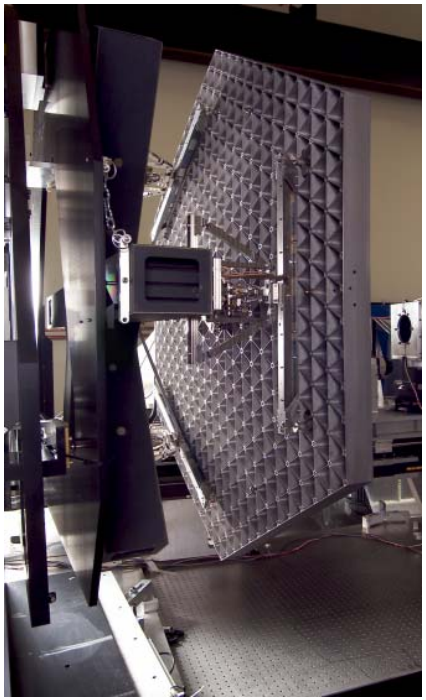
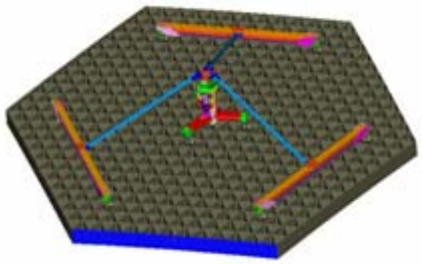
Ball AMSD Final Results

MSFC Tech Days Briefing
August 17, 2004
Ball Aerospace & Technologies Corp.

AMSD 2 Mirror Overview





AMSD Mirror Design

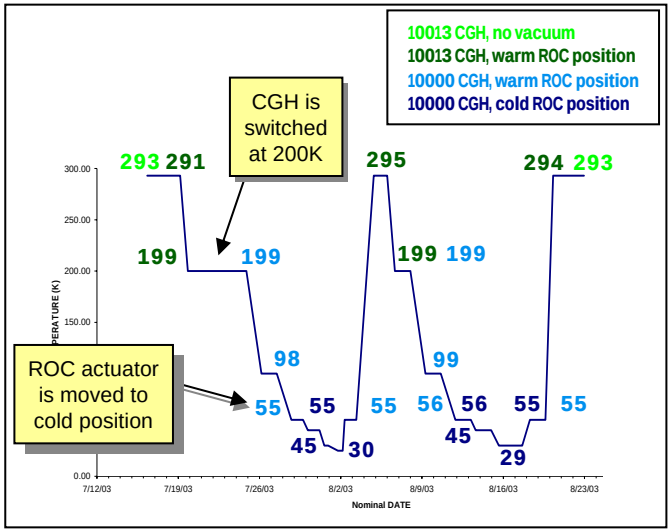
- 1.2 m flat-to-flat light-weighted, semi-rigid, beryllium mirror
- 10.3 kg/m^2 beryllium substrate areal density
- 15.6 kg/m^2 areal density for mirror system including mirror, reaction structure, flexures, actuators
- Figure (RoC) Control and Rigid Body Motion Control
- Beryllium blank is hipped by Brush Wellman, machined and light weighted by Axsys Technologies, and polished by SSG-Tinsley

	AMSD	JWST
Shape	**Concave Off-Axis Parabola**	Concave Off-Axis Ellipse
Radius (at 30K)	**10,000 mm**	15,879.722 mm
Conic	**-1**	-0.99666
Flat-to-Flat Dimension	**1200 mm**	1315 mm *
Off-Axis Distance (to center of mirror)	**1400 mm**	segment A 1323.5 mm B 2634.7 mm C 2285.9 mm
Operational Temperature	**30 to 55 K**	30 to 62 K
Survival Temperature	**25 K**	20 K
Material	**Beryllium**	Beryllium
Substrate Configuration	**Open Cell back**	Open Cell Back
Number of Cells	**864**	600
Areal Density	**10.3 Kg/m^2**	13.4 Kg/m^2

* Nominal, segments are irregular hexagons

AMSD 2 Mirror Chronology

- The beryllium AMSD II mirror was polished, by Tinsley, to approximately 30nm rms prior to integration of the radius of curvature and tip/tilt actuation systems
  - Integration and subsequent stress relieving degraded figure to approximately 80nm rms
- The mirror was then successfully cryo-tested in July 2003
  - Cryo-deformation ~78 nm rms
  - Cryo-deformation repeatability < 10 nm rms
- The mirror was then shipped back to Tinsley where it was polished to <20 nm rms at ambient



