Starshade to TRL5 (S5)
Precision Deployment and Stability Milestones

SIP Telecon
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Industry partners
Tendeg, Applied Composites, NGIS, Southern Research, ASL, JLA, Roccor

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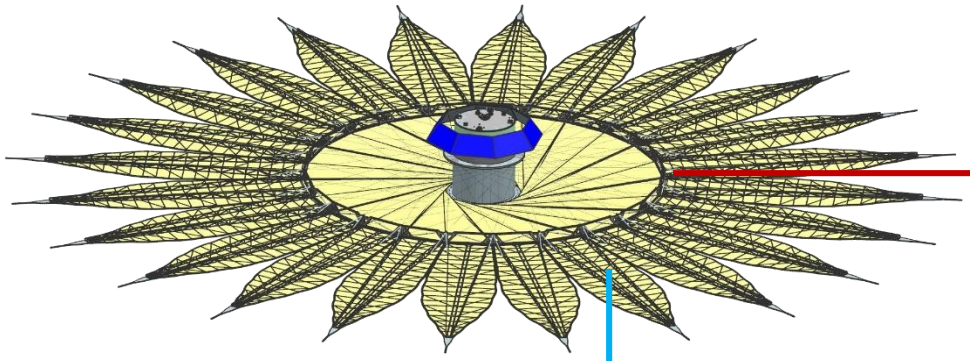
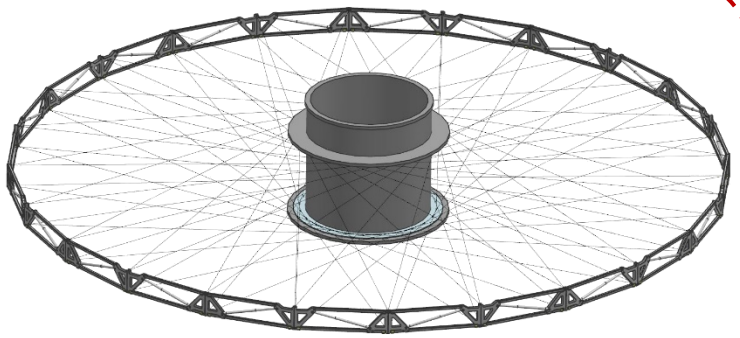
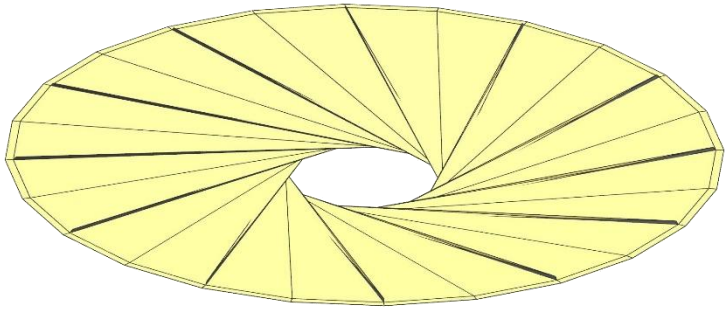
Starshade Mechanical Subsystems



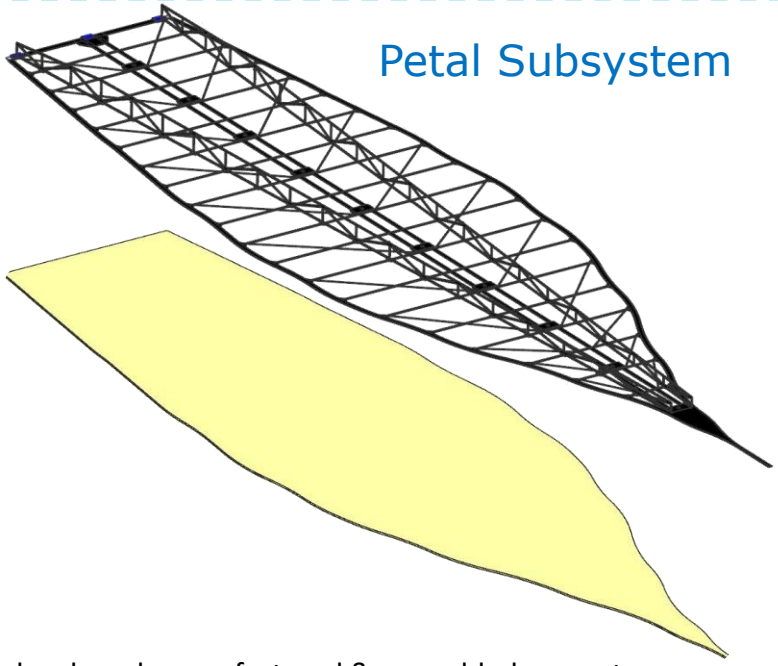


Truss + spokes + hub constitute separable structure w/defined interfaces to petal

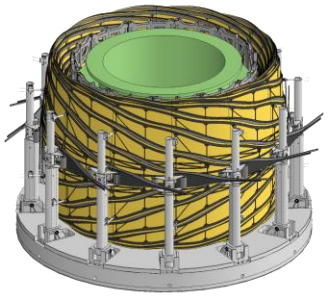


Inner Disk Subsystem

Petal Subsystem



Petal developed, manufactured & assembled separate from inner disk, with defined interfaces at its base



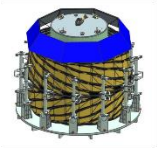
Petal Launch Restraint & Unfurl Subsystem (PLUS)

PLUS controls petal deployment & defines petal L/R interfaces (jettisoned after launch)

Deployment Sequence for the Starshade Rendezvous Concept

Step 1: Petal Unfurling

(a)



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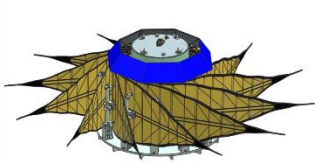

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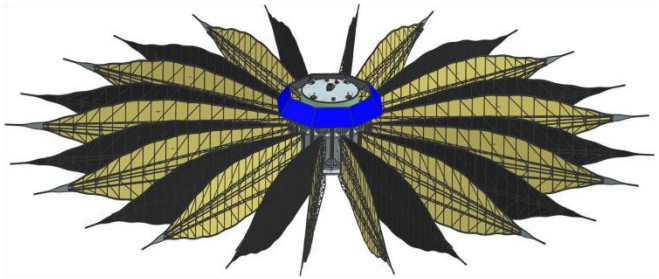
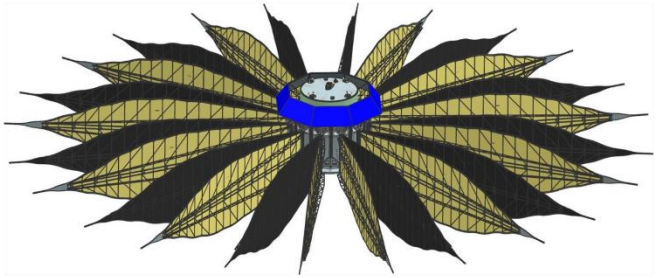


Step 2: Inner Disk Unfolding

(d)



