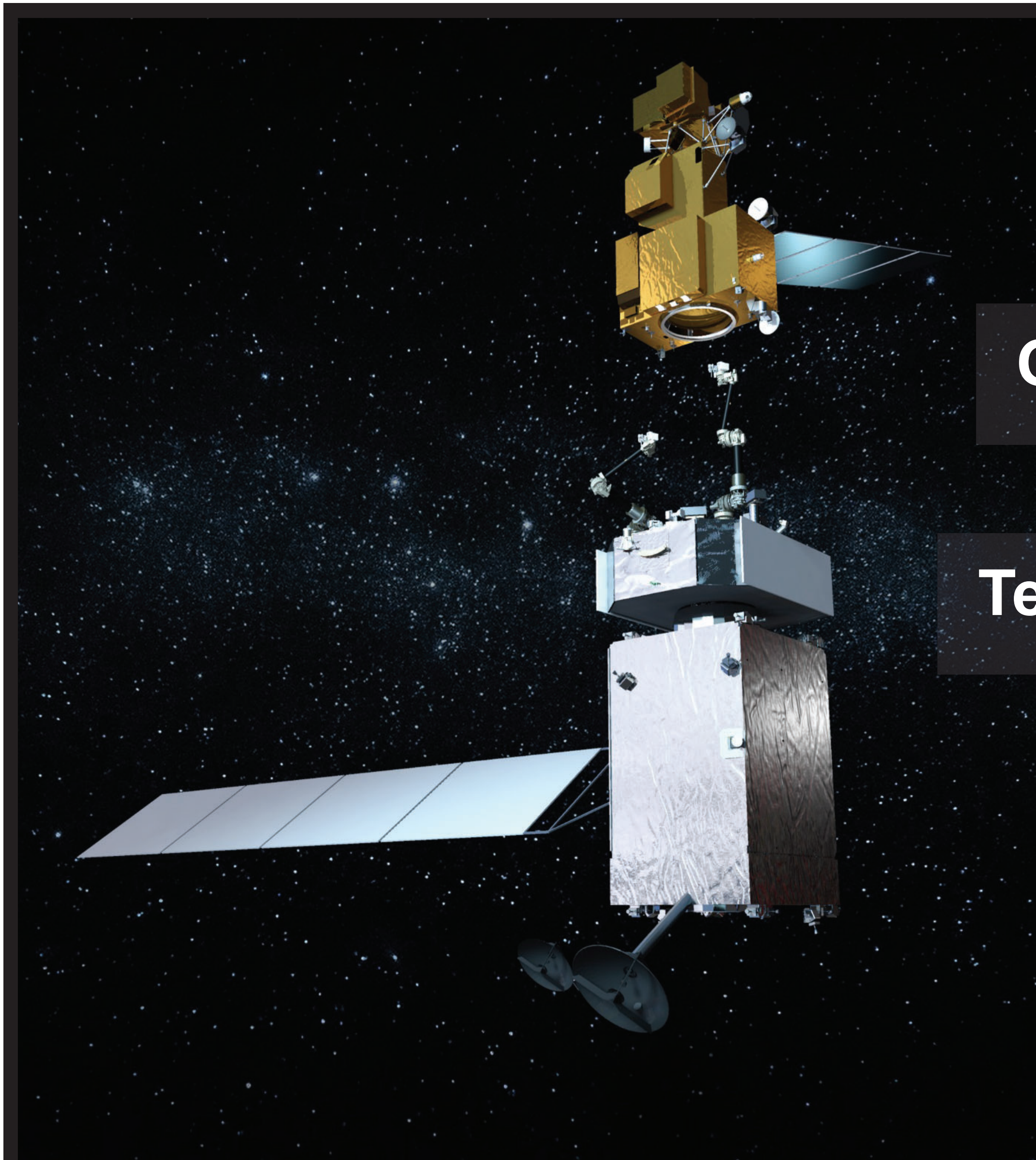


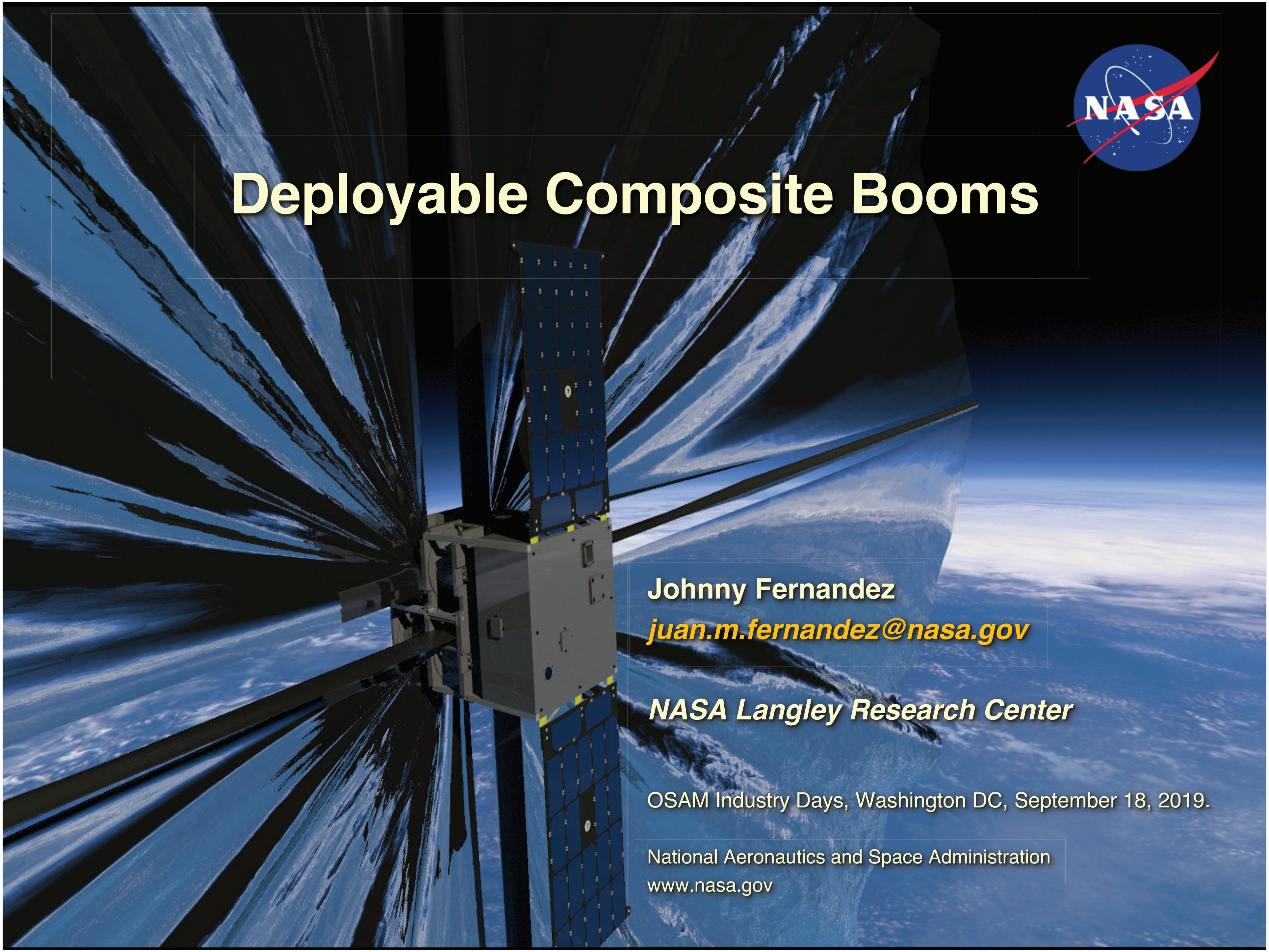
On-Orbit Servicing, Assembly, and Manufacturing Technology Transfer Industry Day

September 18, 2019

Goddard Space Flight Center

Marshall Space Flight Center

Langley Research Center



Deployable Composite Booms

Johnny Fernandez
juan.m.fernandez@nasa.gov

NASA Langley Research Center

OSAM Industry Days, Washington DC, September 18, 2019.

National Aeronautics and Space Administration
www.nasa.gov

STMD Game Changing Development Program
Deployable Composite Booms (DCB)

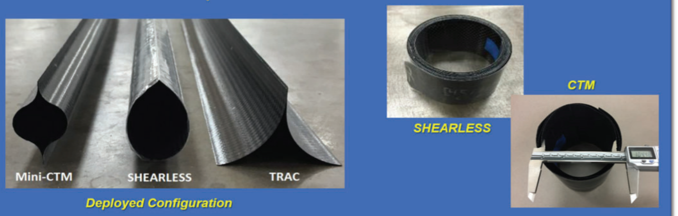
Goal:
- Advance deployable composite boom technology for application in deployable systems for CubeSat / ESPA class small spacecraft and other possible low mass / highly packageable deployable systems (ex., lunar surface application)