AMSD Requirements and Performance

		AMSD	AMSD Achieved Values	JWST
Clear Aperture (Defined by polish to edge dimension)		15	99.8% of 15mm defined C.A.	5
Surface Error (ambient reqt)				
Low-Frequency (> 190 mm/cycle)	nm rms	22 *	16.1	20
Mid-Frequency (< 190 mm/cycle)	nm rms	7	8.8	7
Surface Roughness	nm rms	4	3.6	4
Radius of Curvature (cryogenic reqt)				
Absolute	mm RoC	± 1	-0.6	± 1
RoC Control	mm RoC	0.02	0.016	0.02
Prescription Alignment	mm	absolute N/A controlled to 0.25	controlled to 0.25	absolute 0.7
Horizontal Gravity Sag	nm rms	No reqt	700	200

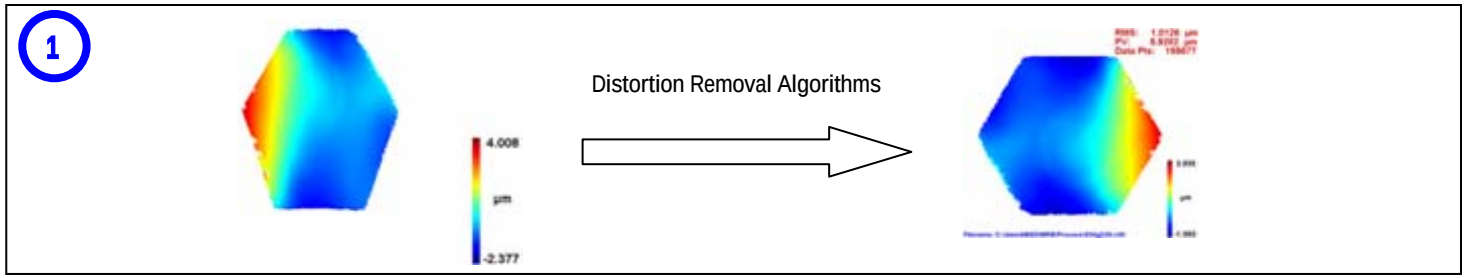
* requirement & achieved value was post cryogenic testing

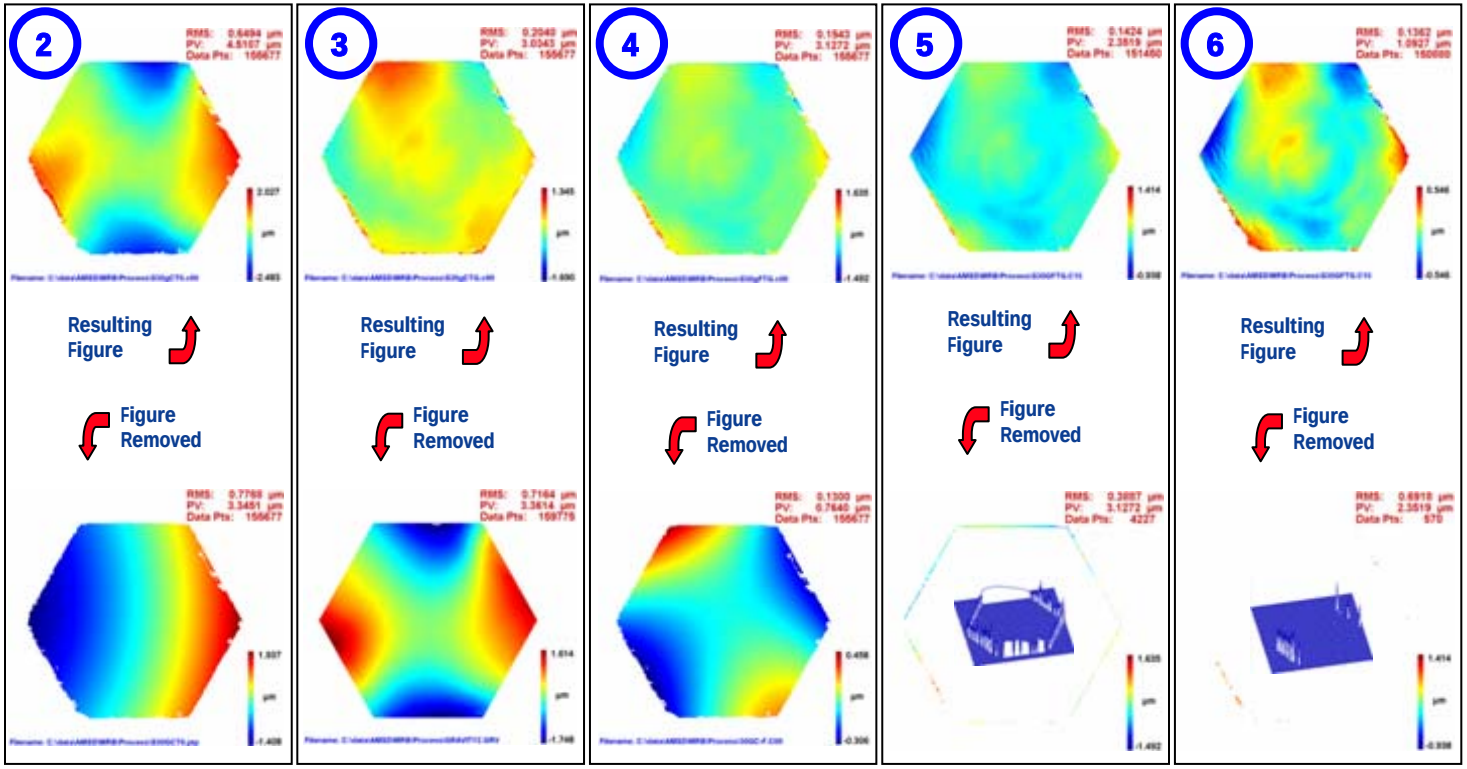
Primary Mirror Segment Frequency Band Definition			
	Cycles / Total PM Aperture	Cycles / PM Segment	Spatial Error Size
Low Frequency	0 to 5	0 to 1	> 1330 mm
Mid Frequency	5 to 30	1 to 7	1330 mm to 222 mm
High Frequency	30 to 83125	7 to 18975	222 mm to 80 µm
Micro-Roughess	83125 to 6,650,00	18975 to 1,310,000	80 µm to 1 µm