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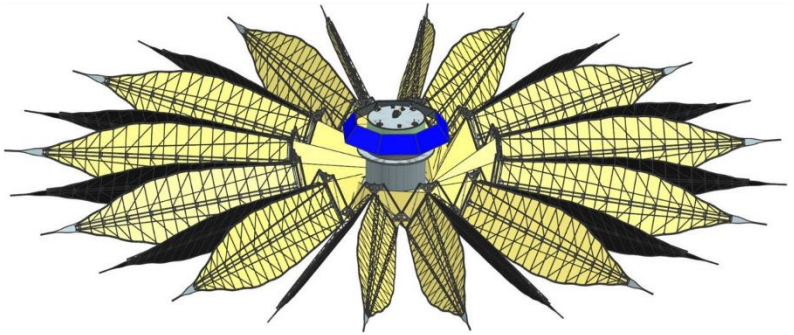

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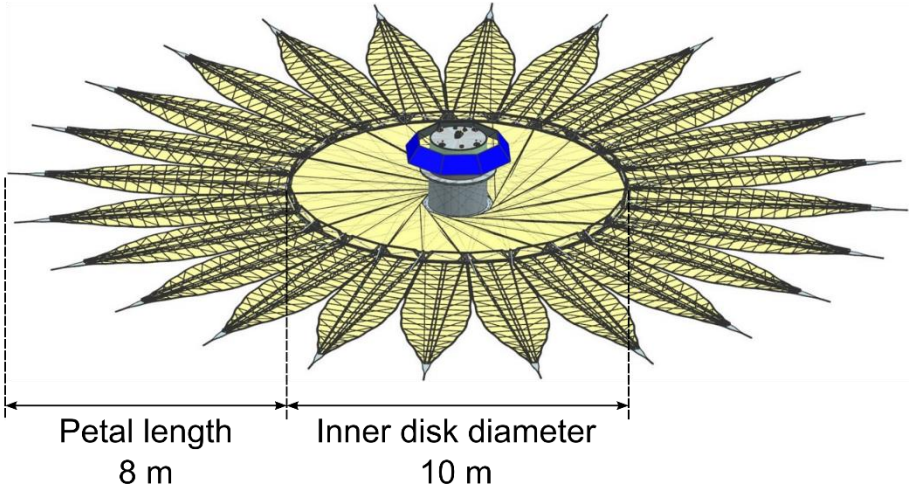

Deployment and Stability Milestones

Key Performance Parameter (KPP)		Risk reduction milestones		TRL5 completion milestones	
KPP 5	Petal thermal-cycle stability & deployment accuracy	5A	Petal test article with *shape-critical* features ¾-scale width ½-scale length 1.5 m x 4 m	5B	Petal test article with *all* features ¾-scale width ¾-scale length 1.5 m x 6 m
KPP 6	Petal in-space thermal stability	6A		6B	
KPP 7	Inner disk deployment accuracy	7C	Inner disk with *low-fidelity* optical shield Full-scale: 10 m diameter	7D	*Medium-fidelity* inner disk w/ petals Full-scale: 10 m diameter
	Inner disk thermal-cycle stability	7A	Perimeter truss bay *components* (longeron and nodes) Full-scale components	7B	Perimeter truss bay *assembly* Full-scale 1.3 m length
KPP 8	Inner disk in-space thermal stability	8A		8B	

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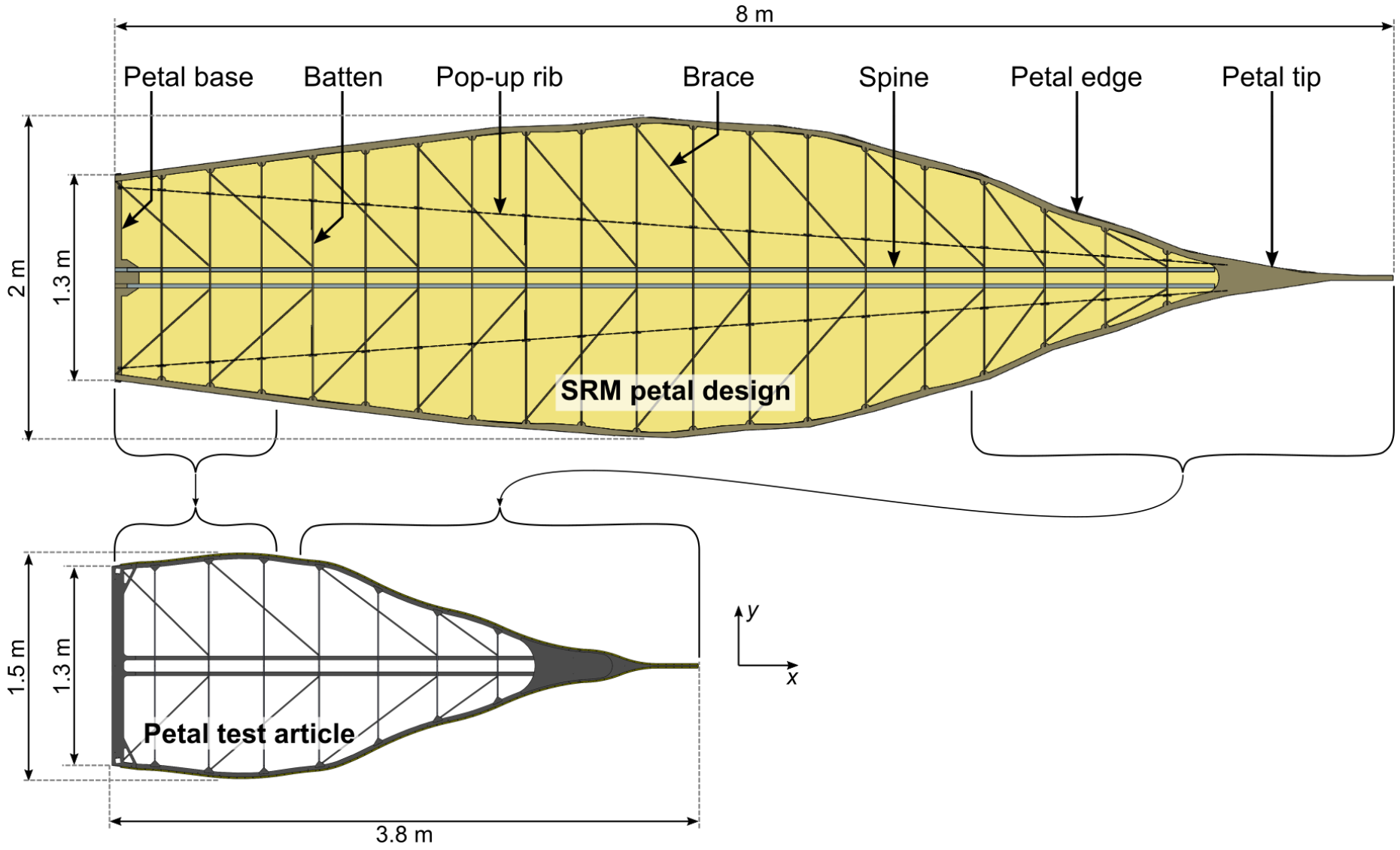
KPP 8	Inner disk in-space thermal stability	8A ✓		8B	

MS 5A: Petal thermal-cycle stability & deployment accuracy

- Constructed petal test article that is ¾-scale in width, ½-scale in length
  - Materials, components, joint geometry representative of SRM design
  - Carbon-fiber-reinforced polymer (CFRP) materials used for structural components
    - M55J/cyanate ester laminates
    - Pultruded unidirectional CF/epoxy rods
  - Engineering epoxy (EA9394) used to bond components together

