AFRL-DE-PS-TP-2007-1006 AFRL-DE-PS-TP-2007-1006

# Stress Coatings for Large Scale Membrane Mirrors (Preprint)

**Ryan Conk et al.**

**15 September 2006**

**Technical Paper**



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# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



**1. REPORT DATE** *(DD-MM-YYYY)*
15-09-2006

**2. REPORT TYPE**
Briefing Charts

**3. DATES COVERED** *(From - To)*
Mar-1-2003 to Aug-7-2006

**4. TITLE AND SUBTITLE**
Stress Coatings for Large Scale Membrane Mirrors (Preprint)

**5a. CONTRACT NUMBER**
F29601-03-C-0040

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**
65502F

**6. AUTHOR(S)**
Ryan Conk

**5d. PROJECT NUMBER**
3005

**5e. TASK NUMBER**
DP

**5f. WORK UNIT NUMBER**
BE

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

AFRL/DES
3550 Aberdeen Avenue SE
Kirtland AFB, NM 87117-5776

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

Air force Research Laboratory
Directed Energy Directorate
3550 Aberdeen Ave SE
Air Force Materiel Command
Kirtland AFB, NM 87117-5776

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
AFRL-DE-PS-TP-2007-1006

**12. DISTRIBUTION / AVAILABILITY STATEMENT**

Approved for Public Release; Distribution is Unlimited.

**13. SUPPLEMENTARY NOTES**
Published in Mirror Technology Days 2006, Albuquerque, NM, October 18-20, 2006.
http://optics.nasa.gov/tech_days/index.html. GOVERNMENT PURPOSE RIGHTS

**14. ABSTRACT**
Finite element modeling and design need further adjustments, but have shown good correlation through successful results and actuator influence. Active boundary control effective in correcting mounting errors and other types of low order aberrations typically seen in membrane applications. Spherical aberration can be controlled (as required) thought 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.

**15. SUBJECT TERMS**

| **16. SECURITY CLASSIFICATION OF:** | | | **17. LIMITATION OF ABSTRACT** | **18. NUMBER OF PAGES** | **19a. NAME OF RESPONSIBLE PERSON** |
|---|---|---|---|---|---|
| **a. REPORT** | **b. ABSTRACT** | **c. THIS PAGE** | | | Ryan Conk |
| Unclassified | Unclassified | Unclassified | SAR | 20 | **19b. TELEPHONE NUMBER** *(include area code)* |

