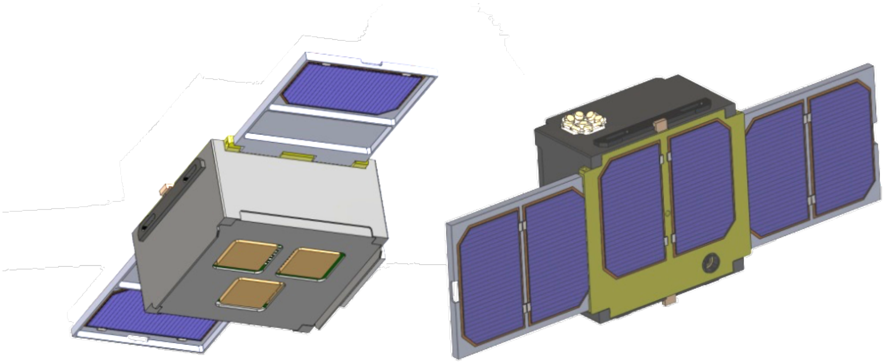
Flight Results from AeroCube-6: A Radiation Dosimeter Mission in the 0.5U Form Factor

Joseph Gangestad, Darren Rowen,
Brian Hardy, Christopher Coffman, and Paul O’Brien
The Aerospace Corporation

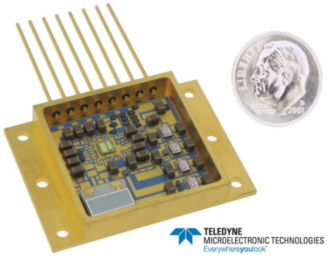
CubeSat Developers’ Workshop
San Luis Obispo, CA
22–24 April 2015

AeroCube-6



- AeroCube-6 is two 0.5U CubeSats.
- Science goal: measure spatial scales of radiation in LEO.
- Launched: 19 June 2014 aboard Dnepr.
- 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:

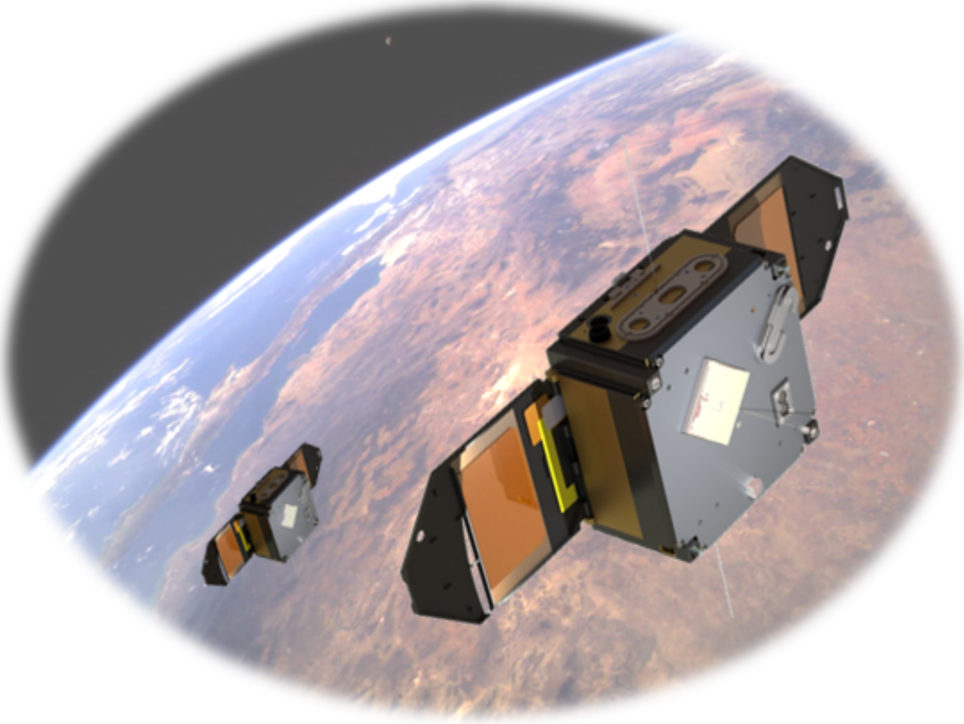


S/C	ID#	Dosimeter	Measures
A	1	Thin Window Low LET Variant	>50 keV electrons & >600 keV protons
A	2	Thin Window High LET Variant	>600 keV protons
A	3	Standard Teledyne	>1 MeV electrons & >10 MeV protons
B	1	Thin Window Low LET Variant	>50 keV electrons & >600 keV protons
B	2	Thin Window High LET Variant	>600 keV protons
B	3	High LET Variant	>10 MeV protons

AEROSPACE

Features of AeroCube-6

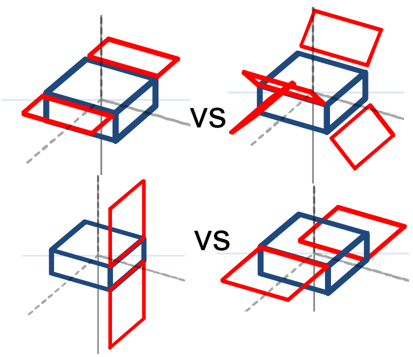
- Radio (915 MHz, 1 W).
- Crosslink via radio.
  - *Functional up to 400 km range.*
- GPS receiver.
  - *20-meter fix accuracy.*
- Magnetic torque rods.
- Magnetometers.
- Earth and Sun sensors.
- Nominal operation: Sun-pointing.
  - *Spin about Z-axis at ~30 deg/s.*
  - *Protects payload from Sun exposure.*



