NASA Mirror Technology Days
August 17, 2004

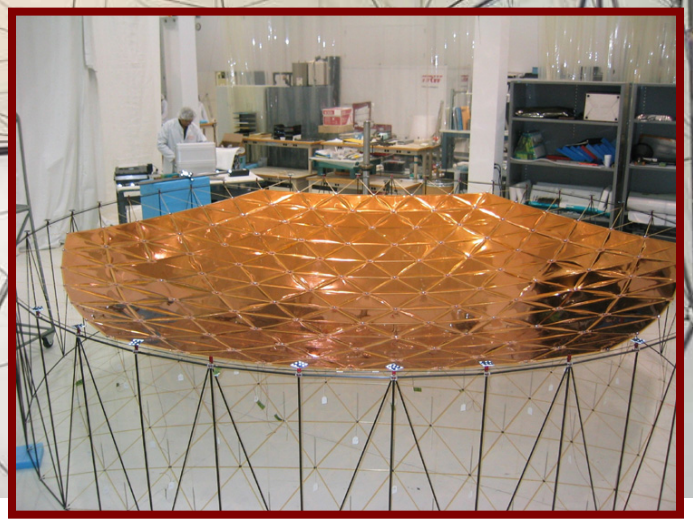
# Multi-Function, Adaptive, Large Aperture Sensor


presented by:
Jim Moore (jmoore @ stg.srs.com)

