High-Precision Adaptive Control of Large Reflector Surface

Houfei Fang, Ubaldo Quijano and Eastwood Im
Jet Propulsion Laboratory
California Institute of Technology

Jim Moore and Jim Pearson
ManTech SRS Technologies

Kon-Well Wang and Jeff Hill
Department of Mechanical and Nuclear Engineering
The Penn State University

Changgeng Lui and Frank Djuth
Geospace Research, Inc.

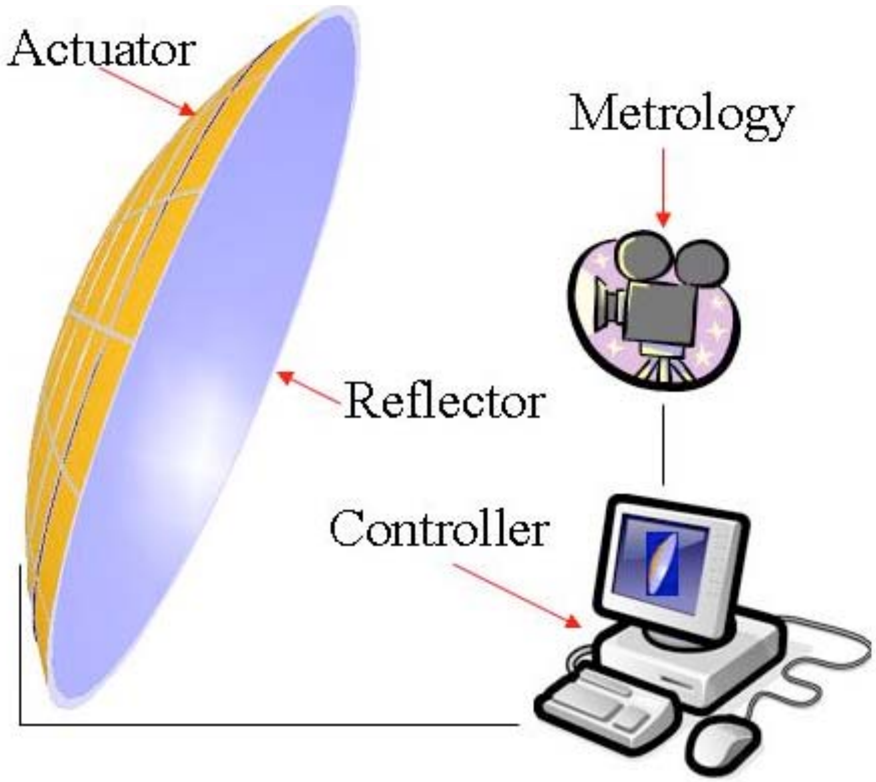
Earth Science Technology Conference 2008
June 24, 2008

Outline

- Introduction
- Inflatable Membrane Reflector Development
- Theoretical analysis of the reflector shape control system
- Development of PVDF based actuators
- Demonstration of membrane reflector
- Conclusion

Architecture of the High-Precision Surface Control System

- It consists of a large deployable reflector, a set of flexible actuators (mounted on the back of the reflector), a wavefront sensing metrology subsystem, and an active (feedback) controller.
- Guided by shape control laws, the controller periodically updates voltage signals to control the actuator strain at various antenna positions, thus maintaining desired shape contour



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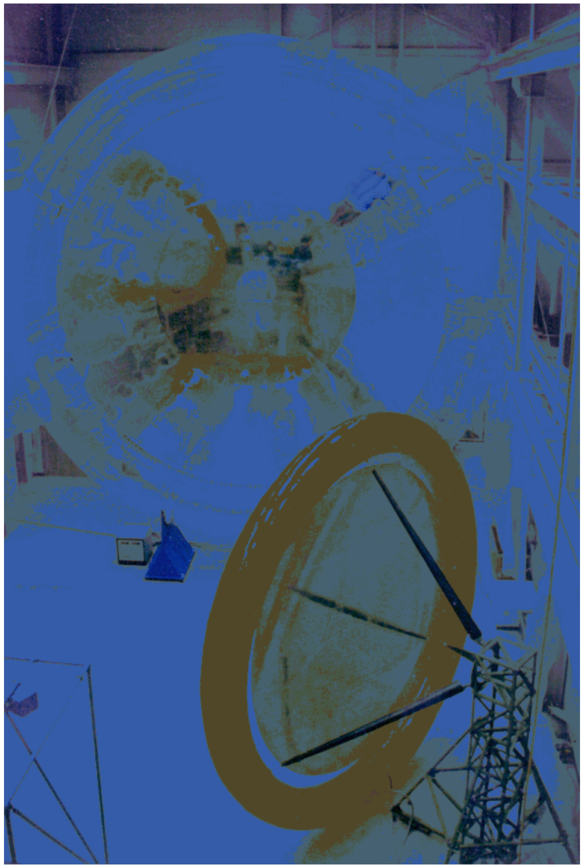
Reflector Design

