Stress Coatings for Large Scale Membrane Mirrors

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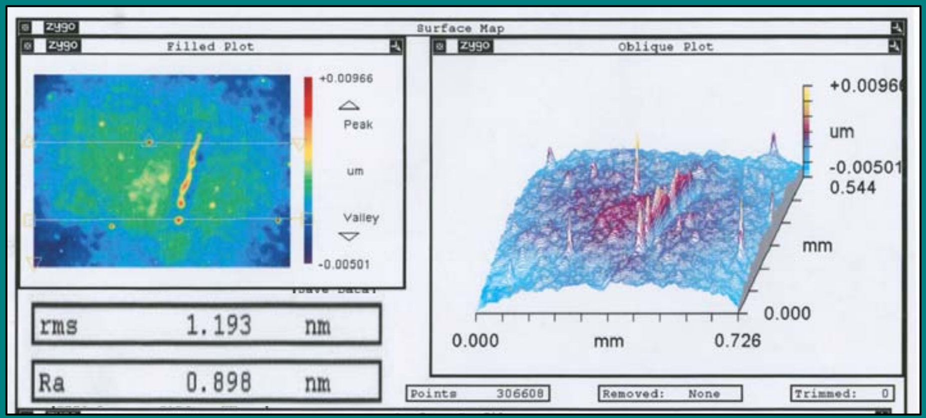
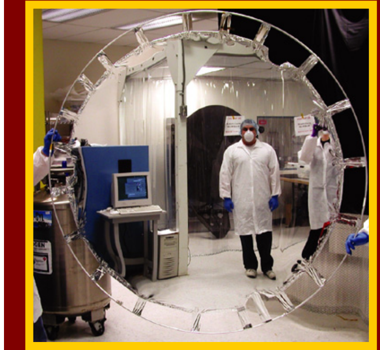
Background

- Pressure Augmented Membrane Mirror Concept
- 0.25m Prototype/Model Correlation
- Stress Coating Distribution
- SRS Testing of 0.75m Membrane Mirror
- Summary and Conclusions

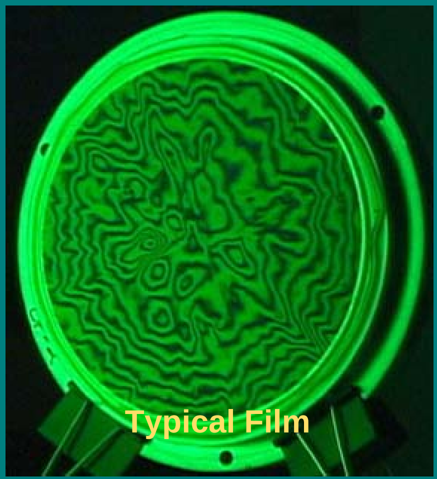
Technology Developed for Precision Membrane Mirror Systems

