Wrapped Petal Starshade Mechanical Architecture

Summary Slides

CL#18-3778

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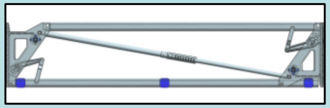
TRL-5 Test Activities NEW Plan w/addl. prototypes PRE-Decadal

Decadal input (Nov. 19)

Full-Scale (1.3-m long) — Unit A / Unit B



Inner Disk Truss Bay (P5-1)

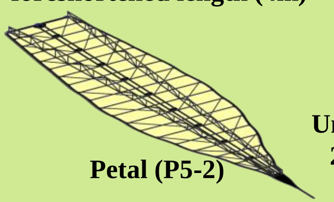
Verify Truss Longeron & Node components length:
*- **as-manufactured***
*- after **thermal cycles***

***Validate** Truss Longeron & Node component model of:*
length vs. I/F Load
length vs. temp

Unit A: *Verify Truss Bay length **as manufactured*** ***Test 5-1*** → ***Validate** Truss Bay model of **length vs. temp.*** ***Test 5-2***

Unit B: *Verify Truss Bay shape:*
*- **as-manufactured***
*- after **thermal cycles***
*-after **storage with creep***
Tests 5-1, 5-5, 5-6 → ***Validate** Truss Bay model of **length vs. I/F Load*** ***Test 5-3***

Full width (~1.6m), thickness (1.6cm), foreshortened length (4m) — Unit 1 / Unit 2



Petal (P5-2)

Unit 1: *Meas. Petal shape: **as-manufactured***
*Verify Petal shape: after **deploy cycles**, after **thermal cycles***
Tests 5-1, 5-4, 5-5

***Validate** Petal model of shape vs. I/F load* *Test 5-7*

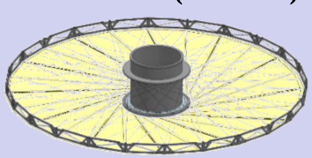
Validate** Petal model of **shape vs. temp. ***Test 5-8***

Unit 2: *Cont. design of edge, shield & DCS I/F's* → *Final Petal Design*

Verify petal shape as-manufactured *Test 5-1*

*Verify petal shape after **deploy cycles*** ***Test 5-4*** → *Validate Petal model of shape vs. I/F load* *Test 5-7*

Full-Scale (10-m dia.)



Inner Disk (P5-3)

*Verify repeatable Disk **deploy tolerances w/ POC Optical Shield*** *(after verifying opacity)* ***Test 5-9***

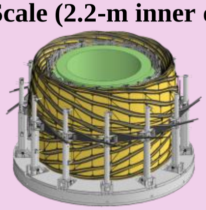
Verify OS opacity at truss-bay & petal I/F's ***Test 5-12***

***Validate** Disk model of shape vs. spoke load* *Test 5-11*

*Verify repeatable Disk **deploy tolerances w/ TRL-5 Optical Shield*** *(after verifying opacity)* ***Test 5-9***

Validate** Disk model of **deployment kinematics ***Test 5-10***

Full-Scale (2.2-m inner dia.)



Deploy. Control System (P5-4)

Verify DCS unfurls with no edge contact ***Test 5-13***

Validate** DCS model of **deployment kinematics ***Test 5-14***

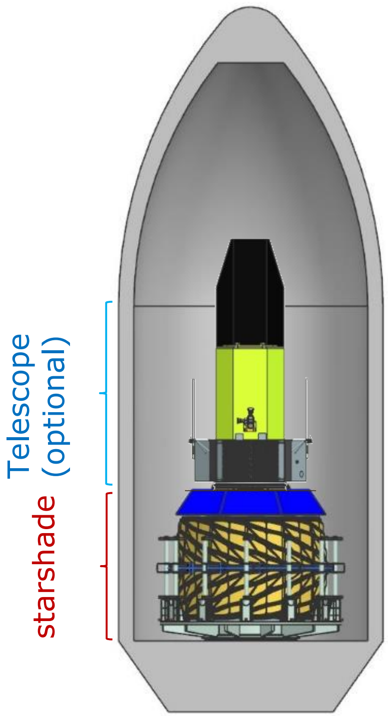
Additional PLUS sub-assy test verification work (TBD): e.g. vibe, cold test,

TBD work as needed: Early environmental tests of critical sub-assys if needed to define sub-system

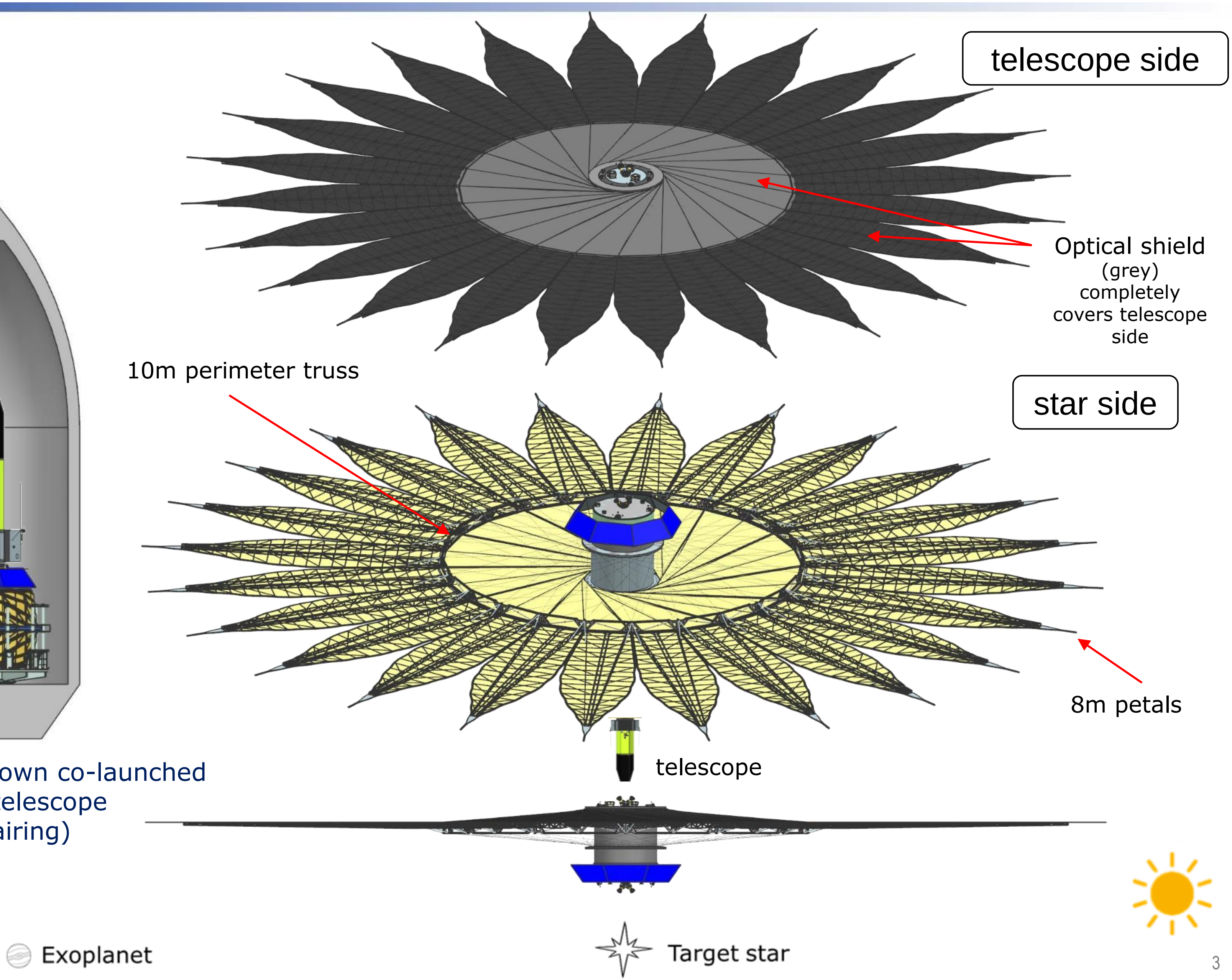
Critical test for this test article

Starshade Wrapped Design

26m NI2 design with 8m petals for ExEp Architecture Trade Study



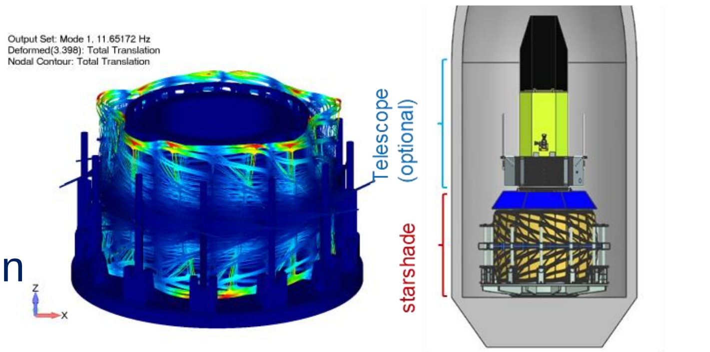
Stowed config shown co-launched
w/1.1m telescope
(5m fairing)



Mechanical System Summary

Stowed Analysis Summary

- 1^{st} major lateral mass mode is at 51 Hz (Req't 10 Hz)
- 1^{st} major axial mass mode is at 142 Hz (Req't 25 Hz)
- Strength margins of safety > 2.7
- Meets launch requirements for mission with telescope on top



Stowed config shown co-launched w/1.1m telescope (5m fairing)

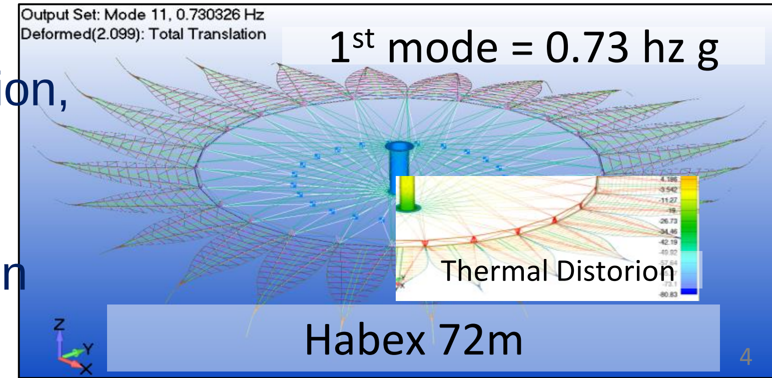
Deployed Analysis Summary

- 1^{st} mode is high at > 1 Hz, 1^{st} in-plane at 17.3 Hz
- High margins
  - Structure Instability due to Spoke Pre-tension
  - Slacking spokes from retargeting thruster fire & thermal loads
- Contrast has low sensitivity to spoke preload or length variation & fault tolerant to missing (broken) spokes

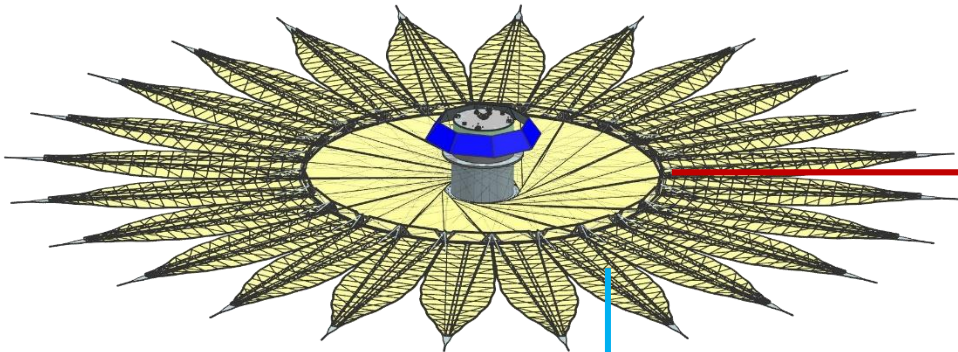
Demonstration of starshade development model

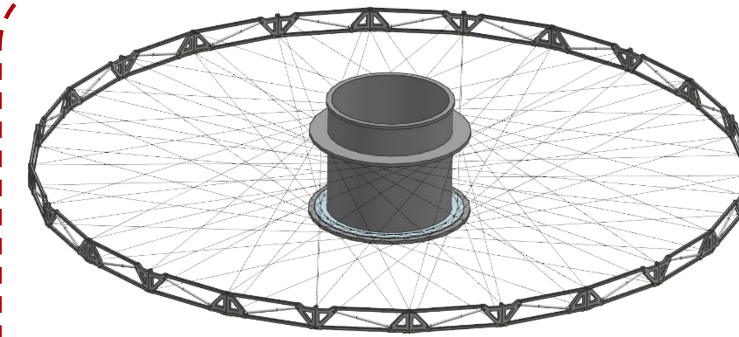
Scalability

- Habex 72m Baseline Design scales in configuration, deployed structural analysis & thermal stability performance (STOP)
- Falcon 9 up to 92m & SLS 150m per configuration study

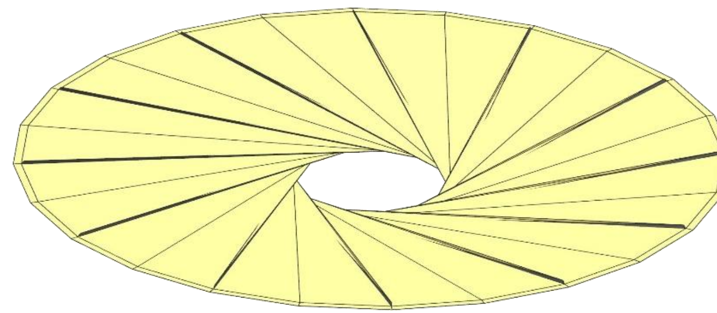


Subsystem Definitions



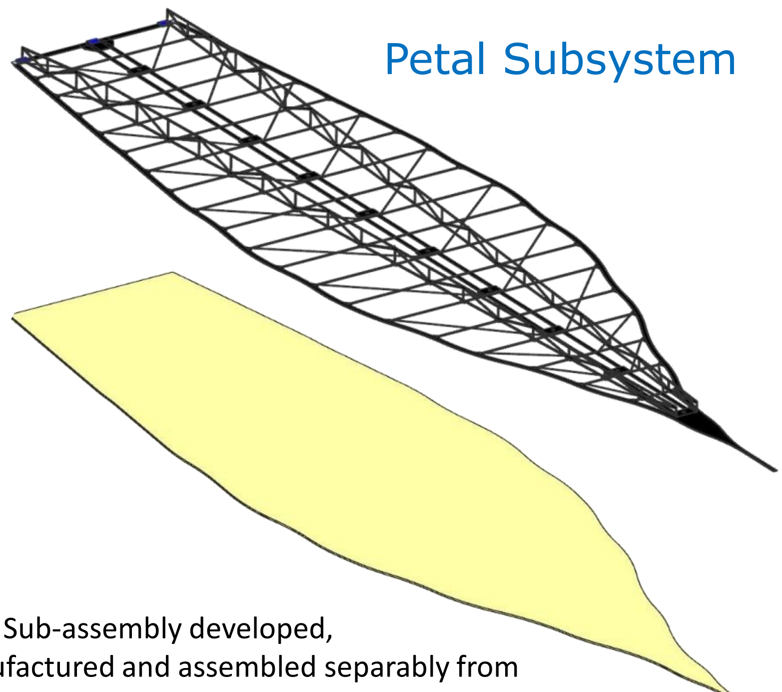


Truss + spokes + hub constitute separable structure w/defined interfaces to petal