- Consist of two thin films, a reflector and a canopy, that are joined around the edges
- The films are joined using a leak tight bonding technique
- The reflector film is typically metalized with a vapor deposited coating (silver or aluminum)
- The reflector is integrated with an inflatable torus
- Compliant features are used to minimize loading changes
- The boundary tension is adjusted to achieve the best shape

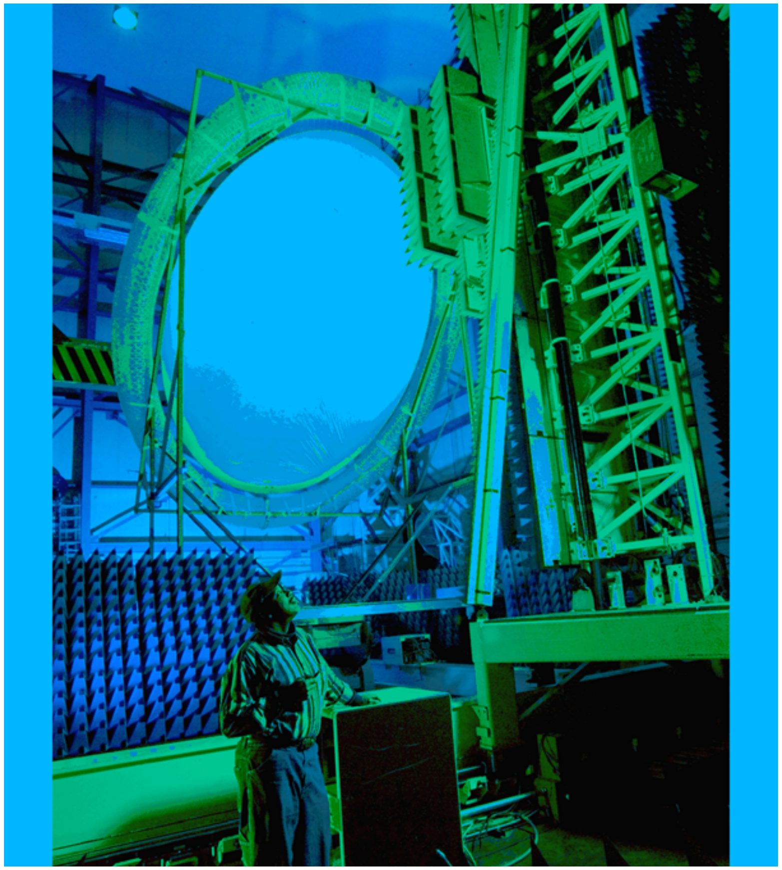


10- and 5-meter inflatable reflector

Inflatable Membrane Reflector

Advantages

- Maximum packaging efficiency
- Simple reliable deployment method
- Offers a solution to aperture sizes >25 m where other antenna technologies begin to be limited by launch vehicle volume and mass restrictions
- Low or zero CTE membrane materials are being develop to minimize in space thermal distortion



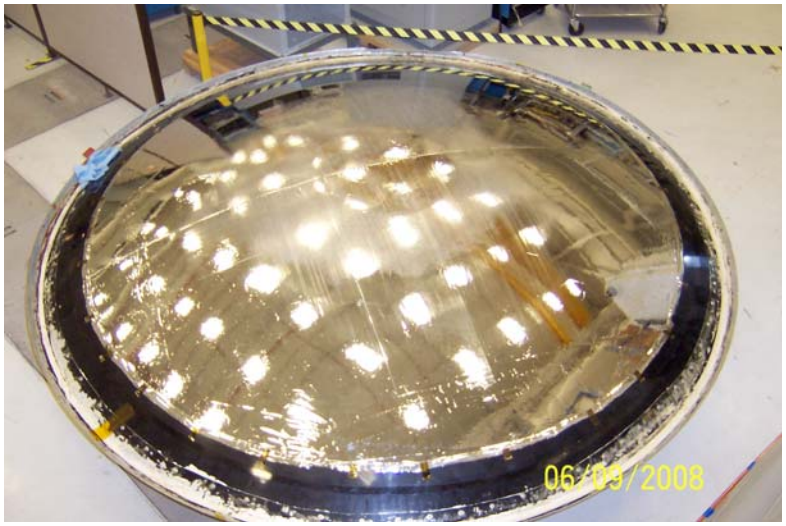
4mx6m Off-Axis Inflatable Antenna

VDA Coating

- The film was secured to the coating drum and put into the vacuum chamber.
- The chamber was evacuated to remove residual solvent and then the film was removed for inspection prior to coating.
- The film was coated and removed.
- ~1200Å of aluminum was deposited onto the ~2-mil CP-1 thin film
- Since the film's diameter was larger than the coating drum length, the film was rotated 90° and coated a 2nd time in order to coat the "wings"

