High Performance Computing (HPC)-Accelerated Inverse Deflectometry for Mirror Segment Metrology – *Update*

Presentation to

NASA Mirror Tech / SBIR / STTR Workshop 2016

Contributors	
Prime Contractor (SBIR) **SURVICE Engineering**	**Subcontractor** **UNC Charlotte / Ctr for Precision Metrology**
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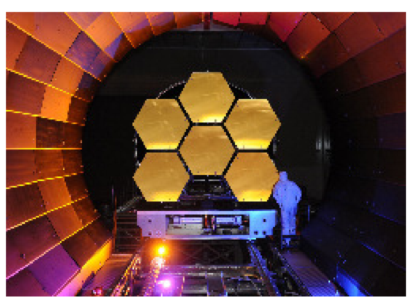
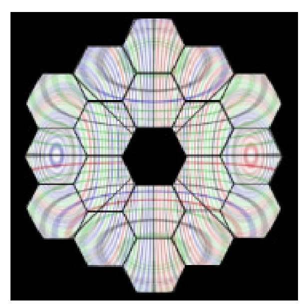
2 NOV 2016

M-TEC™ : *Inverse* Deflectometry + HPC

- Instead of using *deflectometry* to determine the optical prescription (shape) of a telescope mirror
- We have been developing *inverse* deflectometry
- We start by assuming we already know the actual optical prescription of the telescope mirror
  - Then use deflectometry to determine 6 DOF misalignment of mirror segments in the telescope
  - And accelerate the process with *high performance computing* (HPC) to rapidly determine misaligned 6 DOF condition
- Our name for this new metrology technology is *M-TEC™*





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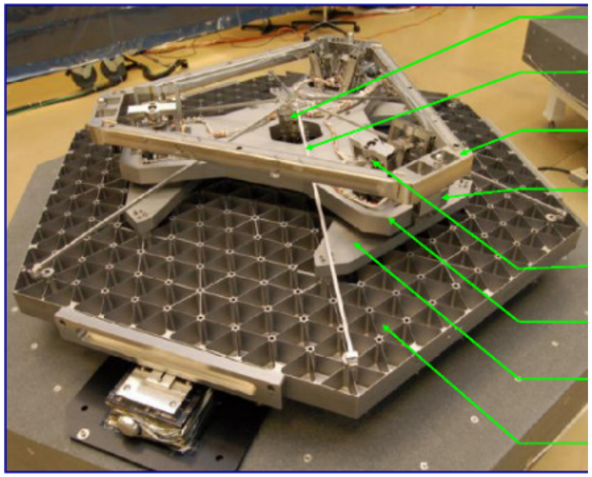
M-TEC™ Permits Direct (Front-Viewing) Determination of Segment Alignment

- Allows front-viewing, *in situ* testing of segment alignment
  - Non-contact
  - At safe distance (greater than one meter)
  - Multi-segmented telescopes and optics
- Versus metrology tech mounted onto reverse



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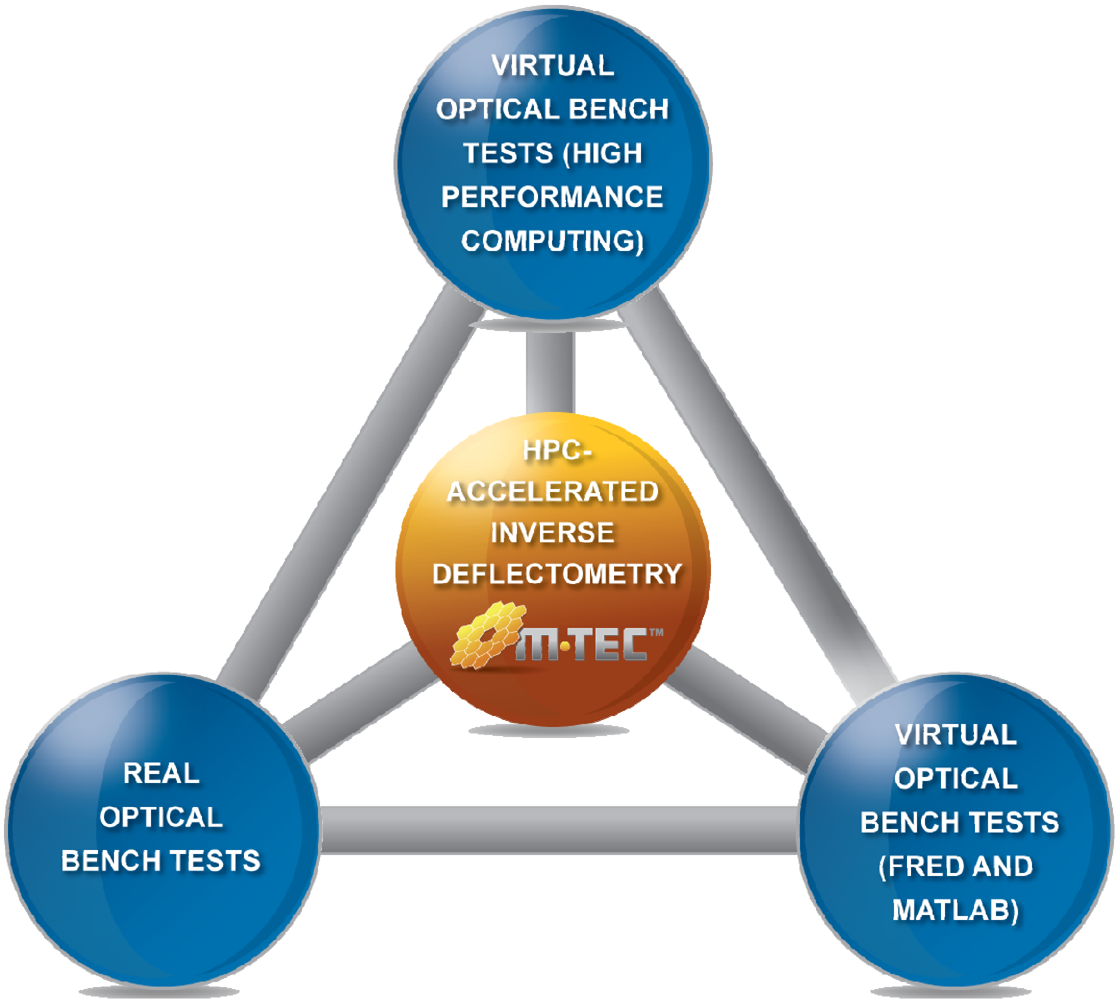
M-TEC™