< 1.5 Nanometer RMS Surface Roughness for Optical Films

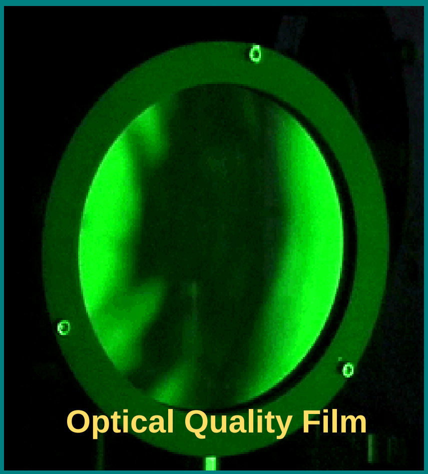




1.5m CP1-DE membrane simply supported by a non-uniform ring

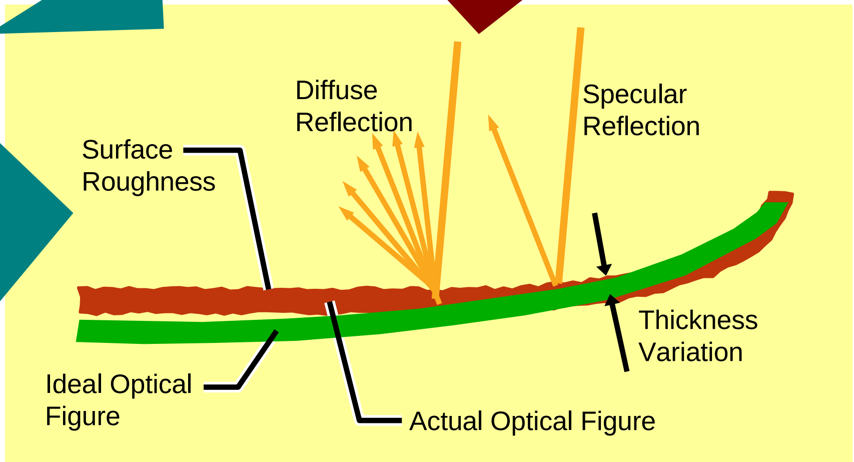


Typical Film



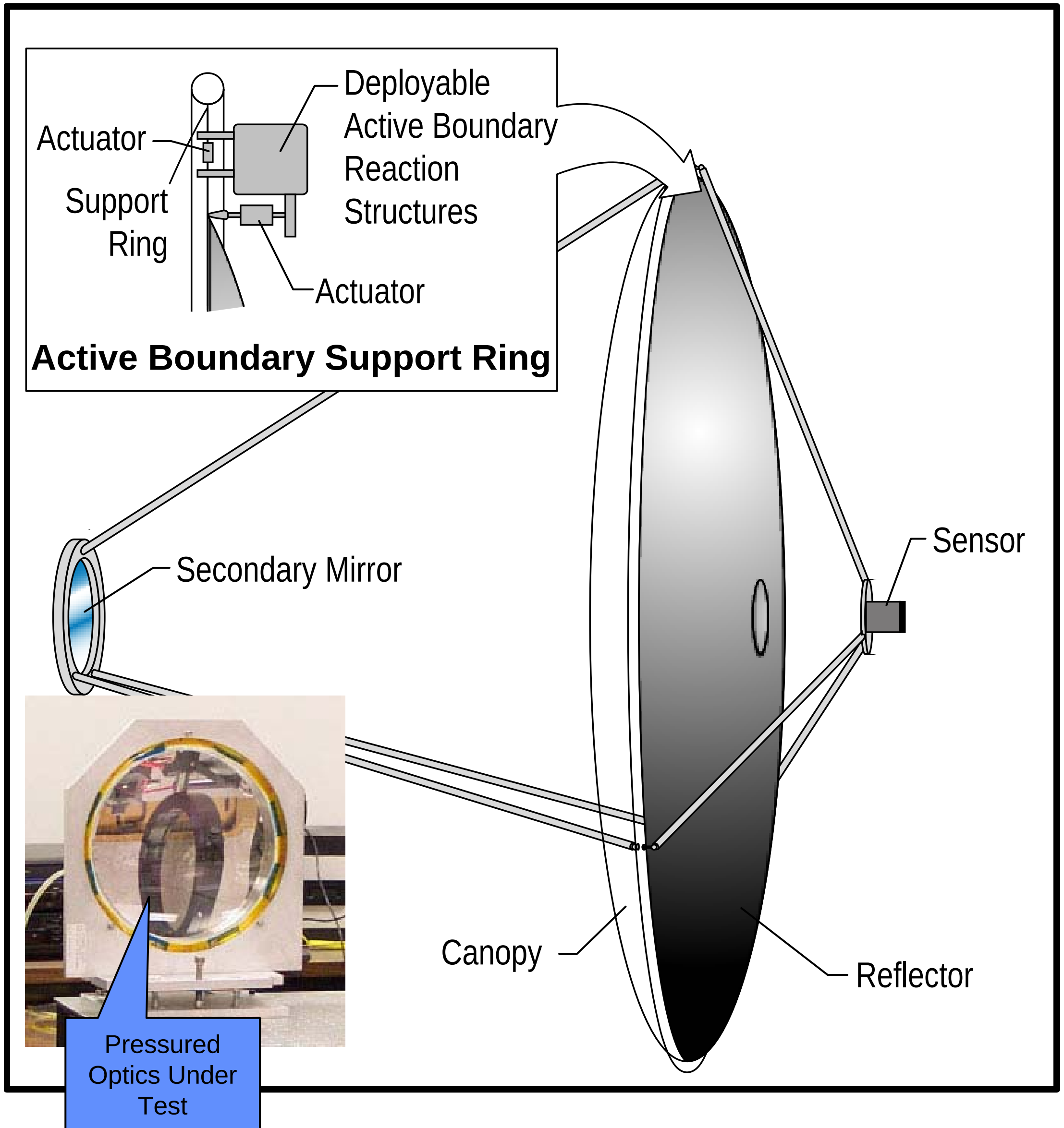
Optical Quality Film

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

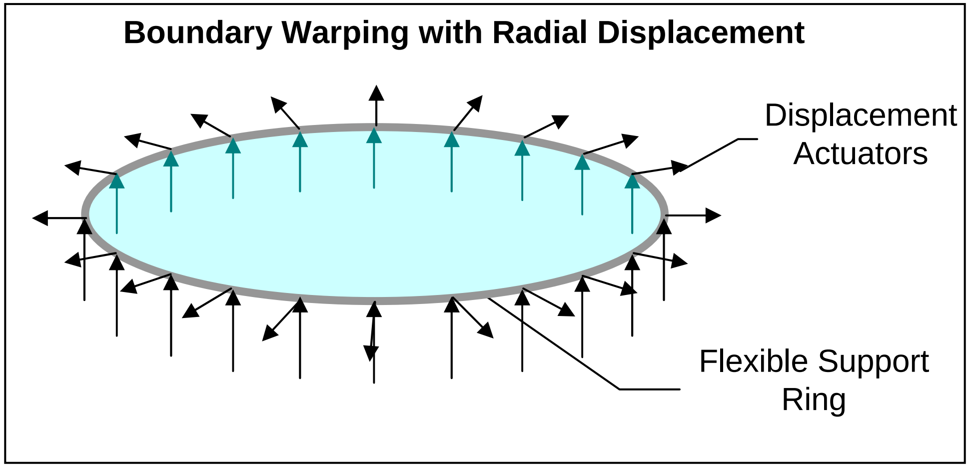
Pressure Augmented Membrane Mirror (PAMM) with Active Boundary Control



- **Target Application**
  - **Lightweight Optic for Imaging Applications**
- **Features**
  - **Reflector/Canopy Formed from 50 micron CP1-DE Polyimide (0.07kg/m^2)**
  - **Pressure Between Clear Canopy and Reflector Induces Curvature**
  - **Active Boundary Control**
    - **Initial Flattening of Mount**
    - **Limited Correction of Figure Errors and/or Incident Wavefront Errors**
  - **Excellent Scaling Relationships (Boundary α R; Aperture α R^2)**

PAMM Design Review

- Evaluated 5+ Boundary Control Configurations.
- Used Finite Element Analysis and IODA to Explore Correctability for Typical Aberrations
  - Spherical
  - Astigmatism
  - Coma
  - Random



