FEMCI

A Finite Element Modeling Technique for Dynamic Analyses of Preloaded Large Thin Film Membrane Structures

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May 18th, 2000

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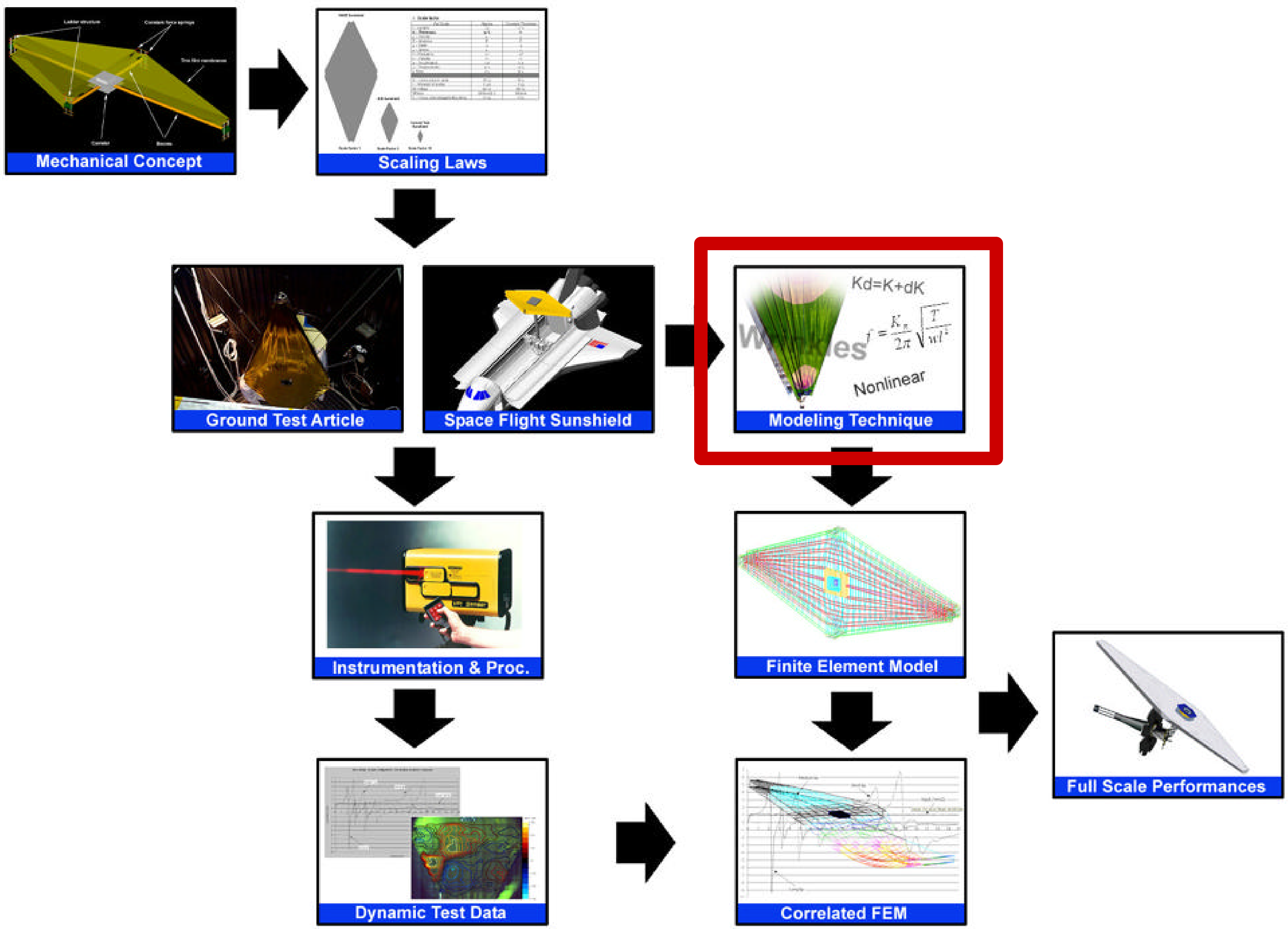
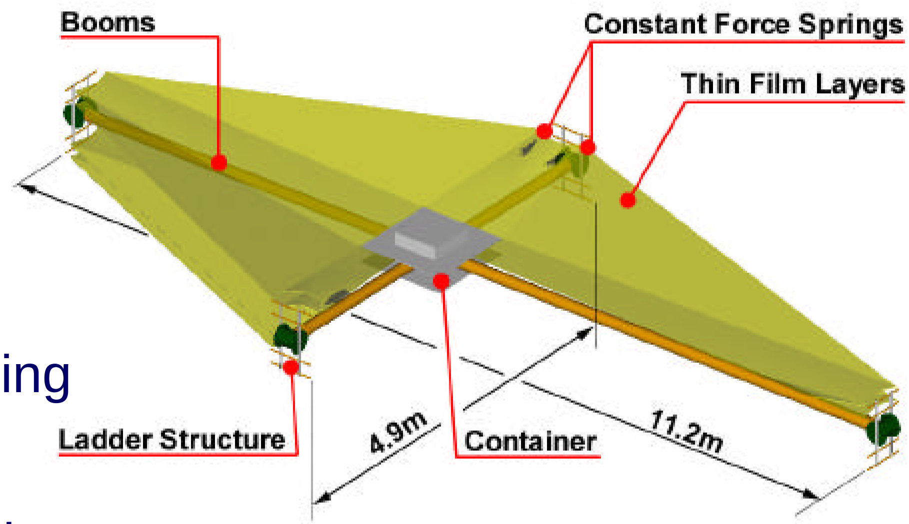
Introduction



