ULTRA-LIGHTWEIGHT STRUCTURES TECHNOLOGY FOR SPACE SOLAR POWER

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NASA Langley

SCTM TIM
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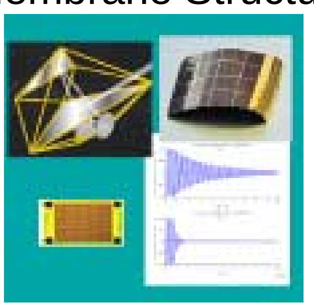
ULTRA-LIGHTWEIGHT MATERIALS & STRUCTURES TECHNOLOGY FOR NASA MISSIONS

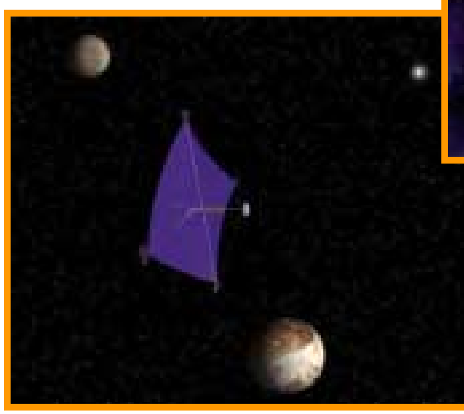
Ultra-Lightweight & Space-Durable Materials

Ultra-Lightweight & Membrane Structures



Adaptive and Resilient Systems

Metrics:
- lower mass (X3)
- lower package volume (X10)
- lower cost:
  (reduced part count)
  (smaller launch vehicle)



Solar Sails

Large Apertures

Space Solar Power Systems

Risk Mitigation
- design tools
- data bases – materials & components
- ground and flight tests

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FY02 SSP FUNDED TASKS

Task	SSP Funding	Co-Funding
Characterization and Assembly of Inflatable / Rigidizable Structures	$55K	$250K (DARPA) $250K (Code R)
Deployment of Membrane Structures	$160K	$175K (Code R)
Active Control of Membrane Structures	$50K	$50K (Code R)
Free Piston Radiator	$35K	

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CHARACTERIZATION AND ASSEMBLY OF DEPLOYABLE / RIGIDIZABLE STRUCTURES

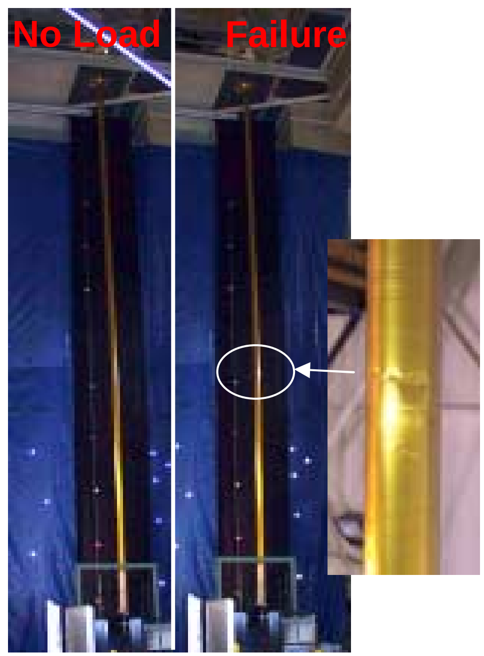
POC: Judith Watson, LaRC

Objective: Characterization of structural performance of state-of-the-art deployable/rigidizable columns and trusses.

Accomplishment: Over 50 columns delivered for characterization testing. Several tested in axial stiffness, bending and compressive failure. Two 15-m columns tested for stiffness and failure. 8-m truss tested in compression to failure of 556 lbs

Plans: Complete testing and analysis of columns for characterization. Develop truss structure with deployment joints

