Development of a Deployable Gravity-Gradient Boom CubeSat

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2009 CubeSat Developers' Workshop

Cal Poly, San Luis Obispo

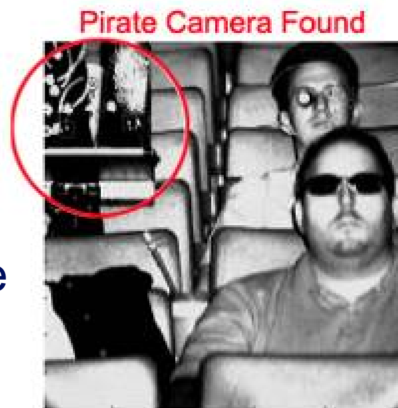
April 22-25

Outline

- Introduction
  - Foster-Miller/QinetiQ North America
  - Flexible composite materials
  - Elastically deployed structures and microsat systems
- Gravity-gradient Solar Array Boom (G-SAB)
  - Cubesat system need
  - Design approach
  - Current design
  - Anticipated performance
- Future development plans

Foster-Miller/ QinetiQ North America

- Large collection of small businesses
- Products in robots, armor, air delivery, sniper detection, wearable electronics
- R&D in advanced materials, electromagnetics, structures, sensors, C4ISR
- Engineering services in many different industries

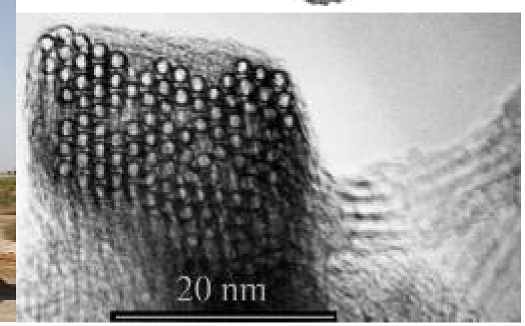






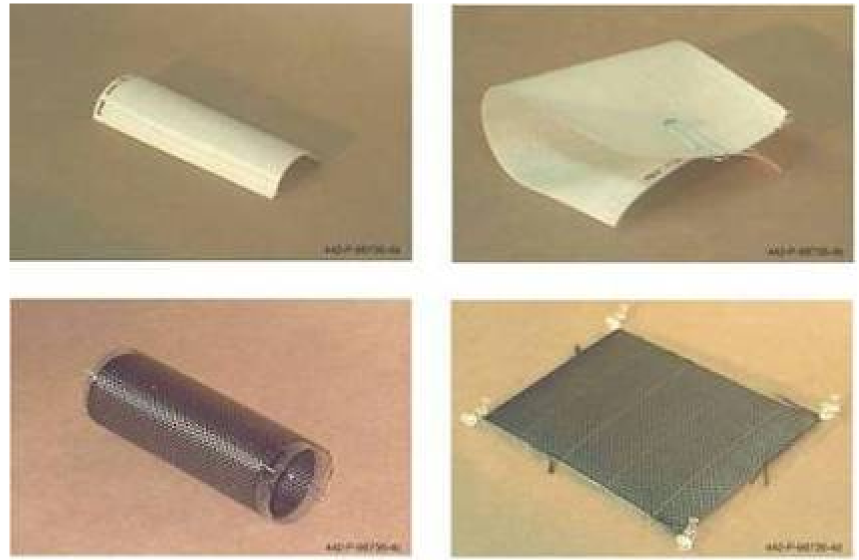






Flexible Composite Materials

- Composite materials have many desirable engineering properties
  - Stiffness, strength
  - Thermal stability
- Proper matrix selection and shell design eliminates both material yield and plastic creep as design concerns
- All materials used have been previously space qualified and flown: 20 years of material flight heritage
- Resultant shells are extremely efficient at carrying both tensile and compressive loads
- Fabricating thin shells of material allows for the repeated elastic bending of curved shells
- Curved shell “tape” hinges replace hinge line, actuator, and latch with single, lightweight component
- Hinge deployment can be passively damped to reduce deployment rates