M-TEC™ Development & Validation Process



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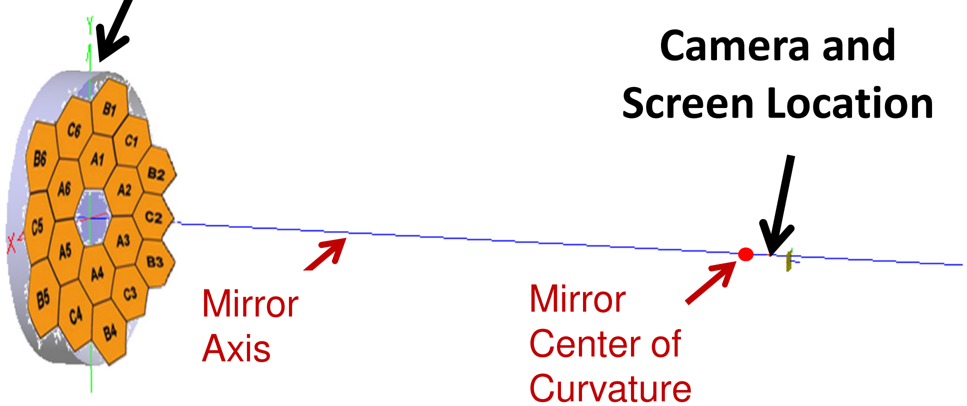
Inverse Deflectometry = New Twist on Prior Art

(Phase Measuring Inverse Deflectometry, or PMID)

Mirror Under Test

Camera and Screen Location

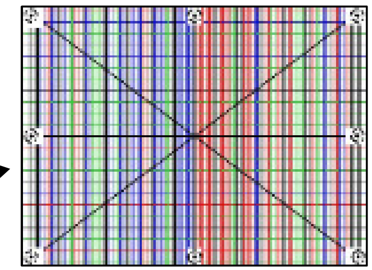


Mirror Axis

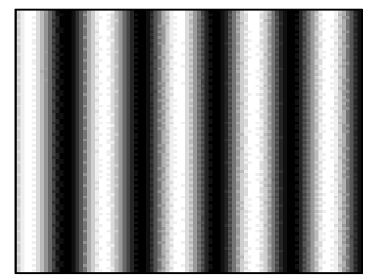
Mirror Center of Curvature

<u>Screen Options</u>:

1. Geometric



2. Sine wave



Leverages prior work in deflectometry; for example

- PMD (Phase Measuring Deflectometry) work by Knauer *et al.*, SPIE Proc. 5457, 366 -376 (2004)
- SCOTS (Software Configurable Optical Test System) work by Su *et al.*, Appl. Opt. 49, 4404 – 4412 (2010)

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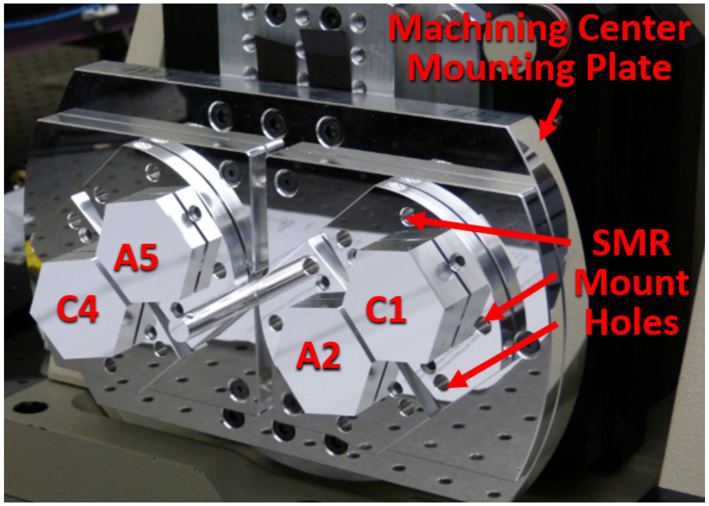
Optical Bench Tests