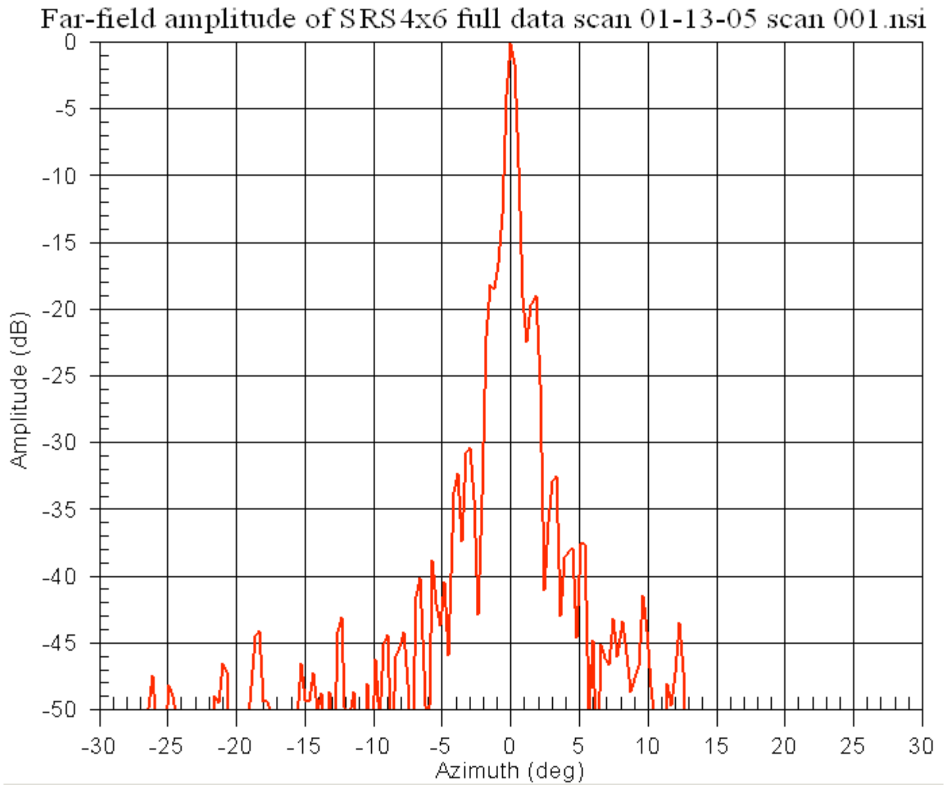
Precisely Shaped Casting Mandrel

- To cast the thin polymer films
- Removal of the coating around the reflector / canopy bond band (i.e. 96” aperture line)
- Marking of the catenary locations
- Attachment of the photogrammetry targets
- Attachment of the actuators



Recent Developments of Inflatable Antenna Technology

- On-axis, off-set, and Cassegrain antennas have been designed and fabricated
- RF characterizations of off-set and on-axis antennas have been performed at frequencies from X-band to Ka-band



8.4 GHz Data for 4-m x 6-m Test Article

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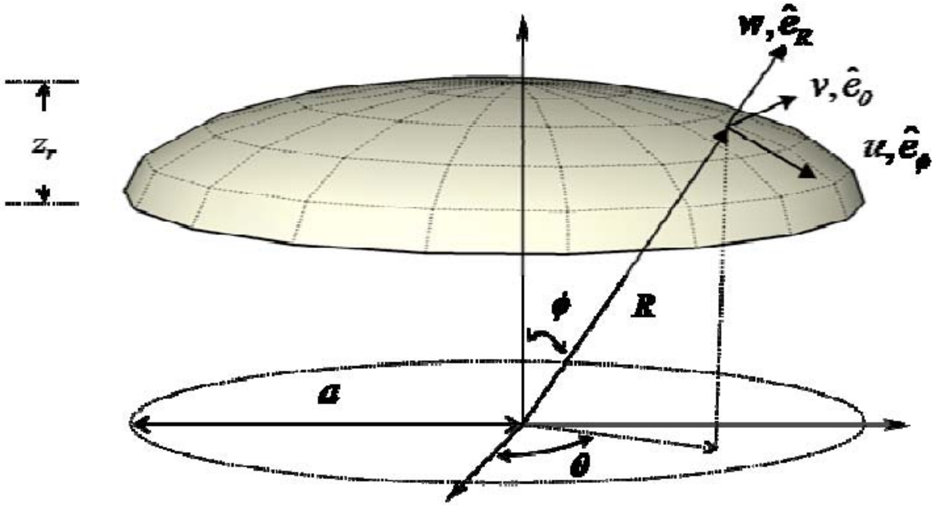
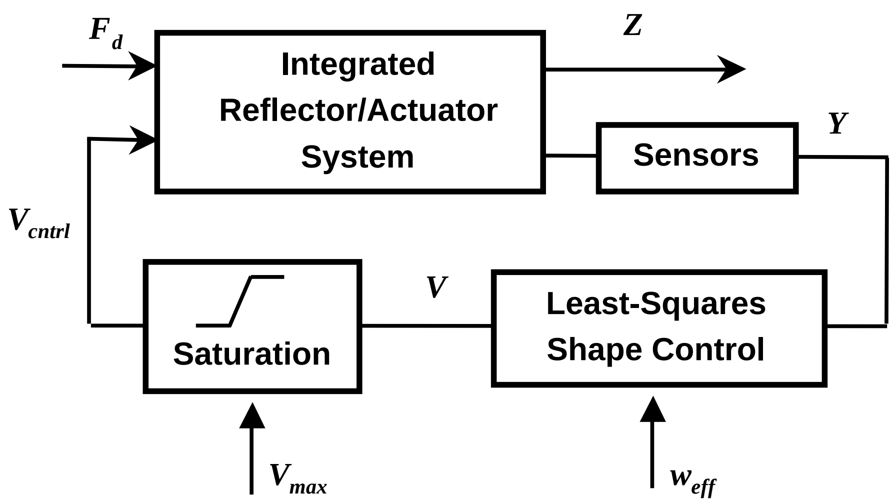
Reflector Modeling

