SIP ATA Contract Overview: Modeling Starshade Petal and Truss Deployment

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Starshade Science Industry Partnership Forum

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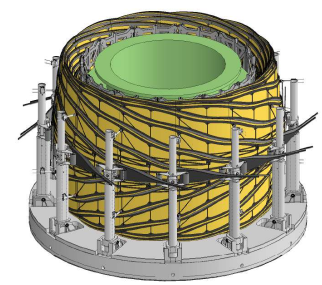
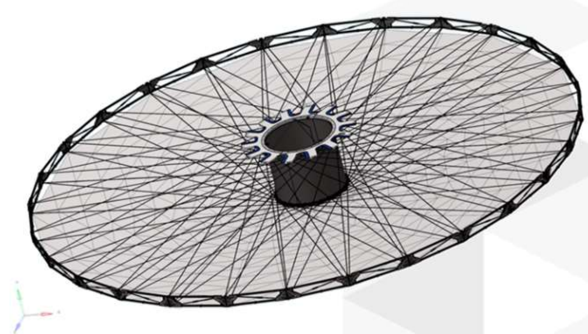
ATA's Starshade Model

- ATA's Task
  - Evaluate structural analysis methodologies and software and assess the benefits of the approaches using petal and truss deployment as case studies
- Task 1: Deployment Simulation of the PLUS
  - <u>Objective:</u> Provide a simulation workflow that makes this problem tractable for simulation of the full set of petals in a quasi-static manner



- Task 2: Deployment Simulation of the IDS
  - <u>Objective:</u> Build Abaqus and RAPID deployment models of the hub shield and truss



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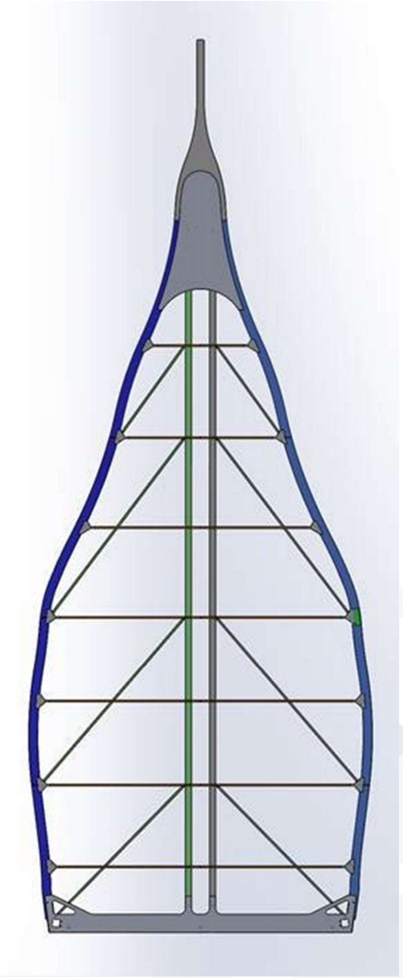
Task 1: PLUS Deployment Simulations

- <u>Objective:</u> Start with single petal
  - Petal prototype (4m)
  - Model the stowing of a single petal (no rib)
  - Model bend and twist tests
    - Correlate to test data from Tendeg
    - *Testing delayed due to COVID19*
- Expand to multiple petal deployment
  - Used same 4m petal, inner and outer
    - Included the carts and snubbers