NASA Need:
- Addresses technology gap for small spacecraft deployable booms between 5 m - 20 m in length; stowable within 0.5 U – 3 U volumes

Technical Approach:
- Boom Application Design Space, Modeling and Optimization
- Boom Dimensional Stability After Stowage
- Large-Scale Boom Fab Process
- Boom-Deployer System Performance Validation

Results / Pay-Off:
- Lightweight, compact, deployable composite boom systems for high acceleration solar sail propulsion systems, high power solar arrays, and high data rate communications for future small spacecraft missions and moon/planetary surface deployables.

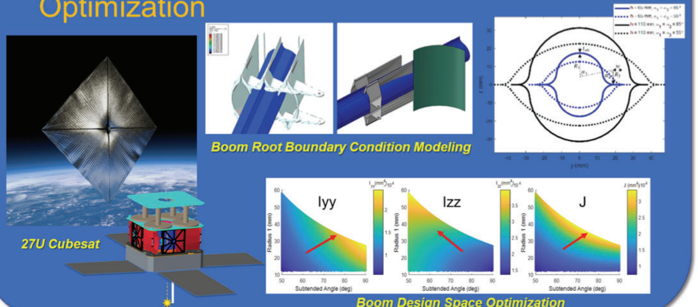
Bistable Rollable Composite Boom Designs Under Development



