



Modeling and Analysis of Structural Dynamics for a One-Tenth Scale Model NGST Sunshield

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Overview



- Introduction
- Membrane Modeling
- Finite Element Model
- Analysis of Sunshield Dynamics
 - Modal Analysis
 - Impulse Test Simulation
- Comparison of Analysis and Experiment
- Closing Remarks



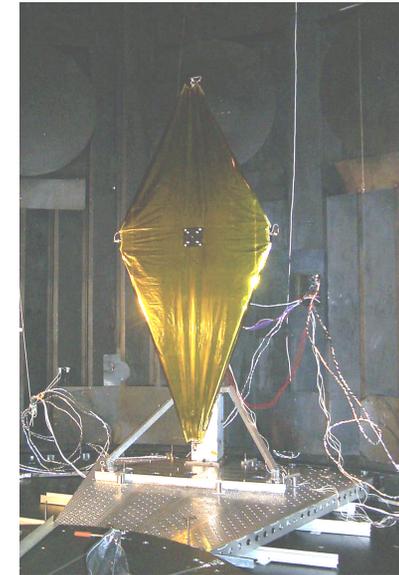
Introduction



- The Next Generation Space Telescope (NGST) will require a lightweight, deployable sunshield to provide passive cooling for optical systems.
- NGST 'yardstick' concept sunshield characteristics:
 - Central support structure
 - Deployable support booms
 - Pretensioned, thin-film membranes
- Technology development needs:
 - Modeling and Analysis
 - High confidence, test validated structural models to predict potential disturbances to observatory due to sunshield dynamics
 - Assessment of membrane wrinkling effects
 - Testing
 - Scale model testing methodologies
 - Advanced, non-contact instrumentation
- Analysis and ground testing of a one-tenth scale model of the NGST 'yardstick' concept sunshield is being carried out to develop and validate capabilities to predict and verify sunshield structural characteristics.



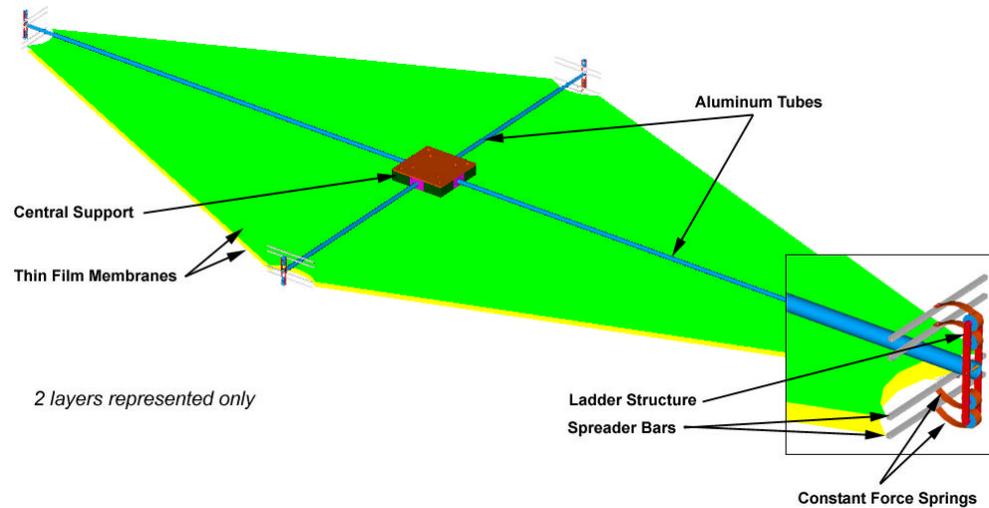
NGST 'Yardstick' Concept



**One-Tenth Scale Model
Sunshield Ground Test Article**



One-Tenth Scale Model NGST Sunshield



Test Article Characteristics:

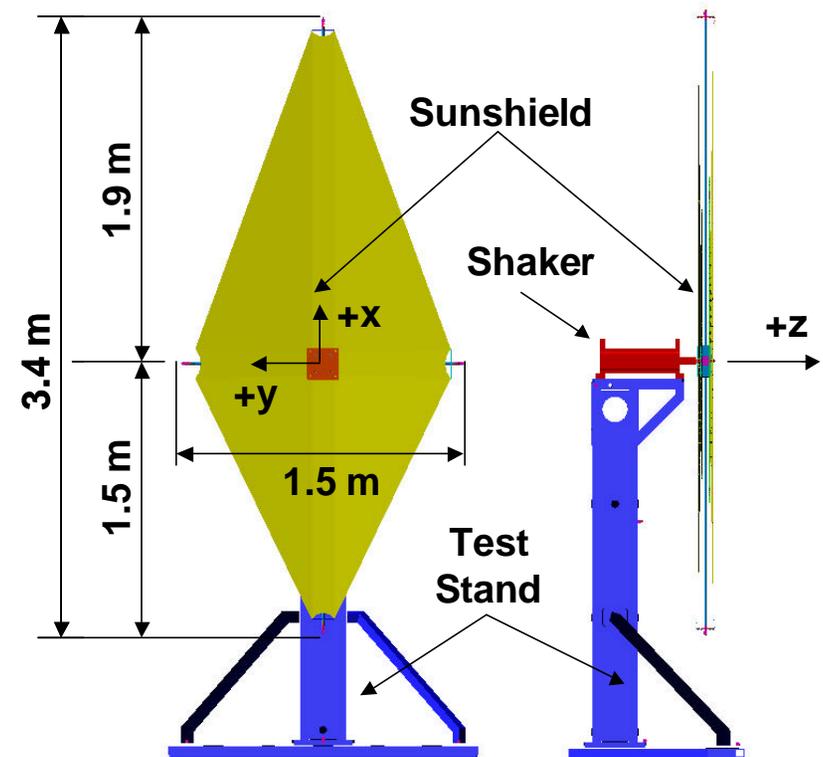
Overall size: 3.4 m x 1.52 m

Membranes: 4 layers of 13 micron (0.5 mil) Kapton

Support booms: Aluminum tubes

Membrane preload: 1.425 N (0.32 lbs) per corner

Schematic of Test Setup with Sunshield in Short Side Down Orientation





Sunshield Dynamic Tests



- Dynamic testing of the one-tenth scale model NGST sunshield in a vacuum environment was completed in August 2000 at NASA GSFC.
- Test objectives:
 - Determine the dynamic characteristics of the sunshield (frequencies, mode shapes, and damping) in order to provide data for model validation studies.
 - Verify the planned on-orbit test methodology for the Inflatable Sunshield In Space (ISIS) flight experiment.
 - Characterize the linearity of the system.
 - Characterize the influence of gravity.
- Types of tests:
 - Random excitation tests
 - Impulse excitation tests
 - Sine dwell tests
- Instrumentation:
 - Accelerometers
 - Force transducers
 - Laser vibrometer



Membrane Modeling



- A challenging aspect of sunshield analysis is modeling the behavior of partially wrinkled thin-film membranes.
- Finite element modeling techniques for membranes:
 - Standard elements formulations:
 - Ignore membrane wrinkling
 - Numerical problems may occur
 - Cable network method:
 - Approximate/engineering approach for modeling wrinkled membranes
 - Based on the established principal that load transfer in wrinkled regions takes place along wrinkle lines
 - Advanced techniques:
 - Use of tension field theory and special material models to account for wrinkling effects on membrane stress distributions.
 - 'Fine-scale' analysis of wrinkling enables the prediction both stress distribution and wrinkling details (wrinkle amplitude, wavelength, etc).
- The one-tenth scale model NGST sunshield finite element model utilized in the current study was developed using the cable network modeling approach.

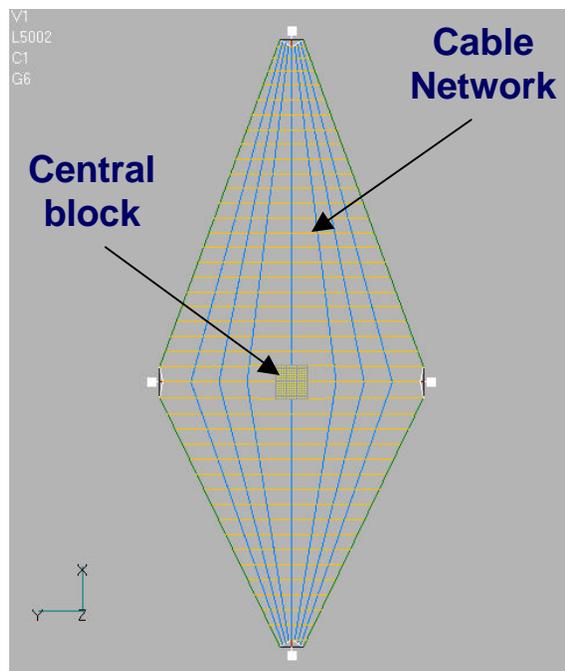


Finite Element Model

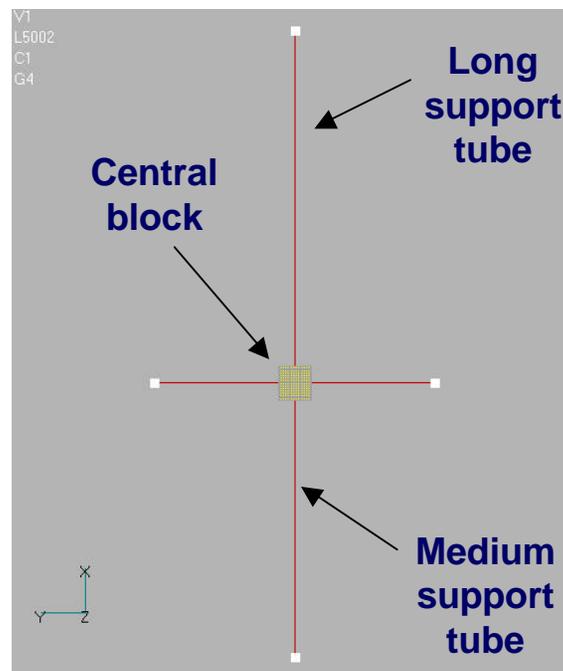


- Partially wrinkled, thin-film membranes modeled using 'cable network' technique
 - Developed by M. Mikulas/University of Colorado-Boulder
 - Implemented in UAI NASTRAN by S. Lienard at NASA GSFC
- Central block, support tubes, and tip hardware modeled using standard techniques
- Base-drive shaker support condition modeled (0.4 Hz rigid body translational mode of sunshield)