  1. Single petal with a rib, stow and deploy
  2. Pair of petals with ribs, stow and deploy



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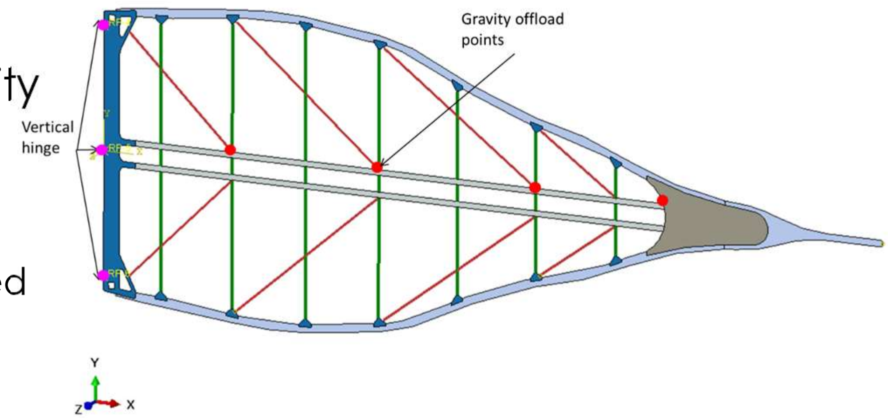
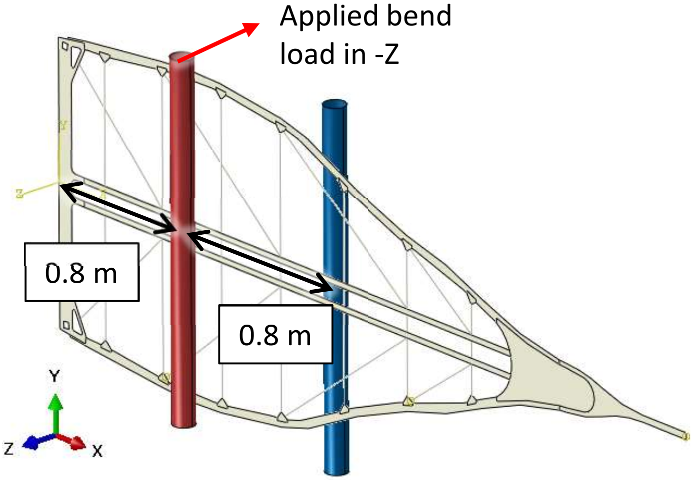
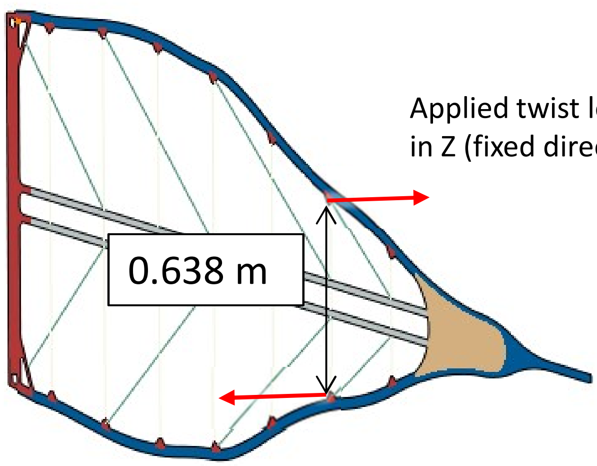
Single Petal Tests

- Modeled prototype 4m petal: quasi-isotropic carbon-carbon composite with isotropic carbon fiber braces/battens
- Created single petal furl to study capability of large displacement
- Bend test
  - Simulate three-point-bend test
  - Load applied using two rigid mandrels spaced 0.8 meters apart
- Twist test
  - Examine the sensitivity of the petal to out-of-plane loads

