Deployable Spacecraft Structures

SIP Forum #2 Presentation, 2/6/2020

Thomas Murphey, PhD
tmurphey@opterusrd.com
(505) 250-3006

Patrick Rodriguez
patrick@opterusrd.com
(505) 795-3896

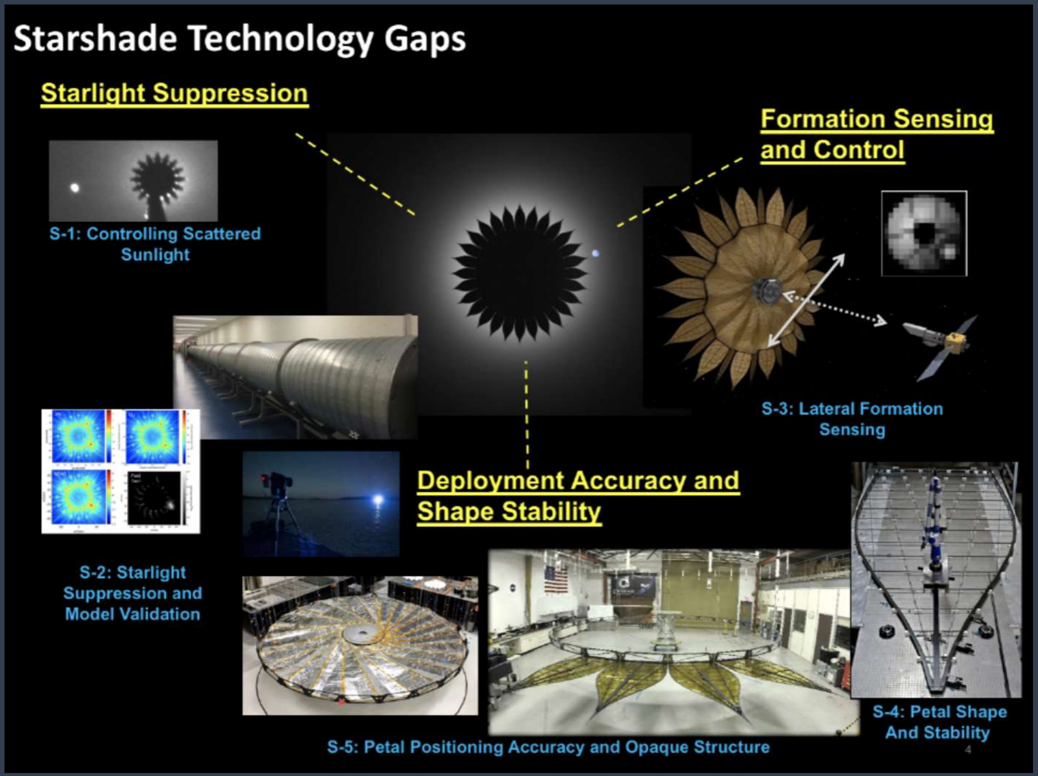
Overview – Starshade to TRL5 (S5)

- Key Technology Gaps
- Error Budget Reduction
- Work Scope
- Preliminary Analyses
- Material Test Data Generation
- Next Steps
- Summary

OPTERUS

Addressing Key Technology Gaps

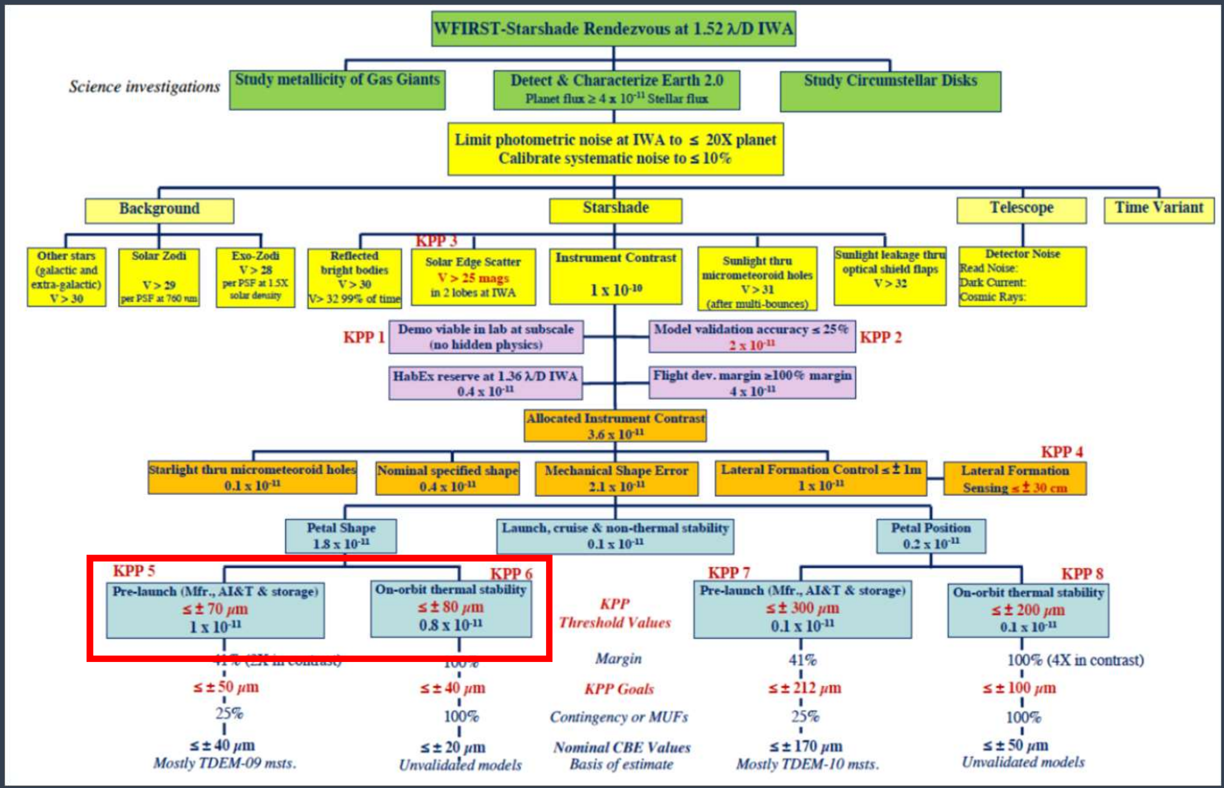
- Deployment Accuracy and Shape Stability
  - Combined test/analysis approach
  - Targeting estimates on Starshade Petal dimensional stability
  - Petal dimensional stability driven by material dimensional stability



