Electron Losses and Fields Investigation

Eric Qu

Deployables MCDR
February 17, 2016
Requirements
- Tuna Can Overview
- Test Results
- Future Test Plans

Stacer
- Stacer Design
- Test Results
- Testing Plans

RFAs
ELFIN CONFIGURATIONS

Deployed

Stowed
Tuna Can Assembly

- Utilizes the 3U+ extra volume on the -X panel, as per the PPOD spec
- Stows 2 sets of fiberglass tapespring antennas: VHF, UHF
- Antennas are press-fitted between the 2 wedges onto 4 contact pads
- Consists of a stowed (rolled-up state) and deployed state
- Stowed by taut 20-lb Spectra line, and released via burning the line with resistors
- Tuna can is made of Windform LX 2.0
TUNA CAN INTEGRATION

Tuna Can to \(-X\) Panel Integration

\(-X\) Panel to Top Hat Integration
**Antenna Elements**

- Comprised of Astroquartz III, S2 Fiber and lined with a CuBe alloy with black oxide coating
- Extra section on one end comprised of only CuBe, called the “Rat tail,” which makes electrical contact with pads on the –X panel
- The other end has a section comprised of only fiberglass
- Manufactured by LoadPath
- Held in their stowed state by Spectra Line

<table>
<thead>
<tr>
<th>Antenna Elements</th>
<th>Length (in.) (TBR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VHF</td>
<td>24.0</td>
</tr>
<tr>
<td>UHF</td>
<td>9.0</td>
</tr>
</tbody>
</table>
Antenna

Beryllium Copper Rat Tail

Rat Tail Pad

Communications Subsystem
RESISTOR CONFIGURATION

- Used to burn through the taut Spectra line
- Two pairs of redundant resistors
- Each resistor dissipates 3.4 W
- Option to burn all four resistors at once as backup

VU1 – Primary Resistor Set
VU2 – Backup Resistor Set
Tuna Can v4.8, 2x 24-Ohm SMT resistors, Loadpath EM elements, 20-lb Spectra line
Tuna Can v4.8, 2x 24-Ohm SMT resistors, Loadpath EM elements, 20-lb Spectra line
<table>
<thead>
<tr>
<th>Deployment Date</th>
<th>Tuna Can Version</th>
<th>Resistor Burn Info</th>
<th>Elements Used</th>
<th>Spectraline Strength</th>
<th>Burn Voltage</th>
<th>Burn Time</th>
<th>Deployment Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/10/2015</td>
<td>4.6 (Windform)</td>
<td>2x 24 Ohm SMT</td>
<td>VPM</td>
<td>20-lb</td>
<td>9 V</td>
<td>7 s</td>
<td>Both UHF and one VHF deployed instantly while the other VHF remained in the stowed state. This particular VHF was cracked at the bending location, and after manually pushing it out slightly, the entire element deployed after 4 seconds.</td>
</tr>
<tr>
<td>11/2/2015</td>
<td>4.6 (Windform)</td>
<td>2x 24 Ohm SMT</td>
<td>VPM</td>
<td>20-lb</td>
<td>9 V</td>
<td>8 s</td>
<td>UHF elements deployed instantly, and the VHF elements deployed a second later.</td>
</tr>
<tr>
<td>11/10/2015</td>
<td>4.7 (PLA)</td>
<td>2x 24 Ohm SMT</td>
<td>Loadpath EM</td>
<td>20-lb</td>
<td>9 V</td>
<td>8 s</td>
<td>Only UHF elements were used. These deployed instantly.</td>
</tr>
<tr>
<td>11/24/2015</td>
<td>4.7 (PLA)</td>
<td>2x 24 Ohm SMT</td>
<td>Loadpath EM</td>
<td>20-lb</td>
<td>9 V</td>
<td>8 s</td>
<td>All four elements deployed instantly</td>
</tr>
<tr>
<td>11/25/2015</td>
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<td>2x 24 Ohm SMT</td>
<td>Loadpath EM</td>
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<td>9 V</td>
<td>10 s</td>
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<td>11/25/2015</td>
<td>4.7 (PLA)</td>
<td>2x 24 Ohm SMT</td>
<td>Loadpath EM</td>
<td>20-lb</td>
<td>9 V</td>
<td>17 s</td>
<td>One VHF element deployed while the other VHF deployed slightly. The UHF elements did not deploy. This was because the spectraline that held the UHFs down did not burn, and the crossing of the lines underneath the -X panel held the VHF line in place, not allowing the other VHF to deploy.</td>
</tr>
<tr>
<td>11/25/2015</td>
<td>4.7 (PLA)</td>
<td>2x 24 Ohm SMT</td>
<td>Loadpath EM</td>
<td>20-lb</td>
<td>9 V</td>
<td>10 s</td>
<td>No elements deployed, as neither spectraline burned.</td>
</tr>
<tr>
<td>11/28/2015</td>
<td>4.8 (PLA)</td>
<td>2x 24 Ohm SMT</td>
<td>Loadpath EM</td>
<td>20-lb</td>
<td>9 V</td>
<td>10 s</td>
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<td>10 s</td>
<td>All four elements deployed instantly</td>
</tr>
<tr>
<td>1/14/2015</td>
<td>4.9 (PLA)</td>
<td>2x 24 Ohm SMT</td>
<td>Loadpath EM</td>
<td>20-lb</td>
<td>9 V</td>
<td>10 s</td>
<td>All four elements deployed instantly</td>
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<tr>
<td>Tuna Can Version</td>
<td>Fixes</td>
<td>Issues</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>-------</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.6</td>
<td>Strengthened clamp tightness</td>
<td>3 mm over diameter limit, notable strain placed on elements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.7</td>
<td>Fixed clamp misalignment, attempted altered clamp cross section</td>
<td>3 mm over diameter limit, notable strain placed on elements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.8</td>
<td>Reduced clamp length, increased stowed space, introduced antenna caps</td>
<td>2 mm over diameter limit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.9</td>
<td>Further increased clamp tightness, filleted edges to reduce Spectra Line abrasion, shifted antenna cap holes</td>
<td>1 mm over diameter limit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.10</td>
<td>Decreased antenna separation distance, shifted antenna cap holes</td>
<td>TBD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tuna Can v4.8
Untapered