Post Cryogenic Processing

- Following the material selection of beryllium for the JWST primary mirror a follow-on of the AMSD project was started to prove out the polishing of the AMSD II mirror to JWST requirements
- The first step was to modify the optical metrology station at Tinsley to support polishing to the JWST requirements
  - Previous AMSD requirement was 50nm rms, new requirement was 22nm rms
  - Goals
    - Surface figure repeatability consistently < 12 nm-rms
      - Achieved 4 nm-rms
    - Alignment measurement repeatability < ¼ mm
      - Achieved ¼ mm
- A mount de-integration plan was devised
  - The ROC actuation system remained on the mirror during all polishing
  - The tip/tilt actuation system was removed for polishing but re-installed for figure testing
- The schedule for all processing was monitored closely for comparability to JWST

Data Processing Flow



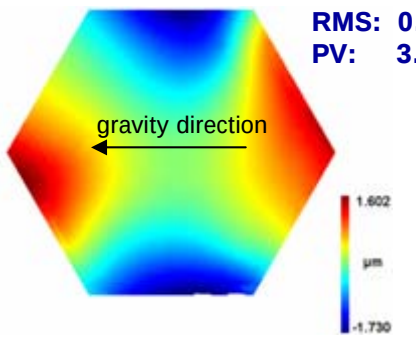
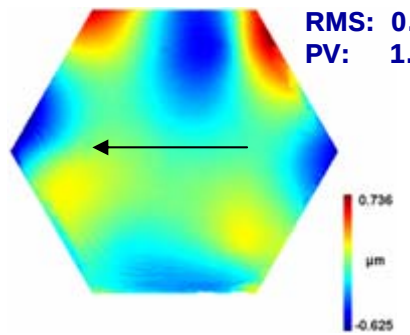
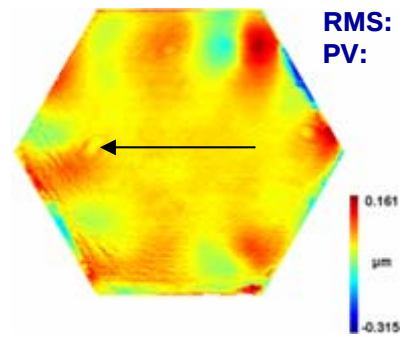
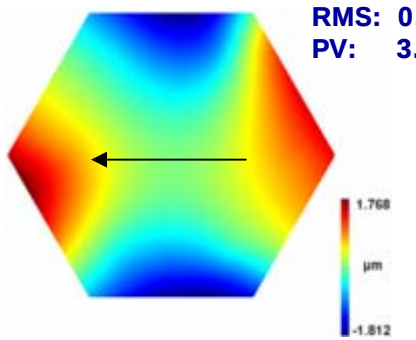
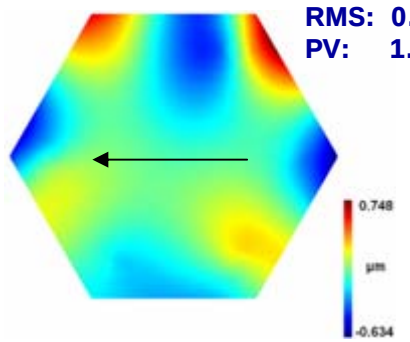
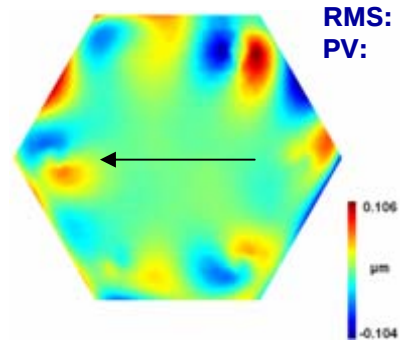