* From Starshade to TRL5 (S5) TDP

Error Budget Reduction

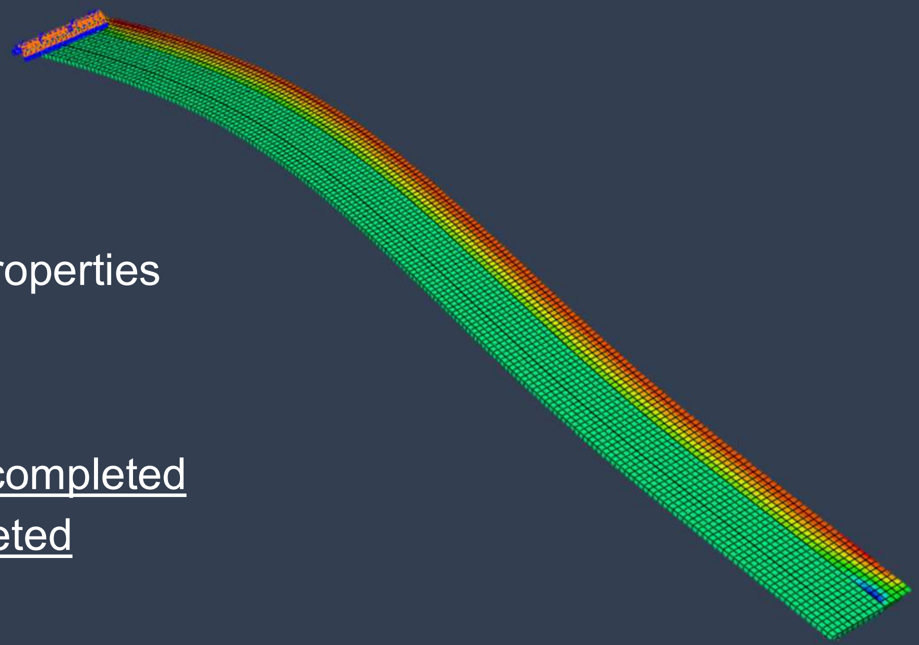
- Opterus work addresses Petal Shape
  - KPP 5 (≤ ± 40 μm)
  - KPP 6 (≤ ± 20 μm)
- Pre-launch/on-orbit shape stability are relevant



* From Starshade to TRL5 (S5) TDP

Work Scope – Guiding Material Selection

- Opterus tasked with evaluating different materials relative to their impact on Petal dimensional stability
- Combined test/analysis approach includes:
  1. Preliminary, comparative Petal edge analyses
  2. Coupon-level material testing (CFRP resin)
  3. Full Petal analyses using test validated resin properties

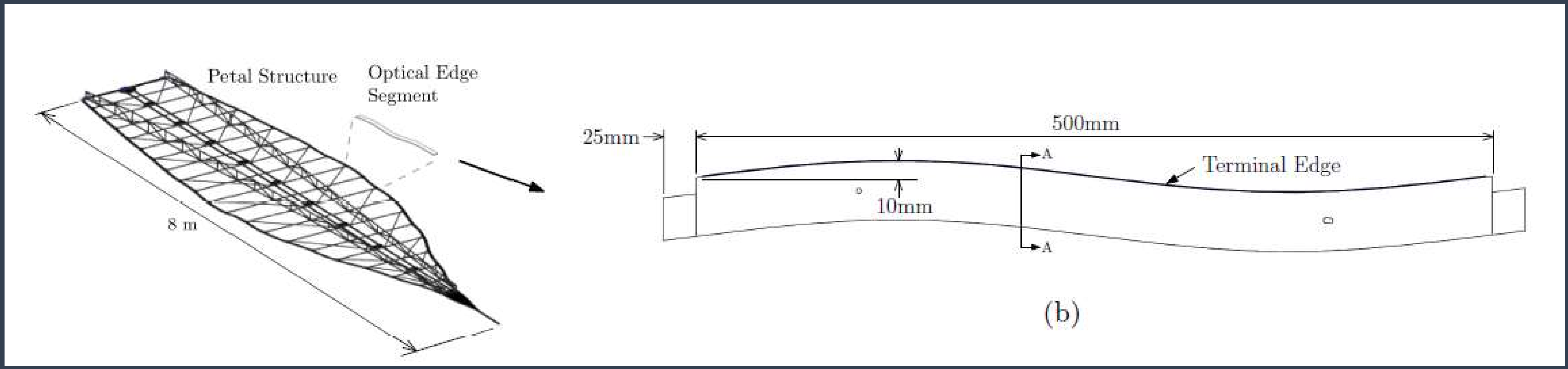


- Since the last Face to Face
  1. Preliminary, comparative petal edge analyses <u>completed</u>
  2. Coupon-level resin test design/test plan <u>completed</u>

