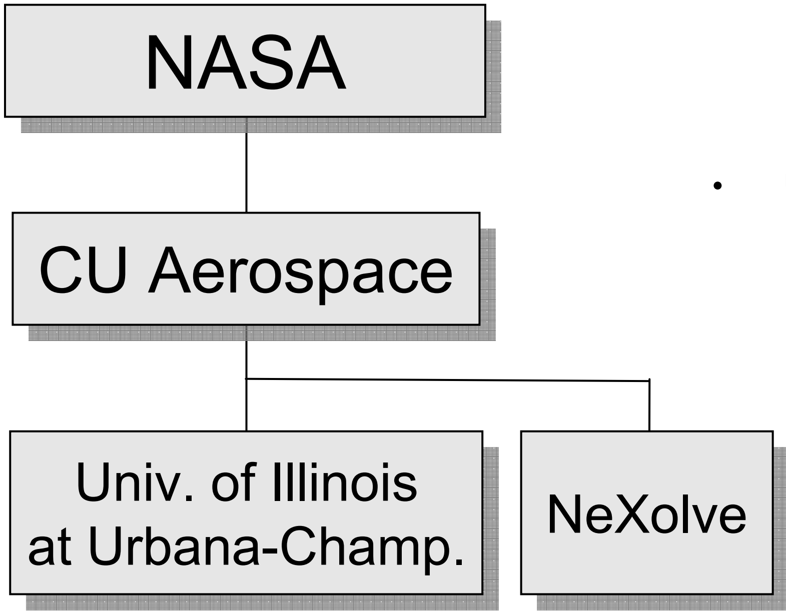
Design and Testing of the CubeSail Payload

7th Annual CubeSat Developers' Workshop
April 21-23, 2010

CU Aerospace
University of Illinois at Urbana-Champaign
NeXolve
NASA

Julia K. Laystrom-Woodard

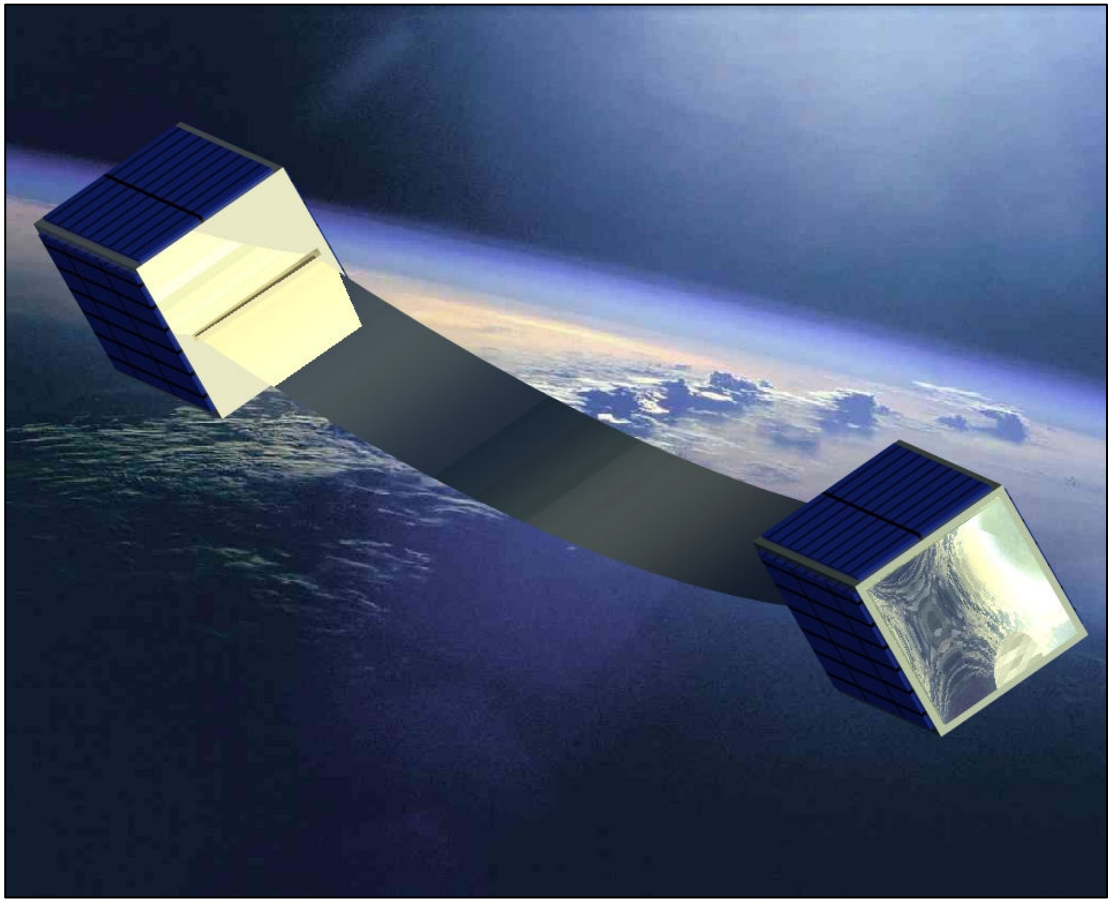
CubeSail Team



- **CU Aerospace (Champaign, IL)**
  - Prof. Rod Burton (Principal Investigator) – rburton@illinois.edu
  - Dr. David Carroll (Program Manager) – carroll@cuaerospace.com
  - Engineers
    - Julia Laystrom-Woodard – laystrom@cuaerospace.com
    - Gabriel Benavides – benavides@cuaerospace.com
- **University of Illinois at Urbana-Champaign**
  - Prof. Victoria Coverstone (Co-PI) – vcc@illinois.edu
  - Prof. Gary Swenson (CoPI) – swenson1@illinois.edu
  - Graduate students
    - Andy Pukniel – apukniel@gmail.com
    - Alex Ghosh – alex@agespast.org
    - Chad Carlson – ccarlso2@illinois.edu
    - John Warner – jgwarner@illinois.edu
    - Kevin Bassett – kpbasset@illinois.edu
  - Undergraduate students
    - Ariel Moctezuma – amoctez@illinois.edu
    - Chris Habib – chabib@illinois.edu
- **NeXolve Corporation (Huntsville, AL)**
  - Greg Farmer – greg.farmer@nexolve.com
- **NASA Marshall (Huntsville, AL)**
  - Les Johnson – charles.l.johnson-1@nasa.gov

UltraSail CubeSat Flight Experiment

- Perform a first-ever autonomous successful solar sail flight experiment at low cost, using two 1.5 kg CubeSat satellites to deploy a 20 m^2 UltraSail



UltraSail/CubeSat

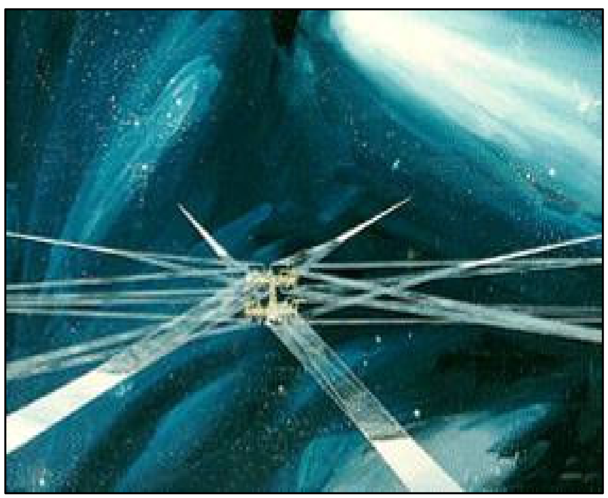
- The proposed flight experiment builds on existing technology developed by CU Aerospace and Illinois
  - The UltraSail concept was developed on a NASA Phase 2 STTR (2003-2006)
  - CubeSat ION-1 and ION-2 have been developed by Illinois (2001-present)
  - The UltraSail-CubeSat concept was proposed on a NASA Phase 1 SBIR (2007-2008)