SRS TECHNOLOGIES

NORTHROP GRUMMAN
Space Technology

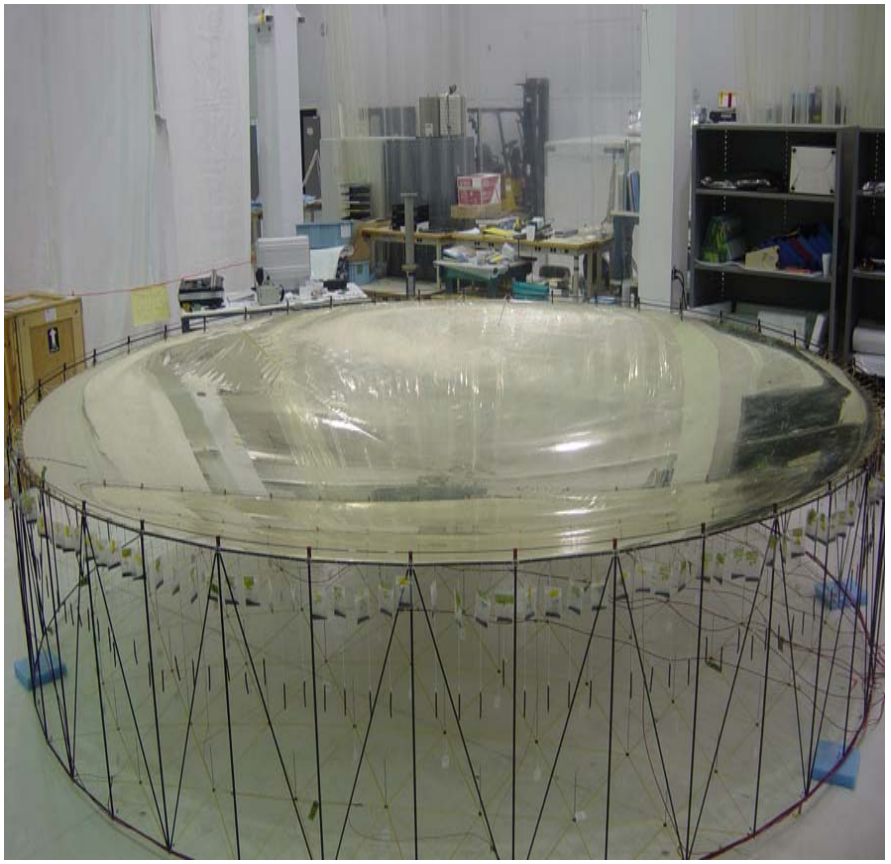
Astro Aerospace

# 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

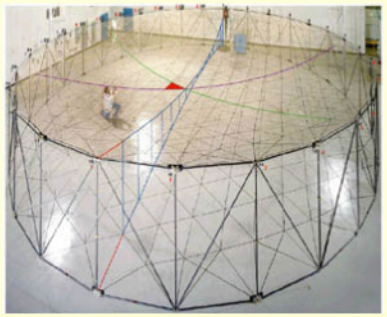


# Technology Approach



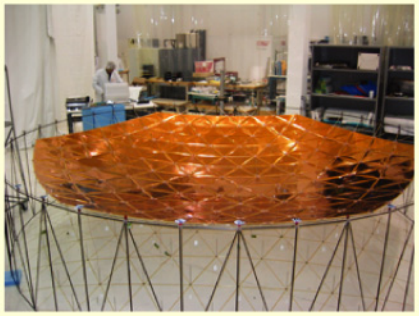
## Key Features

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



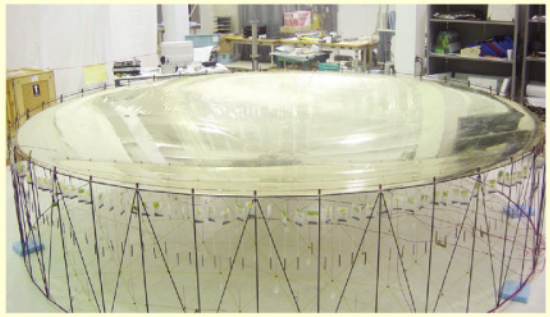
Northrop Grumman Astromesh Structure

+

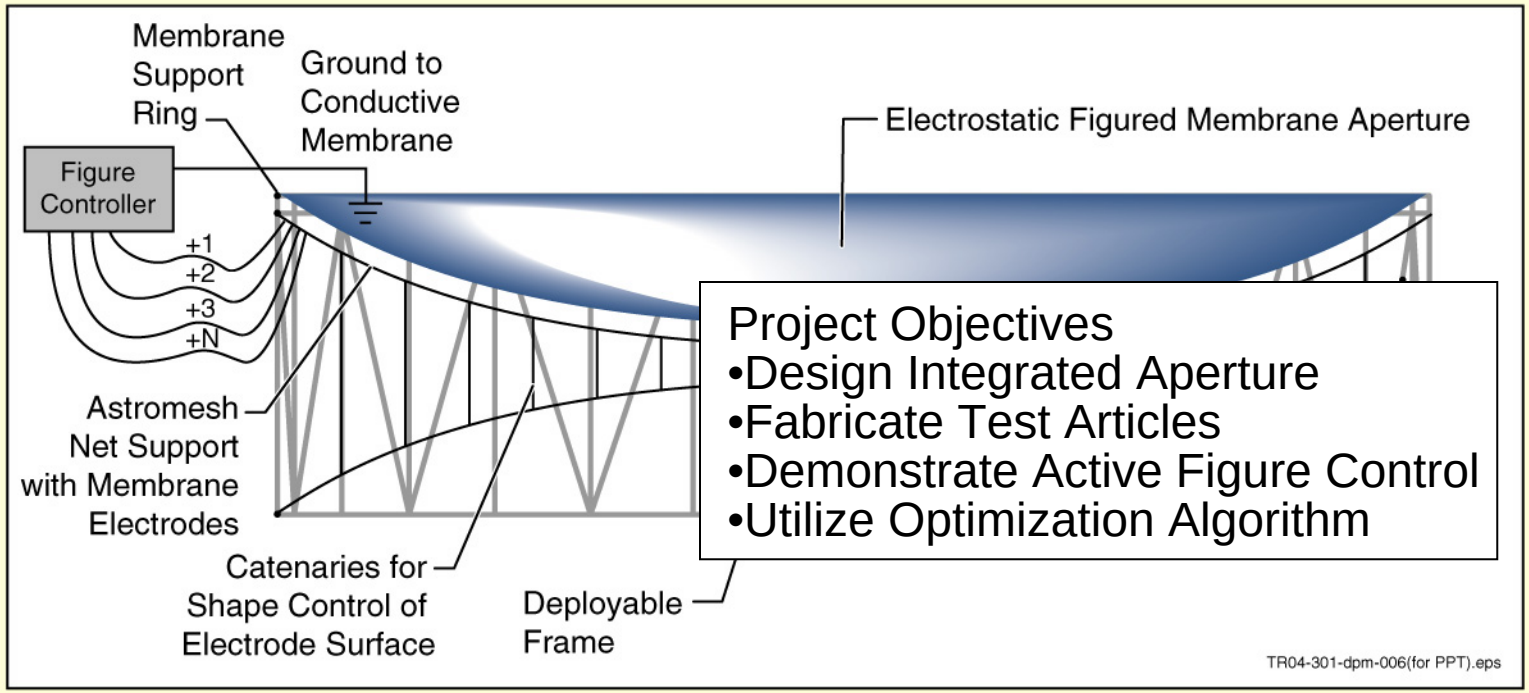


SRS Deployable Membrane Electrodes

+



Precision Deployable Polymer Mirror

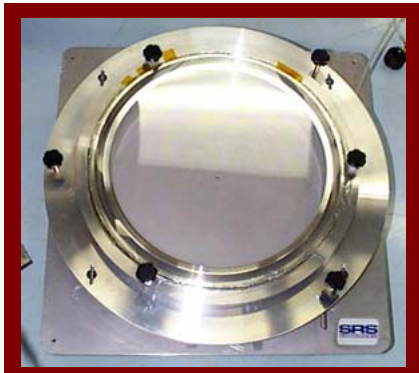



Project Objectives
- Design Integrated Aperture
- Fabricate Test Articles
- Demonstrate Active Figure Control
- Utilize Optimization Algorithm