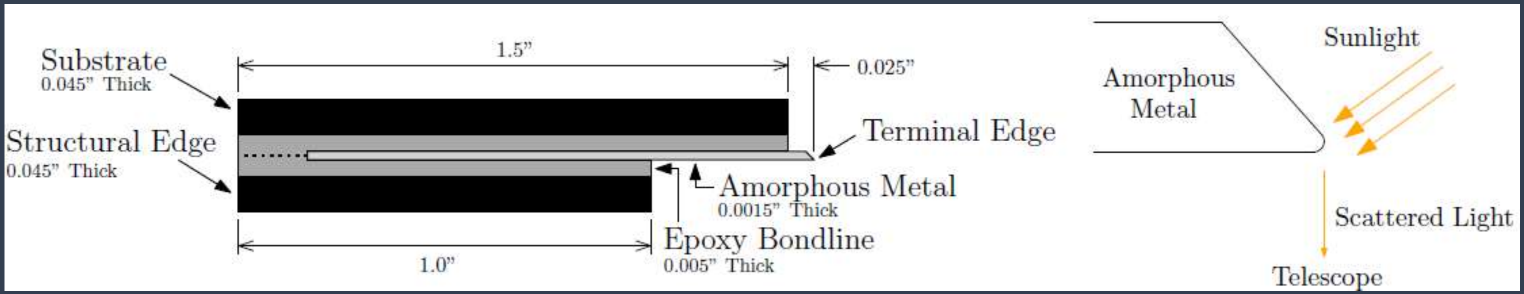
OPTERUS

Preliminary Analyses: SPIE Prototype Geometry

Global Geometry



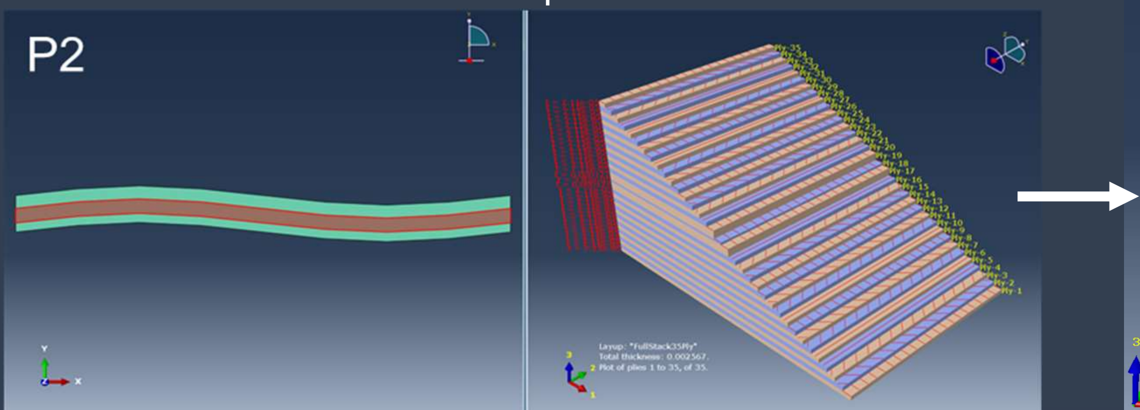
Local Geometry



SPIE Prototype Geometry in Abaqus

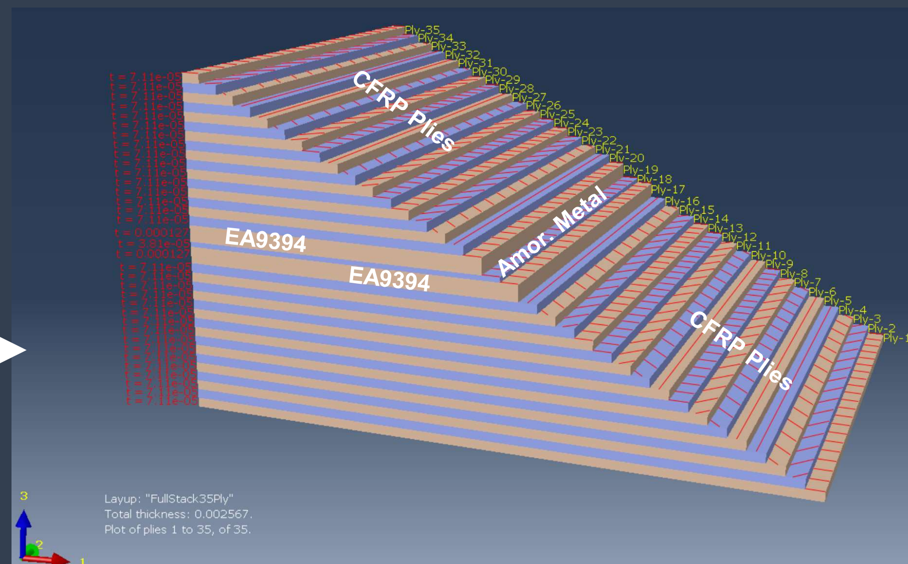
Vertically Unchanging Material "Stack-Ups"