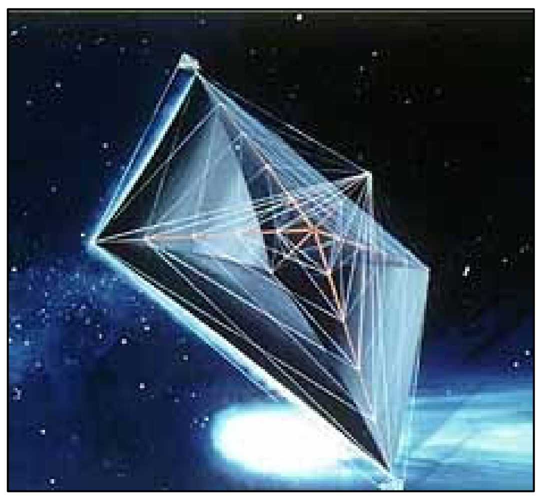
Motivation

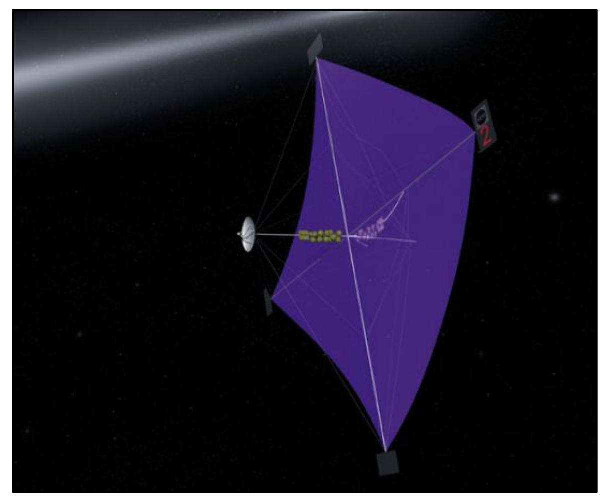
- Solar sailing concept dates back to the ideas of Tsiolkovsky and Tsander from early 1900s.
- Numerous conceptual studies have been developed since, including:
  - Early detection and warning of solar events (Heliostorm)
  - Analysis of helioseismology and heliomagnetism (Solar Polar Imager)
  - Exploration beyond heliopause (Interstellar Probe) to name a few
- Why, despite over 100 years of conceptual development, have only two successful in-space solar sailing deployments occurred, to date?

Motivation (cont'd)

- Two reasons for slow emergence of solar sailing technology:
  - Stowage and deployment of the sail material and stiffening structure (booms, masts, stays, etc.)
  - High risk combined with high launch costs associated with investment in a poorly-characterized technology.

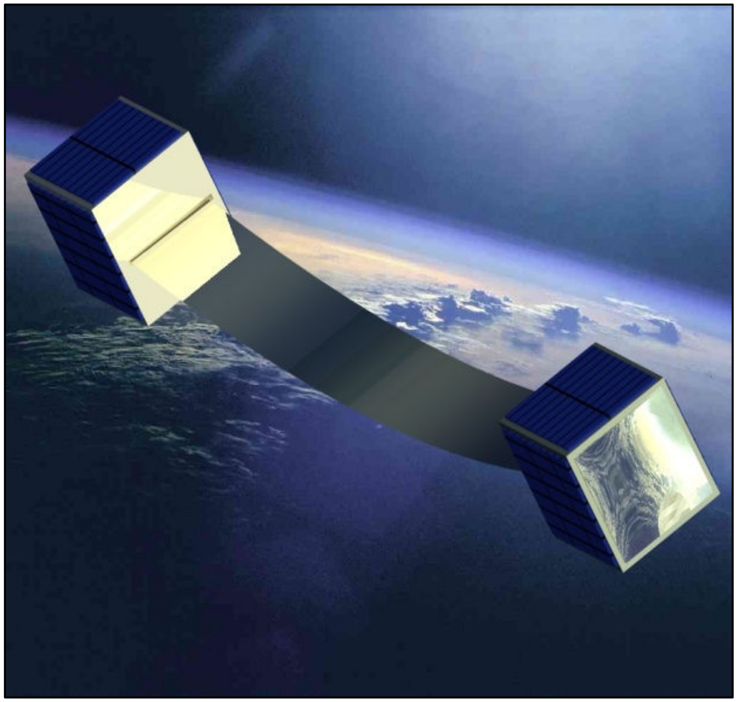






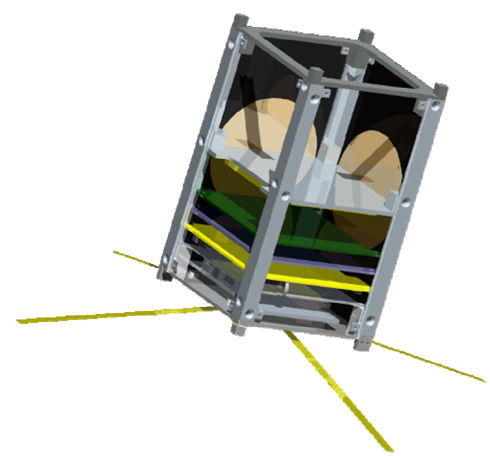
Purpose of the Work

- **Goal:**
  - Perform a first-ever autonomous successful solar sail flight experiment at low cost, using two 1.5 kg CubeSat satellites to deploy a 20 m^2 UltraSail
- **Method:**
  - Utilize UltraSail stowage and deployment method
  - Utilize UIUC CubeSat nanosatellite design and 3-axis attitude capability
  - Reduce risk with a scaled down demonstration in LEO
  - Reduce cost by using secondary payload opportunity
- **Results:**
  - Mission design for a first autonomous, on-orbit solar sail deployment experiment.
  - Sail stiffening accomplished with no external hardware
  - The characterization of the deployment method(s), in-space sail behavior, and performance during orbital maneuvering will contribute to an increase in the technology readiness level



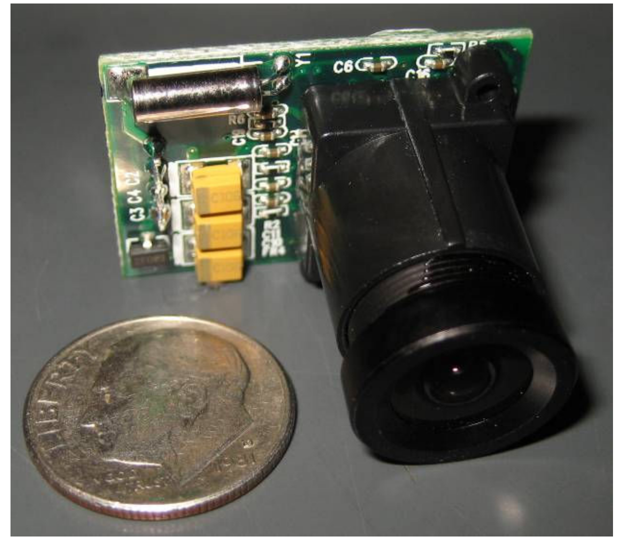
University of Illinois – CubeSat Class

- University of Illinois, Champaign-Urbana, IL
  - Professors
    - Gary Swenson (ECE)
    - Victoria Coverstone (AE)
    - Matt Frank (CE)
  - Teaching Assistants
    - Chad Carlson (ECE)
    - Alex Ghosh (AE)
    - Kevin Bassett (ECE)
    - John Warner (AE)
- Taylor University, Upland, IN
  - Hank Voss