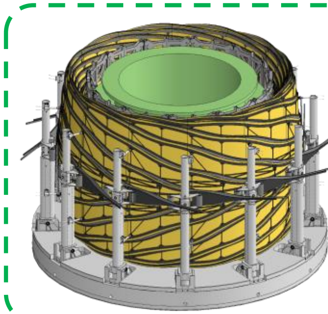


Inner Disk Subsystem

Petal Subsystem



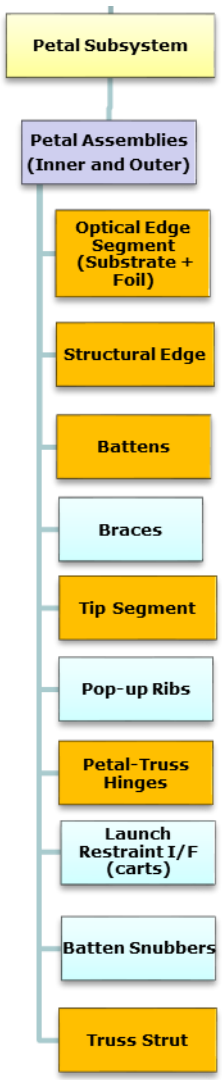
Petal Sub-assembly developed, manufactured and assembled separably from inner disk, with defined interfaces at its base



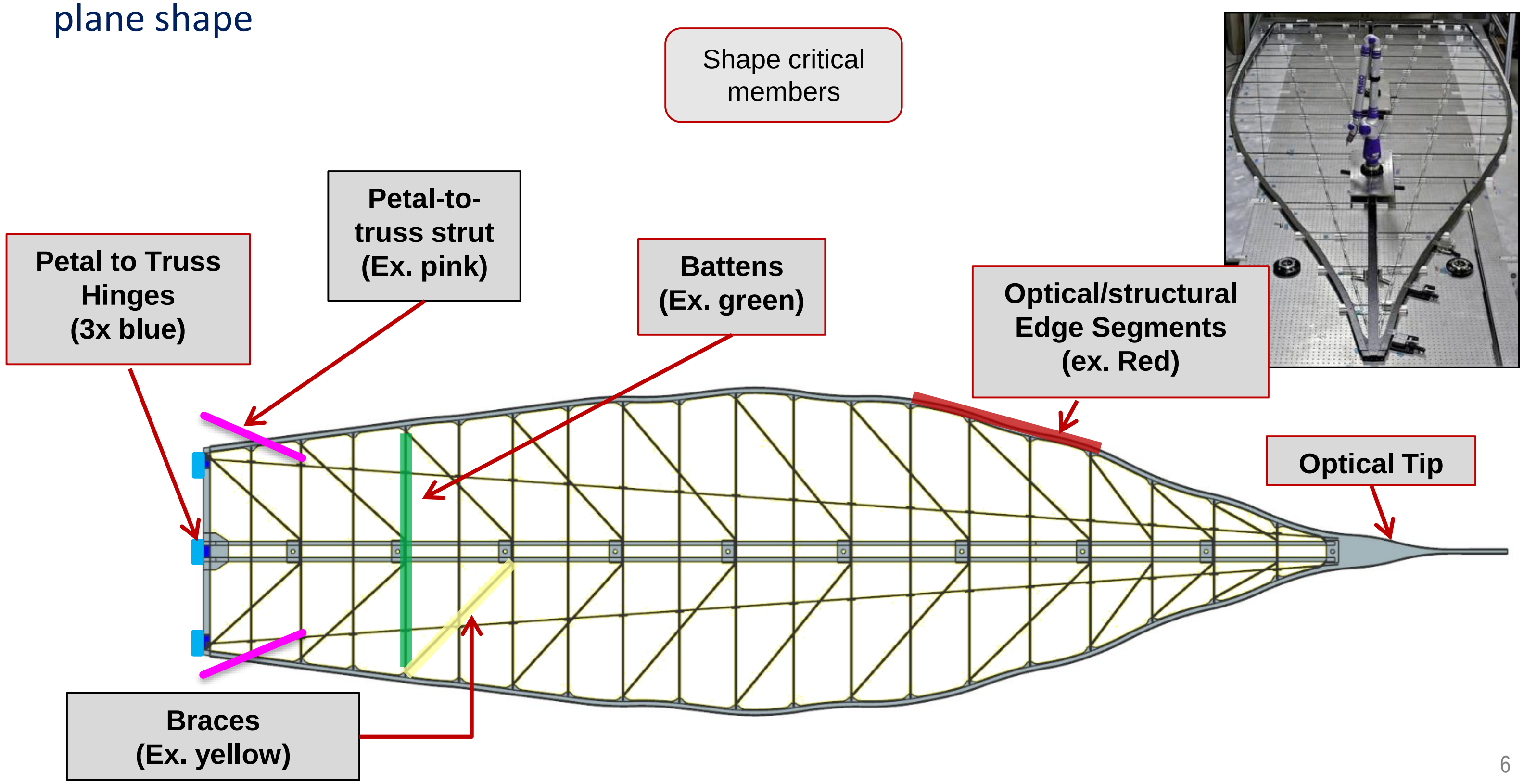
Petal Launch Restraint & Unfurl Subsystem (PLUS)

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

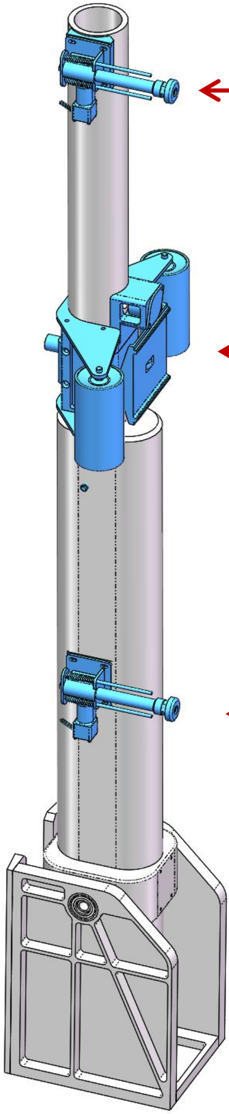
Petal Shape Critical Components



- Petal designed specifically to address in-plane shape stability
  - Battens maintain petal width (COTS & precise)
  - Edges are width-wise-thin and “go where battens tell it to”
  - Braces (diagonals) provide in-plane shear stiffness to maintain shape
- Petal hinges maintain petal position relative to truss (w/std avail. precision)
- Petal-to-truss struts provide out-of-plane support & must minimally influence in-plane shape



Roller Arm Assembly in Launch Restraint Config



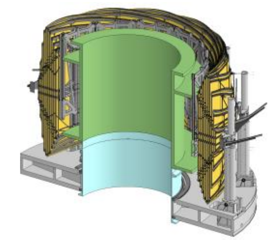
Upper Batten Snubbers
(Shown engaged)

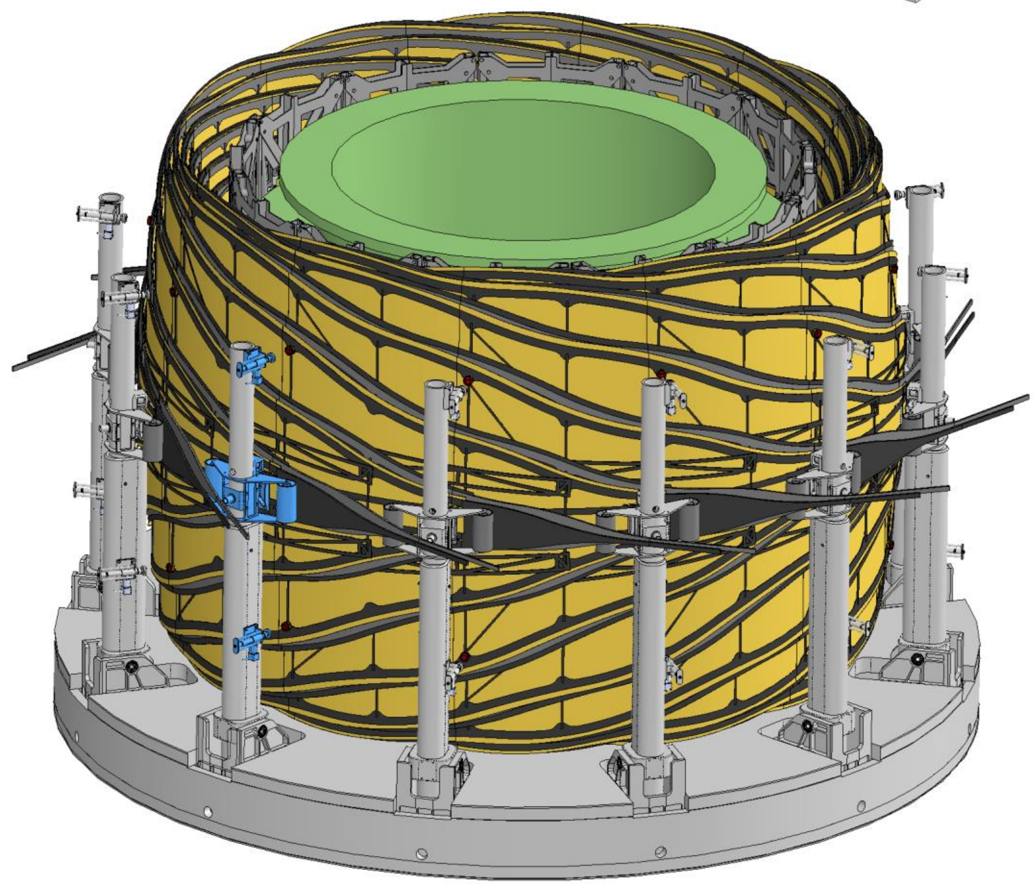
Launch Restraint Cart Preload Assy
(Shown engaged)

Lower Batten Snubbers
(Shown engaged)

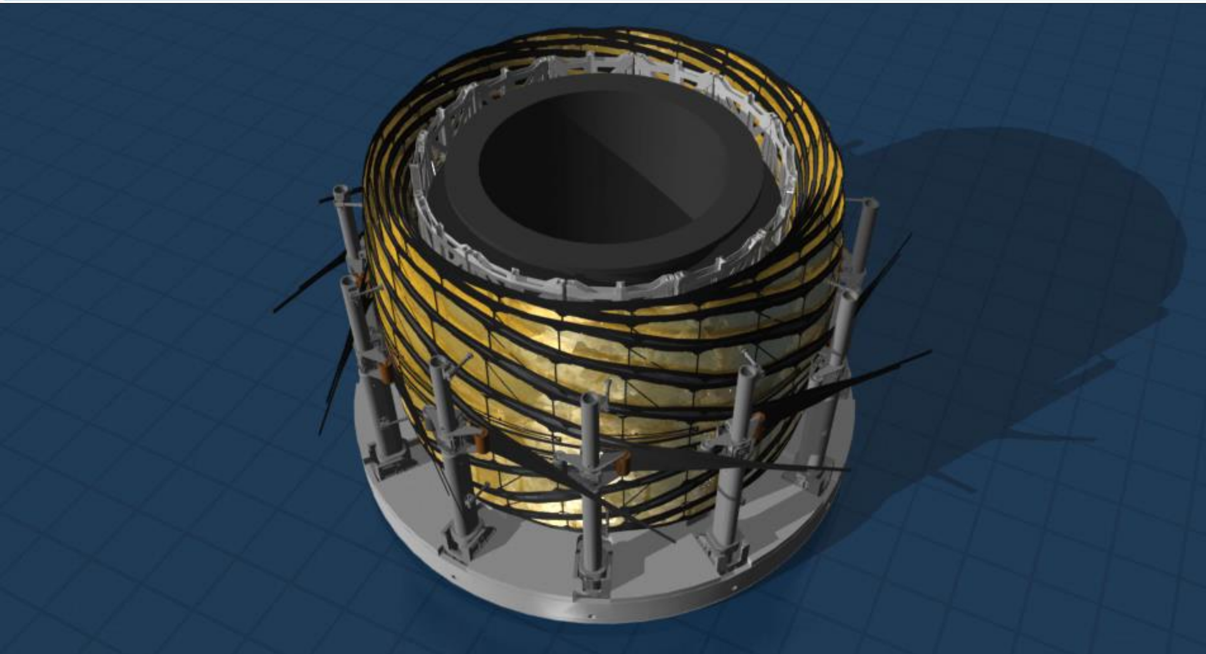
Trunnion
(attaches to carousel plate)