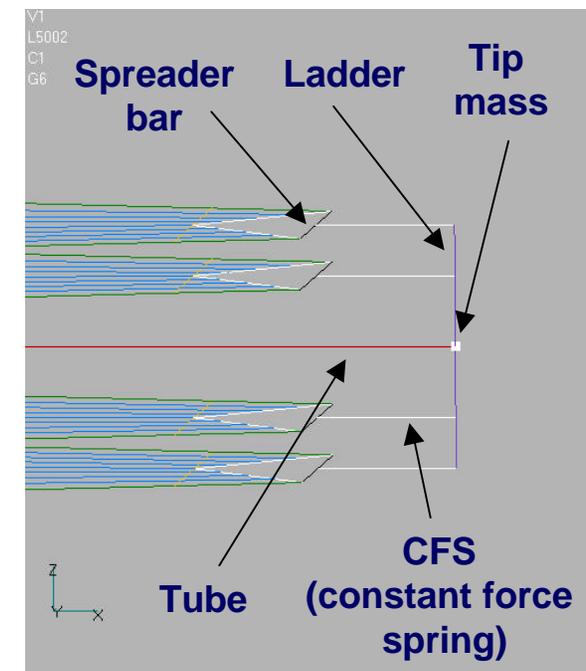
Full FEM



Support Structure



Tip Hardware

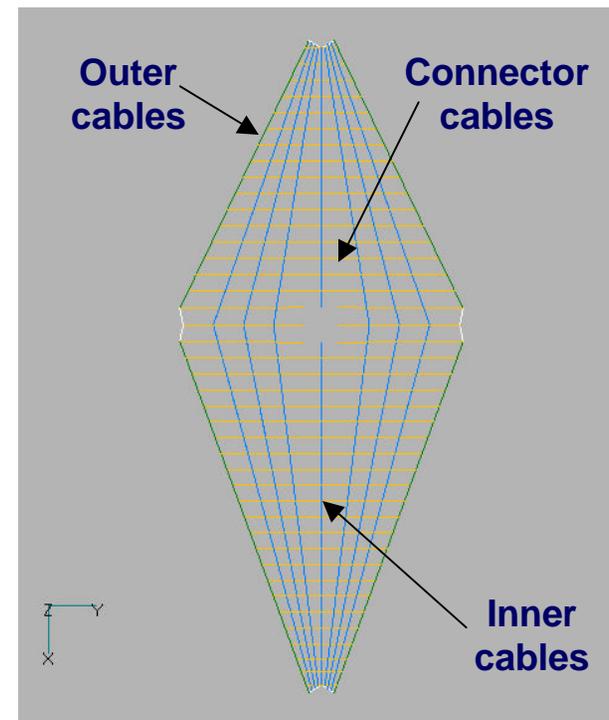
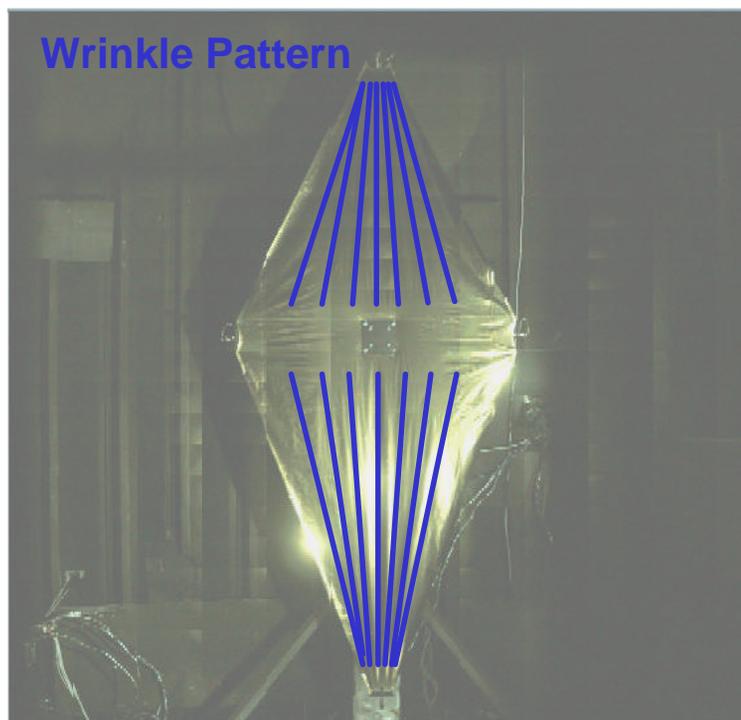




Membrane Cable Network



- The wrinkle pattern in the longitudinal direction is dominant
 - 10 psi longitudinal stress
 - 5 psi lateral stress
- The membrane is meshed with a network of preloaded 'cables' mapped to the wrinkle pattern of the structure.
 - Longitudinal cables are oriented along the wrinkle pattern (load path)
 - Transverse cables act as a connection between cables and represent the mass distribution
 - Approximate representation of the load paths and mass distribution in the structure





Analysis of Sunshield Dynamics



- Finite element analysis of the sunshield was completed using UAI NASTRAN (Version 20.1).
- Nonlinear static analysis
 - Preloads due to constant force springs
 - Gravity loading
 - Export stiffness matrix
- Modal analysis
 - Import stiffness matrix from nonlinear static analysis
 - Calculate frequencies and mode shapes
 - Calculate modal effective mass
- Other dynamic analyses
 - Frequency Response
 - Transient Response (Impulse test simulation)



Modal Analysis Results



- UAI NASTRAN Normal Modes Analysis (SOL 3)
- Modal analysis completed for the following cases:
 - CFS preloads only
 - CFS preloads + Gravity loading with short side down orientation (-X direction)
 - CFS preloads + Gravity loading with sunshield in long side down orientation (+X direction)
- Effective mass (EFFM) calculations used to select 'significant' sunshield modes

Mode	No Gravity		Gravity Short Side Down		Gravity Long Side Down		Description
	Frequency (Hz)	EFFM (%)	Frequency (Hz)	EFFM (%)	Frequency (Hz)	EFFM (%)	
A	2.54	16.0	2.18	9.67	2.61	17.73	Long side of all membrane layers moving in-phase.
B	3.33	5.5	3.33	11.05	2.81	0.39	Short side of all membrane layers moving in-phase.
C	3.66	46.6	3.55	41.32	3.67	48.05	First long tube bending mode
D	5.51	4.9	4.71	3.64	4.79	4.31	Membrane/tube interaction mode
E	5.71	12.8	5.54	14.54	5.55	13.27	First medium tube bending mode
F	6.63	5.9	6.43	9.49	6.32	8.91	Membrane/tube interaction mode