Inflatable Sunshield In Space Flight Experiment - Overview

Sunshield Mechanical Design

- Container
  - Stores and restrains shield components during launch phase
  - Interfaces with deployable mast
  - Includes inflation system and electronics
- Thin film membranes (4 layers)
  - Thermal shield
  - 13microns thick Kapton
- Inflatable booms (4)
  - Support the membranes
- Ladder structures
  - Maintain membrane spacing
- Constant force springs
  - Apply tension to the membranes



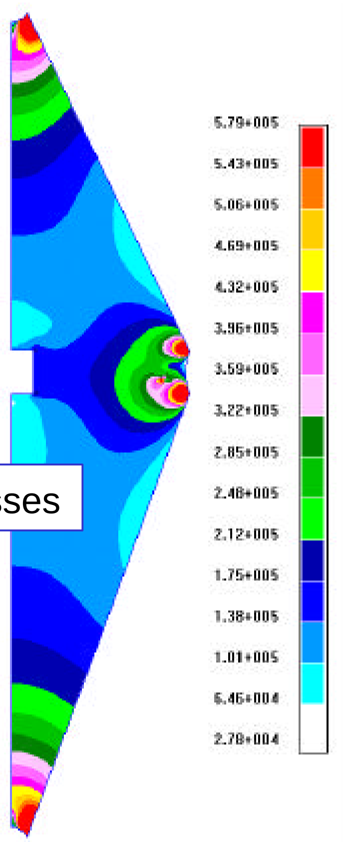
Modeling Challenges

- Modeling of multi-layer, thin-film sunshield structures is challenging due to the negligible bending stiffness exhibited by thin-film membranes.
- Preloading is required to develop out-of-plane stiffness in the membranes, and must be accounted for in dynamic analysis.
- Additionally, the presence of wrinkles alters the structural behavior of the membranes.

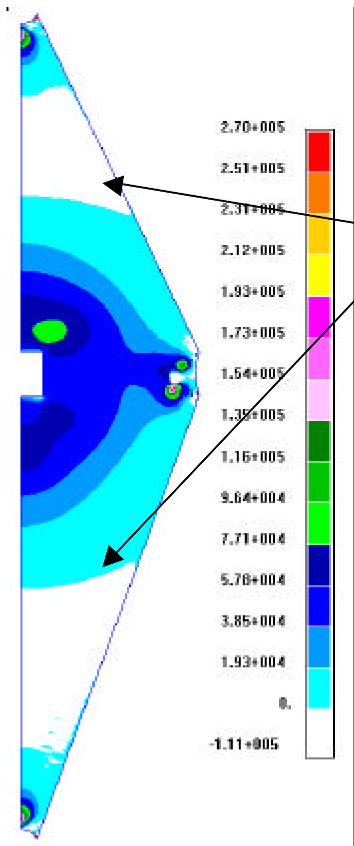
Stress Analysis - Wrinkle formation

- Flat half membrane layer with boundary condition of symmetry.