*Arm in Launch Configuration



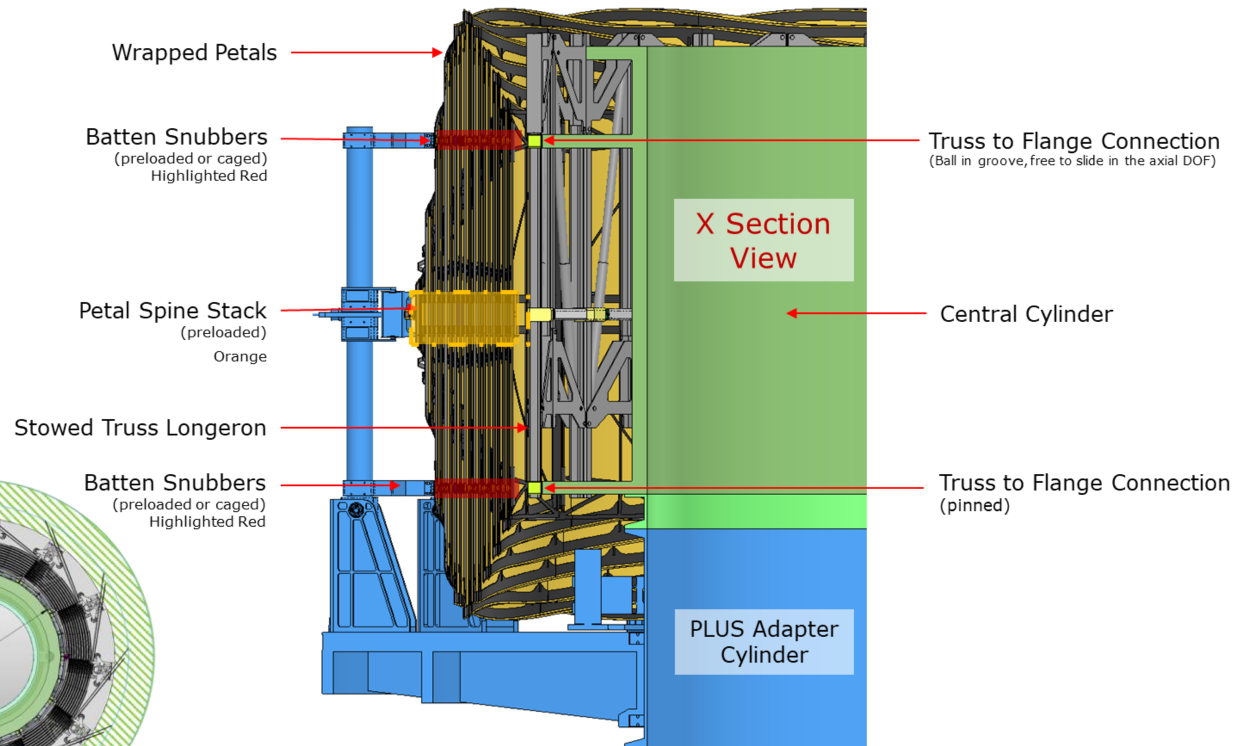


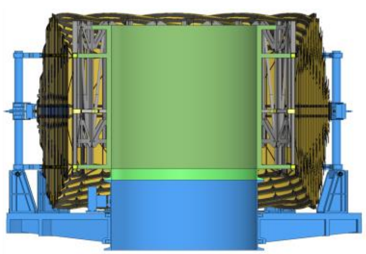
PLUS Visualization & Hardware Deployment Overlay



- PLUS testbed incipient deployments w/future upgrades to include medium fidelity launch restraints, rollers, and a pair of medium fidelity CFRP petals (simulators to serve as boundary conditions for pair of interest), more in TRL discussion

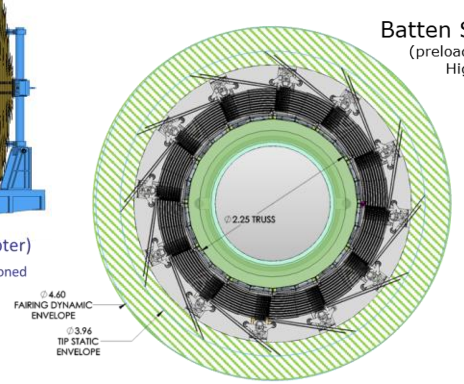
Cross Section View

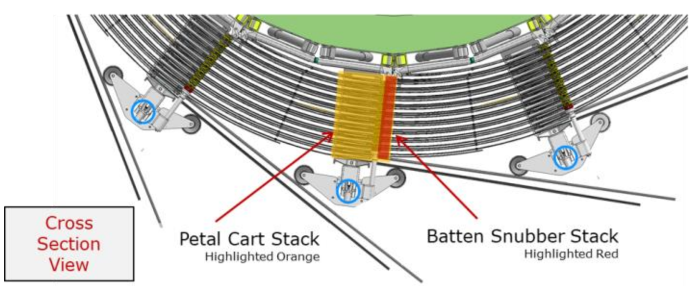




PLUS (Roller Arms, Carousel, PLUS Adapter)

*** Roller-arm/carousel/plus adaptor assy jettisoned after launch (total mass = 608 kg)





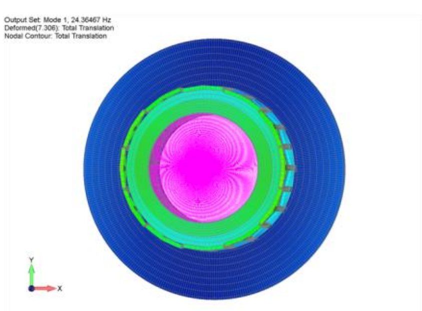
Stowed Configuration Modal Analysis

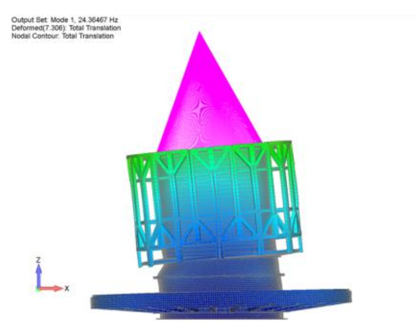
Dedicated Mission

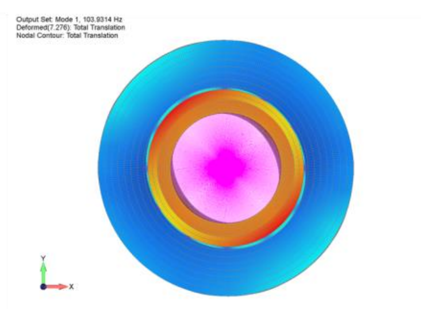
- The primary modes were also checked assuming the dedicated mission configuration
  - Telescope mass was taken from *"Exo-S STDT Final Report," Table 7.2-1*
  - Mass = 1,644 kg, Axial CG = 1.7 meters
    - Per Table 7.2-1, the propellant required for Starshade would decrease from 2000 kg to approximately 49 kg
    - Propellant mass in the FEM was conservatively left at 2000 kg
  - Impacts to the Petal tip, structural edge, and roller arm modes due to the additional telescope mass were negligible
- Critical frequencies and mass participation fractions
  - First primary lateral mode = 24.50 Hz (Mass participation = 1,770 kg)
  - First primary axial mode = 104.24 Hz (Mass participation = 2,842 kg)

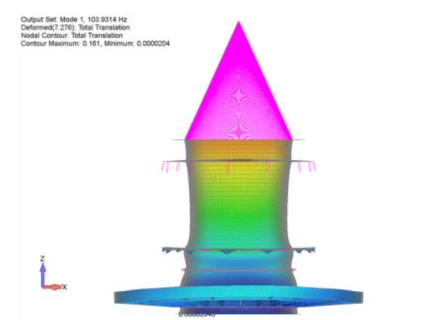
- Requirement: First primary lateral mode greater than 10 Hz
- First primary lateral mode
  - Frequency = 24.36 Hz
    - Mass participation = 619 kg (1,366 lb)
      - Mass participation fraction = 0.11
    - Additional lateral modes occur in this frequency range
  - Petals and roller arms are hidden for clarity

- Requirement: First primary axial mode greater than 25 Hz
- First fundamental axial mode
  - Frequency = 103.93 Hz
    - Mass participation = 1,709 kg (3,767 lb)
      - Mass participation fraction = 0.30
  - Petals and roller arms are hidden for clarity









Stowed Analysis Summary

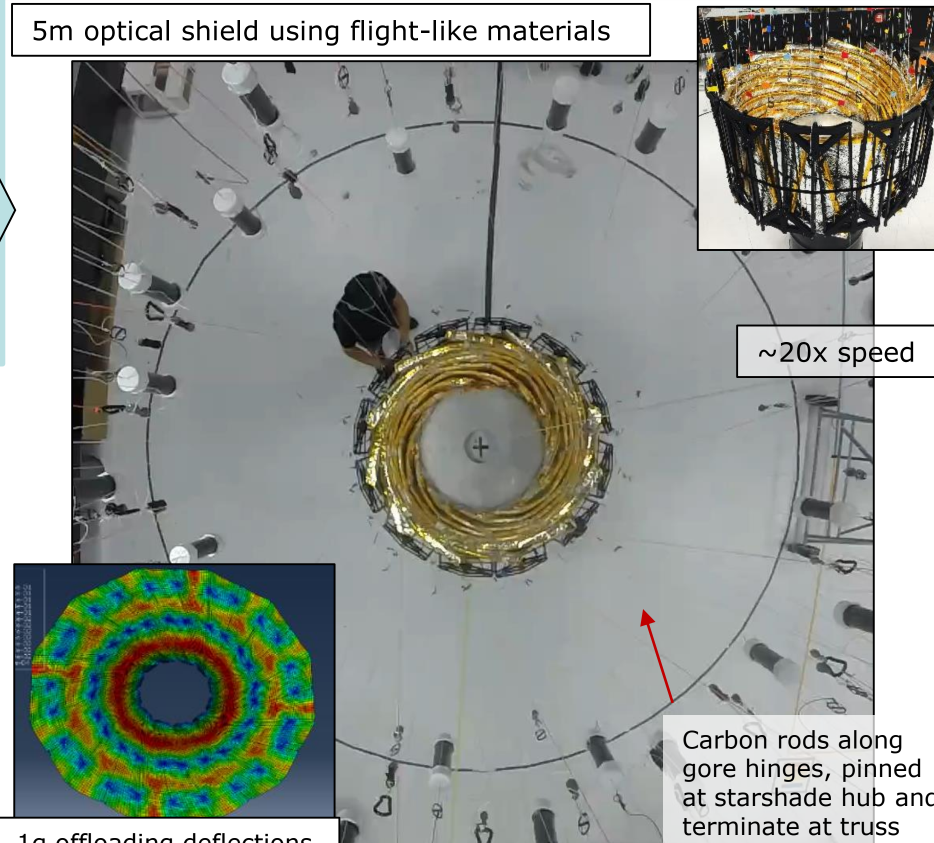
- Rendezvous Mission
  - 1st major mass lateral mode is at 51 Hz (Req't 10 Hz)
  - 1st major mass axial mode is at 142 Hz (Req't 25 Hz)
  - Strength margins of safety > 2.7 against falcon 9 user's guide
  - Peak displacements within dynamic fairing envelope
  - Petal edge and tip relative displacements show large margin on petal to petal interaction
- Dedicated Mission (with telescope)
  - 1st major mass lateral mode is at 25 Hz (Req't 10 Hz)
  - 1st major mass axial mode is at 104 Hz (Req't 25 Hz)

Inner Disk Optical Shield Deployment & Simulations

5m prototype (1/2 flight scale):

- flight-like materials, learn about required features to enable flight design (e.g. gravity offloading & test)
- Understand shield, spacecraft, truss, & petal relative deployment and required features (e.g. carbon rods for hub/starshade structural connection, analysis pending)

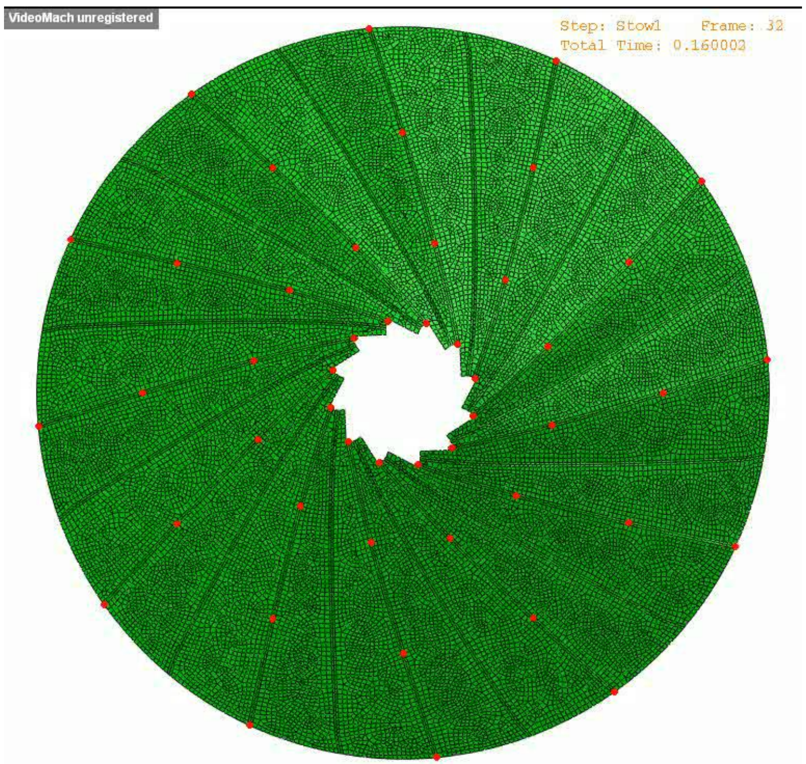
5m optical shield using flight-like materials



~20x speed

Carbon rods along gore hinges, pinned at starshade hub and terminate at truss

1g offloading deflections in Abaqus model

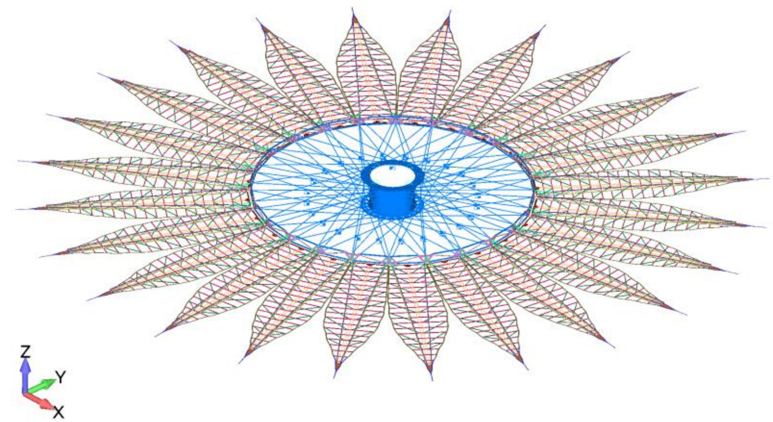


Deployment Simulation Model in Abaqus:

- Preliminary Abaqus deployment simulation model developed (T. Murphey) & utilized to understand 1g offloading
- Capability exists to combine a future, more developed model with the perimeter truss ADAMS model

Modes & Structure Margin

- Wrapped Starshade is ~600kg,
  - 20% of BOL system mass, 50% of EOL system mass
- Modes of interest
  - 1st system mode 1.06Hz
  - First significant truss and petal in-plane mode at F656 = 17.3 Hz (width preserving)

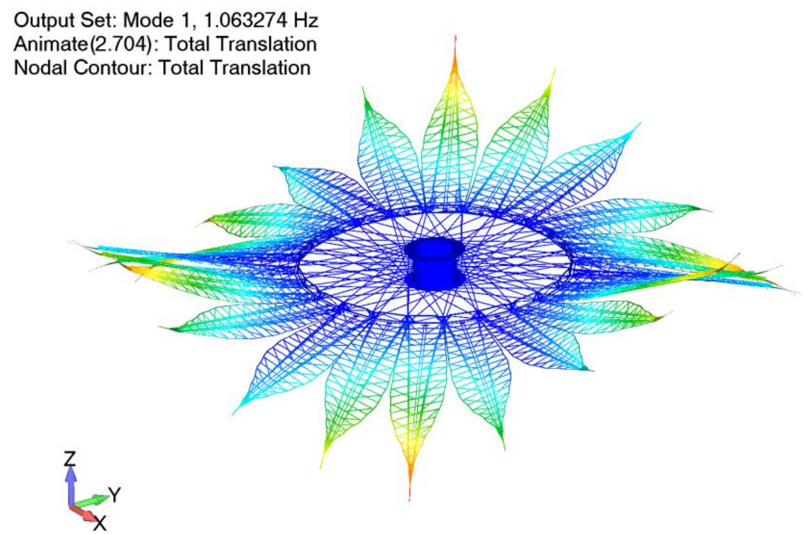


Margin on Structure Instability due to Spoke Pre-tension

Why analyze elastic instability?