# Stress Coatings for Large Scale Membrane Mirrors

**F29601-03-C-0040**
**FA9453-03-C-0185**


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Brief what's on slide

# Background

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

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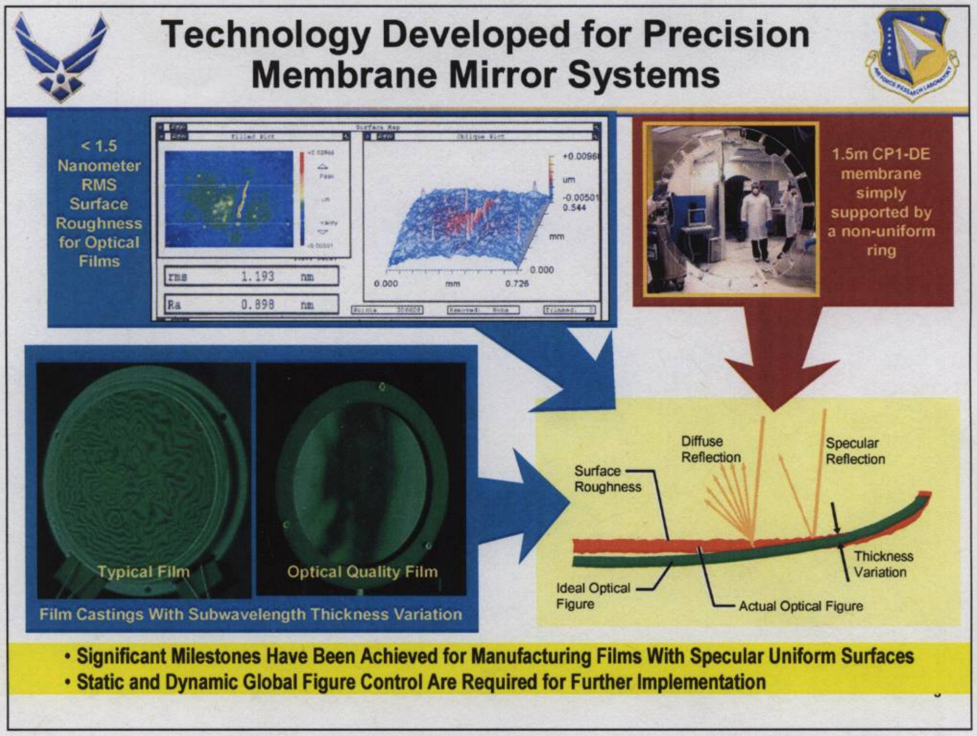
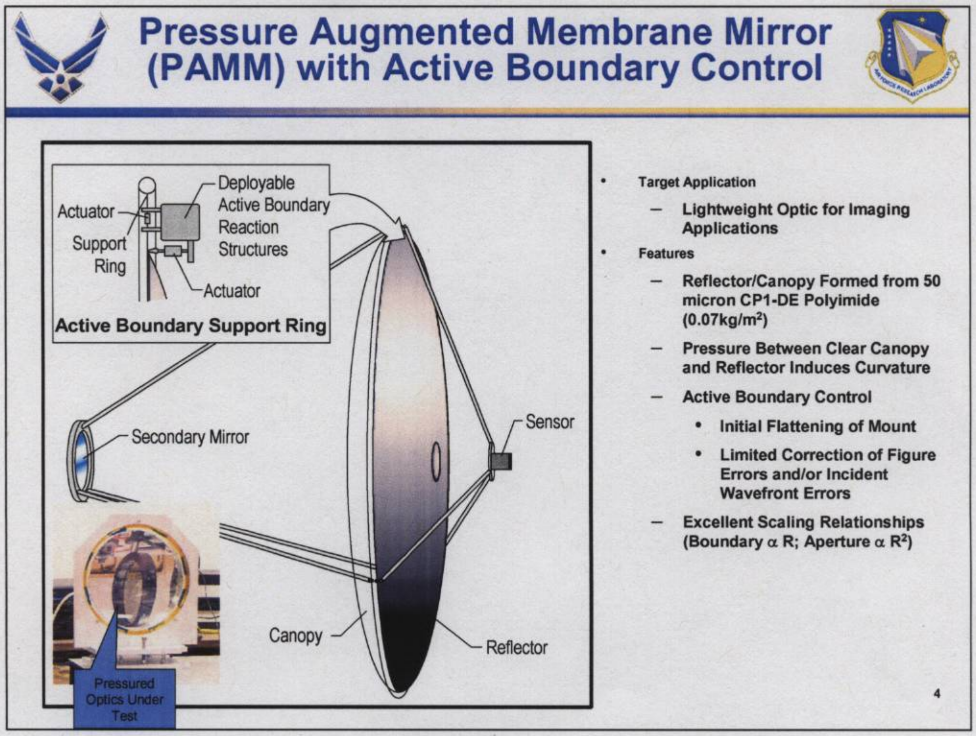
Brief what's on slide



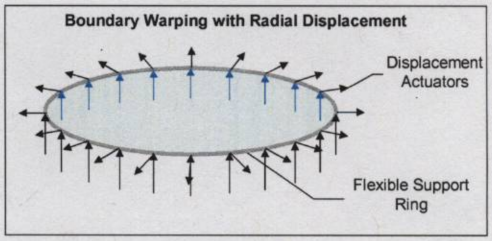

Over the last several years, thin film membranes have been developed to provide an ultra-lightweight alternative to conventional large optics. During this development SRS has improved there production capabilities and have manufactured optical quality thin film membranes with subwavelength thickness variation.