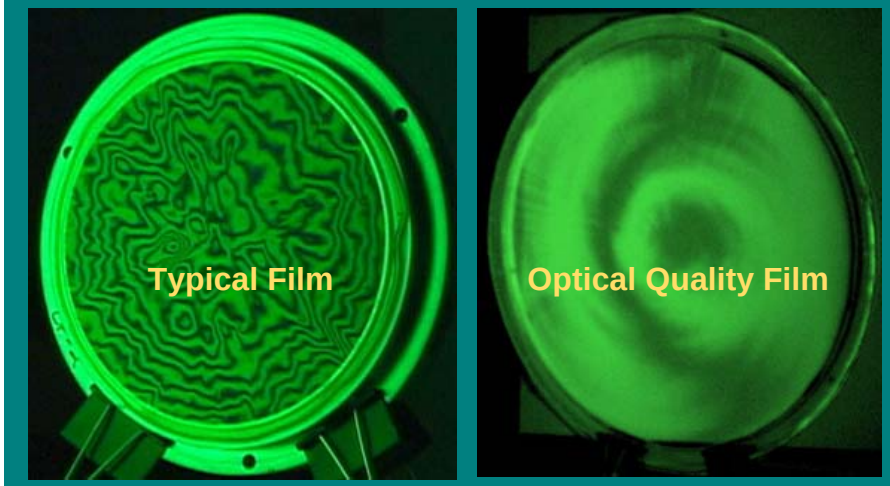
# Technology Background



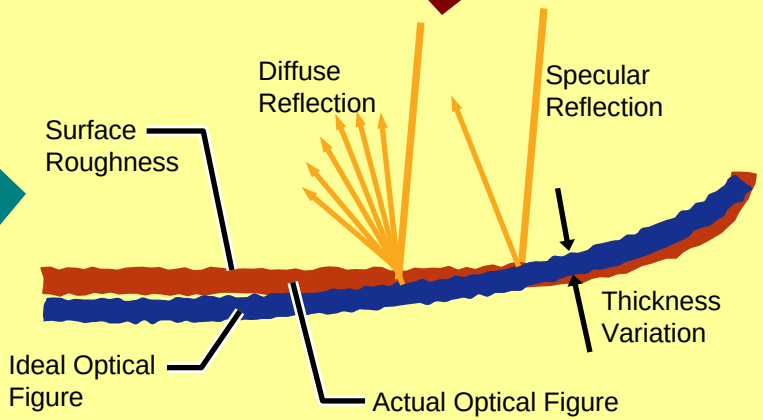
- Materials Development has improved over last 6 years
  - Flight of Large Area on GEO Sats
  - Production Enhancement (Lamda/20, 1.5 nm surface)
- Technology Development
  - Large Apertures
  - Flat Membrane for Radar/Communications



