SIP#2 ATA Update

Prepared for:

Starshade Science Industry Partnership Forum

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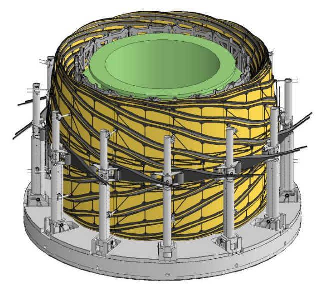
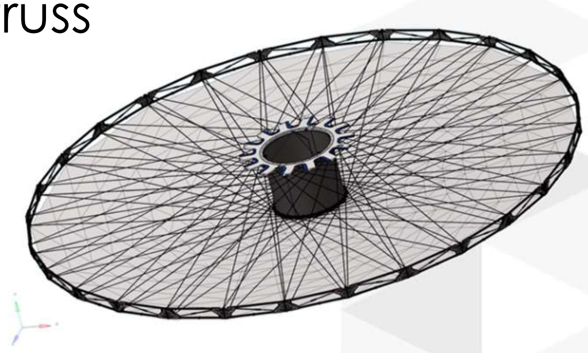
ATA's Starshade Model Updates

- 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
  - Objective: Provide a simulation workflow that makes this problem tractable for simulation of the full set of petals in a quasi-static manner
  - Status: Created Abaqus model of single petal



- Task 2: Deployment Simulation of the IDS
  - Objective: Build an Abaqus and RAPID deployment model of the hub shield and truss to simulate on-orbit deployment
  - Status:
    - RAPID: Model complete
    - Abaqus: Significant progress made



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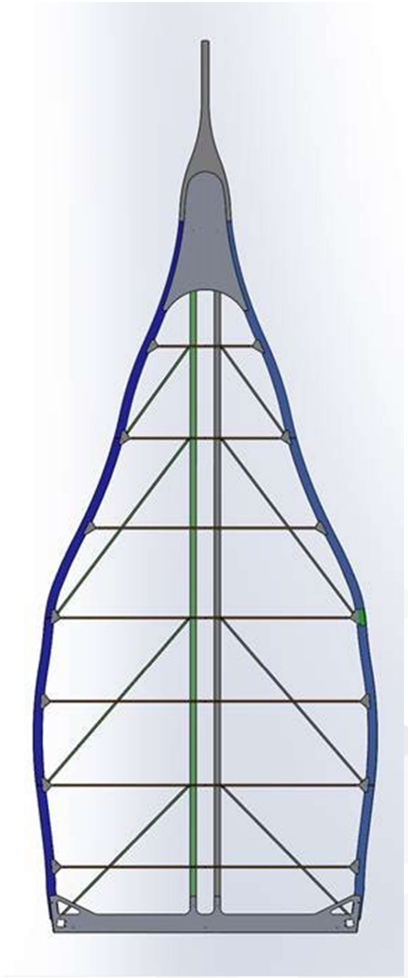
Task 1: PLUS Deployment Simulations

- <u>Objective:</u> Start with single petal
  - Petal prototype (4m)
  - Model the stowing and deployment of a single petal (no rib)
    - Correlate to test data from Tendeg
- Expand to multiple petal deployment
  - 6m petal, inner and outer. Validate with test data. Do the same with a pair of petals.
    - This would include 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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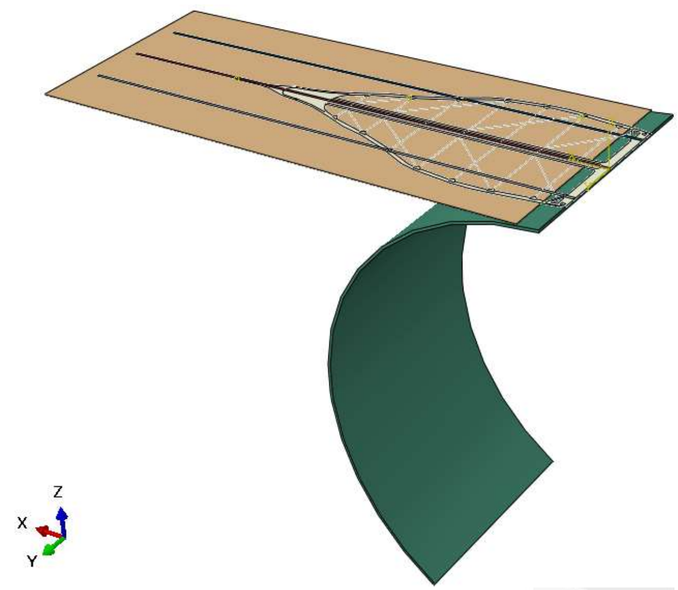
Single Petal Wrap Model Overview

- Model created in Abaqus to simulate single petal furl test done at Tendeg
- Model includes
  - Petal
  - Straps
  - Hub
  - Table
- Goals
  - Simulate test
  - Include gravity
  - Include tension on straps to hold down petal
  - Slow rotation of hub