This only solves the local surface variation requirements, we are still left with the global surface figures shape. The method for achieving the parabolic global shape has been to encapsulate the membrane and pressurize the mirror. This method has gotten us close to the shape, but far from the accuracies required for optical applications. For this project SRS investigated various methods to improve this global figure. The goal is to achieve a low enough error that an AO system would be able to correct the residual error.

## 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

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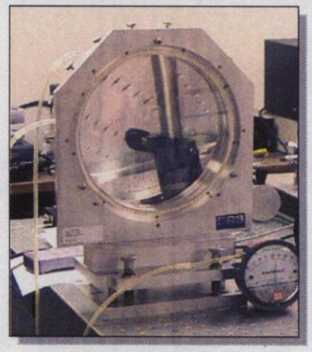
SRS used FEM to determine the promary aberrations with the membrane mirror. These include spherical, astigmatism, coma, and other random aberrations. Since our main goal is still to reduce the weight as much as possible we can not have actuators directly behind the mirror. SRS determined that astigmatism can be corrected with normal actuators on the boundary of the membrane and that the coma aberrations can be corrected with radial actuators on the boundary.

## 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.

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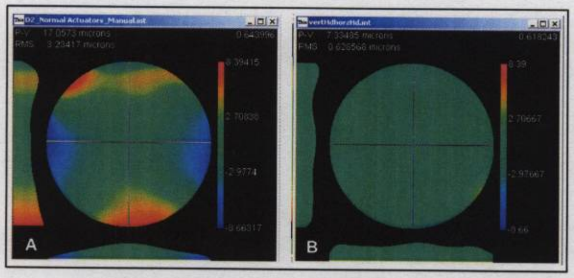
SRS first developed a 25m prototype membrane mirror with boundary controls to verify the FEM analysis

# 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 | 2.52 | 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)**

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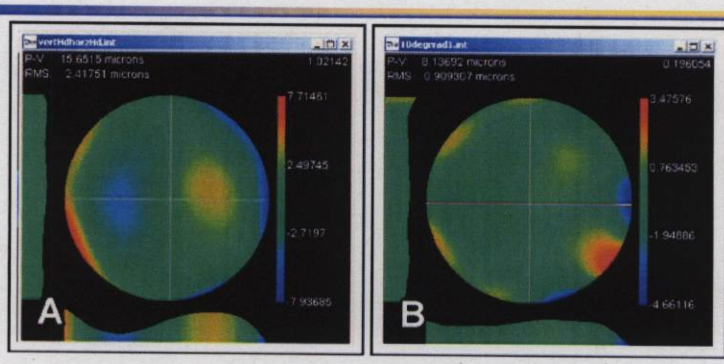
Using the normal actuators RMS surface error was reduced from 3.24 microns to 0.628 microns

Micrometers were used on the 75cm PAMM to increase the sensitivity of the actuation

# 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.

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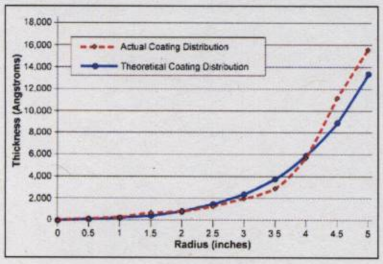
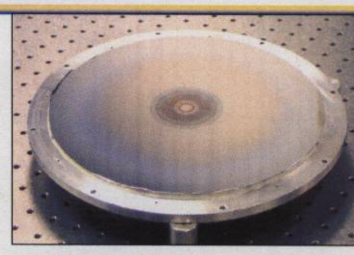
Brief what is on slide