*P1/P3 stack-up not shown



Laminate Stack-Up Approach

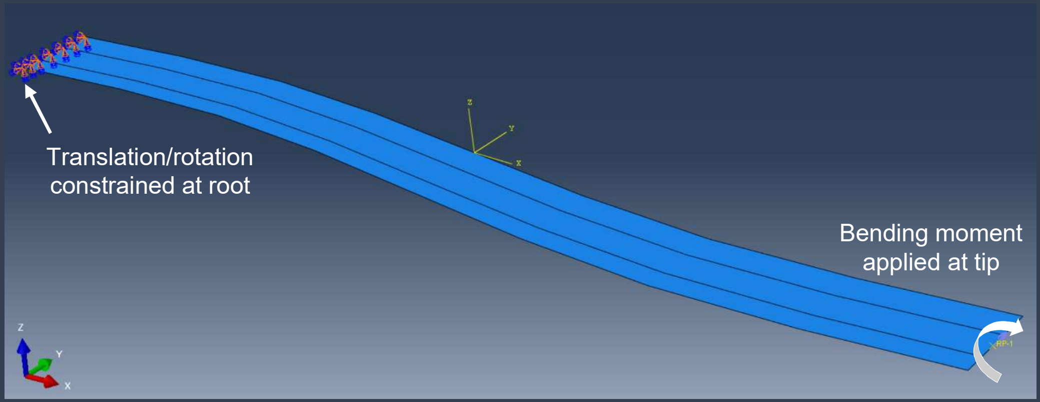
- Accounts for material orientation & thickness
  - CFRP plies
  - Epoxy (EA9394) bond lines
  - Amorphous metal optical edge



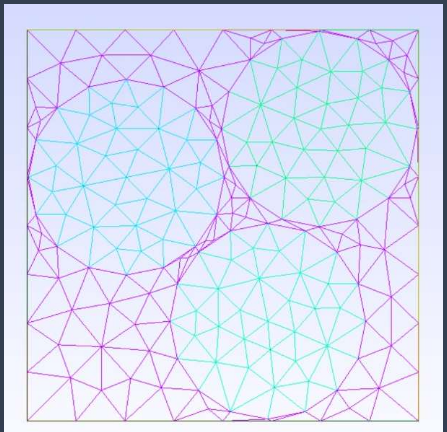
OPTERUS

Modeling Approach: Abaqus/MultiMechanics (MM)

- Global geometry
  - 3D deformable shell
- BCs & Loads
  - Petal fully constrained at root
  - Bending moment applied at Petal tip (from SPIE paper)
- Material properties
  - Combined Abaqus/MM
  - MM RVE allows CFRP viscoelasticity



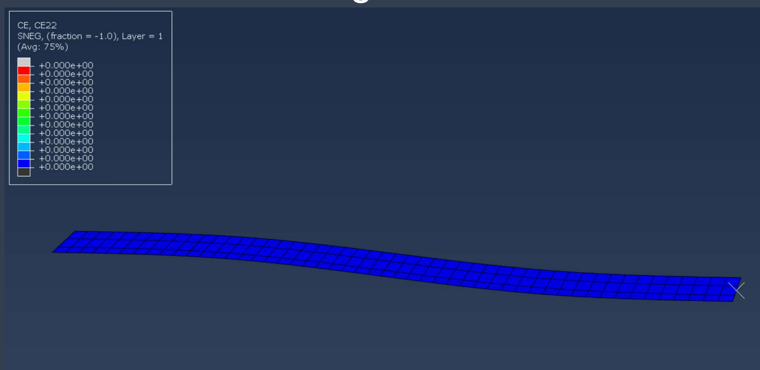
#	Resin Identifier	Resin Description	Nanosilicate	Toughener
1	F7C	Pure epoxy	No	No
2	F7	Epoxy with toughener	No	Yes
3	Epoxy (38% NS)	Epoxy with nano-silicates, no toughener	38%	No
4	F7 (10% NS)	Epoxy with toughener and nano-silicates	10%	Yes
5	F6	Cyanate ester	N/A	N/A