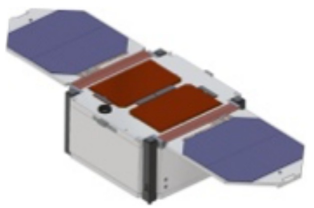
AEROSPACE

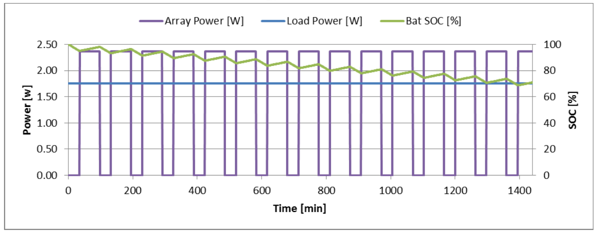
Systems Engineering Approach

- 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.



Trade Analysis

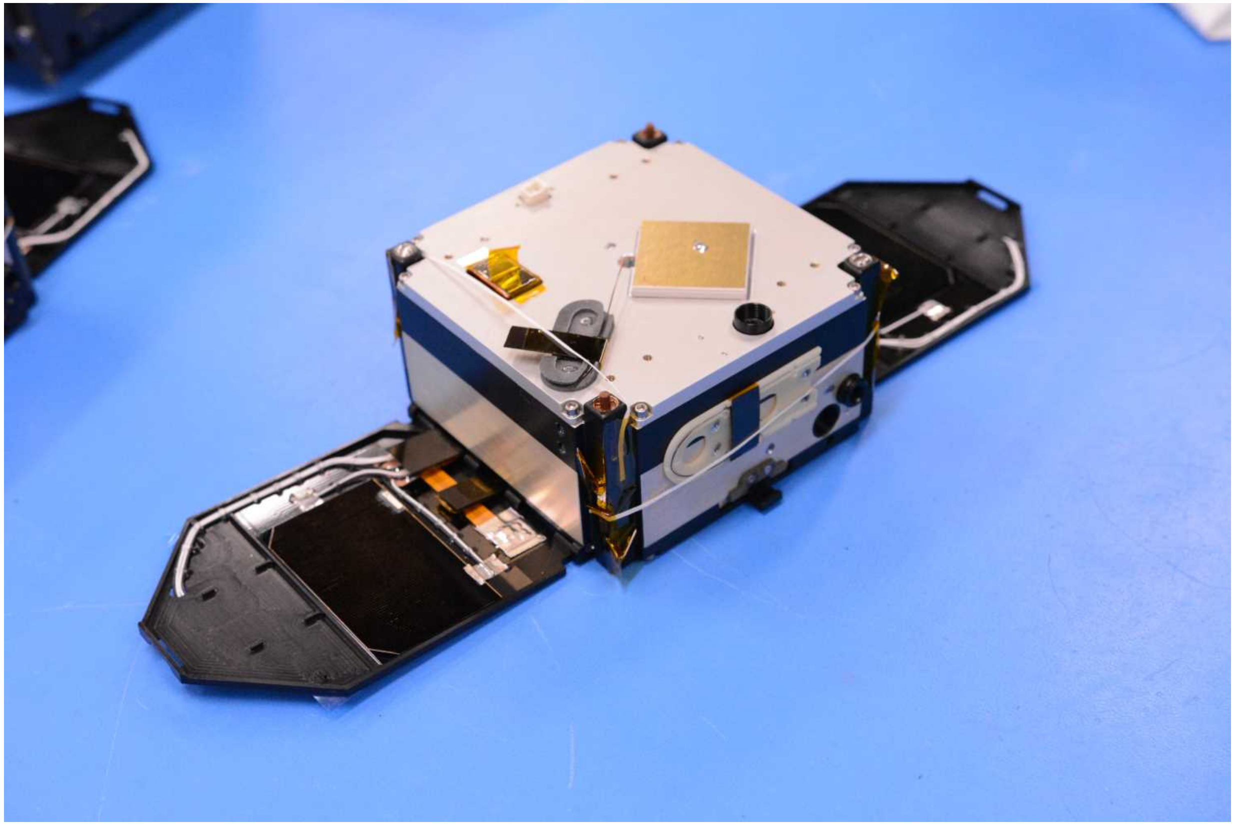




Power budget analysis

Satellites inside of Satellites…

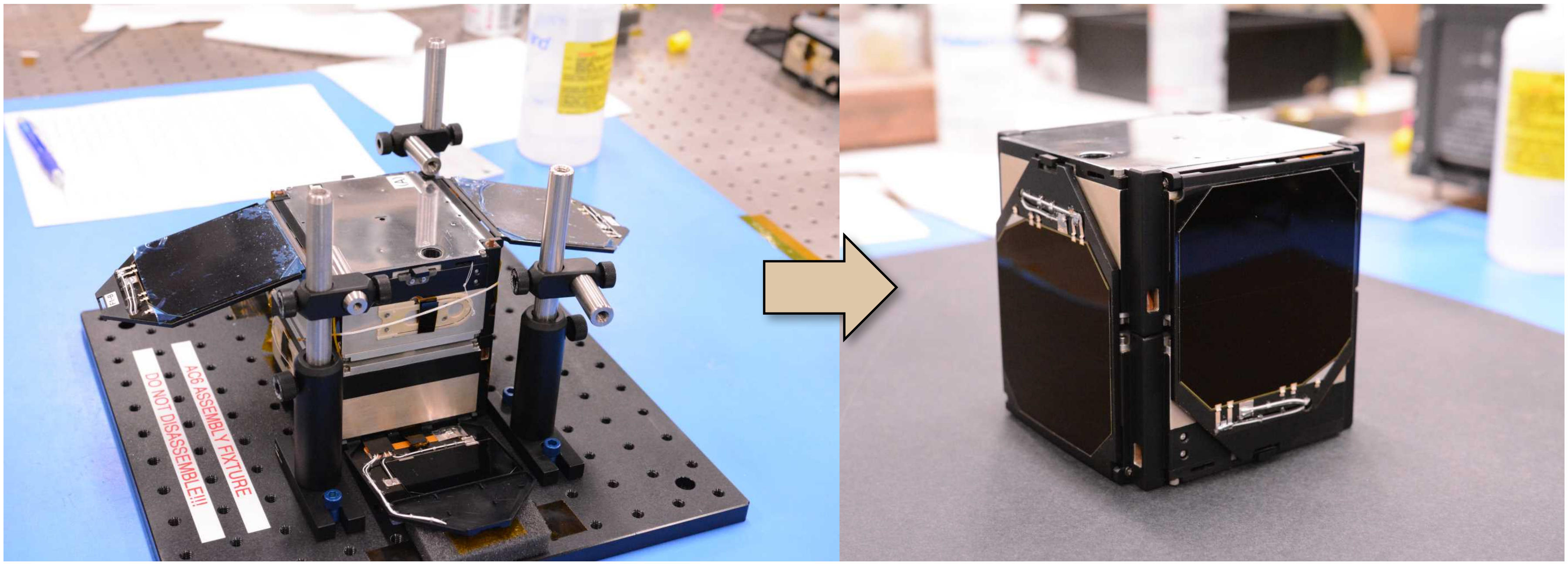
Step 1: AeroCube-6, alone



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.