ILC Dover
13-m Thermoset Column



L'Garde
15-m Aluminum Laminate Column

8-m SSP TRUSS FAILED IN COMPRESSION

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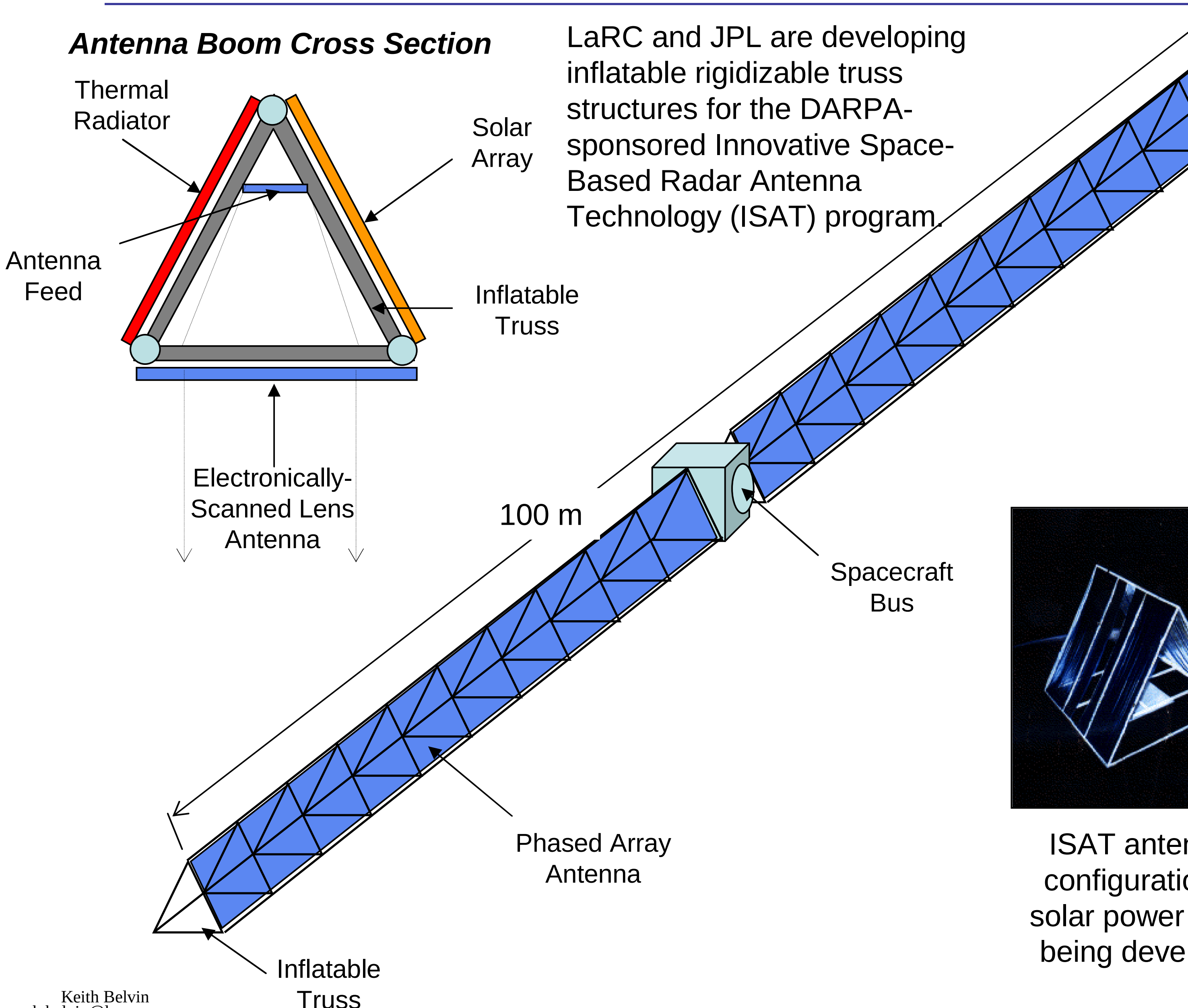
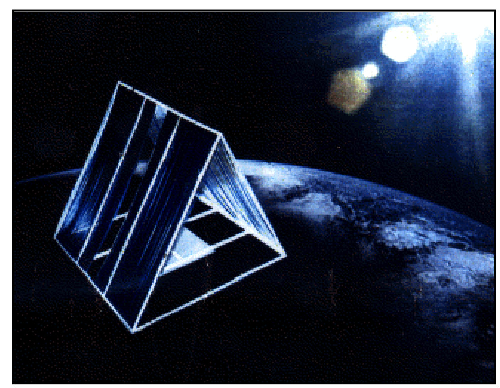
INFLATABLE TRUSS STRUCTURES FOR SPACE-BASED RADAR SYSTEMS

LaRC and JPL are developing inflatable rigidizable truss structures for the DARPA-sponsored Innovative Space-Based Radar Antenna Technology (ISAT) program.

Antenna Boom Cross Section





ISAT antenna is similar in configuration to SPS-2000 solar power satellite concept being developed by Japan.