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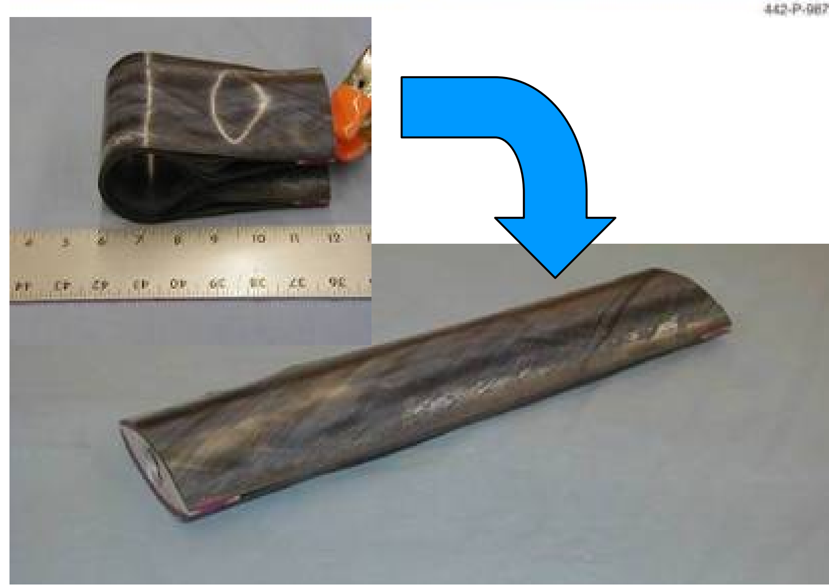
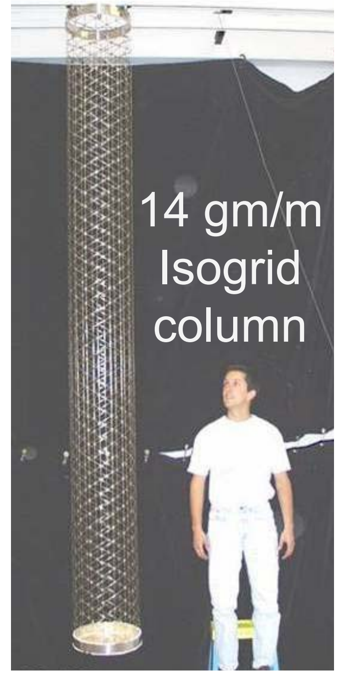
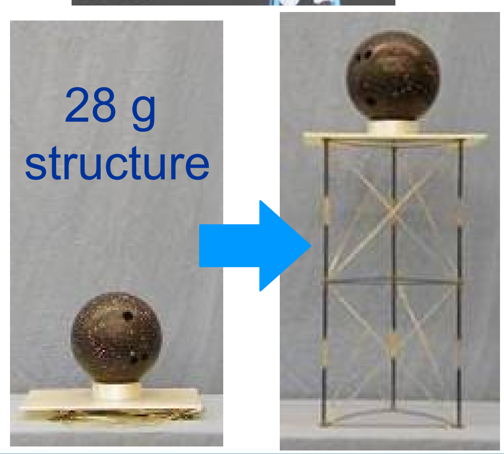
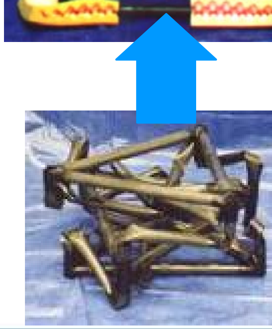