Astigmatism can be corrected with normal actuators

Coma aberrations with radial actuators

Spherical still a problem

0.25m Prototype

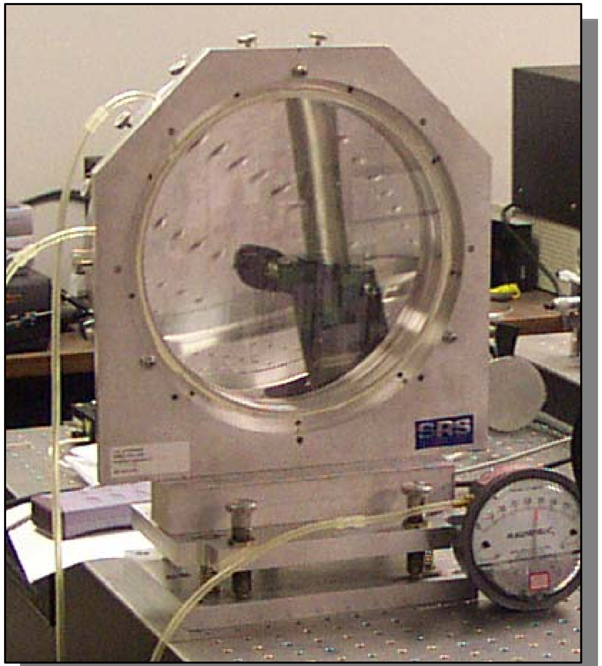
- 0.25m (10”) clear aperture, focal length of 32-inches prototype mount fabricated.
- Predicted pressure: 0.0585 psi.

$$p_d = \frac{1}{f}\left[h\left(s + \frac{E}{(1-v)} \times \frac{a^2}{16f^2}\right)\right]$$

- Pressure required: 0.050 psi.

• Mount incorporates boundary actuators that allow radial and out-of-plane control (18 actuators each)

• This mount is used to correlate the FEM analysis to actual membrane mirror test.

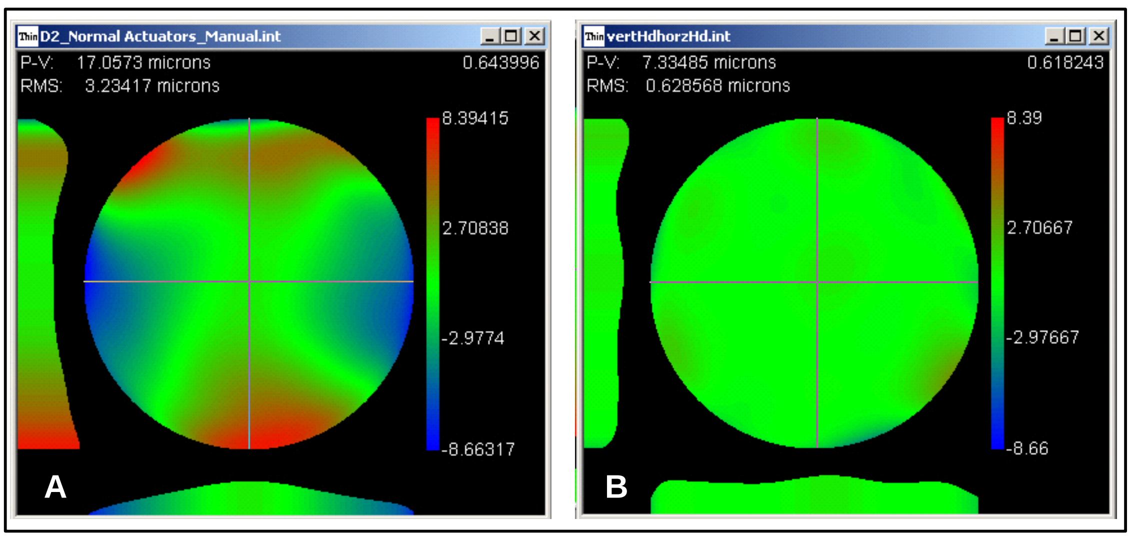


Astigmatism Error Correction

- All normal actuators were stroked in 20 microns to establish a bias.
- RMS surface error reduced from 3.234 microns to 0.628 microns.
- Micrometers for normal actuators will be used in the 0.75-meter PAMM, which will further reduce the shape error.

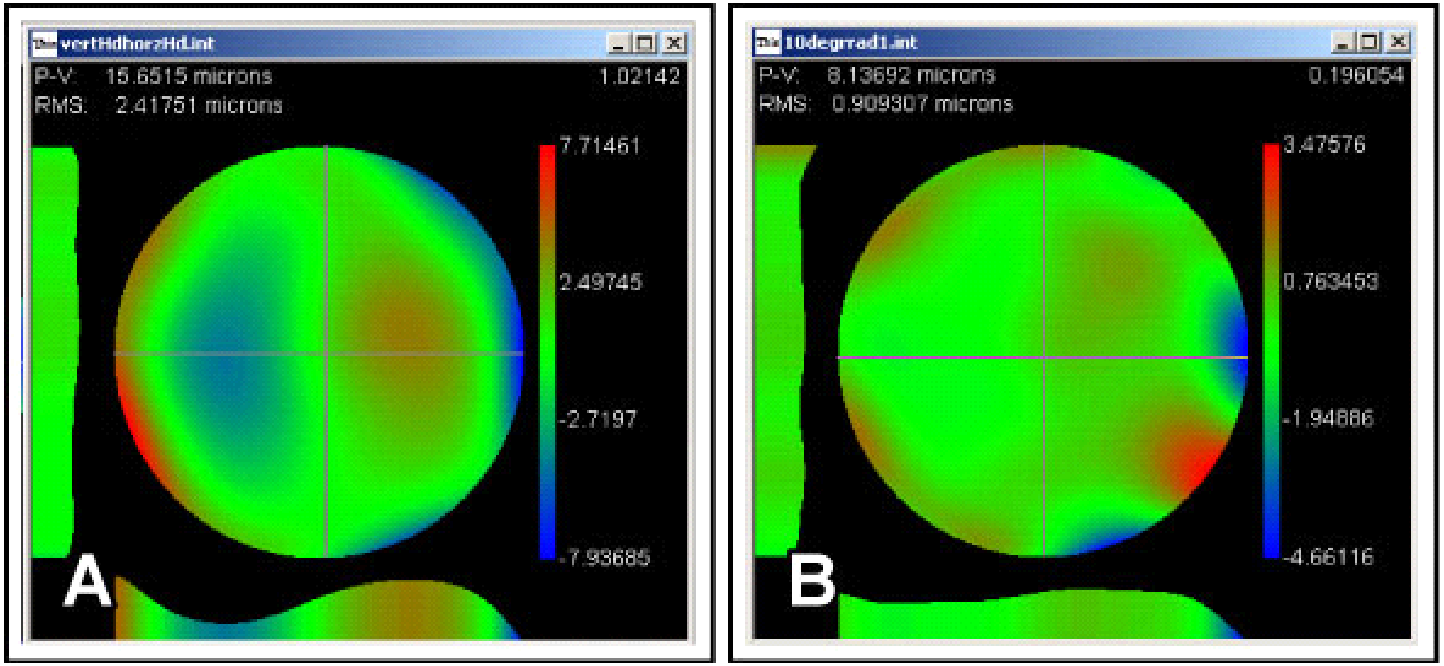
Actuator	Iteration (Actuator Stroke in Microns)				
	1	2	3	4	5
1	-5.44	-1.38	2.64	0.22	0.12
2	-11.30	-2.88	-0.69	7.87	0.16
3	-9.12	-1.69	-3.25	5.21	0.10
4	1.20	6.05	1.17	-5.92	-0.03
5	8.30	10.02	5.70	-9.05	-0.06
6	7.49	2.88	1.51	-1.46	-1.11
7	4.91	-5.44	-4.51	5.05	-2.63
8	2.67	-6.23	-3.83	5.90	-0.94
9	-2.01	-4.63	-1.79	3.70	3.87
10	-6.34	-3.58	-2.06	-1.57	5.14
11	-6.34	1.29	1.84	-6.31	0.02
12	-4.43	6.85	7.95	-3.64	-4.68
13	-2.28	5.50	5.15	2.58	-3.28
14	2.62	0.60	-4.17	3.11	0.52
15	7.95	-0.86	-6.92	0.13	1.57
16	7.98	-1.12	-2.37	-0.34	0.69
17	4.07	-2.78	1.17	-1.51	0.32
18	0.14	-2.53	2.51	-3.92	0.27
X-Astigmatism Error (in microns)	-1.10	1.46	2.44	1.32	0.26
Y-Astigmatism Error (in microns)	-4.58	-1.63	0.92	0.70	0.20