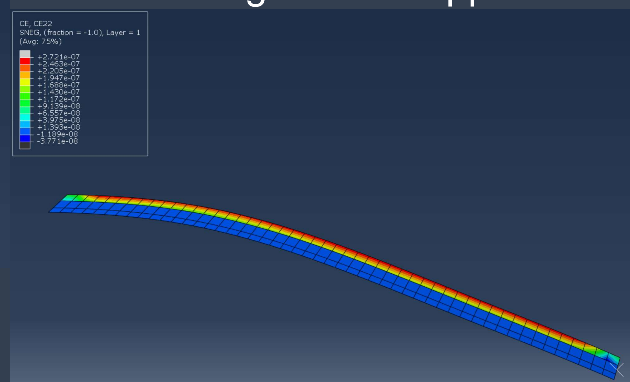
OPTERUS

Modeling Approach: Petal Edge Stowage

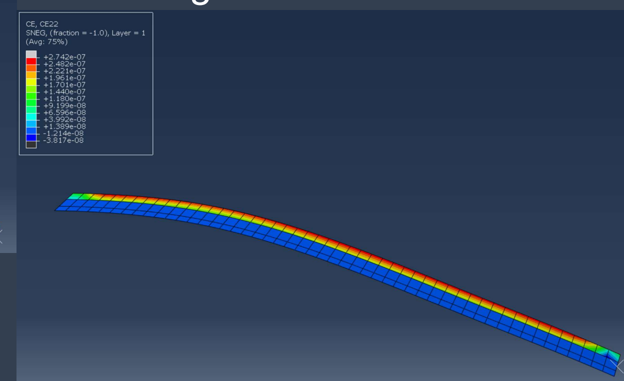
Petal Edge: Unloaded



Petal Edge: Load Applied



Petal Edge: Load Held for Time



Stow petal edge (constant load) – observe time-dependent deformations

OPTERUS

Preliminary Analyses: Results & Key Outcomes

#	Resin Identifier	Resin Description	Tip Displacement (m)	Edge Elastic Strain (με)	Edge Creep Strain (με)	CFRP Visco.
1	F7C	Neat epoxy	0.121	286.4	0.274	On
2	F7	Epoxy w/ T	0.121	286.4	0.274	On
3	F3GHT	Epoxy w/ NS	0.120	284.6	0.273	On
4	F7 10%	Epoxy w/ T and NS	0.122	289.7	0.277	On
5	F6	Neat cyanate ester	0.120	284.3	0.272	On
6	***F7***	***Epoxy w/ T***	***0.122***	***283.8***	***0.274***	***Off***
*T = toughener, NS = nanosilicates, all reported values correspond to 5 minute stow (i.e. load still applied)						

1. Time-dependent deformations (viscoelastic) small compared to elastic deformations
2. Time-dependent deformations minimally influenced by changing CFRP resin
3. Time-dependent deformations dominated by epoxy bond lines (EA9394)

Moving Forward: Experimental Approach

- Next steps - Opterus focused on generating material test data
- Time-dependent deformations go beyond viscoelastic response to loading
  - Physical aging
  - Hygroscopic stability (moisture absorption)
  - Thermal stability
- Test design targets an understanding of both isolated and coupled environment driven material deformation

Test Design: Bi-material Strip & Photogrammetry

- Cantilevered "Bi-material" strip coupons
- Coupon deflection driven by changes in time/temp/humidity
- Cantilever tip deflection tied to curvature
- Cantilever curvature tied to strain mismatch

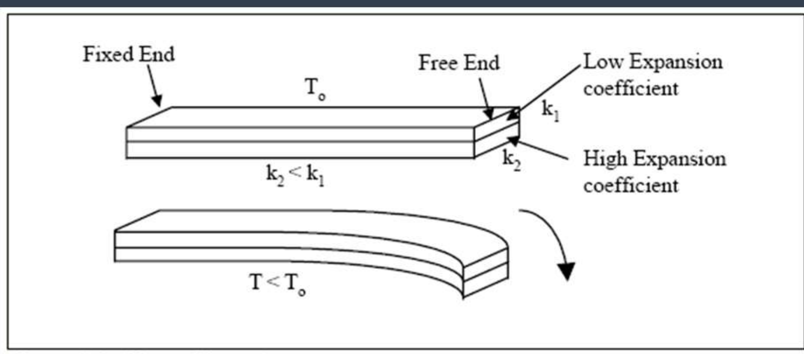
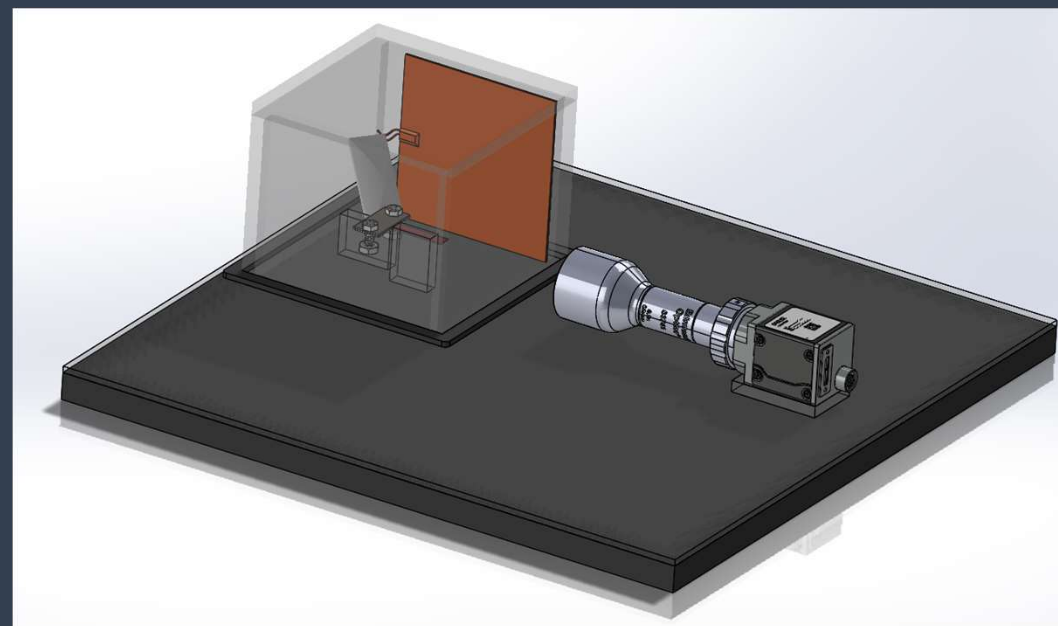


Figure 7-2. Bimetallic strip

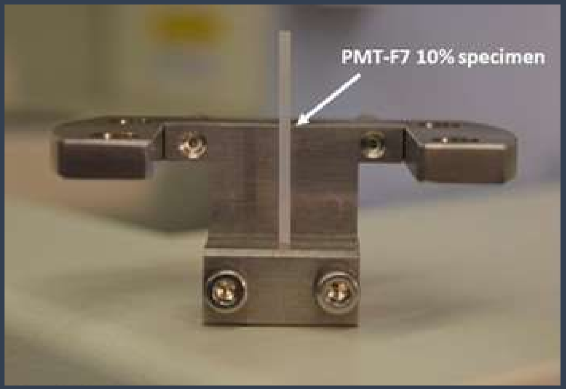


Coupon Fabrication

Resin cured between shimmed caul plates

Coupon thickness is defined here!

