Flight Results from AeroCube-6: A Radiation Dosimeter Mission in the 0.5U Form Factor

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AeroCube-6

- AeroCube-6 is two 0.5U CubeSats.
- Science goal: measure spatial scales of radiation in LEO.
- Orbit: 620 x 700 km x 98 deg.
- Payload: 3 dosimeters on each satellite.
  - Including 3 new variants that have never flown before.
- Nominal sample rate is 1 Hz.
  - Dosimeters A1 and B1 can burst at 10 Hz.
- Using differential drag to control spacecraft in-track separation.

Dosimeter Payload:

<table>
<thead>
<tr>
<th>S/C</th>
<th>ID#</th>
<th>Dosimeter</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>Thin Window Low LET Variant</td>
<td>&gt;50 keV electrons &amp; &gt;600 keV protons</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>Thin Window High LET Variant</td>
<td>&gt;600 keV protons</td>
</tr>
<tr>
<td>A</td>
<td>3</td>
<td>Standard Teledyne</td>
<td>&gt;1 MeV electrons &amp; &gt;10 MeV protons</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>Thin Window Low LET Variant</td>
<td>&gt;50 keV electrons &amp; &gt;600 keV protons</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>Thin Window High LET Variant</td>
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</tbody>
</table>
Features of AeroCube-6

- Radio (915 MHz, 1 W).
- Crosslink via radio.
  - *Functional up to 400 km range.*
- GPS receiver.
  - *20-meter fix accuracy.*
- Magnetic torque rods.
- Magnetometers.
- Earth and Sun sensors.
- Nominal operation: Sun-pointing.
  - *Spin about Z-axis at ~30 deg/s.*
  - *Protects payload from Sun exposure.*
Systems Engineering Approach

• Applied Model Based Systems Engineering (MBSE) to support early…
  – *Concept trade space exploration,*
  – *Integration of thermal design into the system,*
  – *Mass, power and link budget analysis for selected system design,*
  – *Identification of design drivers and problem areas,*
  – *Requirements for fault tolerant flight software.*

• MBSE uses linked subsystem models (analytical and parametric) to drive the whole system design of a satellite instead of using static documents.

• System model provided first order systems design analysis to support peer reviews and milestone reviews.
Satellites inside of Satellites…

Step 1: AeroCube-6, alone

AeroCube-6 uses the 0.5U form factor, plus two deployable wings that include experimental solar cells.
Satellites inside of Satellites…

Step 2: AeroCube-6, mated

The wings of each AeroCube-6 wrap around the body of the other, creating a package that conforms to the 1U CubeSat standard.
Satellites inside of Satellites…

*Step 3: Integration into P-POD*

The mated pair of AeroCube-6 was integrated into its P-POD with a 2U companion from another institution.
Satellites inside of Satellites…

Step 4: P-POD Integration into UniSat-6

The P-POD was then integrated into UniSat-6, a carrier and stand-alone satellite built by GAUSS.
Satellites inside of Satellites…

*Step 5: UniSat-6 Integration onto Dnepr*

UniSat-6 was then mated to the Dnepr launch vehicle.
Ride to Orbit

Deploy
- Conjoined 1
- Eject from PPOD & detumble
- Deploy one set of wings

Separate
- Prepare for separation
- Separate

Operate
- Individual s/c control
- Ops Normal

30 min
2 days

The spring-loaded separation mechanism induced a 12 km/day in-track drift

Photo: DLR, CC-BY 3.0
Crosslink Results

• Sending and receiving of pre-packaged message
• Low cost, minor recode of existing space-to-ground radio
• Range limited by low gain antenna patterns

Dual Antenna Configuration

1.2 kbps crosslink demonstrated up to 400 km.
Magnetic Attitude Control

- Magnetic torque rods provide all attitude control.

- Two nominal operational profiles:
  - Sun-pointing: drive \( \hat{n}_{cmd} \) to Sun.
    - Largely constant throughout orbit.
  - Differential drag: drive \( \hat{n}_{cmd} \) along pre-defined profile.
    - Choose \( \hat{n}_{cmd} \) to min/maximize drag.
    - Changes rapidly over one orbit.
    - Cannot point >30 deg from Sun.

- Good tracking performance cannot be guaranteed for arbitrary \( \hat{n}_{cmd} \) at every instant due to magnetic field constraint and limited torque.
Attitude Control Performance

- Challenge: control law allows spin rate to vary while spin axis points at target.
  - *When satellite reaches maximum spin rate* (40 deg/s), *control must pause to de-spin*.
- Plots at right show example optimal (i.e., commanded) vs. measured differential drag profile.
  - *AC6A was following the minimum drag profile*.
- Typical pattern: follow profile closely for ~20 min, pause to de-spin, then catch up.
Differential Drag Performance

AC6A was leading AC6B in-track. To close the vehicles, required AC6B in high-drag mode and AC6A in low-drag mode.

"Ratio of BSTAR" is the drag ratio of AC6B to AC6A. If the ratio = 1, there is no differential. While the semimajor axis difference is negative, the two spacecraft are closing.
In-Track Separation vs. Time

AeroCube-6: In-Track Formation since July 2014

- Max separation: 800 km
- Diff. drag initiated
- Deployment: ~12 km/day
- Uncontrolled interval
Sample Dosimeter Results

AC6 investigating spatial and temporal behavior of radiation environment. Thousands of orbits of data have been collected thus far.

A1: >50 keV e-, >600 keV H+  
South Atlantic Anomaly

A2: >600 keV H+
Having two spacecraft at a well-known in-track separation provides heretofore unavailable information on the fine structure of the LEO radiation belts.

Temporal separation of data due to in-track separation of spacecraft.

Two spacecraft measuring the same variability strongly suggests the existence of fine spatial structure.
Conclusions

- AeroCube-6 on orbit for 10 months and still going strong.
- Demonstrates a CubeSat mission explicitly planned as a testbed for mission assurance and advancing TRL of payloads.
- Form follows function: model-based systems engineering showed that the mission could be done in 0.5U.
  - *Saves on cost and complexity.*
- For modest attitude control needs, magnetic systems are adequate.
- Differential drag remains a potent tool for formation control with CubeSats.
  - *For many missions, chemical/electric propulsion is overkill.*
- Making journal-worthy discoveries with only a pair of 0.5U CubeSats.