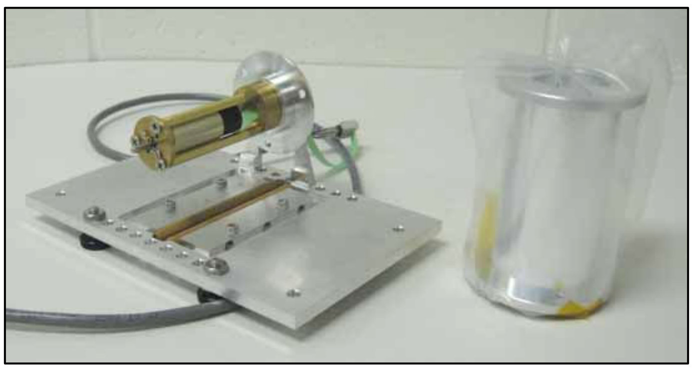
Payload Subsystems

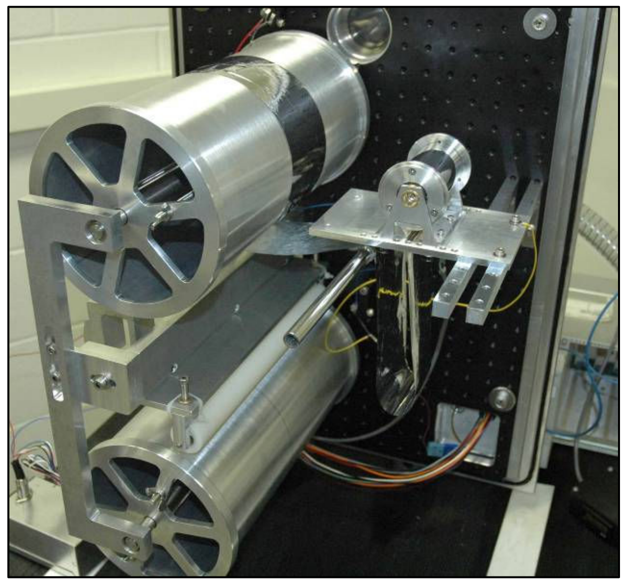
- Relaxation of mass requirement allows expansion of payload
- Primary payload
  - Reel Assembly
  - Solar Sail Film
  - Slit
  - Separation Release Unit (SRU)
- Secondary payload
  - Auxiliary battery (each CubeSat)
  - Camera (single frame; each CubeSat)
  - Bus interface

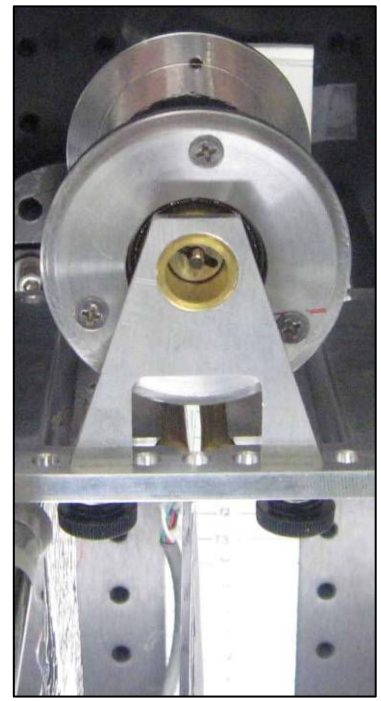


Design, Fabricate and Test Subcomponent Film Deployment

- 10^{-4} Torr vacuum chamber with optical polycarbonate door
- Rear optical table provides versatility
- National Instruments data acquisition system and supporting instrumentation.
- Mechanical / electrical feed-throughs
- Take-up reel with film tension control and measurement



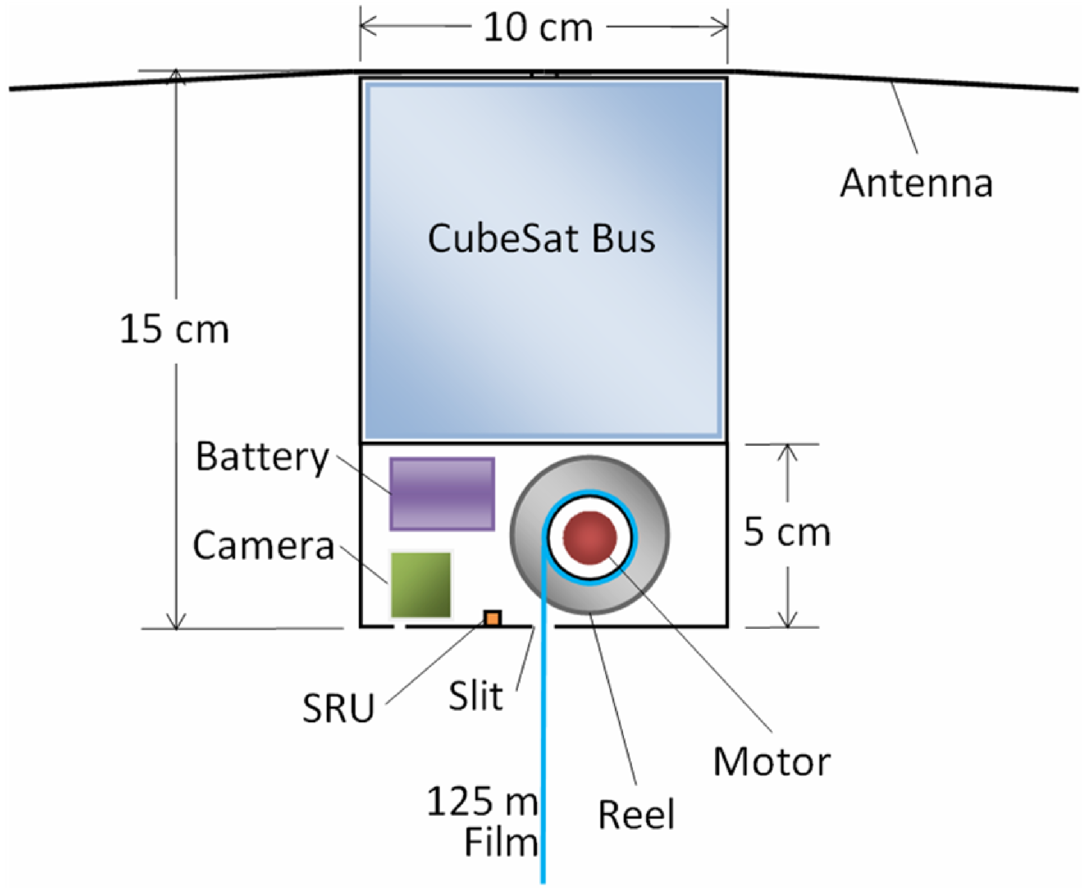




Partially assembled test reel (left) next to one of two wound bobbins (6.25 μm Mylar film, both sides coated with aluminum) delivered by MSRS. Full test reel assembly (middle & right) mounted in the vacuum chamber.