Lightweight Elastic Deployable Structures

0.15 kg/m² 3D Isogrid
175:1 Volume expansion







Deployable Micro-Sat Systems

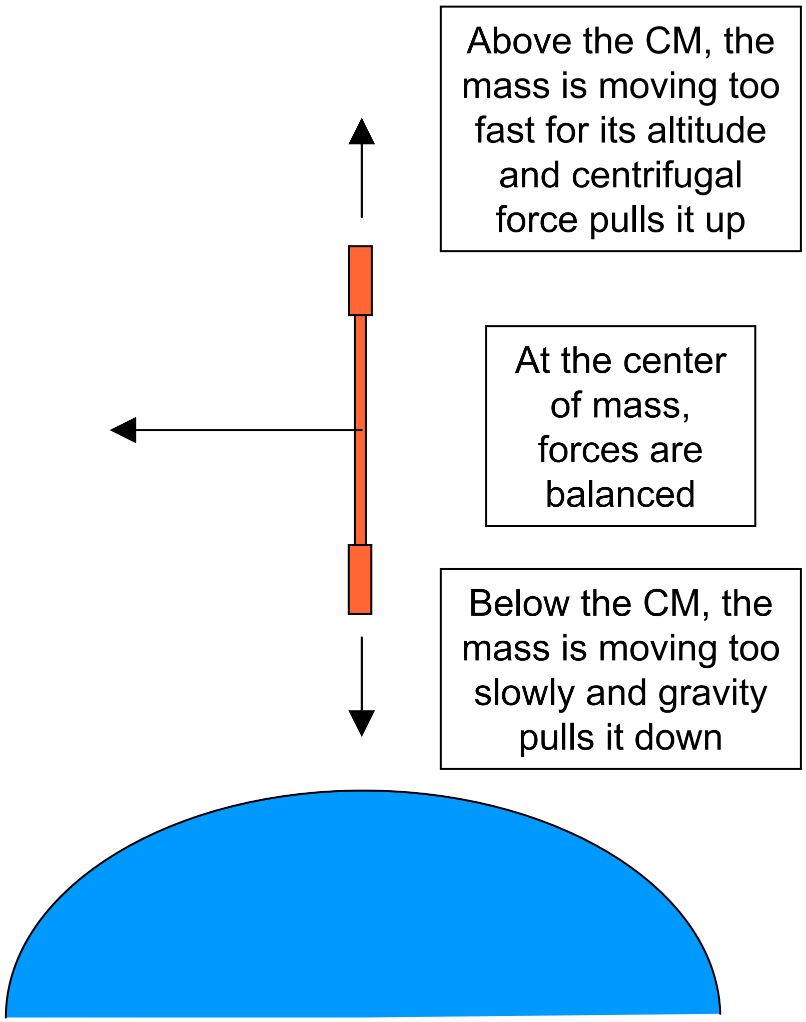
- Exploration of ways to give picosats the capabilities of normal sized satellites
- Deployment of traditional spacecraft appendages
  - Solar arrays
  - Antennae
  - Remote sensors
- Picosat scales pose interesting challenges and opportunities
  - Non-linear structural scaling
  - Mechanisms
  - Flexible materials
- Current work focusing on a deployable gravity-gradient CubeSat

Gravity-gradient Solar Array Boom System Need

- Cubesats are chronically under powered
  - Limited array area
  - Limited array pointing
  - Orbital average power of 3U cubesat is ~6 W
- Attitude control of cubesats taxes resources
  - Occupies volume
  - Active control requires power
- Gravity-gradient boom potentially provides solution
  - Deployed boom provides array area
  - Gravity gradient controls two out of three rotational angles
    - Needs large boom with mass concentrations on either end
    - Differential in gravity pull aligns boom with vector towards earth

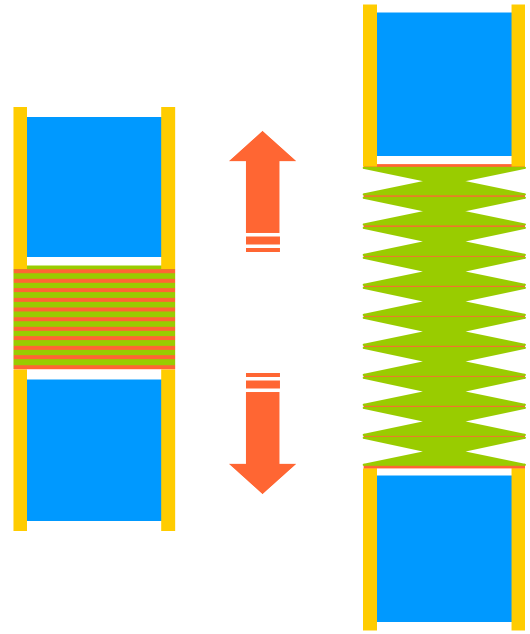
What is Gravity Gradient Stabilization?