Positive stresses



Major principal stress



Minor principal stress

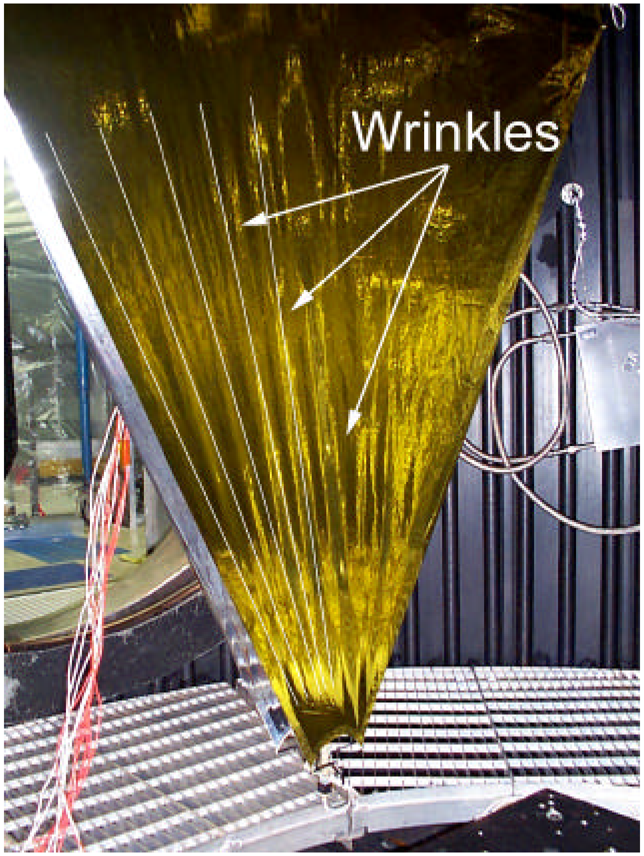
Negative stresses: wrinkled regions

Singularities occur during dynamic solving process due to negative stresses in plate/membrane elements!

Wrinkle Pattern

- Visual assumptions:

  Thin film membranes subject to discrete tensile loads exhibit global wrinkling patterns along straight lines emanating from the load points.