Deployed Configuration

Stowed/Coiled configuration

Boom Application Design Space, Modeling & Optimization

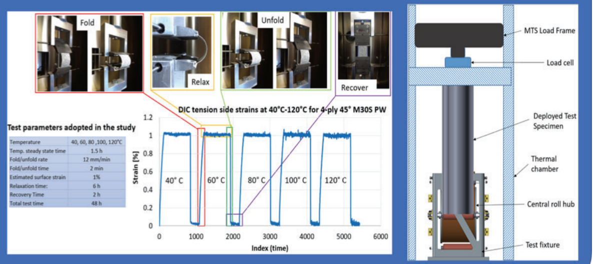


27U Cubesat

Boom Root Boundary Condition Modeling

Boom Design Space Optimization

Boom Dimensional Stability After Stowage



Column Bending Test (CBT) Procedure for Material Viscoelastic Characterization

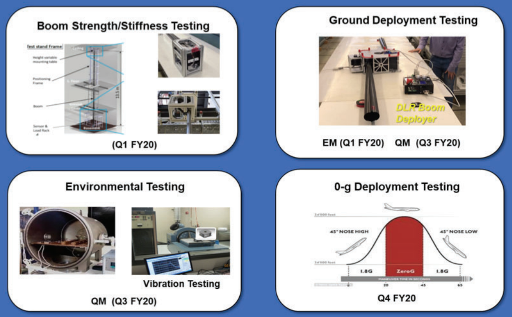
Rolled Boom Relaxation Test

Large-Scale Boom Fabrication Process

16.5 m Low CTE Carbon Foam Production Mold

Convection Cure Oven, Work Cart/Part Tray and Fab Process GSE

Boom-Deployer System Performance Validation

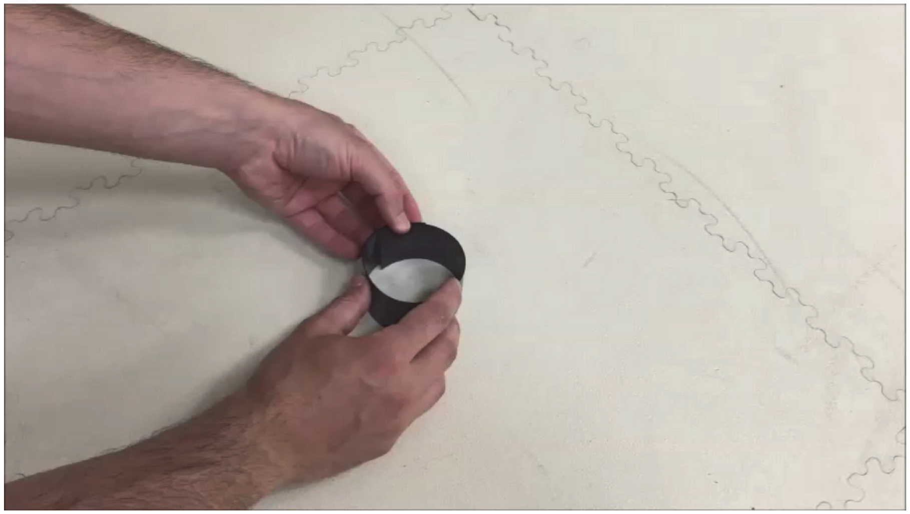


Standard (Monostable) Booms vs Bistable Booms

- **Standard monostable booms can store a lot of strain energy when coiled and thus blossom/bloom inside the deployer mechanism during deployment potentially jamming or stalling.**
- **In general, bistable booms store less strain energy when coiled and have a slower more controllable and coherent deployment.**
- **Current research aims to tailor the beneficial bistability effect of some of these composite booms.**

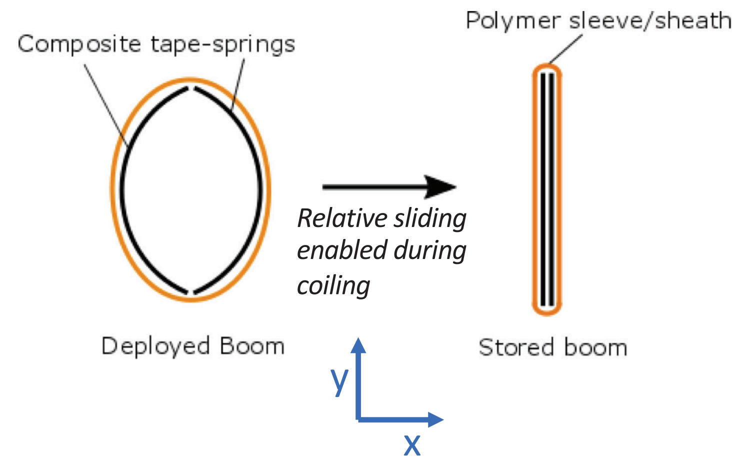
Monostable boom: faster and less predictable deployment.
- Requires additional constraint mechanisms, incurring in more complex and heavier boom deployers.

Bistable boom: slower and more controllable/coherent deployment.
- Minimal constraint mechanisms are required.
- Manageable strain energy for lower risk actuation and possible self-deployment concepts.