Resin thickness controllable down to 0.002”



Coupon Dimensions

- Steel thickness – 0.002”
- Resin thickness – 0.020”
- Unsupported strip length – 2”
- Strip width – 0.125” (width does not drive measurement accuracy)

Measurement accuracy of ~ 1 microstrain

OPTERUS

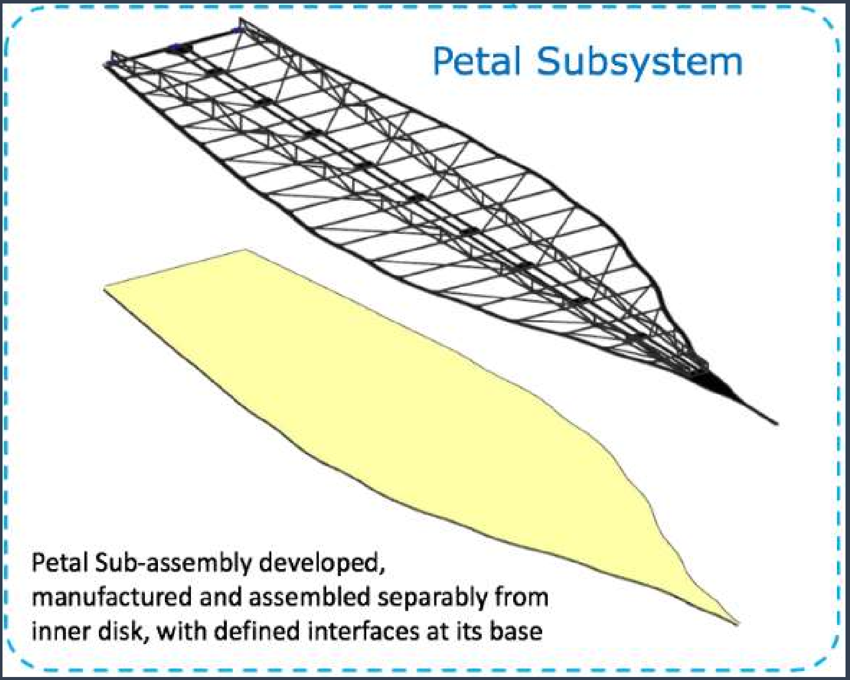
Test Cases

Case	Time (minutes)	Temp (°C)	Humidity (RH%)	Notes
1	43200	Ambient	Ambient	One-month, ambient, physical aging
2	1440	55	Ambient	24 hours, elevated temp, temp stability
3	1440	Ambient	99	24 hours, high humidity, hygroscopic
4	1440	55	99	24 hours, combined temp & humidity

- Time scale encompasses hours to weeks
- Temperature scale encompasses both room temperature stowage & deployment
- Humidity scale encompasses worst-case scenario

Moving Forward: Full-Scale Petal Simulation

- Full-scale petal simulation incorporates all CFRP structural elements & bonded joints
- Petal-edge modeling approach will scale to full petal
- Tailored material models incorporating test generated data should provide prediction on shape stability



Summary

- Key Technology Gaps → Deployment Accuracy & Shape Stability
- Error Budget Reduction → KPP 5 & KPP 6
- Work Scope → Coupled analysis/test approach
- Preliminary Analyses → Time-dependent deformations small, bond lines drive
- Material Test Data Generation → Test design complete, prelim. coupon geo and test cases
- Next Steps → Preliminary analysis methods and test data extended to full-scale petal simulation

Deployable Spacecraft Structures

Big Gains for Small Spacecraft ™

Thomas Murphey, PhD
tmurphey@opterusrd.com
(505) 250-3006

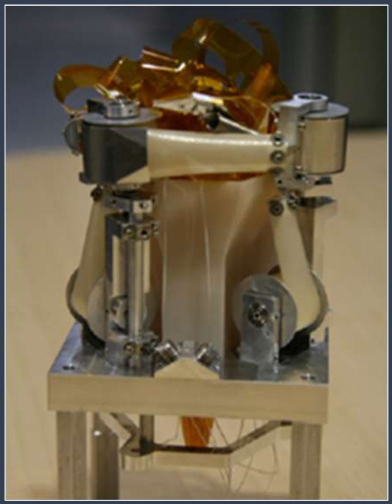
Patrick Rodriguez
patrick@opterusrd.com
(505) 795-3896