Diamond-turned off-axis parabolic mirrors



Optical Layout

Sinusoidal Fringes on Screen Seen Via Mirrors

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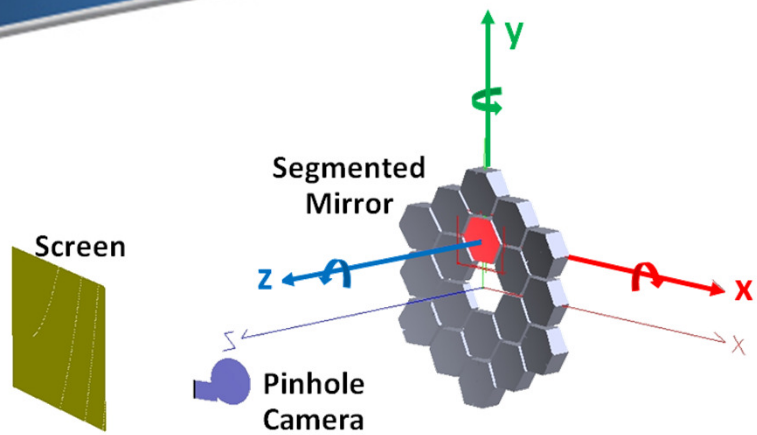
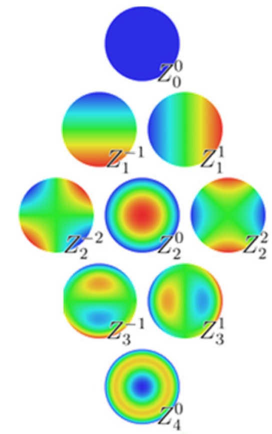
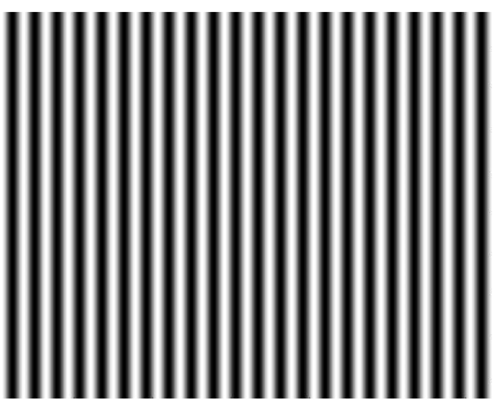
Zernike Analytic Methodology



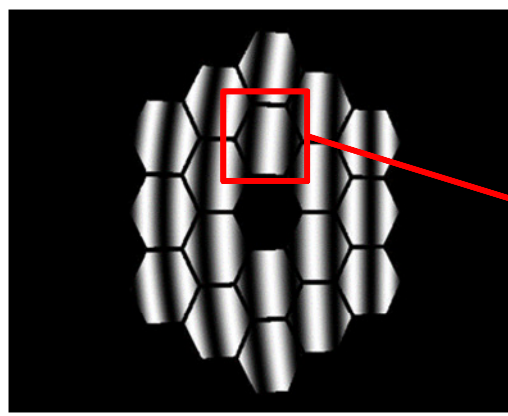
- Goal: 6 DOF misalignment
  Range: ±2 mm & ±2 mrad
  Sensitivity: 100 µm & 100 µrad
  (JWST 1.6 m segment scale)
- Low-order Zernike fit
- Track Zernike coefficients with misalignment
- Simulate with FRED