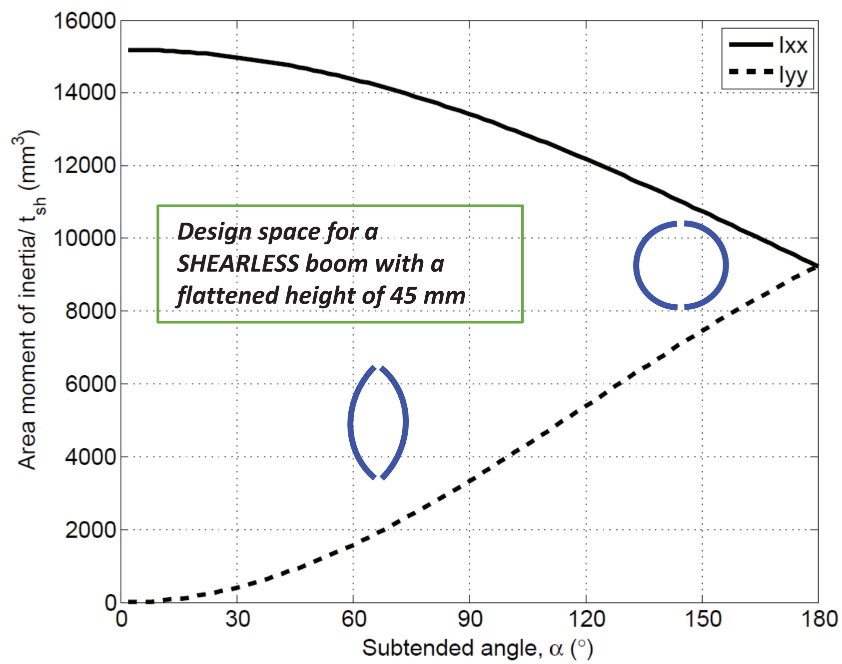
Bistable SHEARLESS Boom

- **SHEA**th-based **R**ollable **LE**nticular-**S**haped & low-**S**tiction (SHEARLESS) boom: **Patent US 9,863,148 B2, Published: Jan. 9, 2018.**
- Two unbonded cylindrical shells form a bi-convex shape inside a low-friction polymer sleeve that couples them in bending & torsion.
- Design allow sliding of composite shells during coiling and deployment inside the sheath; enables more compact packages without detrimental shear effects.
  - Enables very small wrap diameters (< 1.5") and has high packaging efficiency (> 95%) allowing long booms on small satellites.
  - Shell cross-section subtended angles of α = 135° - 160° are a good design compromise between maximizing moment of inertia and leading to uncoupled edges during coiling.
  - Extensive boom laminate study to maximize the boom length for a given volume constraint (max boom coil outside diameter).



Relative offset between tape-springs when coiled.

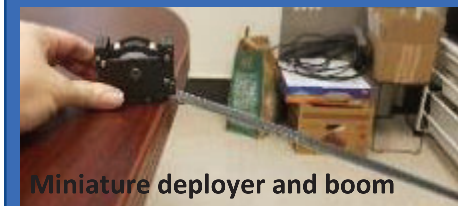
Coupled edges of the inner tape-springs in deployed configuration.

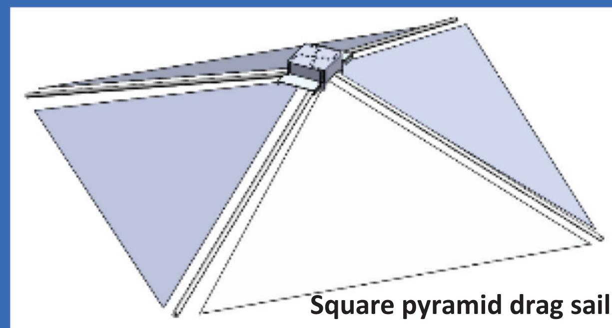


SHEARLESS Boom Applications

Drag Sail deorbiting system for small satellites and rockets

- Firefly's Alpha upper stage
- 1U CubeSat (Aerodynamic Deorbit Experiment – ADE)


Miniature deployer and boom

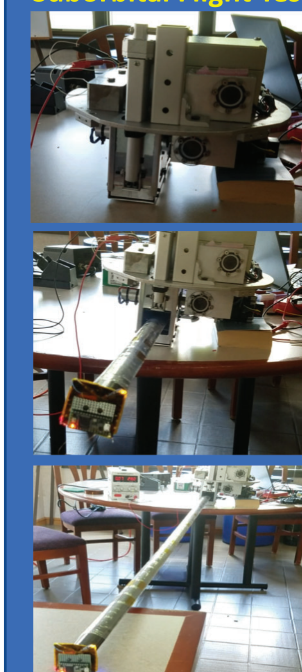

Square pyramid drag sail

VDA coated sleeves for thermal control

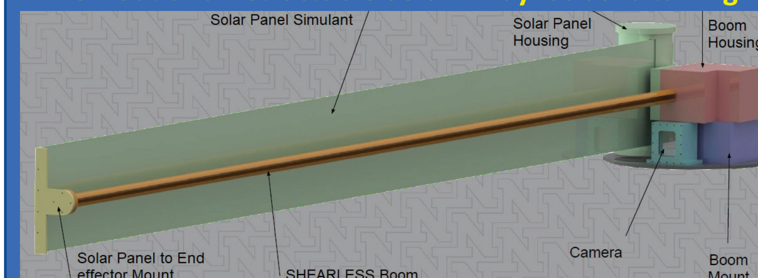
SiO_2 coated sleeves for ATOX protection in LEO