AEROSPACE

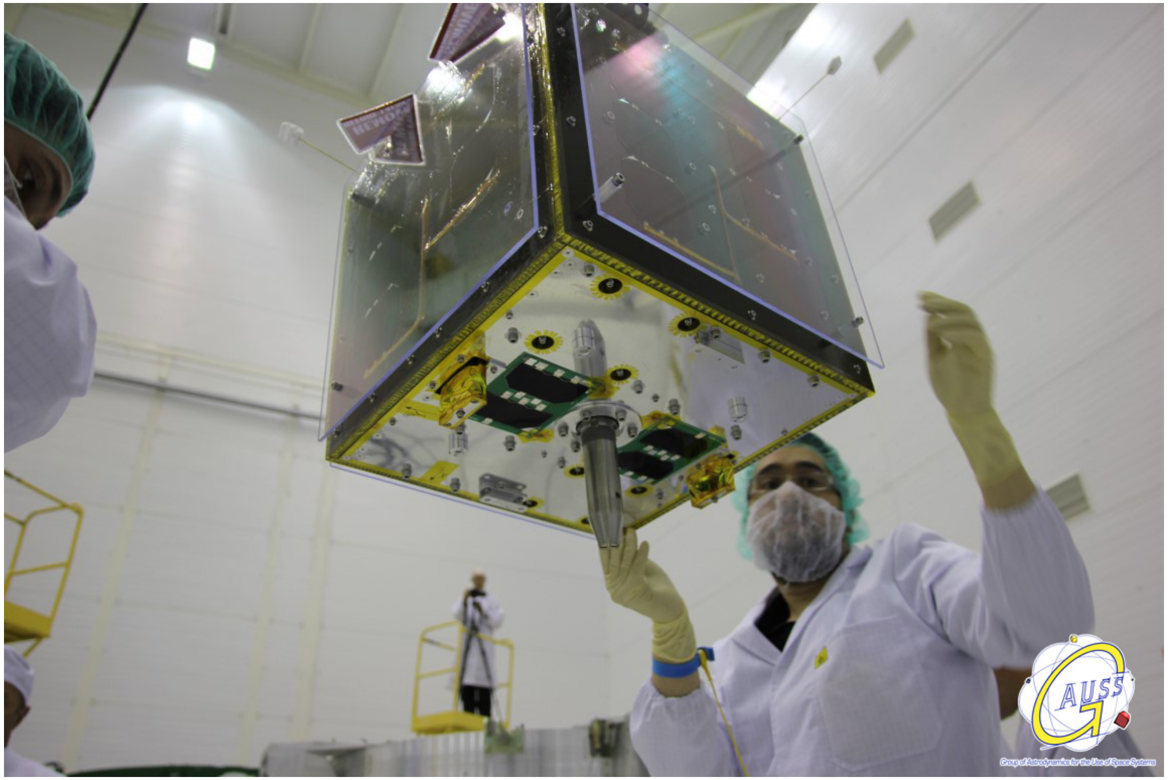
Satellites inside of Satellites…

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

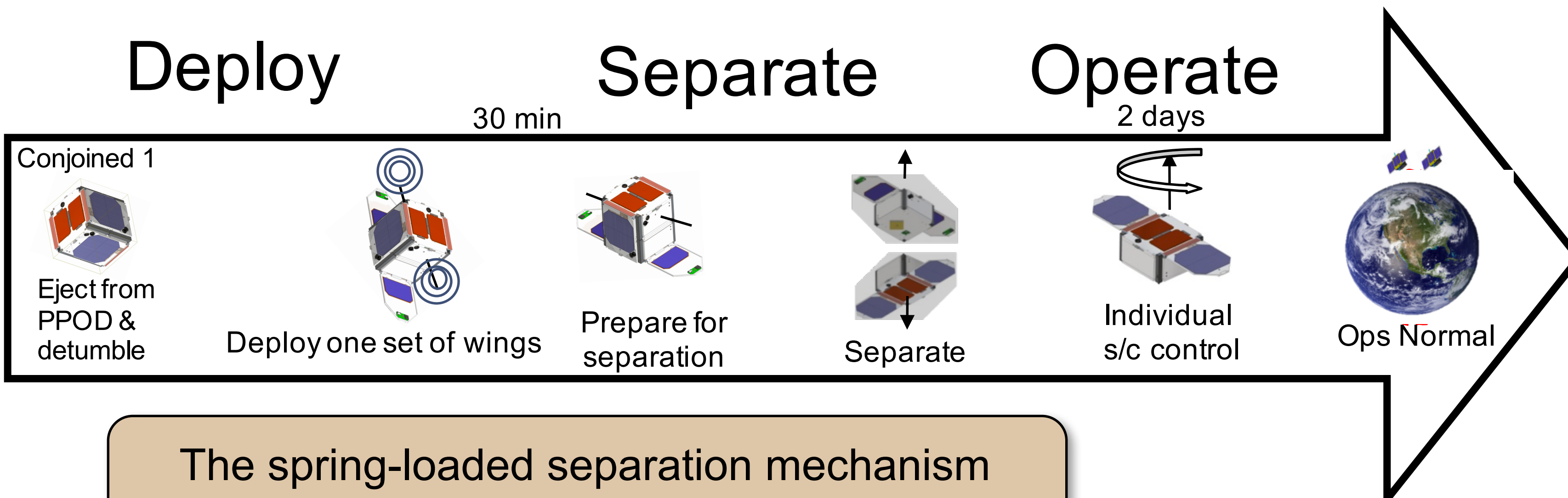
UniSat-6 was then mated to the Dnepr launch vehicle.