## Stress Coating For Reduced Spherical Aberration

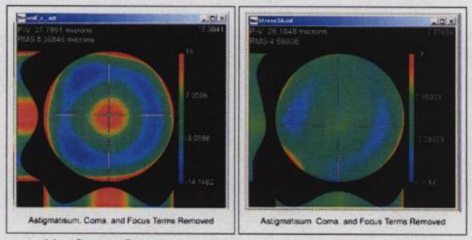


10 Inch Test Article with Variable Coating

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

- 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**

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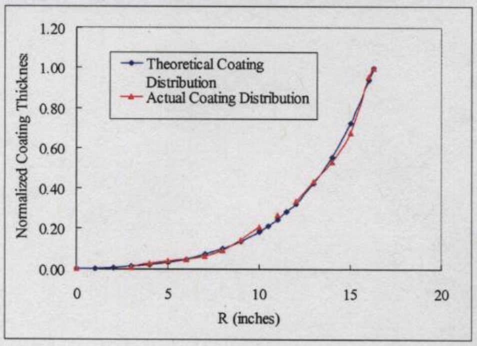
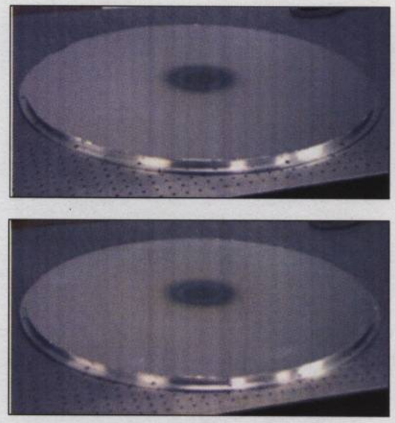
We are still left with the large spherical aberration. Mike Wilkes developed a formula specifying a nonlinear coating prescription to shape the membrane mirror into a parabolic shape

From the ten inch coating sample a 54% reduction in spherical aberration was achieved

## 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.**

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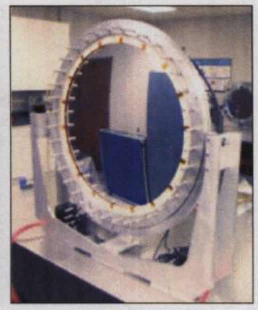
Here is the coating profile for the 75cm membrane and the actual measurement of the coating

## 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.

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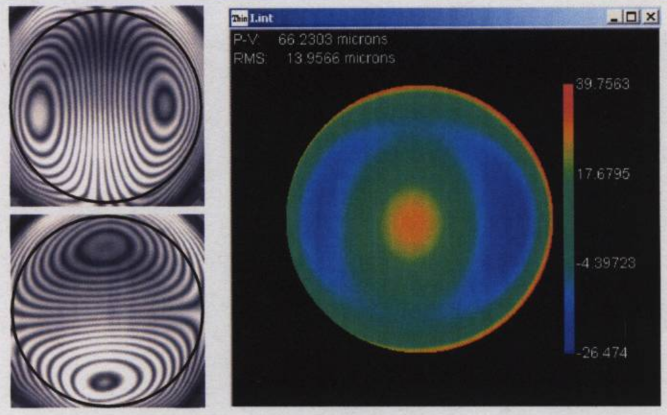
For the phase II, SRS delivered 1 uniformly coated membrane for a basis to evaluate the 2 variable thickness coated membranes

## 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.

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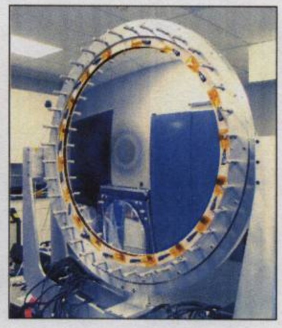
For the uniformly coated membrane a PV error of 66 um was measured with an RMS of 66um

## 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.

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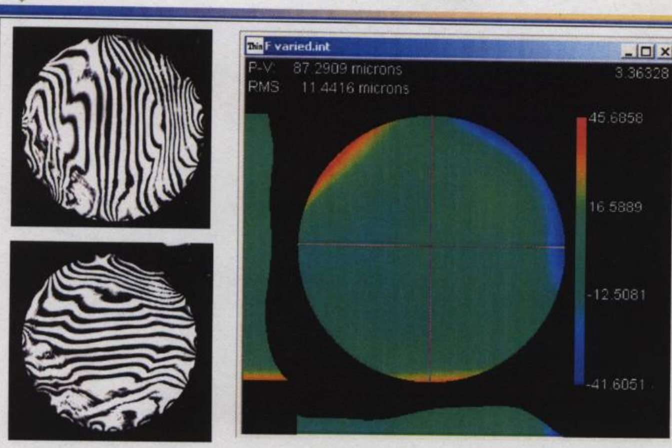
Brief what is on slide

