NASA Mirror Technology Days
August 17, 2004

Multi-Function, Adaptive, Large Aperture Sensor

presented by:
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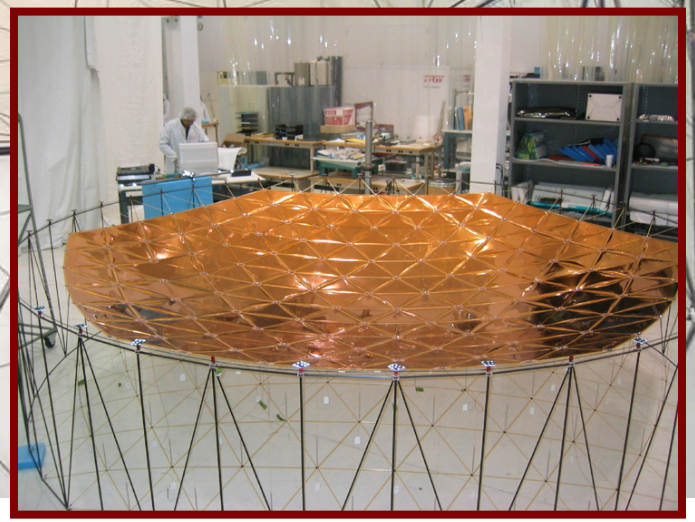
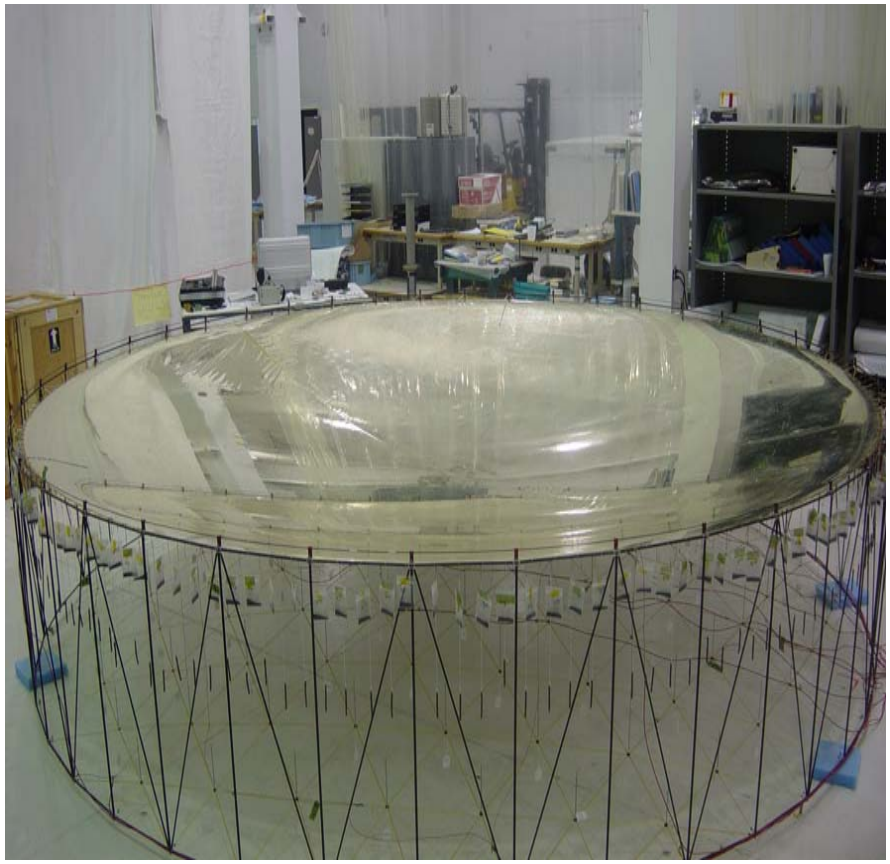
SRS TECHNOLOGIES

NORTHROP GRUMMAN
Space Technology
Astro Aerospace



Agenda

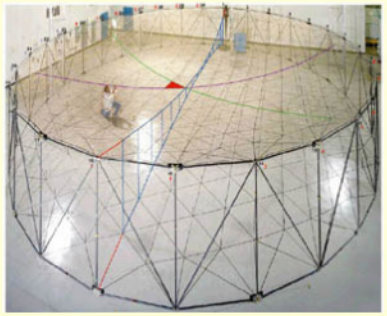
- Present the Concept of Integrating Flight Heritage with R&D Developments
  - Membrane Optic Development
  - Active Global Figure Control of Membrane Mirrors
  - Deployable Support Structure
- Provide a Background on the status of ultra light optical surfaces
  - Scale
  - Production tolerances
  - Current Uses
- Present Design Studies, Fabrication and Test Results
- Provide Suggestions for Technology Roadmap



Technology Approach

Key Features

- **Space Flown Support Structure**
- **Flight Qualified Materials**
- **High Package Efficiency**
- **Control Authority**
- **Adaptive to Tailored Optical Membrane Materials**



Northrop Grumman Astromesh Structure

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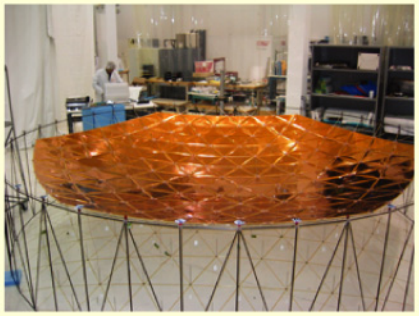