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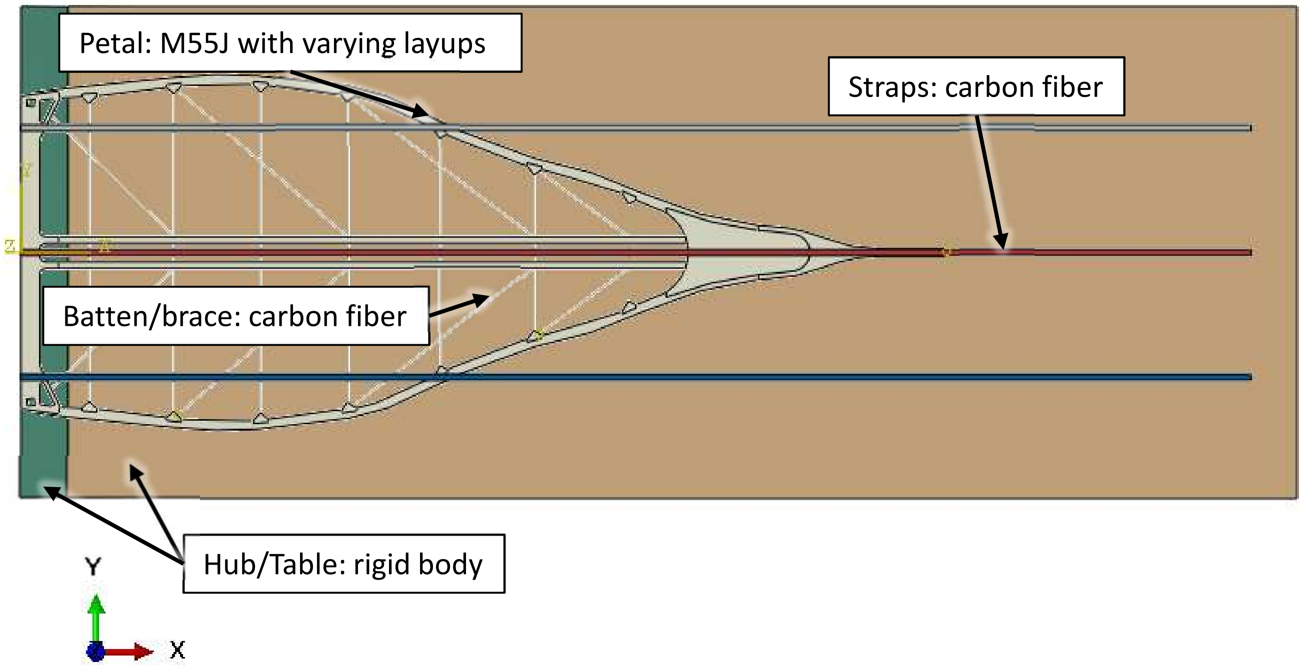
Single Petal Model

- Materials
  - Petal: quasi-isotropic carbon-carbon composite
  - Batten/brace: isotropic carbon fiber rod
- Element types
  - Petal: 2D elements
  - Batten/brace: 1D beam elements
  - Straps: 2D elements
  - Hub/Table: rigid body
- Boundary Conditions
  - Fix edge of petal and straps to hub
- Loading
  - Gravity in -Z
  - Straps
    - Outboard: 5lb each in +X
    - Center: 20lb in +X
  - Rotate hub at speed of 0.3deg/sec over 5min
- Model uses general contact



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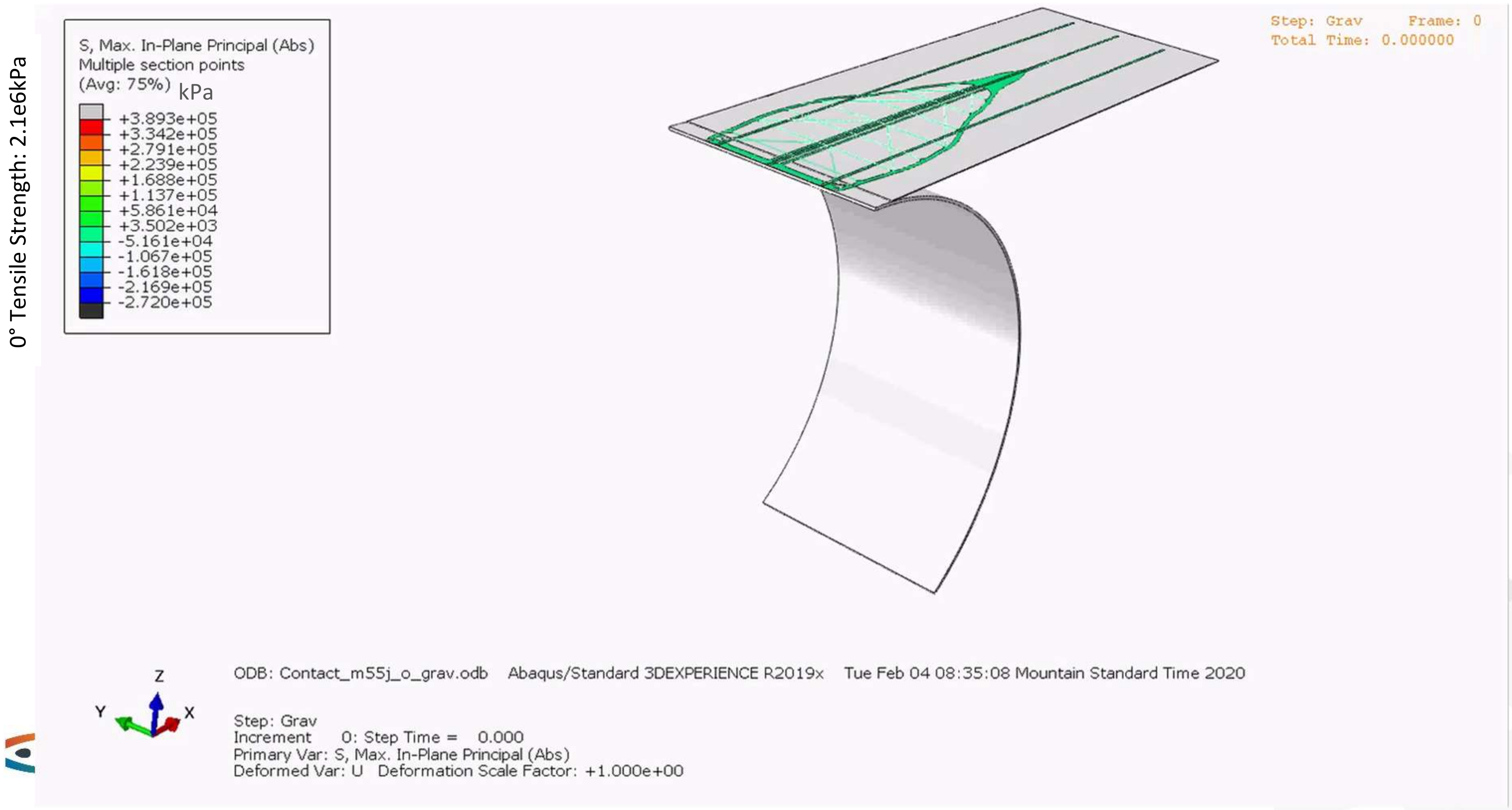
Current Solution: Wrap Test

- Wrap Test includes
  - Gravity settling step
  - Pull on straps
  - Rotate hub, taking straps and petal with it



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Single Petal Model Future Work