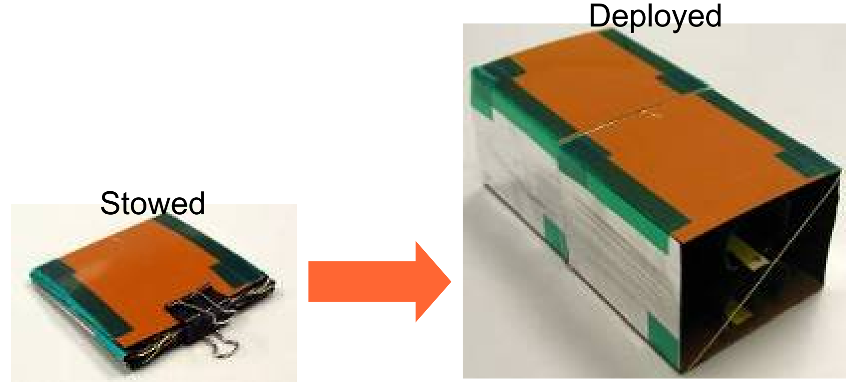
- Objects stay in orbit because of the balance between gravitational forces and centrifugal forces
- These forces are not balanced in portions of the spacecraft away from the center of mass, along the gravity vector
  - Further away from earth, the net force is up
  - Closer to the earth, the net force is down
- Spacecraft will naturally align themselves with their maximum moment of inertia along the radius vector
- Intentional selection of mass properties maximizes this effect
  - 'Dumbbell' shape and mass distribution
  - Lightweight, long central boom
- Combination of G-G with magnetic torquers provides stabilization
  - Mag-Torque damps oscillations
  - Allows recovery in case of inversion



G-SAB Approach

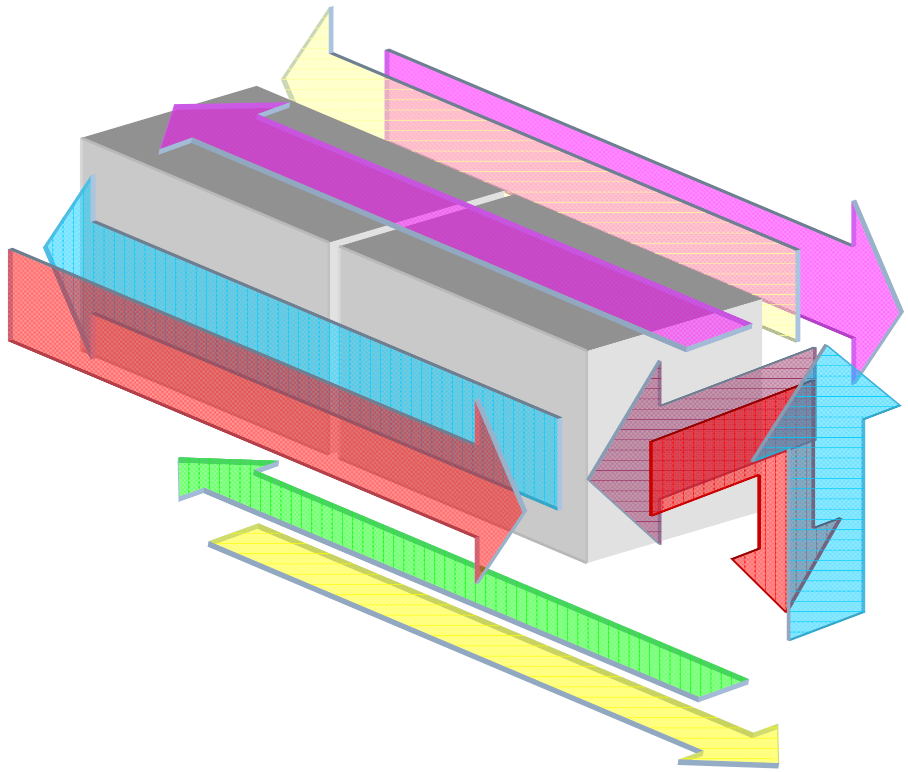
- Strain energy deployment
  - No power required
  - Mechanical timer and release latch
- Boom packages around outside of standard cubesat
  - Does not impact design of ‘standard’ systems
  - Starts generating power before deployment
- Multiple options for deployment
  - Accordion
  - Z-fold
  - Outer wrapped
- Selected outer wrap back and forth approach