- As a pre-tensioned structure, we want to verify the tension in the spokes is not close to buckling the compression portion of the structure (perimeter truss)

Deisgn Spoke Load	Spoke load to buckle perimeter truss	Margin
16 lbs	1536	HIGH



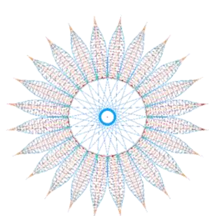
Deployed Analysis Summary

- 1^{st} mode is high at > 1 Hz
- 1^{st} in-plane mode is at 17.3 Hz & is petal width preserving
- High margin on Structure Instability due to Spoke Pre-tension
- High margin on slacking spokes from retargeting thruster fire
- High margin on bounding case thermal loads slacking spokes
- Contrast is insensitive to spoke preload or length variation
- Fault tolerant to missing (broken) spokes (negligible impact)

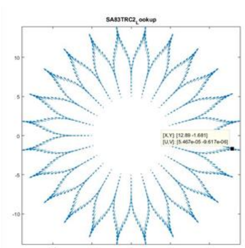
Agenda

STOP analysis refresher of results for representative cases* :
  - Thermal analysis (temperature) results
  - Thermal distortion results
  - Resulting contrast due to nominal thermal distortion & comparison to the error budget
- CTE variability monte-carlo study results

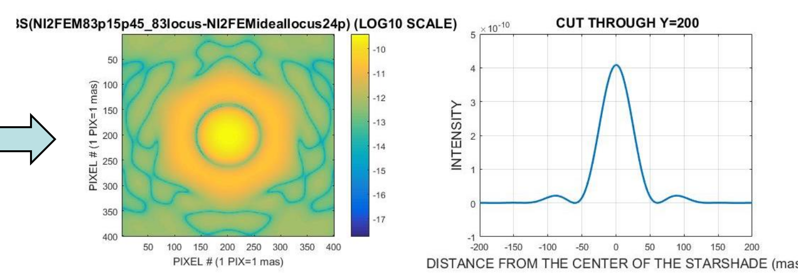
* Subset of sun angle cases showing representative temperatures & distortions/results, full set in backup



Thermal analysis temperature results mapped to structural FEM



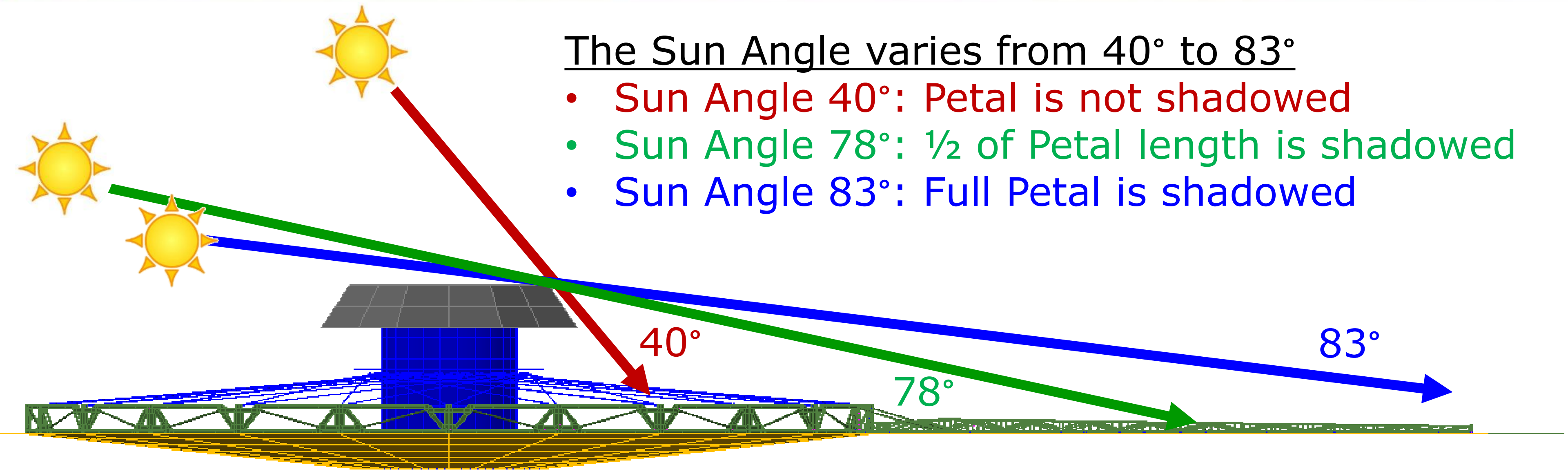
Quiver plot of resultant thermally induced shape distortion



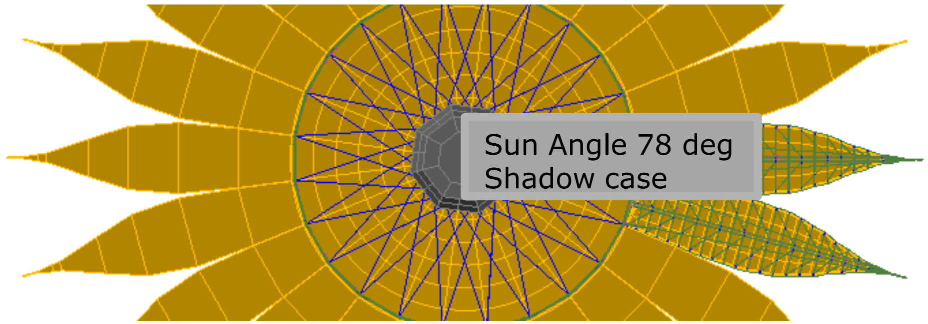
Sun Angles and Shadowing by Hub

The Sun Angle varies from 40° to 83°

- Sun Angle 40°: Petal is not shadowed
- Sun Angle 78°: ½ of Petal length is shadowed
- Sun Angle 83°: Full Petal is shadowed

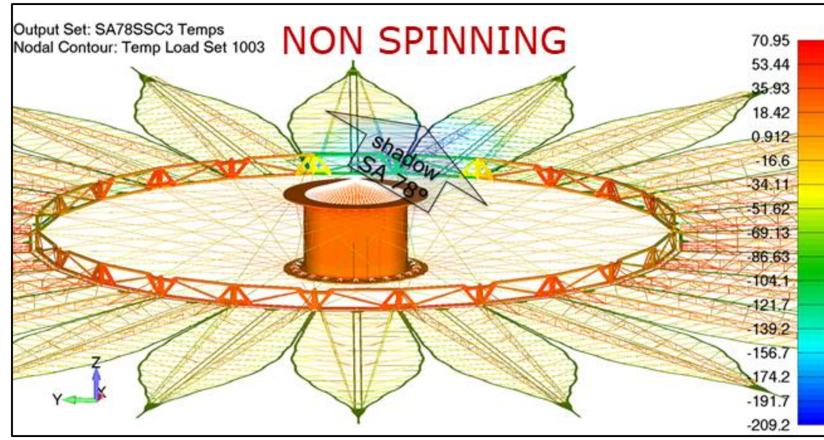


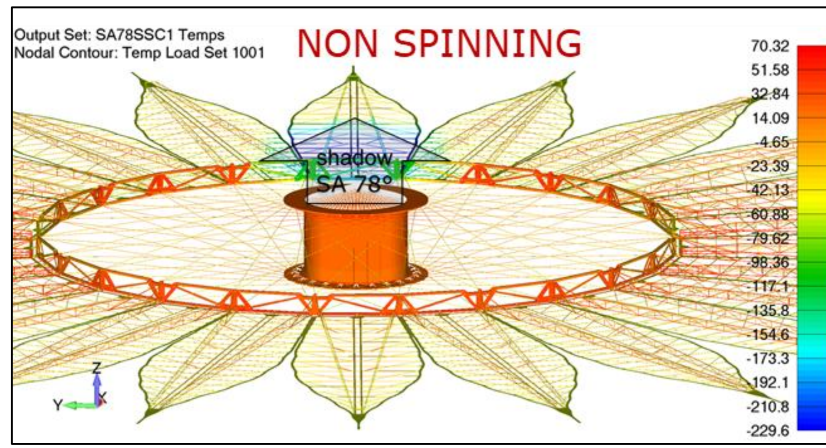
*** Slow rotation run every 3.75°. @1/3 RPM this is every 1.875 seconds, 96 positions. Temperatures available at each of the 96 locations.

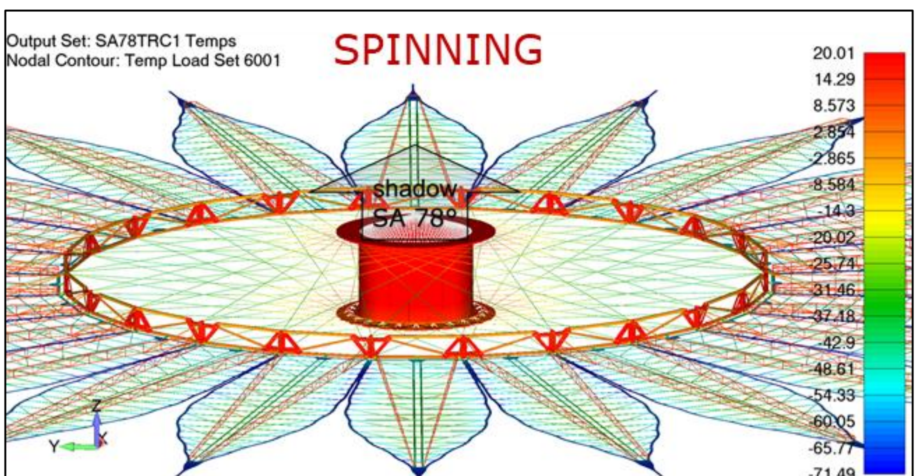


Non-spinning Shadow Orientation Conclusions

	Comment	Gradient	Max/Min Temp
NON-Spinning	Shadow clocking orientation has little effect on max/min temps, only moves cold portion of starshade	300 C	70 C / -230 C
Spinning	Averages temperatures symetrically aound spin axis Transient has negligible effect on contrast	90 C	65 C / -95 C







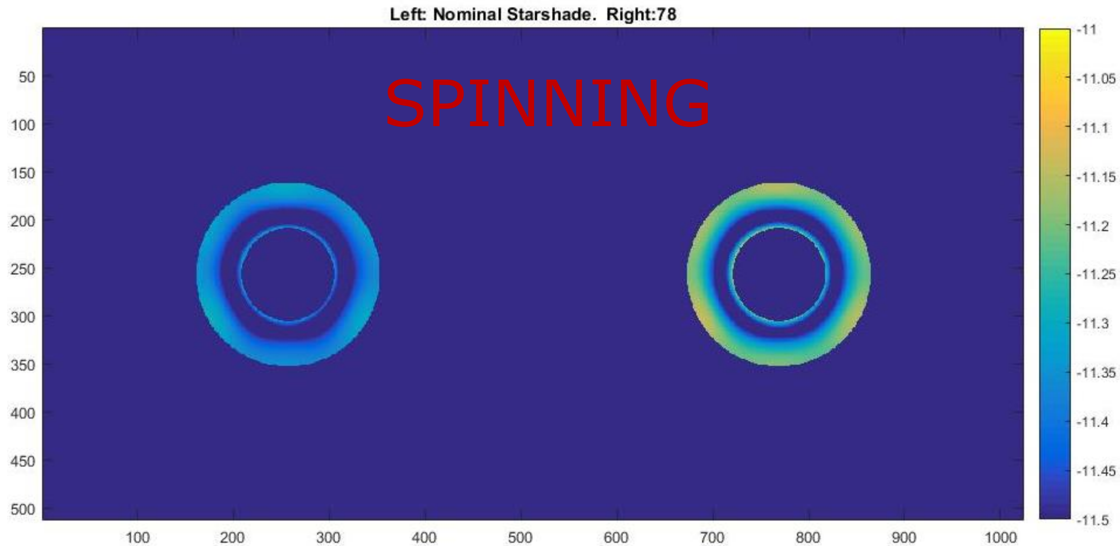
Sun Angle 78
Comparison of Spinning to Non-Spinning

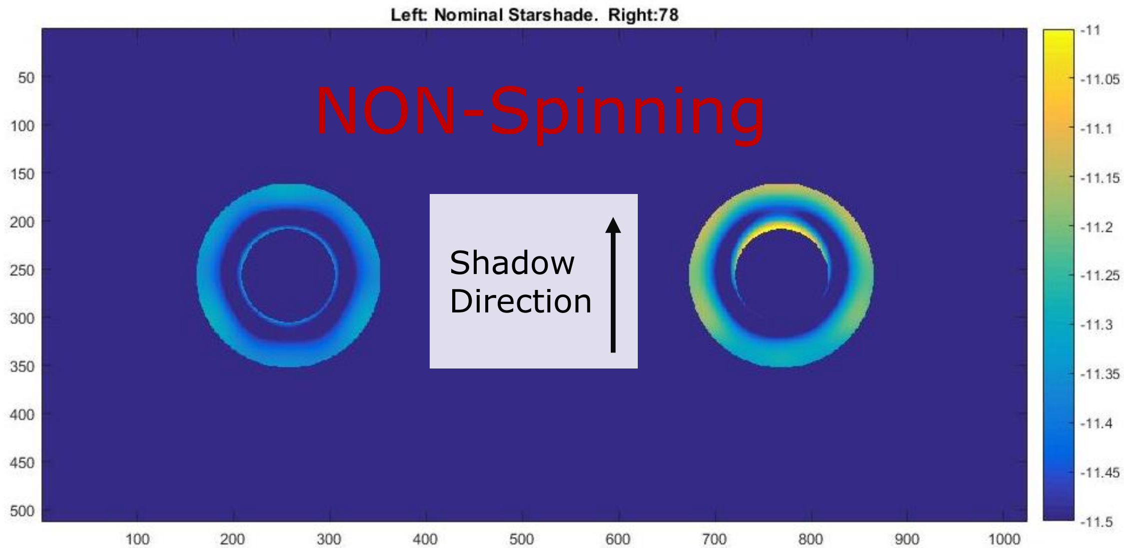
Spinning

- Spinning has a telescope axis-symmetric contrast
- Contrast varies radially

NON-Spinning

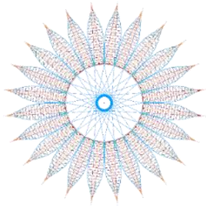
- Largely distorted shadowed petals :
  - Shift high contrast annulus toward shadow
  - Reduce contrast in petal distorted zone



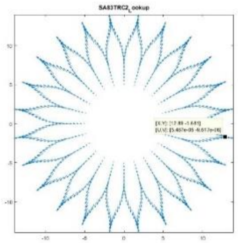


What did we do?