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

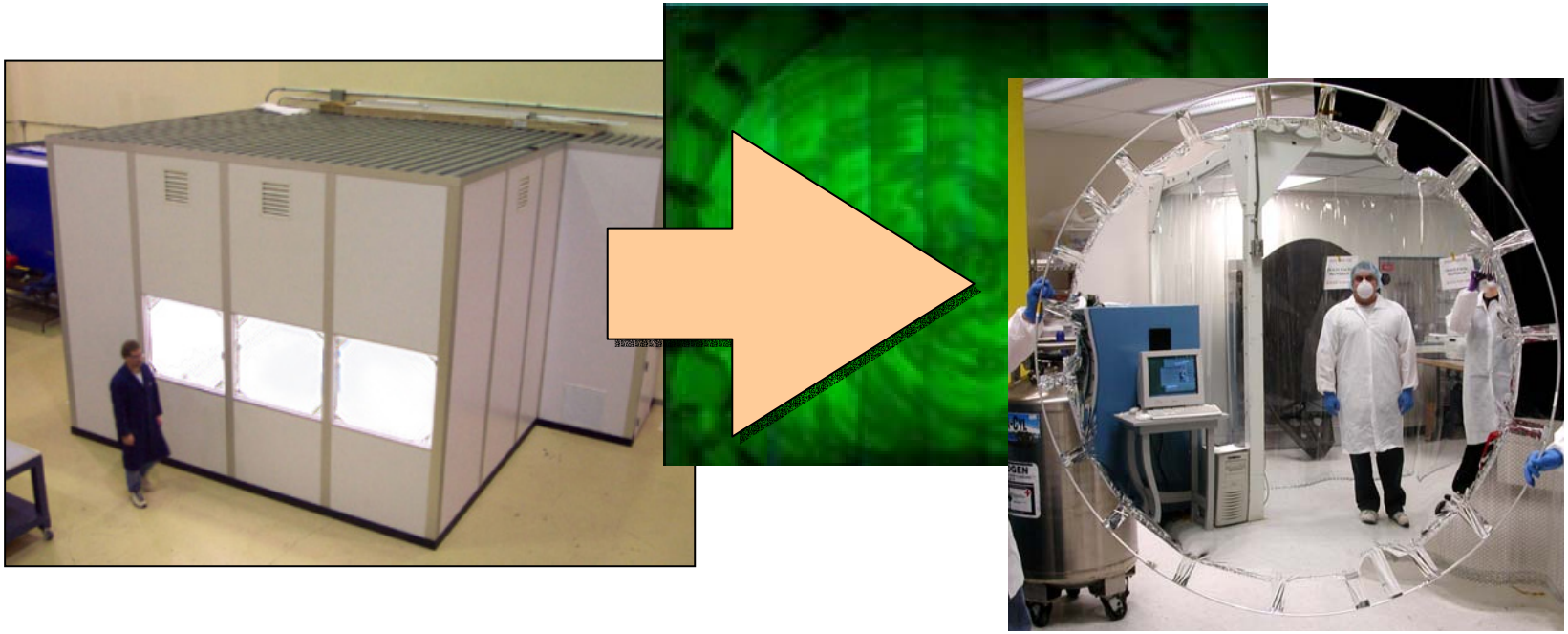
# Casting System Infrastructure



**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**

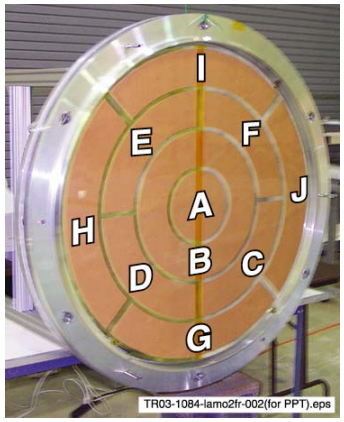
- **Optical Lens Covers at Select IR Frequencies**
- **Lightweight Optical Over-layers SPIE 2003**
- **High Energy Laser Reflectors**
- **Optical Flats, Beam splitters.**