SRS Deployable Membrane Electrodes

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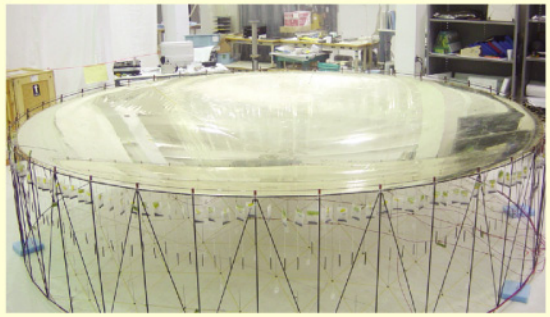
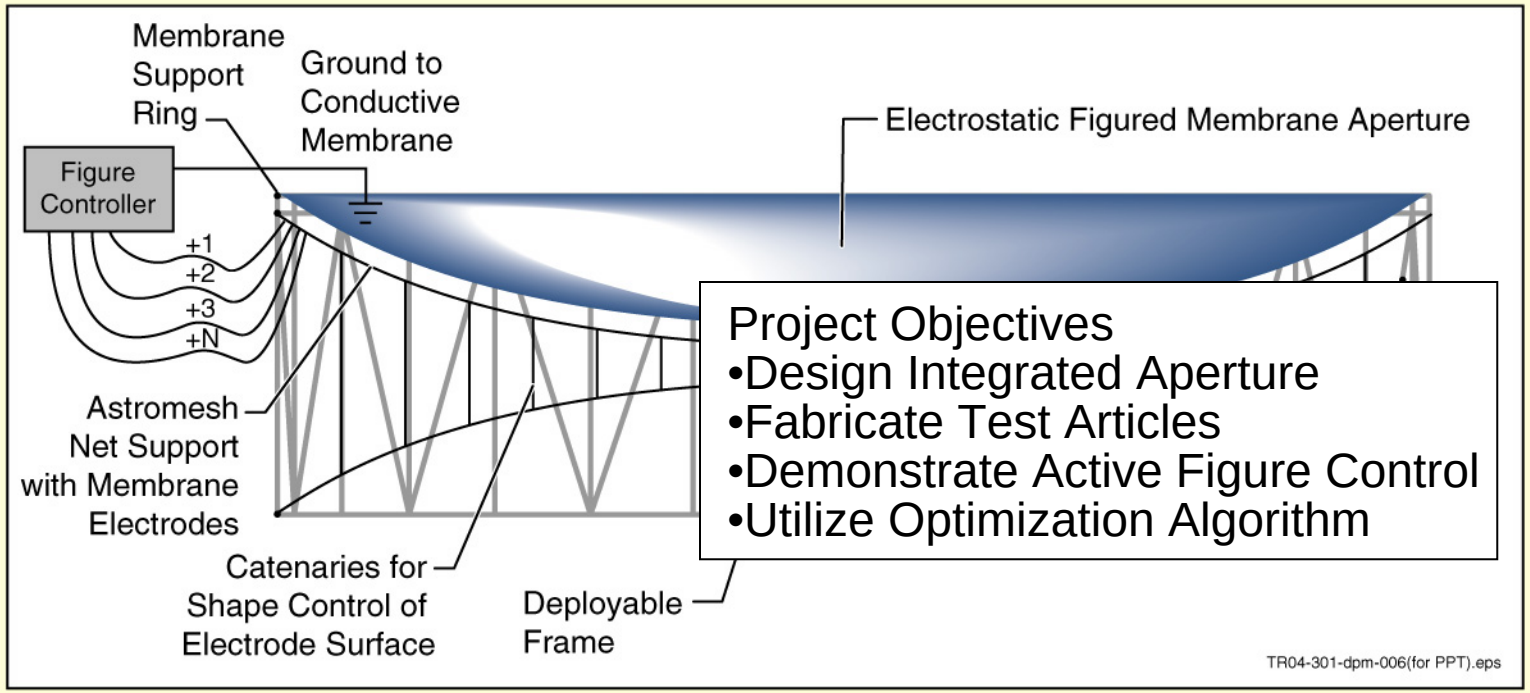


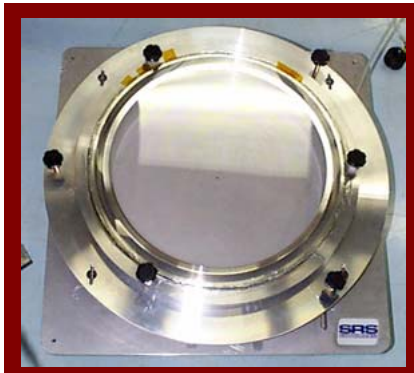
Precision Deployable Polymer Mirror



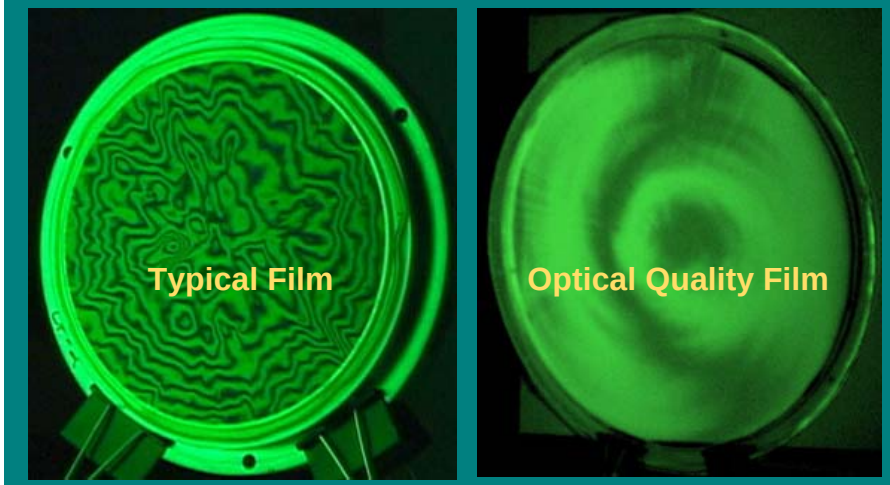
Project Objectives
- Design Integrated Aperture
- Fabricate Test Articles
- Demonstrate Active Figure Control
- Utilize Optimization Algorithm