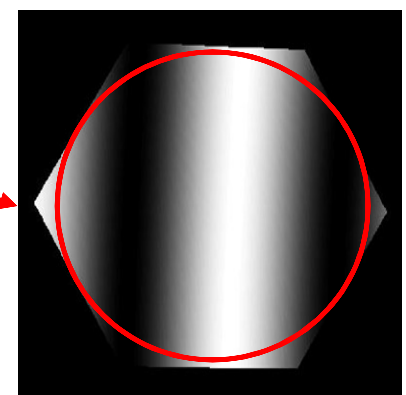
Screen Pattern



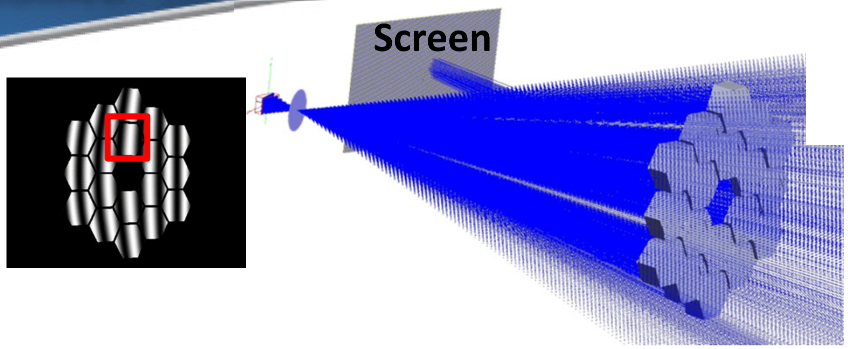
Simulated Camera Image

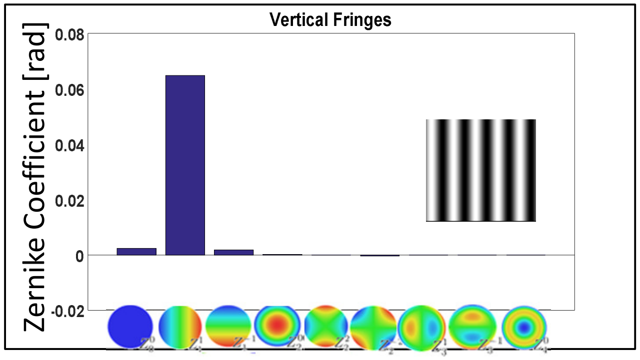


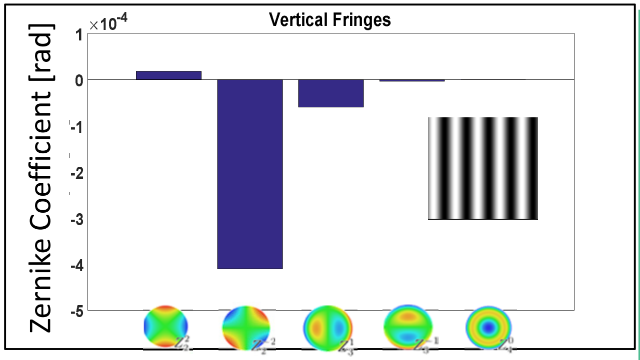
Individual Segment

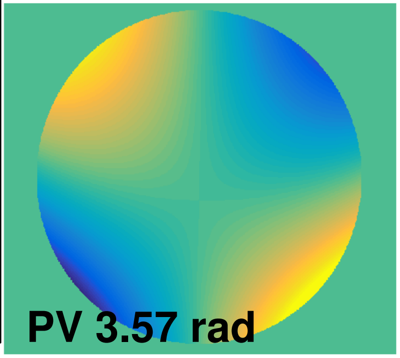


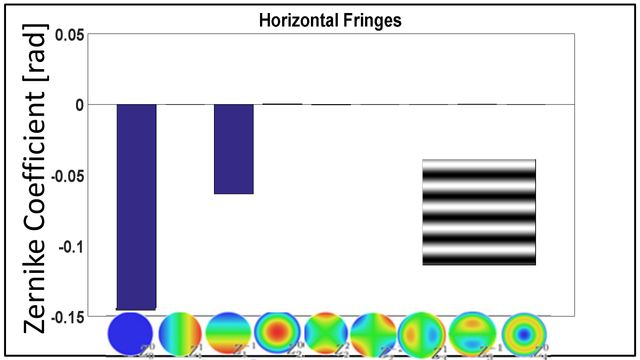
Zernike Signature of JWST-scale Aligned

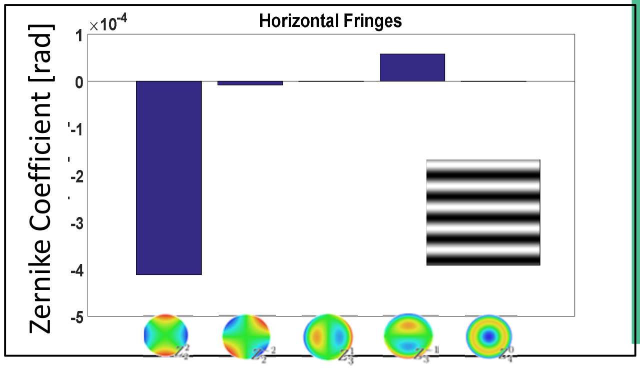


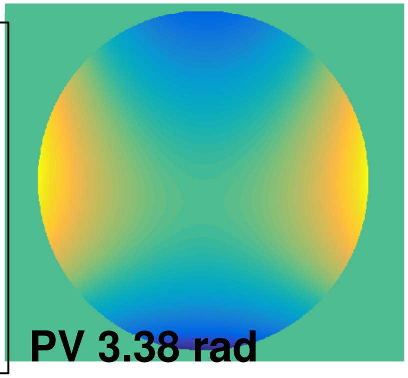




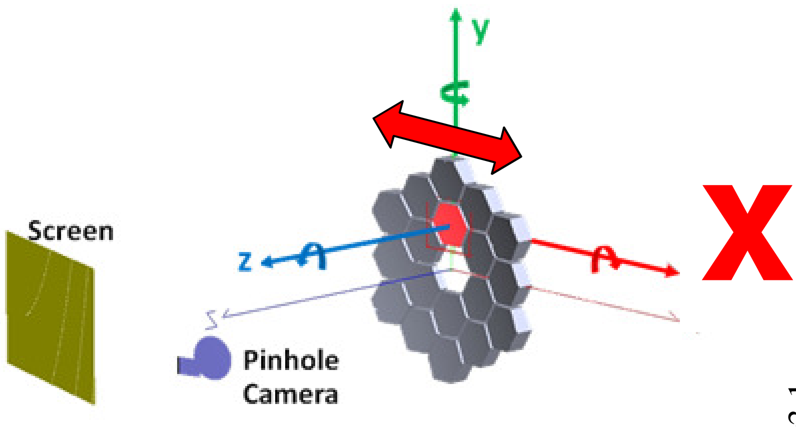