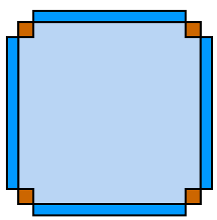




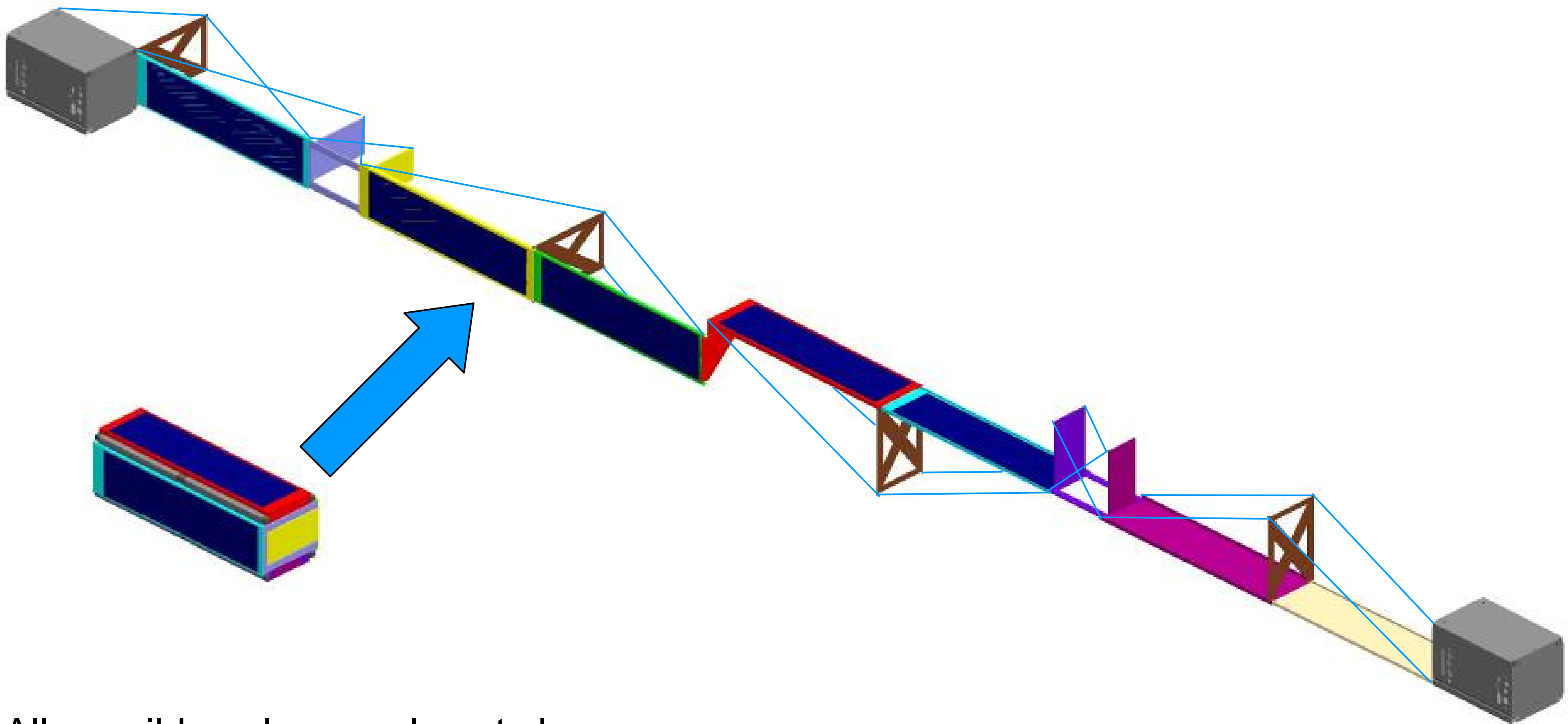
Back and Forth Wrapped Approach

- Split 3U cubesat into two 1.5 U sections
- Boom wraps up and down the long axis of the combined 3U package
  - 7 x 3U panels
  - 3 x 1 U panels
  - 1 x 90° bend provides multiple angle sun exposure
- Back and forth wrapping uses maximum possible launch volume
  - 5 of 6 sides
  - Only two panels per side to maximize panel thickness
- Panels stow in the 6.5mm protrusion allowable in the cubesat specification
  - 730 cm^3 extra volume (22%)
  - G-SAB uses this for the boom and for the restraint system