## 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.

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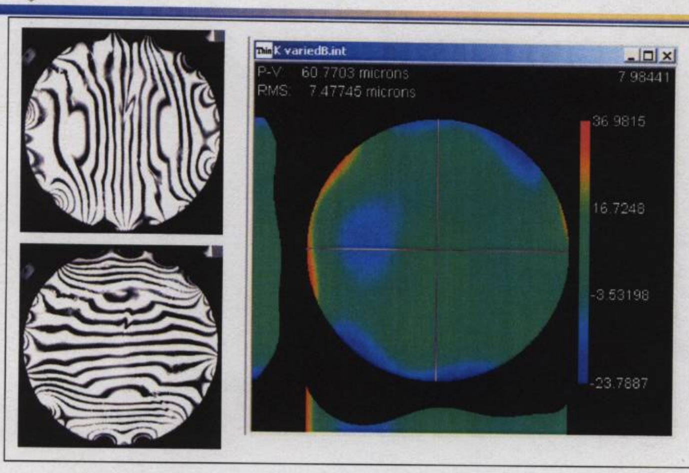
The measurements for the 1st varied stress coating showed an rms reduction of 66% and a P-V reduction of 57%

## 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.

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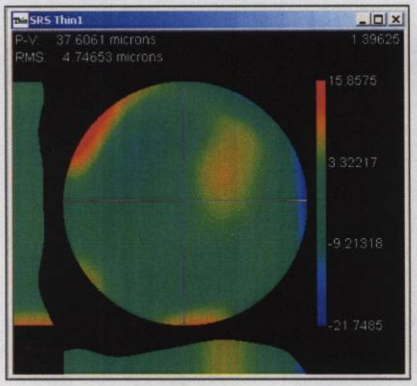
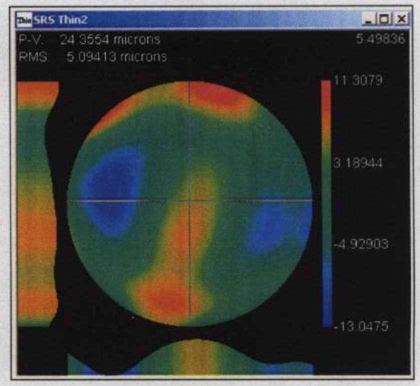
The 2nd variable stress coating showed even better improvement with an 82% rms reduction and a 76% p-v reduction

## 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%.

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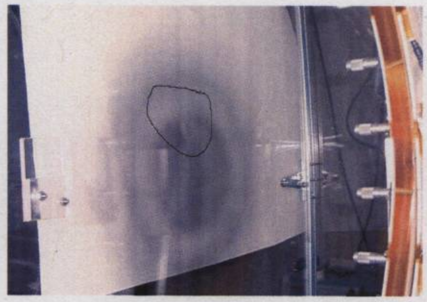
State what is on slide

# AFRL Testing

- **Large radius of curvature variations due to temperature gradient in lab**



- **Tear-like defect in coating**
- **Implement with AgilOptics MEMS-like AO system**

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AFRL has begun its analysis of the pressure augmented mirror.

The goal is to first perform a surface characterization of PAMM and then determine if the AgilOptics deformable mirror that we have available can correct the residual errors

There is a tear-like defect in the coating that prevents us from using the center region of the mirror. Also there have been large radius of curvature variations due to the temperature changes in the lab. 100's of waves of deviation have resulted in an hour time span

We are identifying processes to stabilize the temperature in the lab and we plan to take interferometer measurements shortly to quantify the residual aberrations.

## 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.

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State the summary