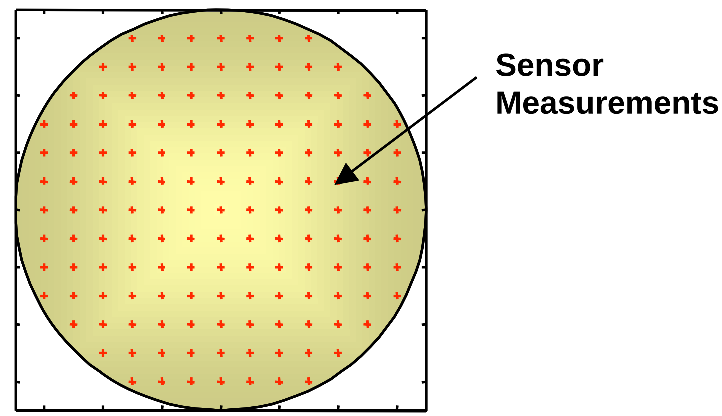


- Shallow spherical shell approximation
- Pre-tensioned membrane shell with bending stiffness (internal inflation pressure)
- Simply supported boundary conditions at the rim
- Modeled using Ritz method and a Fourier-Bessel expansion

Theoretical Analysis of the Reflector Shape Control System

Control Algorithm





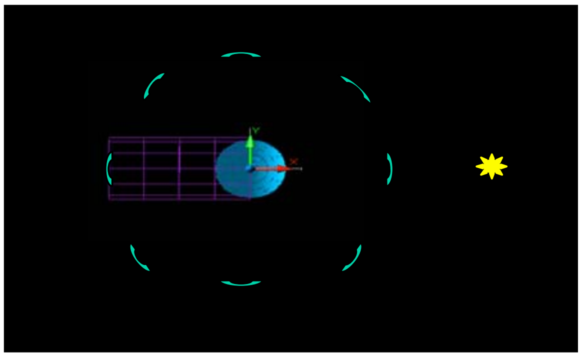
Sensor Measurement Locations

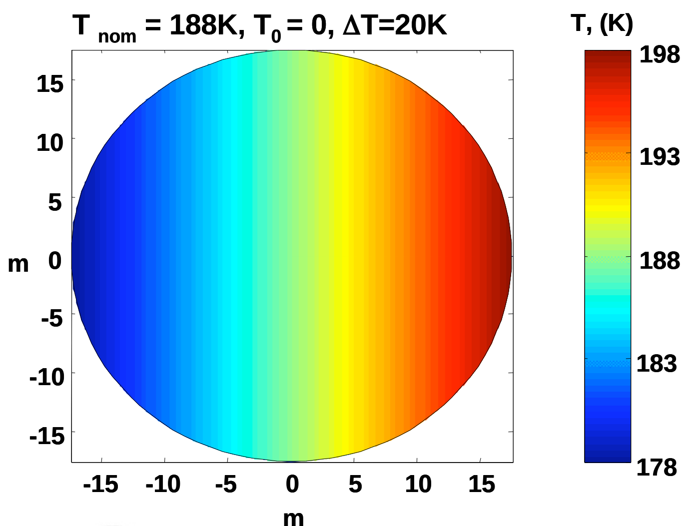
- A Least-Squares shape control
- LS controller input is the displacement from all metrology sensor measurements
- Using the equation obtained from the reflector model the desire actuation voltage can be calculated.
- Saturation block accounts for PVDF voltage saturation effects