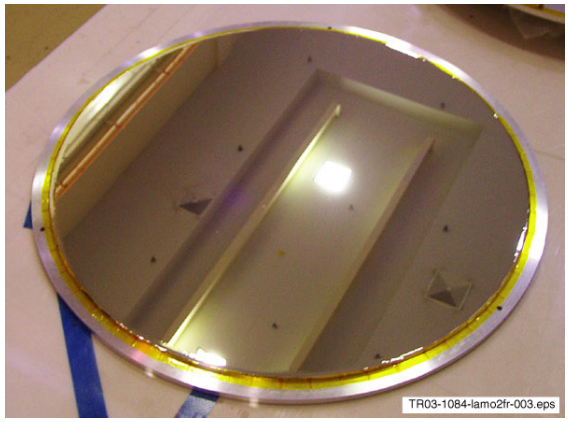


SRS TECHNOLOGIES
www.srs.com

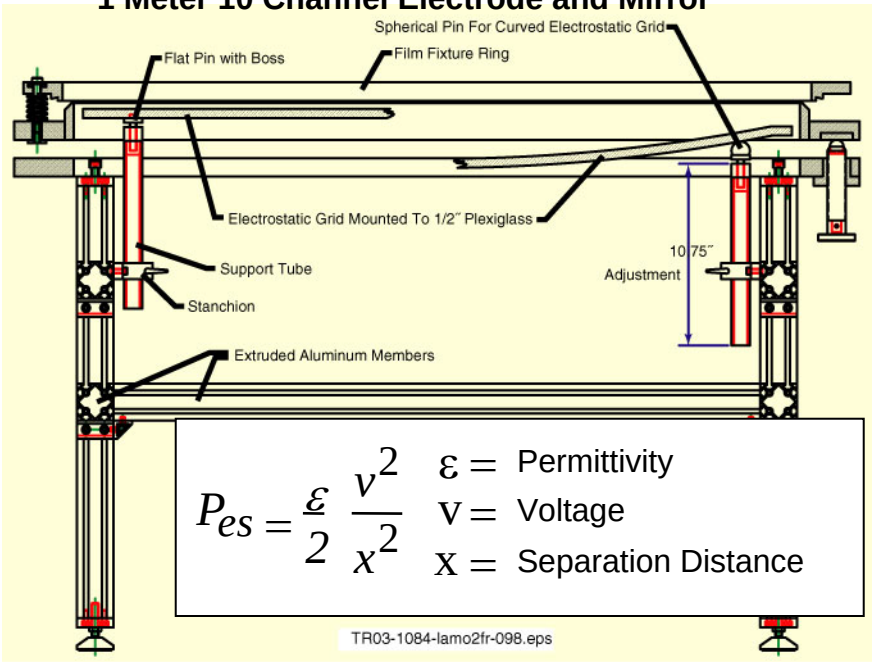
# Control System Pathfinder

NORTHROP GRUMMAN
Space Technology
Astro Aerospace

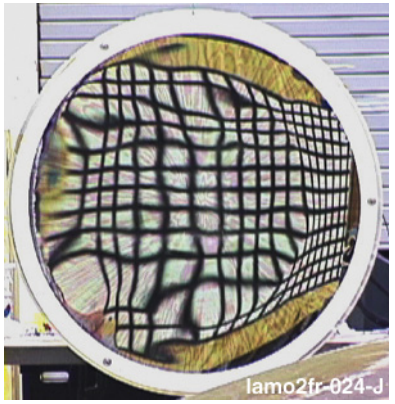


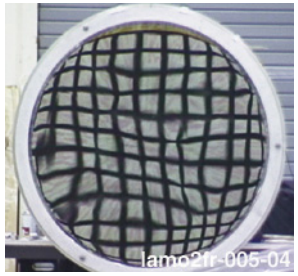

**1 Meter 10 Channel Electrode and Mirror**

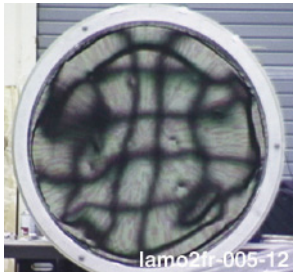







**Actuator Influence Testing**


**Radius of Curvature Adjustment**

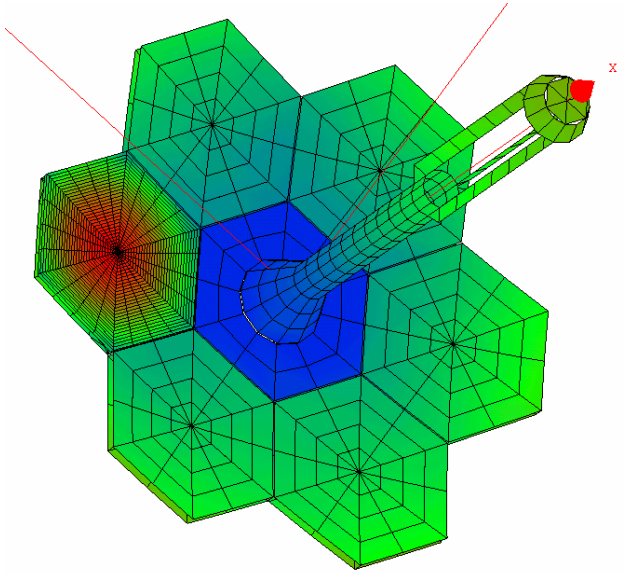
## Results

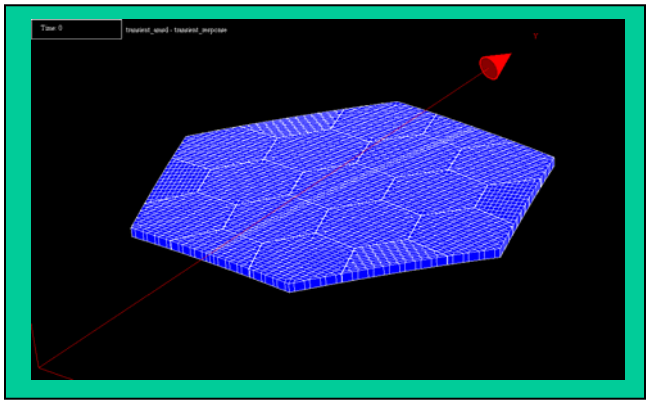
- **Radius of Curvature (ROC) Adjustable from Infinity to 15 Meters**
- **Best Image Achieved at 17 Meters ROC**
- **Dynamically Stable at All Settings**
- **Limited Arcing at Maximum Settings (No Damage to Film)**
- **High Stress Level compared to end item use**