- Abaqus model of single petal wrap appears realistic for this configuration
- Future Work
  - Incorporate more realistic material properties
    - Capture the flexural properties of the petal in a model
  - A series bend tests to be performed
    - Get petal bay stiffness and capture applied force
    - Correlate Abaqus model to these values
  - Model Tendeg test with the petal on edge

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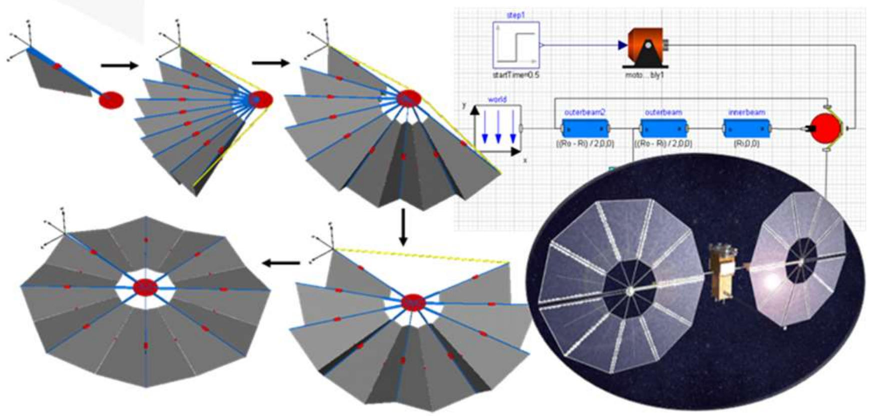
- Starshade IDS model created and analyzed using ATA's RAPID toolset



- What is RAPID?
  - Efficient simulation for design exploration
- Technology Explanation
  - RAPID is an ATA developed toolset for nonlinear simulation (transient deployment, random vibration, modal analysis)
  - Modular models simplify the modeling process
  - Akin to multi-body analysis tools such as ADAMS, but far more powerful, extensible, and efficient
- Benefits
  - Uses a library of parameterized structural and mechanism modeling elements typical for deployable systems
  - FEA superelement import and connection capability with CAD and FE mesh visualization
  - A fabric modeling capability to predict the response of tensioned fabric structures

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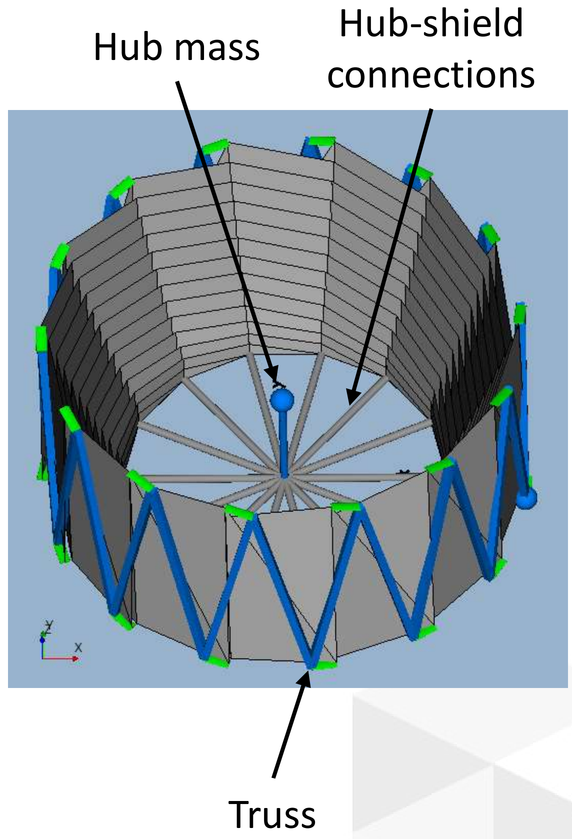
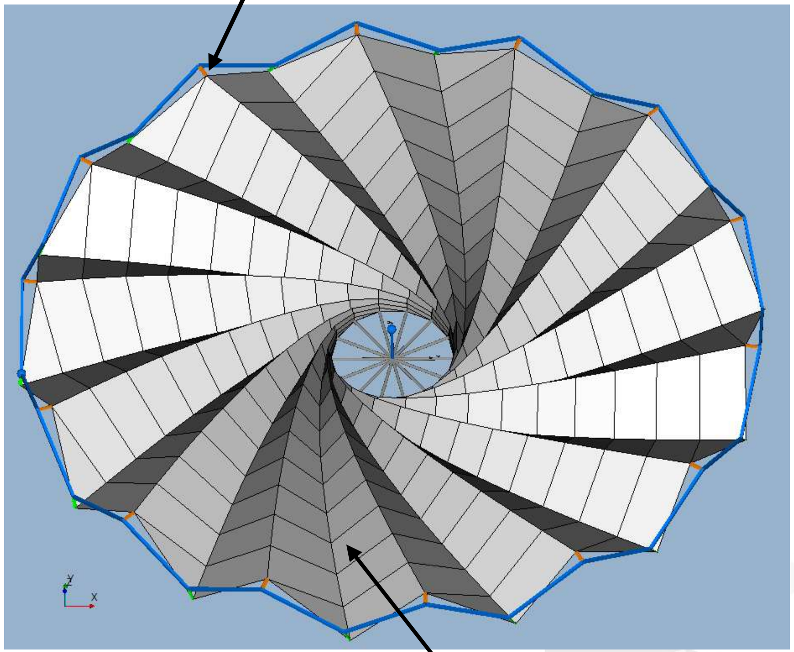
IDS Deployment Analysis Using RAPID

- Hub is represented by a single rigid body with correct inertia properties
  - Connected to shield with rigid members
- Truss model is a rigid approximation of the design
  - Sizing and motion modeled to be near nominal
    - Primarily using the truss to drive deployment of system, so specific deployment details are not necessary
  - Total mass is correct, rotational inertia terms are approximated



IDS Deployment Analysis Using RAPID (Cont.)