Tapered

Tapering Jig
Room Temperature Deployments  
(March 2016)  
20 Deployments

Hot & Cold Case Deployments  
(April 2016)  
4 Deployments

Vacuum Deployments  
(May 2016)  
3 Deployments

Hot & Cold Case Vacuum Deployments  
(June 2016)  
4 Deployments

Thermally-Aged Hot & Cold Case Vacuum Deployments  
(July 2016)  
4 Deployments
EXPANDED VIEW (STACER)
Lomonosov (Lomo) Stacer Pictures

Stowed

Deployed
Description

- Custom design provided by Kaleva Engineering Systems
- Identical Stacer Assembly vetted and tested for ELFIN-Lomonosov
- Requires removal of safety pin from -Z side of stacer mount base prior to deployment
Stacer Assembly

- Contains stacer boom and fluxgate magnetometer, and electrically connected to FGPCB stacer electronics board for data acquisition
- Stacer chute connects to +Y rails via four 2-56 socket head brass screws
- Stacer base connects to torquer coil with two 4-40 socket head brass screws and +Z stacer bracket (see figure)
STACER FUNCTIONALITY

Functionality

1. Safety pin needs to be removed from coils
2. Deployment is initiated by a TiNi P10 Pull-Pin
3. Pull-Pin removal is actuated by the Shape Memory Alloy Release (SMAR) ran at 11.25 W (12.4 W with margin)
4. Three kick-springs initialize the motion of the stacer boom
5. Deployment of the stacer boom is stopped with a flywheel braking mechanism
6. Rotational orientation of fluxgate magnetometer determined by comparing magnetic field readings with the MRMs
Functionality

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4. Three kick-springs initialize the motion of the stacer boom
5. Deployment of the stacer boom is stopped with a flywheel braking mechanism
6. Rotational orientation of fluxgate magnetometer determined by comparing magnetic field readings with the MRMs
Side view deployment with magnetometer
Room Temperature Deployment

Cold Deployment

Assembly into ELFIN, Environmental Testing

Hot Deployment
<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Develop a detailed test plan that highlights the design and functionality of the antenna release mechanism</td>
<td>Complete</td>
<td>Test data will be presented in the Deployables CDR.</td>
</tr>
<tr>
<td>2</td>
<td>Very little information was provided on how the boom works. Since the CubeSat has an active control system, make sure that the boom is rigid enough to avoid movement of the sensor with respect to the satellite body during instrument deployment.</td>
<td>Complete</td>
<td>The mechanism has been fully vetted from a previous IGPP mission. Test data will be presented in the Deployables CDR.</td>
</tr>
<tr>
<td>3</td>
<td>Plan to explain the safety of stacer to the launch provider</td>
<td>Complete</td>
<td>This RFA stemmed off of inhibits on the stacer.</td>
</tr>
</tbody>
</table>
## Peer CDR Deployables Recommendation Status