Back and Forth Wrapped Solid Model: Deployed

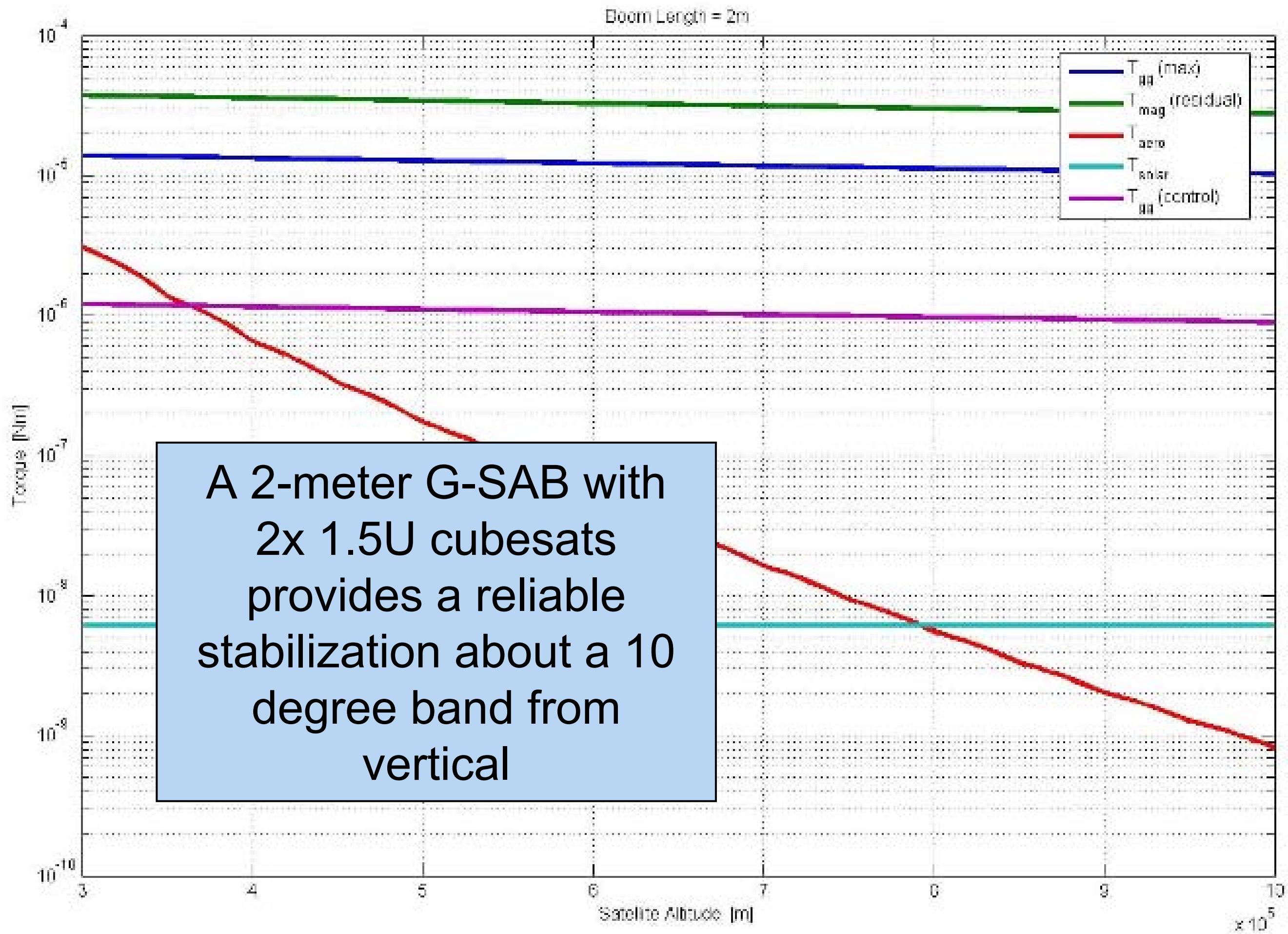


All possible solar panels not shown

Back and Forth Wrapped Concept: Basic Deployment Process

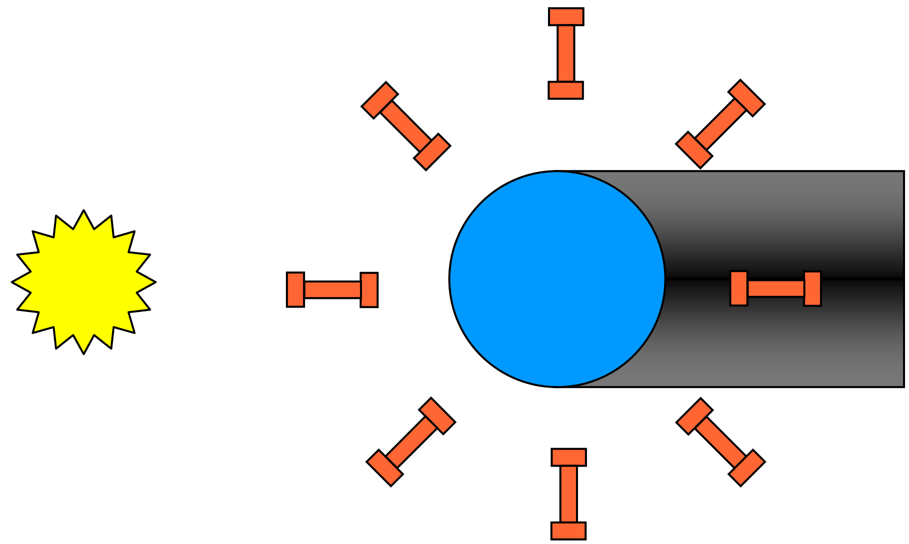
Full Structural Prototype

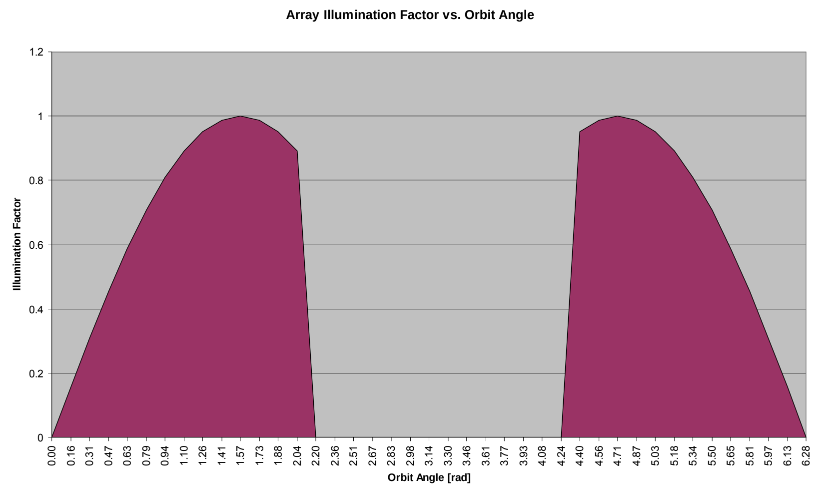
Gravity Gradient Provides Effective Passive Stabilization in 2 out of 3 Angles of Orientation



Solar Power Estimation

- G-SAB provides large area for power generation
  - 0.39 m^2 total surface area
  - Maximum projected area perpendicular to the boom axis at any instant is 0.11 m^2
  - Minimum is 0.07 m^2
  - Average around the yaw angle is 0.1 m^2
- Spacecraft tracks with gravity vector around the orbit
  - Standard α-angle progression
  - Earth's shadow covers one of the nulls
  - Orbital average illumination factor is 45%
- Actual additional power generated depends on selection of cells
  - Orbital average of 0.045 m^2 of projected solar array area
  - Solar constant of 1.37 kW/ m^2
  - 23.7 W orbital average power, 60 W peak with triple junction cells
  - 7.3 W orbital average power, 20 W peak with thin film cells





G-SAB Anticipated Performance Parameters

- Deploys from 2 standard 1.5U CubeSats
  - Only fills volume available outside of CubeSats
- 2.4 m long gravity-gradient boom possible
  - Provides passive stabilization in LEO to within 10 deg of vertical
- Boom deploys with local stiffeners
  - 2 Hz first mode
  - Stiffer is possible if required
- Boom includes integrated solar arrays
  - Provides up to 0.39 m^2 of solar array area
  - Average projected area of 0.13 m2
- Solar cells on both sides of panels provides greatly increased solar array area
  - Max of 60 W
  - Additional orbital average power in LEO of 20+ W

Future Development Plans

Basic Gravity-gradient Solar Array Boom

- Design
  - Inclusion of wiring harness
  - Launch restraint
- Manufacturing
  - Fabrication with flight-like materials
  - Inclusion of cells and wiring
- Testing
  - Offloaded deployment testing
  - Post deployment performance
    - Stiffness
    - Strength
    - Electrical performance

Exploration of Technology's Potential

- Longer booms
  - Thinner, nested structures
  - Using portions of the main spacecraft body
- More power
  - Active control of yaw
  - All arrays on one side
- Other applications
  - Antennas
  - Magnetometer booms
  - Power only for active ACS cubesats
  - ???