Remove Piston, Tilt, Power | Remove Gravity | Remove Alignment | Mask to 15mm from Edge | 4X Data Clipping to Remove Noise

Not used for ambient processing

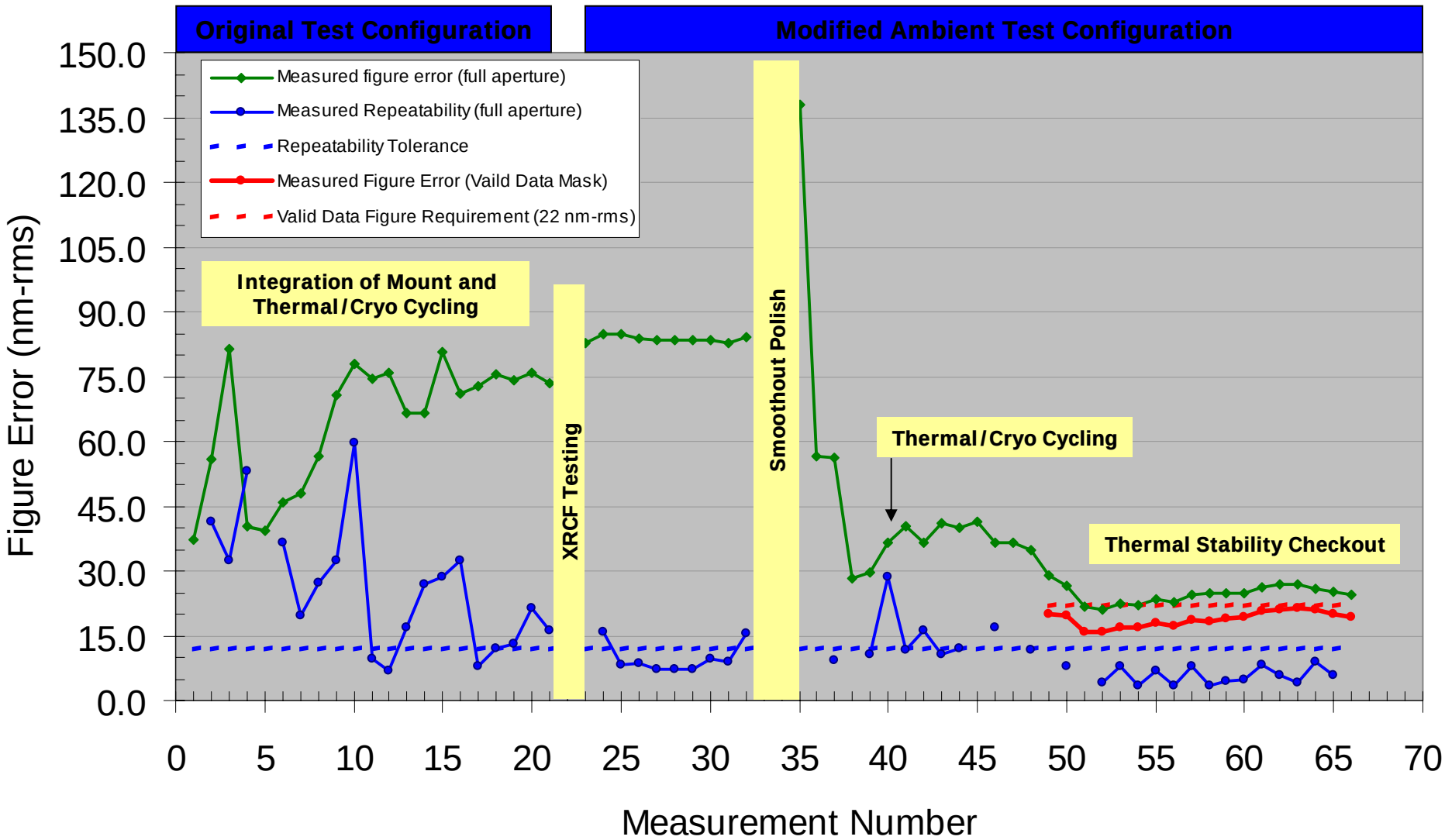
AMSD Gravity Characterization and Backout

- Measurement techniques were used to measure the effects of gravity
- Final finite element model (by SAO) showed excellent correlation to measured data