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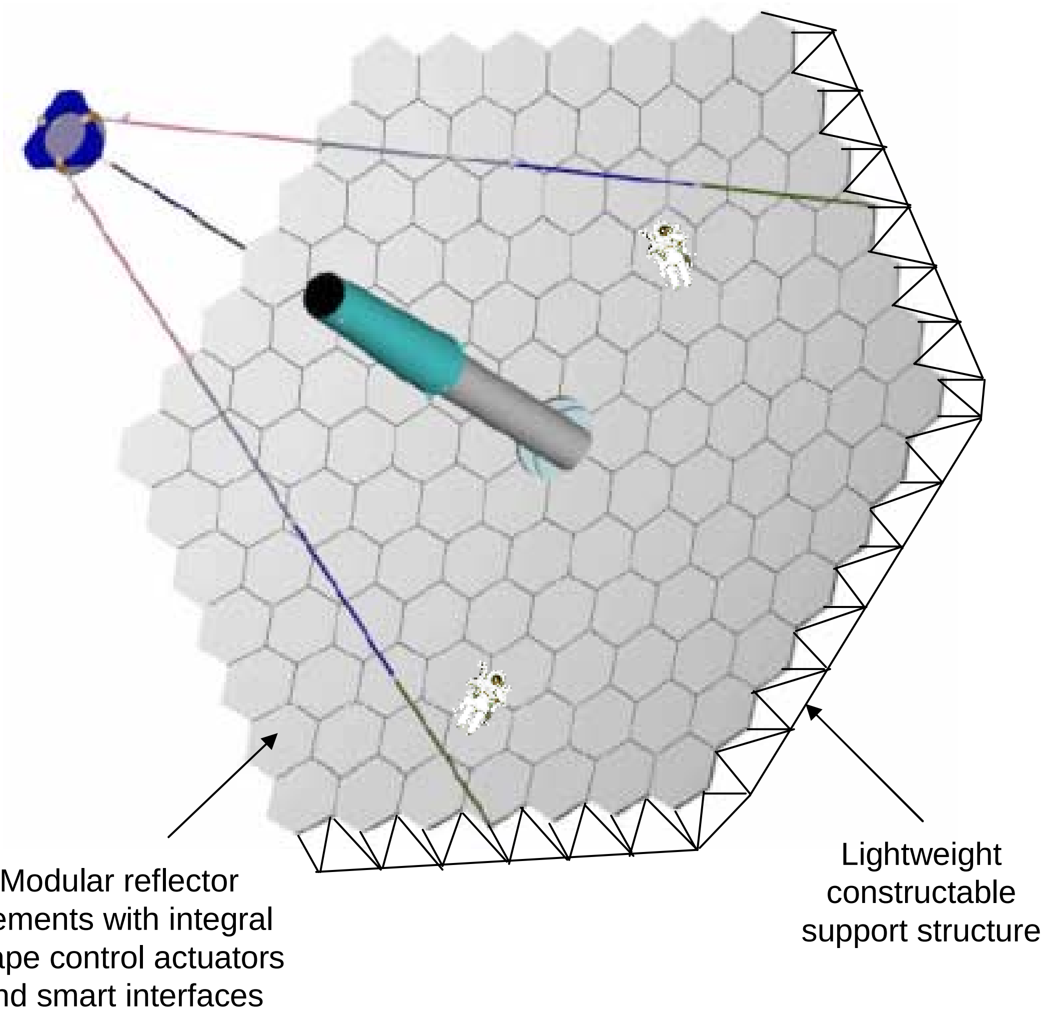
CONCEPTS FOR ASSEMBLY OF LARGE SPACE STRUCTURES AND APERTURES

Objectives

- Develop concepts and technologies for enabling the construction of > 20 meter-class apertures from deployable and modular elements
- Quantify the benefits and tradeoffs associated with human vs. robotic assembly for use in future mission planning.

Technology Development

- Concepts for structural assembly and control
- Test validated models of human and robotic performance
- Lightweight deployable truss elements and structural joints
- Robotic end effectors
- Modular reflector elements



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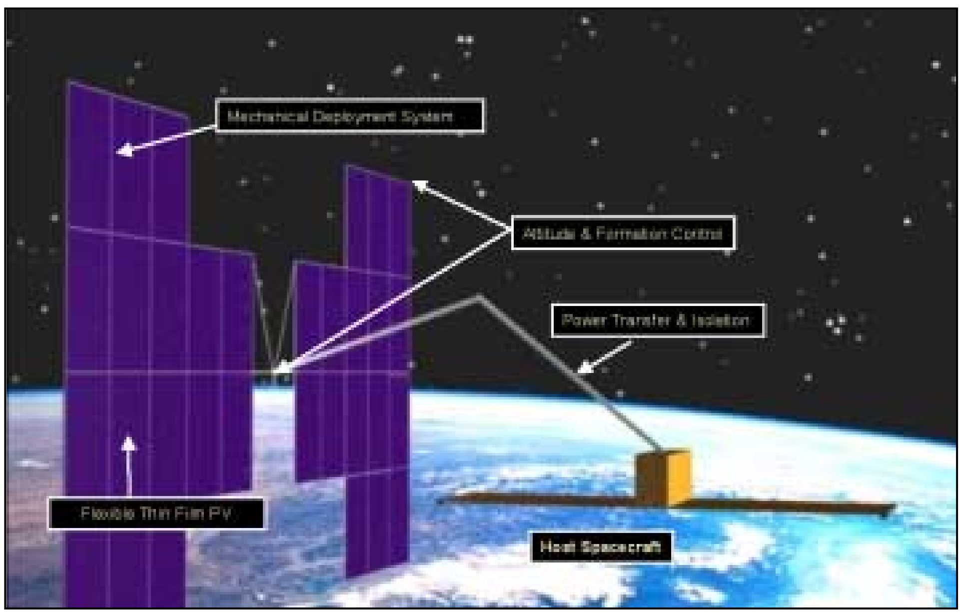
DEPLOYMENT OF MEMBRANE STRUCTURES