AEROSPACE

Ride to Orbit


Photo: DLR, CC-BY 3.0

+23 hours

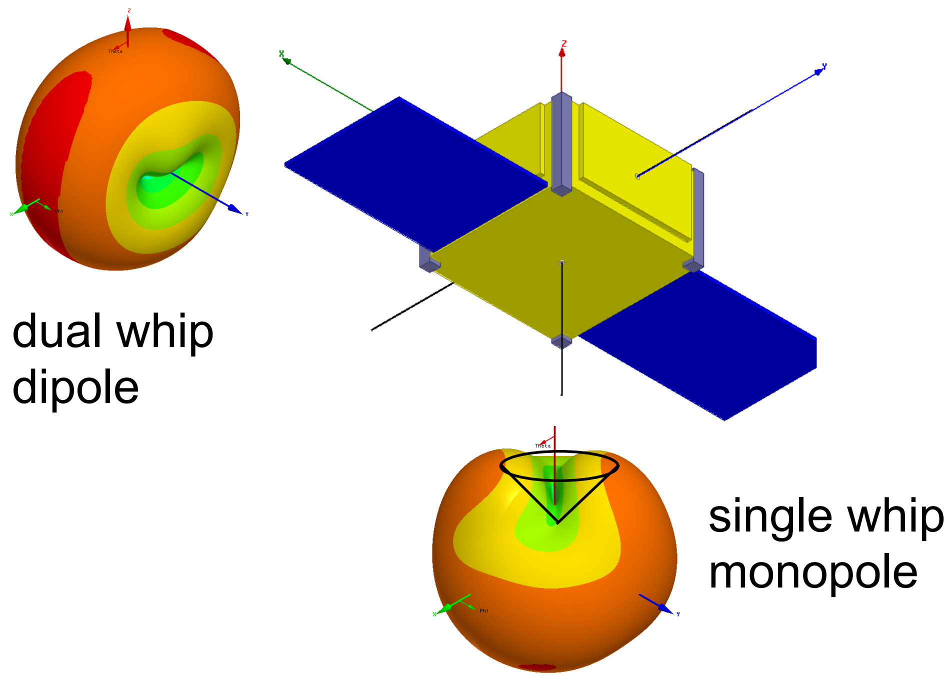


The spring-loaded separation mechanism induced a 12 km/day in-track drift

AEROSPACE

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

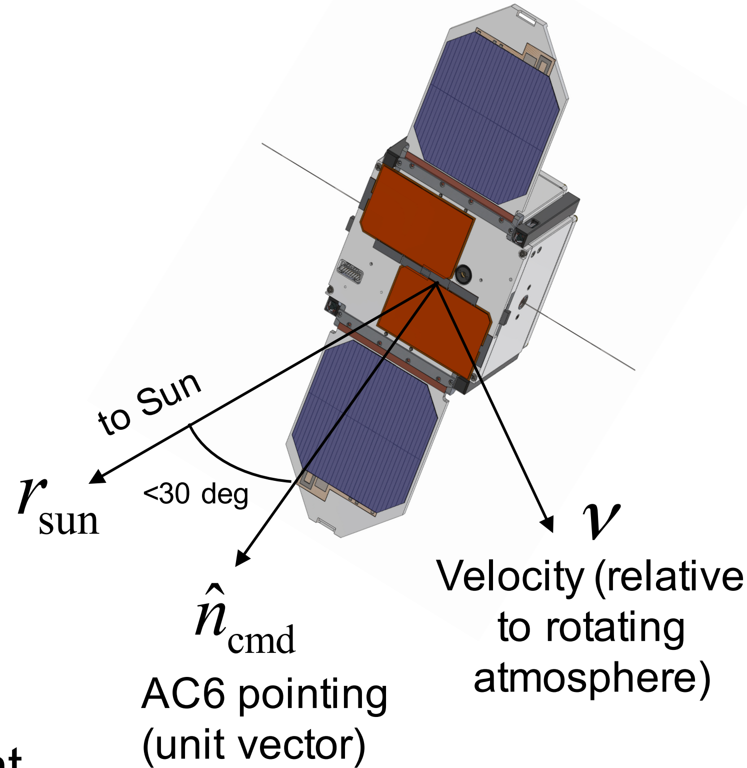


Dual Antenna Configuration

1.2 kbps crosslink demonstrated up to 400 km.

Magnetic Attitude Control

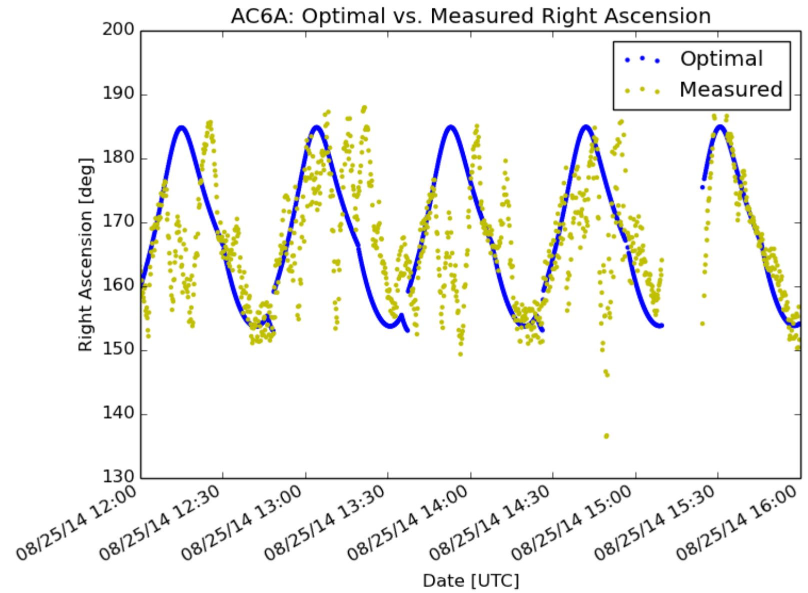