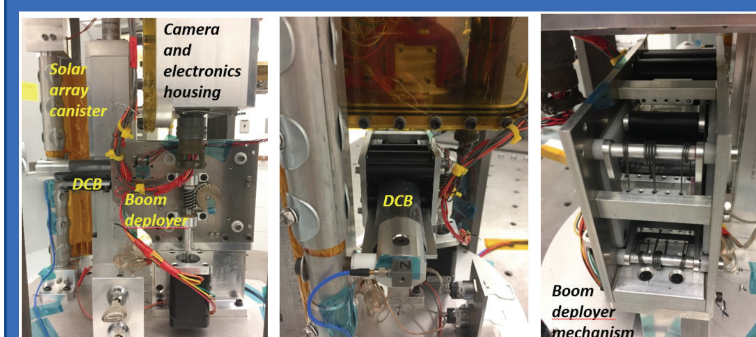
Gravity Gradient Boom for 3U CubeSat

Instrument Boom: Suborbital Flight Test



Roll-out and Retractable Solar Array: Suborbital Flight



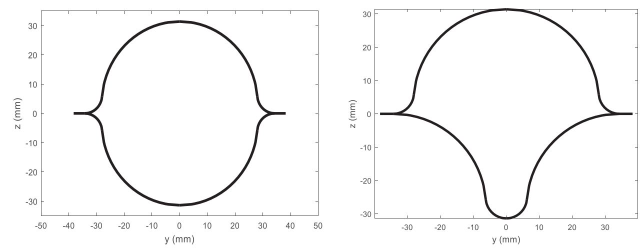


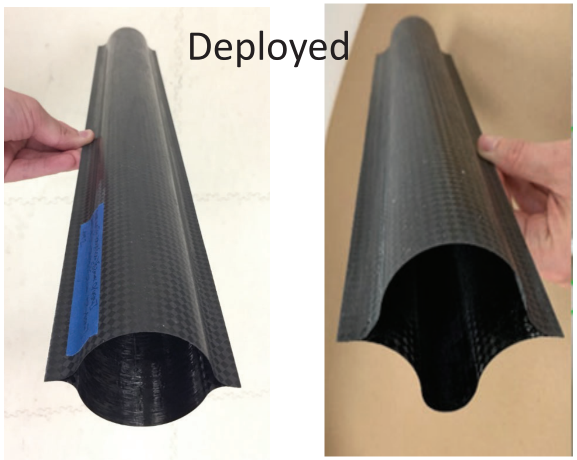
Bistable CTM Boom

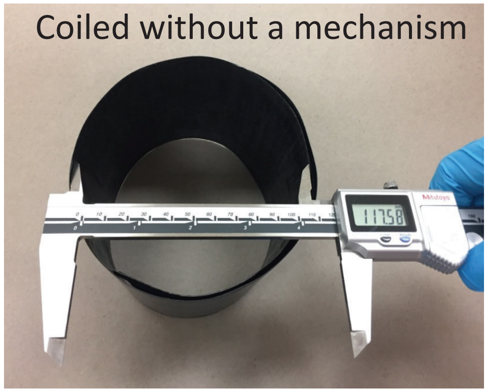
- **Bistable CTM Boom. New Technology # LAR 194221-1. Patent pending.**
- Two omega-shaped thin shells bonded on two flat regions at each edge to form a closed-section boom with large stiffness and high dimensional stability.
- Cross-section defined by circular, parabolic or ellipsoidal arcs that form symmetric or asymmetric designs. Asymmetric designs promote bistability (stable coiled state) and more compact booms.
- Boom enables coiled diameters < 4” and has a packaging a efficiency of ~50% allowing high performance booms on small volumes of small sats.
- Parametric tool with optimization to define boom cross-section that satisfied a set of mission requirements while maintaining bistability.
- New manufacturing facility at LaRC and CFRP molds that allow affordable fabrication of CTM booms up to 16.5 m long at a production rate of 1-2 boom/week.