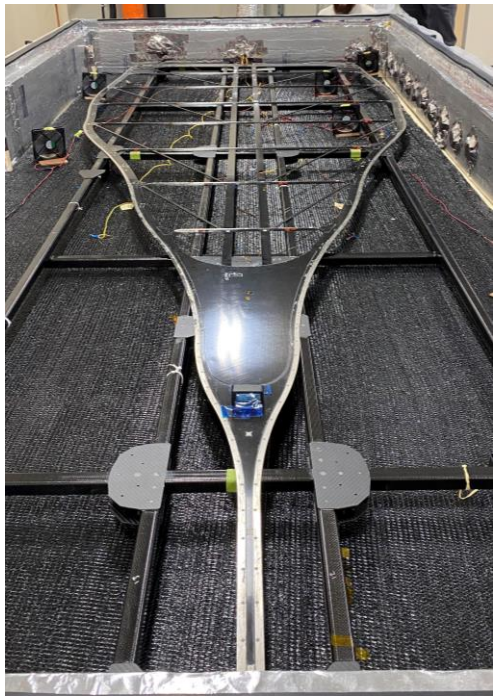
- Omitted features that are not critical to preserving the width profile of the petal:
  - Out-of-plane ribs
  - Opacity blanket
  - Launch restraint interfaces

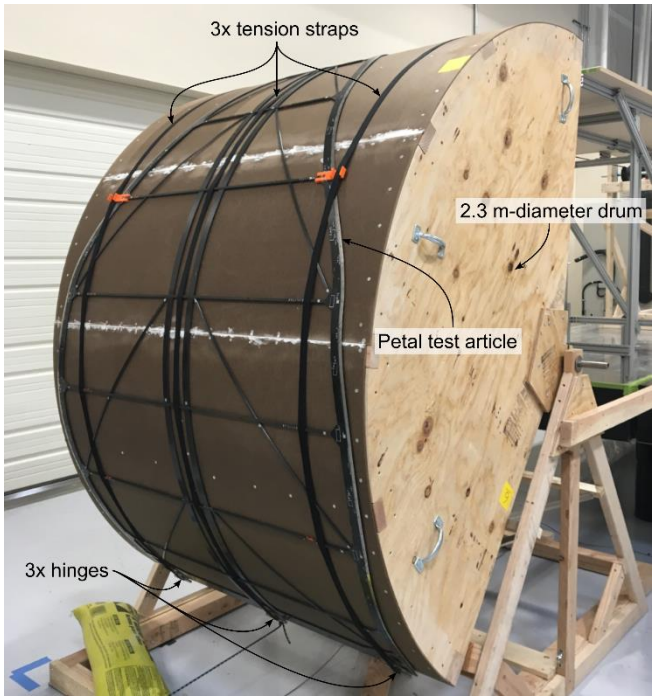
MS 5A: Petal thermal-cycle stability & deployment accuracy

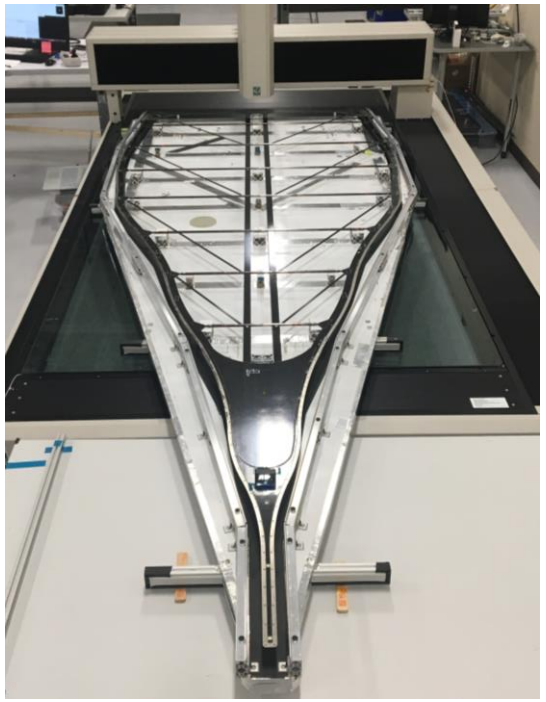


MS 5A: Petal thermal-cycle stability & deployment accuracy

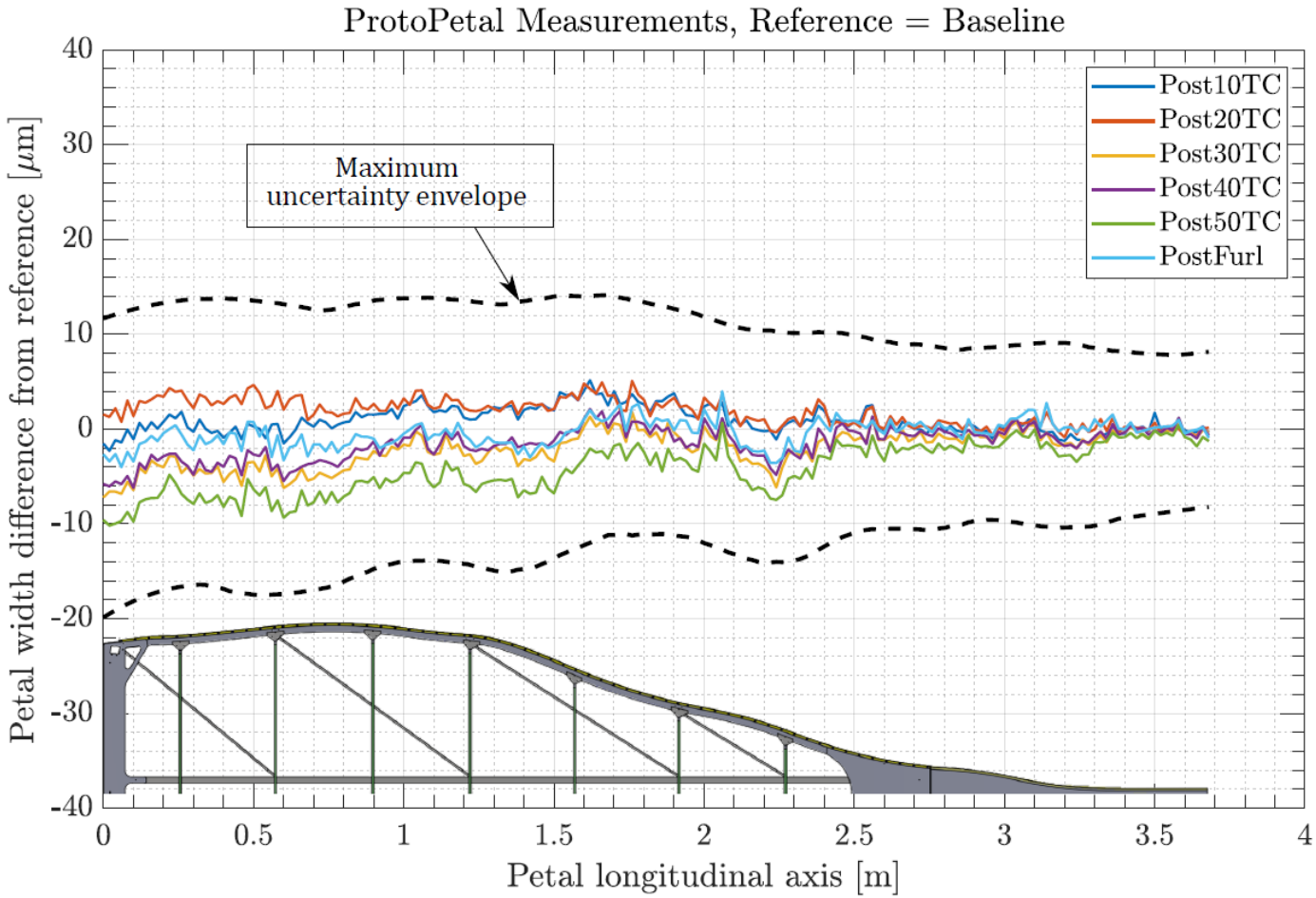
- Subjected petal test article to 50 thermal cycles (± 50°C)
- Subjected petal test article to 5 furl-and-deploy cycles (simulating wrapping around 2.3 m-diameter)
- Measured petal shape after thermal cycles, furl cycles, compare to reference shape to calculate width change
  - MicroVu measurement machine (microscope on a *x*-*y* translation stage) used for petal shape measurement