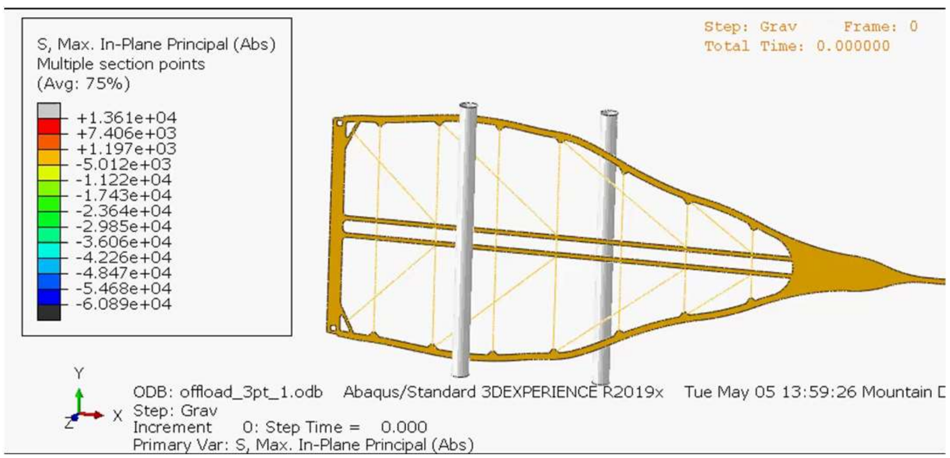




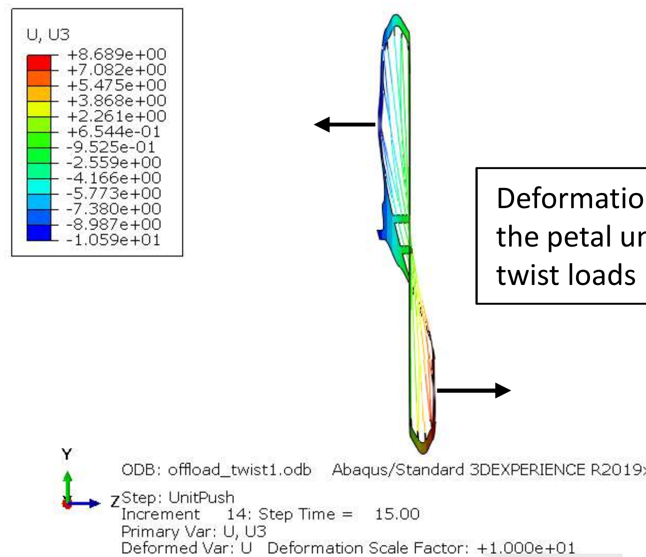


Single Petal Test Model Results

- Bend Test
  - Petal bends 100 mm deflection with a force of 20 N
- Twist Test
  - The petal becomes unstable when the twist load exceeds 2.5 N
  - Testing in this config appears to be very sensitive to out-of-plane loads, will need to carefully arrange gravity offload



Deformation of the petal under bend loads



Deformation of the petal under twist loads

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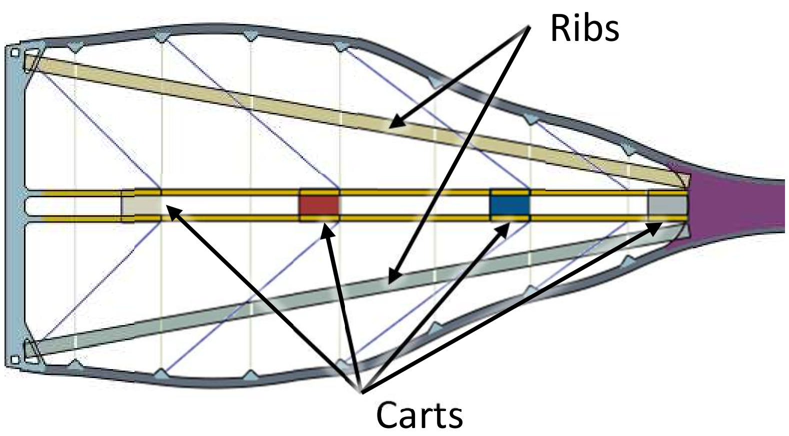
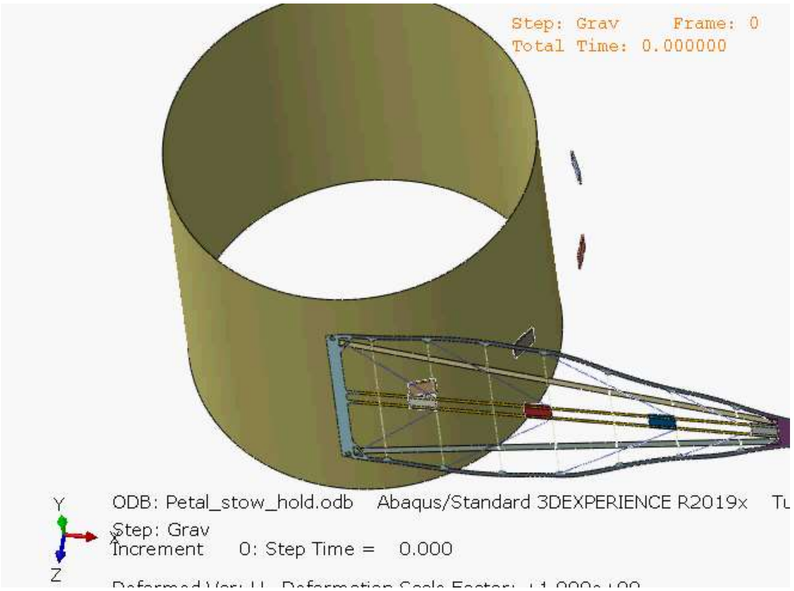
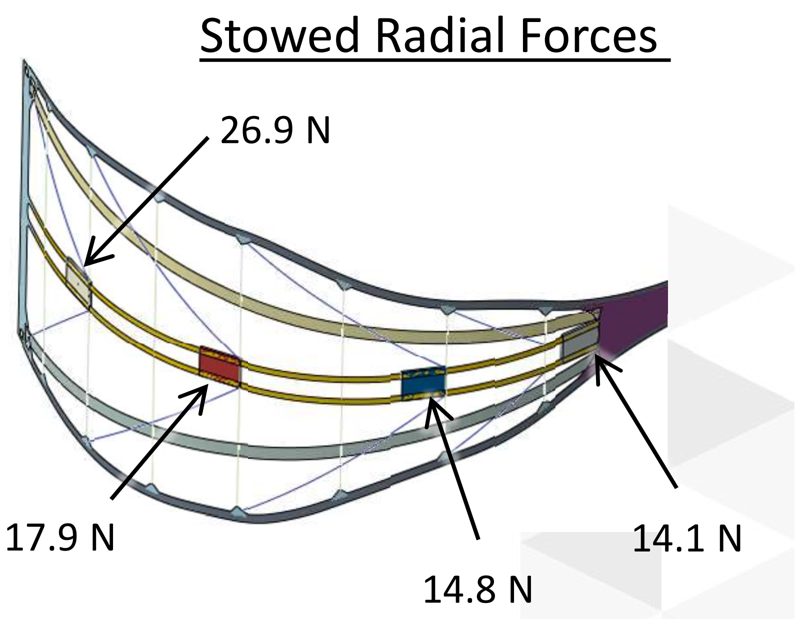
Single Petal Furl & Deploy