- Thermal elastic distortions are caused by the combination of temperature and CTE
- Thermal analysis results (temperatures) were mapped to the structural model
- CTE material cards were populated with CTE lookup tables, CTE vs temp
  - CFRP ply data test data characterization produces “nominal” CTE curves
  - Ply CTE data combines with layup to produce nominal layup CTE curve based CFRP layup design
  - Wrapped design utilizes 2 different layups
    - Structural Members (most) - Quasi-iso layup from NGAS
    - Optical Edge - Quasi-iso layup with the addition of the amorphous metal foil and 5 mil epoxy each side
    - Truss longerons - Quasi-iso layup with the addition three invar fittings that attach petal hinges
    - Uni-directional pultruded members utilized for JPL’s SWOT program
  - What about variation in CTE? Sensitivity to variation in mean CTE by layup type, and variation in CTE from component to component (for a given layup design) will be varied in a wide enough range to capture bounding variations and to check sensitivity to these bounds.



Thermal analysis temperature results mapped to structural FEM



Quiver plot of resultant thermally induced shape distortion

Thermal Distortion Contrast Results

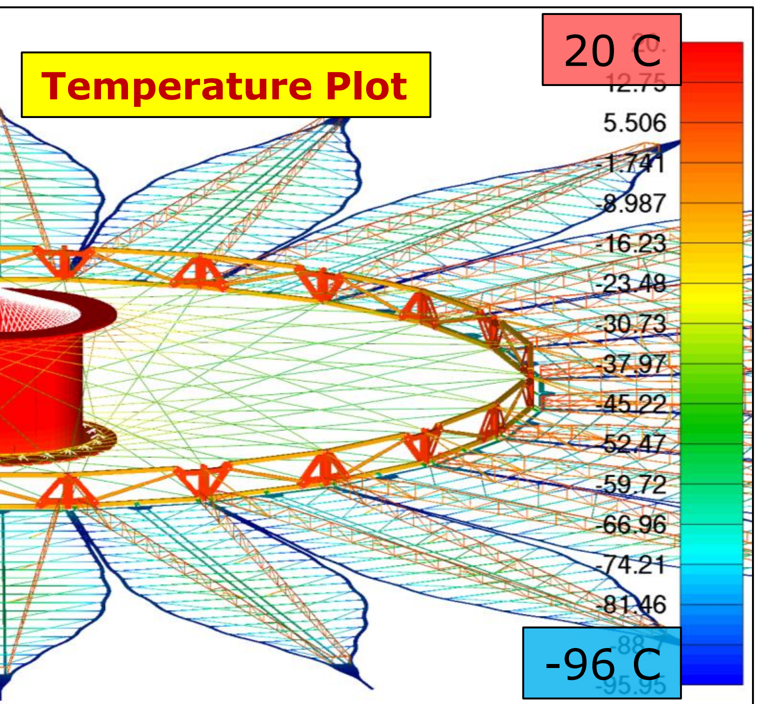
Case	***CBE*** ***Delta Contrast x 1e-12***	***Max Expected*** ***Delta Contrast w/ 100% contingency x 1e-12***	***Max Expected*** ***% of Starshade Allocated Shape Error (3.4 e-11)*****
Spinning			
40 deg*	*0.002*	*0.01*	*>1%*
78 deg	*0.398*	*1.592*	*4.6%*
83 deg*	*0.655*	*2.62*	*7.7%*
Non-Spinning			
40 deg	*0.06*	*0.24*	*>1%*
78 deg	*0.45*	*1.81*	*5.3%*
83 deg	*0.56*	*2.24*	*6.5%***

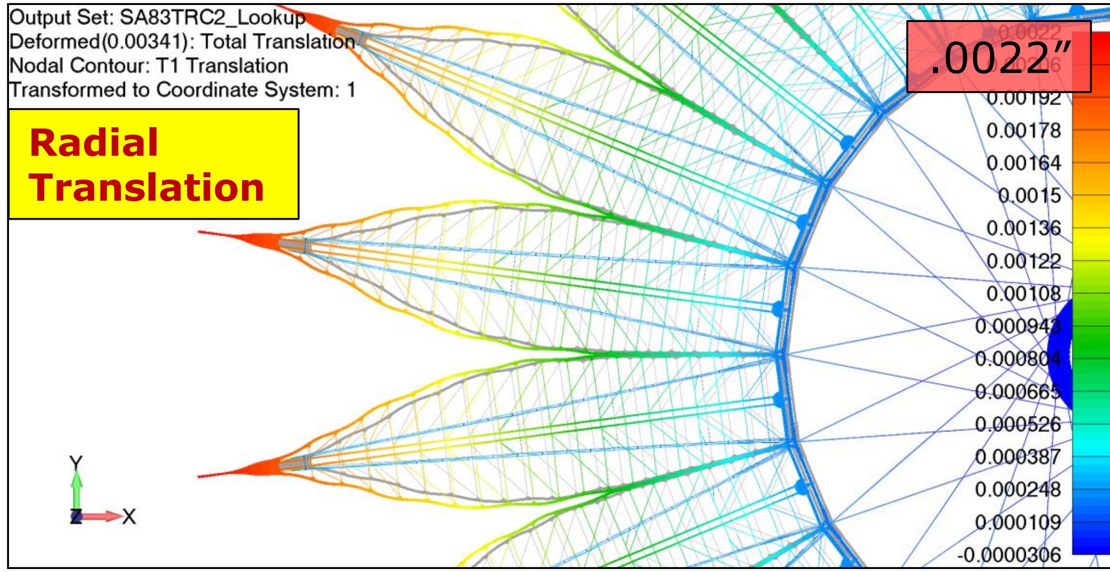
* Utilizes CTE for truss longeron w/ petal interface fittings affecting longeron CTE (w/no CTE design compensation)

** Error budget carries CBE contrast from spinning results, non-spinning shown for reference only

SA83 SPINNING Distortions

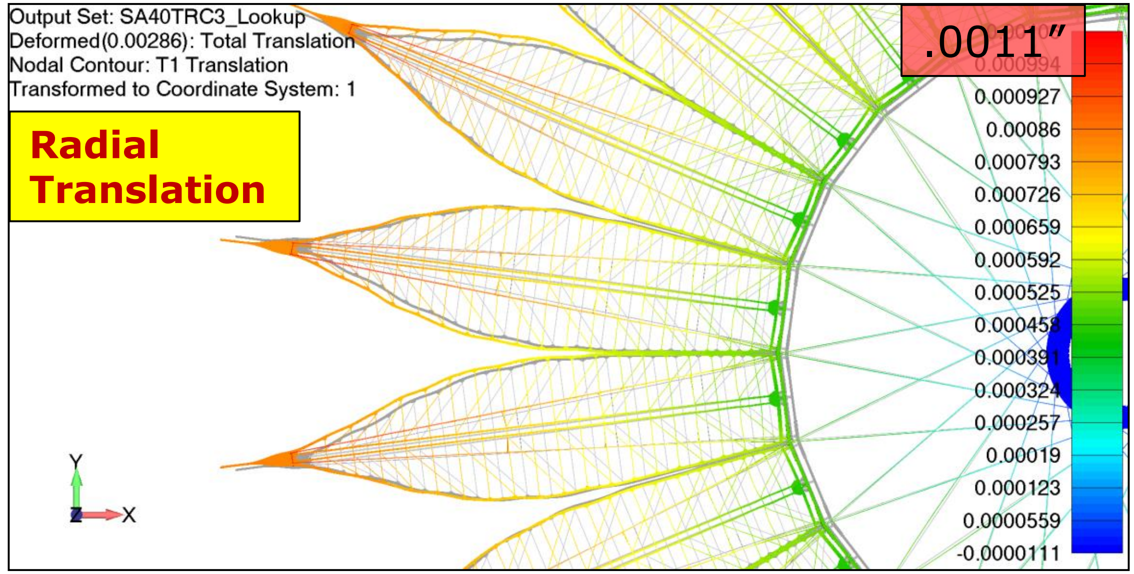
- **Raw** distortions on order of 50 microns (0.002")
- Distortions correspond to temperature results (thermal analysis), e.g.
  - Truss @ 20 C (room temp) = almost no shape change
  - Petal dT = -65 C, 50 microns (0.002")

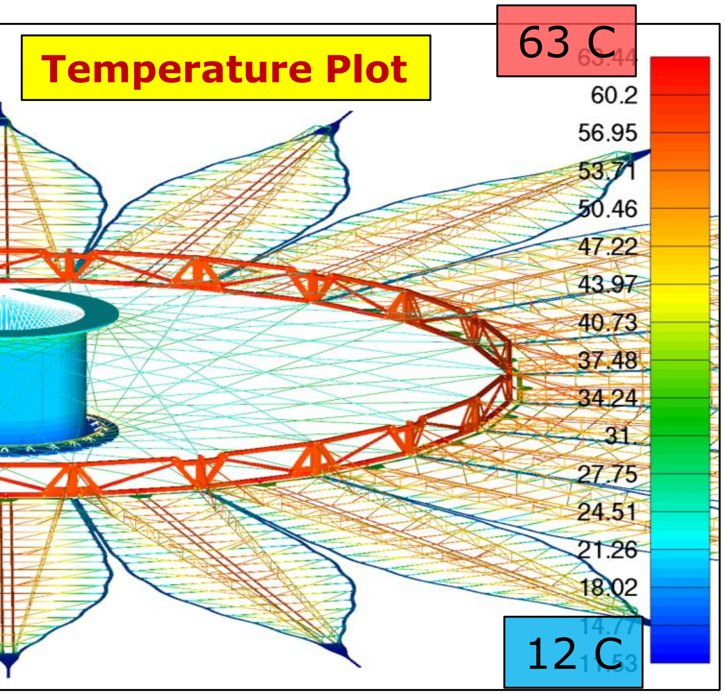


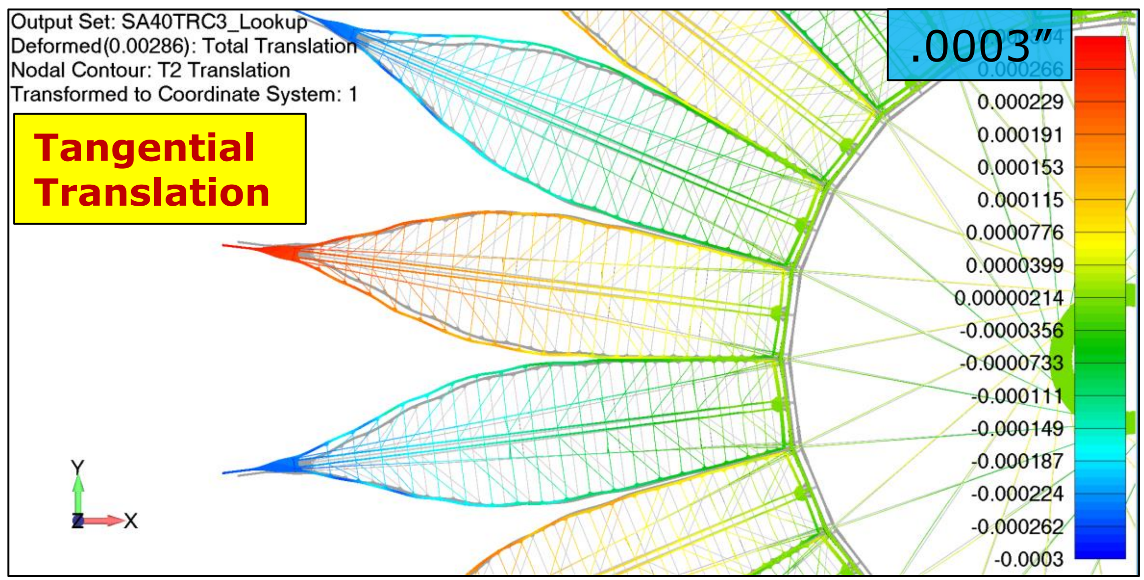


SA40 SPINNING Distortions

- **Raw** distortions on order of 50 microns (0.001”)
- Distortions correspond to temperature results (thermal analysis), e.g.
  - Truss @ 60 C (dT = 40C), ~25 micron radial expansion
  - Petal dT = ~+40 C, 30 microns (0.002”)