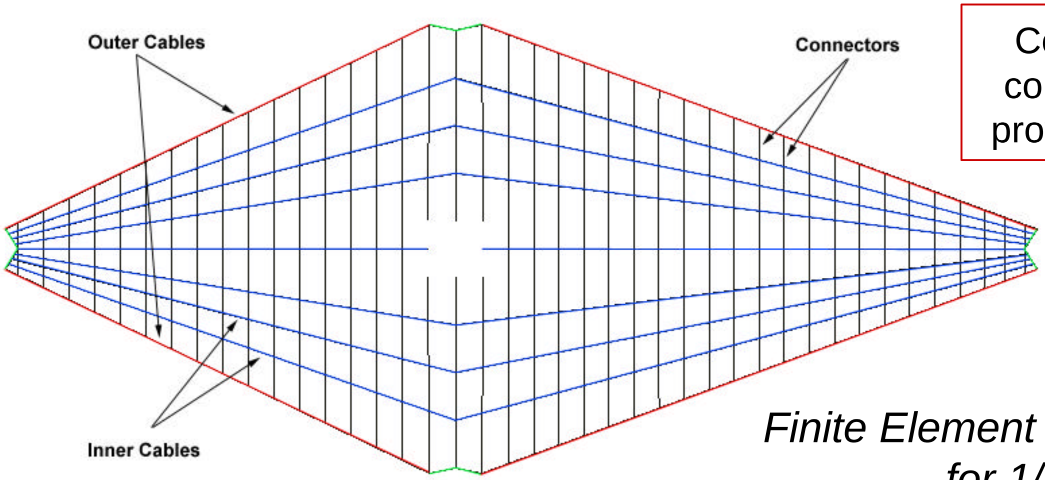
One tenth scale test article

Cable Network Method

- The cable network method was developed specifically to model pretensioned, wrinkled membrane structures.
  - Technique originated by M. Mikulas/U. Colorado-Boulder
  - Further development by S.Lienard/NASA GSFC
- Based on the established principal that load transfer in wrinkled regions takes place along wrinkle lines.
- 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 in the structure.
  - This approach provides an approximate representation of the load paths and mass distribution in the structure.
- Method is limited in that it requires prior knowledge of the wrinkle pattern to generate the cable network and does not account for in-plane shear effects.

Cable Network Method - cont.

- The cable network method has been utilized to model the ISIS sunshield and the one-tenth scale NGST sunshield model.



Connector (transverse cables) connect longitudinal cables and provide uniform mass distribution

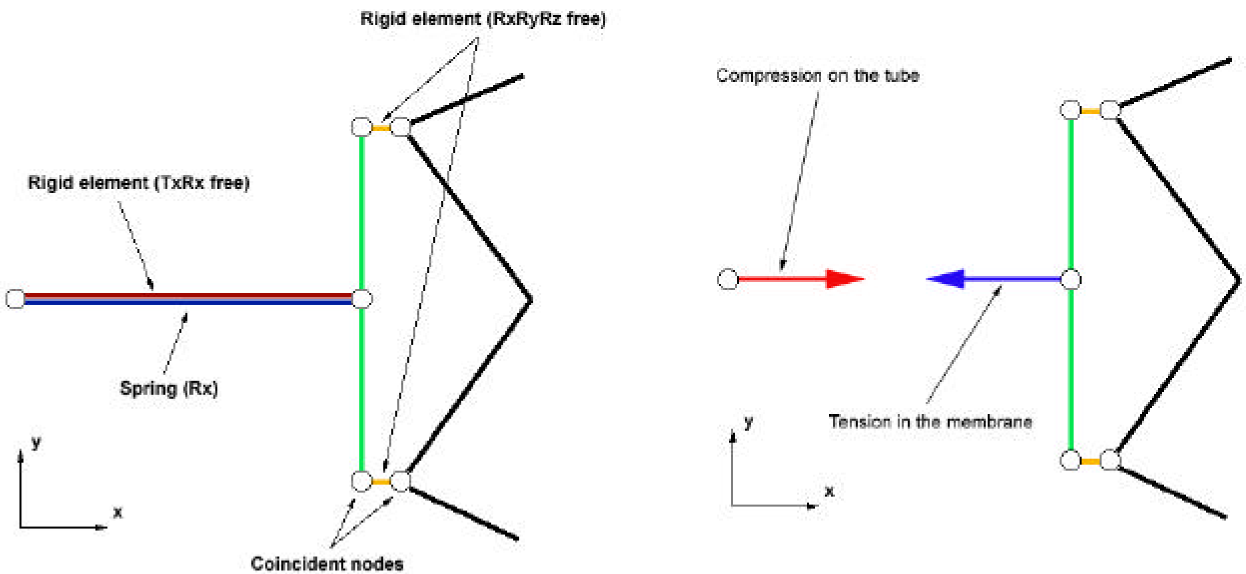
Longitudinal (inner and outer) cables carry loads

Finite Element Mesh of a membrane layer for 1/10th Scale Model Developed using Cable Network Method

- Validation efforts use the one-tenth scale model ground tests to provide data for model correlation.
  - Comparison of cable network model predictions and preliminary test results shows good agreement.
  - Further testing is currently underway.