	Piston, Tilt, Power Removed	Piston, Tilt, Power, Astigmatism Removed	36 Fringe Zernikes Removed
Measurements	 RMS: 0.708 µm PV: 3.32 µm	 RMS: 0.191 µm PV: 1.36 µm	 RMS: 0.036 µm PV: 0.48 µm
Model	 RMS: 0.729 µm PV: 3.58 µm	 RMS: 0.187 µm PV: 1.38 µm	 RMS: 0.024 µm PV: 0.21 µm

(arrow indicates gravity force vector)

AMSD Ambient Surface Figure Convergence

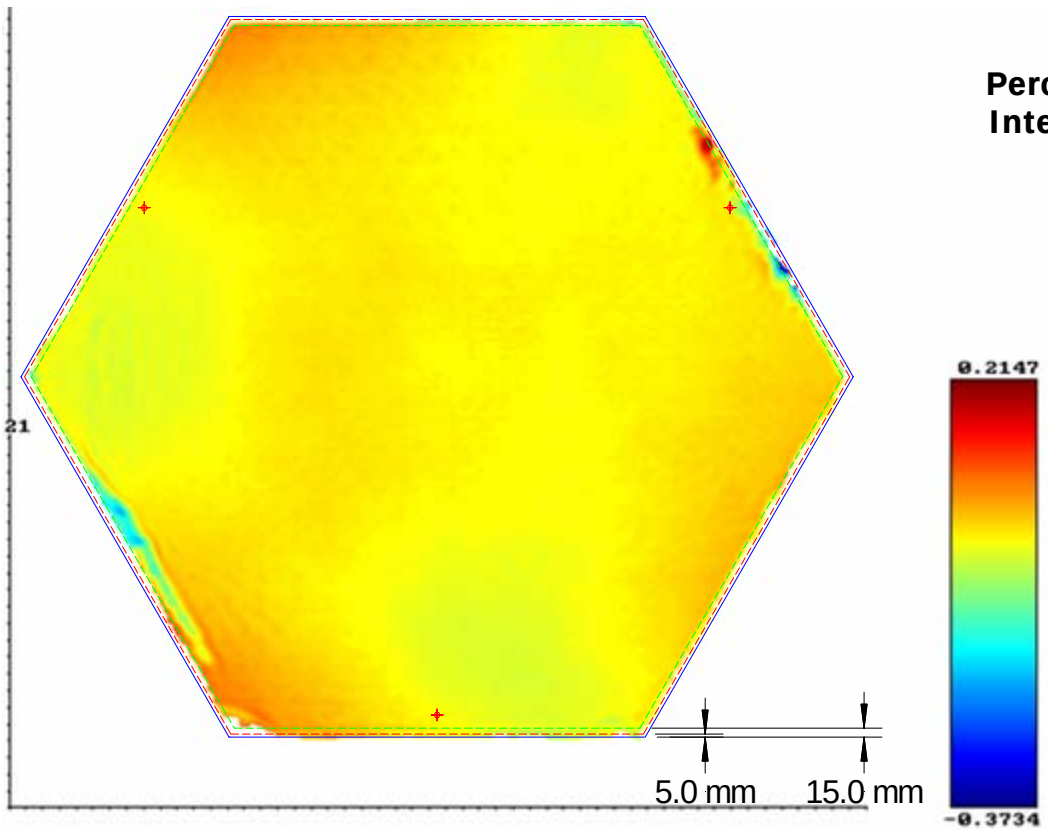


Final AMSD Ambient Surface Figure

RMS = 19.2 nm
PV = 588 nm
(all frequencies captured by interferometer)

Percent Area Captured by Interferometer versus:

Physical edge	**= 97.1%**
5mm C.A. Band	**= 98.5%**
15mm C.A. Band	**= 102.0%**



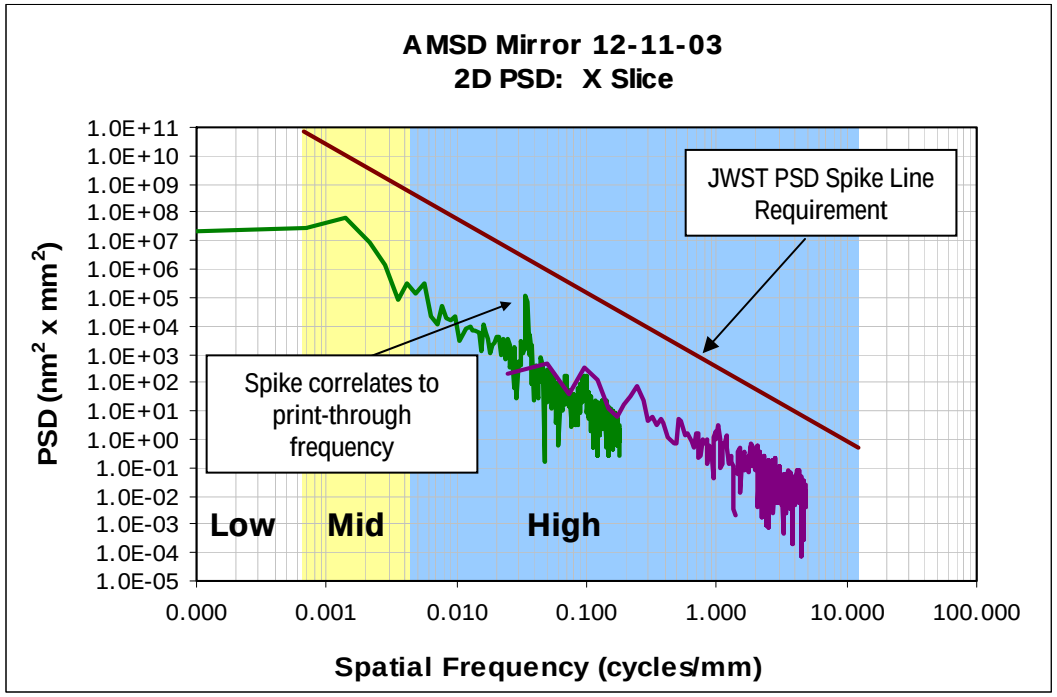
Stated another way, the collecting area of the mirror (area captured by the interferometer) is equivalent to 102% of the area defined by the region inside of a 15mm band.

"Valid Data Mask" only applied (modulation threshold set to 0.4)
No 4x data clipping applied

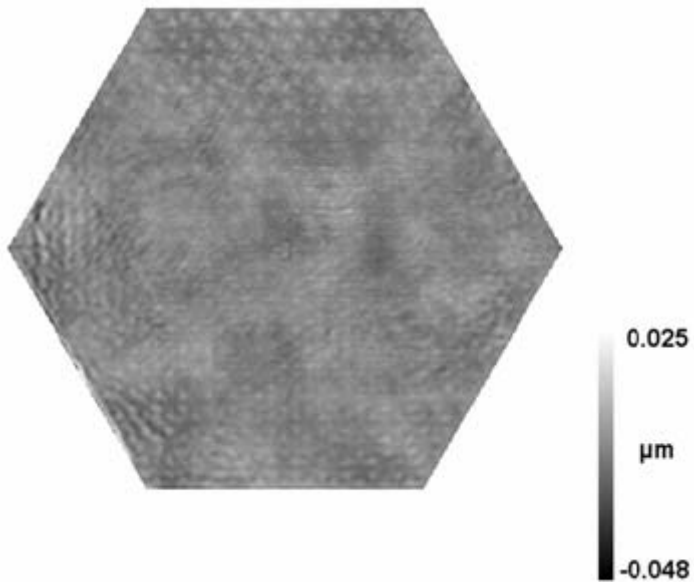
AMSD Power Spectral Density (PSD) Results

	JWST Cryogenic Reqt (5mm C.A.)	JWST Ambient Reqt (5mm C.A.)	AMSD Ambient Reqt (15mm C.A.)	AMSD Achieved (15mm C.A.)
Mid Frequency (this is low frequency at the segment level)	22.5	20	22	16.1
High Frequency (this is mid frequency at the segment level)	7.5	7	7	8.8