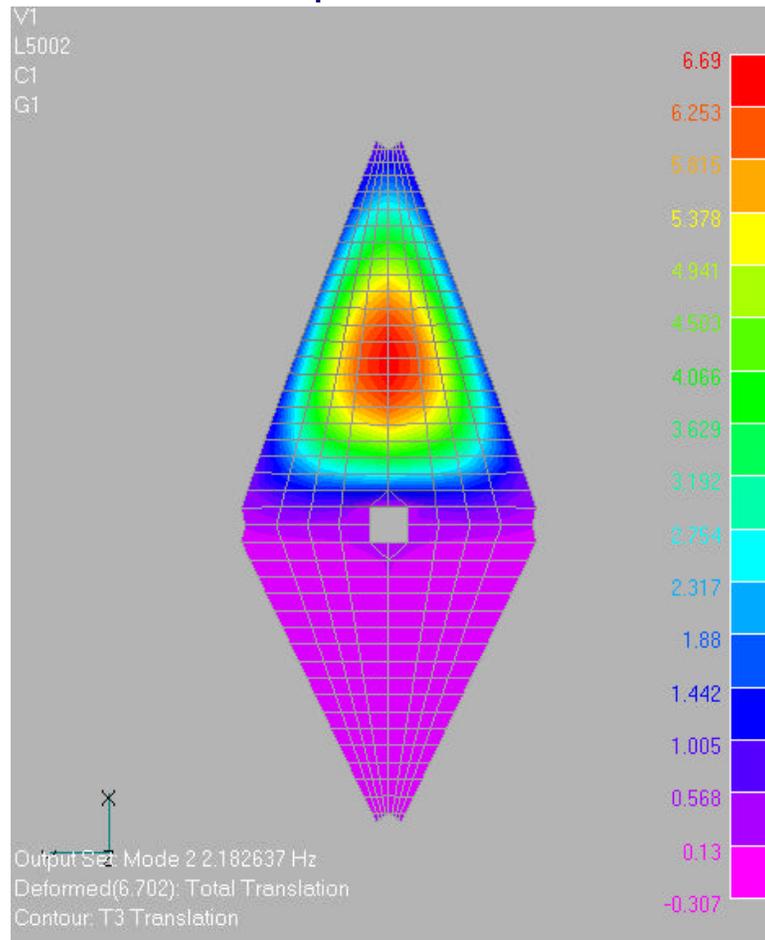


Modal Analysis Results – cont.

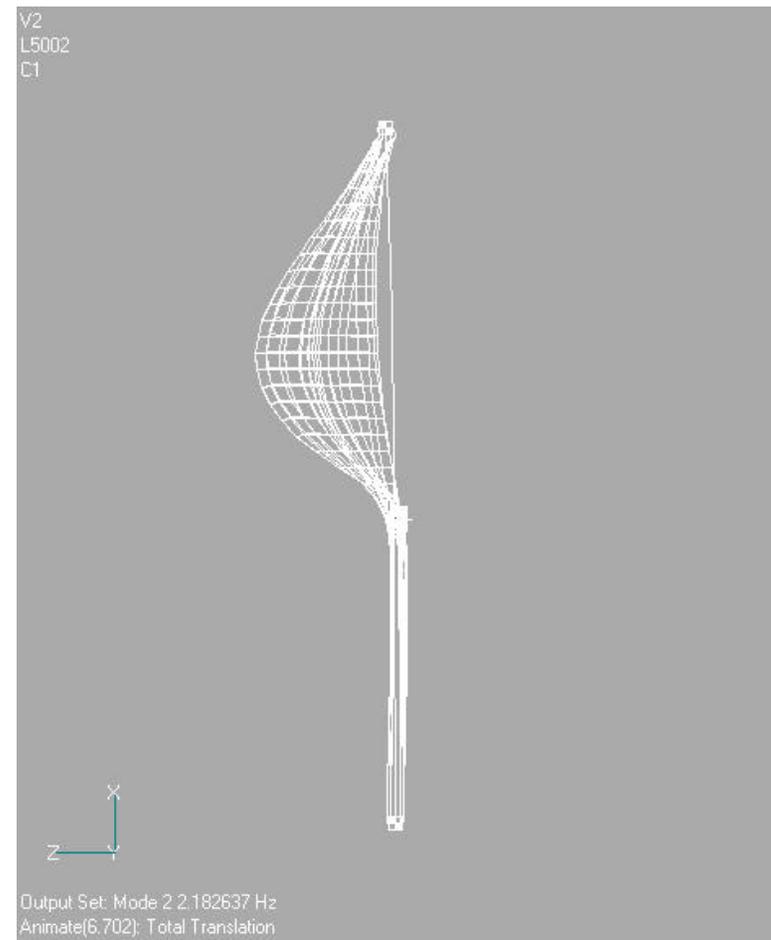


First Mode of Long Side of Membranes ($F = 2.2 \text{ Hz}$)
Test article orientation = Short side down