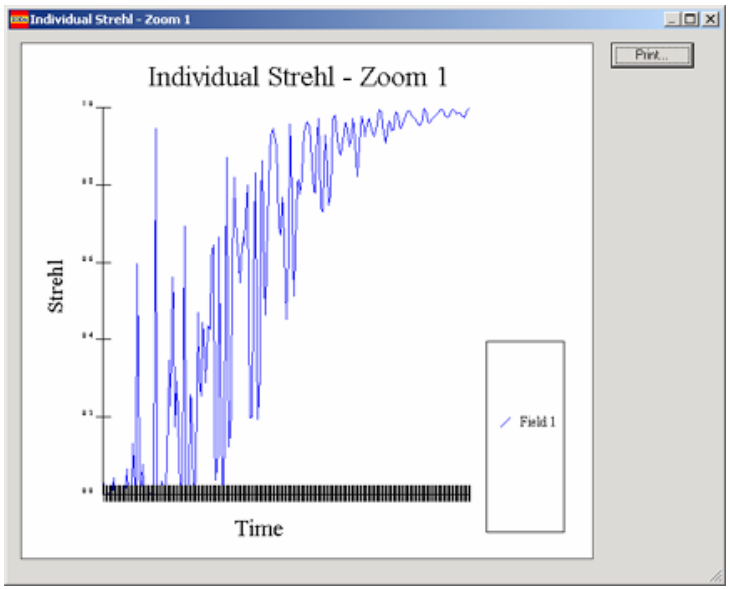
# Opto-Mechanical Design



- 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



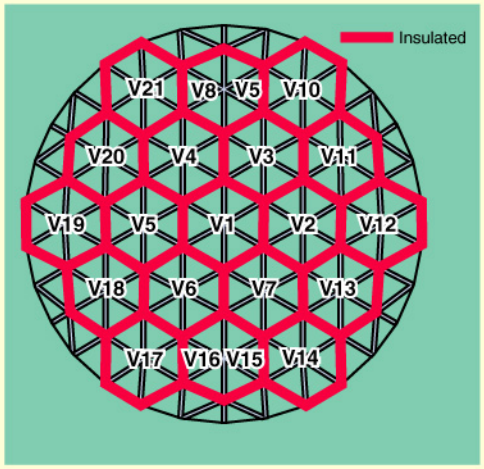


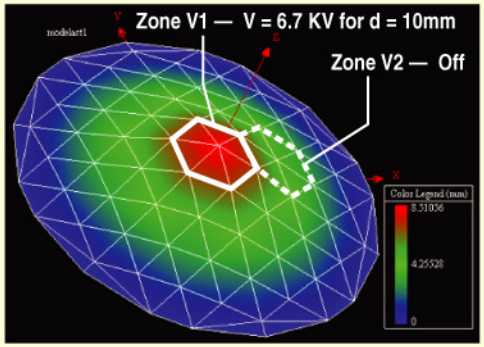


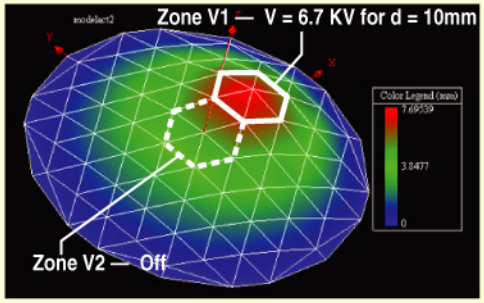
# Electrode Density and Layout



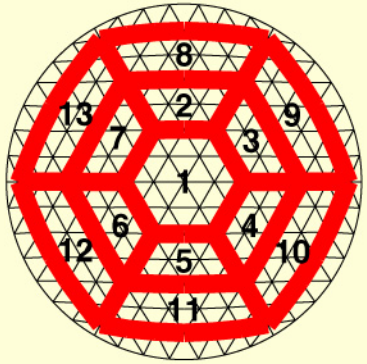
- Several Electrode Layouts Considered
- 13 Channel Configuration Selected for Addressing Primary Spherical Aberration and Cost
- Hex Pattern Would Be Used for Higher Order Control
- Test Configuration Could Accommodate Up to 216 Independent Control Actuators



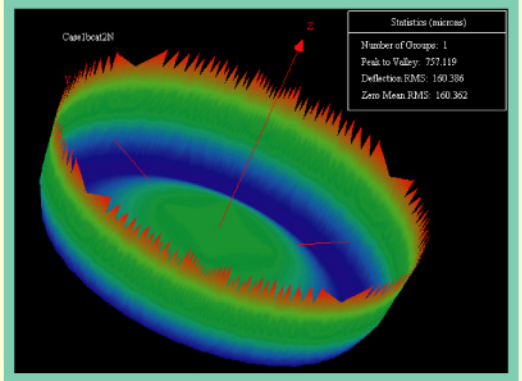




Iso Potential Regions for 13 Channel Design




| | | 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 |




031028Ae1605.eps

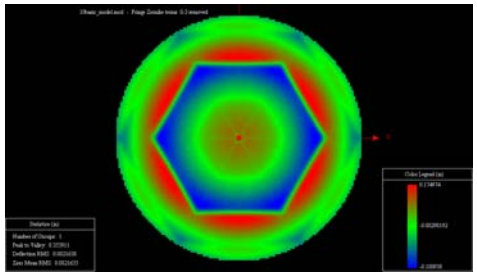
SRS TECHNOLOGIES
www.srs.com

# Pre-Test Modeling of 13 Channel Test Configuration

NORTHROP GRUMMAN
Space Technology
Astro Aerospace

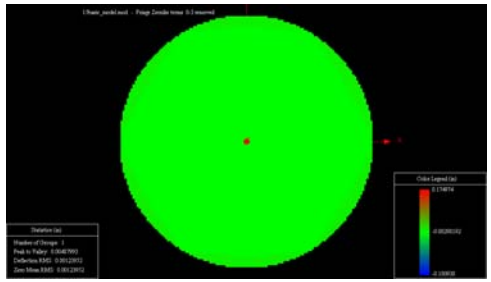
Figure Error MAPS
Scale 4,425μm to -4,560μm