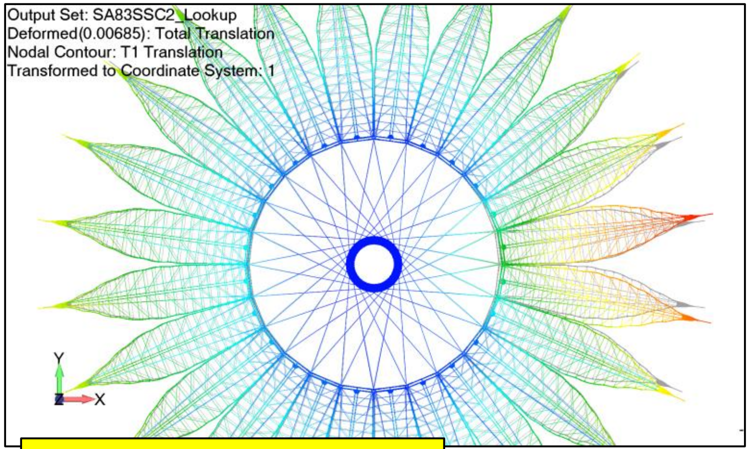


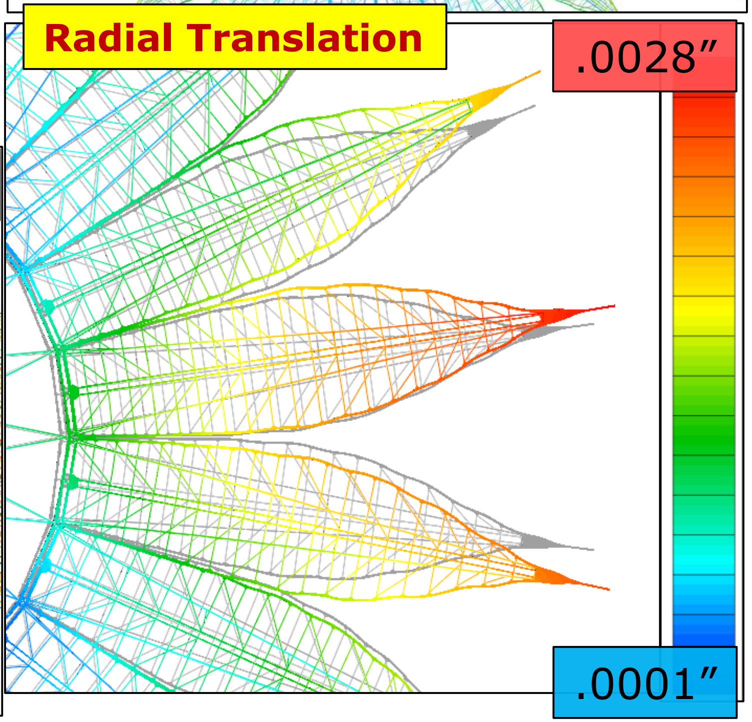


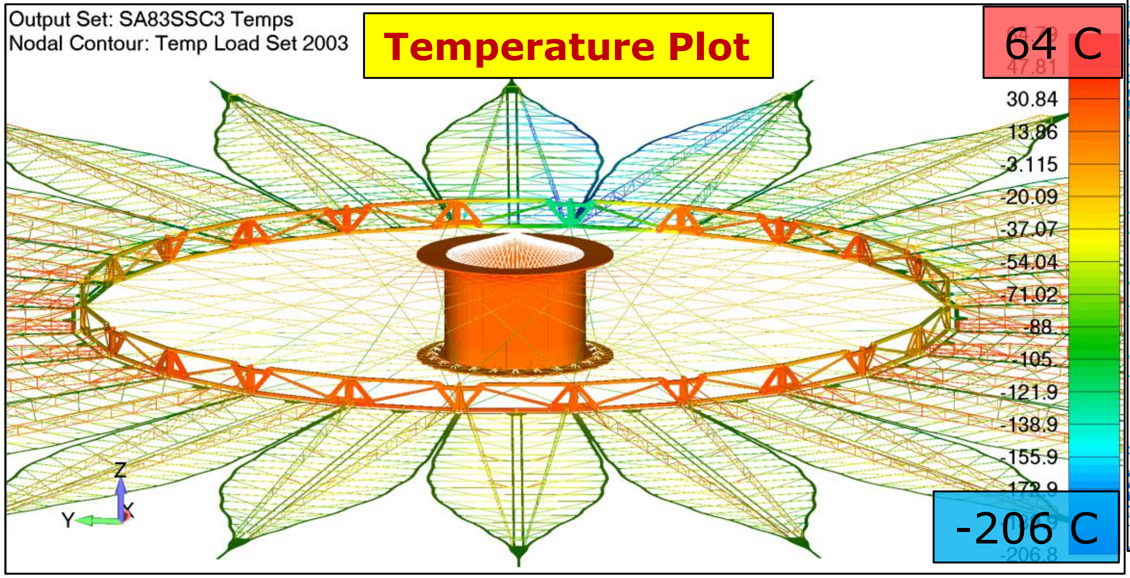


Sun Angle 83, NON-spinning, Distortions

- Sun Angle 83 degrees produces representative distortions and worst case contrast, shown as example of NON-spinning results
- <u>**Raw**</u> distortions on order of 75 microns (0.003")
- Distortions correspond to temperature results (thermal analysis), e.g.
  - Truss HOT @ 70 C (dT = 50C), ~25 micron radial expansion
- Cold Petals are longer, disrupts apodization function

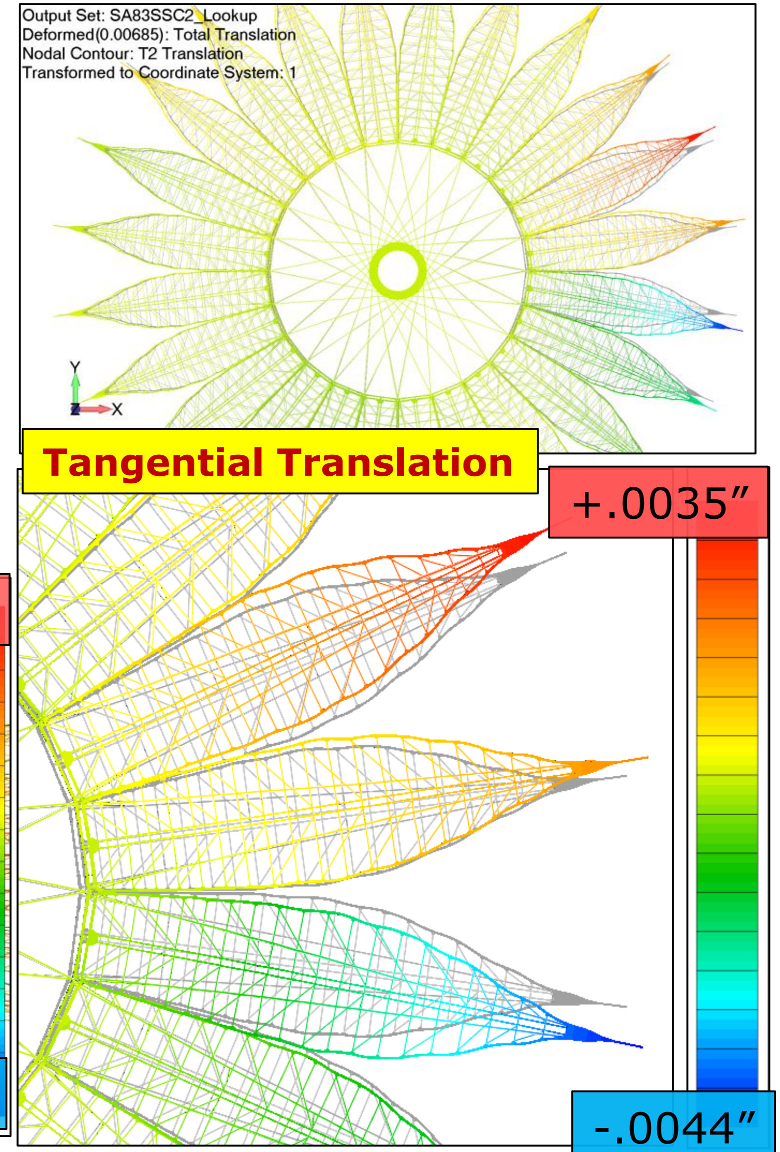


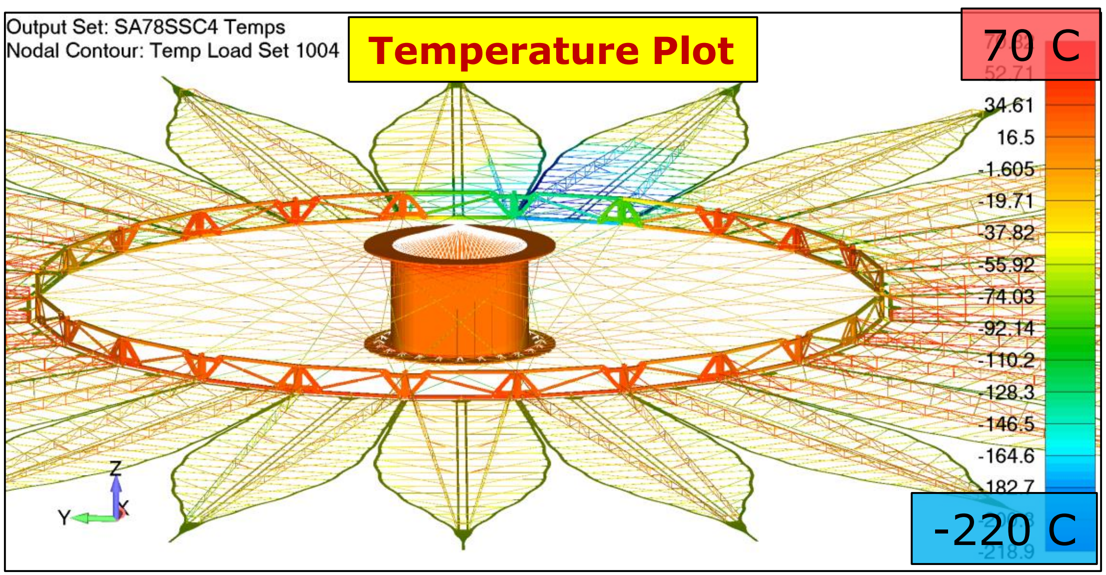




Sun Angle 83, NON-spinning, Distortions

- Sun Angle 83 degrees produces representative distortions for the steady state sun angle cases and is the worst case contrast for steady state, shown as example of NON-spinning results
- <u>Raw</u> distortions on order of 100 microns (0.004”)
  - Truss bays in shadow are cold, and grow (neg CTE), and splay petals apart from eachother





Summary

* Preliminary analysis shows max expected thermally deformed starshade meets requirements for both spinning and non-spinning configurations over working sun angles

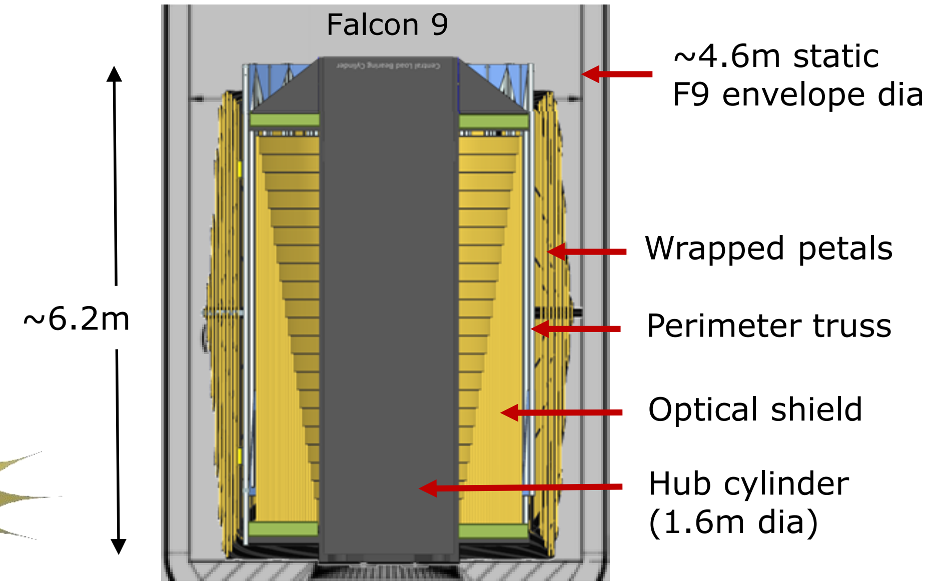
Case	***CBE*** ***Delta Contrast x 1e-12***	***Max Expected*** ***Delta Contrast w/ 100% contingency x 1e-12***	***Max Expected*** ***% of Starshade Allocated Shape Error (3.4 e-11)*****
Spinning			
40 deg*	*0.002*	*0.01*	*>1%*
78 deg	*0.398*	*1.592*	*4.6%*
83 deg*	*0.655*	*2.62*	*7.7%*
Non-Spinning			
40 deg	*0.06*	*0.24*	*>1%*
78 deg	*0.45*	*1.81*	*5.3%*
83 deg	*0.56*	*2.24*	*6.5%***

* Utilizes CTE for truss longeron w/ petal interface fittings affecting longeron CTE (w/no CTE design compensation)

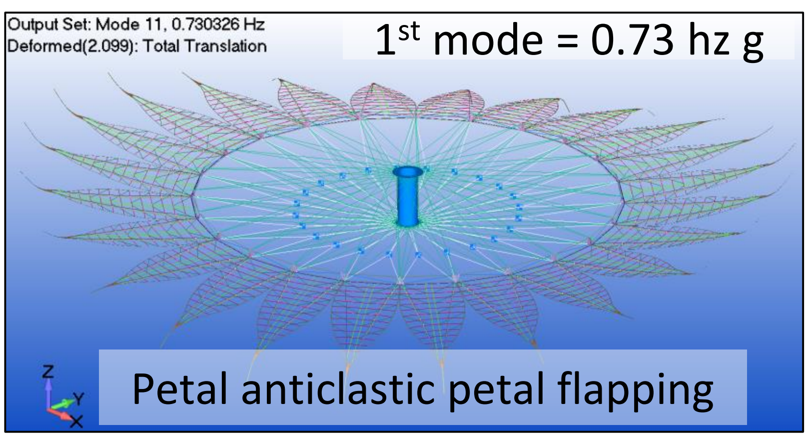
** Error budget carries CBE contrast from spinning results, non-spinning shown for reference only