- Magnetic torque rods provide all attitude control.
- Two nominal operational profiles:
  - *Sun-pointing: drive $\hat{n}_{cmd}$ to Sun.*
    - Largely constant throughout orbit.
  - *Differential drag: drive $\hat{n}_{cmd}$ along pre-defined profile.*
    - Choose $\hat{n}_{cmd}$ to min/maximize drag.
    - 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.

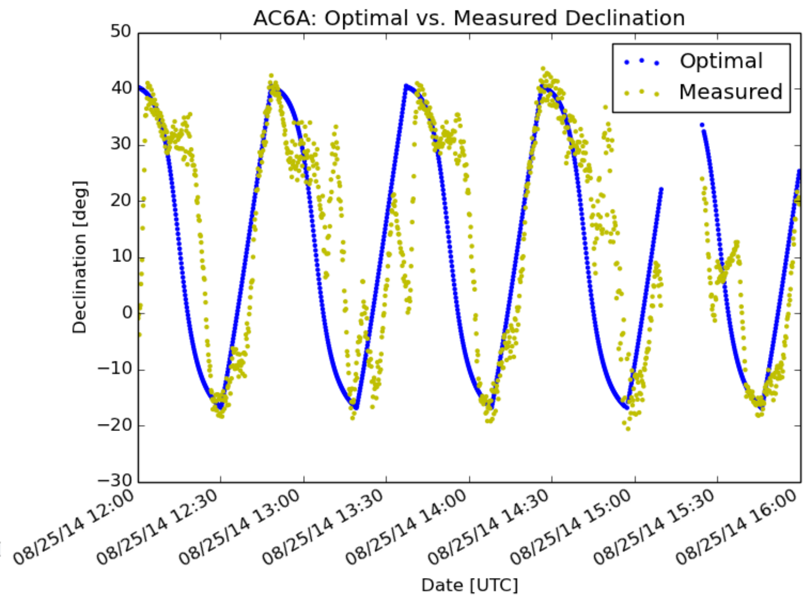


AEROSPACE

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.