- Shield is modeled with each panel as a flexible module
  - Correct shield origami dimensions used (provided by Manan)
  - Correct total mass used (assumed to vary evenly)
  - Currently using roughly estimated stiffness properties for shield and shield-to-truss connections
  - Shield-to-truss connections modeled as strings (can go slack) between truss nodes and shield corners
- Spokes between truss and hub not modeled



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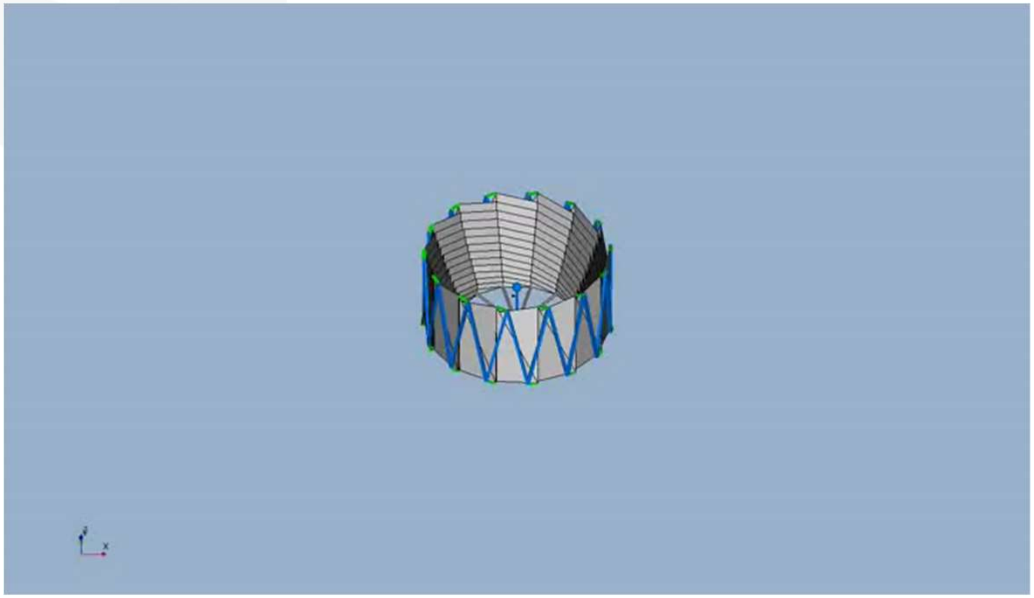
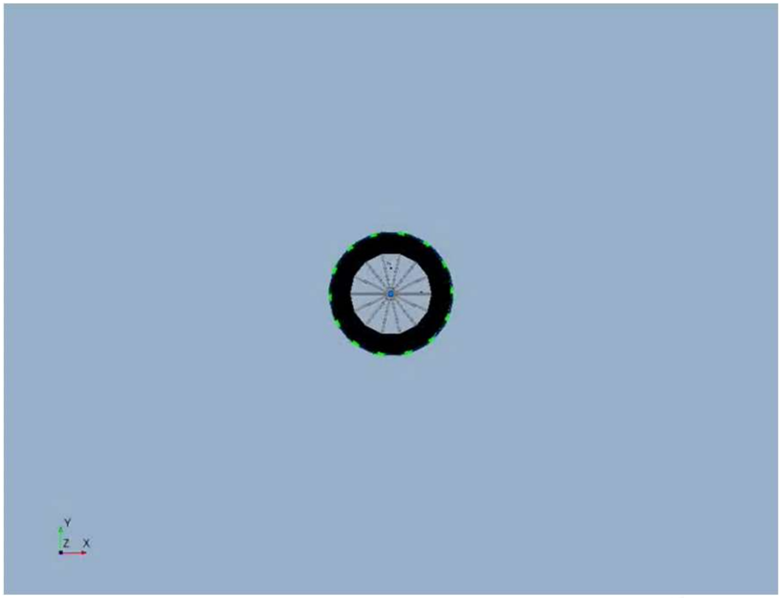
IDS Deployment Analysis Using RAPID (Cont.)

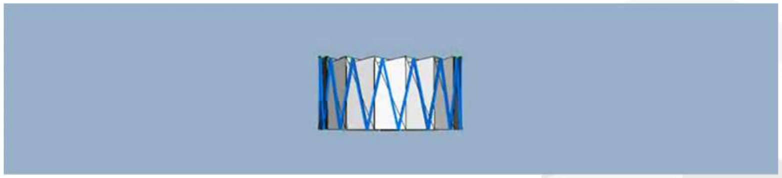
- Deployment simulation
  - Deploys via enforced relative angular motion of rigid truss members at each node
- Assumptions:
  - All bodies (hub, shield, truss) are in a free-free state, unmoving at the start of deployment
    - Currently ignoring the effects of initial rotation rate
  - Truss hinge angles deploy at a constant rate
    - This likely doesn't match actual deployment, but more data needed to get closer
    - Unlikely to affect general conclusions
  - ~15 minute deployment time
    - A little faster than test, but should not affect the conclusions