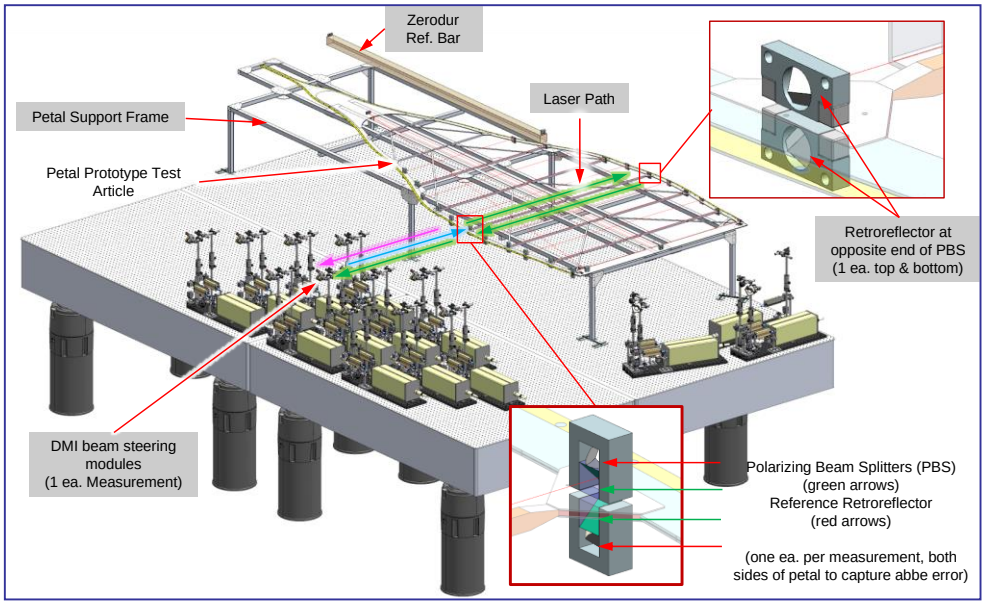
MS 5A: Petal thermal-cycle stability & deployment accuracy

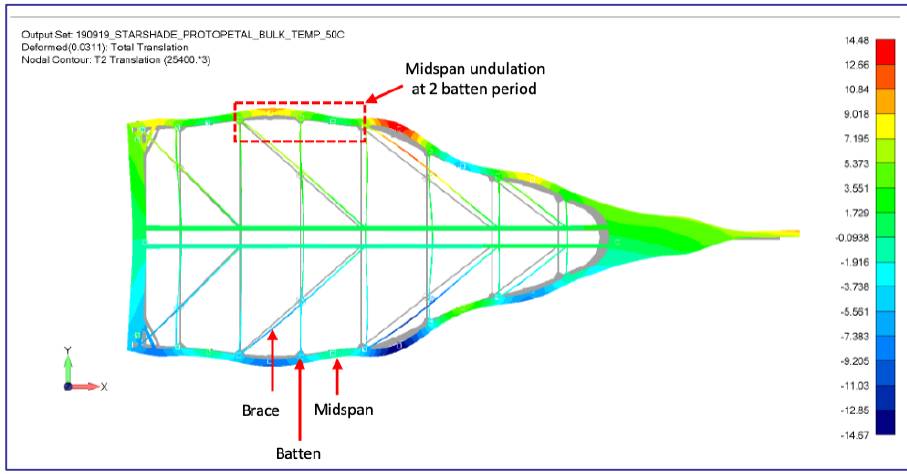


- Measured width changes were within allocations, with margin
- Exoplanet Technical Analysis Committee (ExoTAC) deemed Milestone 5A has been

Milestone 6A: Petal in-space thermal stability

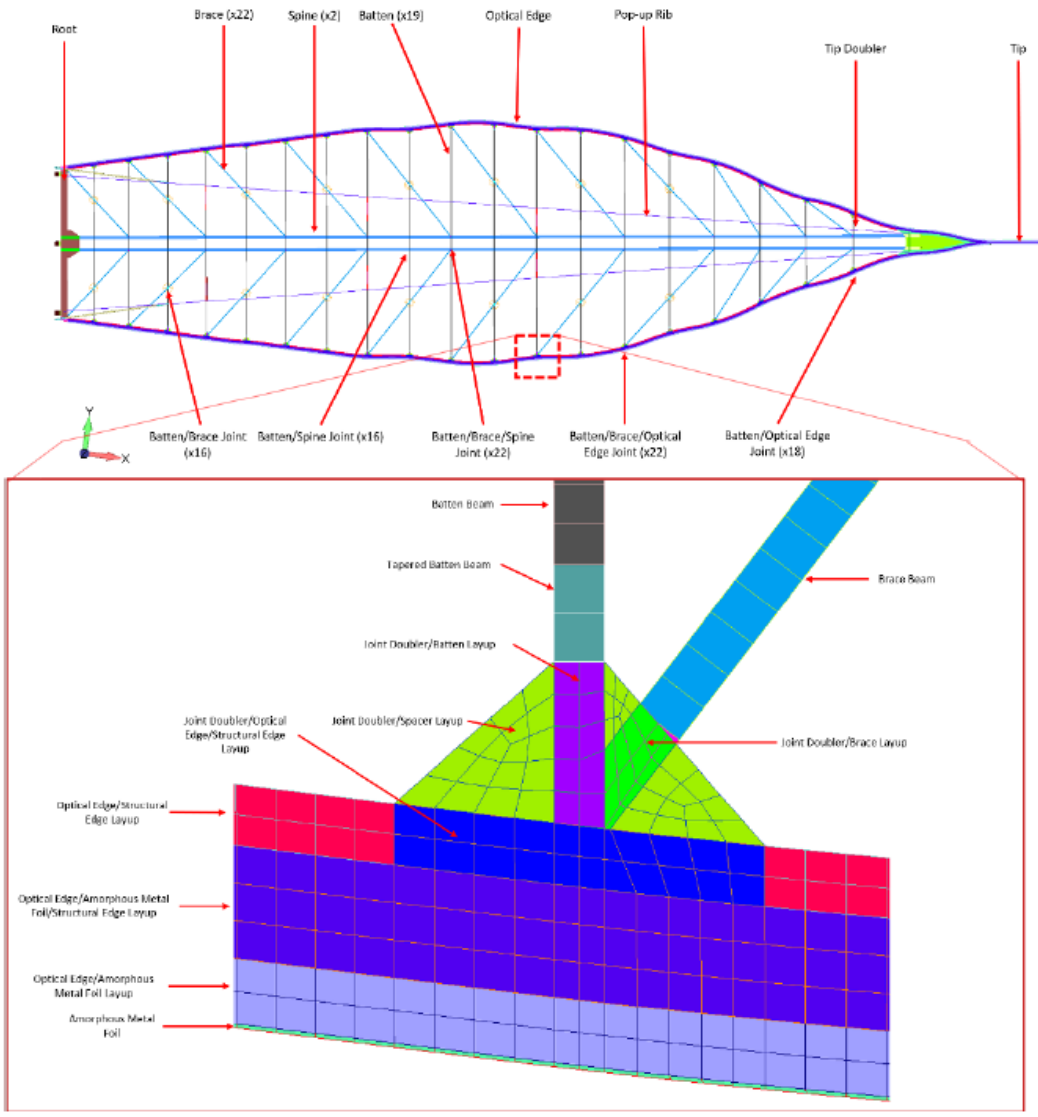
- Approach:
  - Validate petal thermo-elastic deformation modelling (FEMAP/Nastran) approach using experiments on the petal test article
  - Use validated model to predict in-space deformations due to expected in-space thermal loads
- Subjected petal test article to thermal soaks, measured change in critical dimensions using laser interferometry
- Developed finite element model that matched measured dimensional changes to within measurement uncertainty*