Theoretical Analysis of the Reflector Shape Control System

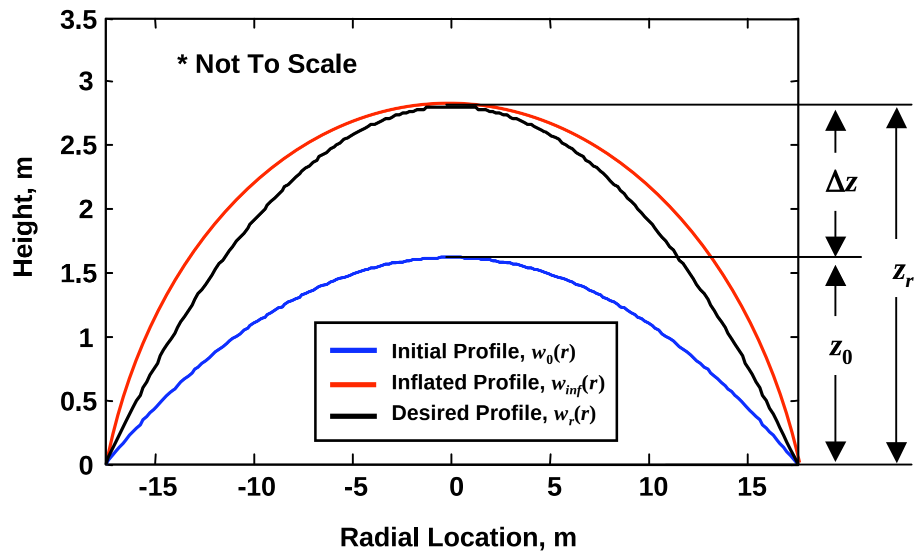
Sources of Shape Error

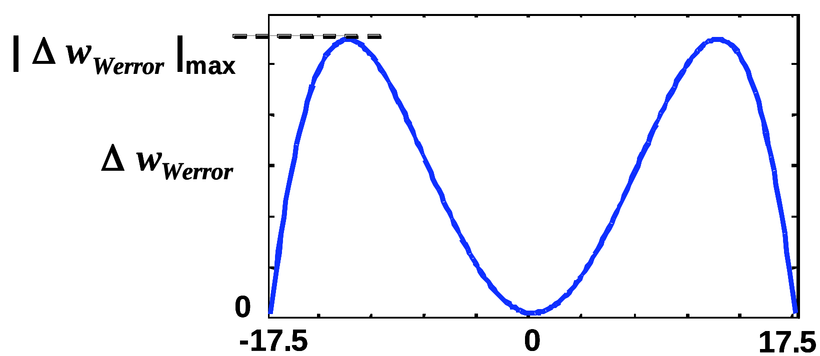
Thermal loading - Consider uniform and thermal gradient loading





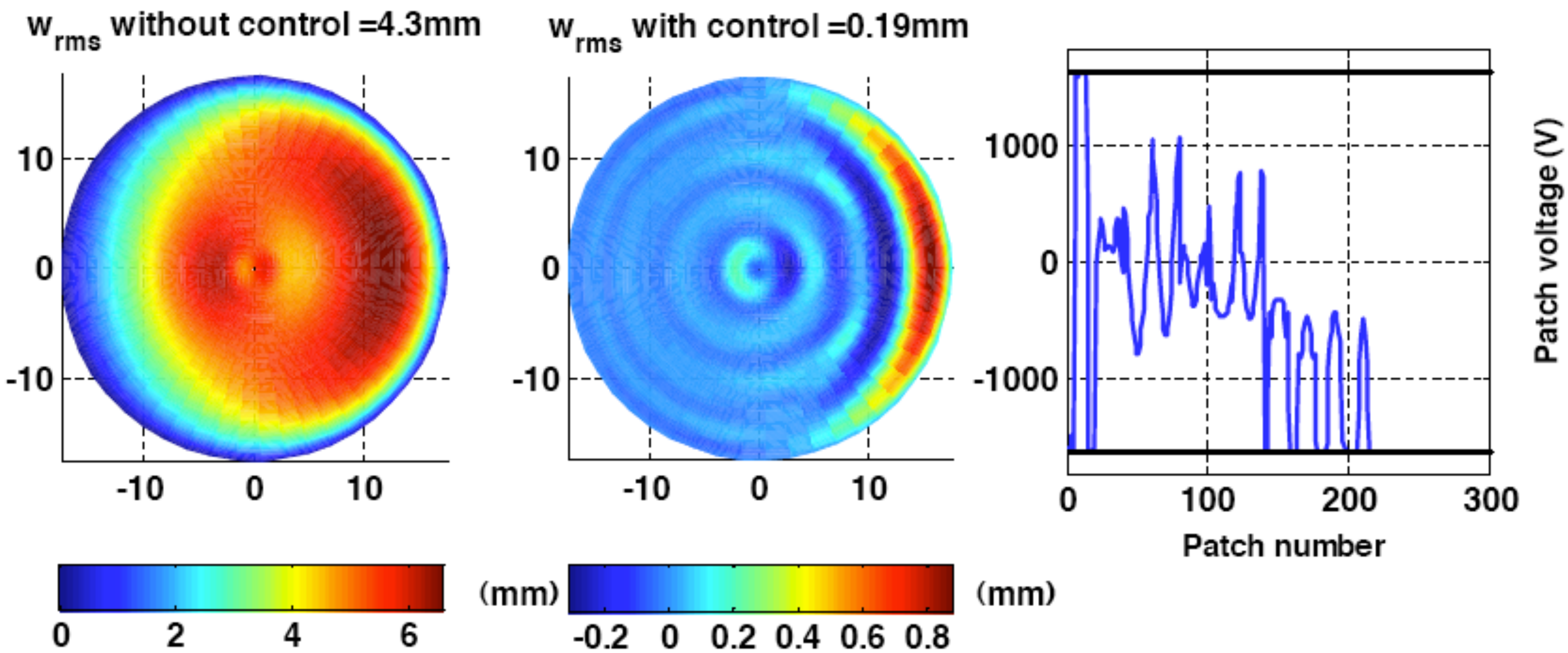
W – Error: Spherical shape not achieved on inflation