IDS Deployment Animations

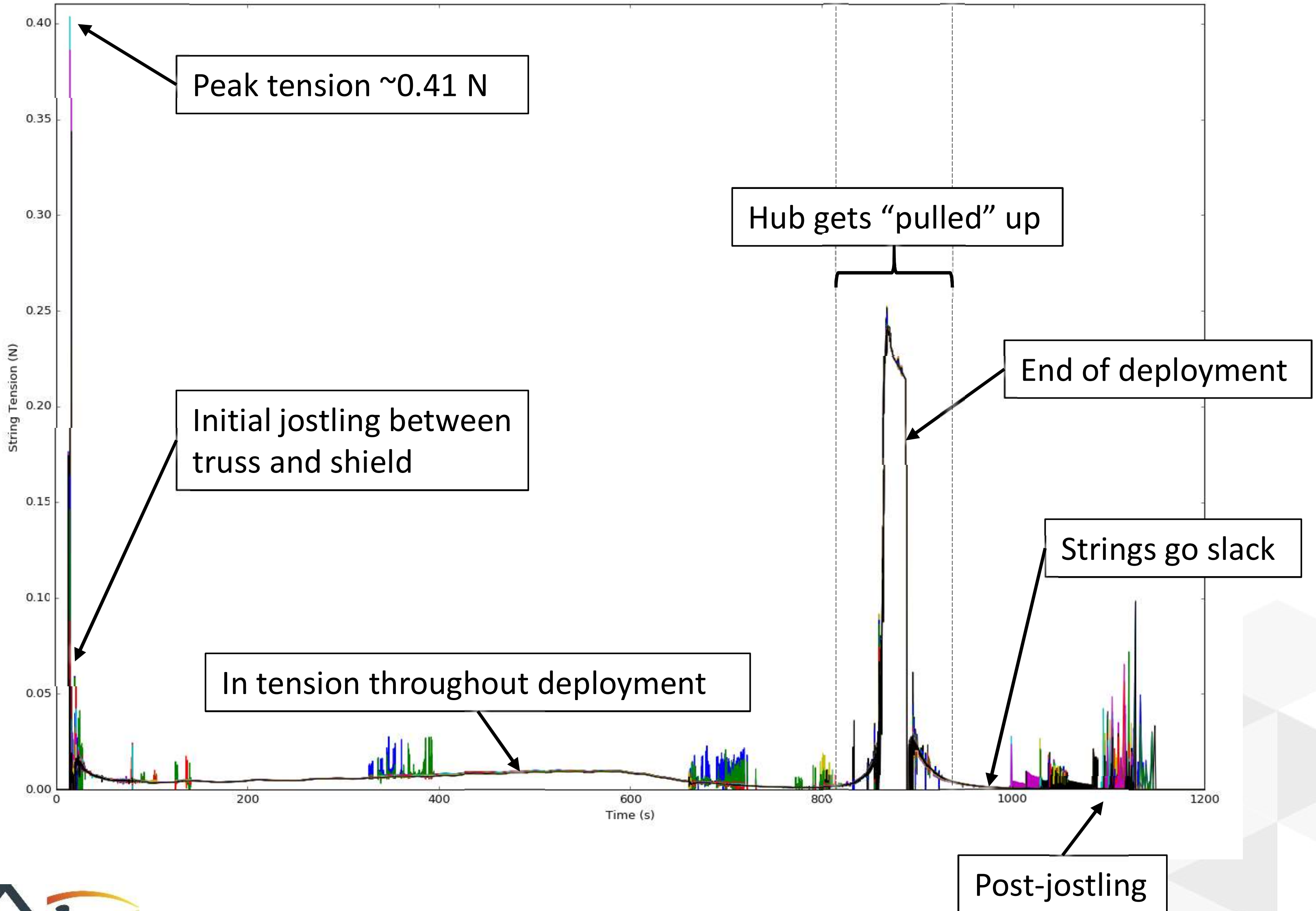


~10x animation speed

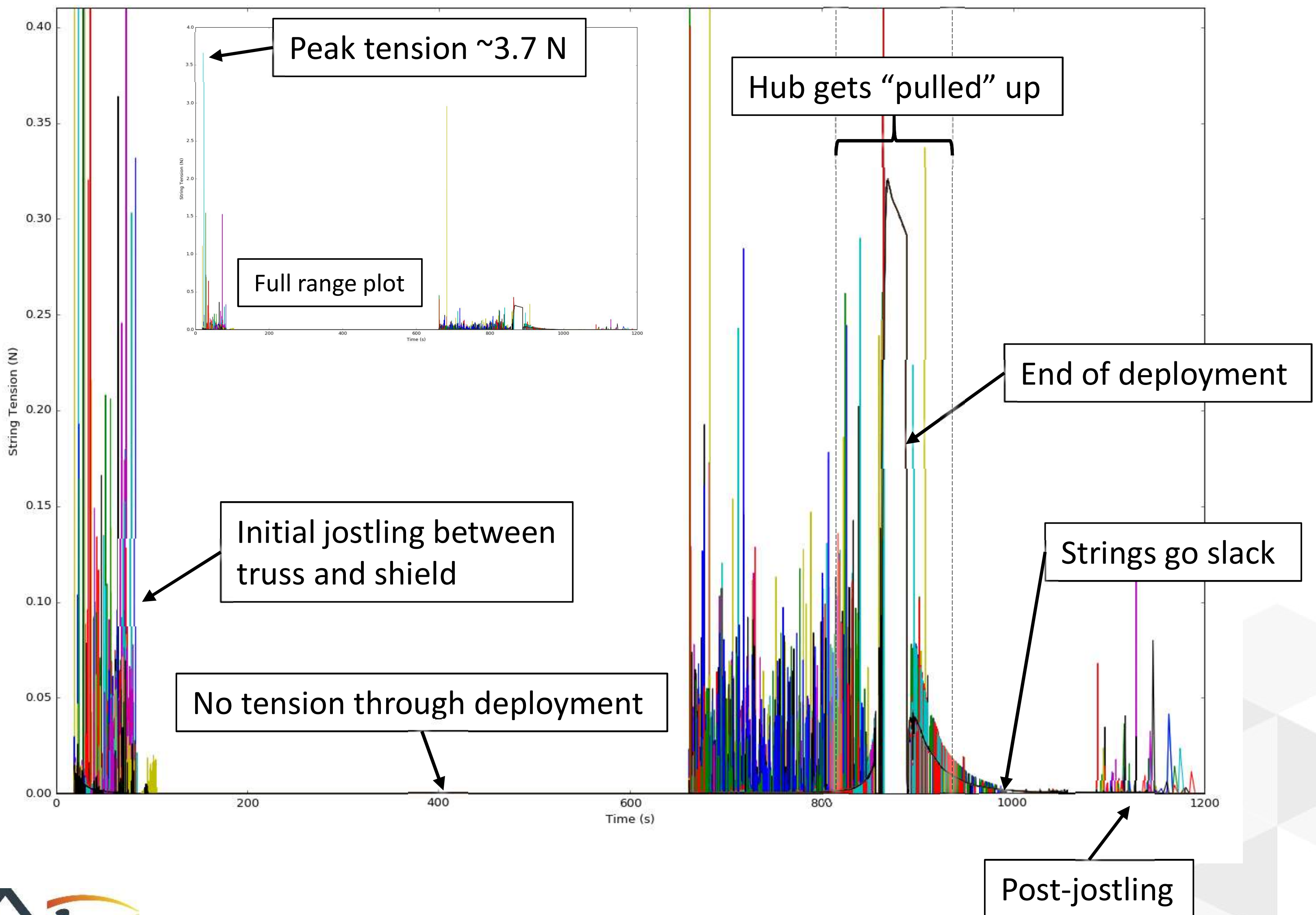




IDS Truss-Shield Connection (Top Strings Only)



IDS Truss-Shield Connection (Bottom Strings Only)