Reduced Astigmatism Error



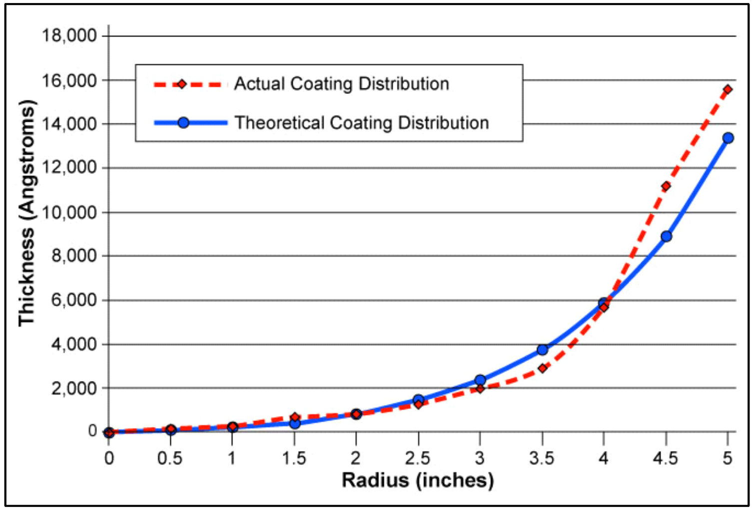
Astigmatism Aberration Corrected with Normal Actuators (Both Plots have first order spherical, focus, coma terms removed)

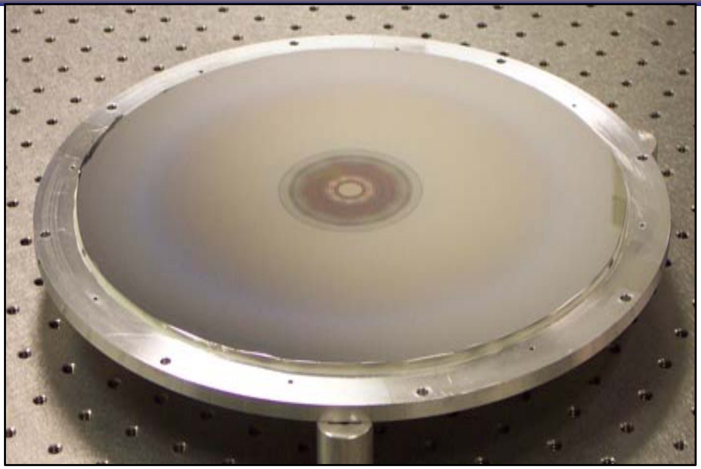
Coma Error Correction



- Testing was further conducted using radial actuators.
- RMS surface error decreased from 2.417 microns to 0.909 microns, with main reduction in coma aberration.
- Electrostatic pressure will be used for radial actuation in the 0.75-meter PAMM, which will further reduce the shape error.

Stress Coating For Reduced Spherical Aberration

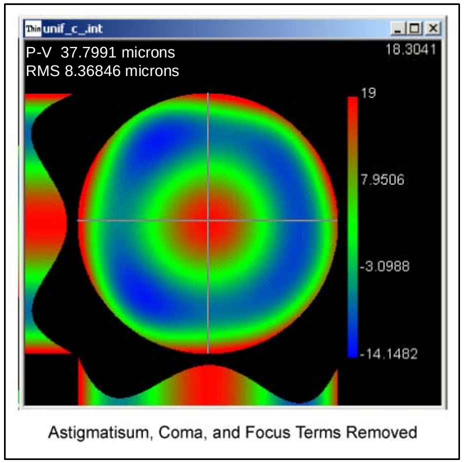




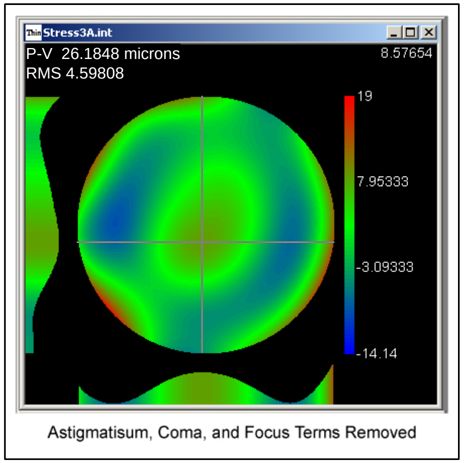
10 Inch Test Article with Variable Coating

$$h_C(R) = h_0 + h_2(kR)^2 + h_4(kR)^4 + h_6(kR)^6$$

- Nonlinear coating Prescription for Parabolic Shape developed by Mike Wilkes (AFRL)
- Significant improvement in spherical aberration achieved.
- Coating thickness distribution theory will be used for the 0.75-meter PAMM.