RMS = 2,086μm
PV = 9040μm



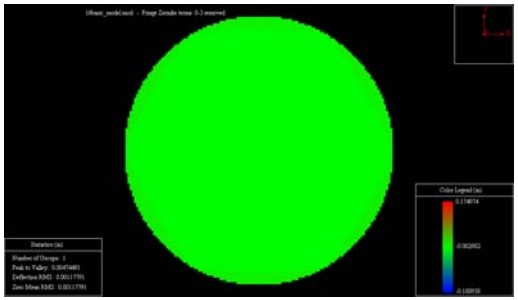
Baseline Uncorrected Case

RMS = 31.48μm
PV = 123.9μm



1st Iteration Correction

RMS = 29.9μm
PV = 120.5μm



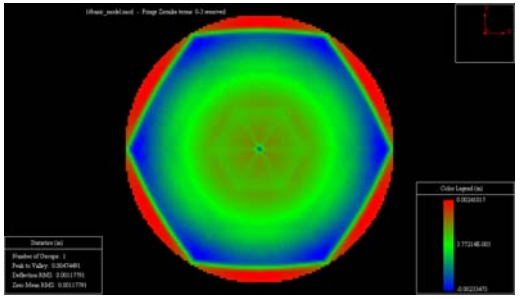
2nd Iteration Correction

## 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**



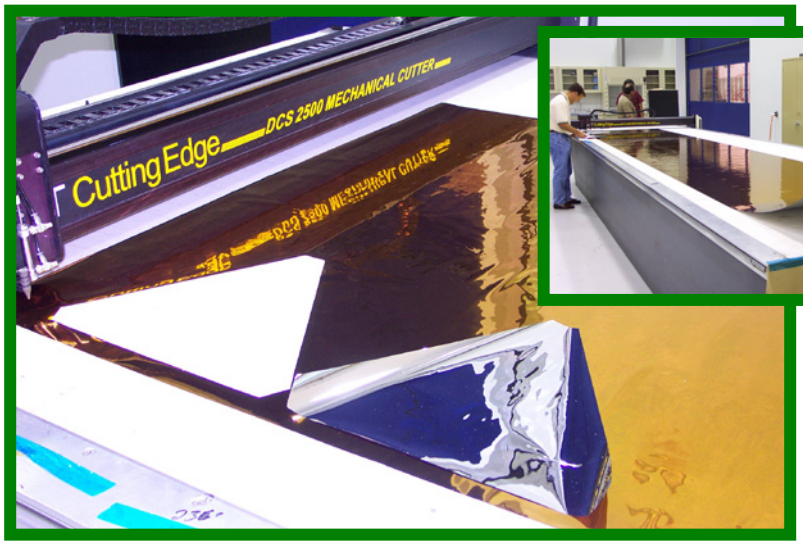
2nd Iteration Correction
Scale +60 μm to -60 μm

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

SRS TECHNOLOGIES
www.srs.com

# Electrode/Astromesh Integration Procedure

NORTHROP GRUMMAN
Space Technology
Astro Aerospace





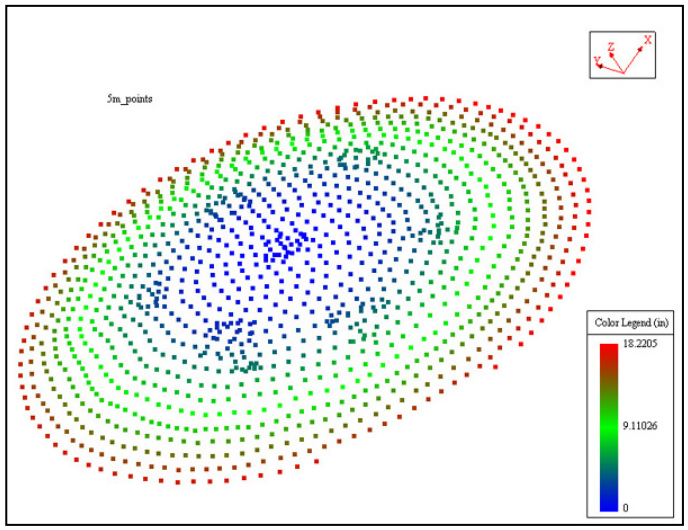


- **Laser Cutting of Electrodes**
- **Electrodes Attached to Front Net Prior to Tensioning**
- **Nets Integrated with Astromesh Structure**
- **Tie Assemblies Tensioned to Preload Nets**
- **Shape Characterization Testing Performed**
- **Control System Integration**