Preloading

- Static: Forces
  - Tension per membrane layer: 1.425N
  - Compression per boom: 5.7N



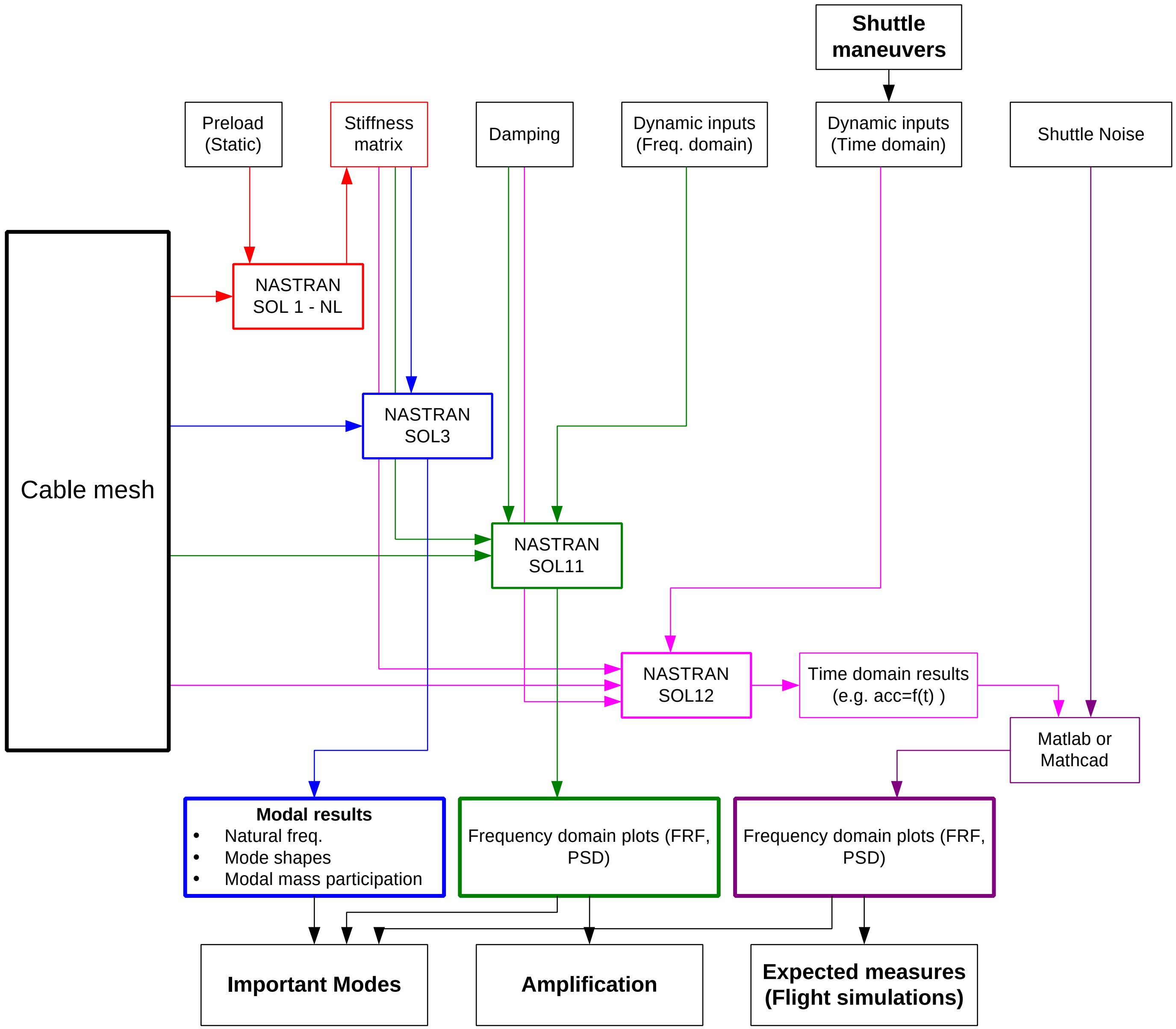
- Note: Degree of freedom Tx of the rigid element is constrained for dynamic analysis