Technology Background

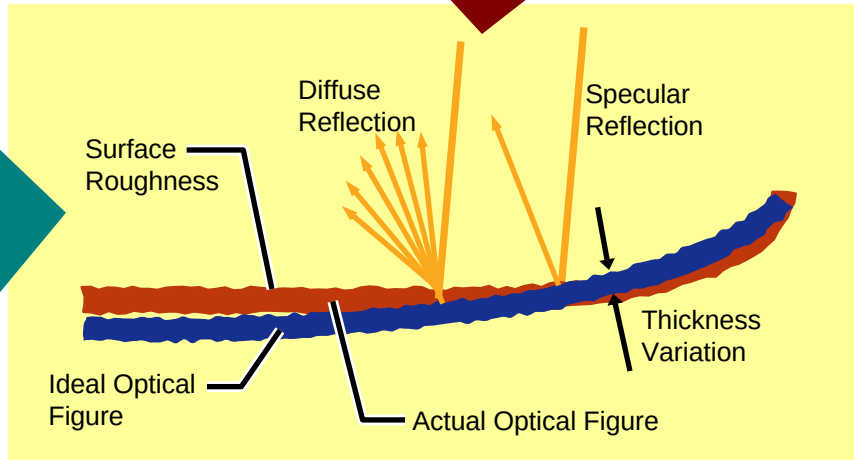
- Materials Development has improved over last 6 years
  - Flight of Large Area on GEO Sats
  - Production Enhancement (Lamda/20, 1.5 nm surface)
- Technology Development
  - Large Apertures
  - Flat Membrane for Radar/Communications



17″ Diameter Membrane at NASA for Testing (Diamond Turned Mount)



Film Castings With Subwavelength Thickness Variation



- Significant Milestones Have Been Achieved for Manufacturing Films With Specular Uniform Surfaces
- Static and Dynamic Global Figure Control Are Required for Further Implementation

Casting System Infrastructure

Precision Membrane Production Using a Custom Manufactured Large-scale Casting System.

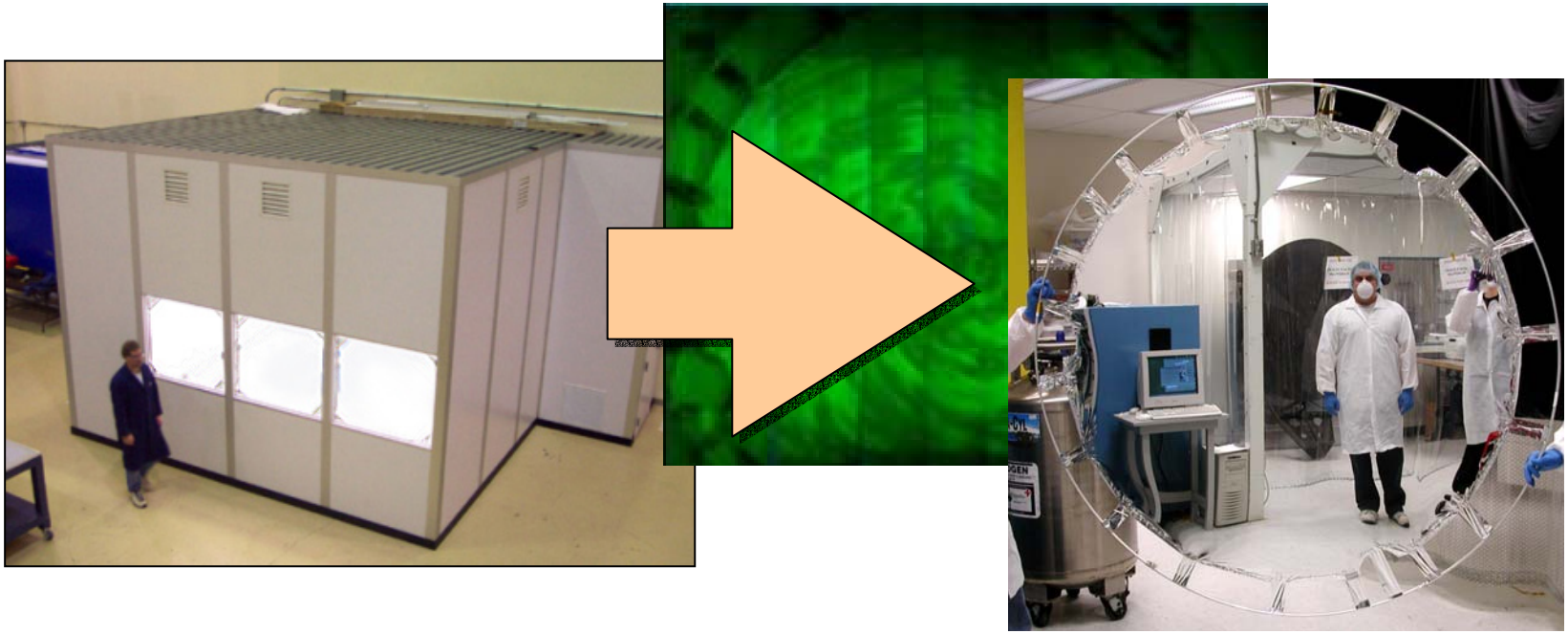
- **1.5-Meter Membrane optical Flats Manufactured Have Been Successfully Coated.**
- **System Designed for Casting up to 3 Meter Flat or Net Shape Mirrors**

•Optical Lens Covers at Select IR Frequencies

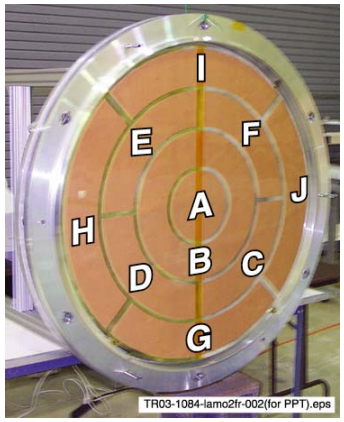
•Lightweight Optical Over-layers SPIE 2003

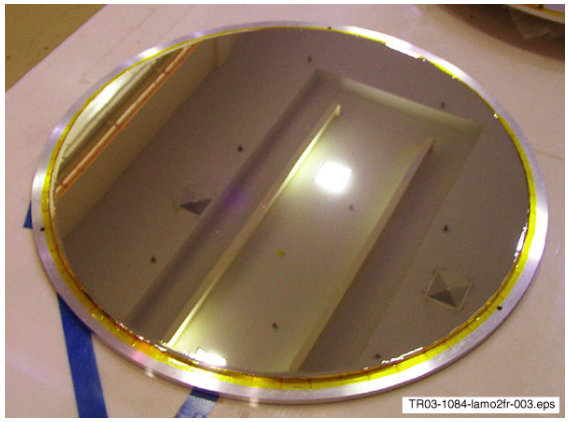
•High Energy Laser Reflectors

•Optical Flats, Beam splitters.