In-Space Flight Experiment

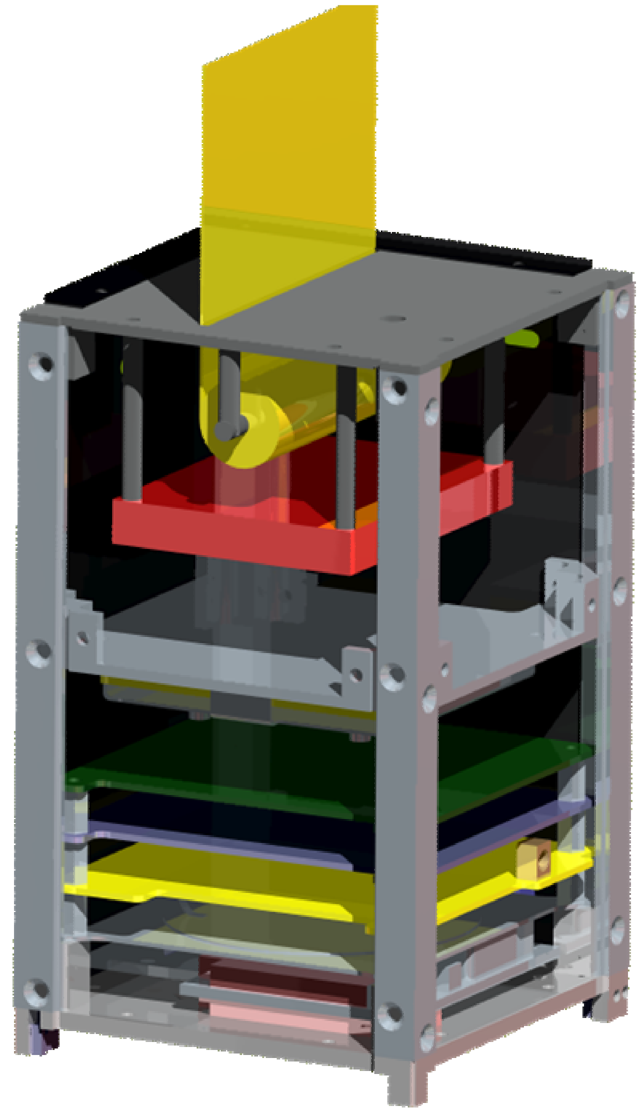
- Concept based on combining UltraSail with CubeSat
- Flight Experiment Objectives
  - Demonstrate deployment
  - Demonstrate stability
  - Demonstrate orbit raising
  - Measure effective thrust
  - Perform simple mission



CubeSail -- Showing deployment of 125 m sail film from one of two nearly identical CubeSat satellites

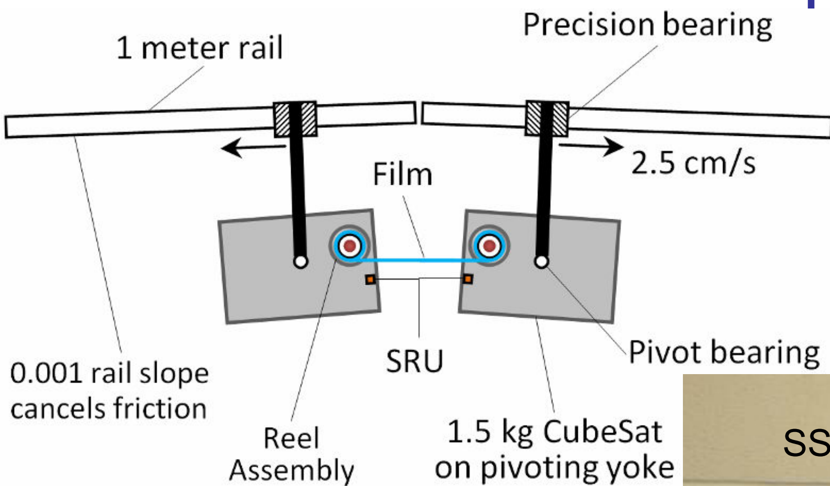
Design, Fabricate and Test Subcomponent Film Deployment

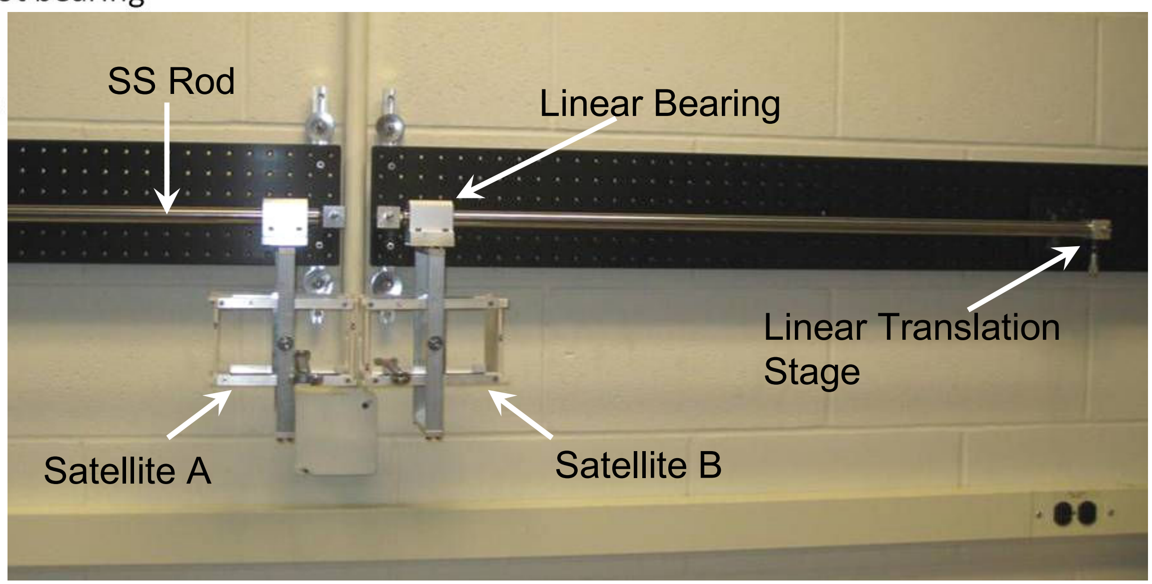
- **10x10x15 cm (payload 90x90x84 mm)**
- **77 mm x 125 m 6.2 μm aluminized double-coated Mylar**
- **Film deployment mechanism**
  - Prepackaged, commercially available, DC Motor, gearbox, encoder (MicroMo)
  - Motor and gearbox assembled with vacuum lubricant, PTFE wire jackets
  - Motor assembly packaged inside bobbin (direct drive)
  - Bearing mount to CubeSat frame
  - Encoder allows precision control of film deployment
  - Conductive slit at c.g.