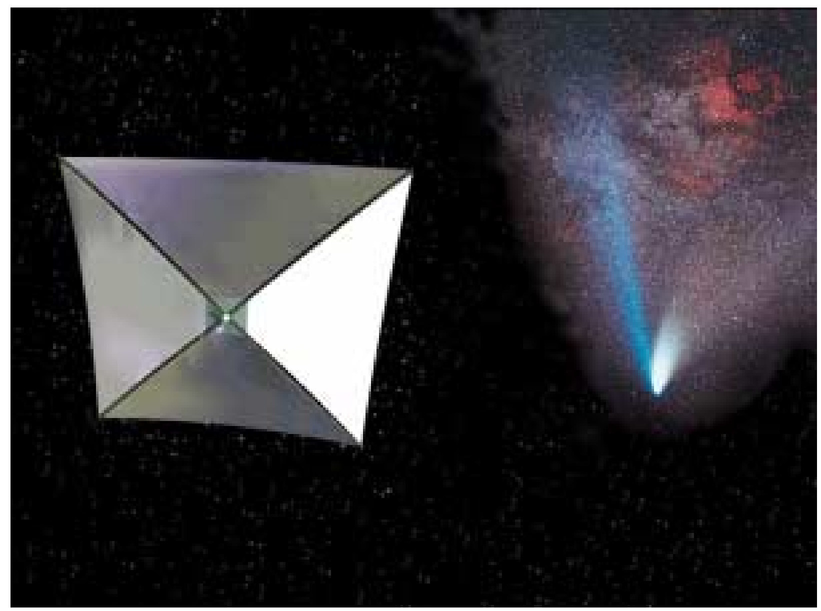
<u>Objective</u>: Develop lightweight deployable structural elements for SSP systems, and validate concepts for packaging and controlled deployment in ground testing.

<u>Approach</u>

- Continue development of lightweight inflatable booms and deployment control mechanisms.
- Integrate inflatable boom with large membrane, and demonstrate controlled deployment.
- Characterize structural dynamics of membrane structure in vacuum.
- Develop analytical models for predicting deployment dynamics and structural dynamics



AFRL PowerSail concept for large membrane solar array flying in formation with a spacecraft requiring high power



Solar sails will enable low-cost rapid transit throughout the solar system, and station keeping in unstable orbits

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SOLAR SAIL STRUCTURAL DYNAMICS

POC: Dr. Kara Slade, LaRC

Objective: Perform subsystem integration of solar sail membranes and booms for ground test and analysis correlation of constant thickness scaled models.

Justification: Understanding the dynamics of large flexible structures is critical for control of deployment and pointing.

Accomplishment: Completed initial testing of two quadrant 10 meter prototype sail model and constructed two 2 meter constant thickness scale models.

Plans: Integrate new 10 meter membranes from SRS Inc. with deployable booms from CTD Inc. Perform shape and dynamics measurements in vacuum to validate hardware and analysis/design tools.

10 meter solar sail in vacuum chamber. Bright spots are laser reflecting from targets on sail. Laser is used to measure vibration modes and frequencies.

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SOLAR SAIL BOOM DEPLOYMENT ANALYSIS