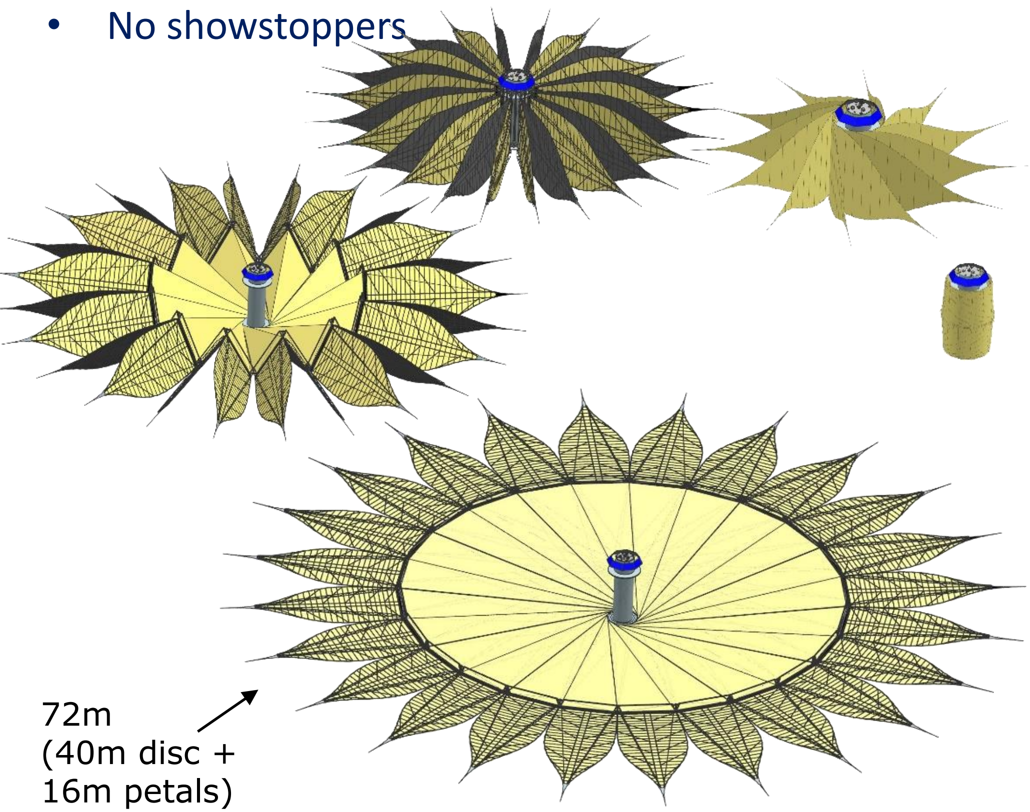
Scalability to HabEx
Configuration & Deployed Analysis

- 72m point design per HabEx STDT study (40m disc, qty 24, 16m petals)
- Rendezvous launch in Falcon 9 (5m fairing)
- Baseline configuration scaled
- Modal analysis promising w/ 1st mode @ 0.72hz
- Error budget scales linearly with starshade size
- No showstoppers



Starshade mass (CBE)= ~2,350 kg
* Based on structural FEM model





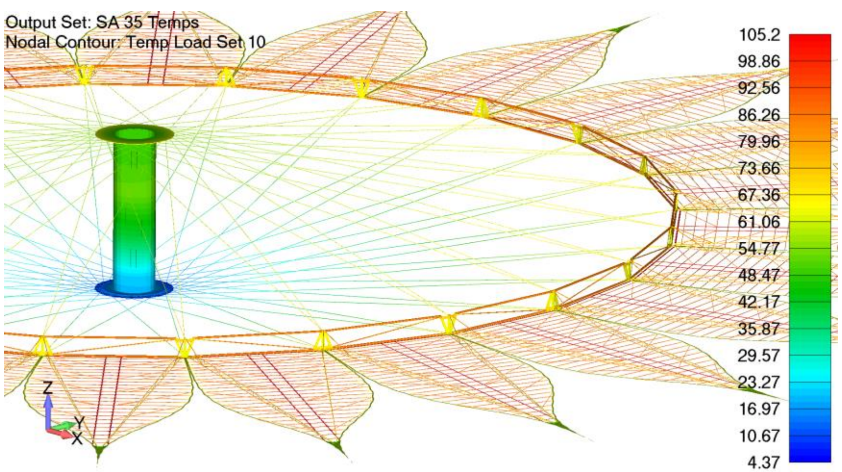
Habex STOP Analysis

Case	***CBE*** **Delta Contrast x 1e-12**	***Max Expected*** **Delta Contrast w/ 100% contingency x 1e-12**	***Max Expected*** **% of Starshade Allocated Shape Error (3.4 e-11)****
Spinning			
35 deg	*0.446*	*1.784*	*5%*
59 deg	*0.044*	*0.176*	*<1%*
83 deg	*0.027*	*0.108*	*<1%*

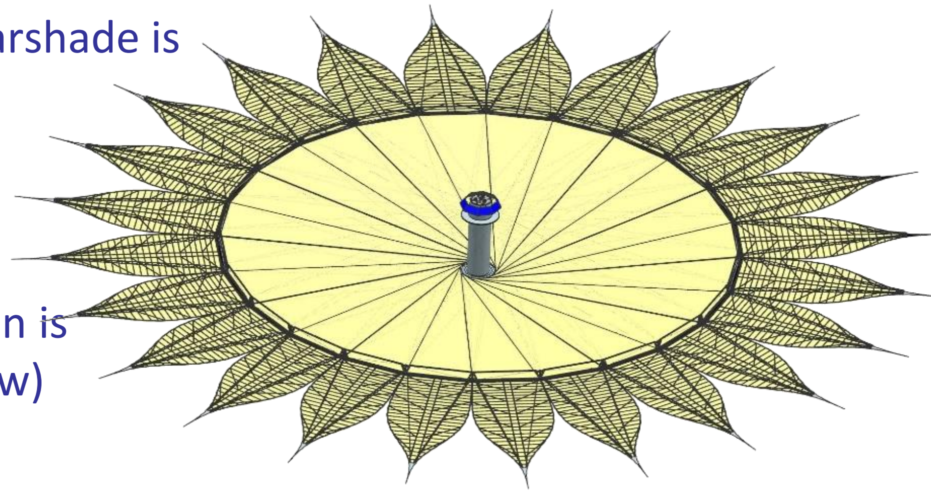
Notes:

- Only ran spinning cases run for sun angles 35, 59 & 83
- CTE numbers by component from trade study applied to habex config (less longeron fittings, but incl. edge foil)
- Thermal config assumes raw CFRP & black kapton shield on sun side, no thermal optimization
  - Conservative because trade study has shown silicon kapton overlay reduces temperature extremes for structure and thus deformations

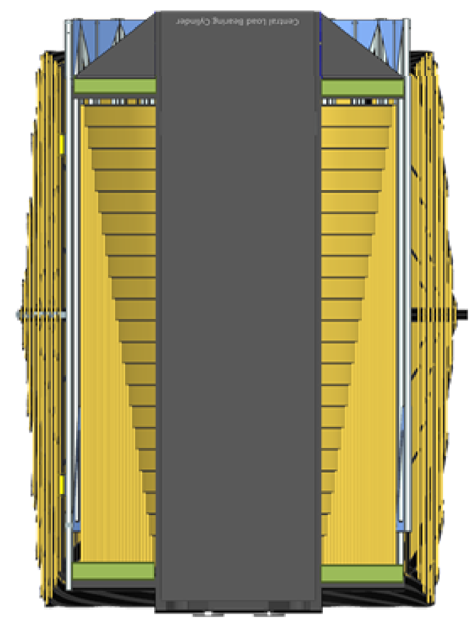
** HabEx shape error allocation is currently *similar* to the 26m design, comparison drawn for reference only



Scalability Factors



- For a given fairing size, maximum size of starshade is limited by:
  - Diameter of the fairing
    - Sufficient volume for propulsion tanks
    - Sufficient volume for optical shield (min is assumes multiple layers lay flat for stow)
    - # of petals and wrap "pitch"
      - Min # of petals 16, fewer petals wrap thinner (but taller)
      - Min pitch = petal thickness (5/16" up to ½")
  - Height of fairing
    - Fewer petals = wider petals = taller stow height (& thus interplay with stow diameter)
    - Sufficient volume for propulsion tanks
      - Smaller hub cylinder requires taller cylinder for same vol. of tanks & S/C
- Many knobs to turn to tailor design to desired starshade size and meet fairing specs



Summary

- Habex 72m Baseline Design
  - Wrapped design scales in both configuration and deployed stiffness to be credible for a HabEx 72m design
  - Preliminary STOP analysis shows wrapped 72m design meets thermal performance requirements
- Falcon 9 supports up to 92m per configuration study
- SLS block 1 8.4m dia fairing supports up to ~150m per configuration study (LUVOIR)
- Scalability Breaking Point
  - Design is versatile and parameters can easily be tailored to meet starshade overall size requirements, while still meeting deployed stiffness, with also meeting launch vehicle requirements

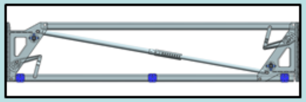
Thermal Distortion Analysis

- Two analyses for the impact of thermal distortion on contrast:
  - STOP Analysis: uses thermal mapping and nominal CTE values (temperature dependent) to compute contrast for each sun angle
  - Monte-Carlo Analysis: uses random distributions on CTEs to determine statistical distribution on contrast for each sun angle

RFA #5: Test Article Descriptions
Prototype Test Plan

*** 1-page summaries of each TRL-5 test article on subsequent slide ***

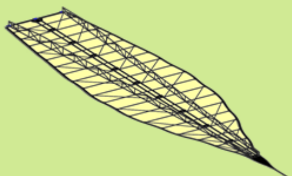
Full-Scale (1.3-m long)



Inner Disk Truss Bay (P5-1)

- **Unit A** → *Verify Truss Bay length **as manufactured*** — ***Test 5-1*** → *Validate Truss Bay model **of length vs. temp.*** — ***Test 5-2***
- **Unit B** → *Verify Truss Bay shape **as manufactured*** — ***Test 5-1*** → *Validate Truss Bay model **of length vs. I/F Load*** — ***Test 5-3*** → *Verify Petal shape & Truss-Bay length after **thermal cycles*** (*Petal & Truss-Bay are tested at same time, in same chamber, but they are not connected.*) — ***Test 5-5*** → *Verify Petal shape & Truss-Bay length after **storage with creep*** (*Petal & Truss-Bay are tested at same time, in same chamber, but they are not connected.*) — ***Test 5-6***

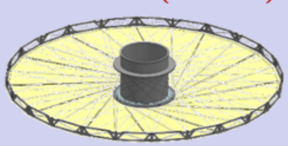
1/2-Scale (4-m long)



Petal (P5-2)

- **Unit A** → *Verify Petal shape **as manufactured*** — ***Test 5-1*** → *Verify petal shape after **deploy cycles*** — ***Test 5-4*** → ***Test 5-5*** → ***Test 5-6***
- **Unit B** → *Verify petal shape **as manufactured*** — ***Test 5-1*** → *Verify petal shape after **deploy cycles*** — ***Test 5-4*** → *Validate Petal model **of shape vs. I/F load*** — ***Test 5-7*** → *Validate Petal model **of shape vs. temp.*** — ***Test 5-8***

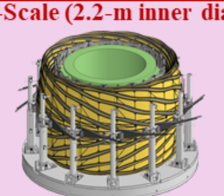
Full-Scale (10-m dia.)



Inner Disk (P5-3)

→ *Verify repeatable Disk **deploy tolerances** w/ OS (after verifying opacity)* — ***Test 5-9*** → *Validate Disk model of **deployment kinematics*** — ***Test 5-10*** → *Validate Disk model **of shape vs. spoke load*** — ***Test 5-11*** → *Verify OS opacity at truss-bay & petal I/F's* — ***Test 5-12***

Full-Scale (2.2-m inner dia.)



Deploy. Control System (P5-4)

→ *Verify DCS unfurls Petals with no edge contact* — ***Test 5-13*** → *Validate DCS model of **deployment kinematics*** — ***Test 5-14***

RFA #5: Test Article Description
Prototype 5-1: Disk Truss Bay

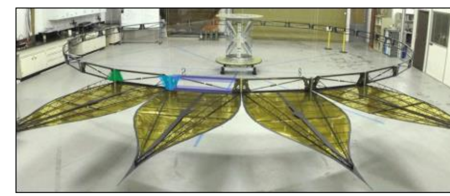
- Truss Assembly
  - Node Assy
  - Cable spooler/motor Assy
  - Truss-Hub Restraint I/F
  - Longeron incl. Petal Hinge I/F
  - Shorteron
  - Diagonal Assy
  - Spokes Assy

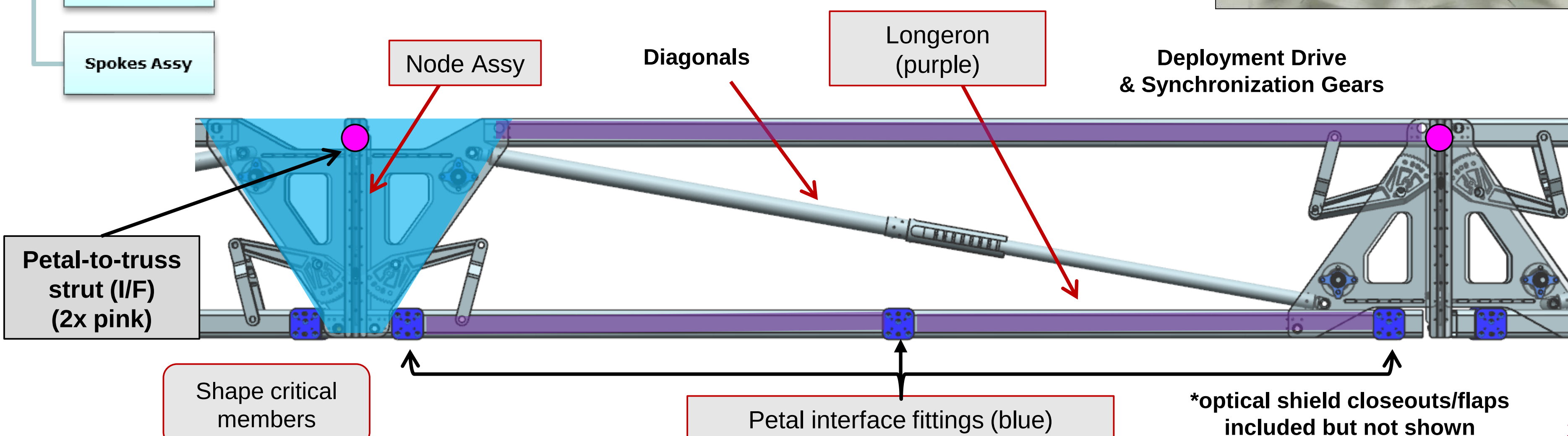
- **Tests**: Verify truss bay dimensions (manufacture), Validate Truss Bay model of length vs. temperature
- **Critical components for tests**: longeron & node
  - average longeron length + node width defines the disk radius (petal position)
- **Scale**: Full (1.3-m long) Truss Bay assembly of medium fidelity (or better)
- **Components**:
  - Longerons are quasi-iso CFRP* tubes with invar petal I/F fittings & I/F to gear assy's
  - Nodes are quasi-iso CFRP* plates with CFRP 'clips' (jointery) & I/F to gear assy's
  - Diagonals are quasi-iso CFRP* tubes with invar end fittings
  - Optical shield close-outs/flaps included (black kapton XC), (not shown in image)
  - Interfaces to Petal: Petal Strut & Petal interface fittings (invar)