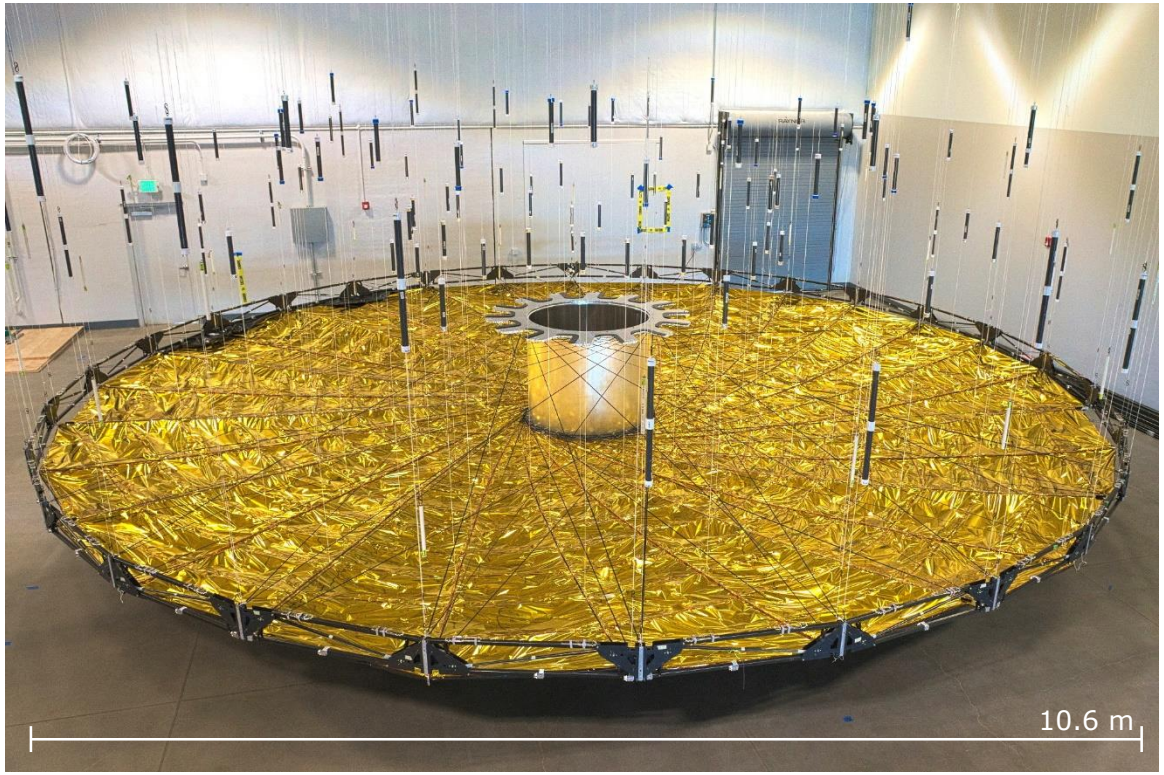
Milestone 6A: Petal in-space thermal stability

- Validated model predicts in-space thermo-elastic deformations of SRM petal to be within allocations
- Milestone 6A currently under ExoTAC review

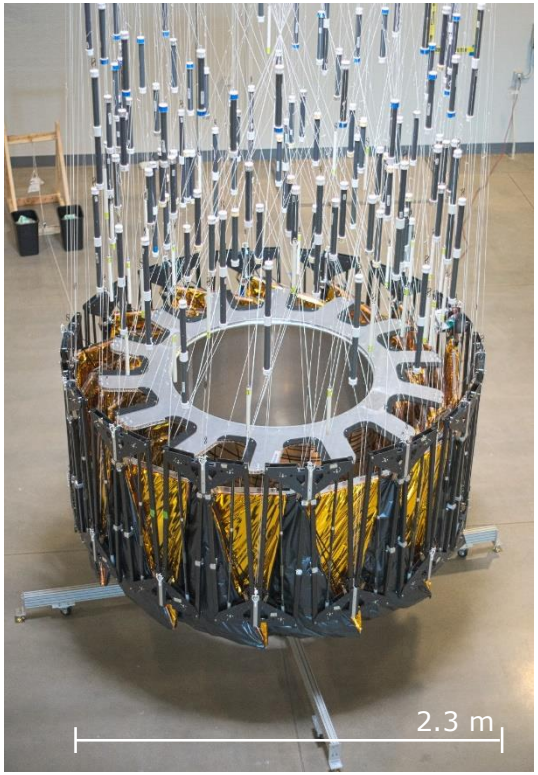


Milestone 7C: Inner disk deployment accuracy

- Built full-scale (10 m diameter) inner disk test article
  - Perimeter truss, spokes are medium-fidelity (flight-like materials, geometry)
  - Optical shield is low-fidelity
- Deployed 22 times, measured deployed shape each time to quantify deployment accuracy