Theoretical analysis of the reflector shape control system

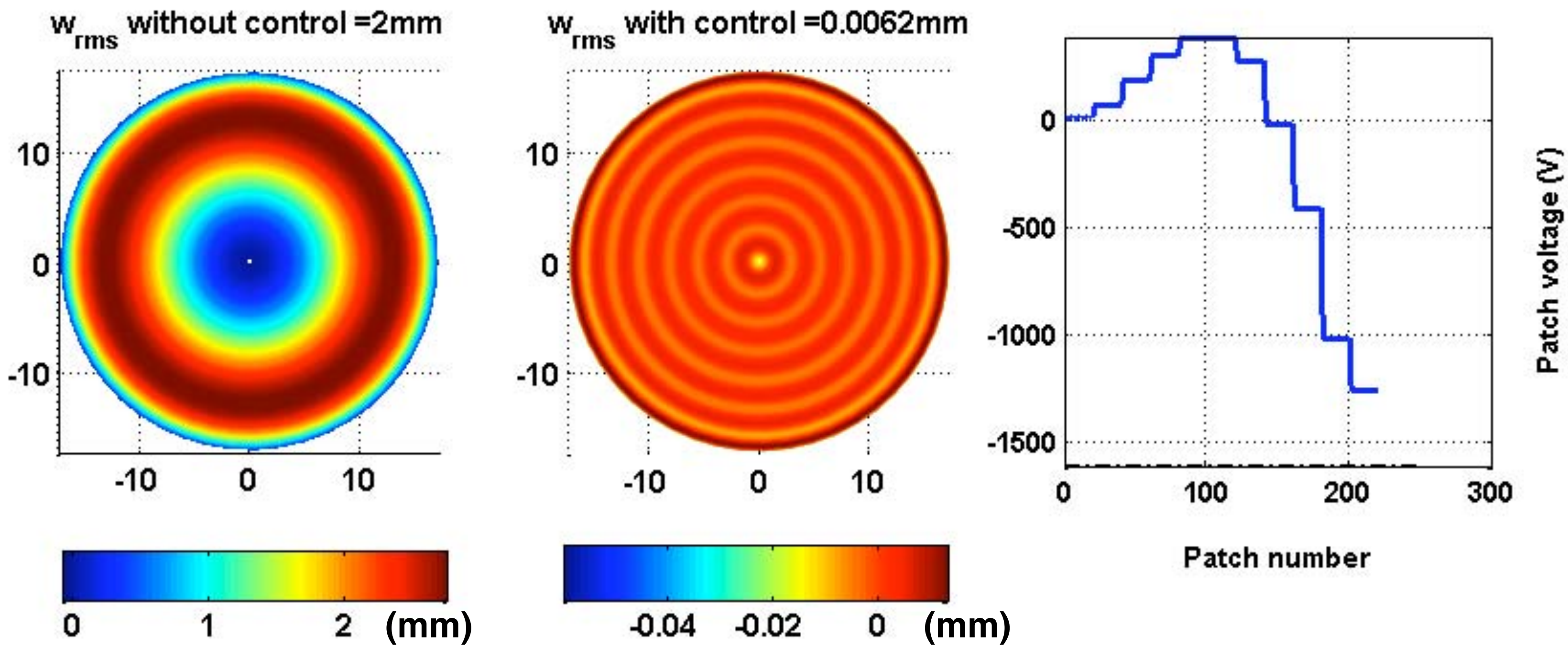
Sample results — uniform + gradient thermal loading