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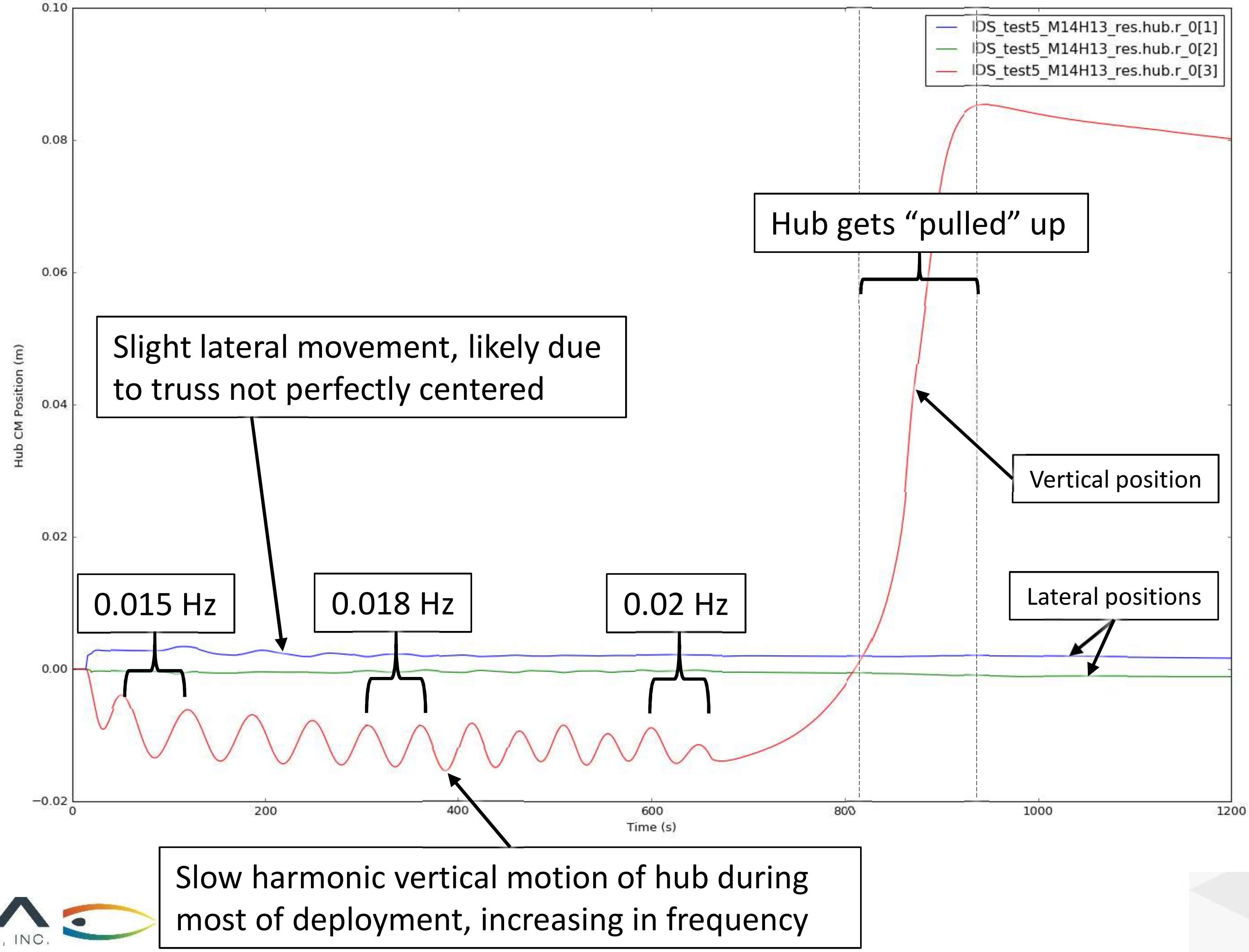
IDS Hub Position



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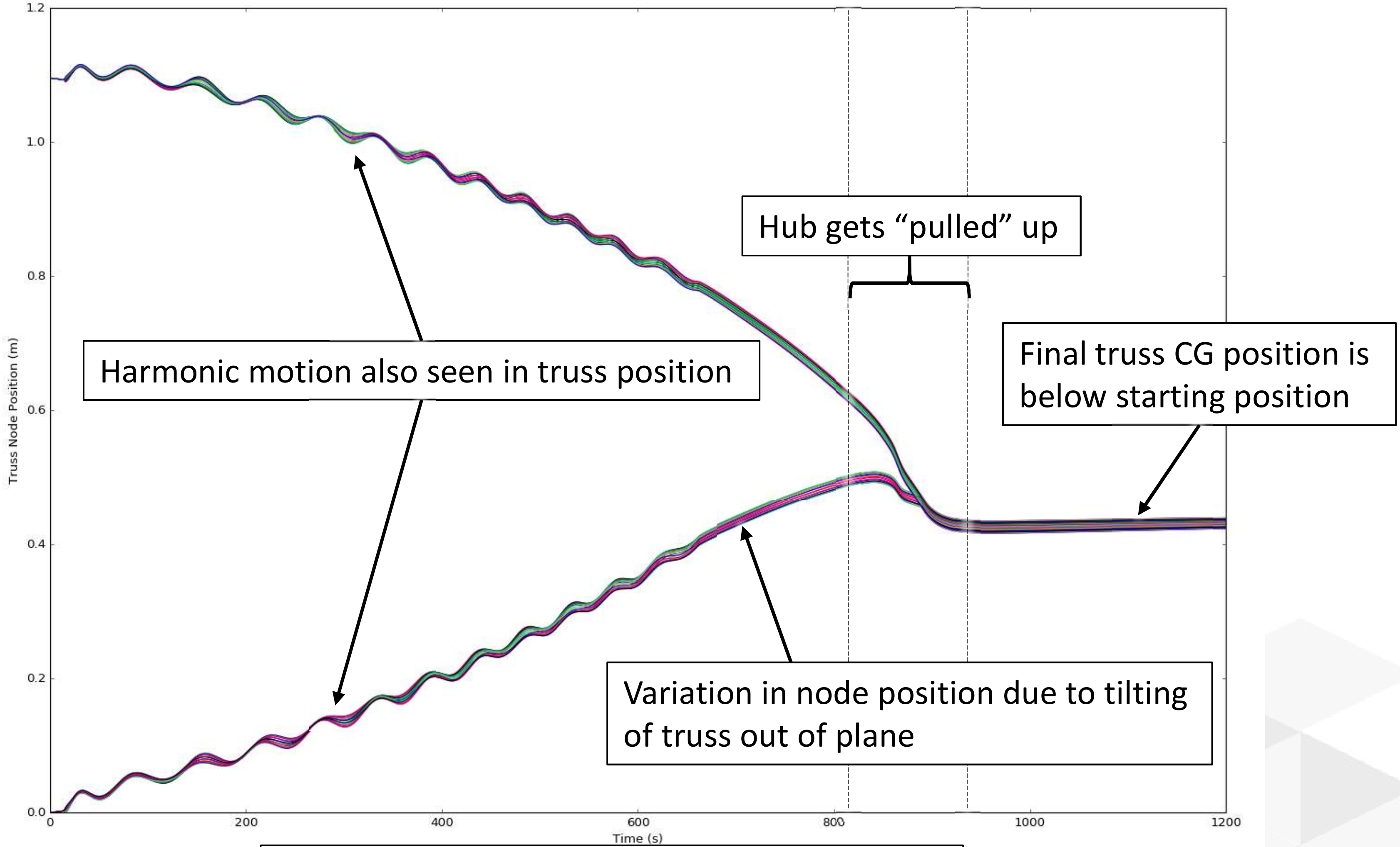
Truss Node Vertical Positions