Hardware for lifting, rotating, coupling and curing 16.5 m CTM booms and molds

Symmetric and Asymmetric bi-CTM

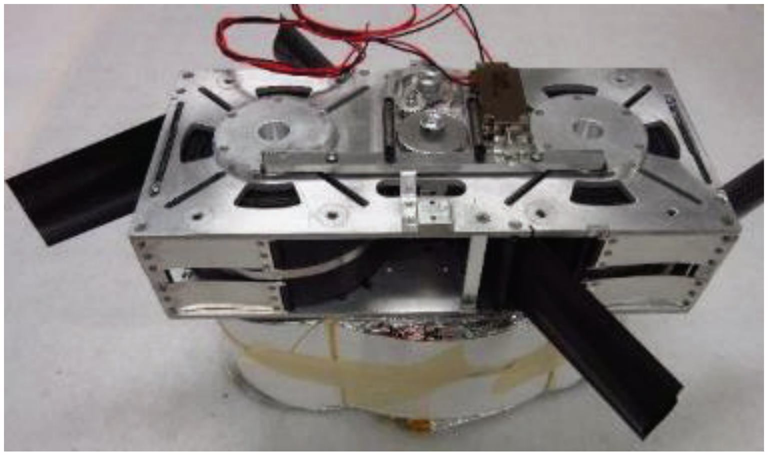






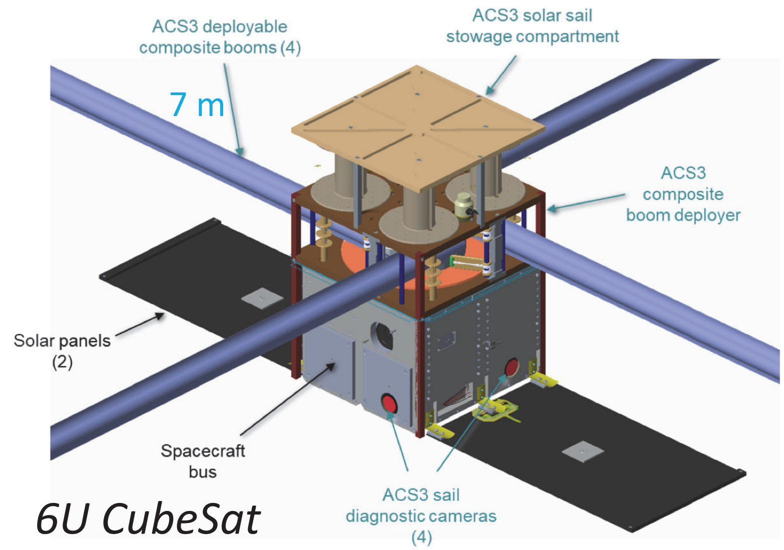
CTM Booms enabling Solar Sails

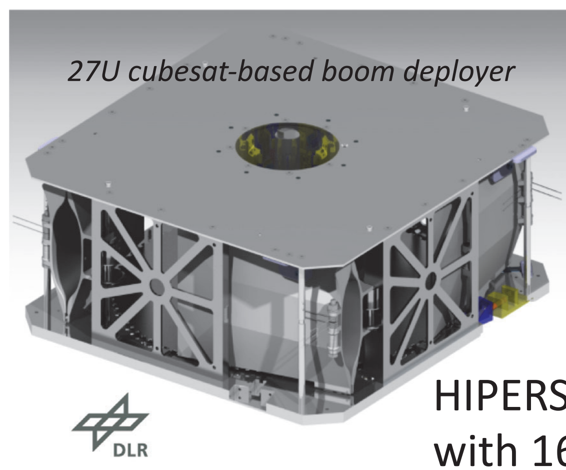
NEA Scout compatible CTM booms-solar sail system (CS3)

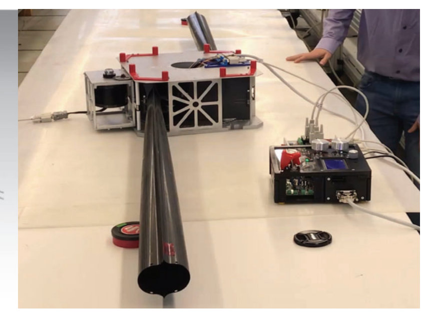


Click to play movie.