Solving Process

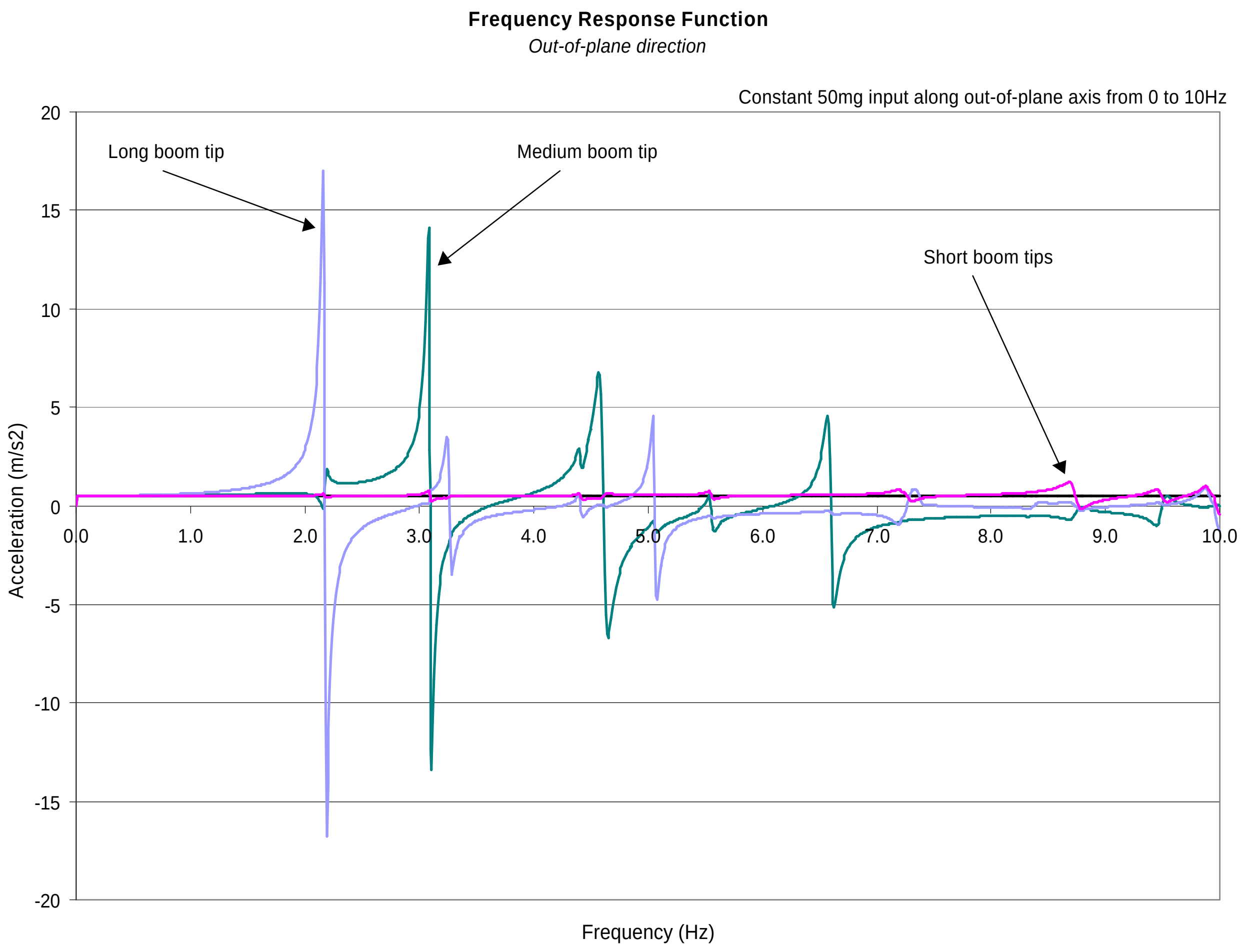
- Static: Geometric Nonlinear
  - The preload produces large stiffness change that has to be applied using iterative process to generate accurate strain/stress distribution.
  - Export of the updated stiffness matrix representing state of strain energy present in the structure.