Seems like shield is acting as a spring between hub and truss masses. Frequency change due to changes in shield geometric stiffness.

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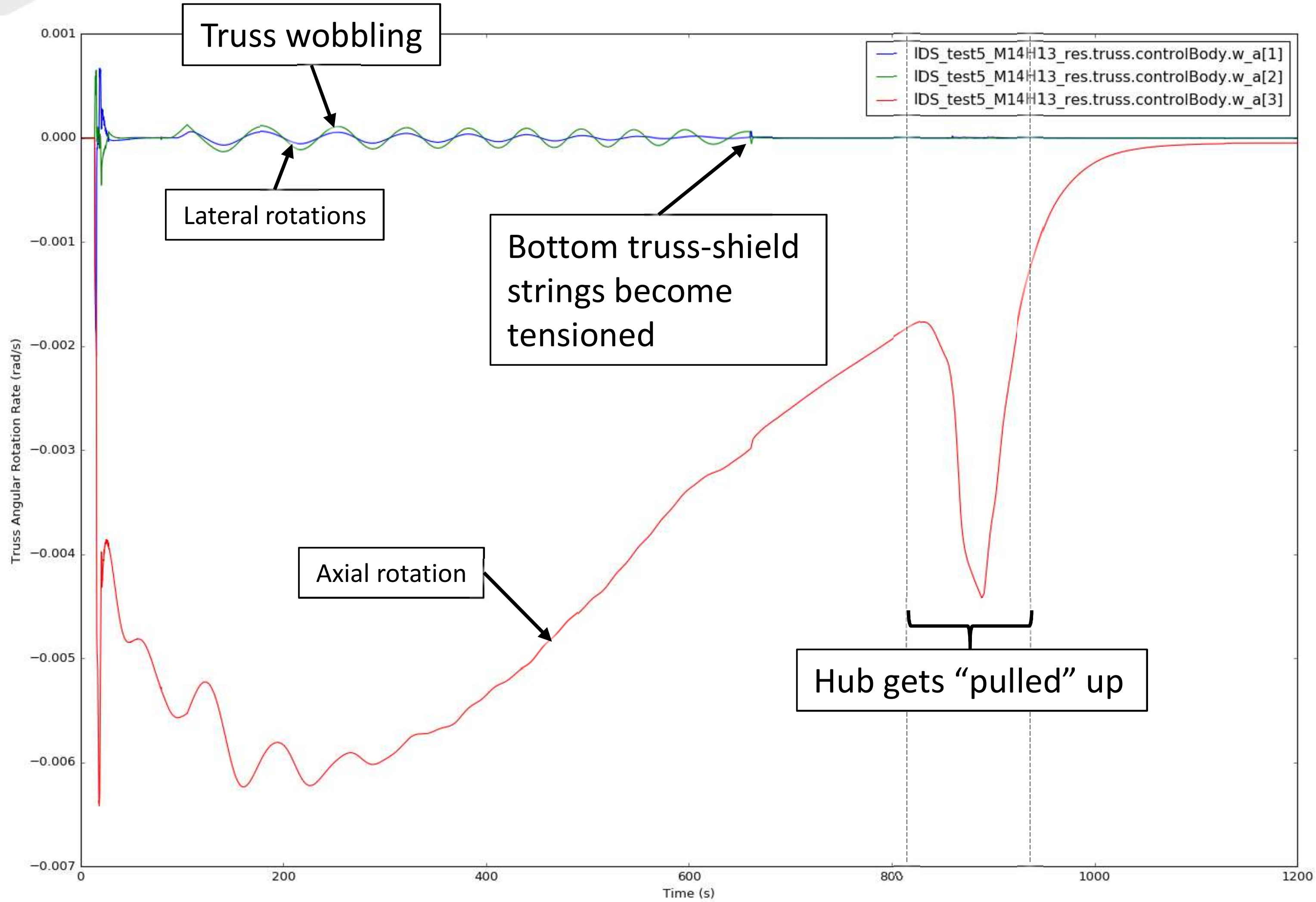
Truss Angular Rotation Rate



IDS Deployment Conclusions

- Deployment characteristics of interest:
  - Some initial jostling between shield and truss until all strings are tensioned
  - Top shield-truss connection strings consistently in tension, bottom strings slack until ~2/3 deployment
  - Hub gets pulled up near end of deployment due to change in shield/truss CG

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
    - Explore kinematic behaviors, loads to help drive design
    - Will rely heavily on analysis to ensure flight requirements are met for on-orbit deployments
- Analysis Approach Metrics:
  - Enable efficient simulations compatible with Monte Carlos, prefer to avoid Abq/Explicit
  - Demonstrate comparable behavior as deployment test