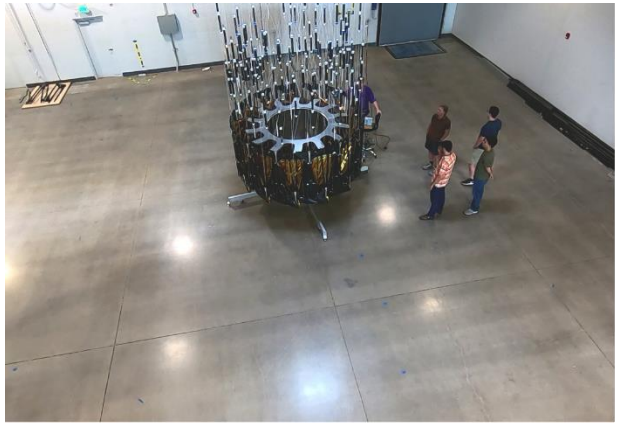


Deployed



Stowed

Milestone 7C: Inner disk deployment accuracy



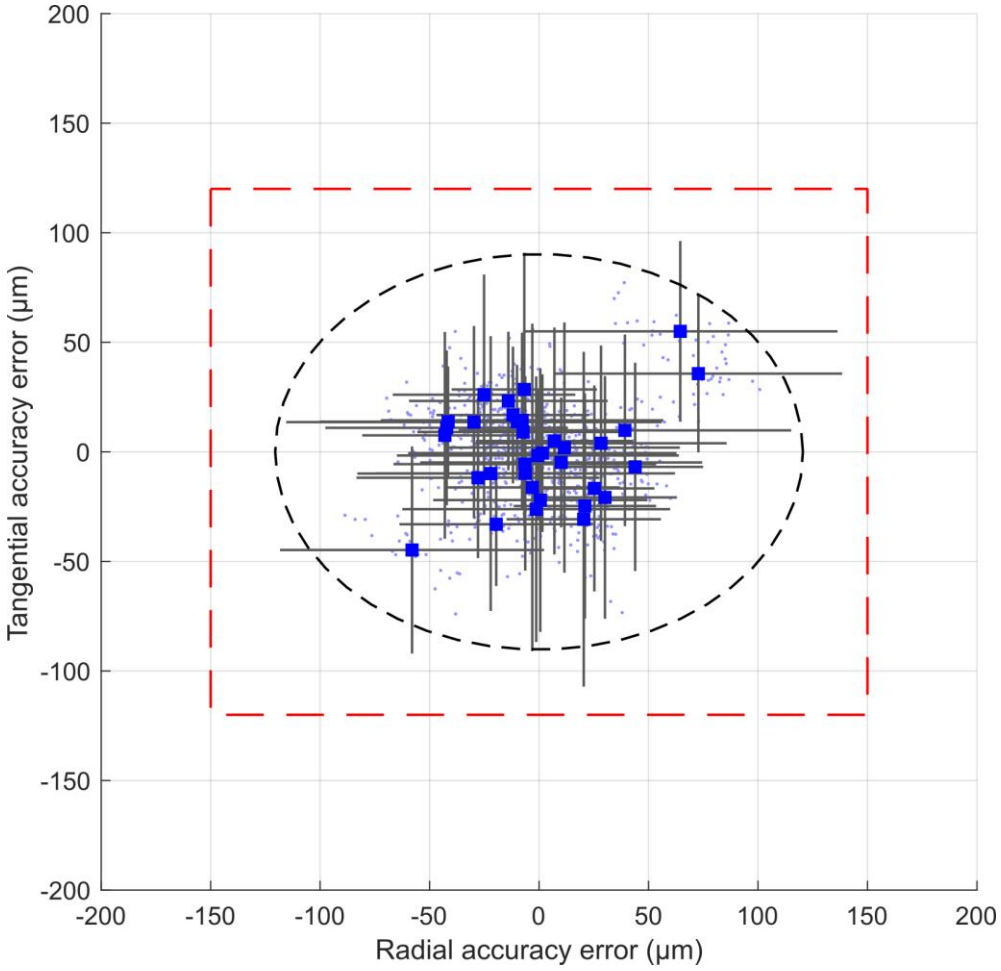
Stowed

Partly deployed

Fully deployed

- Inner disk test article is gravity offloaded to simulate in-space deployment
- Position of petal interface points measured using laser tracker after each deployment

Milestone 7C: Inner disk deployment accuracy



150 µm radial random allocation, 3σ
120 µm tangential random allocation, 3σ

Accuracy errors of 34 petal interfaces over 22 deployments

Mean accuracy errors of 34 petal interfaces

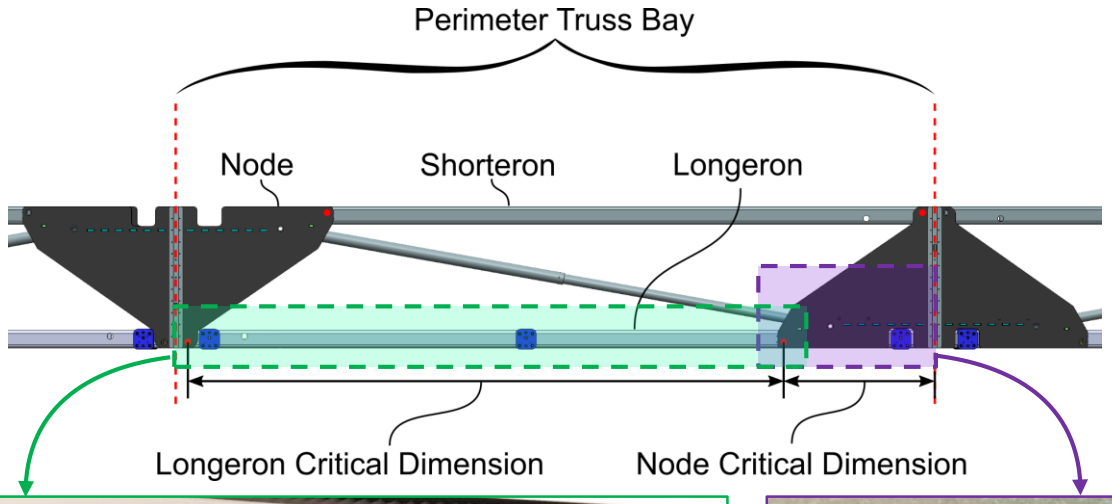
Conservative 3σ bounds on spread of the 34 petal interfaces over the 22 deployments

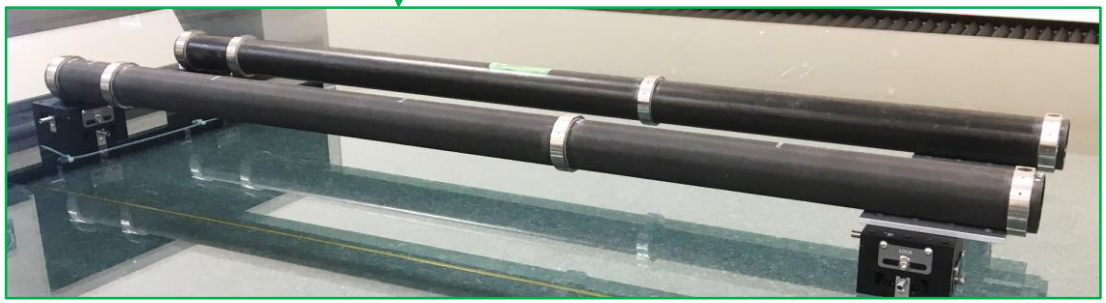
3σ bounds on deployment accuracy calculated using Monte Carlo analysis: 121 µm radial, 91 µm tangential

- Measured accuracy errors within allocations, with margin
- ExoTAC deemed Milestone 7C met

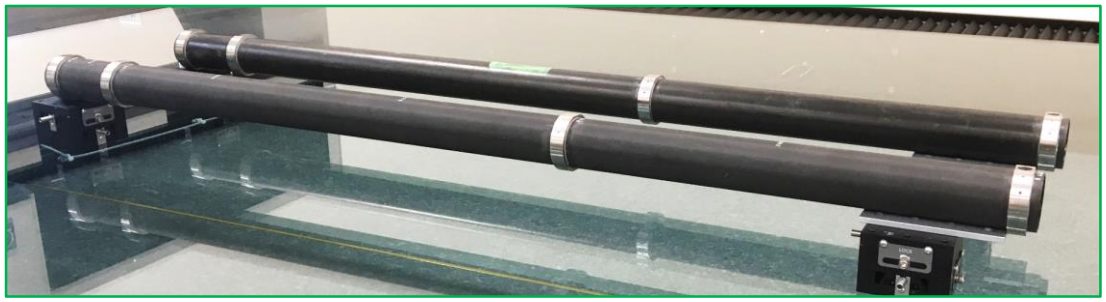
Milestone 7A: Inner disk thermal-cycle stability