Bearing Rail Experiment

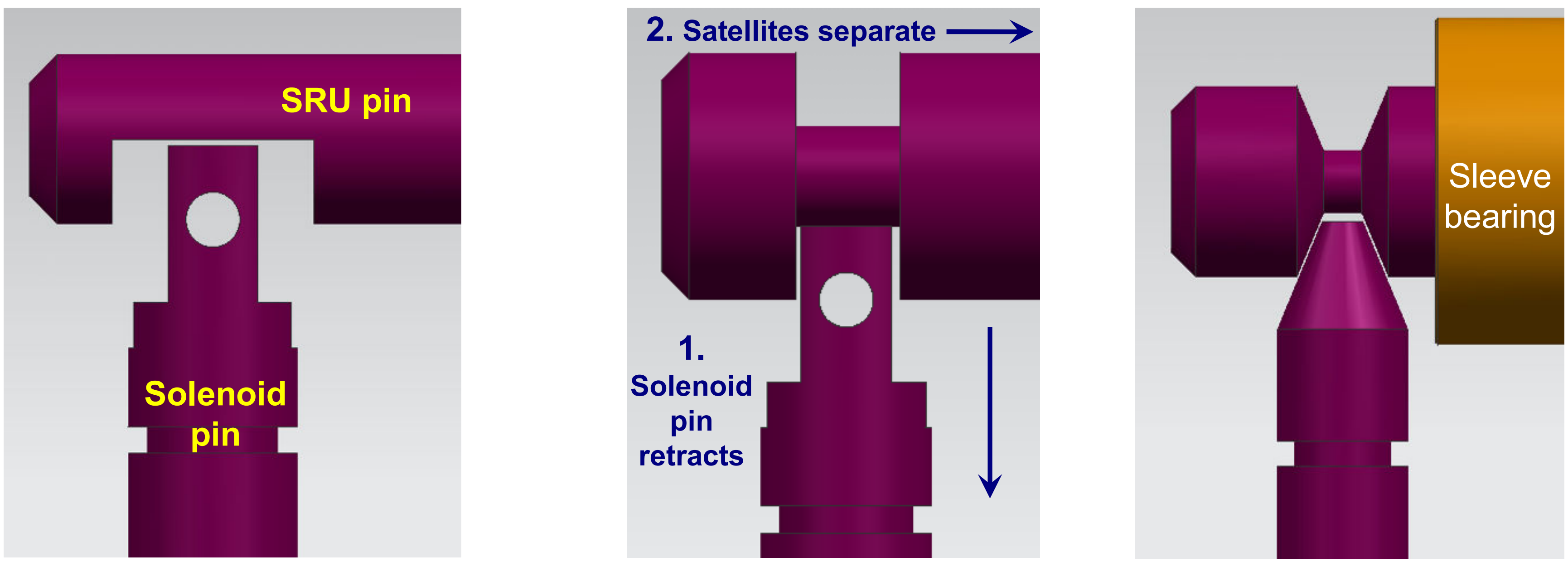
- CubeSat Bearing Rail Experiments
  - Demonstrate SRU operation and dynamics





Solenoid Separation Release Unit (SRU)

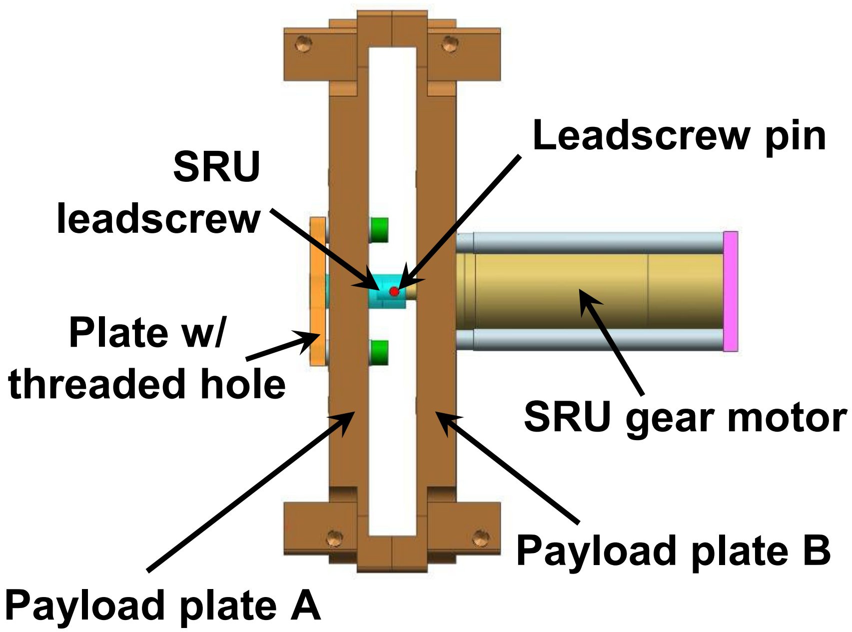
- The first generation (a) had tolerances that were too large.
- The second generation (b) had tighter tolerances, but resulted in too much friction between the pins which impeded retraction of the solenoid pin.
- The third generation conical design (c) caused tipping of the two satellites resulting in friction between the SRU pin and the sleeve bearing.

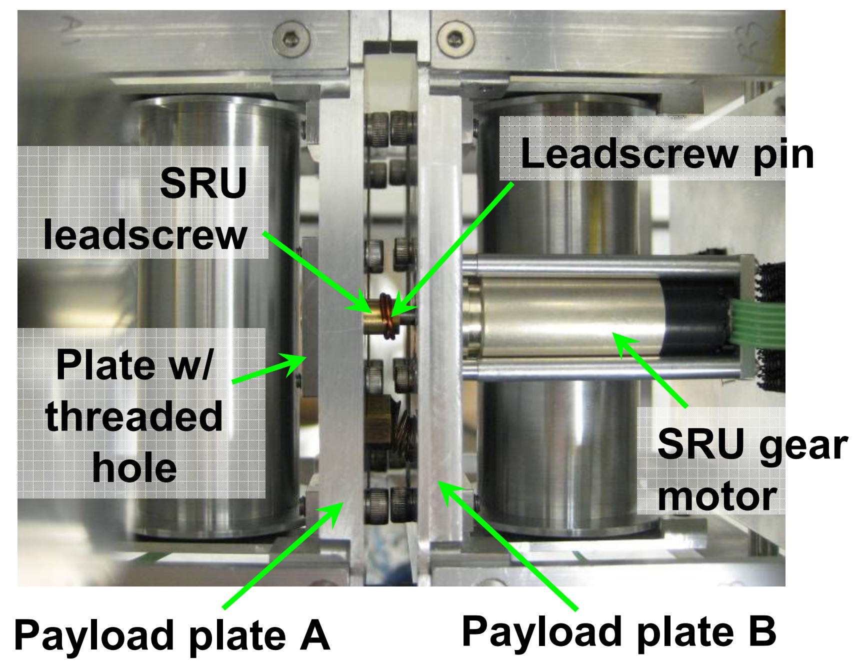


(a) (b) (c)

Solenoid Separation Release Unit (SRU)