Contour Plot of Out-Of-Plane Displacements



Mode Shape Animation



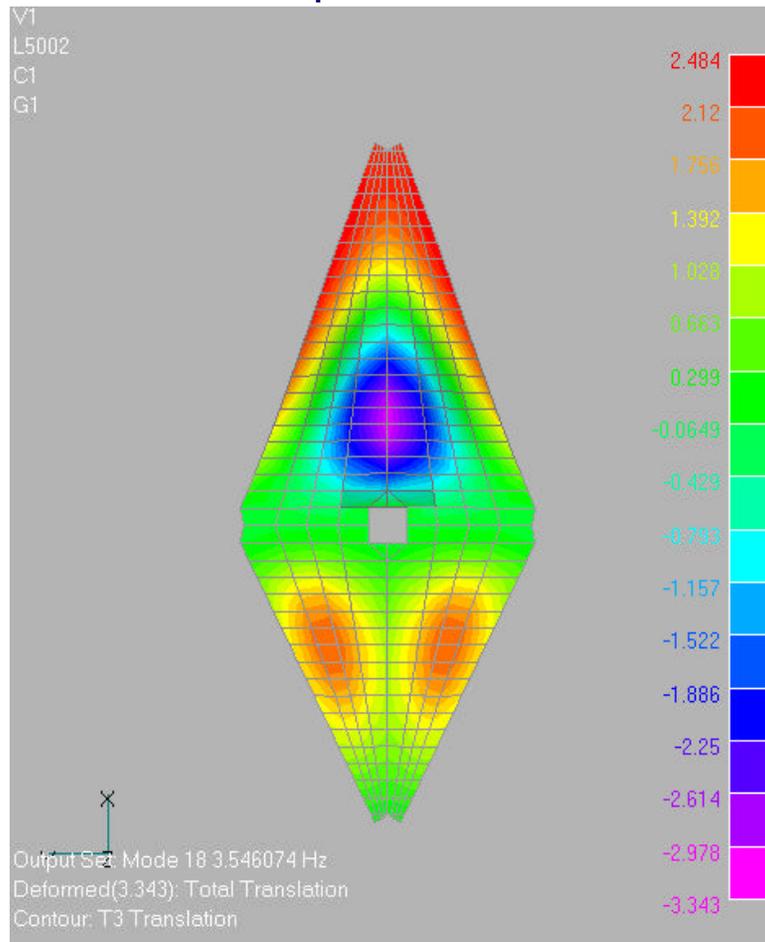


Modal Analysis Results – cont.

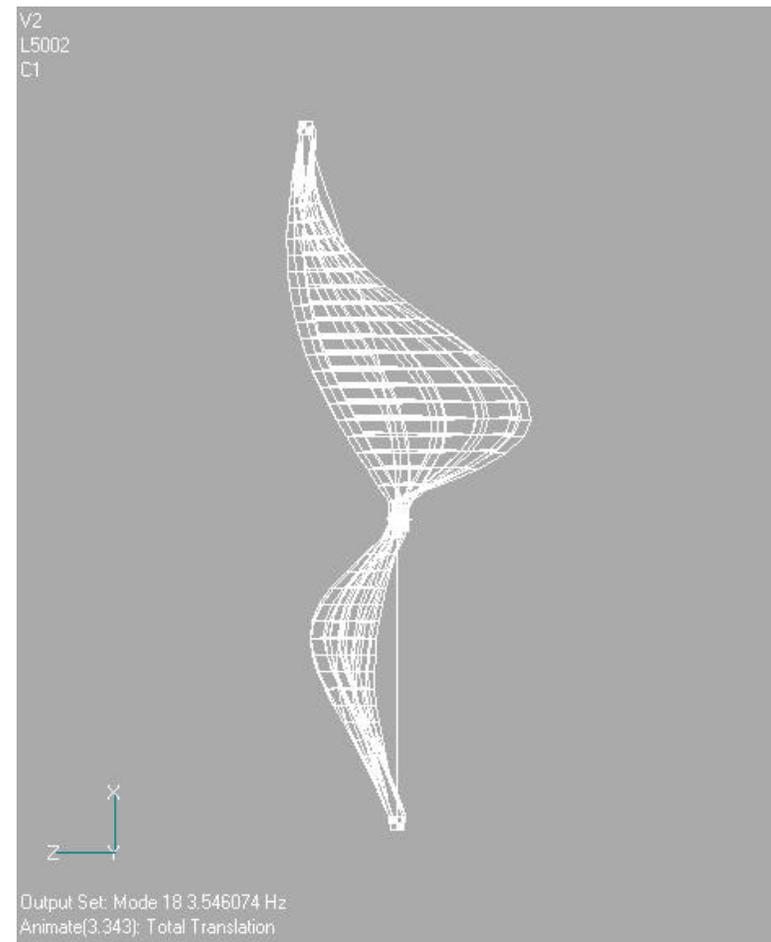


First Bending Mode of Long Tube ($F = 3.5 \text{ Hz}$)
Test article orientation = Short side down

Contour Plot of Out-Of-Plane Displacements



Mode Shape Animation





Impulse Test Simulation



- UAI NASTRAN Transient Response Analysis (SOL 12)
 - Modal Method (0 – 10 Hz frequency range)
 - Modal damping (using test-derived damping values)
 - Timestep = 0.0078125 s, Number of timesteps = 2048 , Total time = 16.0 s
- Loading:
 - Static: CFS preloads, gravity
 - Dynamic: force time history at shaker/sunshield interface from ground tests
- Time domain results recovered at key locations:
 - Accelerometers
 - Laser vibrometer measurement points
 - Force transducer at shaker/sunshield interface
- Frequency domain results calculated during post-processing using MATLAB
 - Power spectral densities
 - Transfer functions
 - Input = Applied load at shaker/sunshield interface
 - Output = predicted response at accelerometer, laser measurement locations