ACS3 Solar Sail (80 m^2) with 7 m CTM booms

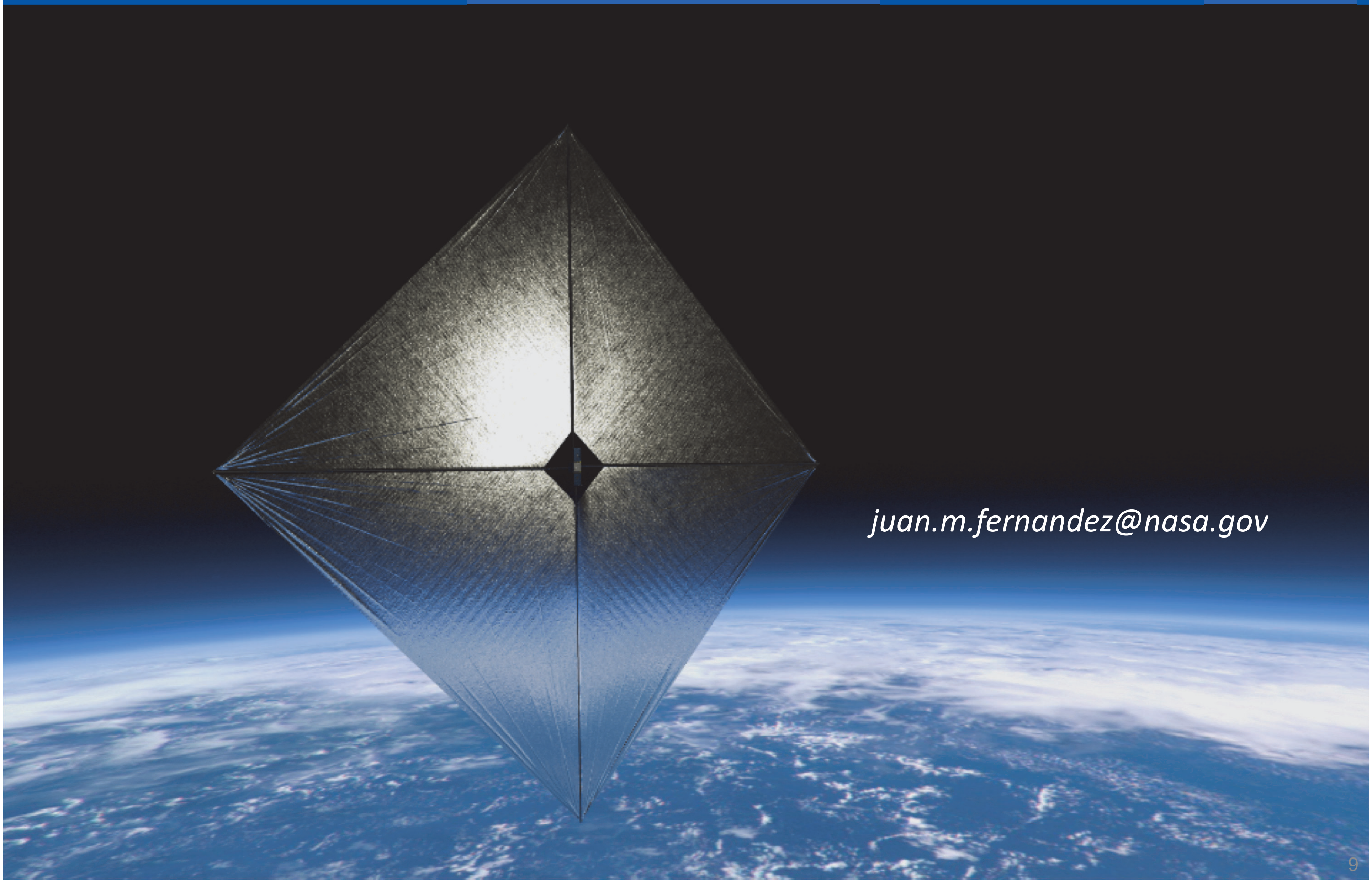






HIPERSail Solar Sail (500 m^2) with 16.5 m CTM booms

Questions?



juan.m.fernandez@nasa.gov

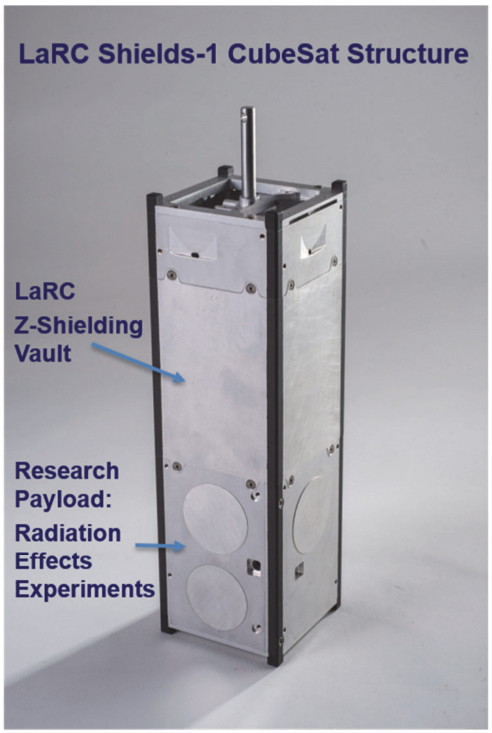
Z-Shielding Industry Day

Dr. Larry Thomsen
NASA Langley Research Center, Advanced Materials and Processing Branch, 6A West Taylor Street, Hampton, VA 23681; 757-864-4211, d.l.thomsen@nasa.gov

16 September 2019

Z-Shielding: Space heritage with Shields-1 NORAD ID 43850

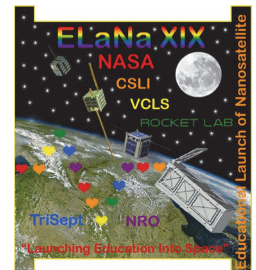
Presently, Shields-1 operates with LaRC Z-Shielding providing radiation protection for the electronics over 10 months in polar low earth orbit.

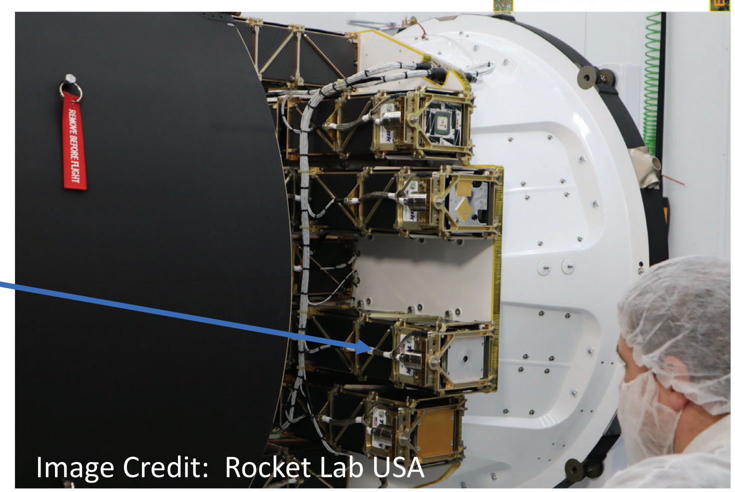


LaRC Shields-1, Preship for ELaNaXIX Mission, July 2018

Shields-1 structure and Final Preship Picture with LaRC Z-Shielding Vault and Experiment, Solar Panels and Thermal Radiator