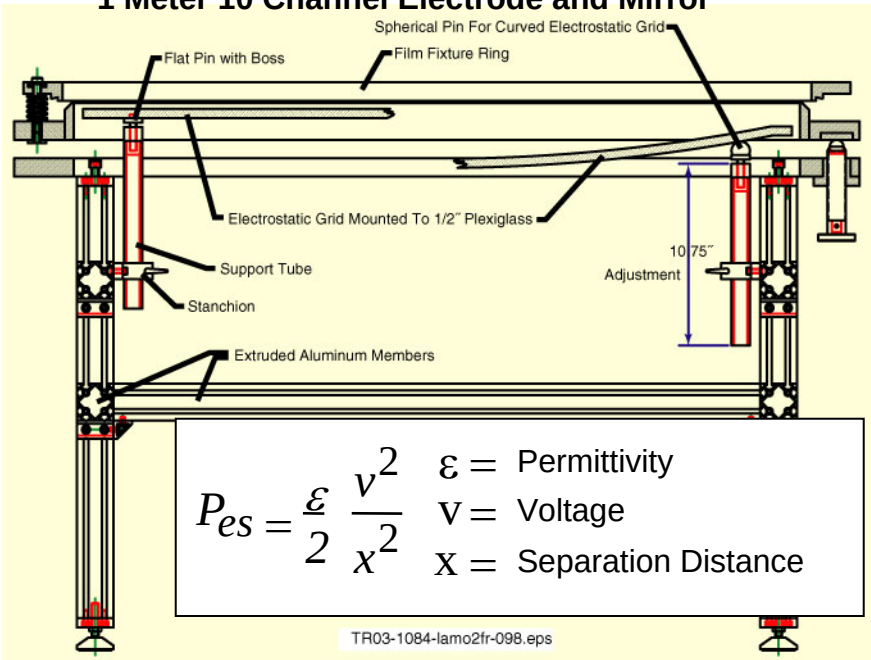


Control System Pathfinder



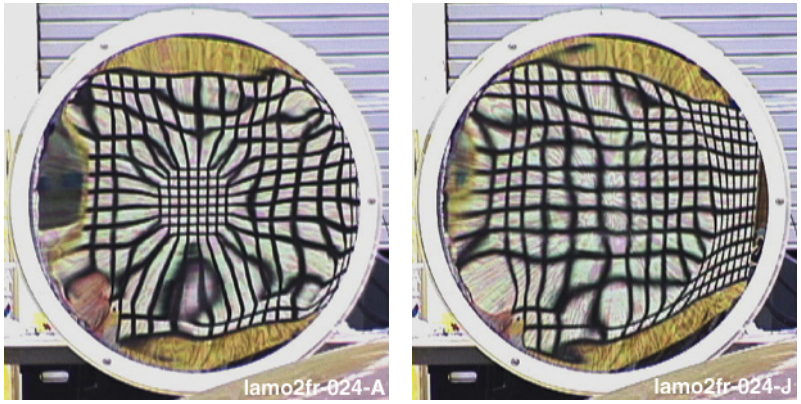


1 Meter 10 Channel Electrode and Mirror



$$P_{es} = \frac{\varepsilon}{2}\frac{v^2}{x^2}$$

$\varepsilon =$ Permittivity
$v =$ Voltage
$x =$ Separation Distance



Actuator Influence Testing

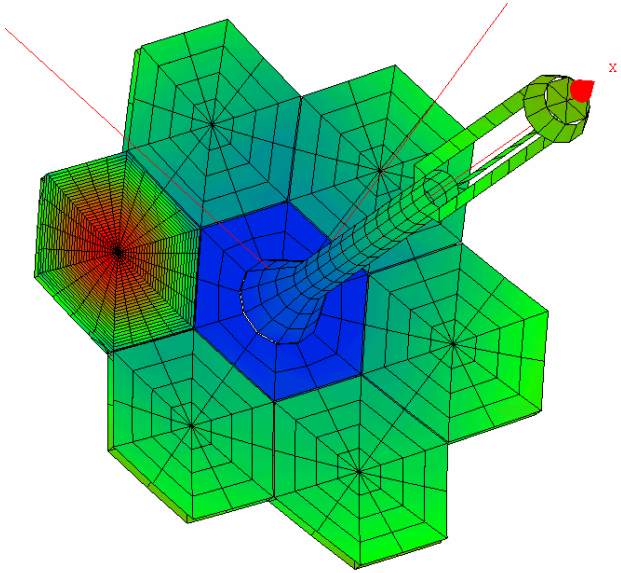
Radius of Curvature Adjustment

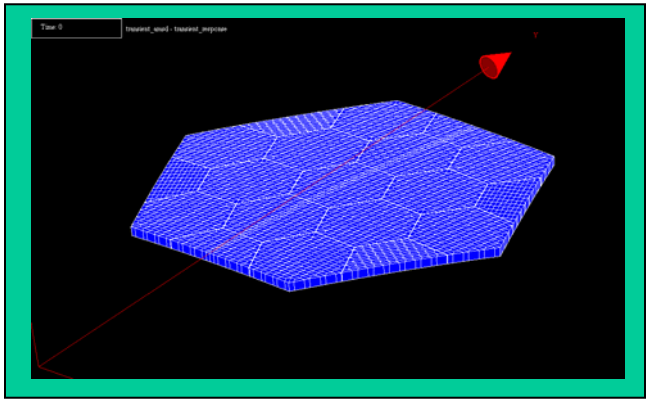
Results

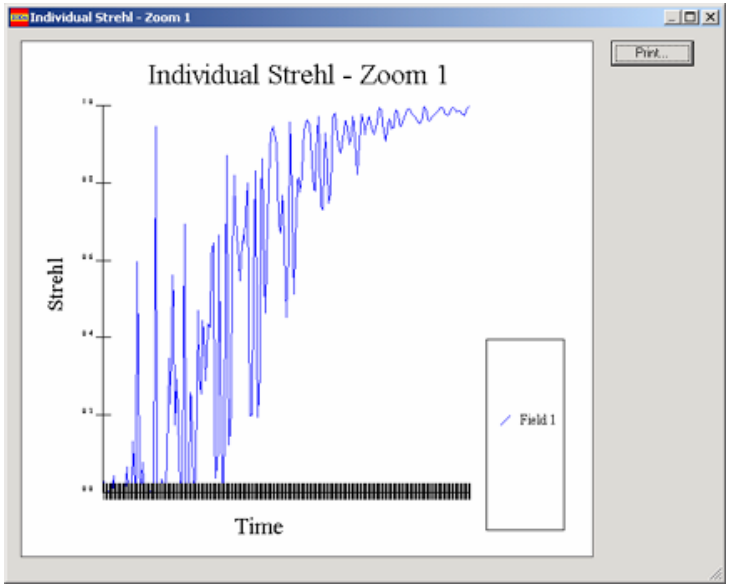
- **Radius of Curvature (ROC) Adjustable from Infinity to 15 Meters**
- **Best Image Achieved at 17 Meters ROC**
- **Dynamically Stable at All Settings**
- **Limited Arcing at Maximum Settings (No Damage to Film)**
- **High Stress Level compared to end item use**

Opto-Mechanical Design

- NASA/SRS Developed Integrated Optical Design (IODA) Software Used for Design Analysis
- Supports Linear and Non Linear FEM Analysis (NASTRAN and ALGOR)
- IODA Used for Evaluation of Electrode Configuration, Generation of Influence Functions, and Control Point Estimates