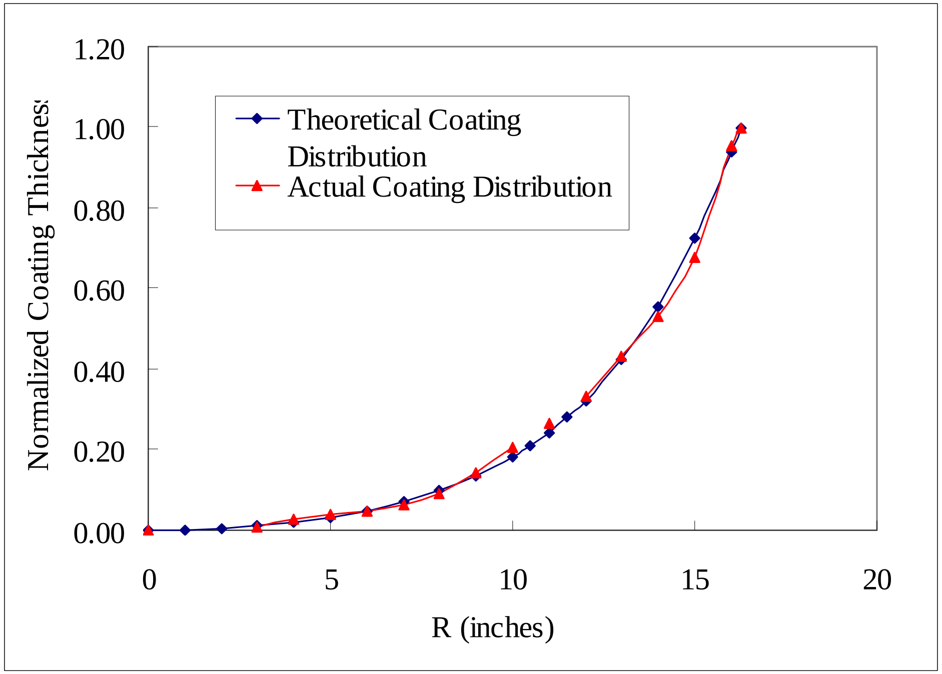
Uniform Coating

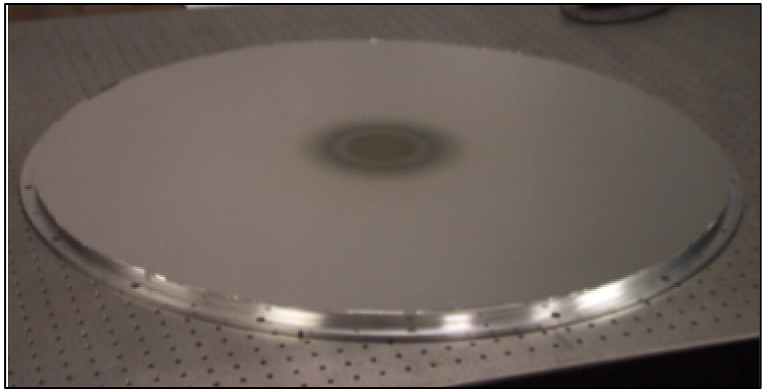


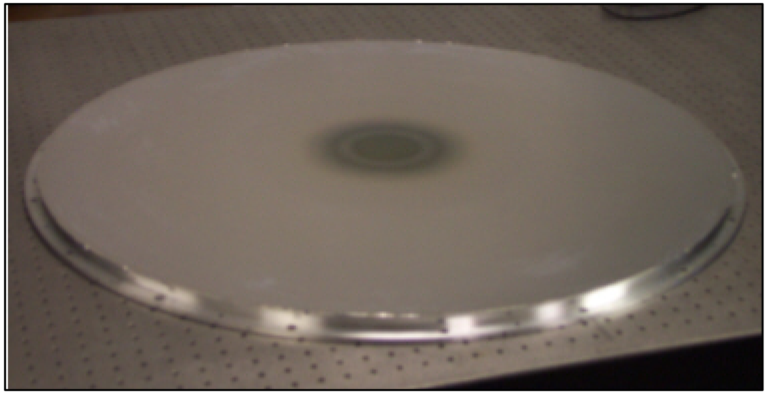
Variable Coating

54% Reduction of Spherical Aberration

Stress Coating For Reduced Spherical Aberration



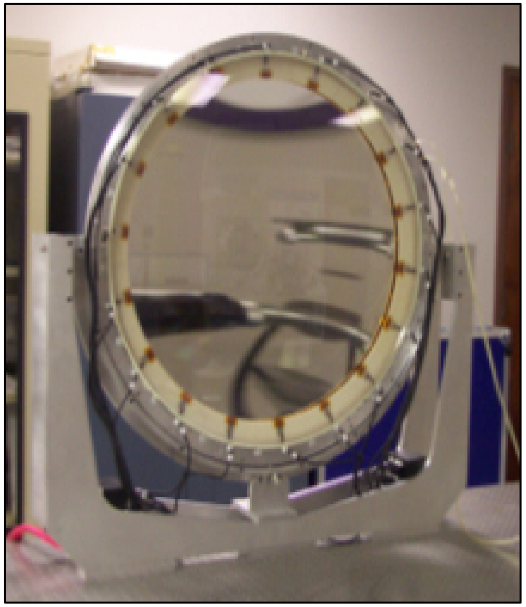


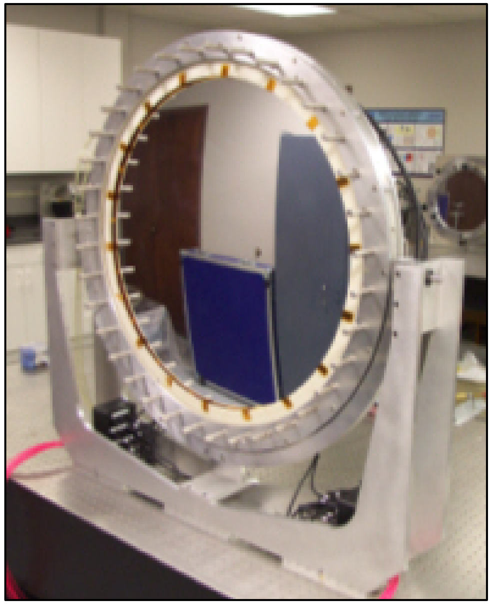


Comparison of Theoretical Stress Coating Thickness and Actual Coated Profile

- **Coating thickness at edge is 18247 Angstroms.**