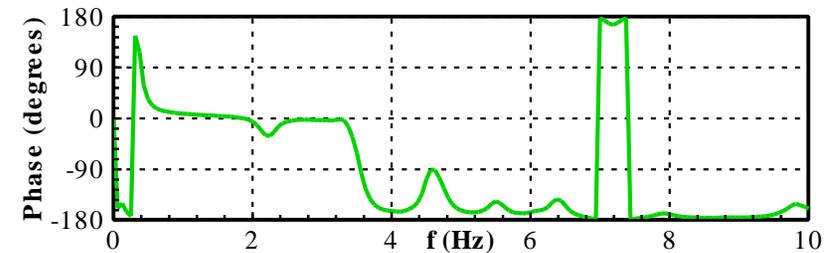
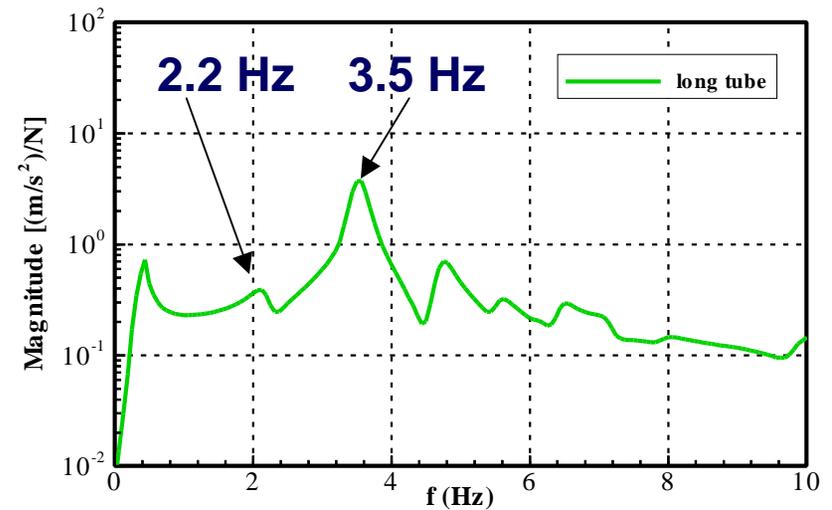
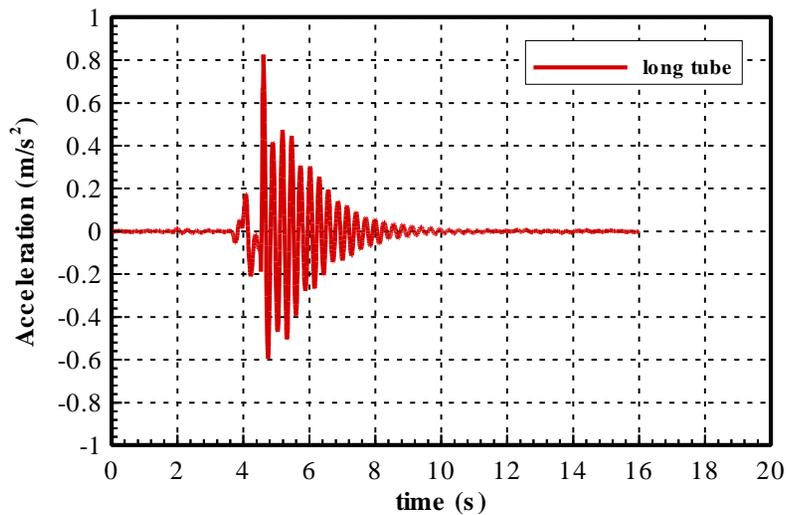
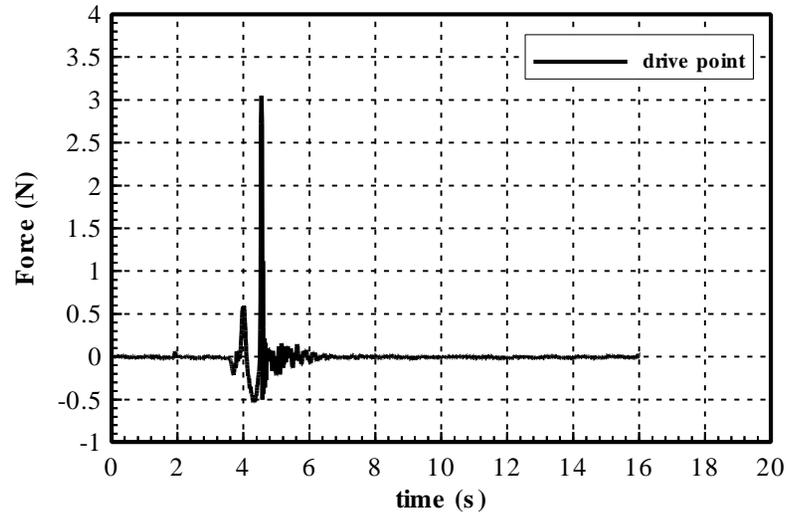
Impulse Test Simulation Results



Time Domain Results



Frequency Domain Results





Comparison of Analysis and Experiment Frequencies and Mode Shapes



- Analysis / Test correlation performed using Dynaview software package
 - Analytical results for preload+gravity case
 - Test results from random excitation tests
 - Orthogonality calculation used to identify mode pairs
- In general, modes dominated by support tube response correlate better than modes dominated by membrane response.

Comparison of Predicted/Measured Frequencies (Short Side Down Orientation)

Mode	Predicted (Hz)	Measured (Hz)	Difference (%)	Description	Notes
A	2.18	3.00	-27.33	Long side of all membrane layers moving in-phase.	
B	3.33	-	-	Short side of all membrane layers moving in-phase.	Poor analysis/test correlation.
C	3.55	3.48	+2.01	First long tube bending mode	Best agreement of all observed modes.
D	4.71	-	-	Membrane/tube interaction mode	Poor analysis/test correlation.
E	5.54	5.07	+9.27	First medium tube bending mode	
F	6.43	5.96	+7.89	Membrane/tube interaction mode	

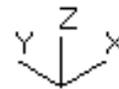
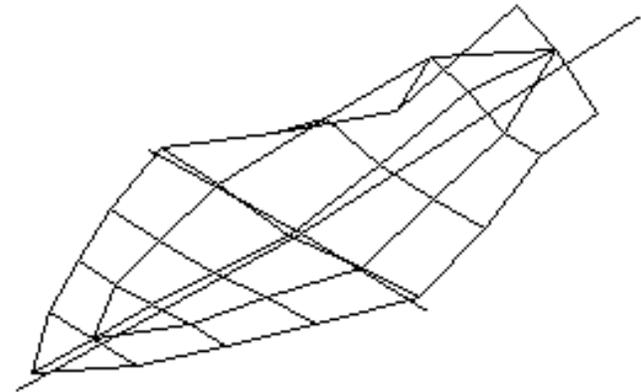
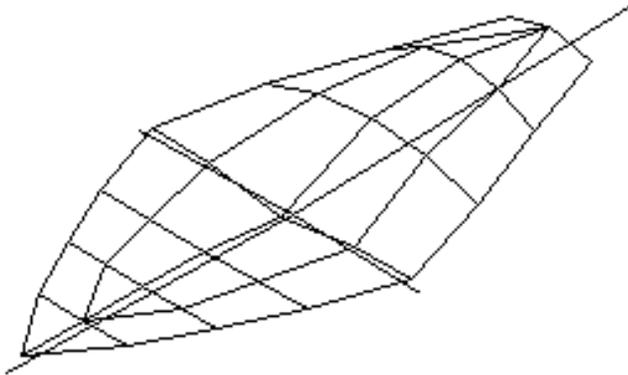