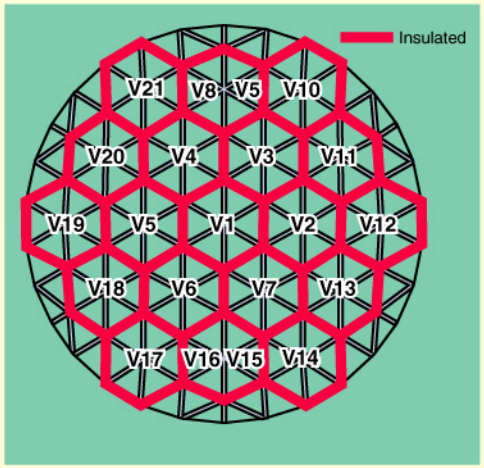


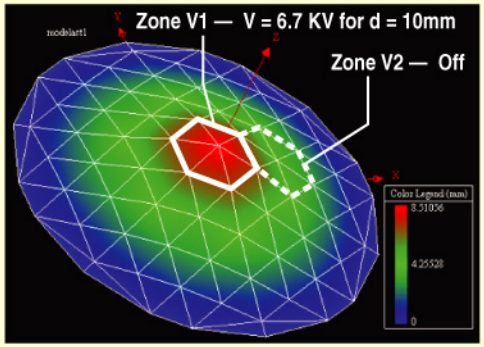


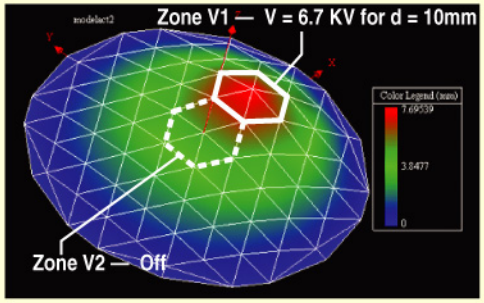


Electrode Density and Layout

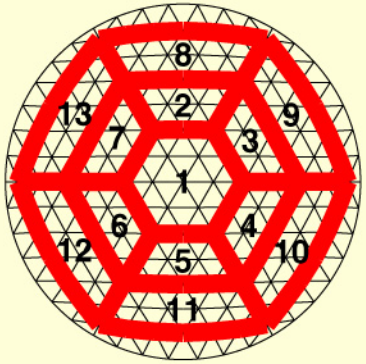
- Several Electrode Layouts Considered
- 13 Channel Configuration Selected for Addressing Primary Spherical Aberration and Cost
- Hex Pattern Would Be Used for Higher Order Control
- Test Configuration Could Accommodate Up to 216 Independent Control Actuators



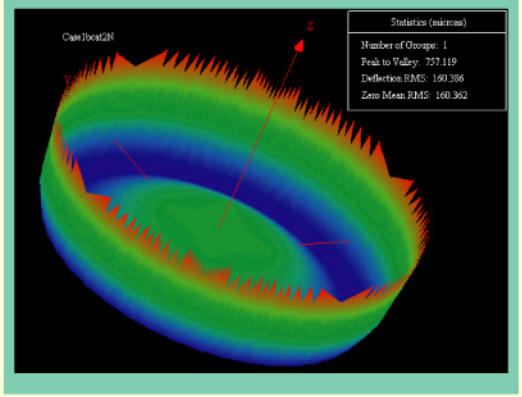




Iso Potential Regions for 13 Channel Design



		5-Meter Flat at 4,750 Volts	5-Meter f/2 at 3,000 Volts
Zernike (Fringe Set)	Z_1 (Piston)	29,545.0	-875
	Z_4 (Focus)	28,614.0	303
	Z_9 (1st Order Spherical)	1,143.0	315
	Z_{16} (2nd Order Spherical)	121.0	209
	Z_{25} (3rd Order Spherical)	3.2	94



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Pre-Test Modeling of 13 Channel Test Configuration

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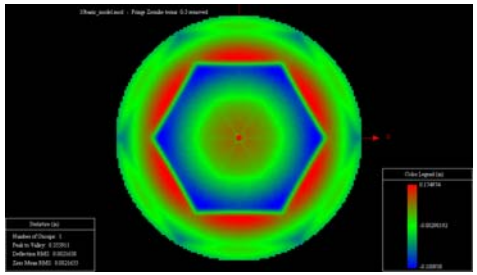
Figure Error MAPS