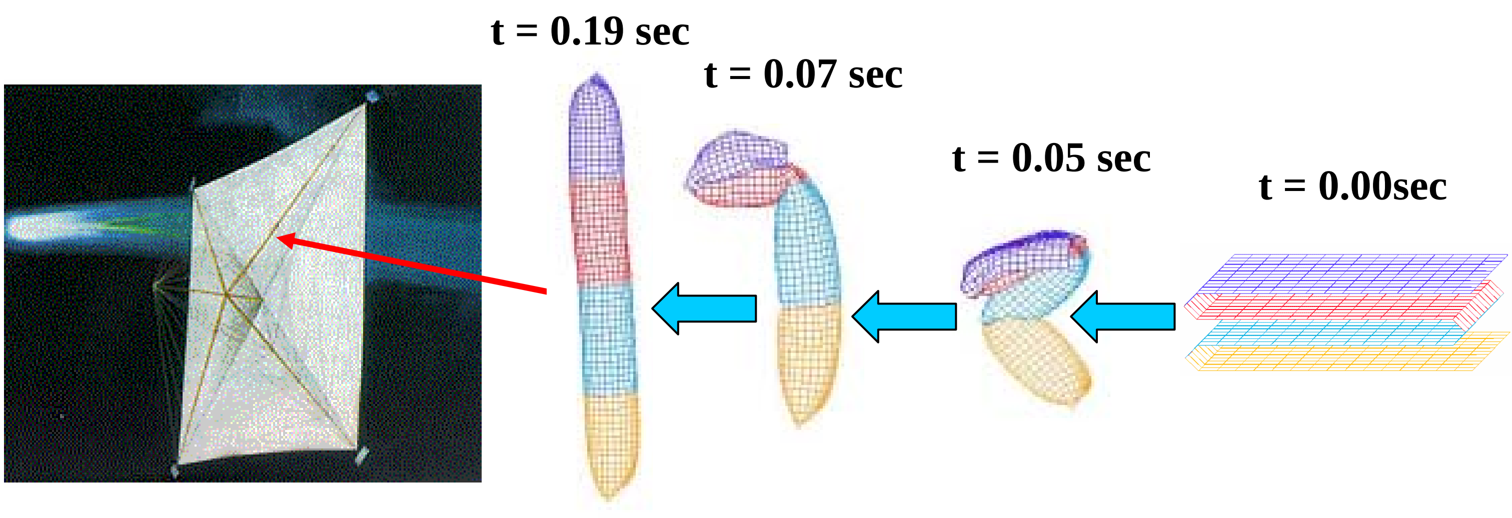
POC: Dr. John Wang (LaRC)

Objective: Model and simulate dynamic deployment of ultra-lightweight solar sails

Justification: Analytical tools to predict dynamics will reduce risk for deployment of large membrane structures

Accomplishment: Simulated the in-space deployment of two stowed solar-sail-booms, Z-folded and rolled configurations, and investigated the effects of inflation mass rate, residual air, and gravity on deployments

Plans: Investigate the deployment issues of a scaled NOAA GEOSTORM solar sail test model



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ACTIVE CONTROL OF MEMBRANE STRUCTURES

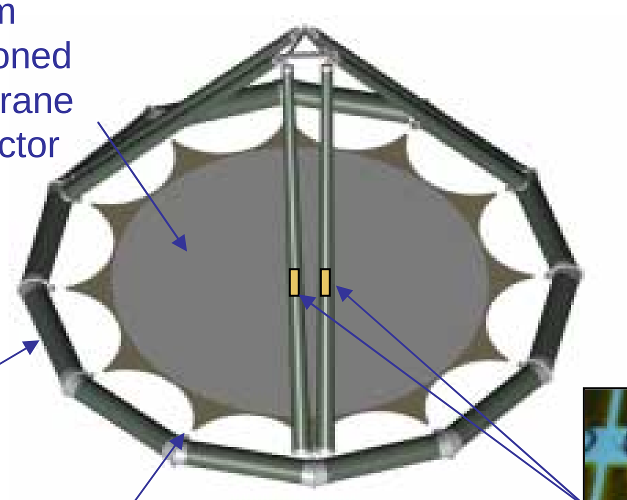
POC: Dr. Lucas Horta (LaRC)

Objective: Demonstrate active control of a tensioned membrane structure to suppress structural dynamics and maintain membrane flatness

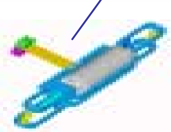
Justification: Active structural control is needed to maintain the surface figure, pointing, and alignment of large flexible membrane structures for SSP systems, such as microwave transmitting antennas, reflectors, and solar arrays.

Accomplishment: Developed a membrane aperture testbed with integral actuators, and with boundary condition actuators for the membrane. Initial system tests confirm control authority and frequency response has been measured.

3 m Tensioned Membrane Reflector



Inflatable Frame



Membrane control actuator

Integral piezoelectric actuators for controlling structural dynamics

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PHOTOGRAMMETRY FOR GOSSAMER STRUCTURES

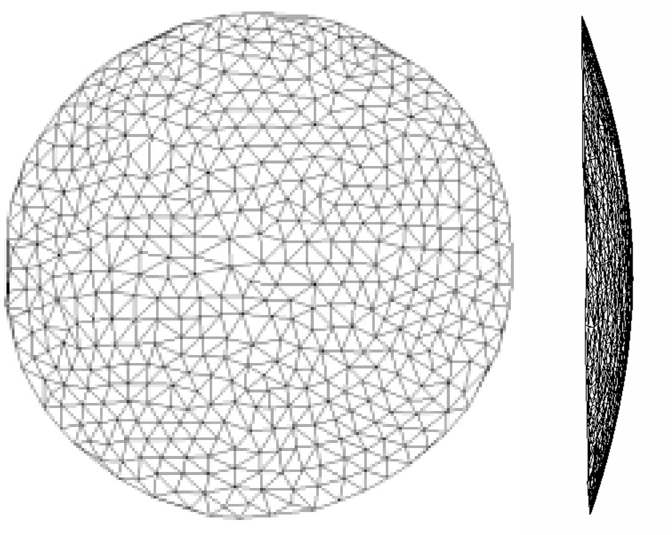
POC: Richard S. Pappa, LaRC

Objective: Develop and demonstrate photogrammetry methods for full-field 3-D shape/dynamics characterization of Gossamer structures.