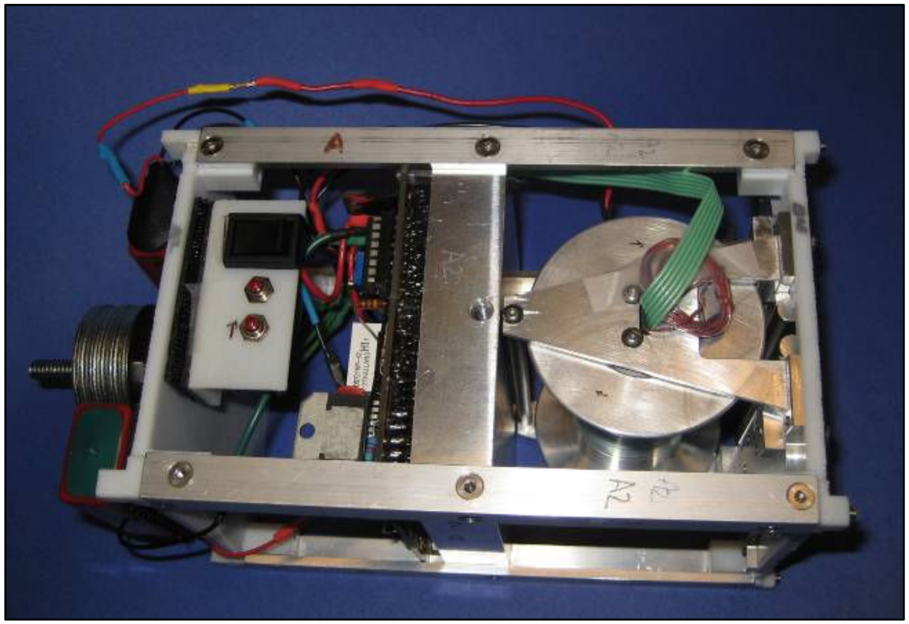
- Leadscrew selected as final SRU design
  - Reliable operation
  - Straightforward hardware design
  - Implementation facilitated by redundant motor purchased for bobbin



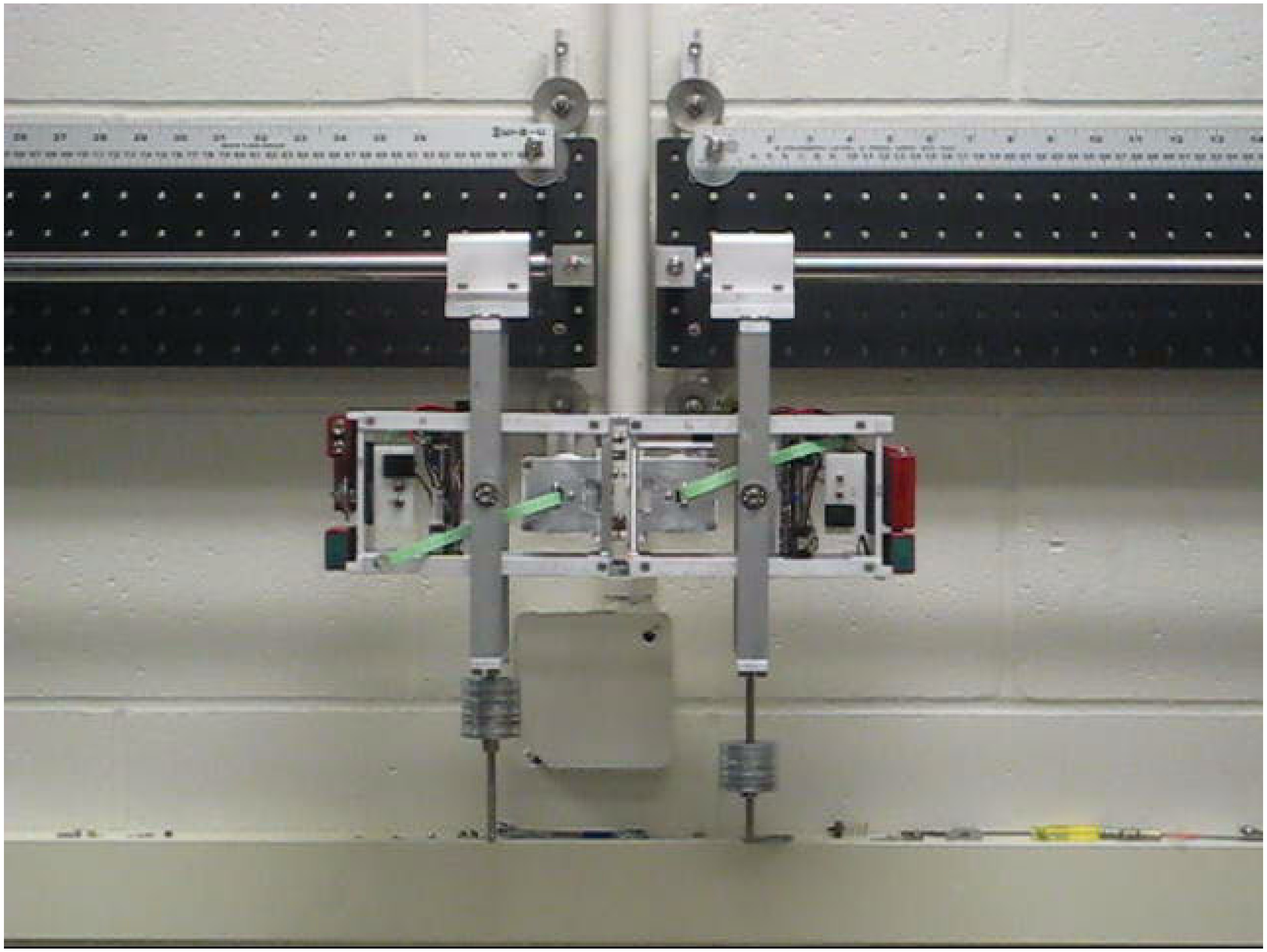


Radio Controlled Open Loop Controller

- RCOLC controls bobbin and leadscrew motors, simultaneously
- To avoid stalling of the gear motor, the SRU release torque is at least 3x the installed torque
- PID controllers dictate target speed and position of the motors

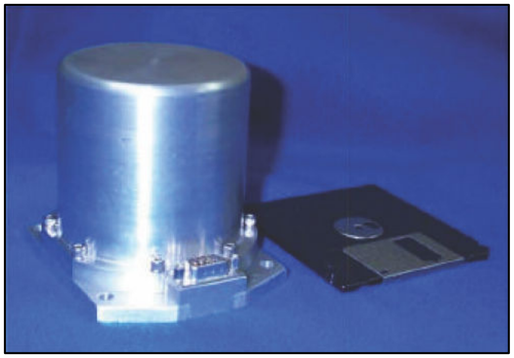


Leadscrew SRU in Action

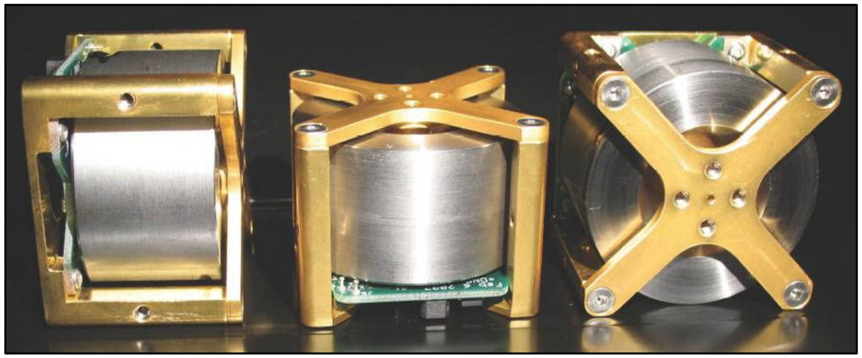


Reaction Wheel Considerations

- Motivated by allowance to exceed 3 kg mass constraint.
- Single-axis RW would enable pitching maneuvers regardless of the external magnetic field.
- Finer control of the pitching maneuvers can be achieved. Also, no need to continuously compute required torquing profiles as the s/c is flying through varying magnetic field.
- Comparable power consumption to magnetic actuation.
- Volume becomes the only constraint.