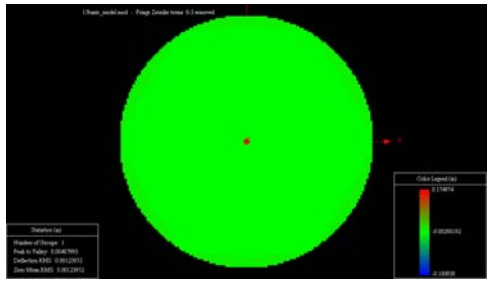
Scale 4,425μm to -4,560μm

RMS = 2,086μm
PV = 9040μm



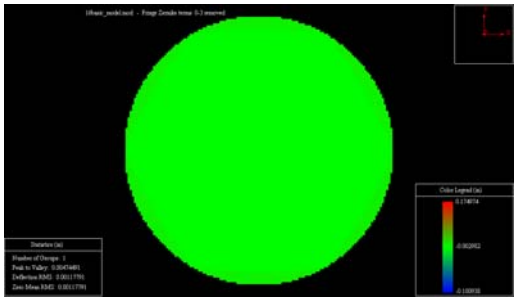
Baseline Uncorrected Case

RMS = 31.48μm
PV = 123.9μm



1st Iteration Correction

RMS = 29.9μm
PV = 120.5μm



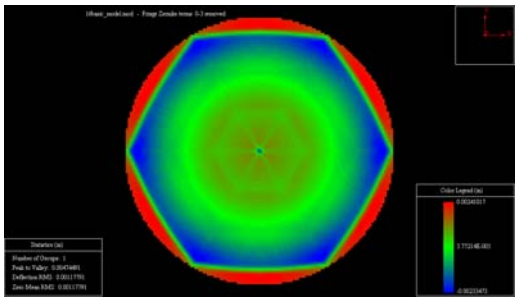
2nd Iteration Correction

Actuator Voltage Settings

	Center Ring	Middle Ring	Outer Ring
Baseline Case	6.50kv	5.45kv	2.40kv
IODA Iteration 1	4,82kv	4.17kv	3.30kv
IODA Iteration 2	4.82kv	4.22kv	3.26kv

Summary of Results

- **IODA Used to Predict Optimum Actuator Settings for 13 Channel Design**
- **98% Improvement Predicted Using Initial Prediction**
- **2nd Iteration Resulted in Little (0.5%) Additional Figure Improvement**