- Approach: subject key components of the inner disk perimeter truss to thermal cycles, and verify dimensional stability
- Inner disk deployed stability is set almost entirely by the perimeter truss, which consists of a number of repeating units called “bays”





Milestone 7A: Inner disk thermal-cycle stability

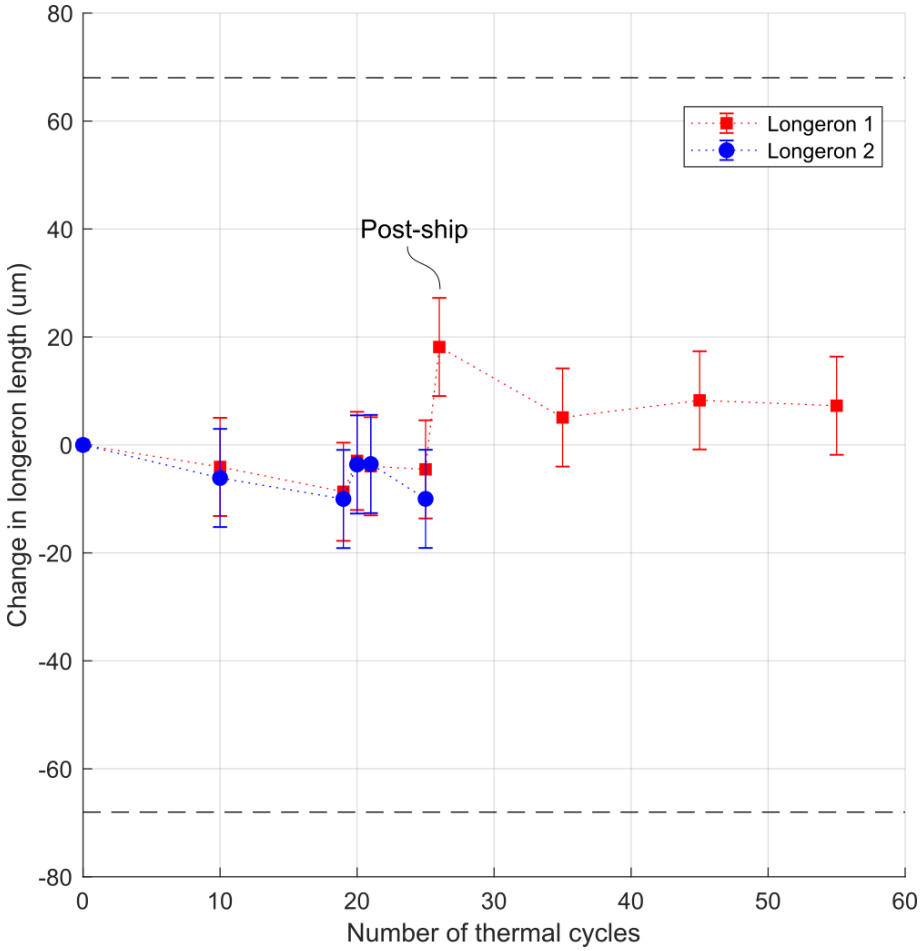


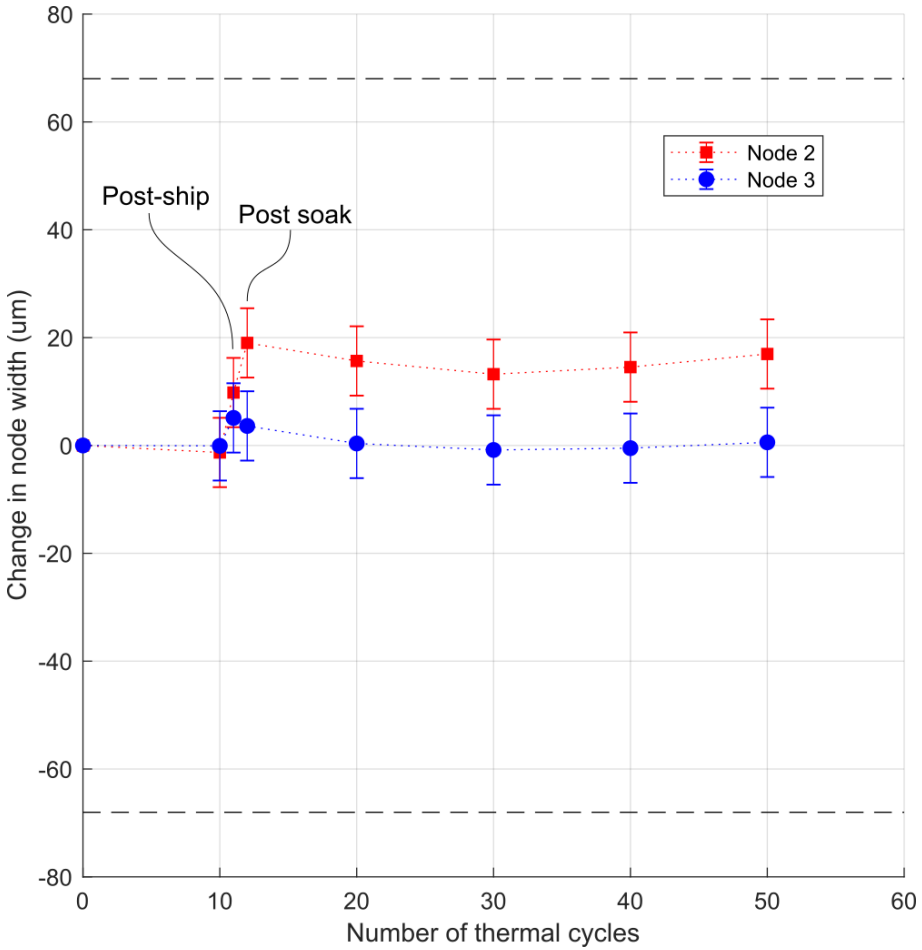
Longerons

Node

- Longeron and node components are flight-like in terms of materials, constructions, and dimensions
  - CFRP (M55J/cyanate ester)
  - Invar fittings
  - Engineering epoxy (EA9394) for bonded joints
- Subjected to 50 thermal cycles each (70°C to –25°C)
- Critical dimensions measured before and after thermal cycles using MicroVu measurement machine

