# IXPE Mirror Fabrication: Diamond Turning of Mirror Mandrels

## MIRROR TECH DAYS 2018

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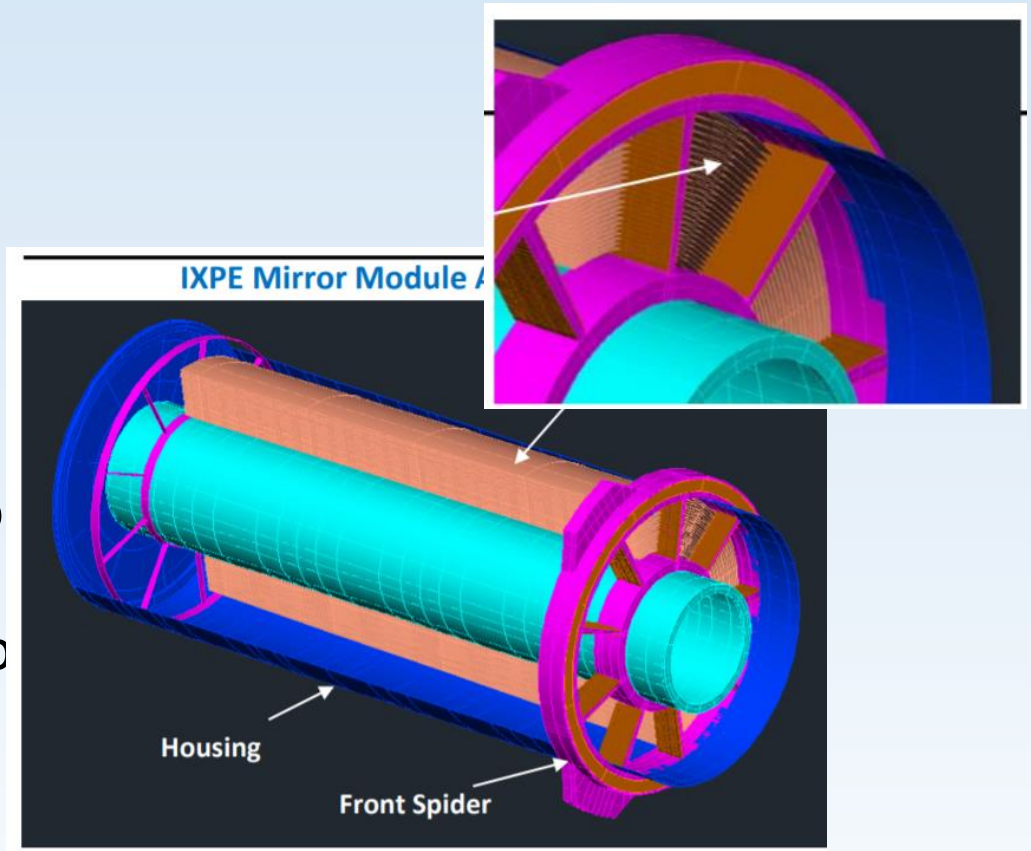
## ***Overview***

- Background
- Requirements
- Horizontal Drum Lathe platform
- Mounting Considerations
- Metrology
- Results
- Next Steps

# Imaging X-Ray Polarimetry Explorer

- Set of three mirror module assemblies (MMA) focus X rays onto three corresponding focal plane detector units
- Uses a single rigid spider to support the 24 nested shells and attach module to structure.



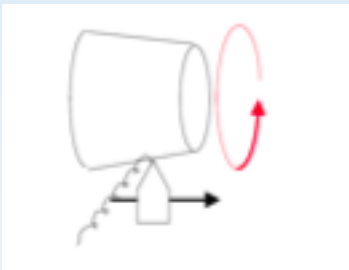

https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170007528.pdf

B. D. Ramsey, "Optics for the Imaging X-ray Polarimetry Explorer (Conference Presentation)," Proc. SPIE 10399, Optics for EUV, X-Ray, and Gamma-Ray Astronomy VIII, 1039907 (3 October 2017);

# Mandrel Prep

## Mandrel Preparation – 24 mandrels from 160 to 270 mm diameter by 700 mm long

1. CNC machine mandrel from Aluminum bar

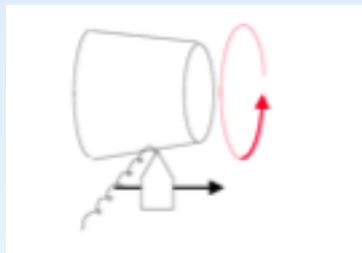


Astro Machine

2. Clean, activate surface, & plate with electroless nickel

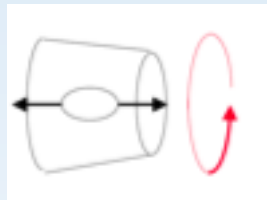
North American EN

3. Precision diamond turn to 400 A rms & sub-micron figure accuracy



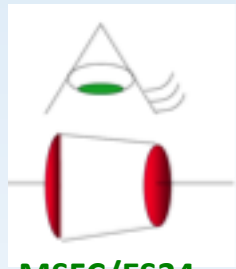
WFT, Inc.

4. Polish & super-polish to 4 Å rms



MSFC/ES34

5. Confirm figure & surface with metrology



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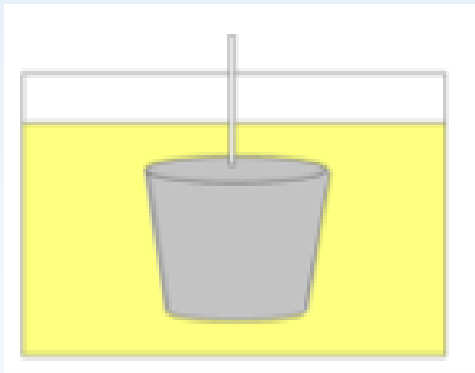
# Shell Fabrication

## Shell Fabrication – 4 shells replicated from each mandrel

**6. Ultrasonic clean & passivate mandrel**



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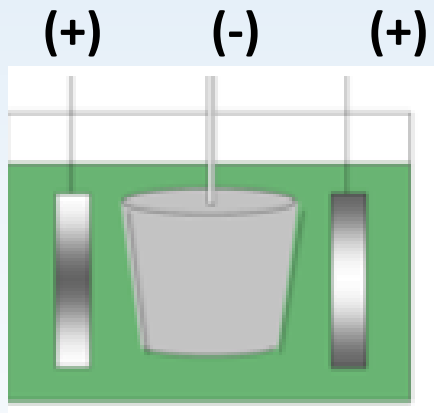
**7. Electroform Ni/Co shell onto mandrel**

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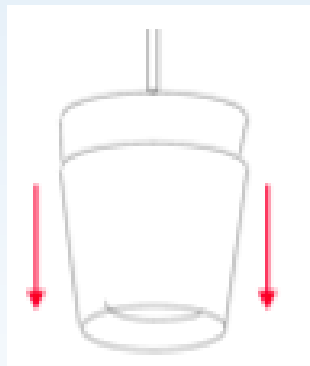
**8. Separate optic from mandrel in cold water bath**



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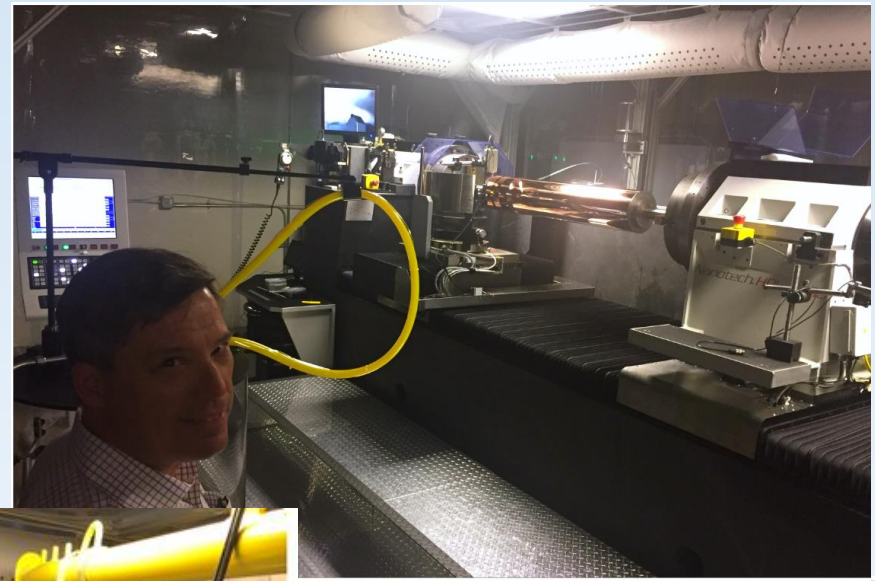
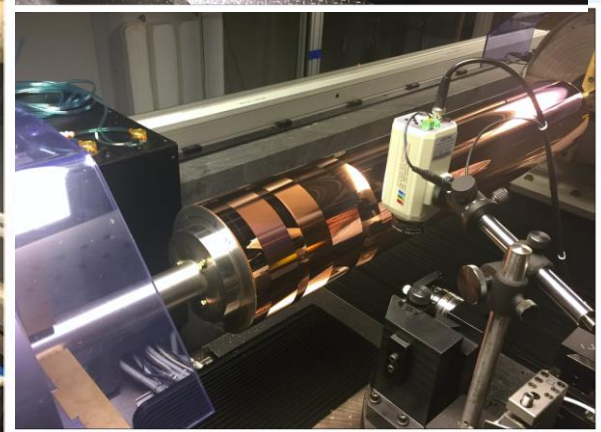
# Shell Requirements

| Parameter | NASA Requirement |
|---|---|
| Length | 700mm |
| Diameter | 160mm to 270mm |
| L/D Ratio | 4.3 to 2.6 |
| Circularity (out of roundness) | 0.0125 mm (0.0005”) |
| P-H Slope Error | 10 microrad |
| Intersection shift | 0.5 mm (0.020”) |
| Radius error | 0.025 mm (0.001”) |
| Axial figure profile | 10 arcsec |
| Bow (parabola) | 1.5 micron |
| Roughness (rms) | 40 nanometers |

# Horizontal Drum Lathe Capabilities

- ***2600mm Length, 2000mm cutting zone***
- ***550mm max diameter***
- ***2500kg max load***
- ***1nm Z resolution, 0.034nm X-resolution***





- Weighs in around 60 tons
- Primary use for precision microstructures such as tailored diffusers, corner-cube reflectors etc.
- We use for variety of additional applications requiring precision micro-optics

# Operating Conditions

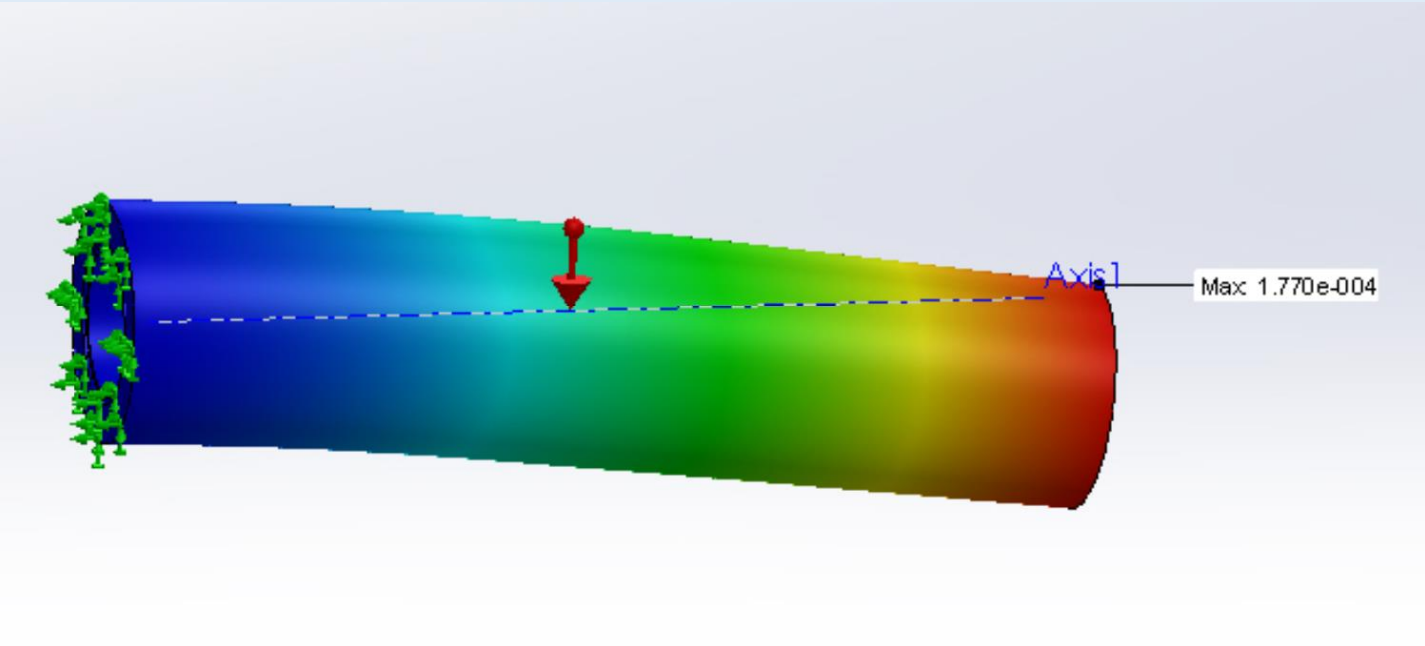
- Environment:
  - Ave. temp 21.74 $^{o}$C
  - Std. Dev 0.148 $^{o}$C
- Headstock Monitor:
  - Ave. temp 21.73 $^{o}$C
  - Std. Dev 0.076 $^{o}$C
- Z-axis:
  - Ave. temp 20.35 $^{o}$C
  - Std. Dev 0.044 $^{o}$C

# Mounting Considerations

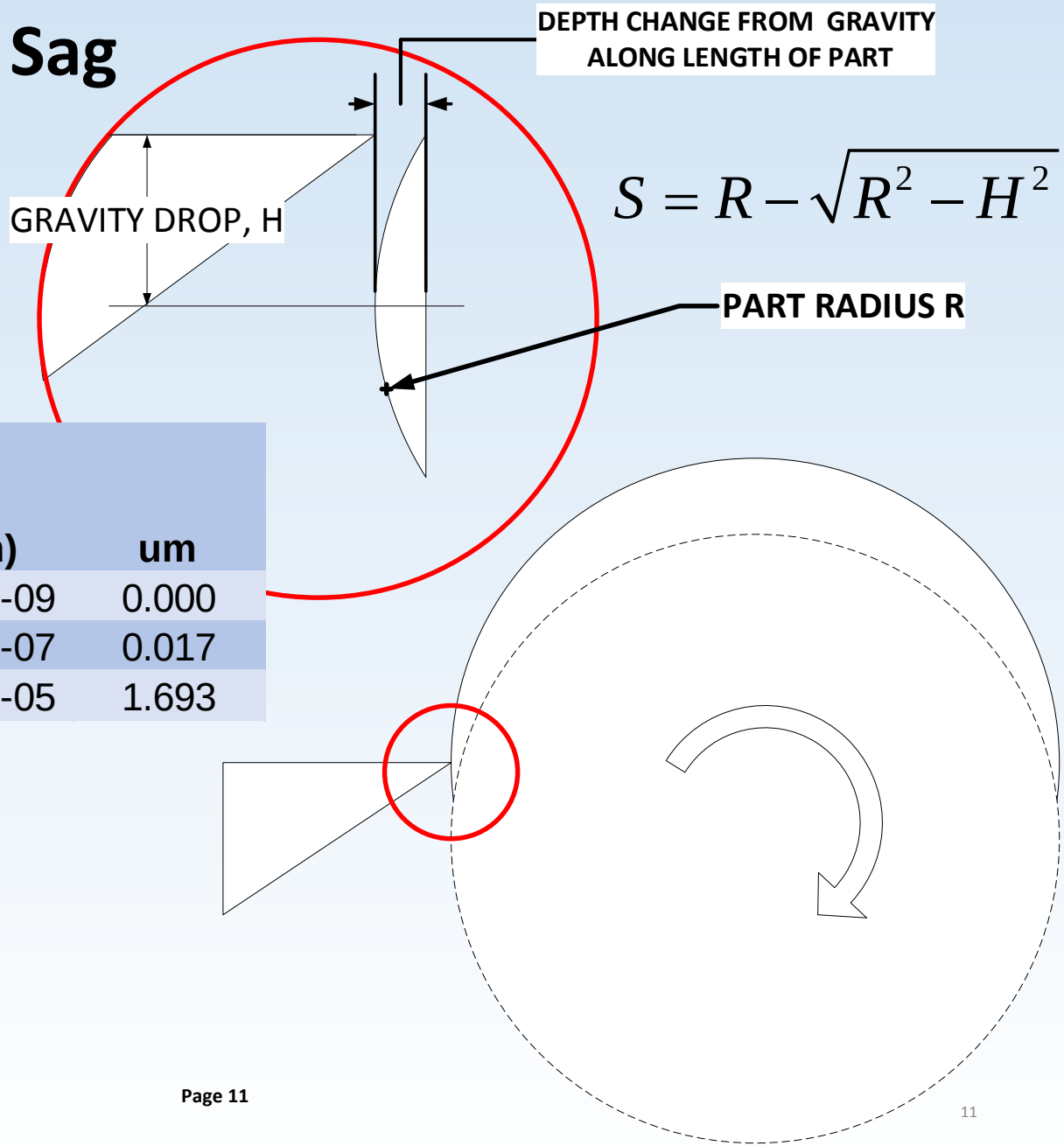
- *Common rule of thumb: L/D > 2.5 needs tailstock support*
- *Early testing indicated compression of mandrel leads to warped surface upon release*
- *Best performance with support by headstock only*
- *Is this a problem?*

# Analysis of Headstock support

- Both FEA and 1st order calcs indicate gravity-induced "drop" of tail end of mandrel to be about 4 microns



# Effect of Tailstock Sag



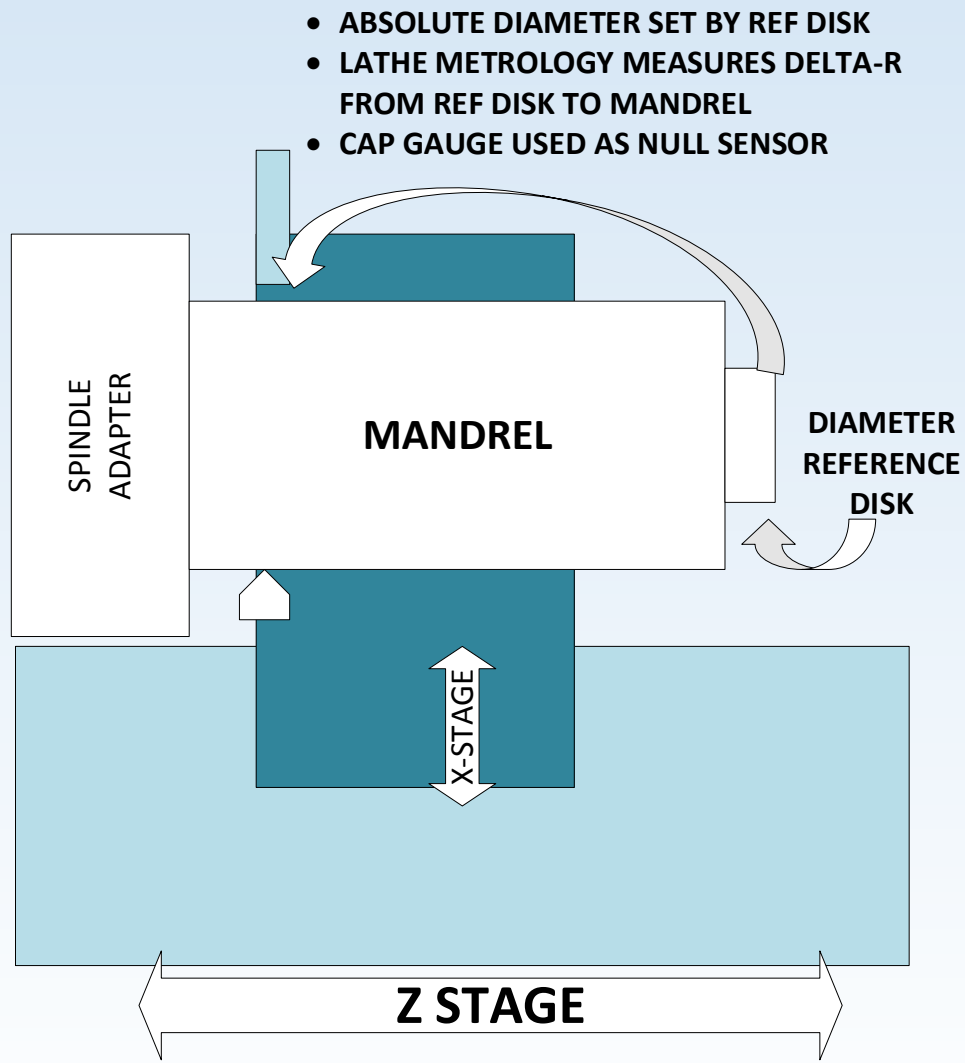

$$S = R - \sqrt{R^2 - H^2}$$

| Vertical Offset (in) | Radius (in) | Sag (in) | um |
|---|---|---|---|
| 0.0002 | 3 | 6.66667E-09 | 0.000 |
| 0.002 | 3 | 6.66667E-07 | 0.017 |
| 0.02 | 3 | 6.66674E-05 | 1.693 |

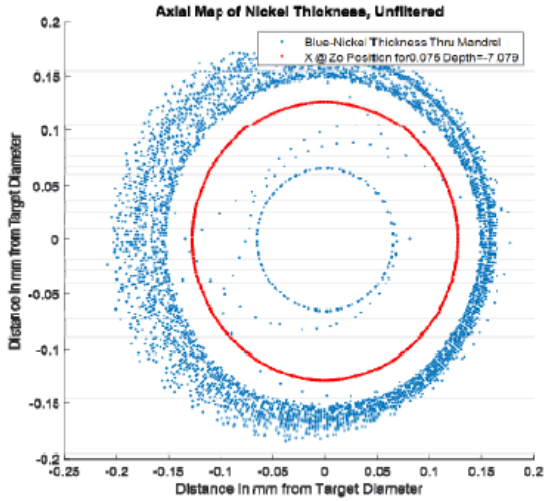
# Metrology: keep it simple.

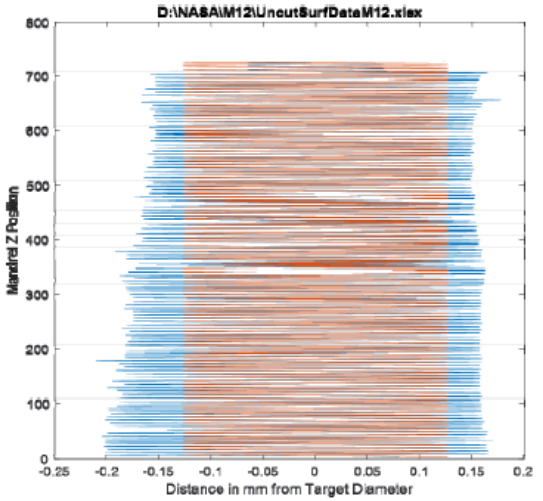
- Matching NASA's CMM: metrology audit, NIST-traceable master reference, or what?

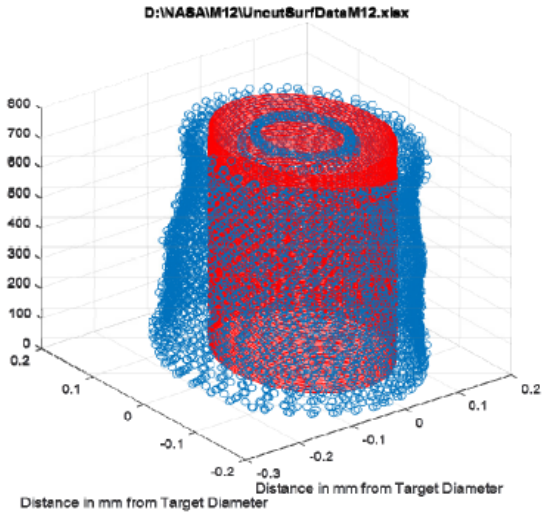
- Solution:
  - Have NASA fabricate a reference disc, and measure
  - We mount disc to each mandrel and use as absolute reference
  - Use inherent HDL accuracy for the rest

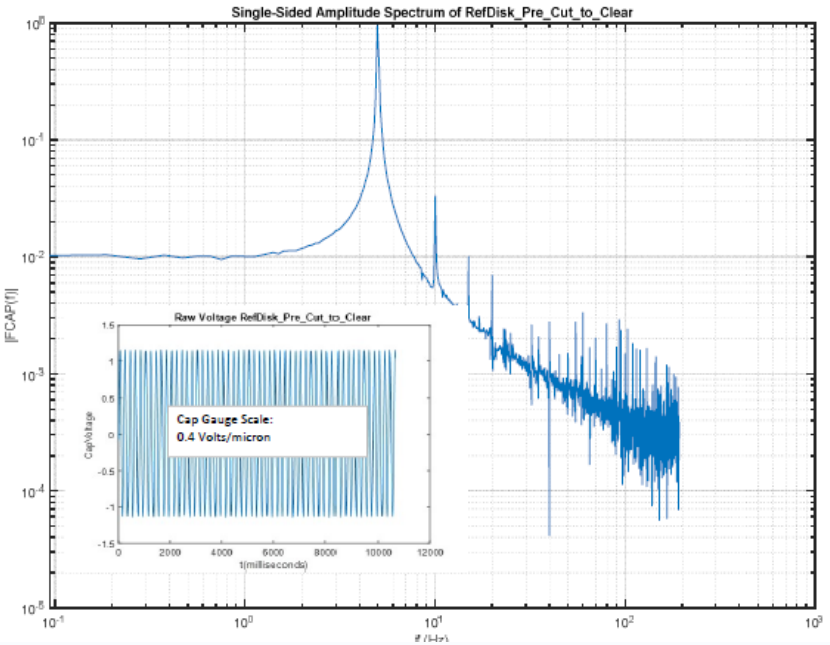


# Uncut Surf Profile

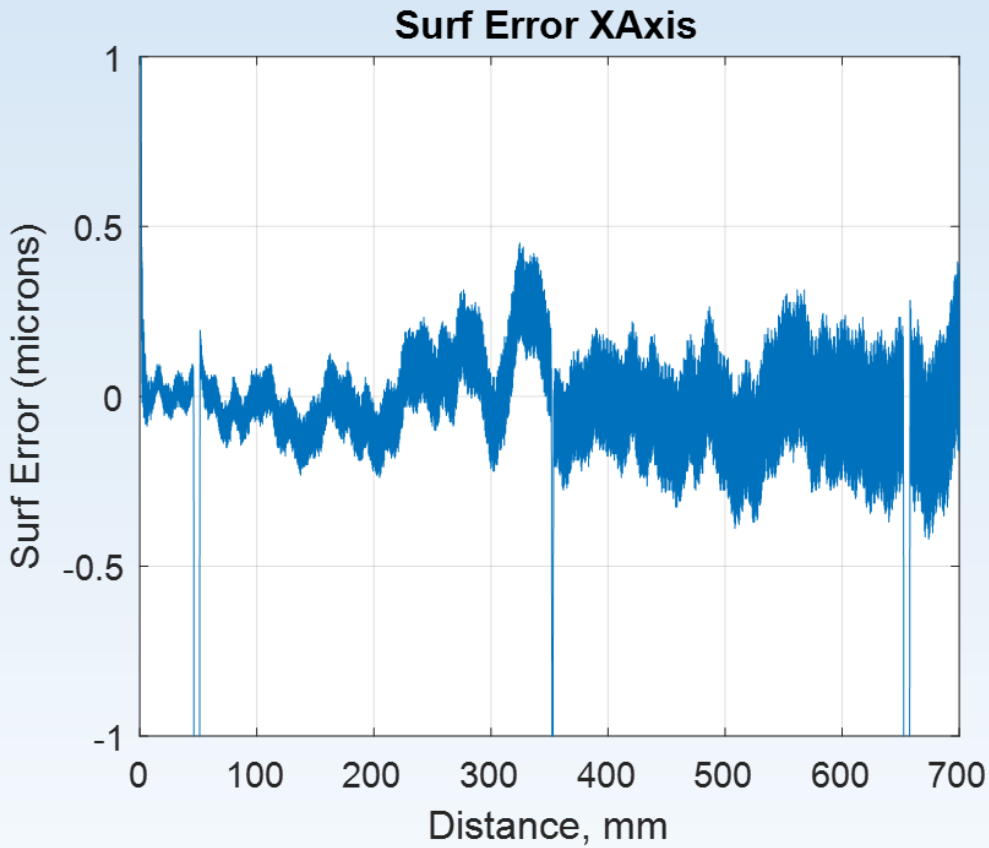


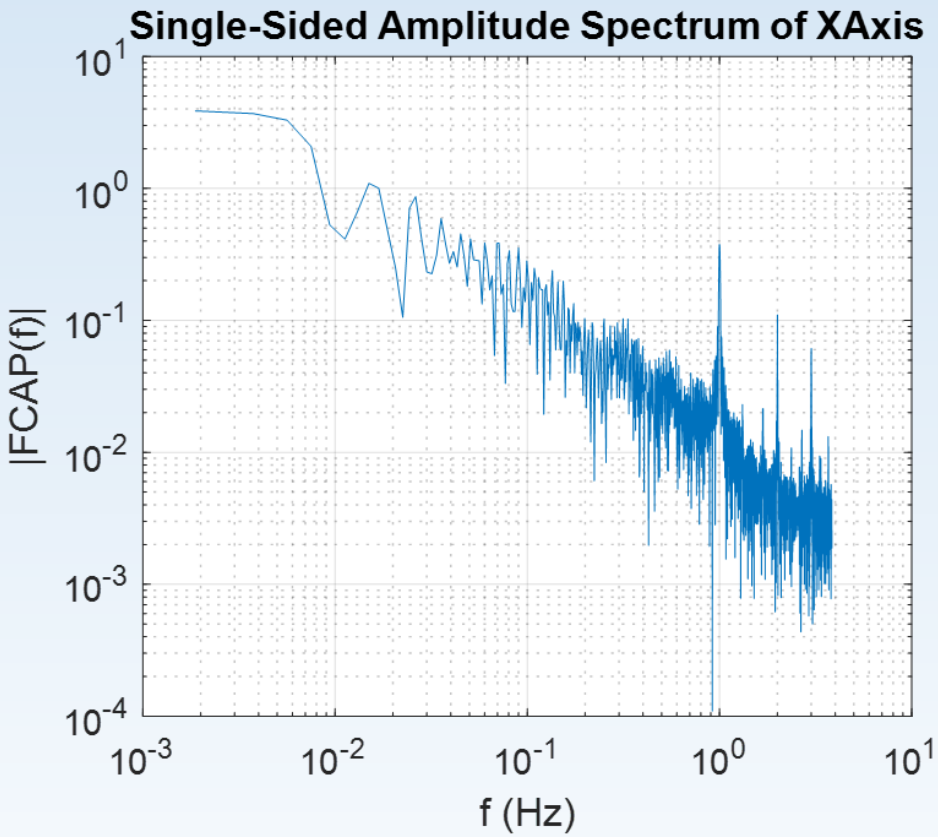



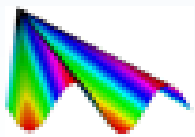



# Typical Surface Profile (acquired while spinning)

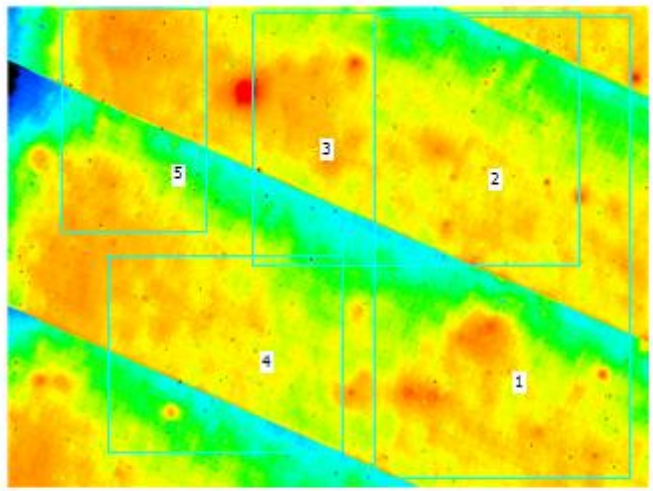


# Surface Roughness

- Surface roughness measured indirectly through casting (potting) surface
- Measured with Confocal 3D laser scanner




| | Rp | Rv | Rz | Ra | Rq | RsK | Rku |
|---|---|---|---|---|---|---|---|
| Seg.1 | 0.4313um | 3.2568um | 3.6881um | 0.0368um | 0.0518um | -7.5849 | 308.1413 |
| Seg.2 | 0.5993um | 3.6423um | 4.2416um | 0.0345um | 0.0479um | -7.7920 | 380.3383 |
| Seg.3 | 0.2309um | 2.7525um | 2.9834um | 0.0495um | 0.0683um | -5.6244 | 165.2545 |
| Seg.4 | 0.1275um | 2.3176um | 2.4451um | 0.0370um | 0.0535um | -8.1145 | 236.3501 |
| Seg.5 | 0.4469um | 3.4805um | 3.9274um | 0.0420um | 0.0615um | -13.0166 | 613.4019 |

# Results: Overview

- All 19 mandrels successfully completed with no rework, on time
- NASA results for 1st 14:

| Parameter | NASA Requirement | | |
|---|---|---|---|
| Length | 700mm | | |
| Diameter | 160mm to 270mm | WFT PERFORMANCE | |
| L/D Ratio | 4.3 to 2.6 | Parabola | Hyperbola |
| Circularity (out of roundness) | 0.0125 mm | 0.57um | 1.42 um |
| P-H Slope Error | 10 uRad | 1.6 uRad | |
| Intersection shift | 0.5 mm | 0.135 mm | |
| Radius error | 0.025 mm | 0.0028 mm | |
| Axial figure profile | 10 arcsec | 8.0 arcsec | |
| Bow (parabola) | 1.5 micron | 1.16 micron | |
| Roughness (rms) | 40 nanometers | 23.5 nm | 40.4 nm |

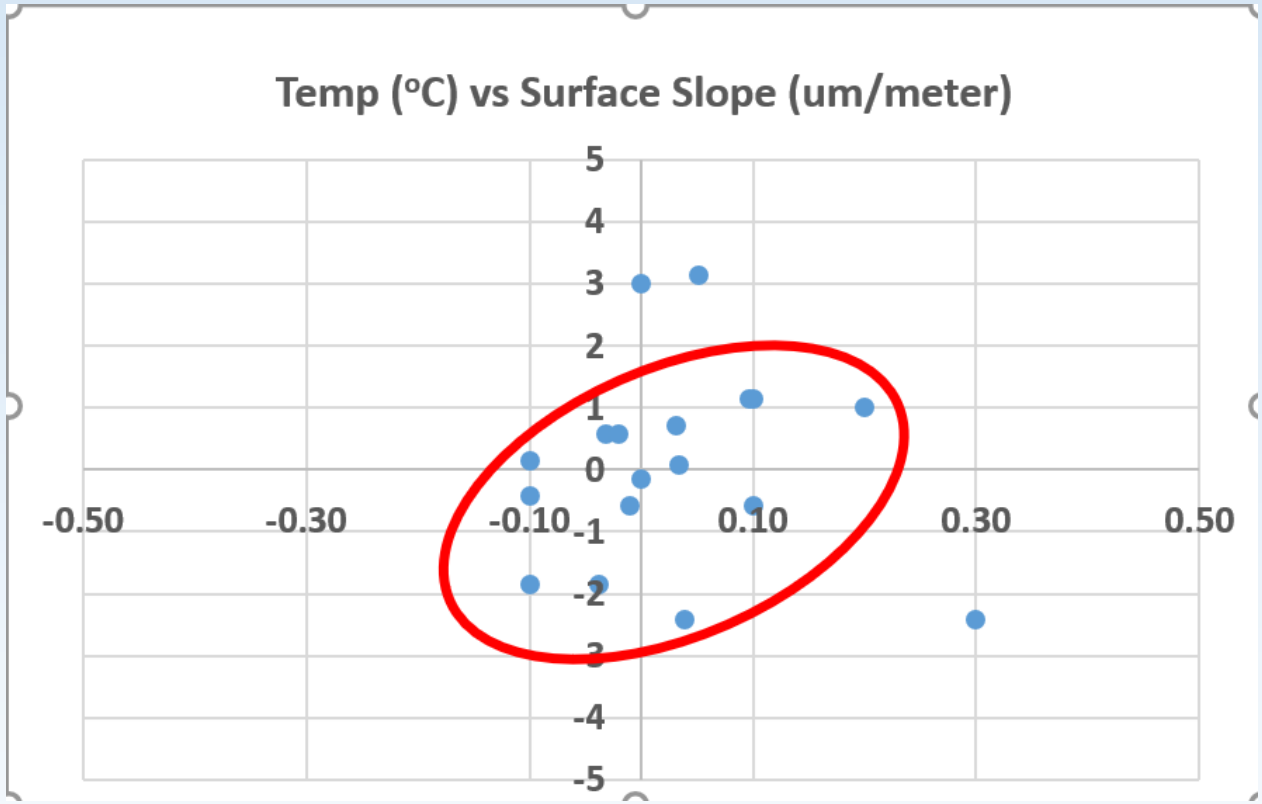
# Distributions

- Under spec for radius, ellipticity by 10x
- Form, roughness are at spec

| | Radius um | Form (PV) um | Ellipticity um | Rq (P) nm | Rq(H)nm |
|---|---|---|---|---|---|
| Average | 0.4 | 1.06 | 0.49 | 46 | 51 |
| STDEV | 0.9 | 0.37 | 0.45 | 14 | 17 |
| Min | -1.2 | 0.40 | 0.10 | 30 | 32 |
| Max | 1.79 | 2.00 | 1.40 | 90 | 88 |

# Temperature Performance

- Not enough data yet to perform good statistical analysis
- Trend shows correlation between surface slope and temperature



# Next Steps

- New Distance Measuring Interferometer will replace cap gauge:
  - Higher surface resolution (picometer vs nanometer)
  - Higher spatial resolution: 30 um vs 3mm
- New Fast Tool Servo has “hooks” for active feedback
- GOAL:
  - Improve final cut performance
  - Decrease processing time

## Acknowledgements:


- ***Many thanks to NASA MSFC:***
  - ***Chet Speegle***
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  - ***Jeff McCraken***
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  - ***Oye Oyeyipo***
  - ***Fredy Zuniga***