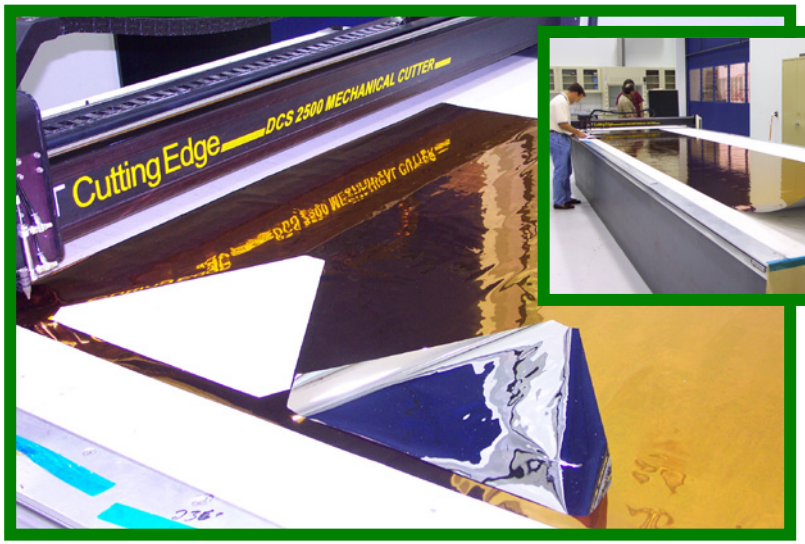


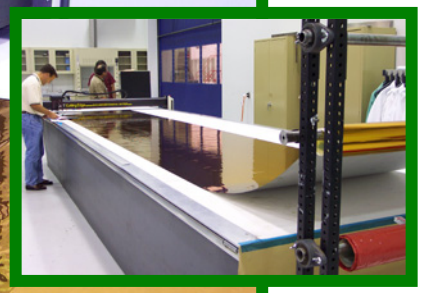
2nd Iteration Correction

Scale +60 μm to -60 μm

Predicted Figure Error Less Than 10 Microns Over 80% of Aperture

Electrode/Astromesh Integration Procedure

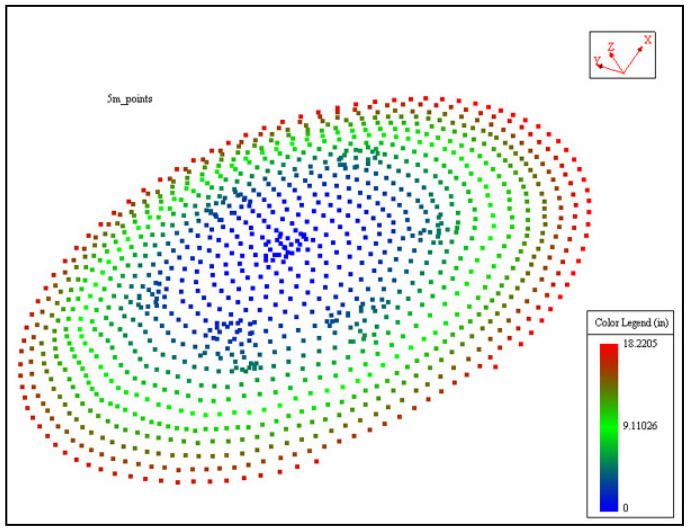




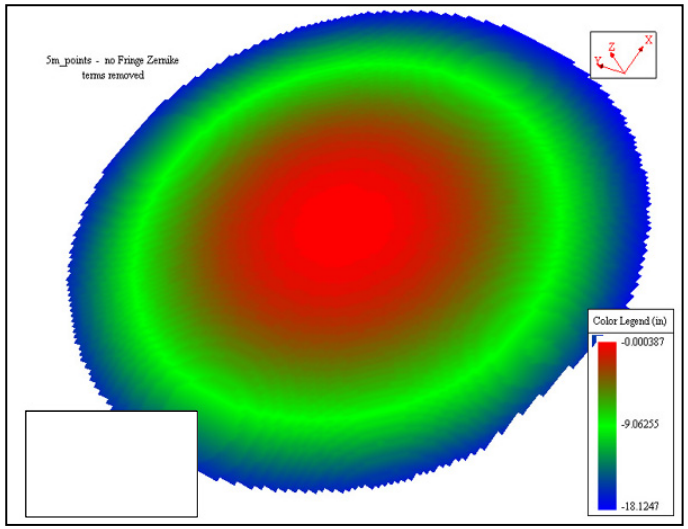
- **Laser Cutting of Electrodes**
- **Electrodes Attached to Front Net Prior to Tensioning**
- **Nets Integrated with Astromesh Structure**
- **Tie Assemblies Tensioned to Preload Nets**
- **Shape Characterization Testing Performed**
- **Control System Integration**

Note: Labor Intensive Initial Process

System Testing

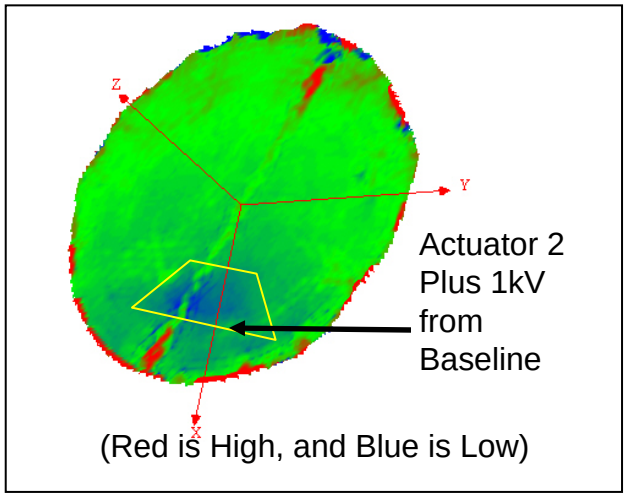


Photogrammetry Points Cloud



Data Displayed in Uniform Grid Format

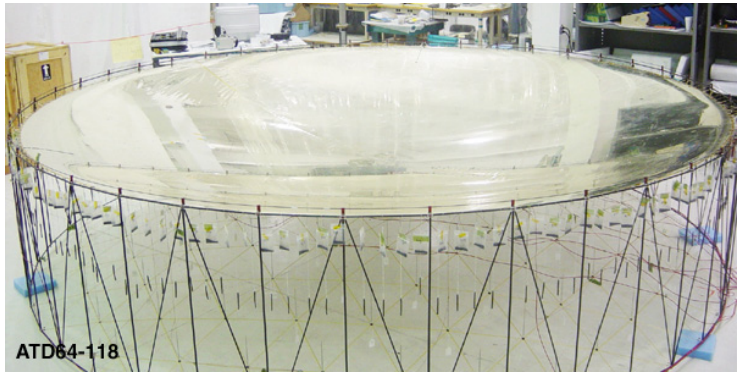
- **Vstars Photogrammetry System Used for Metrology**
- **Testing Performed to Generate 13 Influence Functions**
- **Data Reduction / Figure Optimization Using IODA**



Zernike Surface -
Rigid Body Terms

Influence Function for Actuator 2

System Test Results



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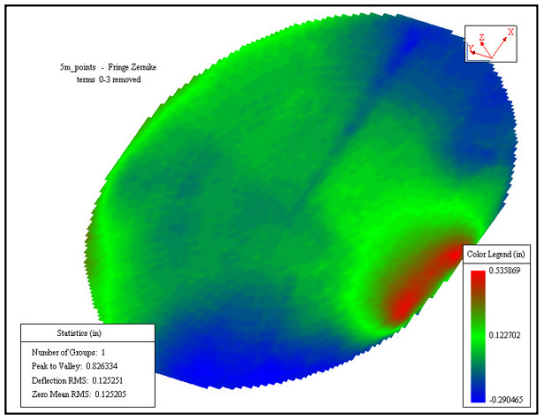