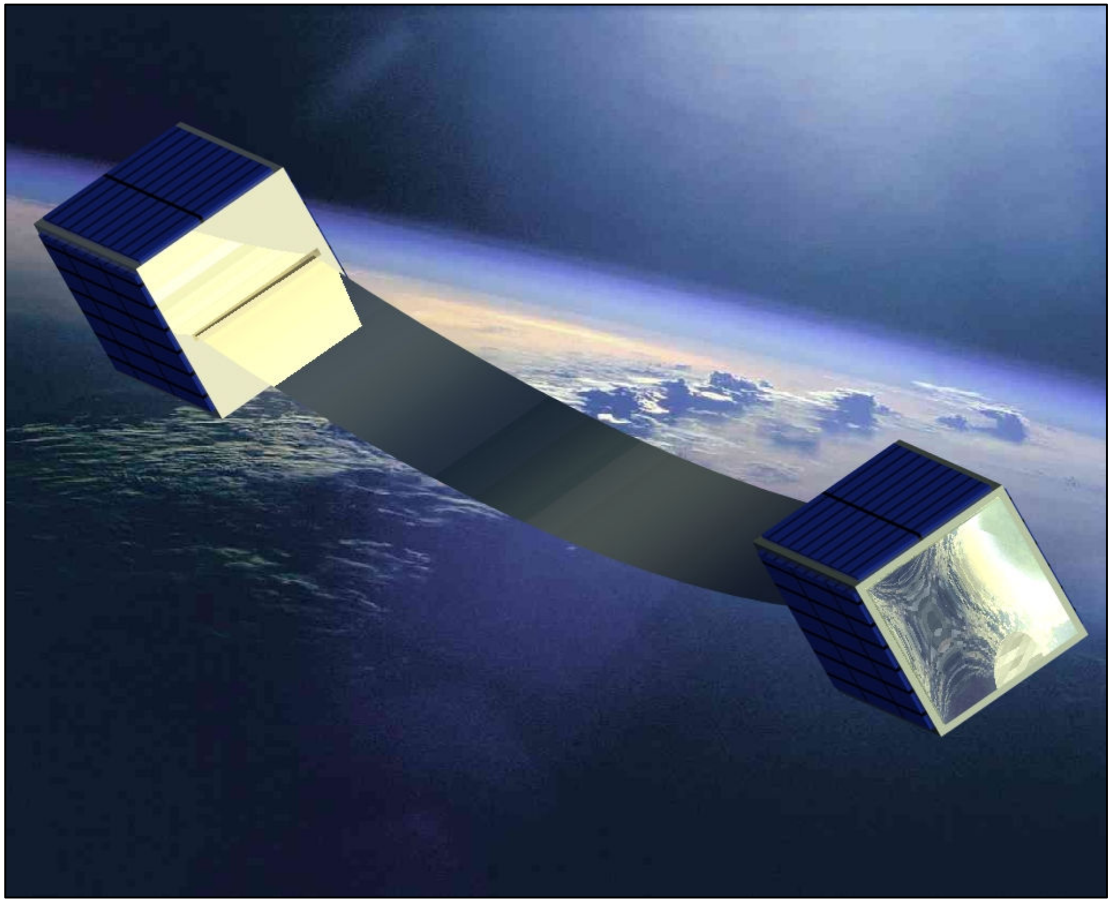
Dynacon MicroWheel 200 Reaction Wheel



Sinclair Interplanetary 30 mN-m-s Reaction Wheel

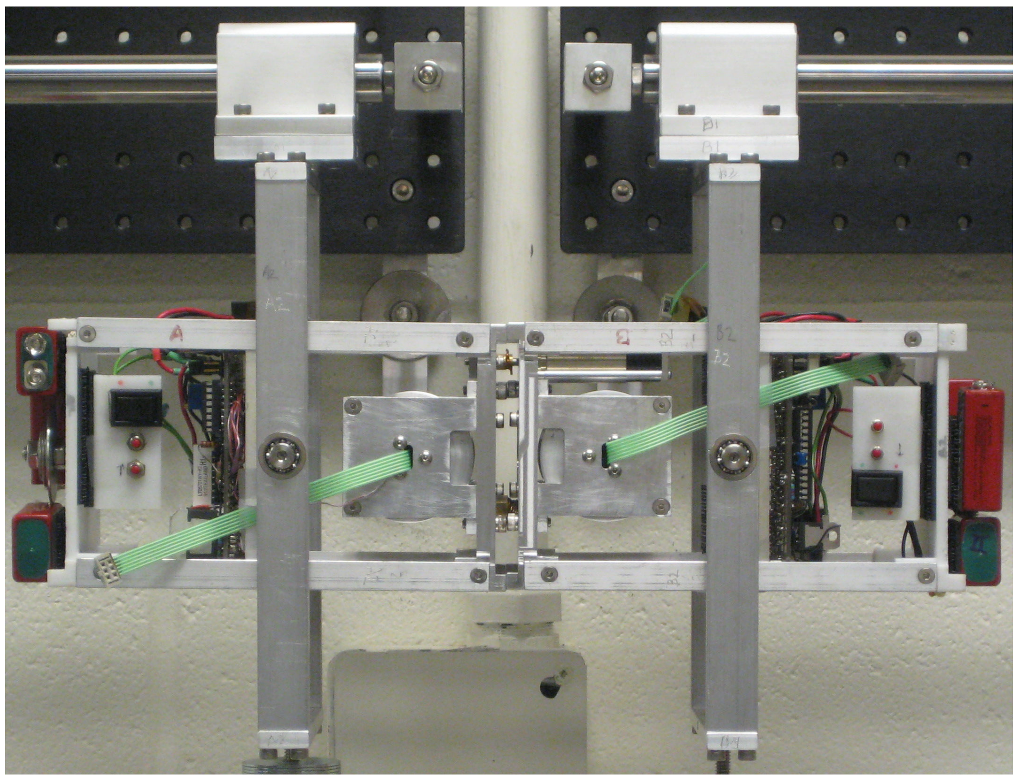
UltraSail CubeSat Flight Experiment

- Perform a first-ever autonomous successful solar sail flight experiment at low cost, using two 1.5 kg CubeSat satellites to deploy a 20 m^2 UltraSail