Mode Shape Correlation



Analysis Model
2 2.18 Hz, 0.0000%

Test Model
5 3.00 Hz, 4.7809%



Mode Shape Animations

- Long side of membranes
- Long tube in-phase with membranes
- Frequency = 2.2 Hz (Analysis) / 3.0 Hz (Test)

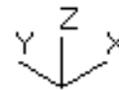
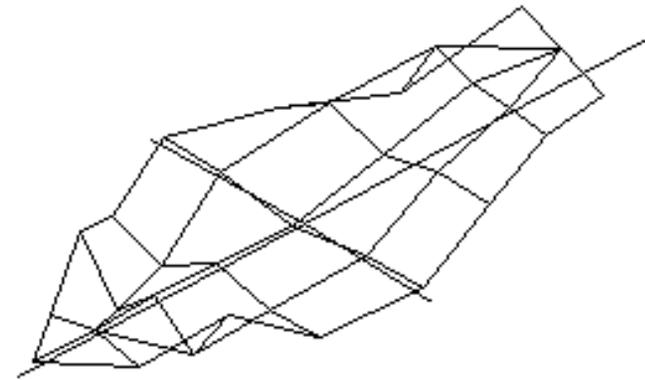
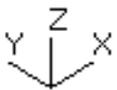
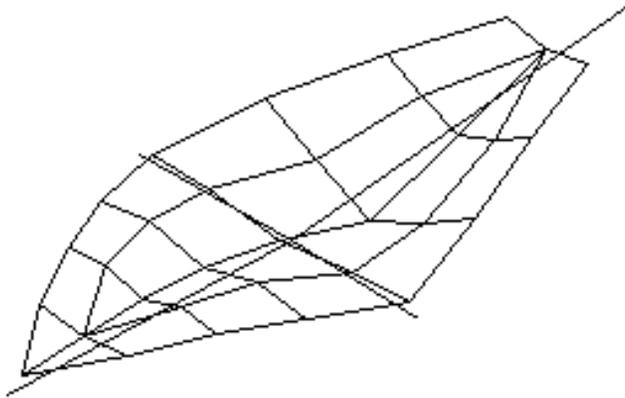


Mode Shape Correlation



Analysis Model
4 3.55 Hz, 0.0000%

Test Model
6 3.48 Hz, 5.2049%



Mode Shape Animations

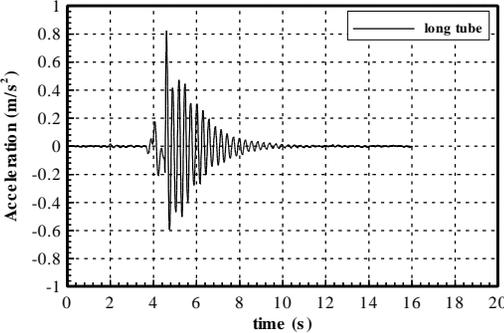
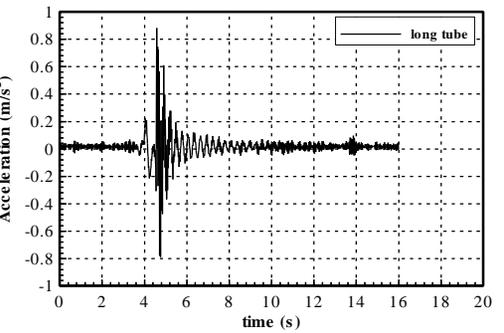
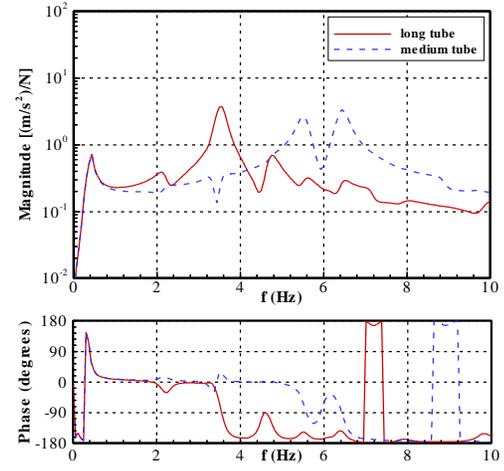
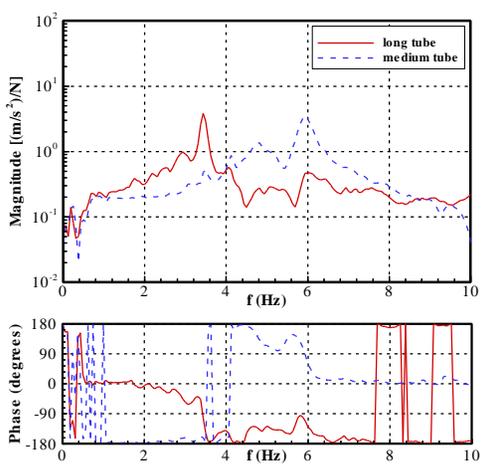
- First bending mode of long tube
- Long side of membranes out-of-phase with tube
- Frequency = 3.5 Hz (Analysis/Test)



Comparison of Analysis and Experiment

Impulse Test Simulation – Support Tube Response



Description	Predicted	Measured
<p>(a) Time domain</p> <p>Acceleration in z direction as a function of time at the tip of the long support tube.</p>		
<p>(b) Frequency domain</p> <p>Frequency response functions for tips of long and medium support tubes.</p> <p>Input = drive point force Output = acceleration of tube tips</p>		



Closing Remarks



- Finite element analysis was used to predict the structural dynamic behavior of a one-tenth scale model of the NGST 'yardstick' concept sunshield.
 - Membranes modeled using approximate engineering technique that accounts for wrinkling effects.
 - Comparison of analytical predictions and test results showed good agreement for modes dominated by support tube motions, but only fair agreement for modes dominated by membrane response.
- Current / Future Work:
 - Development of a new membrane finite element model of the sunshield using "Iterative Membrane Properties (IMP)" method developed by Adler and Mikulas/U. Colorado-Boulder.
 - Follow-on testing of one-tenth scale model sunshield.