- Surface deformations due to combined uniform and gradient thermal load
- Limited actuator saturation
- RMS error reduction to 0.19mm (95.58 %)

Theoretical analysis of the reflector shape control system

Sample results – *w-error*



- Surface deformations due to W-error (w_{max} = 2.8 mm)
- No actuator saturation occurs
- Patches near center are not utilized by the control law
- RMS error reduction to 0.0062mm (99.69 %)

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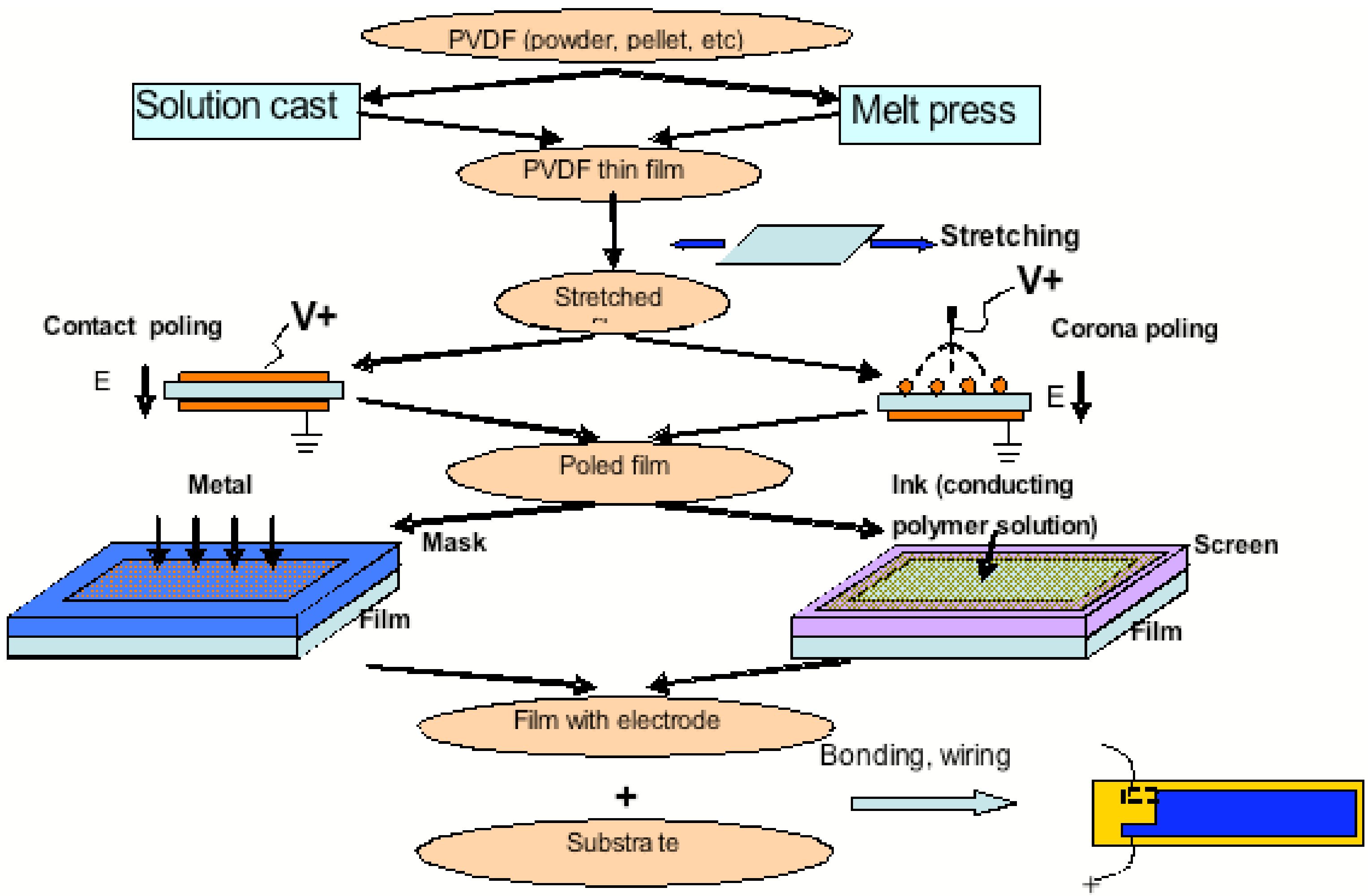
Development of PVDF Based Actuators

Overview of Fabrication Process



Development of PVDF Based Actuators

- Over 170 actuators have been fabricated for a 2.4-m engineering model.
- Actuators have been tested to 4KV, will be operated at the maximum of 2 KV.
- A large number of epoxies have been experimentally studied and the most suitable one has been identified
- Actuator bonding process has been developed.