Justification: Non-contact methods for measuring shape and dynamics are needed to validate the performance of membrane structures.

Accomplishment: Measured shape of 5m inflatable antenna reflector with prosumer digital cameras for comparison with design specifications. Measurement precision was approx. 0.25 mm. Antenna RMS error =1.5 mm.

Plans: Will extend technology to image sequences for measuring deployment dynamics and vibration modes of Gossamer structures for validation of new analytical modeling techniques.



3-D shape determined with photogrammetry

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FREE PISTON RADIATOR

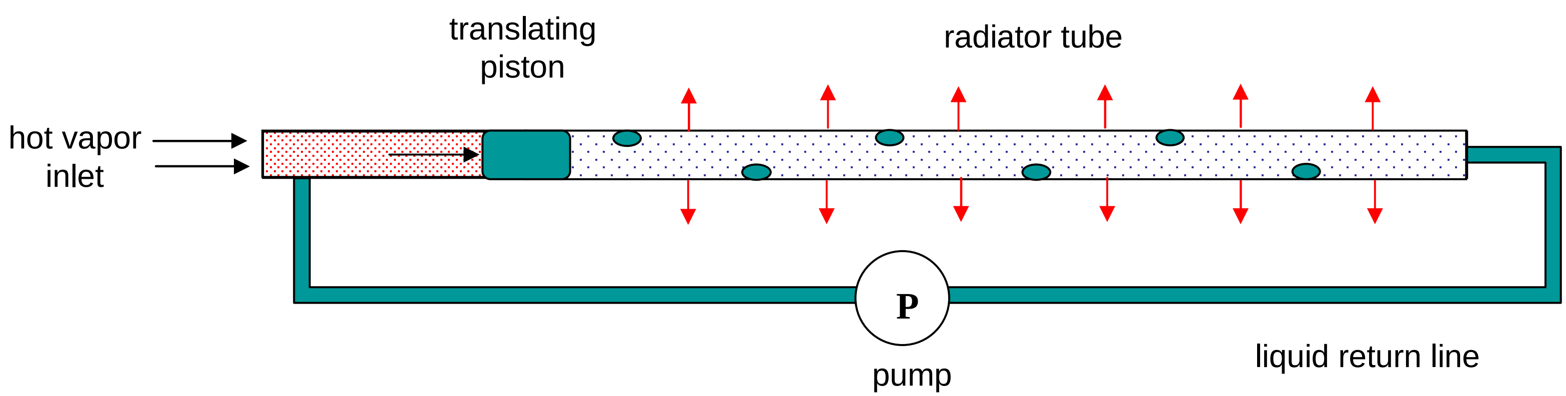
POC: Leonard Weinstein, LaRC

Objective: Investigate advanced radiator concept using a translating piston to sweep up droplets condensed on radiator walls. Develop proof-of-concept free piston radiator, and demonstrate that heat can be transported over distances >> 1 meter.

Justification: SSP systems will require efficient thermal management technology to transport and dissipate waste heat. Radiator concept minimizes fluid mass for heat transport over long distances.