units = nm rms



Print-through portion of Final AMSD Ambient Figure

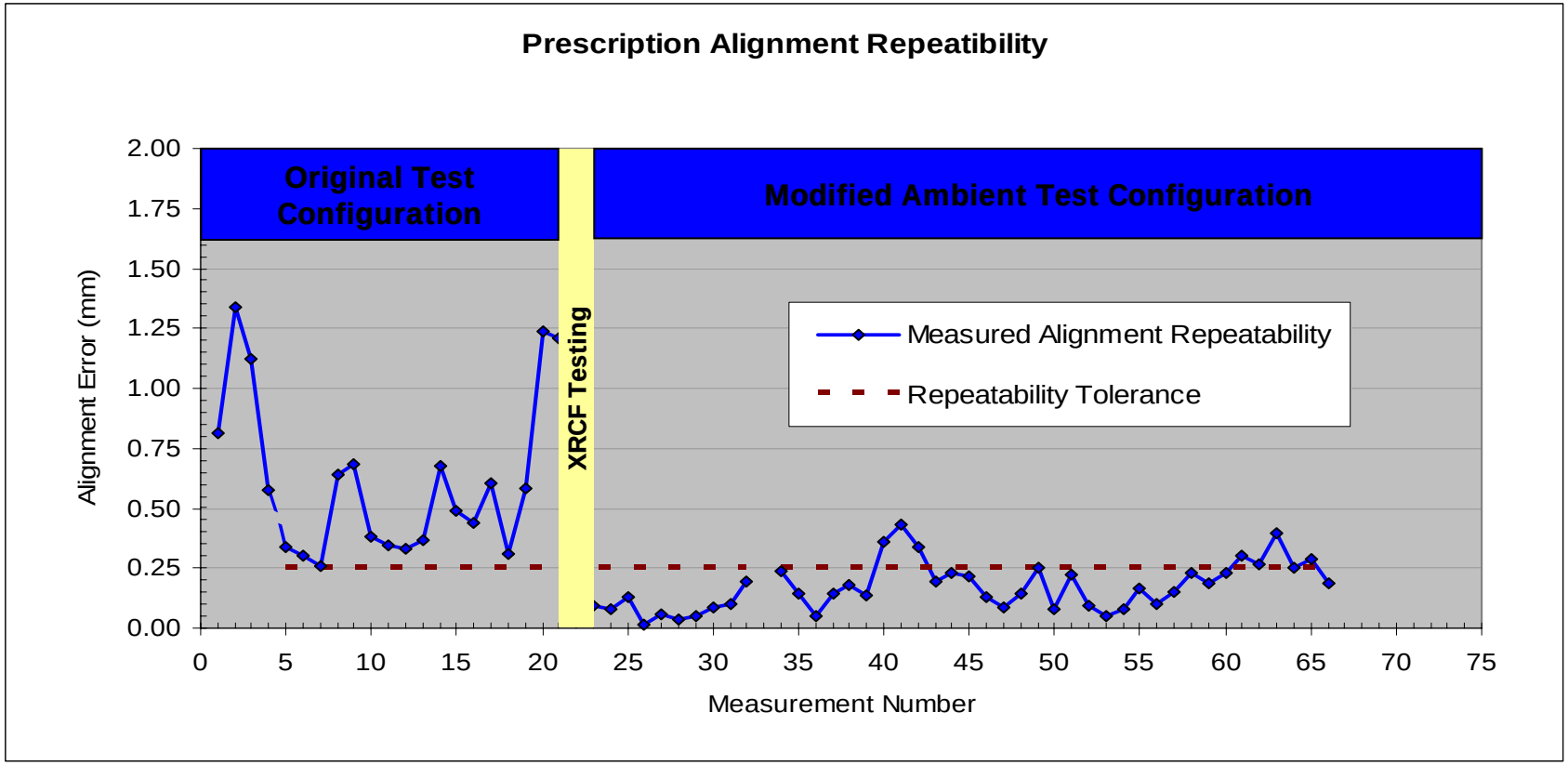


surface map with 36 Zernikes removed and cropped in 50mm in order to view web structure

2.5 nm rms maximum ambient effects from print-through

AMSD Ambient Alignment Repeatability
(optical prescription relative to mirror datums)

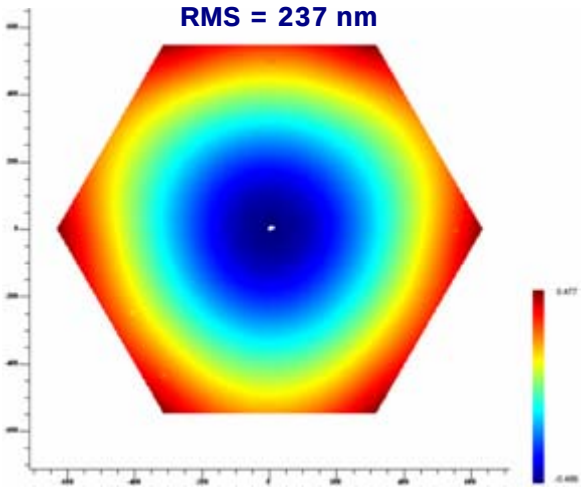
- The prescription of the mirror is checked by aligning the CGH to the mirror datums using secondary fiducials
- AMSD did not have an absolute requirement on prescription alignment but rather a measurement repeatability requirement
  - non-repeatability effects include changing alignment through polishing and all other effects that contribute astigmatism to the measured surface figure



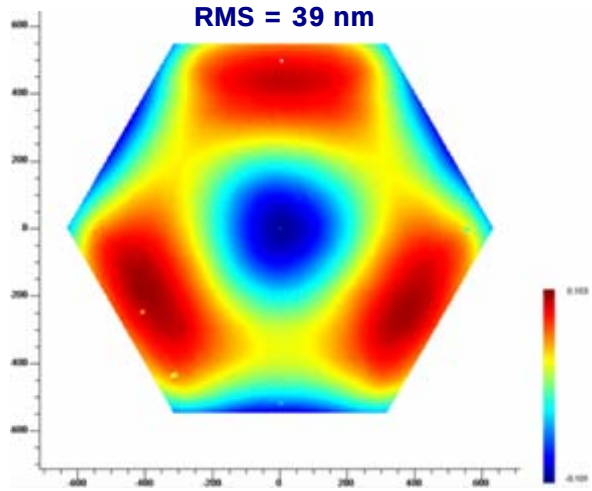
AMSD RoC Actuation Residual Model Vs. Measurement