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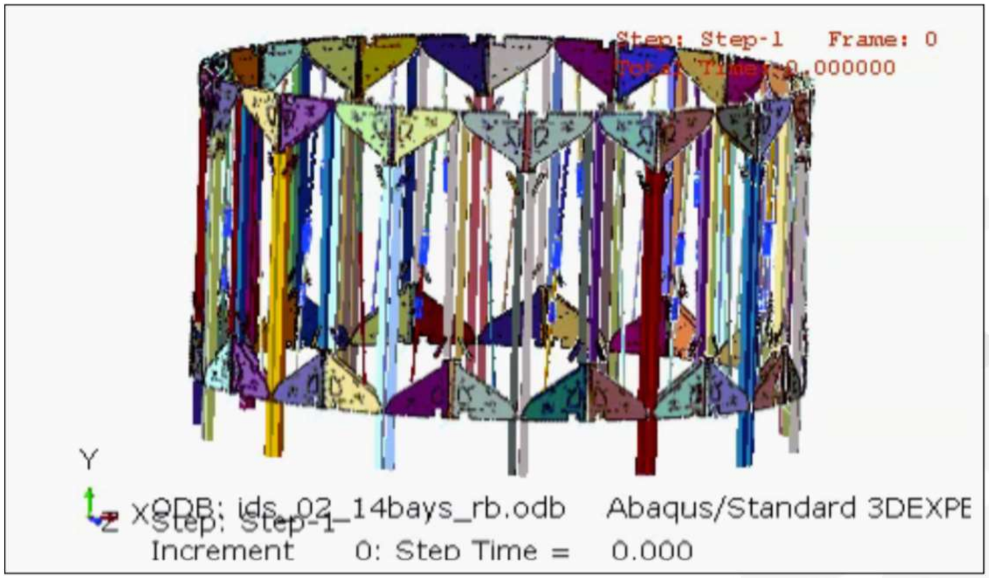
Truss Deployment in Abaqus

- Truss Deployment
  - Developed working model of truss deployment
    - Includes simplified synchronizer, linear ratchet that represents kinematic behavior
    - Includes cable and pulleys, deploy by retracting cable
  - Currently including several simplifying assumptions
    - Rigidized nodes for run efficiency
    - Neglected pulley friction, hinge/pin friction, pin free-play
    - Solution time ~ 30 min



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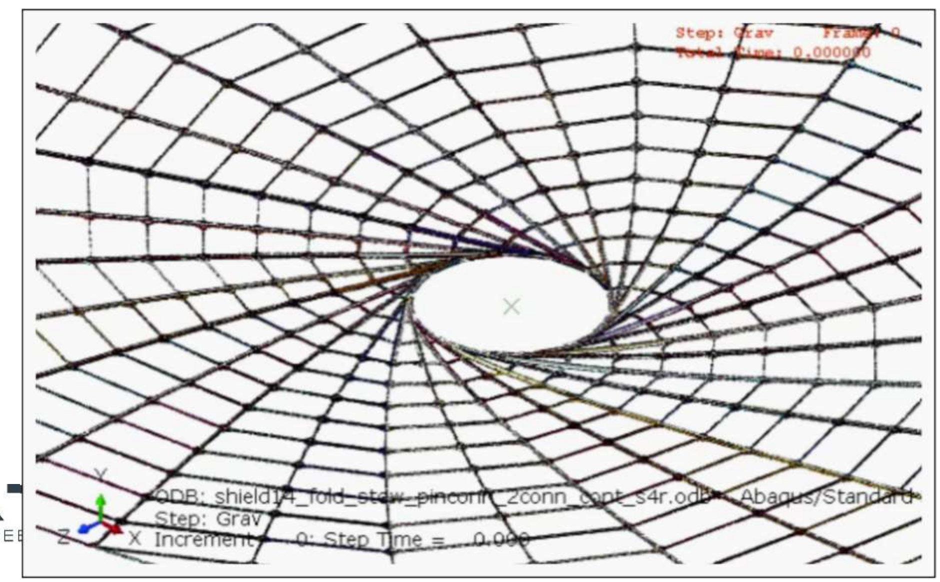
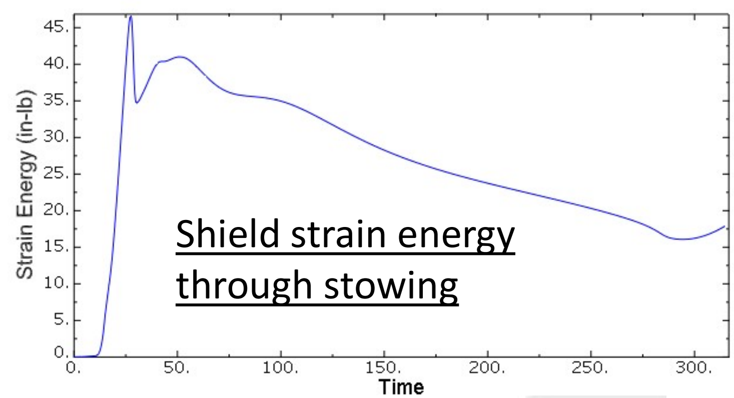
Shield Modeling in Abaqus

- Simulated stowing/deploying process
  - Flexible beams, shells, springs, contact at relevant faces
  - Stowed strain energy must be computed, will affect deployment behavior
  - Deliberately decoupling stowing sim from deployment, prestressed shield to be coupled with truss for deployment
- Stowing simulation ~ 10 hours
- Model is stable in stowed config
- Deployment simulation runs slowly, currently investigating





IDS Abaqus Model Future Work

- Next steps
  - Improve deployment run efficiency
  - Incorporate stowed shield (with strain energy) with stowed truss, simulate entire deployment
  - Refine simplifying assumptions
  - If time, correlate to deployment test data

ATA Starshade Conclusions and Next Steps

- RAPID
  - The IDS model helps with global understanding of IDS deployment and hub movement in 0g
- Abaqus
  - Both the single petal and IDS model show promise that it is possible to create these deployment models in Abaqus and they will give reasonable results

- Both Abaqus models will continue refinement
  - Single petal: test configuration and comparison to test data
  - IDS model: incorporate stowed shield to truss model and simulate deployment

- Contracted through August 30th
  - Deliver final report on these methodologies and their capability and potential to model Starshade deployment