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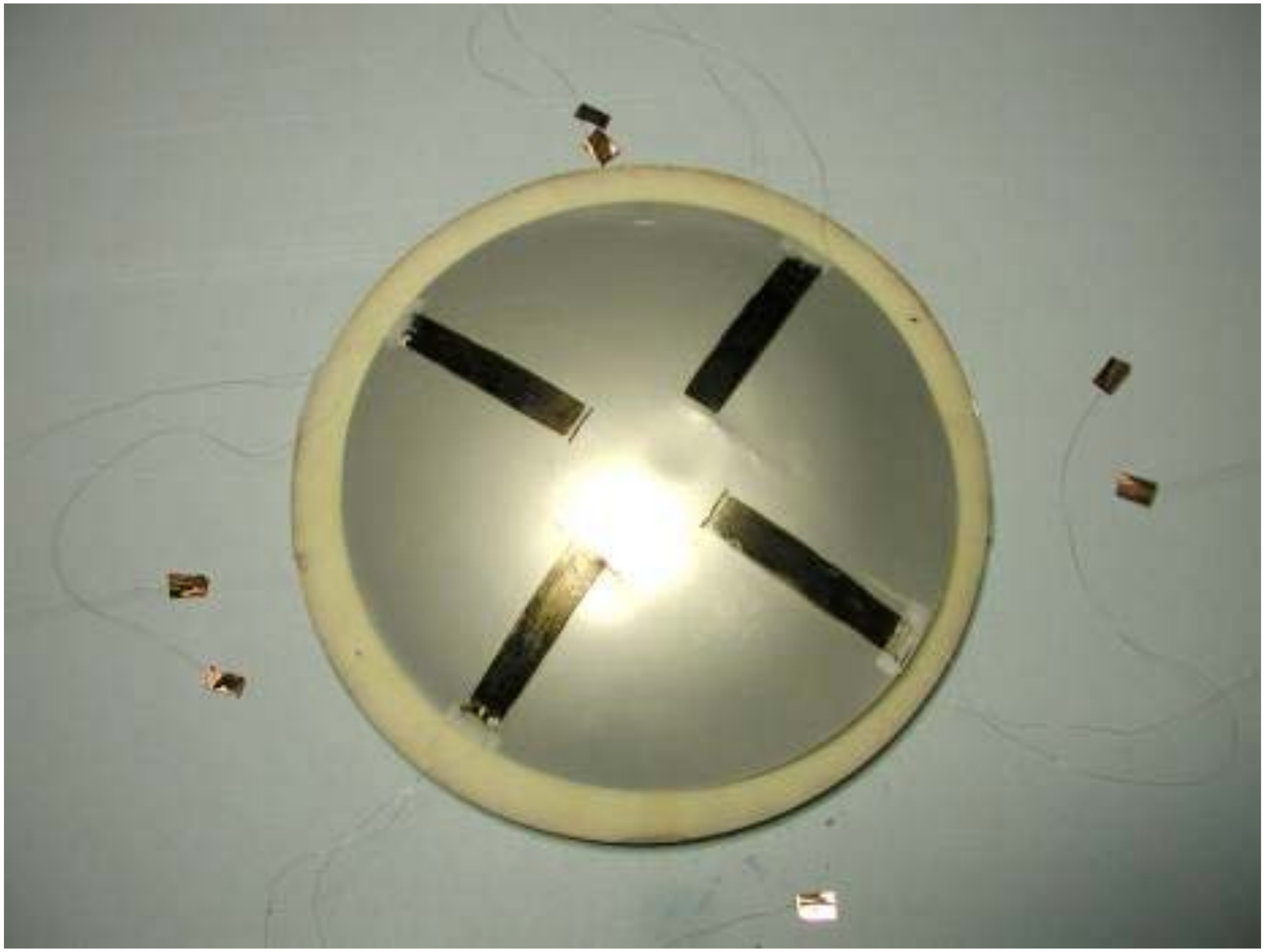
Demonstration of Membrane Reflector

0.2-m diameter engineering model



Demonstration of Membrane Reflector

Demonstration video

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Conclusions

- Analytical model (integrated reflector, actuator, and controller) has been developed and analyzed.
- Fabrication process for Electroactive Polymer (EAP) actuators has been developed. EAP actuators have fabricated.
- 0.2-m diameter reflector engineering model has been fabricated and demonstrated, showing that the EAP actuator technology is promising for the surface control of large in-space deployable reflectors.
- The feasibility of the EAP actuator technology as well as the high precision surface figure control architecture has been demonstrated.
- Future works include the development of 2.4-m diameter reflector engineering model.

End