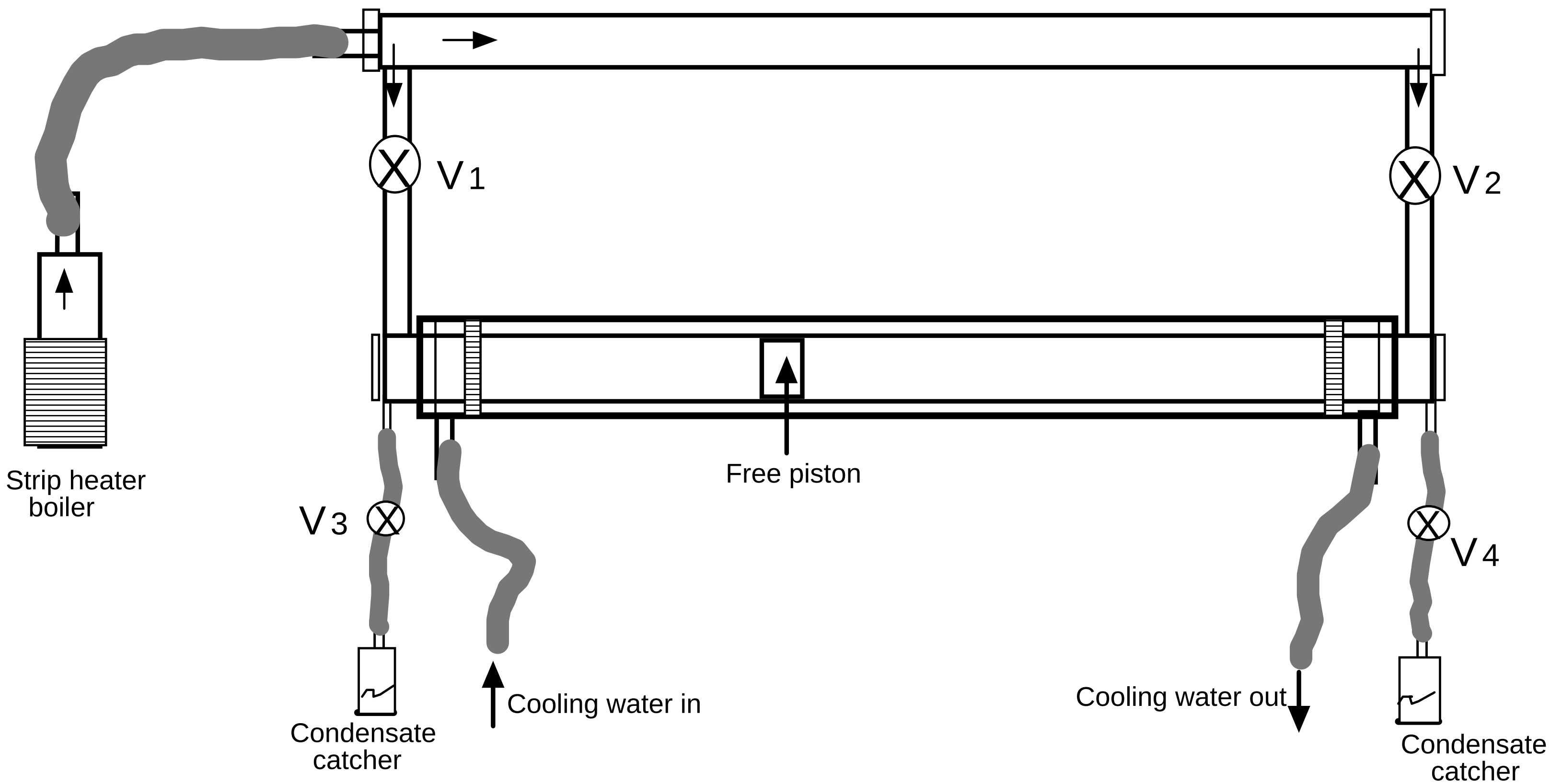
Accomplishment: Lab prototype demonstrator has been designed, and construction is nearing completion. Water cooling of tube is being used to simulate radiation cooling rate.

Plans: Preliminary tests will be conducted as soon as model is completed, to demonstrate concept and examine flow details.



Translating piston reverses direction when it reaches the end of the radiator tube by switching vapor inlet to opposite side.

Lab Simulation of Free-Piston Space Radiator



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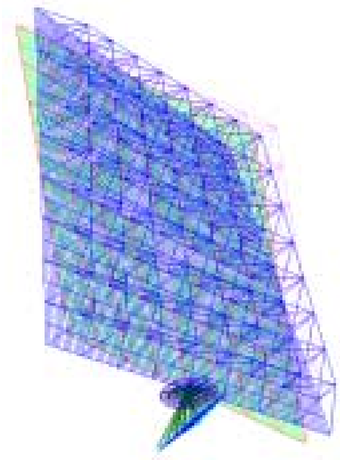
Objective

- Define system-level requirements for SSP structures and thermal management technology development to address NRC recommendations.

Approach

- Develop integrated structural / thermal model of representative SSP system.
- Calculate structural and thermal loads, structural and thermal deformations, and structural dynamics.
- Derive system-level requirements from analytical results.
- Revise SSP structures and thermal technology roadmaps



Structural model of representative SSP system

Major Milestones

- Award contract to develop integrated structural / thermal model of SSP system. - 1Q FY03
- **Complete structural and thermal analysis - 4Q FY03**

Resources

- $60K, 0.15 FTE

Participants

- NASA Langley, TBD contractor

Deliverables

- Integrated structural / thermal model of representative SSP system.
- System-level requirements for structures and thermal technology development.