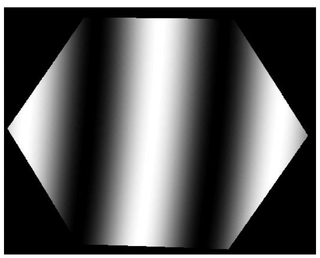


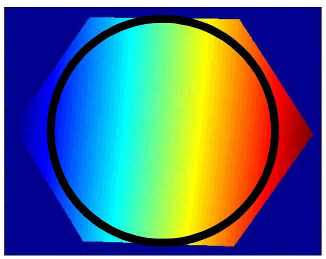


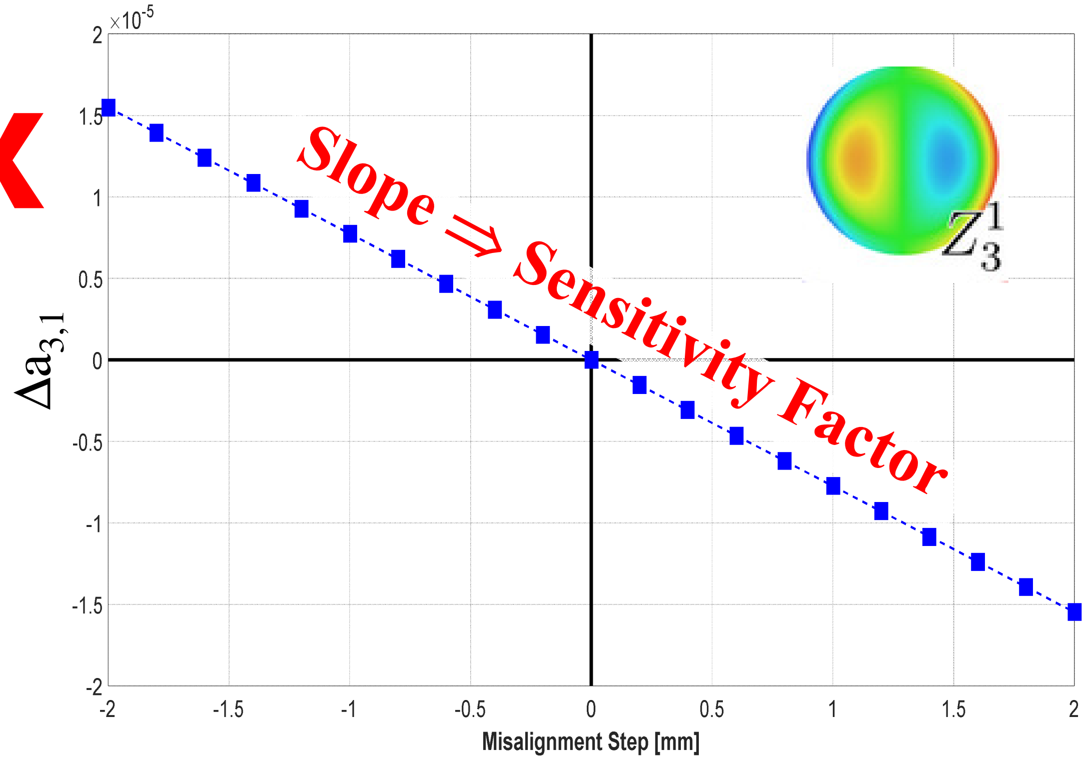


Linear Behavior Observed
e.g., X Translation Misalignment

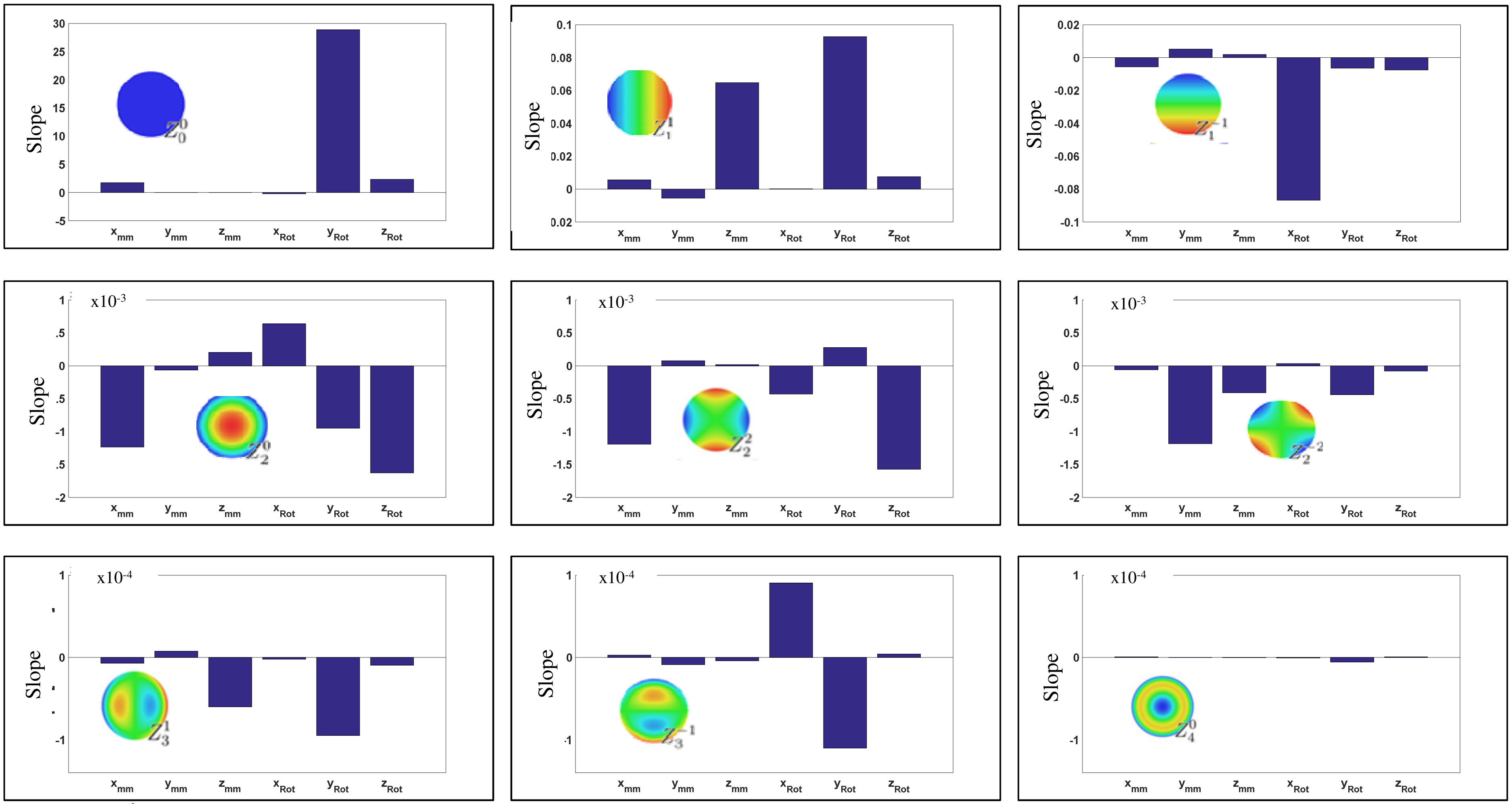




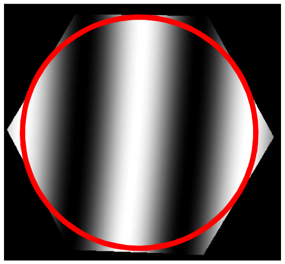


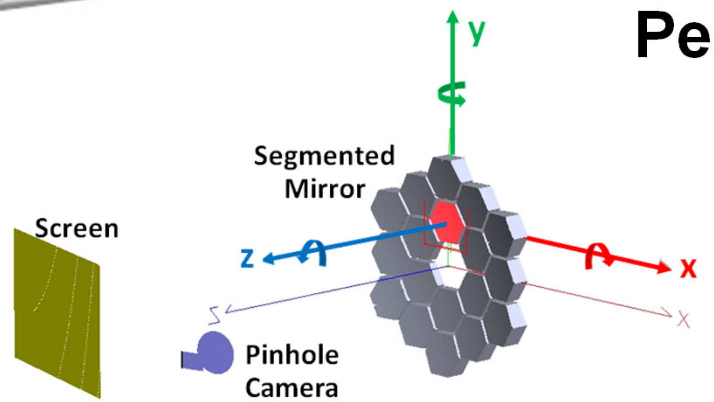


Sensitivity Factors Vertical Fringes



Perform Nonlinear Fit to Mathematical Model





Taylor series expansion of Zernikes vs misalignment:

Experiment or Simulation

$$\Delta a_n^m = f(\Delta x, \Delta y, \Delta z, \Delta x_{rot}, \Delta y_{rot}, \Delta z_{rot})$$

$$\Delta a_n^m = \frac{\partial a_n^m}{\partial x}\Delta x + \frac{\partial a_n^m}{\partial y}\Delta y + \frac{\partial a_n^m}{\partial z}\Delta z + \frac{\partial a_n^m}{\partial x_{rot}}\Delta x_{rot} + \frac{\partial a_n^m}{\partial y_{rot}}\Delta y_{rot} + \frac{\partial a_n^m}{\partial z_{rot}}\Delta z_{rot} +$$