- Added ribs and carts to 4-meter petal, hinged to hub at three locations
- Held petal end in 2DOF, rotated hub to wrap petal against carts
- Held petal carts, released petal end, recorded force on each cart







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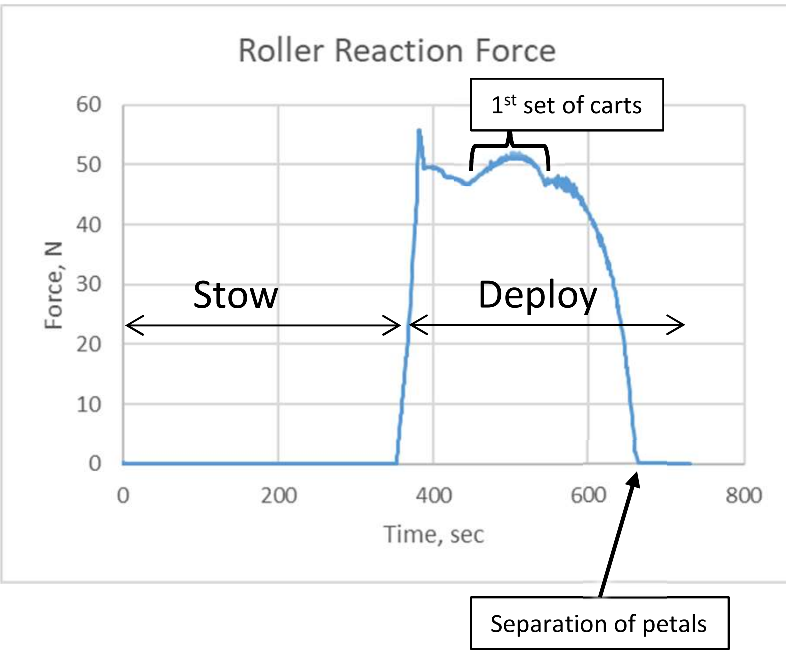
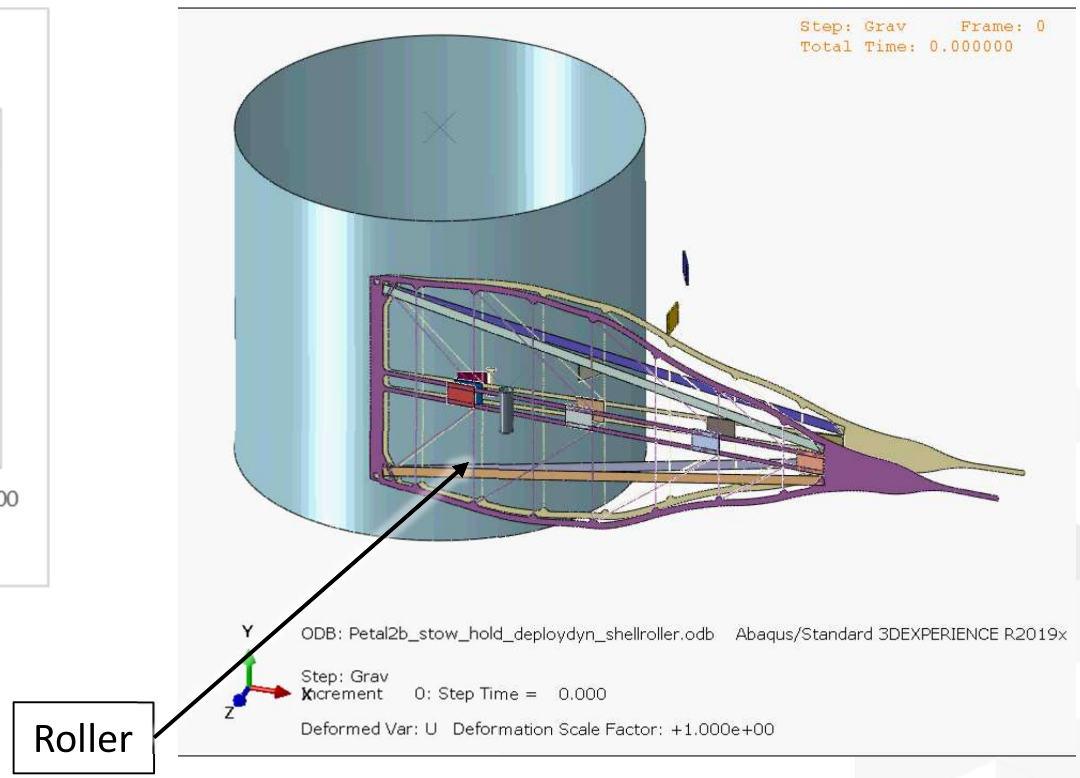
Double Petal Furl & Deploy