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Radius edges of tuna can to minimize abrasion on the Spectra Line</td>
<td>Complete</td>
<td>Change has been implemented into tuna can version 4.10</td>
</tr>
<tr>
<td>2</td>
<td>Check for balling of Spectra Line after a burn</td>
<td>Complete</td>
<td>Implemented into testing plans</td>
</tr>
<tr>
<td>3</td>
<td>Perform an elongation test on the Spectra Line to minimize creep in the line from prolonged stowage.</td>
<td>In Progress</td>
<td>Will implement into testing plans</td>
</tr>
<tr>
<td>4</td>
<td>Test boundaries of the resistors’ burn capabilities by running non-ideal voltages across the resistors</td>
<td>In Progress</td>
<td>Will implement into testing plans</td>
</tr>
<tr>
<td>5</td>
<td>Establish temperature range the tuna can will see</td>
<td>In Progress</td>
<td>Will work with thermal subsystem for these values</td>
</tr>
<tr>
<td>6</td>
<td>Investigate a secondary mechanism to kick-start the deployment of the stowed elements</td>
<td>In Progress</td>
<td>Currently looking for ideas and ways for implementation</td>
</tr>
<tr>
<td>7</td>
<td>Investigate the usage of clamps rather than knots for securing the Spectra Line to the –X panel</td>
<td>In Progress</td>
<td>Currently looking for ideas and ways for implementation</td>
</tr>
<tr>
<td>8</td>
<td>Ensure the resistors are soldered onto the –X panel in a flat state</td>
<td>Complete</td>
<td>Will check under a microscope after soldering</td>
</tr>
<tr>
<td>9</td>
<td>Investigate areas of high stress on the antenna elements</td>
<td>Complete</td>
<td>Implemented into testing plans</td>
</tr>
<tr>
<td>10</td>
<td>Reduce the number of test deployments</td>
<td>Complete</td>
<td>Implemented into testing plans</td>
</tr>
<tr>
<td>11</td>
<td>Tapering the edges of the antenna elements</td>
<td>Complete</td>
<td>Design has been implemented into tuna can version 4.10</td>
</tr>
</tbody>
</table>