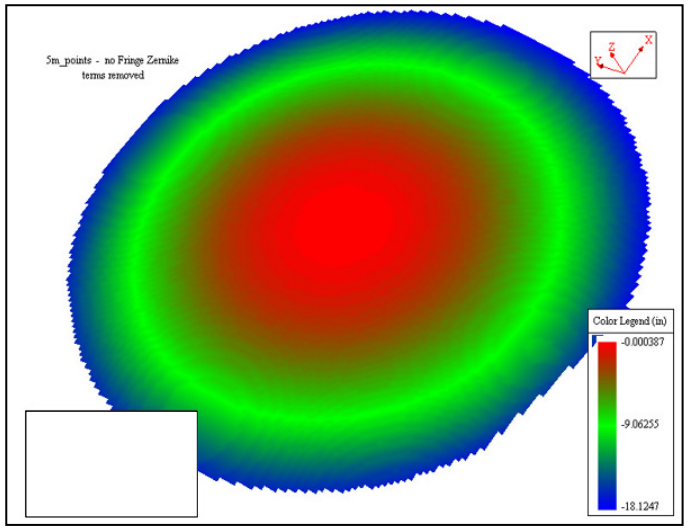
*Note: Labor Intensive Initial Process*

# System Testing



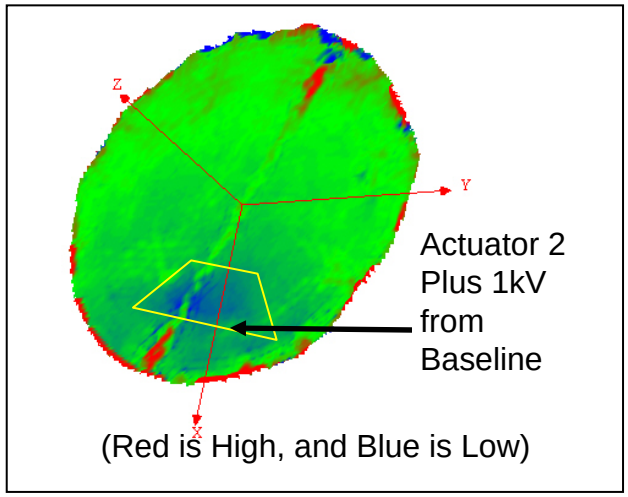



Photogrammetry Points Cloud




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**

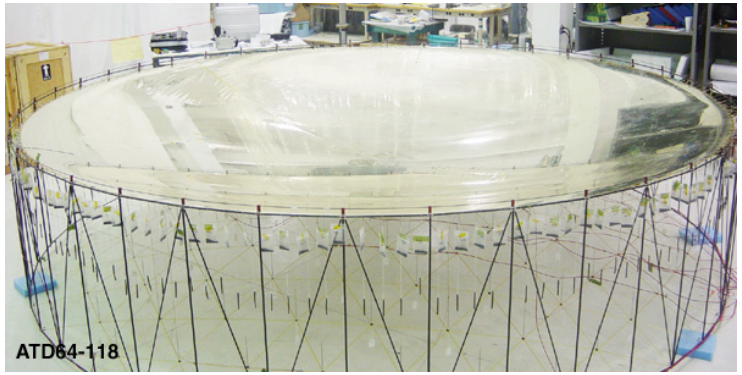



Zernike Surface -
Rigid Body Terms

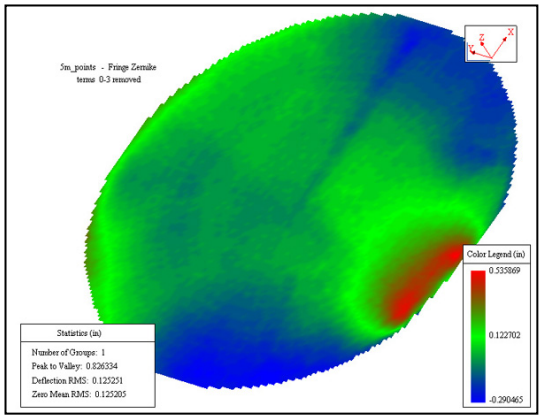
**Influence Function for Actuator 2**

# System Test Results






Video of Spots




## 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



TR04-301-dpm-023(for PPT).eps

Large Scale Net Shape Membrane

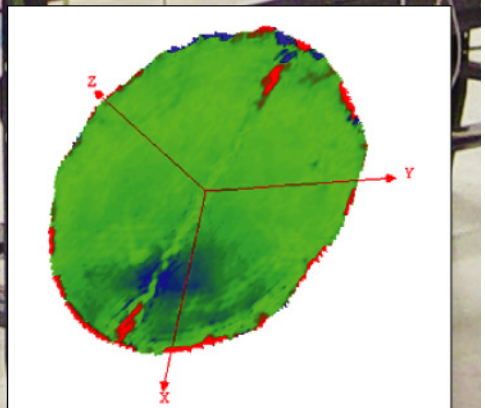
Deployable Thin Film Electrode Elements

Lightweight Astromesh Structure

High Voltage Power Supply and Control System

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

Obtained Surface Data Imported Into IODA

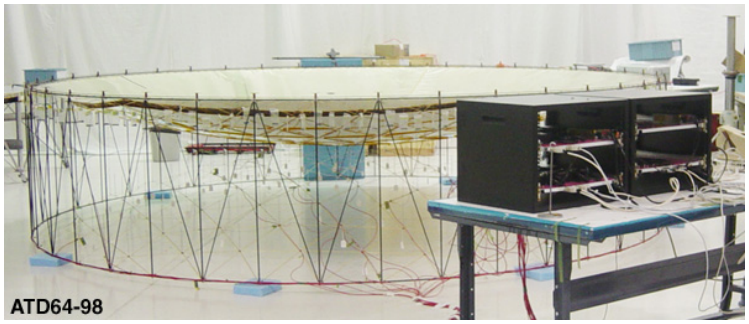



Actuator 2 Influence at +1kv from Baseline

SRS TECHNOLOGIES
www.srs.com

# Large Deployable Membrane Reflector System

NORTHROP GRUMMAN
Space Technology
Astro Aerospace




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

SRS TECHNOLOGIES
www.srs.com

# Technology Payoff

NORTHROP GRUMMAN
Space Technology
Astro Aerospace

## Future Enhancements

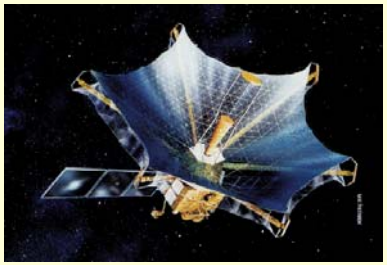
**Membrane Control**
- Scale-Up of Optical Quality Membrane Manufacturing > 2-Meters
- Packaging / Storing
- Flight Interface

**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