- Added 2nd 4m petal to model, simulated wrapping and unwrapping
- Contact allowed at petal/petal, cart/cart, and petal/roller
  - Carts and outer petal to roller are in contact as designed
  - Analysis showed that petal tips are in contact at end of stowing, but no other areas of the petals come into contact during the deployment
- Monitored contact between outer petal and the roller during deployment





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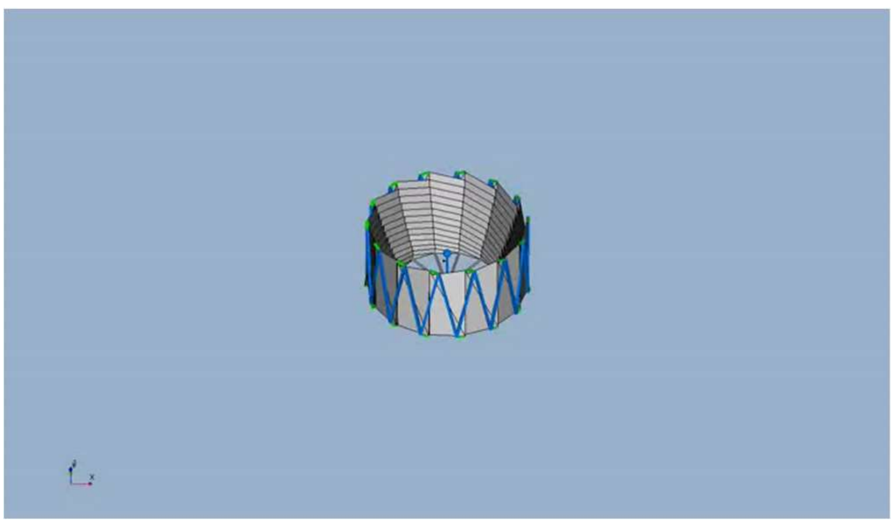
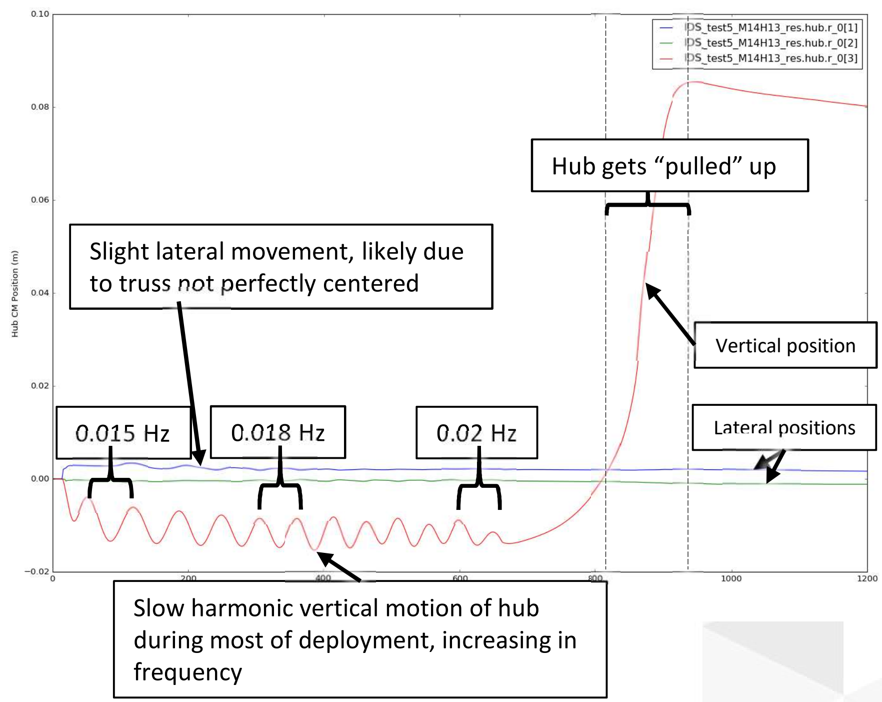
Task 2 - IDS Deployment, RAPID