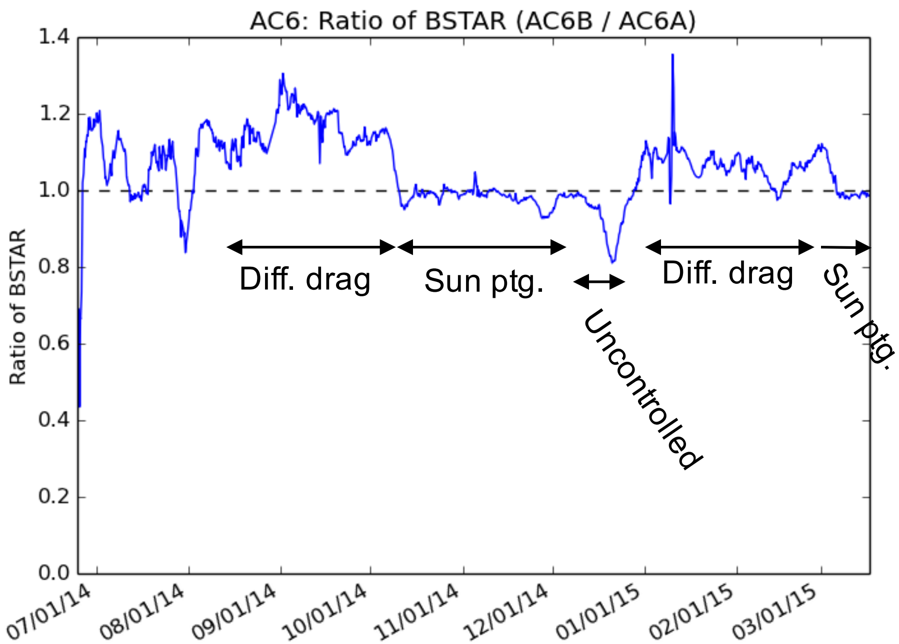


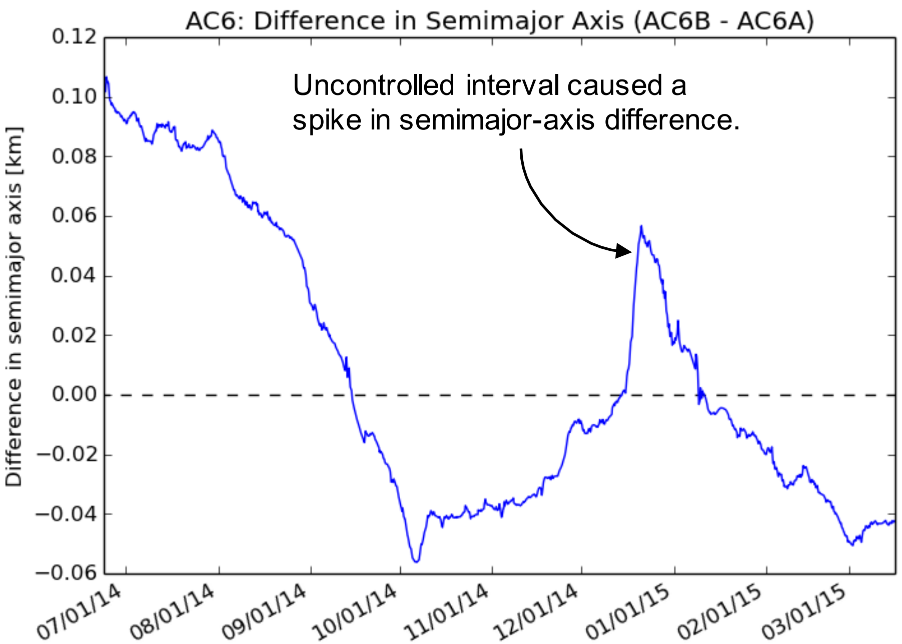


AEROSPACE

Differential Drag Performance

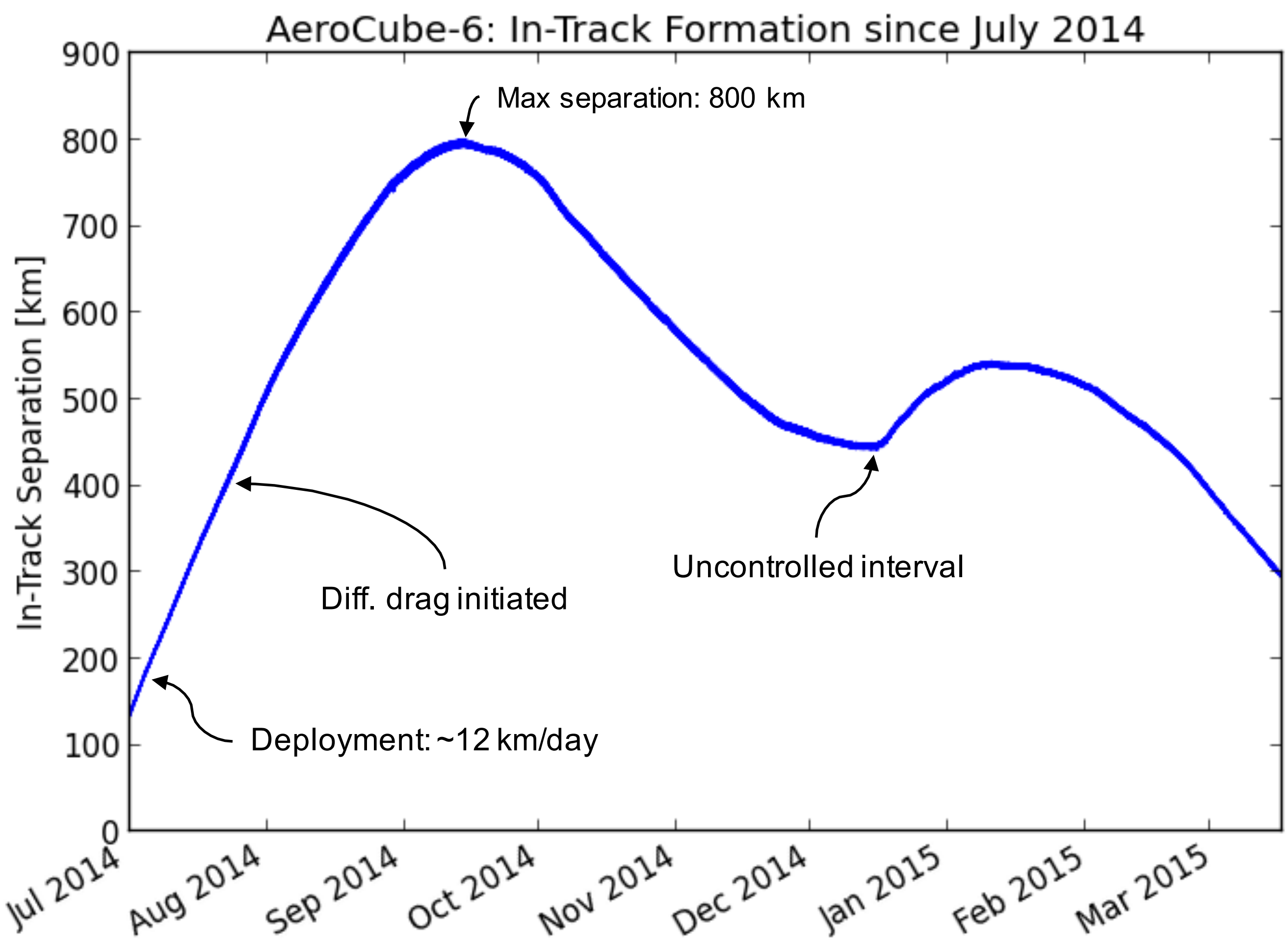
AC6A was leading AC6B in-track. To close the vehicles, required AC6B in high-drag mode and AC6A in low-drag mode.





"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.