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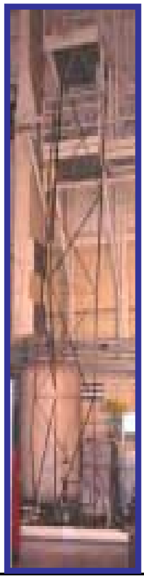
Objective

- Characterization of structural mechanical properties/behavior of state-of-the-art deployable/rigidizable columns

Approach

- Develop data base of stiffness and buckling data for L/D=10 and 100 columns. Test method correlation between short and long columns
- Development of built-up structures from structural elements, including assembly options

Deployment of isogrid boom in thermal vacuum chamber



8 m inflatable truss after buckling test

Major Milestones

- Test results long /short column rigidized specimens- 2Q FY03
- Test results for deployable trusses- 4Q FY03
- Concepts for joining and assembly of large structures in space - 4Q FY03

Resources

- $100K, 0.4 FTE

Participants

- NASA Langley, ILC Dover, L'Garde, CTD

Deliverables

- Data base of rigidizable column stiffness
- Joint concepts and designs for truss structures

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Objective

- Develop lightweight deployable structural elements for SSP systems, and validate concepts for deployment and ground testing of the dynamic response.

Approach

- Continue development of lightweight inflatable booms and deployment control mechanisms.
- Integrate inflatable boom with large membrane, and demonstrate controlled deployment.
- Characterize structural dynamics of membrane structure in vacuum.
- Develop analytical models for predicting deployment dynamics and structural dynamics

10 m Membrane
Structure Testbed

Major Milestones

- Demonstrate controlled deployment of 10 m solar sail in vacuum - 2Q FY03
- Characterize structural dynamics of membrane structure in vacuum chamber - 4Q FY03
- Analytical model to predict structural dynamics - 4Q FY03

Resources

- $175K, 0.6 FTE

Participants

- NASA Langley, ILC Dover, L'Garde, CTD

Deliverables

- Membrane structure testbed for deployment concepts
- Test verified analytical models for predicting dynamics of large membrane structures

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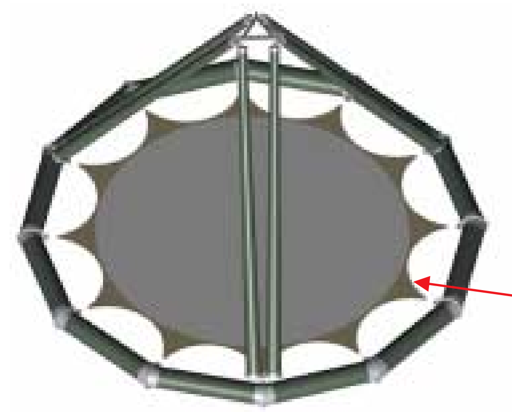
Objective

Demonstrate active control of a tensioned membrane structure to suppress structural dynamics and maintain membrane flatness. Controlling membrane structures is a critical technology for SSP microwave transmitting antenna and reflector.

Approach

- Use Hexapod testbed designed and fabricated in FY-02
- Integrate additional membrane actuators to control static and dynamic shape
- Demonstrate Hexapod closed-loop system performance experimentally



3 m Hexapod membrane aperture testbed

Membrane control actuator

Major Milestones

- Fabricate additional actuators - 1Q FY03
- Complete system ID testing and analysis models - 2Q FY03
- Perform initial closed-loop experiments to control membrane flatness - 3Q FY03

Resources

- $75K, 0.3 FTE

Participants

- NASA Langley, Tennessee State University, ILC Dover

Deliverables

- Membrane aperture testbed to evaluate concepts for active control of membrane flatness and dynamics.
- Control system design approach for membrane structures

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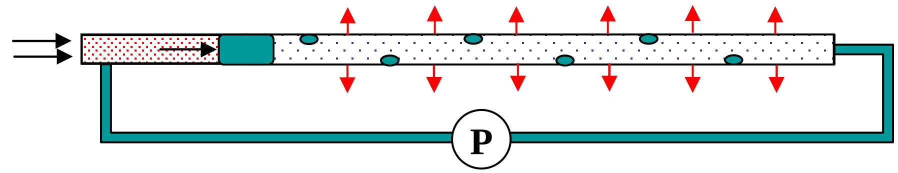
Objective

- Develop efficient thermal management technology to transport and dissipate waste heat from SSP systems.

Approach

- Complete development of lightweight deployable radiator with heat rejection capability > 0.20 kW/kg. Characterize radiator performance in thermal vacuum testing.
- Investigate advanced radiator concept using a translating piston to sweep up droplets condensed on radiator walls. Radiator concept minimizes fluid mass for heat transport over long distances.



Free Piston Radiator

Deployable Radiator

Major Milestones

- Complete thermal vacuum performance testing of deployable radiator - 1Q FY03
- Proof-of-concept demonstration of 5 meter long free piston radiator - 3Q FY03

Resources

- $50K, 0.3 FTE

Participants

- NASA Langley, Lockheed Martin

Deliverables

• Thermal-vacuum performance data for prototype deployable radiator operating at 125ºC. Advances TRL from 4 to 6.

• Experimental demonstration that free piston radiator concept can transfer heat over distances >> 1 meter.

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