- **Expanded for large-scale test.**

Uniformly Coated Testing

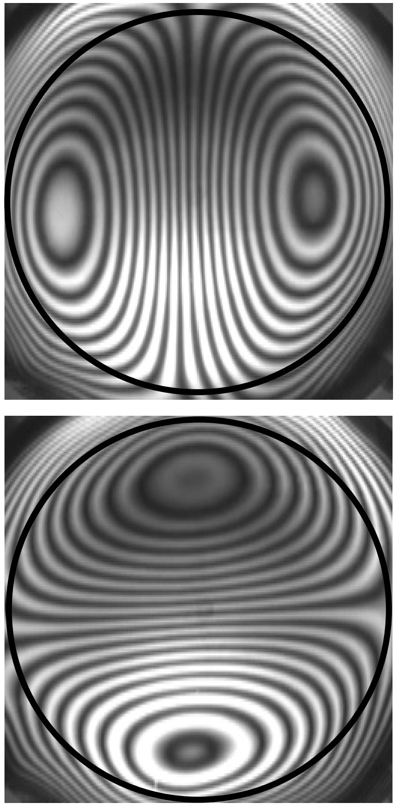


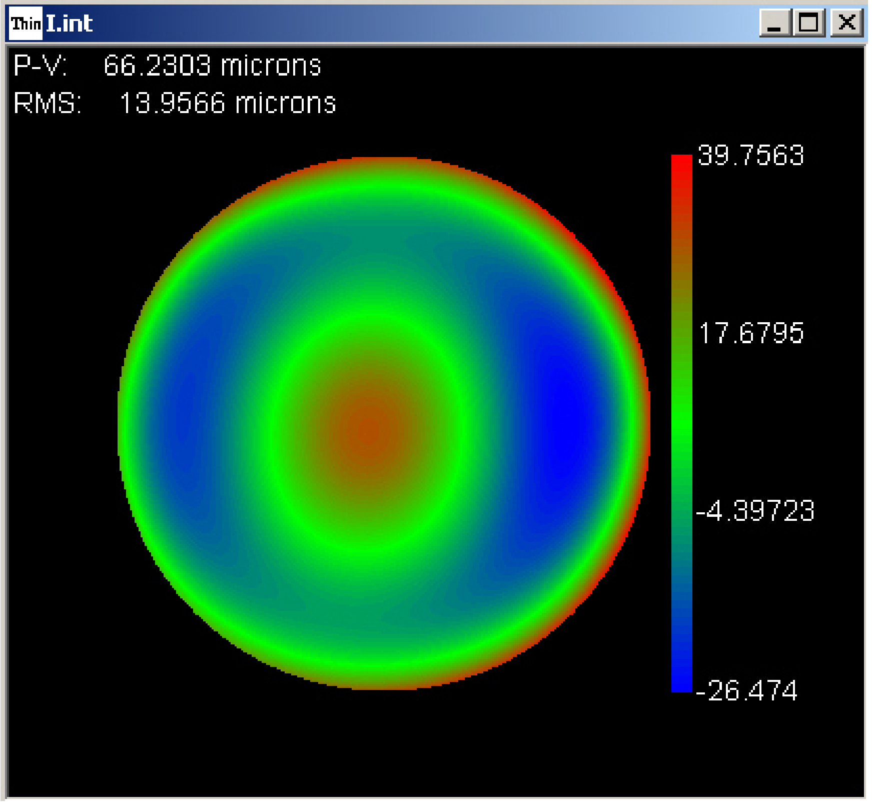


- Uniformly coated membrane mirror.
- Uniform opaque (~2000A) coating of VDA on front and back side of membrane
- Pressure set for focal length of 157cm (0.043psi)

- Uniform mirror will provide baseline test data.
- Varied stress coating membranes will be measured with reduction in spherical aberration the key comparison.