Opterus R&D Overview Slide Deck

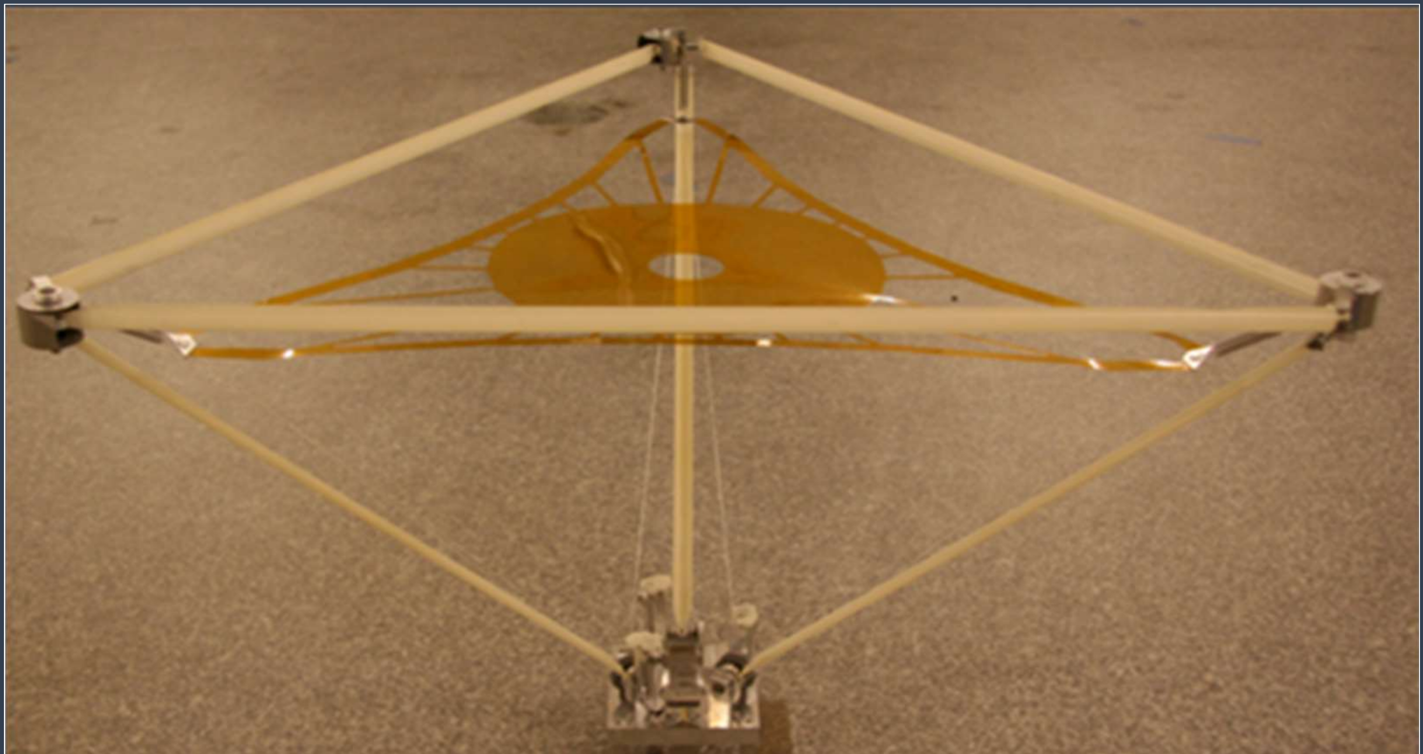
- Contact Thomas Murphey with questions

Thomas Murphey, PhD
tmurphey@opterusrd.com
(505) 250-3006

Deployable Spacecraft Structures



1U CubeSat
(10cm cube)



100 cm Diffractive Telescope (AFRL/USAFA FalconSat/DARPA Moire Co-Program)

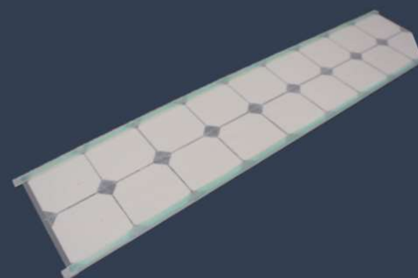
OPTERUS

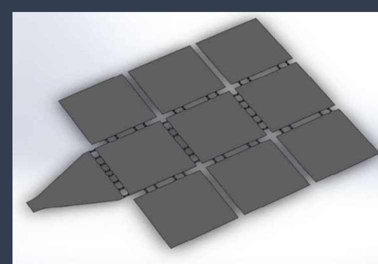
Core Technology Areas

Booms and Hinges

TRL 5-9
Flight Heritage
100% Success

Solar Array Structures





TRL 4-5
Key partnerships established

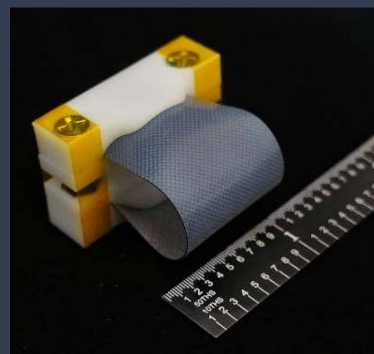
Antennas, Phased Arrays and Reflectors

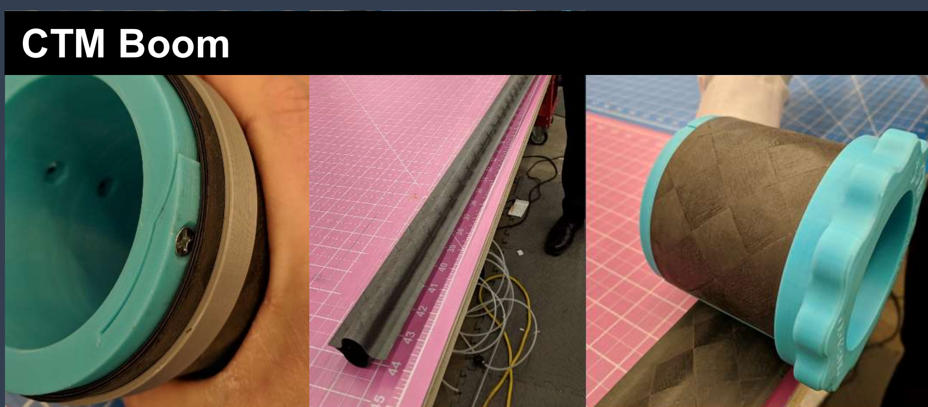
TRL 2-4
Key features demonstrated

OPTERUS

Multiple patents in process

Core Material Innovation: HSC (high strain composites)