Quadratic Terms

$$\frac{1}{2}\frac{\partial^2 a_n^m}{\partial x^2}\Delta x^2 + \frac{1}{2}\frac{\partial^2 a_n^m}{\partial y^2}\Delta y^2 + \ \dots \ + \frac{1}{2}\frac{\partial^2 a_n^m}{\partial {y_{rot}}^2}{\Delta y_{rot}}^2 + \frac{1}{2}\frac{\partial^2 a_n^m}{\partial {z_{rot}}^2}{\Delta z_{rot}}^2 +$$

Cross Terms

$$\frac{\partial^2 a_n^m}{\partial x \partial y}\Delta x \Delta y + \frac{\partial^2 a_n^m}{\partial x \partial z}\Delta x \Delta z + \cdots + \frac{\partial^2 a_n^m}{\partial x \partial z_{rot}}\Delta x \Delta z_{rot} + \ \dots$$

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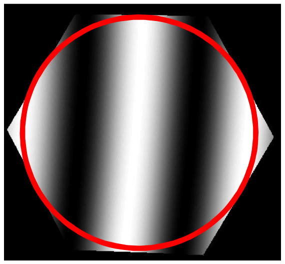
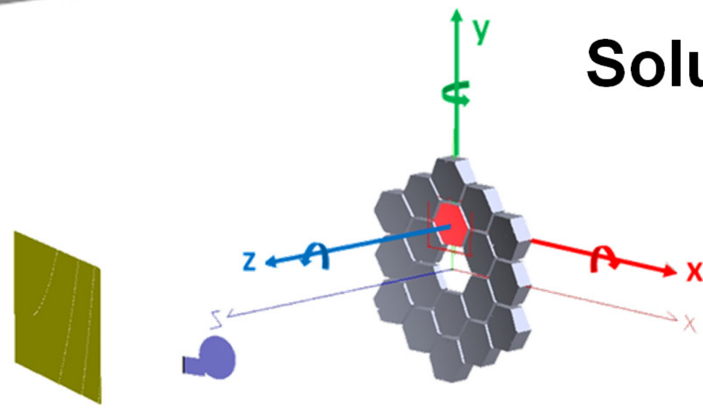
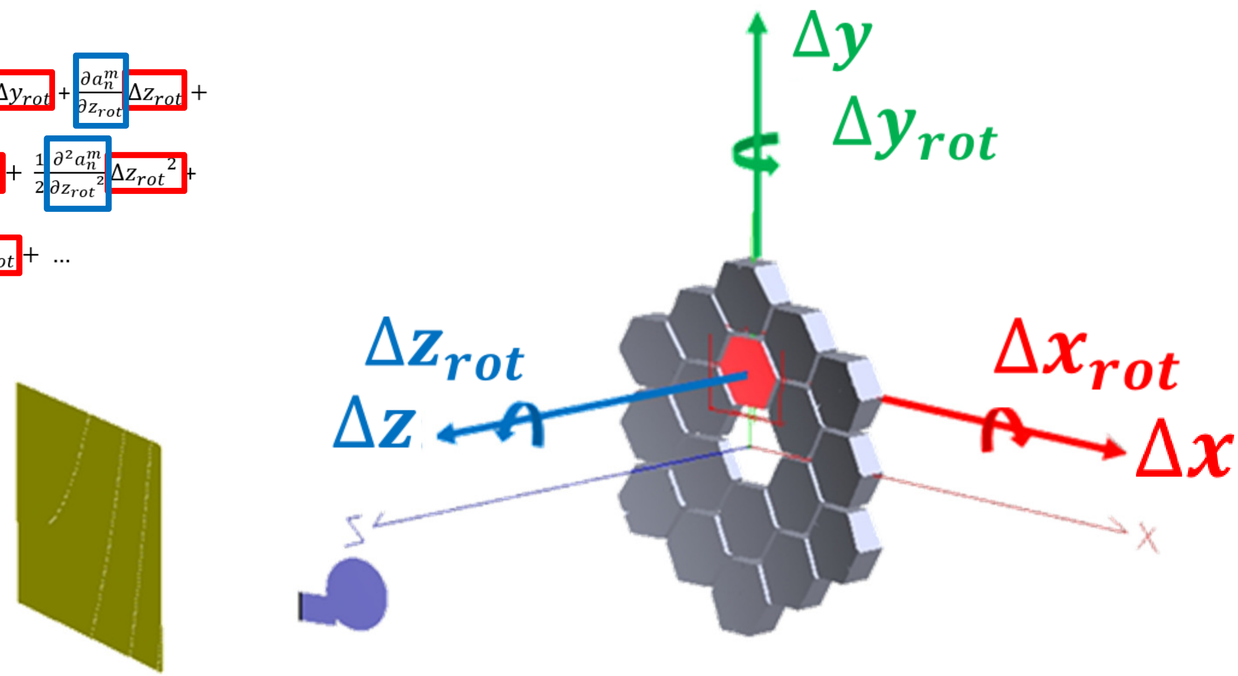
Solution via Nonlinear Fit





