr>
<tr>
<td>Night Sky Testing</td>
<td>Outdoor Night sky testing of IRM</td>
<td>Passed</td>
</tr>
<tr>
<td>Payload Calibration and Sensor Alignments</td>
<td>2 Visible, and 2 IR Imagers aligned with star-trackers and IMU.</td>
<td>Passed</td>
</tr>
<tr>
<td>Vibration</td>
<td>22 grms vibration test</td>
<td>Passed</td>
</tr>
<tr>
<td>Thermal Vacuum</td>
<td>Complete vehicle operations over thermal vacuum cycles</td>
<td>Passed</td>
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Questions?