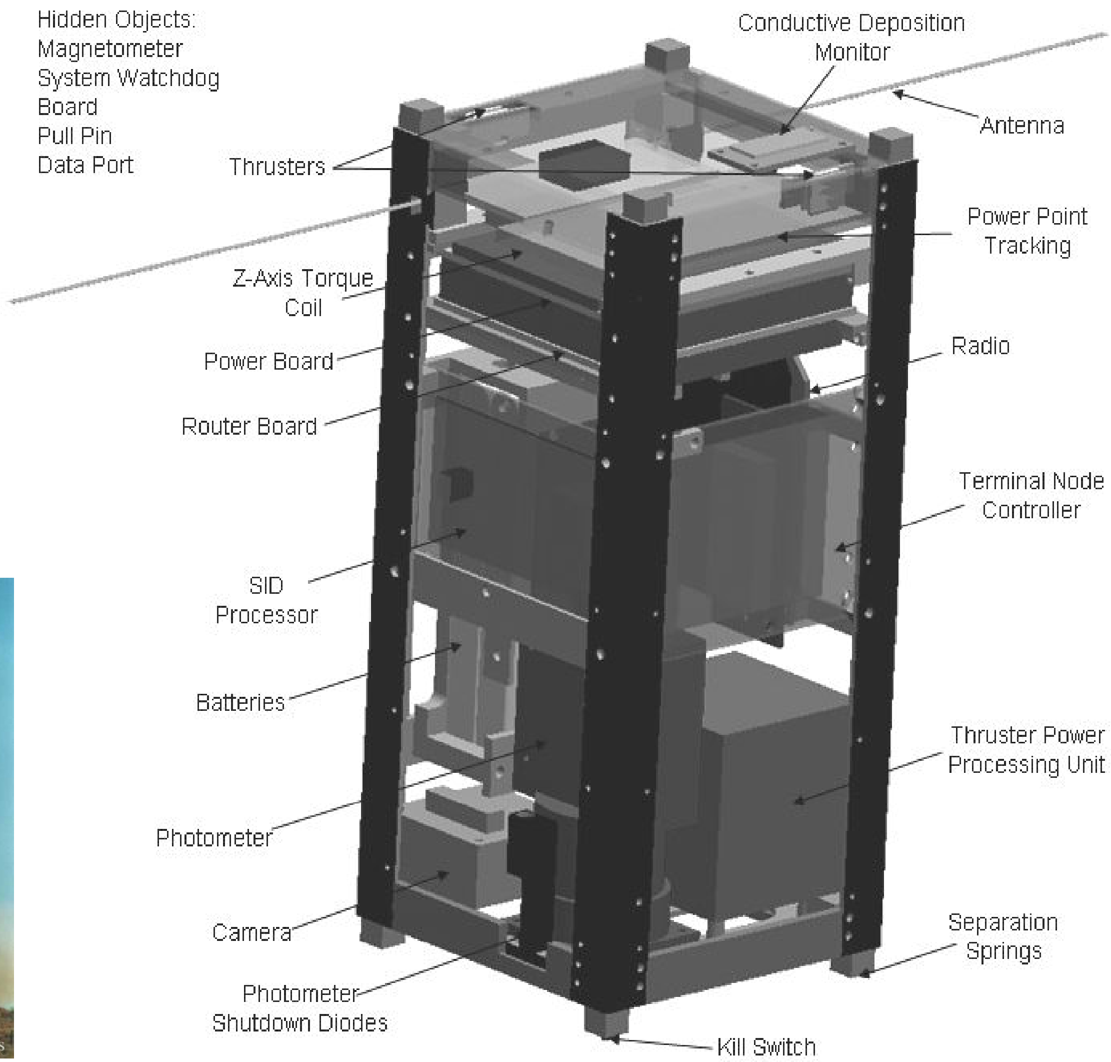
Acknowledgements

- Les Johnson and J. Bonometti at NASA Marshall Space Flight Center
  - Contract NNX09CB37C

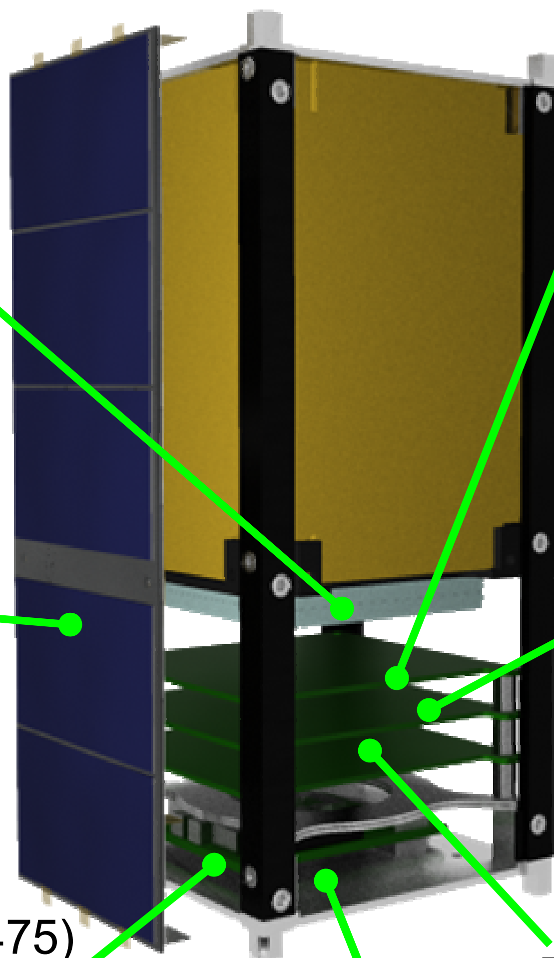


Back-up Slides

ION Bus and Payload



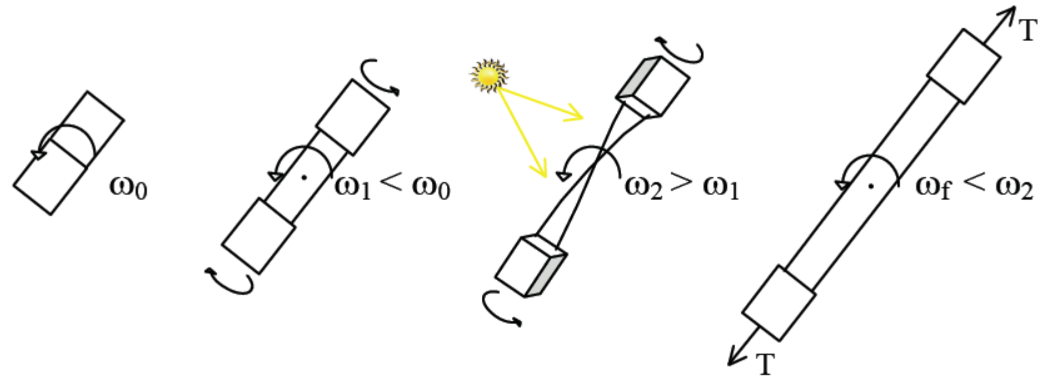
Service Module



- Lithium Polymer Batteries
  - 7.4 V, 2200 mAh (TBC)
  - Integrated cell balancer
- Spectrolab Triple Junction Solar Cells
  - 27% Efficiency
- Radio (Dataradio DM-3475)
  - 70 cm amateur band
  - 0.5 W – 2 W variable Tx power
- Circuit Stack
  - Integrated power and data backplane
    - Supervisor μC with beaconing capability
    - Power Point Tracker / Battery Charger
    - 5 V @ 5 A
  - Expandable and reconfigurable
- CPU (Ti OMAP 5912)
  - Dual Core ARM9 / C55x DSP
  - 192 MHz
  - Linux 2.6 kernel
  - C&DH daemon – iond
  - DSP accelerated TNC
- Trench for system cabling
- Common thermal path to radiator

Deployment and Stabilization Options

Spin Induced :



Vs.

Gravity Gradient: