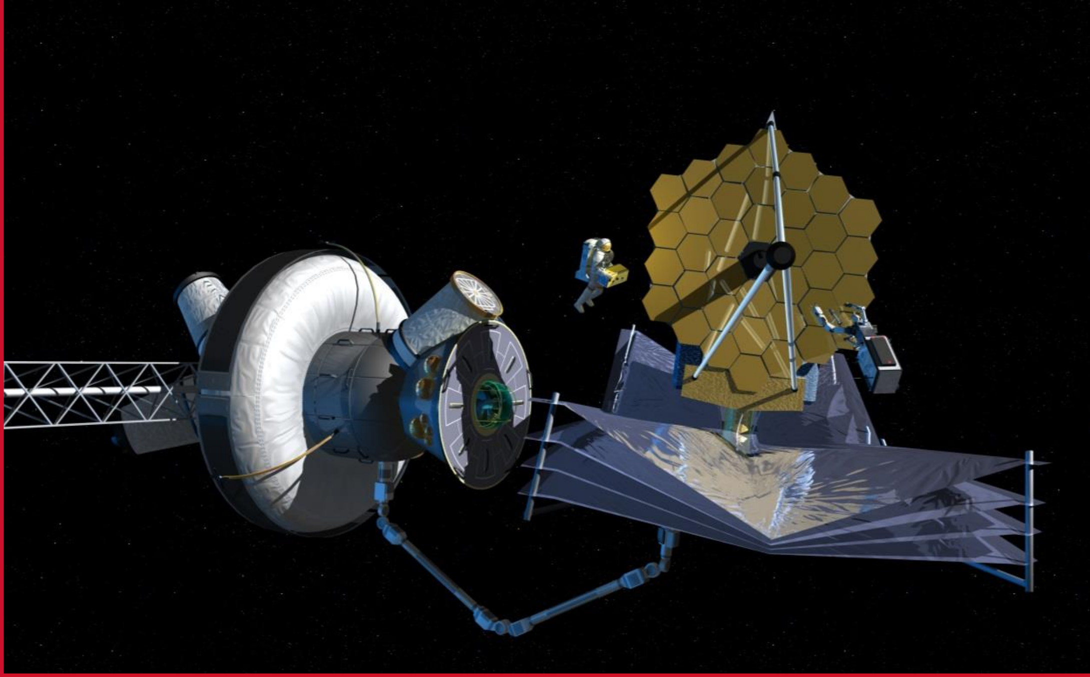


HIGH CONTRAST IMAGING ON SEGMENTED APERTURES WORKSHOP - MIRROR TECHNOLOGY OVERVIEW

GARY MATTHEWS

HARRIS® TECHNOLOGY TO CONNECT, INFORM AND PROTECT™

Discussion Topics

Current technology status of lightweight ULE® mirror segments

- Production capability
  - UV requirements: ~5nm RMS surface
  - Coronagraph Stability: 10 pm/10min RMS WFE (5pm/10min RMS Surface)

Technology challenges

- Edges
  - Minimize or elimination of edge relief
- Metrology
  - Surface errors Measurement and Radius of Curvature Matching

Stability

- Assessment by SAO of current material stability performance

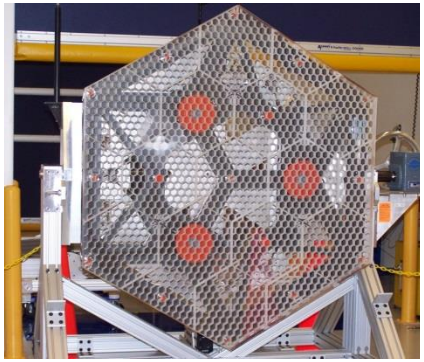
Infrastructure Assessment

Technology Status of ULE® Segments

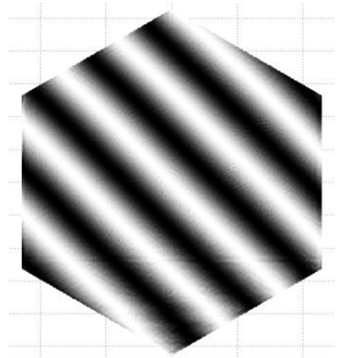
As a follow-on to AMSD, Harris participated in a 16 month mirror segment demonstration project under contract to JPL

- Harris designed, fabricated, and tested lightweight 1.4m Primary Mirror Segment Assemblies (PMSAs) under contract to JPL
- Multiple Mirror Segment Demonstrator (MMSD), achieved the following:
  - PMSA design through CDR
  - Optical finishing and active figure control of 1.4m lightweight segments
  - High level random vibe and shock tests of a lightweight 1.4m segment (10 kg/m^2)
  - Rapid fabrication of multiple 1.4m mirror blanks

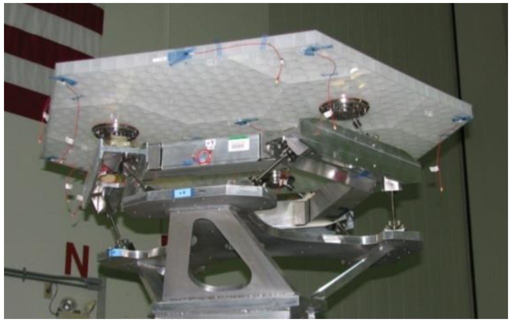
Demonstrations of ULE® Solution



A. OTM PMSA (Optical Test Model)
- Mirror is existing 1.4m AMSD mirror refinished for MMSD
- New MMSD mounts, actuators, reaction structure, elec, controls
- 0-G figure and figure control demonstrated via optical test with both 10 and 16 FCA configurations

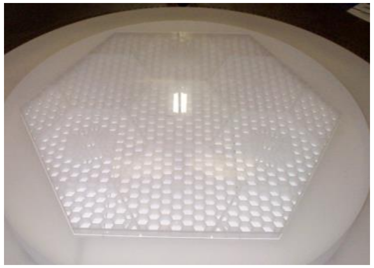


B. Mirror Segment B
- New full size MMSD mirror
- 0-G optical finishing demo
- Finished to 16 nm RMS WFE (no actuation)



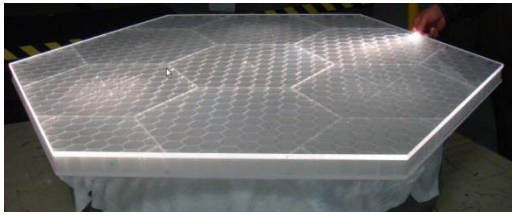
C. Mirror Segment C
- New full size MMSD mirror
- Finished thru LTS (100 um PV)
- Mounted & tested to high level random vibe & shock

Key validations achieved on each of these 10kg/m^2 mirrors



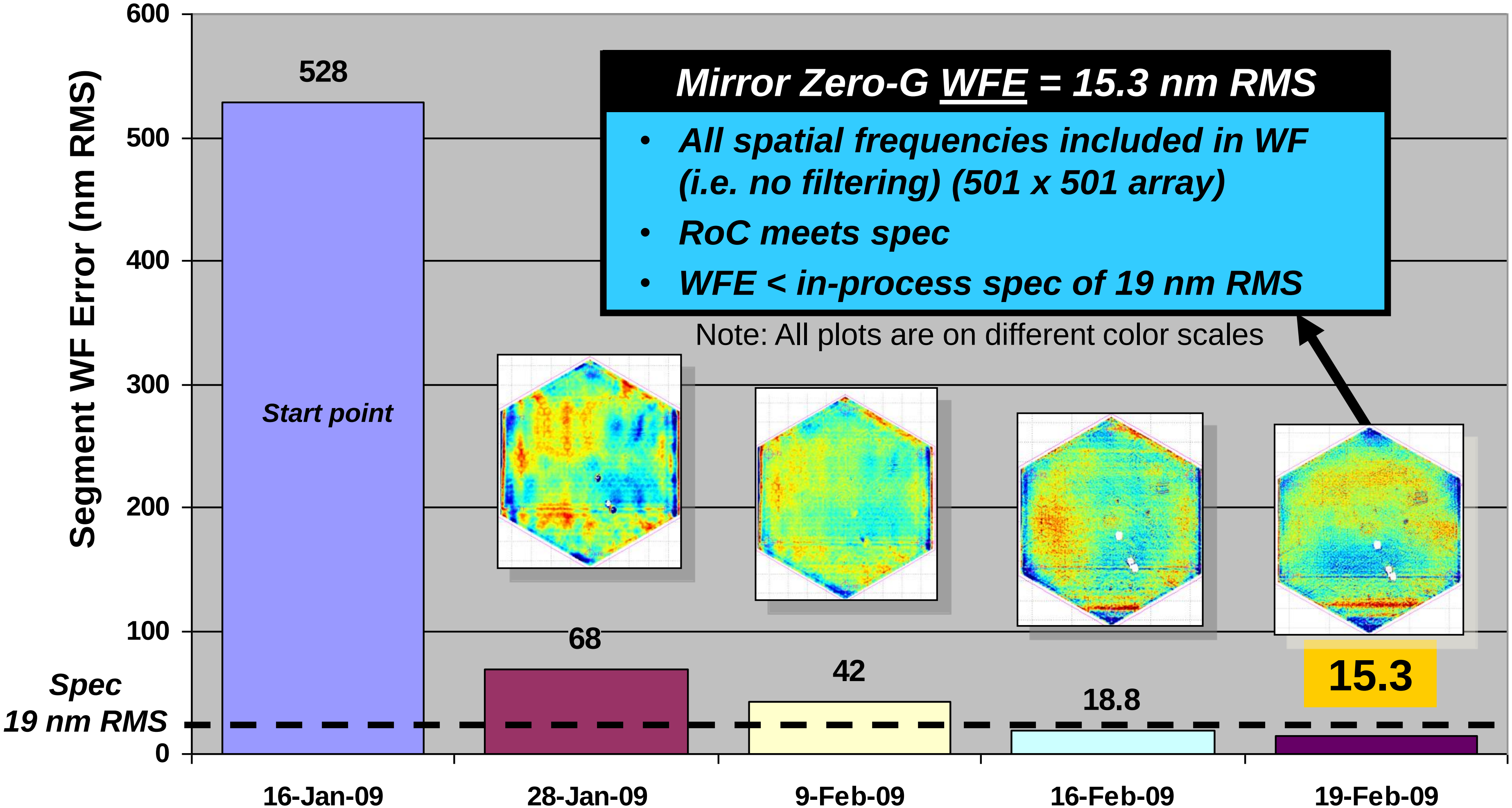
D. Mirror Segment D
- New full size MMSD mirror
- Completed thru plano fusion

Production rate on 3.5 week centers



E. Mirror Segment E
- New full size MMSD mirror
- Completed thru plano fusion

Segment Processing and Figure Convergence



Deterministic processing & test enabled rapid convergence to final spec

Current State Summary

Harris has developed and successfully demonstrated the key technologies for 1.4m PMSAs that perform against a demanding set of requirements

- Optical finishing and wavefront control of lightweight 1.4m segments has been demonstrated to 16 nm RMS wavefront (no actuation)
- A 1.4m lightweight 10 kg/m^2 ULE® glass mirror segment has been successfully tested to high level random vibe and shock loads
- A rapid production rate for 1.4m lightweight mirror blanks has been demonstrated

The PMSA design is robust, blending innovative lightweight solutions with proven materials, processes and methods

The MMSD program demonstrated excellent performance and reliable fabrication of a lightweight 1.4m PMSA solution

Technology Challenges

Stability

- Metric: Assuming growth rate of 2ppm/year , 1” of invar grows 1pm over 10 minutes
- Implies a minimal approach – Potentially a hexapod mounted, passive mirror

Edges

- Minimum edge relief preferable for a large UV segmented system
- Minimal relief is certainly achievable but time intensive
- Production considerations

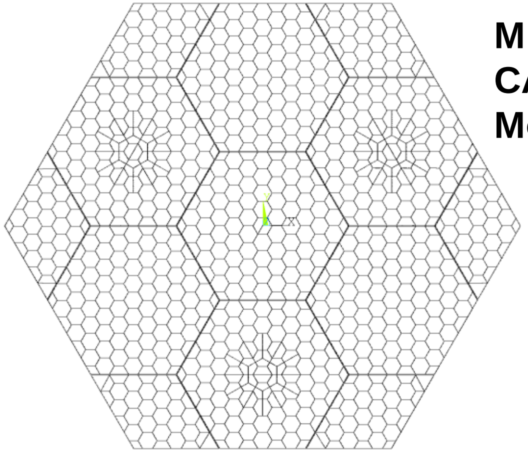
Absolute Metrology

- If you can’t see it, you can’t correct it
- Repeatability is essential
- A passive approach requires RoC matching to extraordinary precision
  - 10 microns out of 40m (40,000,000 microns) equates to 0.25PPM

Stability Considerations

The stability will drive the design

- Minimize external influences
  - Rigid body actuators only
  - Potentially no figure control
  - Very stiff segment: ~500 Hz first mode
- Spec: 10 pm/10 min RMS WFE stability



MMSD CAD Model

Michael J. Eisenhower, SAO, completed a thermal study assessing the performance of a ULE® mirror

- Reference SPIE Conference Proceedings 9602-10, August 2015
- Used actual boule CTE data from MMSD
- Created a “bathtub” thermal control system that would be applied to each mirror segment in the system
- Studied two contributors to segment stability:
  - Effects of changing heat load on mirror segment (slewing telescope changes the reflected energy off of secondary structure)
  - Effects of thermal control system

Pico-meter Stability Modeling

Steady State Performance

- Set Point Change

	SURFACE FIGURE ERROR RMS		
CTE	Uniform	Distribution 1	Distribution 2
Set Point	RMS (pm)	RMS (pm)	RMS (pm)
+1.0 mK	0.174	3.800	0.514
+1.3 mK	0.224	4.940	0.670

Thermal Load Change due to Slew Maneuver

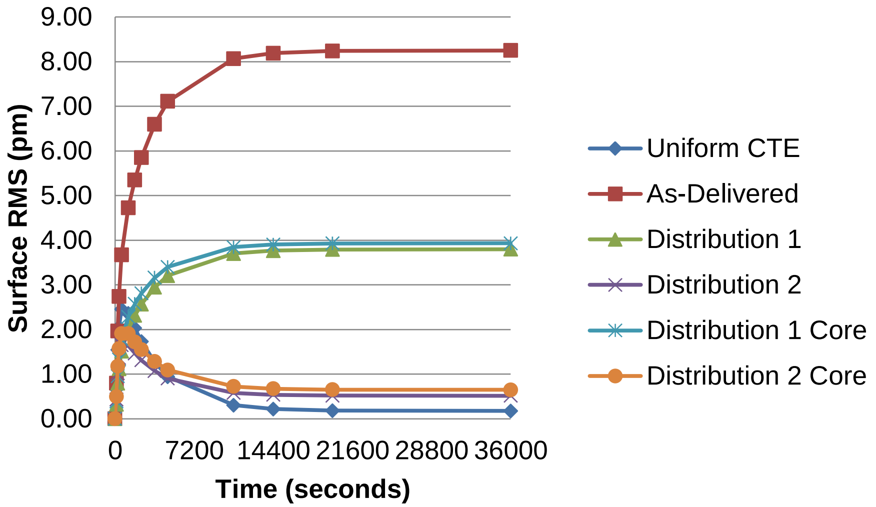
- Heat Load Change

	SURFACE FIGURE ERROR RMS		
	Uniform	Distribution 1	Distribution 2
Heat Load (uW)	RMS (pm)	RMS (pm)	RMS (pm)
50	0.122	0.043	0.068
500	1.214	0.401	0.692
1000	2.411	0.811	1.372
5000	12.056	4.037	6.885

Thermal Control Set Point Change

- Transient change settling time

Single Pulse Transient



Reference SPIE Conference Proceedings 9602-10, Eisenhower, August 2015 for complete discussion

Edge Relief

Corners and edges are the most difficult area during processing

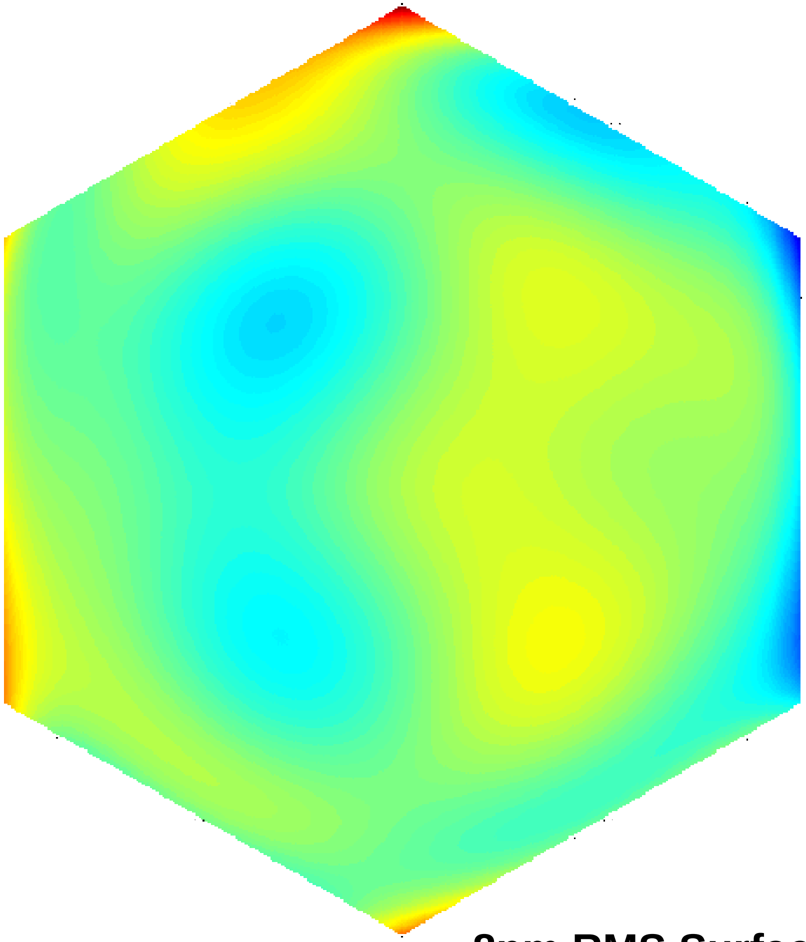
- Rolled edge is very bad
- Stadium is preferred

Some edge is always specified

- For a UV/Exoplanet mission, edge relief needs to be minimized
- But traditional edges can be time consuming and expensive

In a production environment, techniques are used to minimize the processing time

- Large tools – Faster processing – Larger edge relief
- Integral surround glass (like TMT) incorporated into the design speeds processing



8nm RMS Surface

Integral Surround Glass Trimming

Techniques for rapid removal of integral surround glass being developed by TMT

Potentially adaptable to lightweight segments

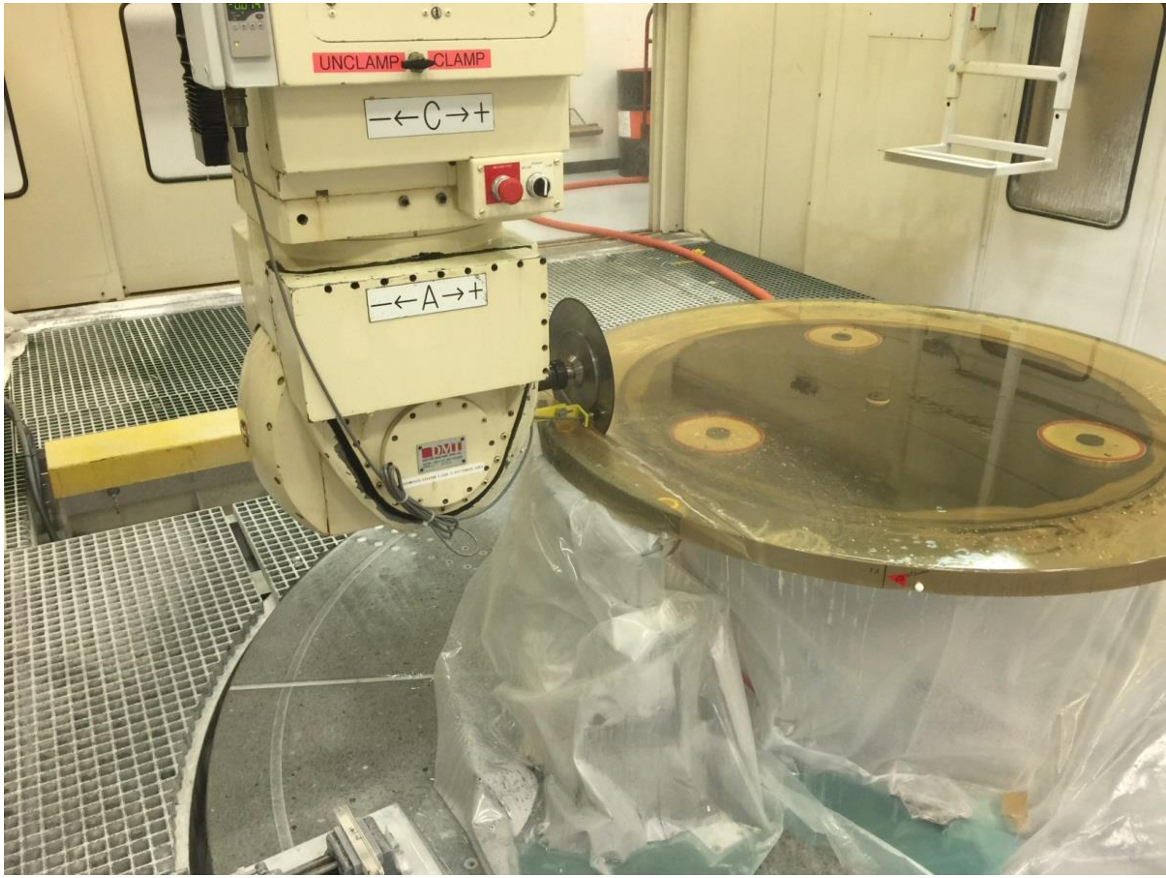


Image courtesy of TMT Corporation

Absolute Metrology and Testing

TMT is developing production optical test capability that would be applicable to producing lightweight segments

Basically a test plate with a CGH to account for the asphere

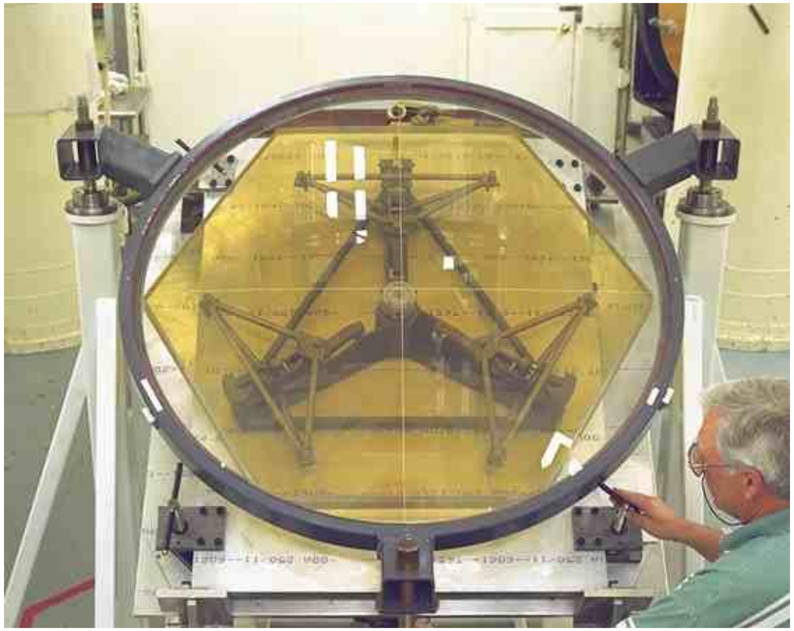
- Developed by Arizona Optical Systems

TMT requirements

- Radius of Curvature – 60m
- RoC Matching – ~2.4mm

Potentially different tests for various requirements

- Some development needed



HET spherical test configuration

Industrial Capacity

Developing a high level production schedule

- Leverage new Harris technology in Capture Range Replication
  - Eliminates about 50% of the post mirror blank production time
  - CRR eliminates generation and grind
  - CRR moves from furnace to final small tool touch up of surface
- Resource loaded schedule shows required infrastructure
- Top level assumption of up to 90 flight mirrors and 15 spares

Initial pass indicates that most industrial infrastructure currently exists to produce all the mirror segments within 4+ years

- Corning can produce the ULE® required
- Large 1.5m+ plano processing capacity at Zygo and Harris
- Abrasive Waterjet capacity in at least three locations (Corning, Ormond, Harris)
- Large 3m furnaces exist at both Corning and Harris
- Small tool processing capacity at Coherent (Tinsley), L3, Harris
- TMT developed test and ion capacity to produce 2 finished mirrors/week

Summary

Recent hardware programs demonstrate that the production capability is within reach

- Existing industrial capacity is close to meeting the required production rates
- Some additional capacity and technology can be leveraged from TMT
- Some technology development and demonstrations still needed to achieve final performance requirements

Picometer stability analysis indicates that material properties and thermal control parameters are achievable

- A passive mirror system may be the best approach
- Structural stability still needs to be assessed
- System trades required