*(M55J with cyanate ester resin, per shared NG materials assumption)

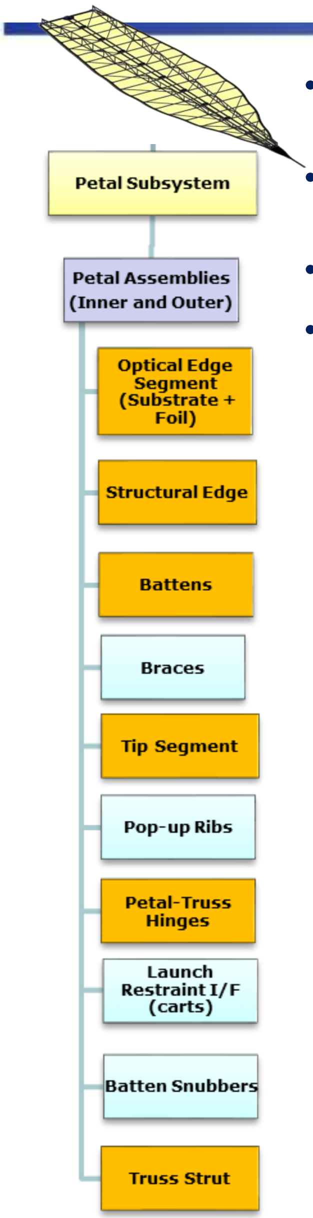
** Critical components boxed in red below, orange on left

*** Materials are medium fidelity (space-flight compatible)





RFA #5: Test Article Description
Prototype 5-2: Petal



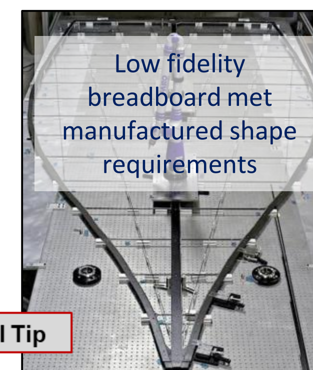
- **Tests**: Verify petal shape as manufactured, shape stability after deploy & thermal cycles & storage (creep), Validate petal model of shape vs. temperature
- **Critical components for tests**: battens*, optical edge, tip, interfaces to truss, & secondarily: braces, spines, interfaces to PLUS (batten length defines petal width*)
- **Scale**: Half (0.65m wide at base, 4m long), medium fidelity (or better)
- **Components**:
  - Materials are medium fidelity (space-flight compatible)
  - Battens are uniaxial pultruded CFRP** COTS material, incl. batten snubbers
  - Optical Edge & Tip Assy's are COTS MBF23 Ni/Fe alloy amorphous metal (MBF23) sandwiched with quasi-iso CFRP* plate, room temp epoxy (reviewed TRL-5 activity developing that product, not discussed in detail here)
  - Interfaces to truss: petal strut assy & petal to truss hinge assemblies (invar hinges)
  - Optical shield including close-outs
  - Spines including carts launch restraints, braces, rib assy

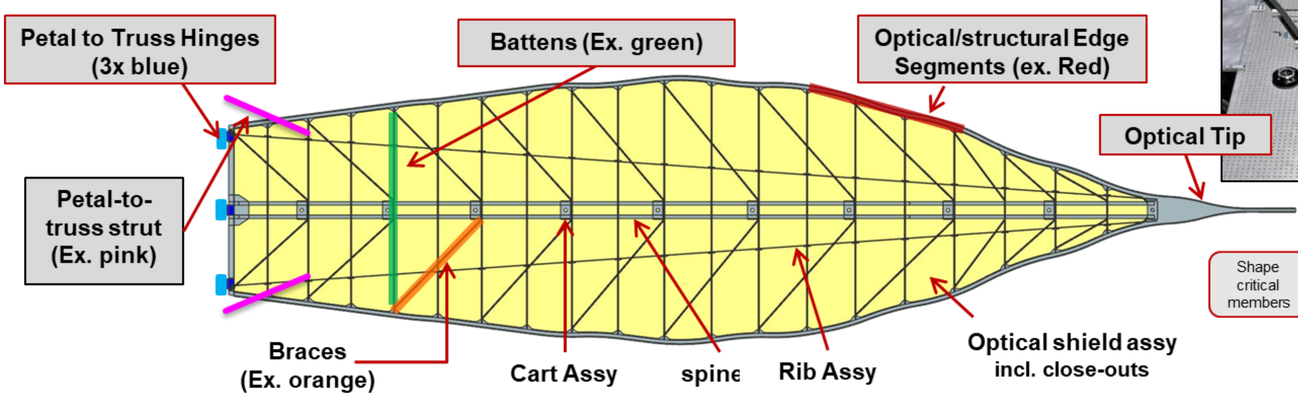
* M55J with cyanate ester resin, per shared NG materials assumption

** T700S data is measured data from JPL SWOT flight program

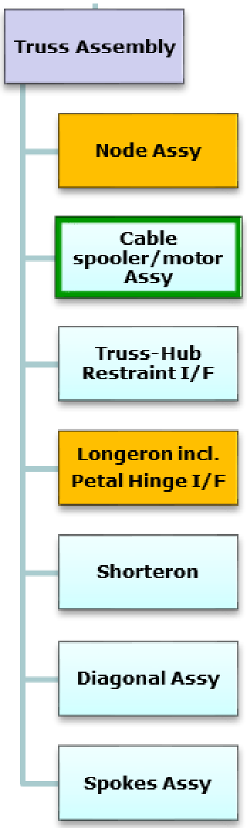
*** Critical components boxed in red below, orange on left

**** Materials are medium fidelity (space-flight compatible)





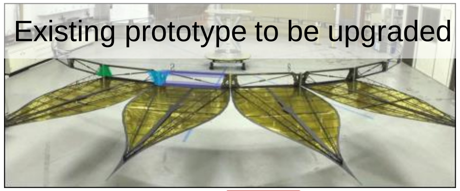
RFA #5: Test Article Description
Prototype P5-3: Inner Disk Subsystem

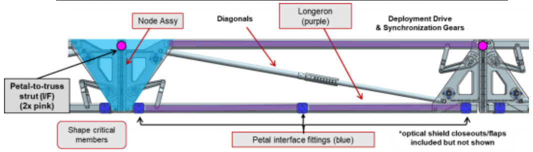


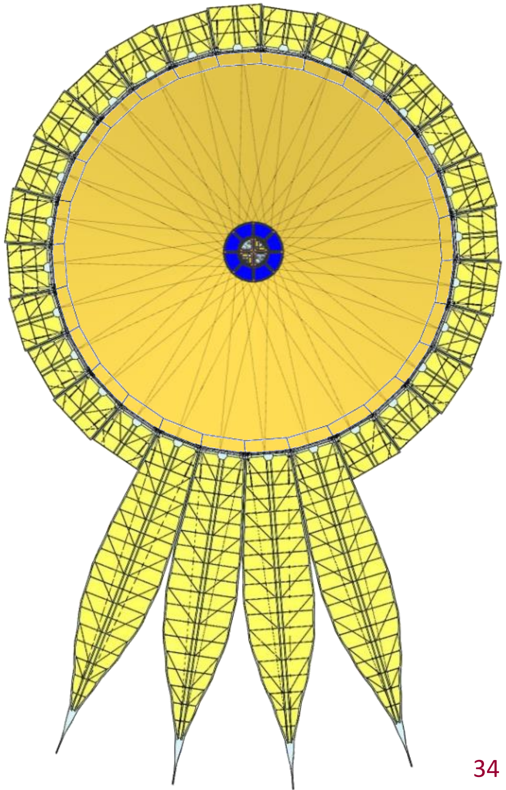
- **Tests**: Verify repeatable truss deployment tolerances with OS installed, Validate Disk model of deployment kinematics, Validate Disk model of shape vs. spoke load, Verify OS opacity at truss-bay & petal I/F's
- **Critical components for tests**: All truss components, spokes, optical shield, petals (bases + full simulators)
- **Scale**: Full (10m diameter) @ medium fidelity ***<u>(upgrade of existing prototype)</u>***
- **Components**:
  - Longerons/shorterons are quasi-iso CFRP* tubes with petal I/F fittings
  - Nodes are quasi-iso CFRP* plates w/ Al center beam
  - Diagonals are quasi-iso CFRP* tubes (Al end fittings)
  - CFRP spoke assemblies (metal fittings)
  - Central hub assy (Al)
  - Synchronization gear assemblies (Ultem)
  - Optical shield close-outs/flaps to petal simulators (black kapton XC)
  - Redundant drive spool/motor assemblies (Al/Steel)
  - Interfaces to Petal: Petal Strut & Petal interface fittings (Al)
    - Full petal simulations on 4 locations (all features, TBD matl.)
    - Petal bases suff. for petal-truss I/F on all bays (all features, TBD matl.)

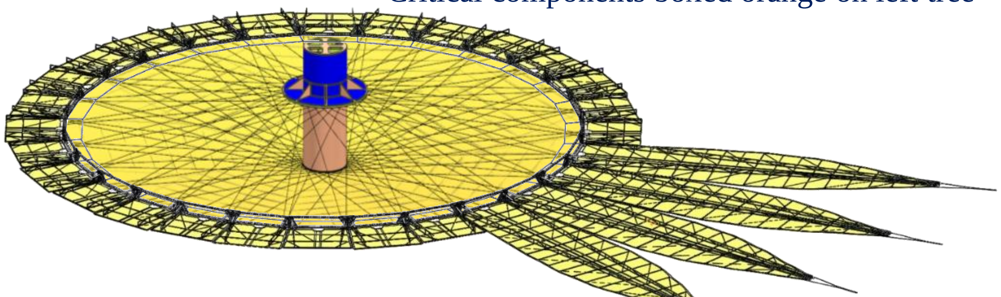
*(M55J with cyanate ester resin, per shared NG materials assumption)

** Critical components boxed orange on left tree

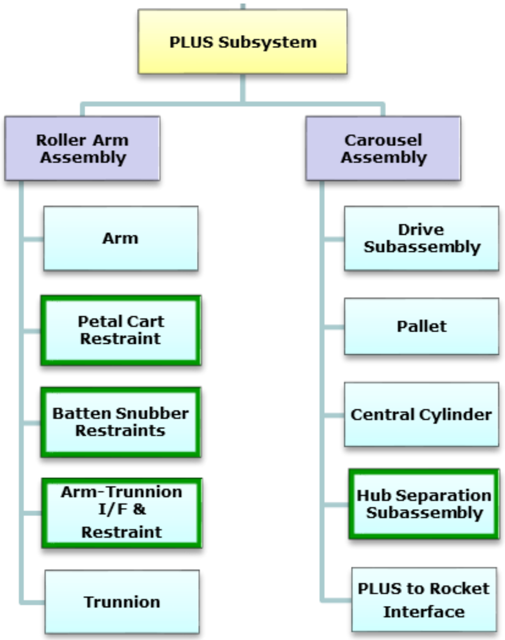




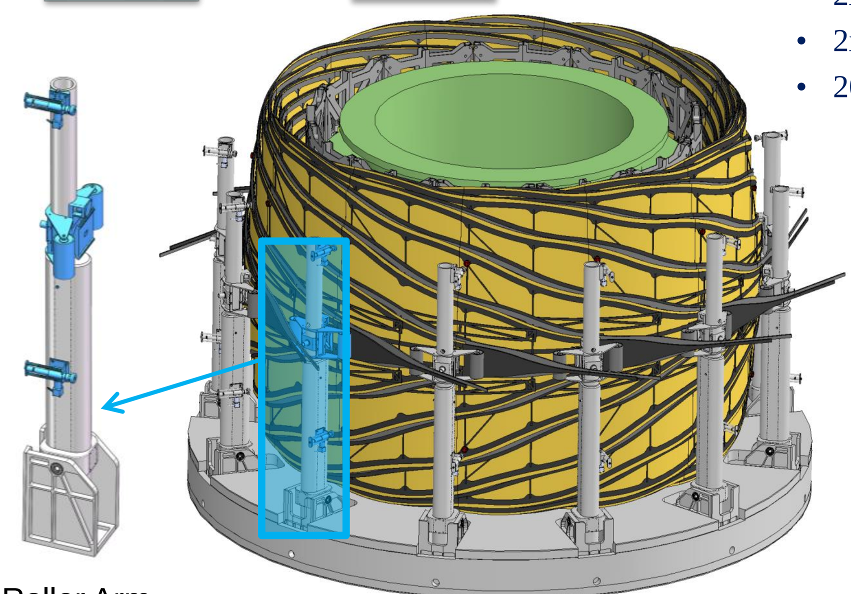




RFA #5: Test Article Description
Prototype P5-4: Deployment Control System



- **Tests**: verifying no edge contact during unfurl and validate the analytical model of deployment kinematics
- **Critical components for tests**: Rollers incl. tip management, 2x 6m composite petals, 2x I/F petals and remaining simulators
  - Key components to enable medium fidelity petal unfurling
- **Scale**: Full 2.25m core + 6m petals (shortened length, full width/thickness ***(significant upgrade/overhaul of existing prototype)***
- **Components**:
  - Roller arm assemblies (all new, medium fidelity): rollers and tip management, batten snubber and cart restraints
  - Carousel motorized drive system (existing)
  - Petals: all petals incl. all features, e.g. rib assy's & optical shields, snubbers, carts
    - 2x 6m composite petals (new)
    - 2x interface petals (boundary condition for CFRP petals) (new)
    - 20 simulator petals (flexural stiffness of petal, existing in starshade lab)


Roller Arm


Existing prototype to be upgraded

Technology Summary

- **A detailed plan for TRL-4/5 is presented that focuses on validating the error budget**
- **Wrapping up the trade study now gives us just enough time to achieve a high level of technology readiness before the initial Decadal Survey input, scheduled for Nov. 2019**
- **An aggressive schedule achieves TRL-5 for all starshade subsystems prior to this date**
  - **We have reasonably high confidence to retire the major performance risk issues (petal shape and position)**