30 Kelvin Measurement

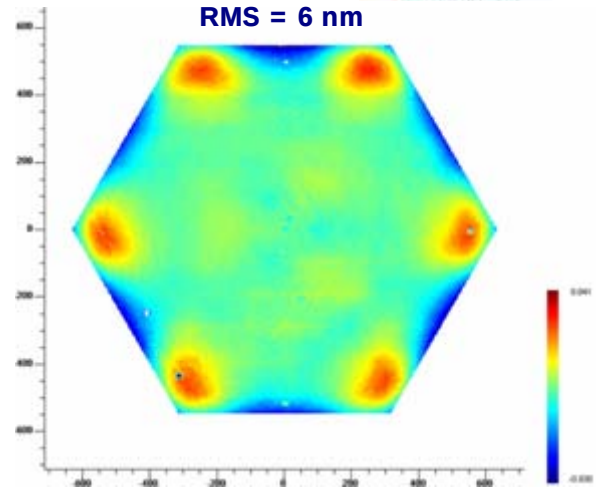
RMS = 237 nm



RMS = 39 nm



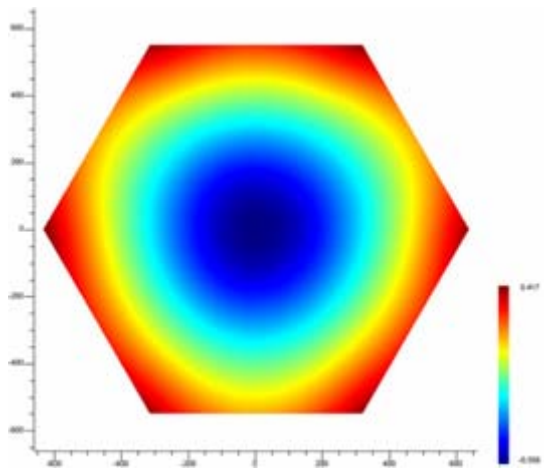
RMS = 6 nm



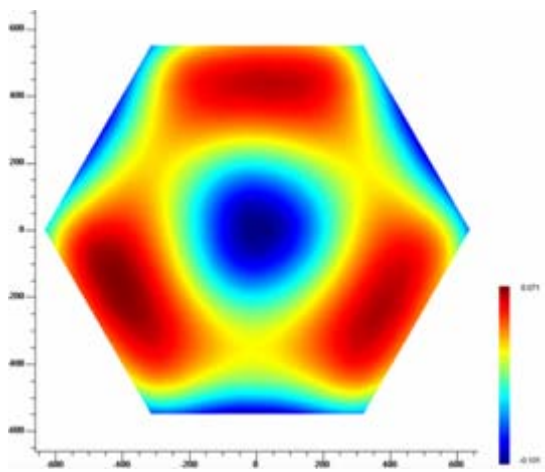
No Terms Removed | **Power Removed** | **36 Zernikes Removed**

Model

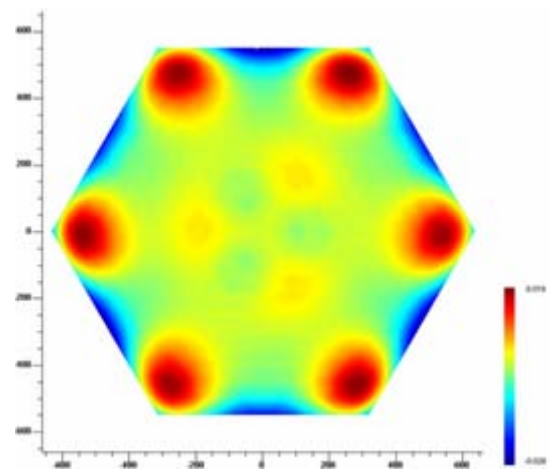
RMS = 249 nm



RMS = 42 nm



RMS = 7 nm



- all data masked to 1100mm F-T-F
  power is equivalent to 1um Radius sag at 1200mm flat-to-flat, measurement data is scaled for 1um radius sag at 1200mm

Summary

- AMSD II mirror has been successfully polished to AMSD requirements
  - High frequency requirement was not met over entire required aperture. This is primarily driven by edge effects that will be corrected for on JWST using improved resolution metrology
  - Schedule to achieve post cryogenic processing is consistent with JWST durations
- Cryogenic performance of the AMSD II mirror led to selection as JWST primary mirror material of choice.