- Starshade IDS model created and analyzed using ATA's RAPID toolset
  - RAPID is an ATA developed toolset for nonlinear simulation (transient deployment, random vibration, modal analysis)
- Helps with global understanding of IDS deployment and hub movement in 0g
- As different Starshade designs are considered, the modeling tools and process used by RAPID for this effort could be used to quickly evaluate alternative designs without requiring extensive design detail
  - Well-suited for conceptual design analysis and defining loads requirements





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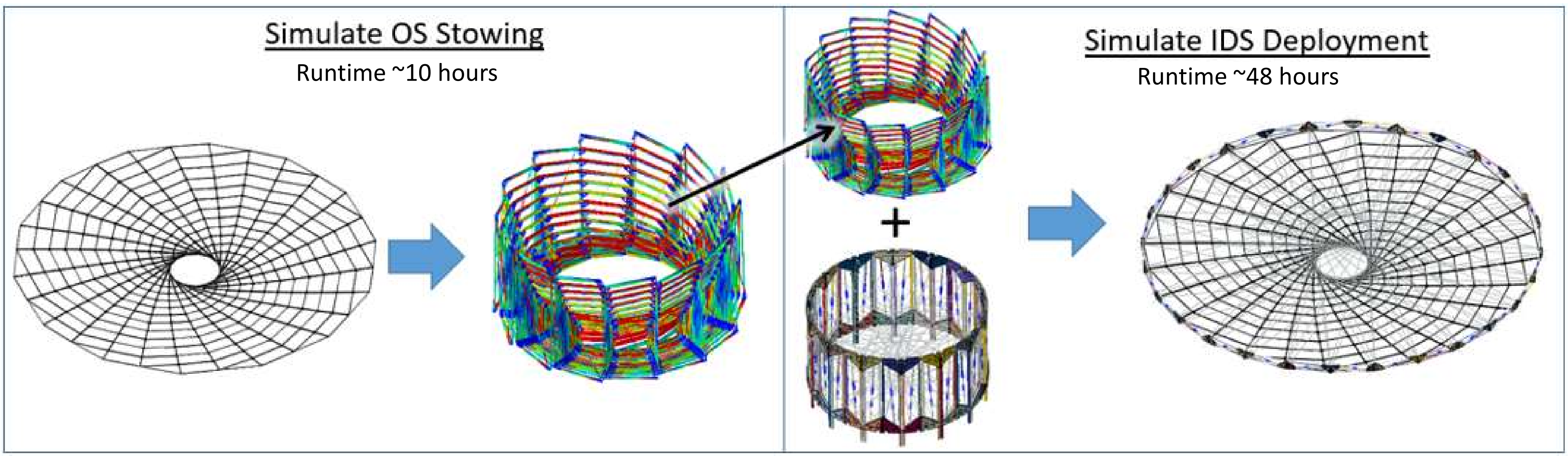
Task 2 - IDS Deployment, Abaqus