Milestone 7A: Inner disk thermal-cycle stability

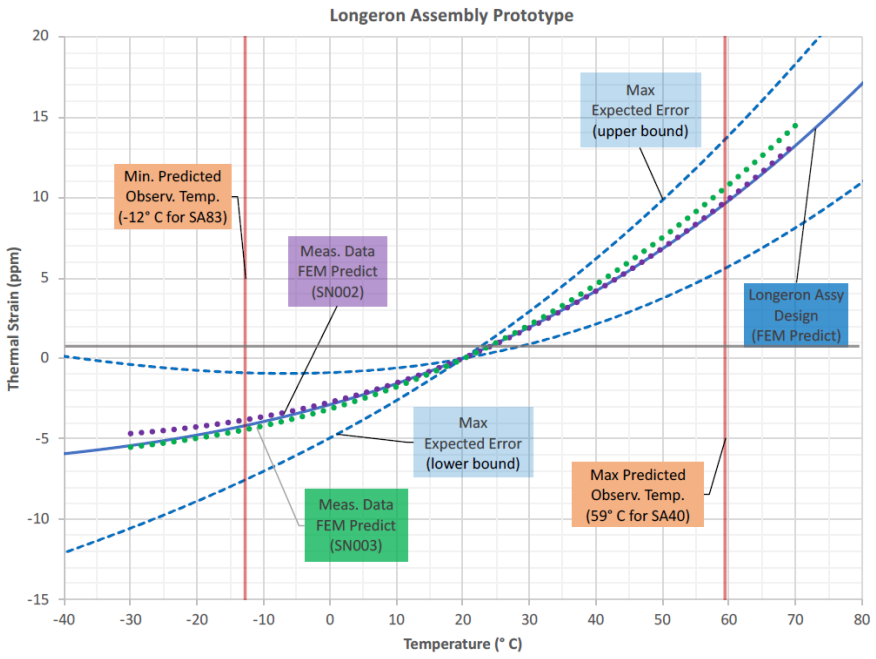


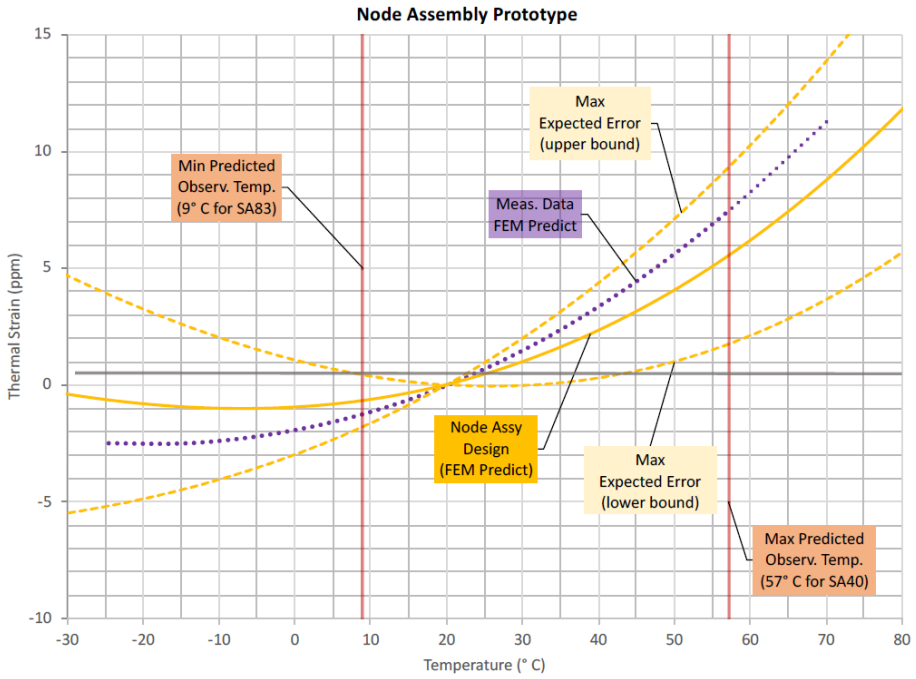


- Change in dimensions within allocations, with large margin
- Milestone 7A has been met, per the ExoTAC

Milestone 8A: Inner disk in-space thermal stability

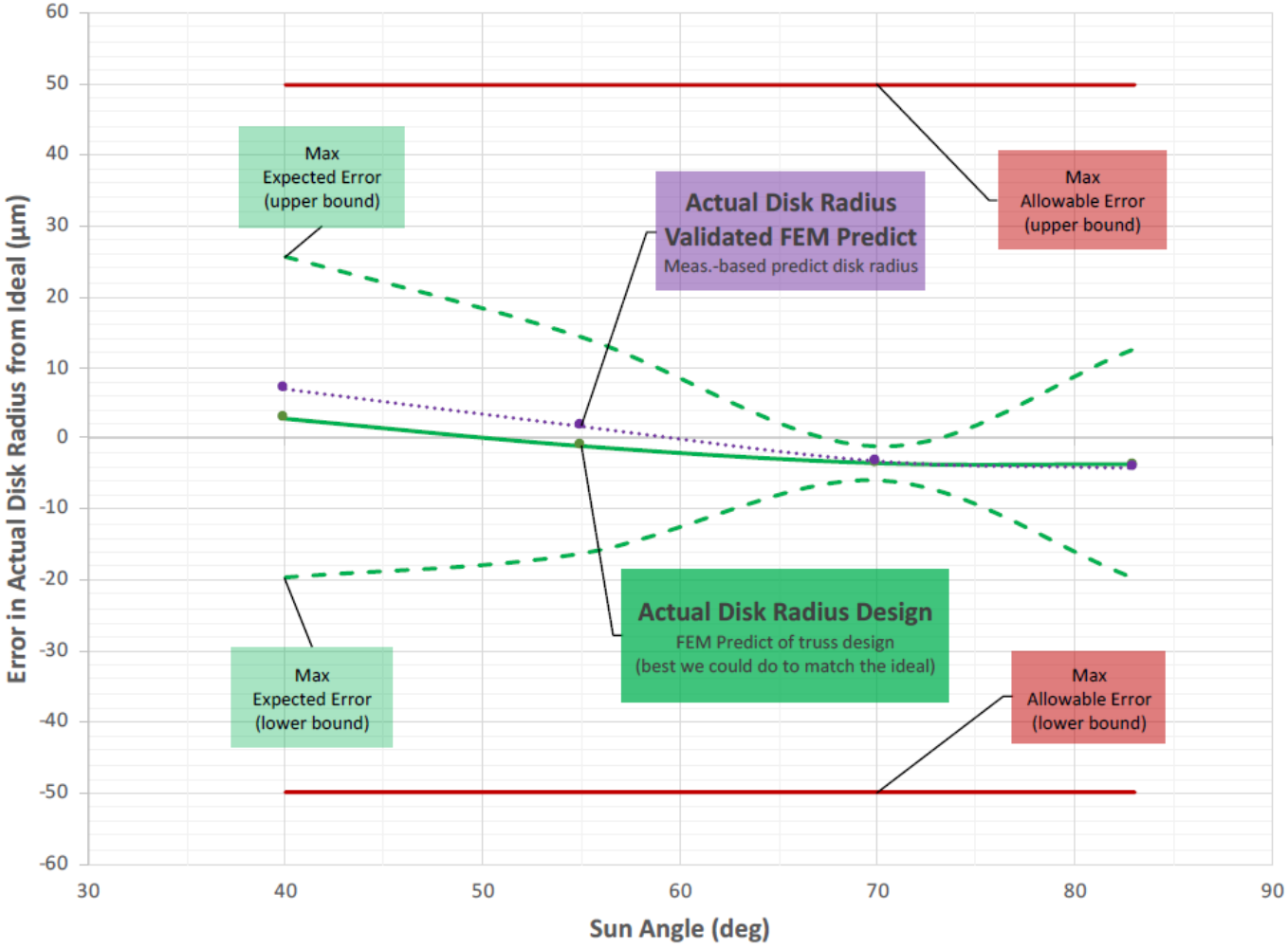
- Approach:
  - Validate thermo-elastic deformation finite element model using experiments on longeron, node test articles
  - Use validated model to predict in-space thermal deformations of the inner disk
- Used NG's Interferometric Metrology Facility (IMF) to measure critical dimensions of the longeron, node test articles over 70°C to -30°C temperature range
- Validated model predicts change in dimensions well:





Milestone 8A: Inner disk in-space thermal stability

- Validated model predicts in-space inner disk deformation well within allocations
- Milestone 8A deemed to have been met by ExoTAC



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