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**UCLA**

24
<table>
<thead>
<tr>
<th>REQ ID</th>
<th>Requirement</th>
<th>Rationale</th>
<th>Parent(s)</th>
<th>Verification Method</th>
<th>Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>STRC-03</td>
<td>Rails shall have a minimum width of 8.5 mm.</td>
<td>Flow-Down</td>
<td>MSN-11</td>
<td>I: Inspection of Development Model and QA</td>
<td>Completed</td>
</tr>
<tr>
<td>STRC-04</td>
<td>The rails shall not have a surface roughness greater than 1.6 μm.</td>
<td>Flow-Down</td>
<td>MSN-11</td>
<td>I: Stock preparation</td>
<td>In progress</td>
</tr>
<tr>
<td>STRC-05</td>
<td>The edges of the rails shall be rounded to a radius of at least 1 mm.</td>
<td>Flow-Down</td>
<td>MSN-11</td>
<td>I: Inspection of Development, Engineering, and Flight Model, and QA</td>
<td>Completed</td>
</tr>
<tr>
<td>STRC-06</td>
<td>The ends of the rails on the ± Z face shall have a minimum surface area of 6.5 mm x 6.5 mm contact area.</td>
<td>Flow-Down</td>
<td>MSN-11</td>
<td>I: Inspection of Development, Engineering, and Flight Model, and QA</td>
<td>Completed</td>
</tr>
<tr>
<td>STRC-07</td>
<td>At least 75% of the rail shall be in contact with the P-POD rails. 25% of the rails may be recessed and no part of the rails shall exceed the specification.</td>
<td>Flow-Down</td>
<td>MSN-11</td>
<td>I: Inspection of Development, Engineering, and Flight Model</td>
<td>Completed</td>
</tr>
<tr>
<td>STRC-08</td>
<td>Aluminum 7075, 6061, 5005, and/or 5052 shall be used for both the main structure and the rails.</td>
<td>Flow-Down</td>
<td>MSN-11</td>
<td>A: Analysis of EM and FM</td>
<td>Completed</td>
</tr>
<tr>
<td>STRC-09</td>
<td>The CubeSat rails and standoff, which contact the P-POD rails and adjacent CubeSat standoffs, shall be hard anodized aluminum to prevent any cold welding within the P-POD.</td>
<td>Flow-Down</td>
<td>MSN-11</td>
<td>I/T: Evaluation of Development Model and spin testing.</td>
<td>In progress</td>
</tr>
<tr>
<td>STRC-11</td>
<td>The ratio of the major moment of inertia to the intermediate moment of inertia shall be greater than 1.2 when stacer is deployed</td>
<td>Flow-Down</td>
<td>MSN-11</td>
<td>I/T: Evaluation of Development Model and spin testing.</td>
<td>Completed</td>
</tr>
<tr>
<td>STRC-12</td>
<td>The structure shall not use magnetic materials as specified in the magnetic cleanliness plan</td>
<td>Flow-Down</td>
<td>SYS-21</td>
<td>T: Testing in UCLA in house magnetic testing facility.</td>
<td>Completed</td>
</tr>
<tr>
<td>REQ ID</td>
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<td>Rationale</td>
<td>Parent(s)</td>
<td>Verification Method</td>
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<td>------------</td>
</tr>
<tr>
<td>STRC-15</td>
<td>The center of gravity shall be located within 2 cm from the geometric center in the X and Y directions when ELFIN is in its stowed state.</td>
<td>Flow-Down</td>
<td>MSN-11</td>
<td>I: Inspection of Development, Engineering, and Flight Model</td>
<td>Completed</td>
</tr>
<tr>
<td>STRC-16</td>
<td>The center of gravity shall be located within 7 cm from the geometric center in the Z direction when ELFIN is in its stowed state.</td>
<td>Flow-Down</td>
<td>MSN-11</td>
<td>I: Inspection of Development, Engineering, and Flight Model</td>
<td>Completed</td>
</tr>
<tr>
<td>STRC-18</td>
<td>The Structures subsystem shall not exceed the mass allocated by Systems.</td>
<td>Flow-Down</td>
<td>SYS-14</td>
<td>I: Components will be weighed</td>
<td>Completed</td>
</tr>
<tr>
<td>STRC-21</td>
<td>The Structures subsystem shall not exceed the power allocated in the ELFIN system power budget.</td>
<td>Flow-Down</td>
<td>SYS-22</td>
<td>T/A: Measured power consumption data during component tests</td>
<td>In progress</td>
</tr>
<tr>
<td>STRC-22</td>
<td>ELFIN's dimensions shall comply with the CubeSat specification $(100.0 \pm 0.1 \times 100.0 \pm 0.1 \times 340.5 \pm 0.3 \text{ mm})$.</td>
<td>Flow-Down</td>
<td>MSN-11</td>
<td>I: Inspection of Development, Engineering, and Flight Model</td>
<td>Completed</td>
</tr>
<tr>
<td>STRC-24</td>
<td>ELFIN shall have the coordinate system with the -Z face of the CubeSat inserted first into the P-POD and the +Y face as the top face of the CubeSat for all externally released documents.</td>
<td>Flow-Down</td>
<td>SYS-37</td>
<td></td>
<td>In progress</td>
</tr>
<tr>
<td>STRC-25</td>
<td>The Structures subsystem shall be designed for a 6 month lifetime.</td>
<td>Flow-Down</td>
<td>SYS-38</td>
<td></td>
<td>In progress</td>
</tr>
<tr>
<td>STRC-26</td>
<td>The Structures subsystem shall be SEU tolerant.</td>
<td>Flow-Down</td>
<td>SYS-39</td>
<td></td>
<td>In progress</td>
</tr>
</tbody>
</table>
LOADPATH SPECIFICATION

PART NO. L
-001 24.0
-002 9.0

SECTION A-A
Scale 10:1

LOADPATH SPRING

Laser etch part number and serial number 1/2" from datum A as shown in detail 1. Replace XXX with part number. Replace @ with revision of this drawing used for fabrication. Replace serial number with the DOM followed by the serial order of the tape spring fabricated that day.