Uniformly Coated – Tuned Shape





RMS 13um

PV 66um

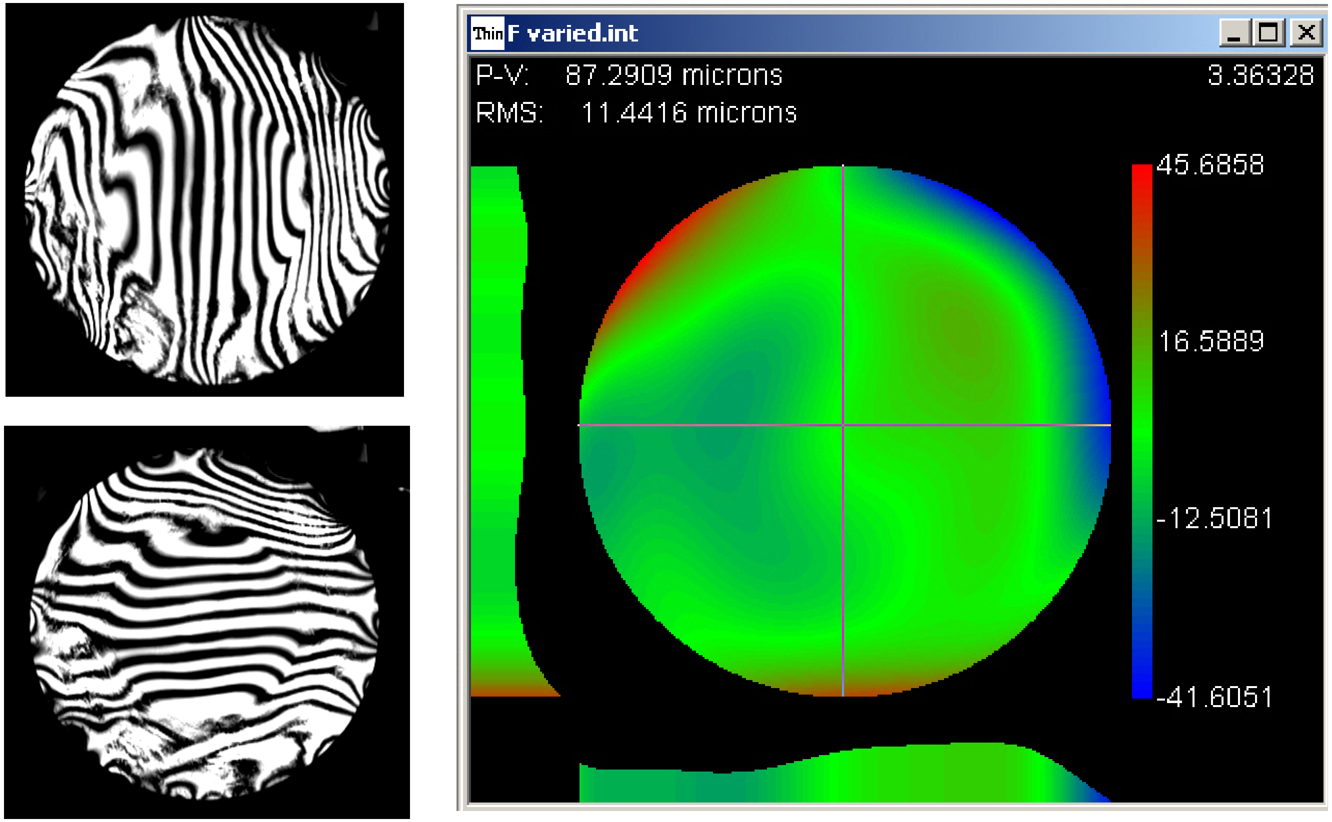
- Only 50.8cm diameter out of 72.4cm CA was measurable due to error
- OPD plot after normal tuning based on computer model actuator calculations
- No coma correction possible due to limited aperture measurement.

1st Varied Stress Coating Testing

- Varied Stress Coating.
- Uniform opaque (~2000A) coating of VDA on mirror side, varied stress coating on back side of mirror.
- Pressure set for focal length of 157cm (0.047psi)

- Varied coating notable on back of membrane. Thickness is essentially zero in center.
- Main purpose of varied stress coating is to control spherical aberration.