- Objective: Develop analysis approach capable of high-fidelity simulation of deployment
  - Need credible analysis process to simulate on-orbit deployments for flight program
  - Will rely heavily on analysis to ensure requirements are met for on-orbit deployments since full testing in 1 g is impractical
- Analysis Approach Metrics:
  - Demonstrate comparable behavior to deployment test
  - Enable efficient simulations compatible with Monte Carlo analysis
  - Must suitably model complex contact and general component flexibility
- Selected Abaqus implicit solver

IDS Deployment Simulation Overview

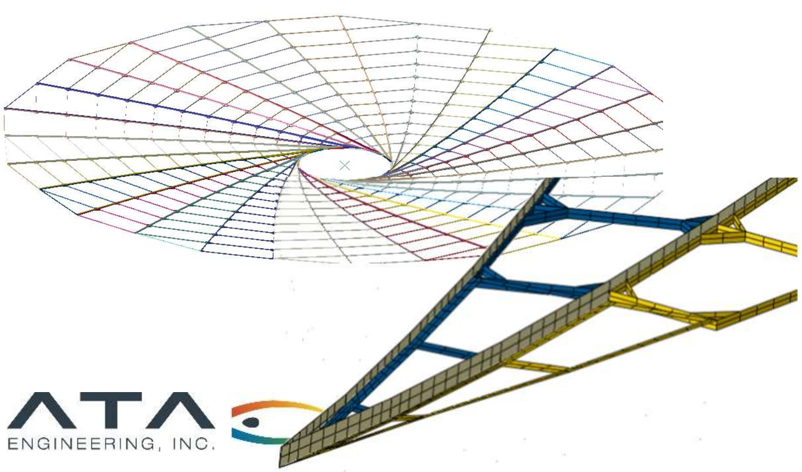
- Created high-fidelity model of truss and optical shield (OS)
  - Simulated stowing of OS to compute prestress and strain energy
  - Coupled stowed shield with high-fidelity model of truss
    - Truss includes all relevant mechanisms and deployment constraints

Analysis Process Overview

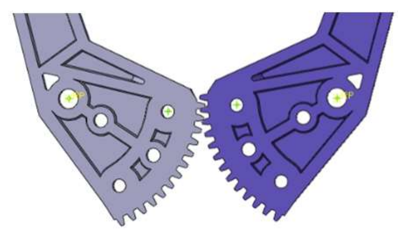


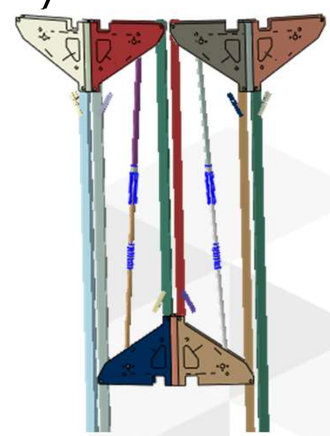
OS and Truss Details

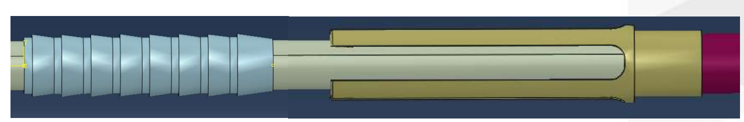
- Optical Shield
  - Explicitly modeled each rib and frame with flexible elements
  - Discrete frame/rib connection points like prototype hardware
  - Contact at nearly all interfaces



- Truss
  - Longerons are flexible, rigidized nodes for simplicity
  - Simplified kinematic models of synchronizers, linear ratchets, deployment cable
  - Truss deployment by retracting deployment cable







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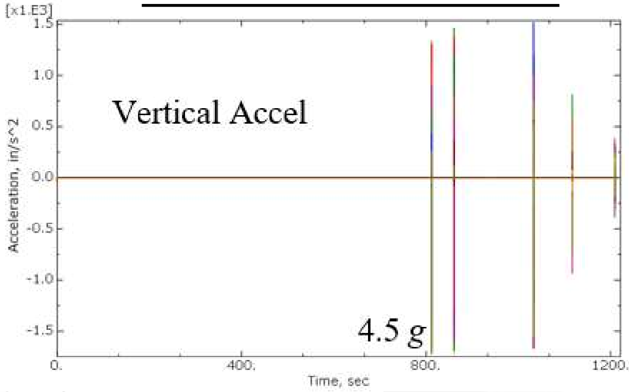
IDS Deployment Animation