Section A-A
Scale 1:1
Tuna Can v4.6, 4x 2-W rating Thru-hole resistors, VPM elements, 10-lb Spectra line
Tuna Can v4.6, 2x 10-Ohm SMT resistors, Loadpath extra elements, 80-lb Spectra line Post-Vibe 1
Tuna Can v4.6
2x 24-Ohm SMT resistors
VPM elements
20-lb Spectra line
Post-Vibe 2
Tuna Can v4.7, 2x 24-Ohm SMT resistors, VPM elements, 20-lb Spectra line
Antenna Strain
To deploy antennas, current is run across resistors
  - During stowage, Spectra line is held flush against 4 resistors and in turn holds antennas in place
  - With enough current, the line is burned through and the antennas released
  - Thermally-aged antenna mechanism to be tested for 3 months and 12 months, to account for variable stowage time
1. Set up video camera to record test
2. Stow antennas by rolling antenna elements up and tying down with Spectra line
3. Connect Tuna Can mechanism to Arduino board
4. Send signal to begin deployment
   ▪ If prompted to specify burn voltage, specify 9V
   ▪ Specify burn time as 7 seconds
5. Record time taken for antennas to fully deploy
6. Inspect antennas and note possible deformations
THERMAL AGING PROCEDURE

- Stow Tuna Can elements and set up video camera
- Place in oven vacuum and thermally age assembly for desired amount of time
  - Consult Thermal team before proceeding – highest temperature assembly is expected to experience is subject to change
- Repeat steps 3-6 in General Testing Procedure
Derivation of Acceleration Factor

- Arrhenius equation used to determine acceleration factor
  - Effects of humidity assumed to be negligible
  - Two arbitrary temperatures, $T_1$ (ambient temperature) and $T_2$ (acceleration temperature), are chosen

\[
\kappa_1 = Ae\left(-\frac{E_a}{RT_1}\right) \quad \kappa_2 = Ae\left(-\frac{E_a}{RT_2}\right)
\]

- Natural logarithm of both sides taken to obtain:

\[
\ln(\kappa_1) = \ln A - \frac{E_a}{RT_1} \quad \ln(\kappa_2) = \ln A - \frac{E_a}{RT_2}
\]

- Solving for $\ln A$ and equating both expressions gives us:

\[
\frac{\kappa_2}{\kappa_1} = e^{\frac{E_a}{R} \left(\frac{1}{T_1} - \frac{1}{T_2}\right)} = \text{Acceleration Factor (AF)}
\]
Temperature coefficient is the measure of rate of change of a system with a change of 10° C in temperature

\[ Q_{10} = \left( \frac{\kappa_2}{\kappa_1} \right)^{\frac{10}{T_2 - T_1}} \]

or

\[ \frac{\kappa_2}{\kappa_1} = (Q_{10})^{\frac{T_2 - T_1}{10}} = AF \]

Most biological systems have $Q_{10}$ in the range of 2 to 3
ACCELERATION FACTOR

- Equation is specific to antenna material, fiberglass
  - Max temperature material can be subjected to is 250°C, according to ISO 2578
  - Determined through past tests that fiber glass has acceleration factor of 420
    - Ambient temperature – 23°C
    - Accelerated temperature – 80°C
  - Relation between real-time and accelerated time:

\[
\text{Accelerated Time} = \frac{\text{Real Time}}{\text{Acceleration Factor}}
\]

- Antenna assumed to be stowed for 90 days prior to launch:

\[
\text{Accelerated Time} = \frac{90 \text{ days}}{420} = 0.214 \text{ days} = 5.14 \text{ hours}
\]

- 5.14 hours of stowage in oven at 80°C to simulate 90 days of stowage
Success defined by affirmative answers to:

1. Did the resistors burn through the Spectra line?
2. Did the UHF and VHF elements unfurl?
3. Did the antennas fully deploy?
   - Fully deployed antennas defined as the Beryllium Copper segment completely unfurled
4. Did they deploy within a reasonable amount of time? (e.g. within 30 seconds for room deployment, 12 hours after thermal aging)
5. Were antennas deployed without deformation?
   - Deformation defined as any abnormality that may impede relay of information
STACER TESTING - LOMO
**LOMO STACER ELECTRICAL TEST PLAN**

**Stacer Acceptance Test**
Deploy using a power supply, and dummy sensor (ambient temp/ambient pressure)

- ETC Board
- Power Board
- Suite Board
- PRM Board

Integrate ST5 sensor to Stacer

- Restow

**Stacer Electrical Test**
Deploy using a dummy sensor, with trigger using ETC/Power/Suite Boards (Bench top, flat test)

**Stacer Qualification Test**
Deploy with ST5 sensor, with trigger using ETC/Power/Suite Boards on Heat Source (70 degrees C/ambient pressure)

Restow
DERIVATION OF ACCELERATION FACTOR
DERIVATION OF ACCELERATION FACTOR
DERIVATION OF ACCELERATION FACTOR