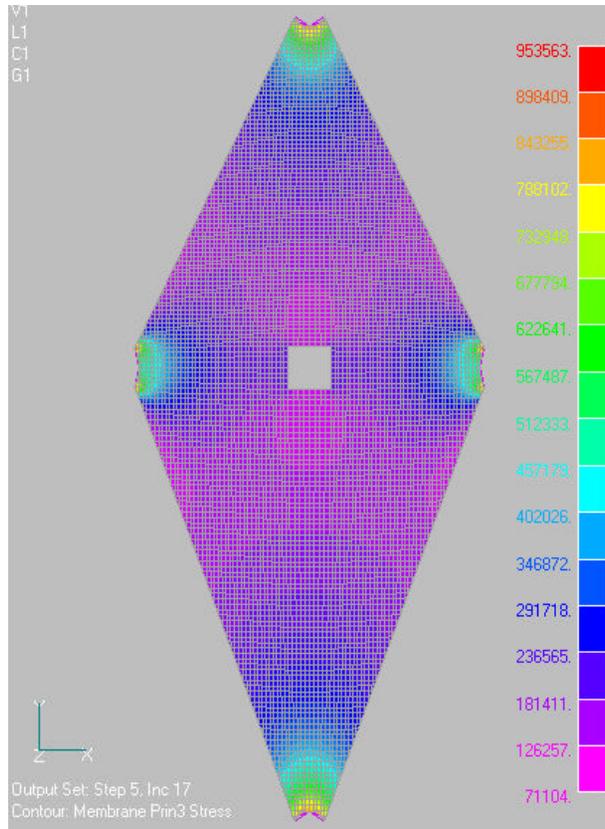


Current Work

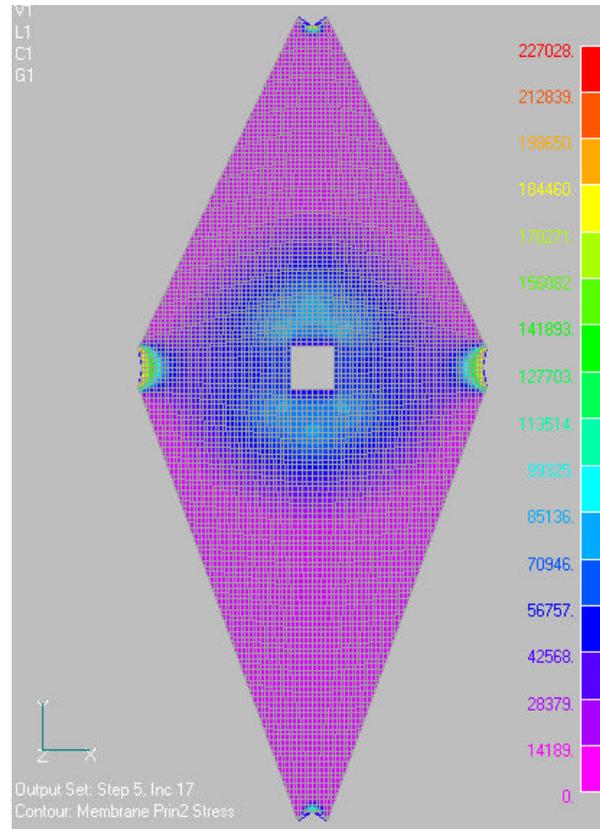
Wrinkled Membrane FEA



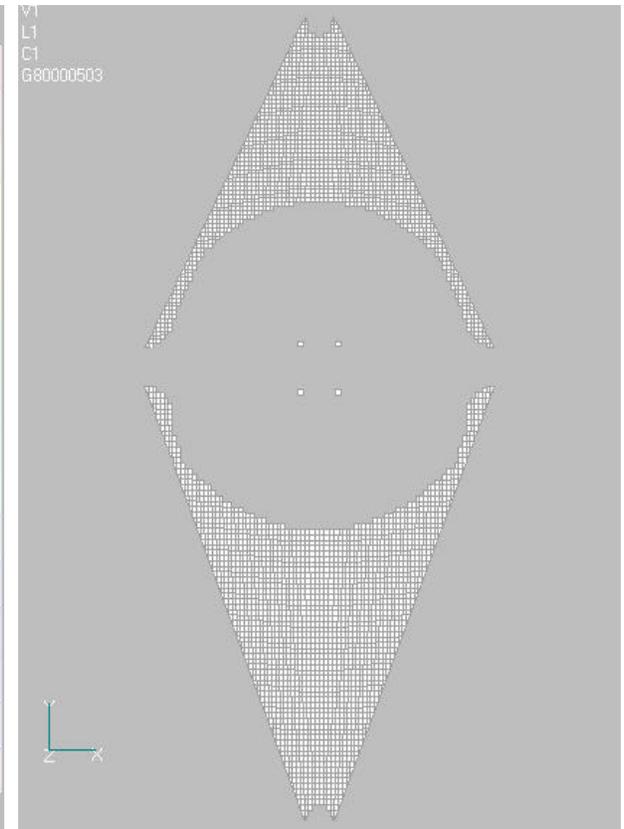
Major Principal Stresses



Minor Principal Stresses



Wrinkle Region



Membrane wrinkling effects modeled using IMP method developed by Adler and Mikulas/U. Colorado-Boulder