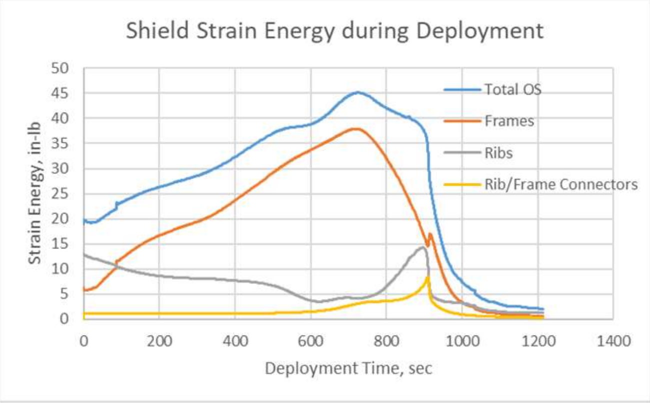
- Deployment simulation has similar qualitative behavior to prototype test results
  - Initially quasi-static deployment and shield unfurling with small "pops" as frames twist/untwist
  - Sequential bays snapping into place in final stages of deployment

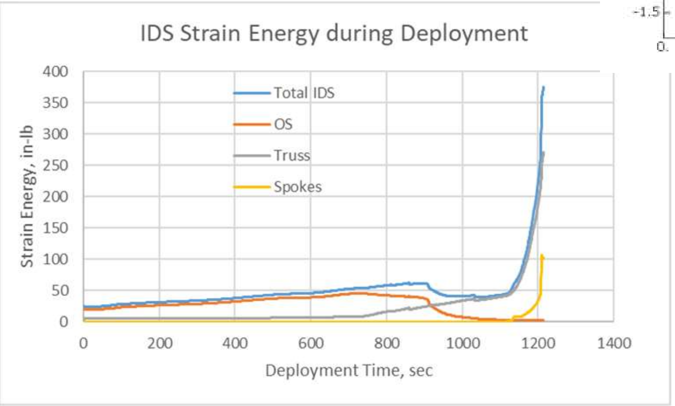
Select IDS Deployment Results

- Model matches available quantitative results from prototype testing
  - Final cable tension = 132 lb from FEM vs. 120-130 lb expected
  - Final spoke tension is 10 or 16 lb from FEM vs. 16 lb expected
- Large node accelerations (4.5 g) during bay snapping may induce large petal response
- Strain energy distribution by component is useful means to drive design updates

Truss Node Acceleration







ATA Starshade Conclusions

- Have demonstrated an analysis method for both low-fidelity (RAPID) and high-fidelity (Abaqus) simulations of Starshade deployment suitable for flight program
  - Both the petal and IDS models show promise that it is not only possible to simulate these deployment models but that they can be solved in a manageable amount of time and give accurate results
  - There does not appear to be any inherent obstacles to using Abaqus to model the PLUS stowing and deployment or the IDS deployment
- RAPID: Low-fidelity
  - The IDS model helps with global understanding of IDS deployment and hub movement in 0g with significantly faster model development and simulation time
- Abaqus: High-fidelity
  - Runtimes are long but not prohibitive
  - Incorporated all major components and kinematics
  - Identified several shortcomings, most related to immaturity of design and lack of understanding of hardware behavior
    - Only software capability shortcomings to date are relatively minor
    - Continued development can mitigate most other shortcomings

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Possible Future Work

- RAPID
  - As different Starshade designs are considered, the modeling tools and process used by RAPID for this effort could be used to evaluate alternative designs
  - Another capability of RAPID is to use component mode synthesis models of various Starshade components (e.g., the petals) to increase the fidelity of the model and investigate the petals' (or other components') dynamic effect on the deployment results
- Abaqus
  - Continue developing the analysis method to alleviate some of the shortcomings with the current analysis process and improve the runtime
  - Model multiple petal sets, perhaps even the entire PLUS, with interactions between all petals
  - Attach the petals to a trusslike structure
  - Modify the current IDS model to represent a flightlike deployment

Backup

Abaqus IDS Modeling Shortcomings

- Minor software capability shortcomings:
  - Cable/pulley friction constitutive model is simplified
  - Prefer beam elements for OS but must use shells, drives up runtime
  - Method of incorporating stowed shield + truss causes slight perturbation to shield stored strain energy
- Runtimes are longer than desired (48 hours)
- Some shortcomings of current model are related to immaturity of design
  - Unsure how to appropriately model softgoods on low-stiffness shield
  - Uncertainty in behavior of OS frame/rib connection method
    - Prototype connection scheme not flight-like and not well characterized