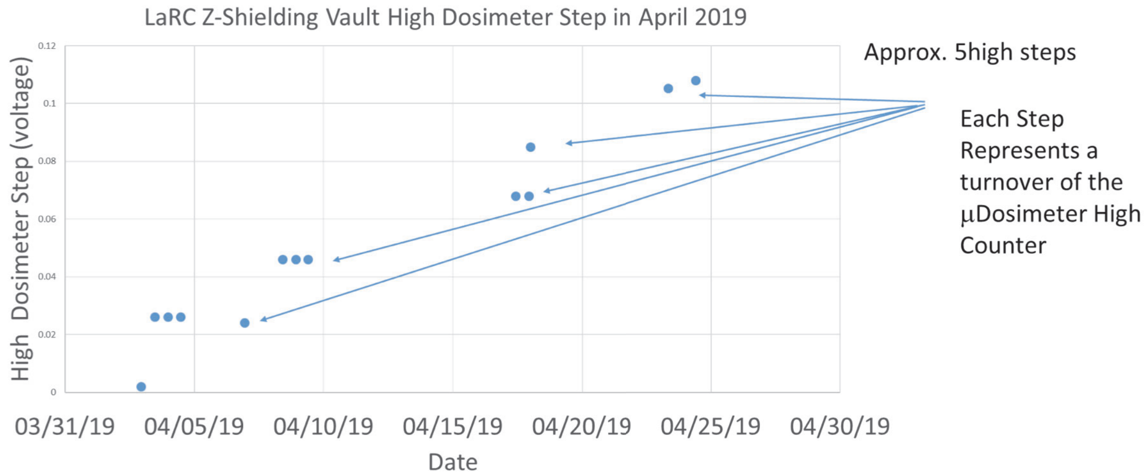
Shields-1 onboard Rocket Lab USA, Electron Rocket, NASA ELaNaXIX Mission, 16 December 2018 Launch





Shields-1 in PPOD deployer, 2nd from bottom, inside Electron Rocket Fairing before encapsulation

Shields-1 Vault Experiment Preliminary Results



High Count = 256 counts (steps) of Medium
Med Count = 256 counts (steps) of Low
High count step = 256 x 256 x 14.4 +/-0.4 uRad/step = 0.9 Rad/step

Approx. 4.5 Rad has accumulated on vault µDosimeter, over a three week period.

SPENVIS Sphere Model Suggests 80 Rad/yr or 1.5 Rad/week
For modeled z-shielding of the same materials in orbit

- Preliminary results: estimated dose rate: 1.5 Rads/week (80 Rads/year)
- Consistent with expected results of 1.5 Rad/week
- Suggests Z-Shielding Vault behaves similarly to a spherical shielding model
- Reduces total ionizing dose on sensitive electronic parts

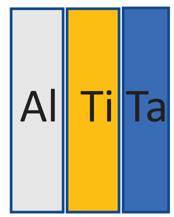
Reference: Donald Thomsen, Kevin Somervill, Mark Jones, Raymond T. Lueg, William G. Girard, Alexander D. Scammell, Jing Pei, James W. Cutler, Robert G. Bryant, “Shields-1 Initial Space Operations, a NASA CubeSat Launch Initiative ELaNaXIX Mission”, SmallSat Conference, 2019, Logan, Utah, 7 August 2019.

Z-Shielding Characteristics

- Low atomic number materials graded or layered to higher atomic number materials

Z-Shielding layered example

Space Radiation
High Energy protons and electrons



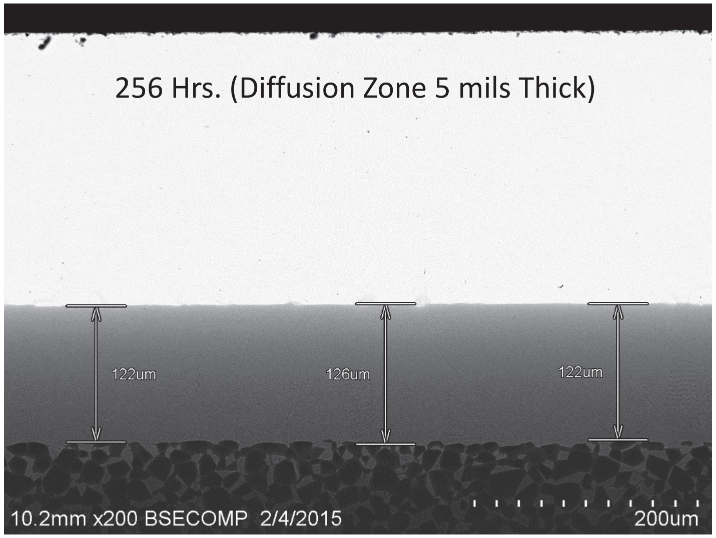
Attenuated protons and electrons

For many low earth orbits: electron radiation can be effectively shielded and the risks for internal charging substantially reduced with Z-Shielding

- One piece structure

Z-Grade Shielding Materials and Technology Development

Z-Grade Shielding from Titanium and Tantalum Diffusion Bonding



Product

Relevant Publications:

U.S. Patent No. 10,039,217, 31 July 2018, "Methods of Making Z-Shielding." D.L. Thomsen III, R.J. Cano, B.J. Jensen, S.J. Hales, and J.A. Alexa.

U.S. Patent Application No 15/949,644, LAR-19109, 12 April 2018, "Method of Making Thin Atomic (Z) Grade Shields", D.L. Thomsen III.

U.S. Patent Application No. 20170032857, 2 February 2017, "Atomic Number (Z) Grade Shielding Materials and Methods of Making Atomic Number (Z) Grade Shielding." D.L. Thomsen III, S.N. Sankaran, and J.A. Alexa.

D.L. Thomsen III, W. Kim, and J.W. Cutler. "Shields-1, A SmallSat Radiation Shielding Technology Demonstration", 29th AIAA/USU Conf. on Small Sat., SSC15-XII-9, August 2015.

U.S. Patent No. 8,661,653, 4 March 2014, "Methods of Making Z-Shielding." D.L. Thomsen III, R.J. Cano, B.J. Jensen, S.J. Hales, and J.A. Alexa.