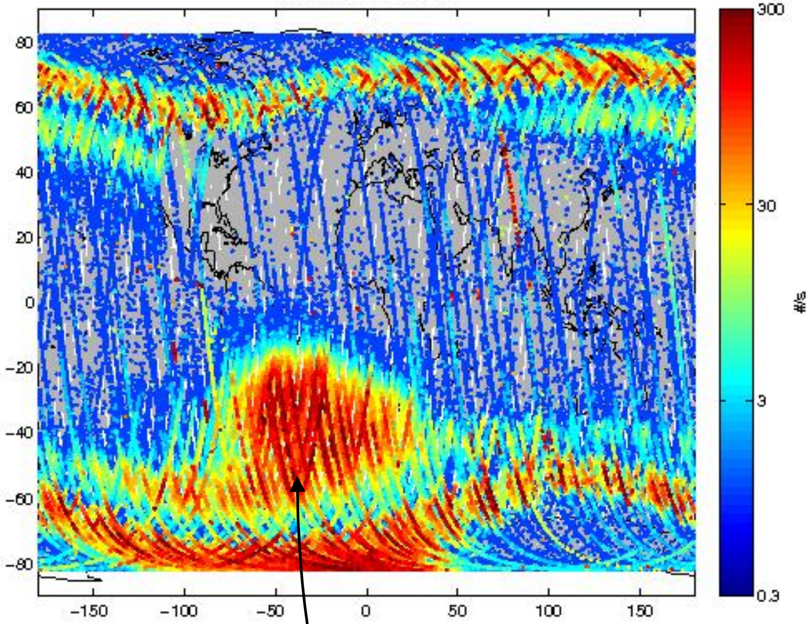
In-Track Separation vs. Time



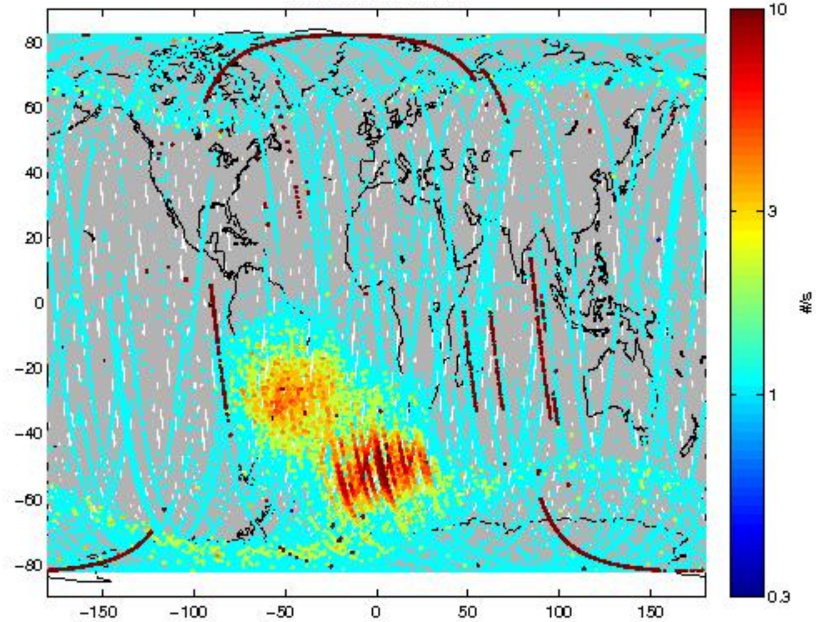
Sample Dosimeter Results

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+



A2: >600 keV H+

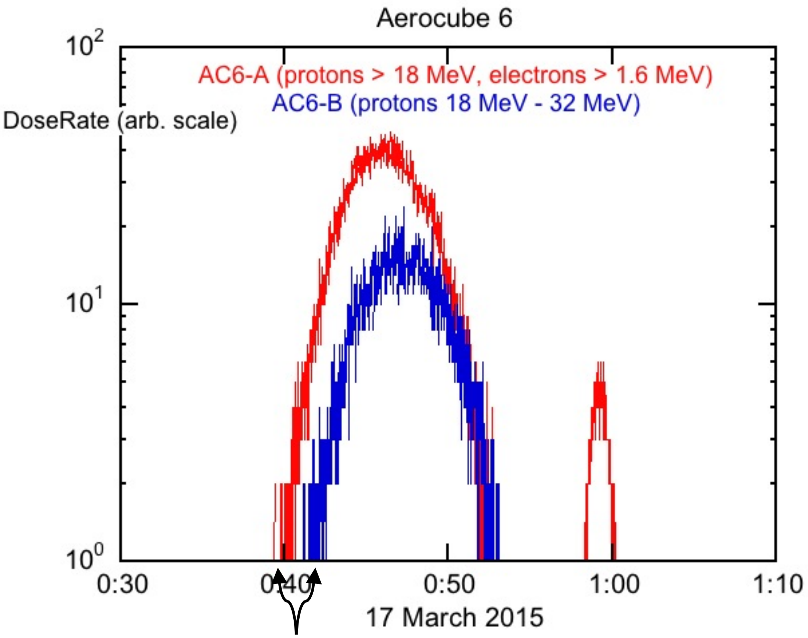


South Atlantic Anomaly

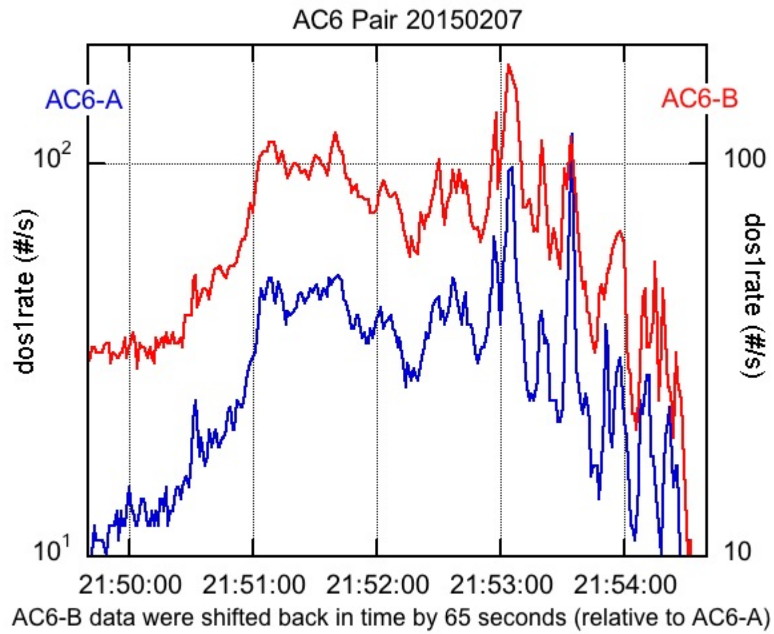
AEROSPACE

Seeking Fine Spatial Structure in LEO Radiation Belts

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.

AEROSPACE

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.