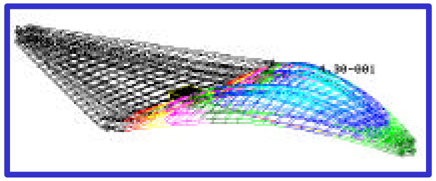
- Dynamic: Modal, Frequency Response, Transient Response
  - Dynamic response must be calculated using an accurate representation of the state of strain energy in the membrane.
  - Import the updated stiffness matrix from static analysis

ISIS Modeling Environment

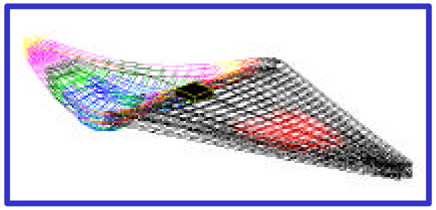


Dynamic Results

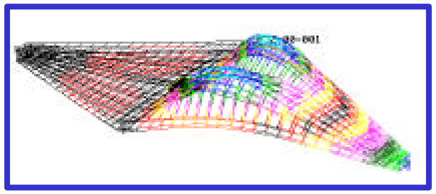




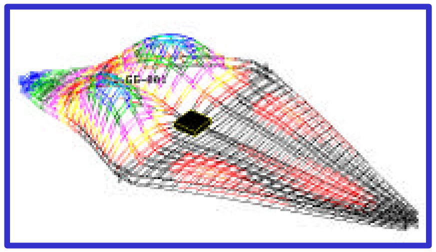
2.17Hz: Long side membrane mode



3.09Hz: Short side membrane mode



3.26Hz: Long boom mode



4.61Hz: Medium boom mode

Modeling Summary

- Several techniques for modeling the structural behavior of pretensioned, wrinkled membrane structures exist.

- The ISIS experiment is modeled using the cable network method.
  - Most mature technique for modeling wrinkled, pretensioned membranes
  - Model shows good correlation with preliminary test results. Additional tests underway to fully validate the technique.

Technique	Pros	Cons	Maturity
Standard Elements (membrane or plate, neglecting wrinkles)	▪ Easy implementation ▪ In-plane shear and thermal effects modeled	▪ Wrinkling effects not modeled ▪ Potential for numerical problems for dynamic analysis ▪ Dynamic results due not convergene as mesh size is refined	▪ Fully developed ▪ Implemented in NASTRAN ▪ Model validation needed
Cable Network Method	▪ Easy implementation ▪ Quick solving time	▪ Requires knowledge of wrinkle geometry (test required) ▪ No in-plane effects modeled	▪ Fully developed ▪ Implemented in NASTRAN ▪ Model validation underway
Iterative Membrane Properties Method	▪ Predicts wrinkle region geometry ▪ In-plane shear and thermal effects modeled	▪ Requires relatively fine mesh in wrinkle regions ▪ Iterative solution required ▪ Long solving time	▪ Under development ▪ Dynamics analysis not developed yet ▪ Implemented in NASTRAN (Requires external code) ▪ Model validation underway

Closing Remarks

- Modeling technique
  - Fully developed in NASTRAN

- Validation underway
  - Ground test article for T/V testing (3.2x1.4x0.1m)
    - Test in air (Early June 2000)
    - Test in vacuum (Late June 2000)
    - Model validation/correlation (Summer 2000)
  - Flight experiment for testing in Space (11.2x4.9x0.3m)
    - Flight planned for May 2001

References

- ISIS Flight Experiment

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  - Michael L. Adams, et. al, "Design and Flight Testing of an Inflatable Sunshield for the Next Generation Space Telescope (NGST)," April 3-6, 2000, AIAA-2000-1797.
  - Sebastien Lienard, John Johnston, et. al, “Analysis and Ground Testing for Validation of the Inflatable Sunshield In Space (ISIS) Experiment,” 41st AIAA Structures, Structural Dynamics, and Materials Conference, Atlanta, GA, Paper No. AIAA-2000-1638, April 2000.

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  - Adler, A.L., Mikulas, M.M., and Hedgepeth, J.M., “Static and Dynamic Analysis of Partially Wrinkled Membrane Structures,” 41st AIAA Structures, Structural Dynamics, and Materials Conference, Atlanta, GA, Paper No. AIAA-2000-1810, April 2000.
  - Lienard, S.L., “Characterization of Large Thin Film Membrane Dynamic Behavior with UAI-NASTRAN Finite Element Solver,” SAE Paper 199-01-5518, October 1999.