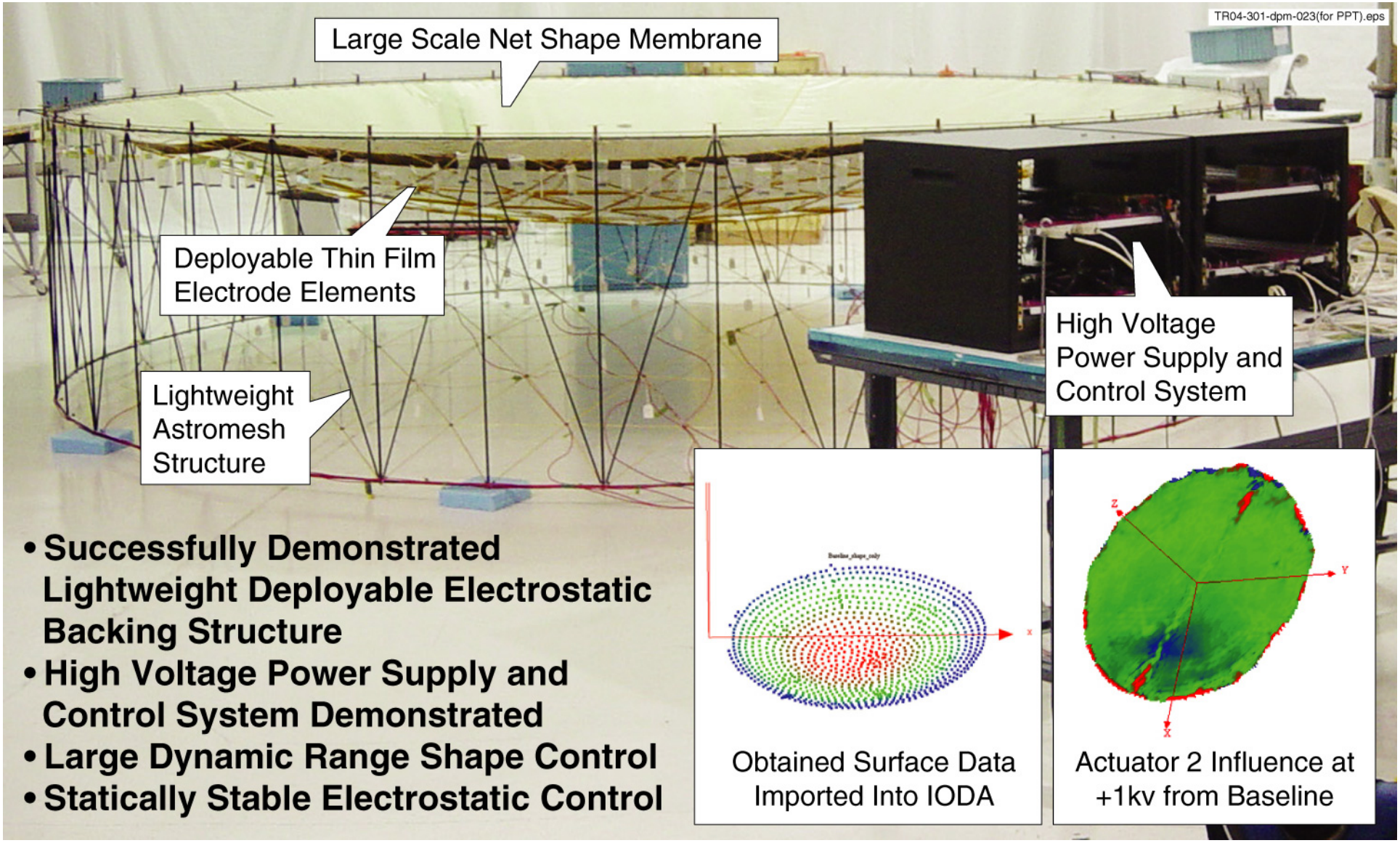
Results

- Best Fit Electrode Voltages 6.5kv, 5.45kv, 2.4kv for Inner, Middle, and Outer Rings
- System Response Dynamically Stable Over Full Range of Control Voltage
- Dynamic Range of 10mm+ Demonstrated
- Arcing and Membrane “Latch-Up” Only Occurred During Initial Set-Up and Caused No Damage
- Measured Figure Errors Dominated by Seam and Astigmatism Caused by Pre-Tensioning Error, Full Aperture RMS Error 1.1 mm;

Conclusions

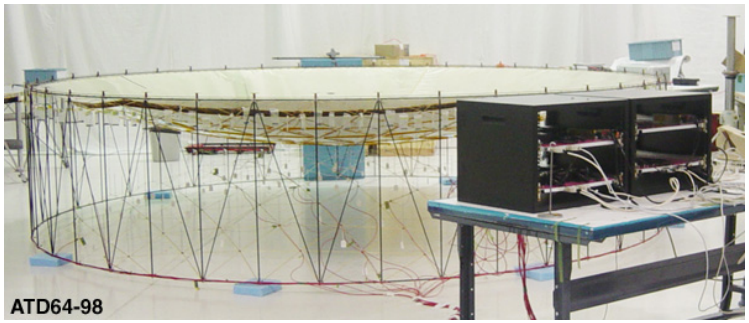
- 70% Reduction of Figure Error Compared to Faceted Electrode.
- Backing Structure, Thin Film Electrodes, Power Supplies, and Controls Work Well. Improved Membrane and Pre-Tensioning Device Required to Achieve Design Potential

Final Test Configuration



- **Successfully Demonstrated Lightweight Deployable Electrostatic Backing Structure**
- **High Voltage Power Supply and Control System Demonstrated**
- **Large Dynamic Range Shape Control**
- **Statically Stable Electrostatic Control**

Large Deployable Membrane Reflector System



5-Meter Ground Test Article

- Successfully Demonstrated Lightweight Deployable Electrostatic Backing Structure
- High Voltage Power Supply and Control System Demonstrated
- Large Dynamic Range Shape Control
- Statically Stable Electrostatic Control

System Facts

- Areal Density
  - 5-Meter Ground Test Article 1.015 kg/m^2 (13 Channels)
  - 5-Meter Flight Weight 1.6 kg/m^2 (Estimate, 216 channels)
  - 20-Meter Flight Weight 0.7kg/m^2 (Estimate, 216 channels)
- Power Requirements
  - 13 channel 16 Watts
  - 216 channels 260 Watts
- 5-Meter Estimated 1st Mode 17Hz at Design Preload (Fixed Edges)
- Deployable Support Structure Flight Proven at 12-Meter; Scalable to 50-Meters Within Current Launch Vehicle Constraints

Technology Payoff

Future Enhancements

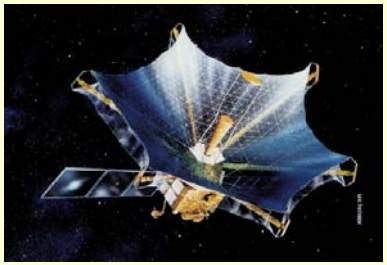
Membrane Control
- Scale-Up of Optical Quality Membrane Manufacturing > 2-Meters
- Packaging / Storing
- Flight Interface

Control System Refinements
- 13 Channels → 216 Channels
- Closed Loop Feed Back and Control
- Flight Weighting

Enhanced Polyimide Material Development
- Reduced Coefficient of Thermal Expansion
- Improved UV/AO Protection
- Integrated Metrology
- Large Scale Coating

Deployable AstroMesh Structure
- Catenary Support Ring
- Membrane Management
- Electrode Wiring

Ultra Light Weight Deployable Mirror



Payoff

Technology Improvements
- Lower Mass
- Lower Launch Volume
- Better Figure

Configuration Options
- Larger Aperture
- Higher Orbits
- Smaller Launch Vehicle
- Higher Frequency Operation

Operational Benefits
- Higher Resolution/Gain
- Longer Time Over Target
- Lower Launch Costs
- Higher Bandwidth Available