2x stronger

8x stiffer

5x lighter weight

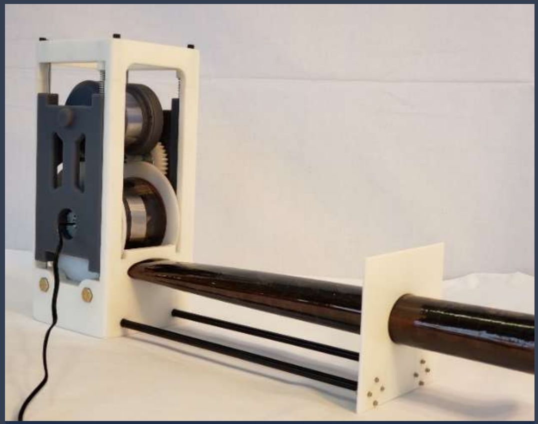
20x more stable

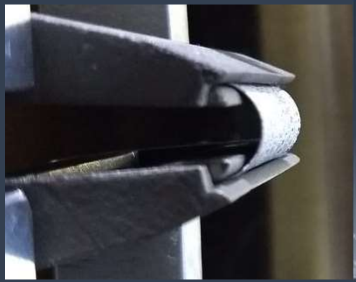
Industry leading source for HSC technologies

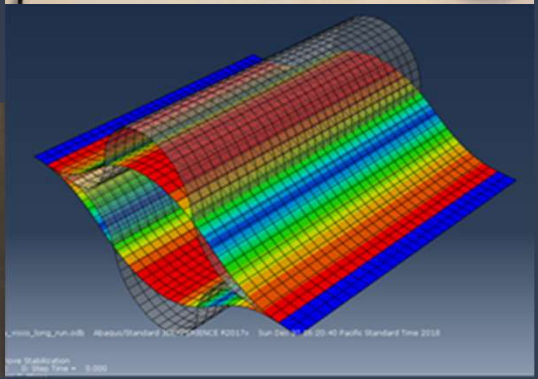
OPTERUS

Capabilities

- Composite design, manufacturing and testing capabilities
  - Specialize in High Strain Composite manufacturing methods
- Deployable spacecraft structures and mechanical systems
  - Conception > Design > Analysis/Simulation > Fabrication
- Simulation and Analysis
  - Deployment simulations
  - Finite Element Analysis
  - Structural architecture development



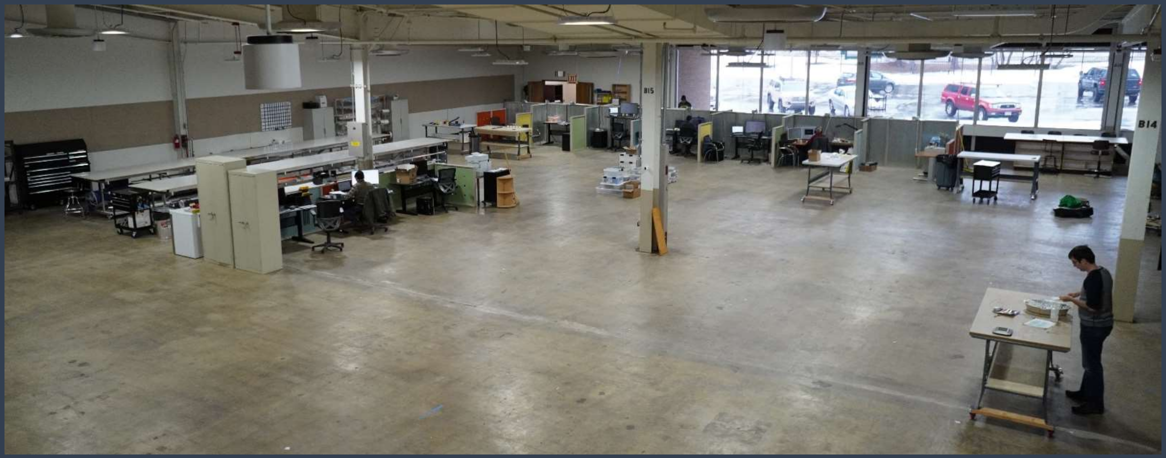




Facilities

- In-house composites fabrication
  - 30 ft modular oven
  - 2x 30ft modular lay-up tables

- Loveland, CO
  (1 hour north of Denver)
  - 9,000 ft^2 for fabrication and testing



OPTERUS

Our Team

Dr. Thomas Murphey
CEO, CTO

Shane Stamm
Chief Engineer

Jeremy Kellog
Composites Production

Erik Pranckh
Engineer

Levi Nicholson
Engineer

Sebastian Mettes
Engineer

Patrick Rodriguez
Engineer II

Gina Olson
Technology Advisor

Tiffany Dailey
Controller