1st Varied Stress Coating – Tuned Shape

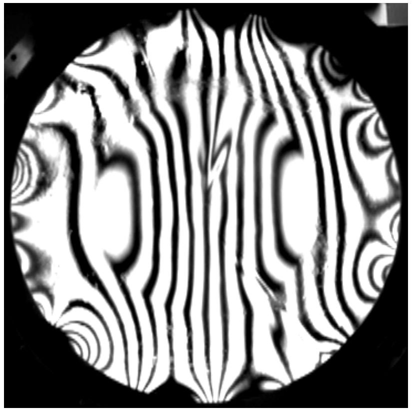


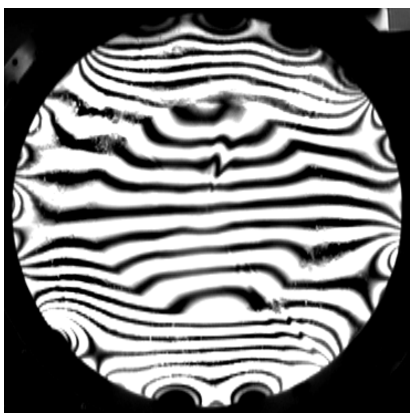
RMS 11um

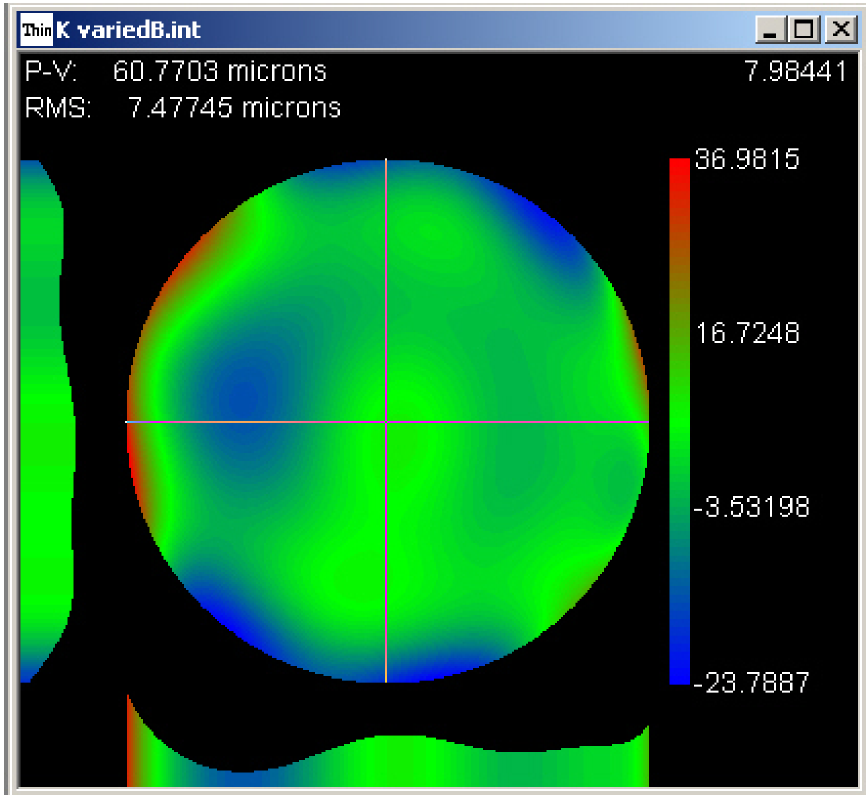
PV 87um

- Full aperture is now available for measurement
- OPD plot after model aided tuning of normal actuators.
- RMS reduction of 65%, PV reduction of 57%.
- Boundary errors and slight coating roughness.

2nd Varied Stress Coating – Tuned Shape







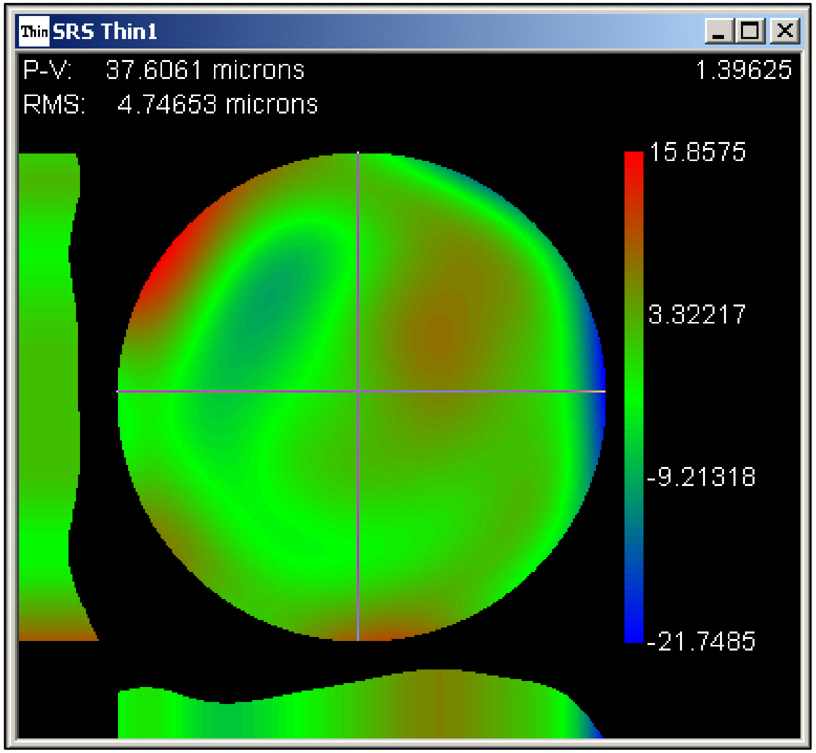
RMS 7um

PV 60um

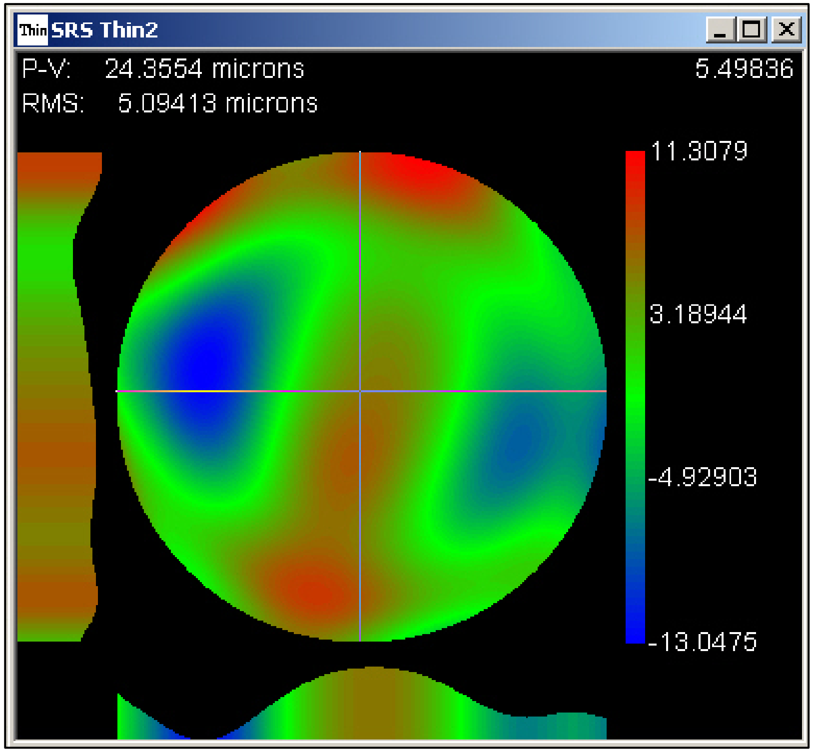
- Better overall tuning on 2nd varied coating using both normal and electrostatic actuation.

- OPD plot after model aided tuning of normal actuators.
- RMS reduction of 82%, PV reduction of 76%
- Again, boundary errors and slight coating roughness.

Apertured Down Varied Coating Results



1st Varied, RMS 4.7um, PV 37um



2nd Varied, RMS 5um, PV 24um

- By reducing the measured aperture by ~15%, another reduction of RMS and PV of over 50%.

Summary

- Finite element modeling and design need further adjustments, but have shown good correlation through successful results with actuator influence
- Active boundary control effective in correcting mounting errors and other types of low order aberrations typically seen in membrane mirror applications
- Spherical aberration can be controlled (as required) through varied stress coatings on the membrane.
  - Improvements must be made to ensure no increase in surface roughness of membrane. Deposition rate and dwell time adjustments.
- Testing will continue at AFRL with inclusion of real-time DM secondary.