System Assessment of a High Power 3-U CubeSat

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Overview

• Advanced Electrical Bus CubeSat Overview
• Driving Requirements and Constraints
• Power Generation and Storage Solutions
• Thermal Management Solutions
• Packaging
• Conclusion
Advanced Electrical Bus CubeSat Project

• Pathfinder technology demonstration mission for high power CubeSats
  – Demonstrate 100 W distribution of electrical power to a target load
  – Develop a reliable retention and release mechanism for deployable arrays
  – Develop solutions for high power system integration

• Objectives
  – *Resettable* retention and release mechanisms
  – Demonstrate *dual function* hinges for array deployment and power transfer
  – End to end power management and distribution efficiency
  – Assess on-orbit *performance* of battery management system
  – Adequate thermal management to demonstrate *operation* of the power management and distribution subsystem in 3-U CubeSat form factor
Driving Requirements

- Distribute 100 W of power to target load
- Maintain electronics within de-rated temperature limits

<table>
<thead>
<tr>
<th>Waste Heat (W) by Operational Mode</th>
<th>Temp Limits (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
</tr>
<tr>
<td>Quiescent, Not Charging</td>
<td></td>
</tr>
<tr>
<td>Quiescent, Charging</td>
<td></td>
</tr>
<tr>
<td>Transmit</td>
<td></td>
</tr>
<tr>
<td>Test</td>
<td></td>
</tr>
<tr>
<td><strong>Discharge Circuit</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>C&amp;DH</strong></td>
<td>0.5</td>
</tr>
<tr>
<td><strong>Boost</strong></td>
<td>0.0</td>
</tr>
<tr>
<td><strong>BMS</strong></td>
<td>0.6</td>
</tr>
<tr>
<td><strong>Batteries</strong></td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Radio</strong></td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>13</td>
</tr>
</tbody>
</table>
3-U Surface Area Constraint

- **Power Generation Capability**
  - 0.03 m$^2$, 28% efficient UTJ cells, 70% Packing Density
  - ~7 - 10 W power generation without active attitude control

- **Thermal Radiation Emissive Power**
  - Assuming .12 m$^2$, $\varepsilon=0.9$, *Steady State* Surface Temp 85 C to maintain high power electronics below temperature limits, Average Sink Temperature of 225 K
  - 84 W of emissive power if entire 3-U CubeSat area is a radiator

- Concluded that power and thermal management needs for 3-U CubeSat require thermal and energy storage solutions
Power Management and Distribution

- 4 Body Mounted + 4 Deployable Arrays (COTS)
  - 7S, 2P configuration
  - 10 W generation
- Super elastic Shape Memory Alloy (SMA) hinges provide deployment spring force and power transfer
- Activated SMA resettable retention and release mechanism
- Boost Convertor Battery Charging System
- 80 W-hr COTS Battery Pack
  - 14.4 V, 7 A
  - Discharged at 1.25 C
- Cell balancing battery management system
- Regulated discharge system
  - 95% efficiency
Thermal Management

• Store thermal energy from 100 W discharge
  – 100 W electrical power \(\rightarrow\) 100 W of heat is unique to this mission
  – Isolate from the rest of the system as much as possible
• Use body area of CubeSat to reject electronics waste heat and generate power
  – Body mounted solar arrays decrease effective emissive power but adequate to reject electronics waste heat
  – Demonstrate that 3-U CubeSat is capable of managing heat loads from power management and control electronics without additional design
• Options considered
Thermal Management Solution

- 100 W Discharge Circuit
  - 350 g Aluminum Heat Sink
  - Silver Coated Teflon surface finish
  - Isolated from chassis with polymers

- PMAD and C&DH waste heat
  - Bulkhead with conductive path to chassis for electronics with high heat loads
  - Thermally conductive, electrically isolating interface between chassis and body mounted solar arrays
  - Arrays reject heat

- Radio – high emissivity coating to reject heat during peak uplink/downlink transients
• 350 g heat sink provides ~3 minutes of run time with 100 W distribution at 20 C initial condition
Mass and Volume

### Deployment Mechanism

- **Concepts**
  - Push Plate
  - ~30% Internal Volume
  - 15% System Mass

- **Preliminary Designs**
  - Collet
  - ~30% Internal Volume
  - 15% System Mass

- **Final Designs**
  - Pin Puller
  - ~20% Internal Volume
  - 5% System Mass

### 100 W Thermal Management

- **Concepts**
  - PCM Heat Sink
  - 40 min run time
  - ~30% Internal Volume
  - >30% System mass

- **Preliminary Designs**
  - Heat Sink
  - 10 min run time
  - 16% Internal Volume
  - 12% System mass

- **Final Designs**
  - Heat Sink
  - 4 min run time
  - 9% Internal Volume
  - 9% System Mass

### Power Generation

- **Concepts**
  - Body and Deployable Arrays
  - 14 W
  - 28% System mass

- **Preliminary Designs**
  - Body and Deployable Arrays
  - 14 W
  - 28% System mass

- **Final Designs**
  - Body and Deployable Arrays
  - 10 W
  - 16% System mass

### Storage

- **Concepts**
  - 80 W-hr COTS pack
  - 12% System mass

- **Preliminary Designs**
  - 80 W-hr COTS pack
  - 12% System mass

- **Final Designs**
  - 80 W-hr COTS pack
  - 12% System mass
## Packaging

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass (g)</th>
<th>Internal Volume (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Payload’</td>
<td>500</td>
<td>300</td>
</tr>
<tr>
<td>PMAD + Battery Packs</td>
<td>800</td>
<td>1000</td>
</tr>
<tr>
<td>Solar Arrays</td>
<td>800</td>
<td>n/a</td>
</tr>
<tr>
<td>Chassis (COTS)</td>
<td>200</td>
<td>n/a</td>
</tr>
<tr>
<td>Retention and Release Mechanisms</td>
<td>210</td>
<td>500</td>
</tr>
<tr>
<td>Harnesses and Cables</td>
<td>220</td>
<td>TBD</td>
</tr>
<tr>
<td>Radio/Antenna (COTS)</td>
<td>440</td>
<td>400</td>
</tr>
<tr>
<td>Secondary Structures</td>
<td>250</td>
<td>n/a</td>
</tr>
<tr>
<td>Passive Attitude Control</td>
<td>200</td>
<td>n/a</td>
</tr>
<tr>
<td>C&amp;DH</td>
<td>80</td>
<td>200</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3500</strong></td>
<td><strong>1500</strong></td>
</tr>
</tbody>
</table>
Conclusions

• High Power (100 W) systems are possible in a 3-U CubeSat with some limitations on operations
  – Peak heat loads can be handled transiently
  – Steady state operation would require deployable surfaces or larger form factor for both power generation and thermal management

• Resettable and robust deployment mechanisms are feasible
  – Challenge to minimize internal volume for ALBus mission specific application

• Dual purpose shape memory alloy hinges for reliable deployment and power transmission are feasible and provide clean integration

• Packaging with margin on mass and volume for other subsystems and/or payloads