$$\Delta a_n^m = f(\Delta x, \Delta y, \Delta z, \Delta x_{rot}, \Delta y_{rot}, \Delta z_{rot})$$

$$\Delta a_n^m = \frac{\partial a_n^m}{\partial x}\Delta x + \frac{\partial a_n^m}{\partial y}\Delta y + \frac{\partial a_n^m}{\partial z}\Delta z + \frac{\partial a_n^m}{\partial x_{rot}}\Delta x_{rot} + \frac{\partial a_n^m}{\partial y_{rot}}\Delta y_{rot} + \frac{\partial a_n^m}{\partial z_{rot}}\Delta z_{rot} + \frac{1}{2}\frac{\partial^2 a_n^m}{\partial x^2}\Delta x^2 + \frac{1}{2}\frac{\partial^2 a_n^m}{\partial y^2}\Delta y^2 + \ldots + \frac{1}{2}\frac{\partial^2 a_n^m}{\partial y_{rot}^2}\Delta y_{rot}^2 + \frac{1}{2}\frac{\partial^2 a_n^m}{\partial z_{rot}^2}\Delta z_{rot}^2 + \frac{\partial^2 a_n^m}{\partial x \partial y}\Delta x \Delta y + \frac{\partial^2 a_n^m}{\partial x \partial z}\Delta x \Delta z + \cdots + \frac{\partial^2 a_n^m}{\partial x \partial z_{rot}}\Delta x \Delta z_{rot} + \ldots$$



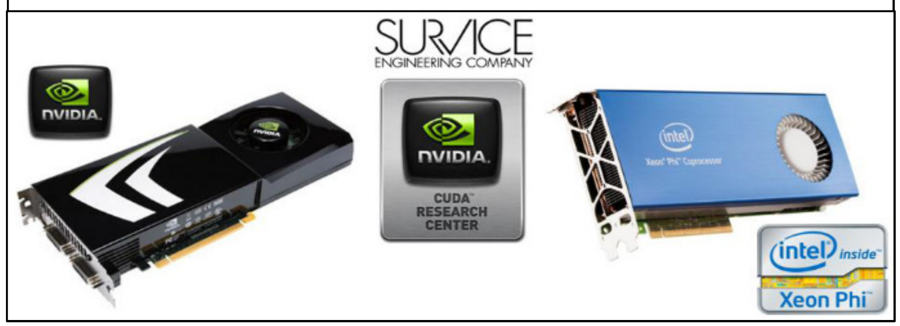
SURVICE Engineering Company

www.survice.com

Nationwide 350+ employee specialty engineering consulting and design firm, serving the US Department of Defense for over 30 years.

- Recognized expert in visualization and high performance computing
  - Only small business with NVIDIA CUDA Research Center accreditation
- Recognized leader in metrology and reverse engineering services (metrology.survice.com)
- Dozens of highly competitive Small Business Innovation Research (SBIR) awards

SURVICE leverages massively parallel computing architectures from NVIDIA and Intel



SmartCEO Magazine *Voltage Award* for Technology Innovation

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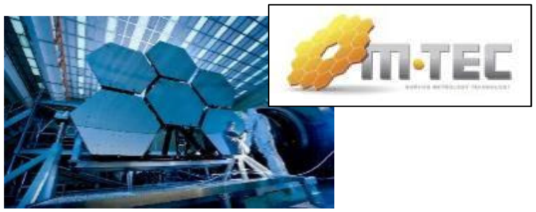
SURVICE Engineering CR&D
HPC and Metrology Devices & Tech



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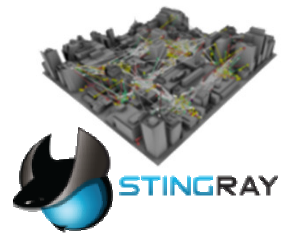
NASA SBIR to develop HPC metrology tech, like James Webb Space Telescope

Hoverbike

DSIAC task with US Army & Malloy Aeronautics Ltd.



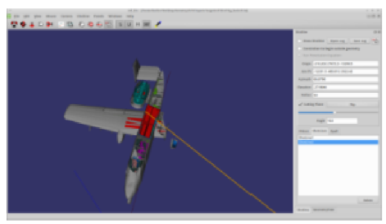
New RF propagation model built for Intel to showcase Xeon Phi

Enhanced-CLR™

Completed MRL-7 demo on **F-35** production line in Palmdale CA.

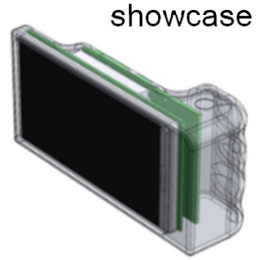
HOLOS™

Working with Intelligent Earth Ltd. on low-cost touch-probe metrology tech



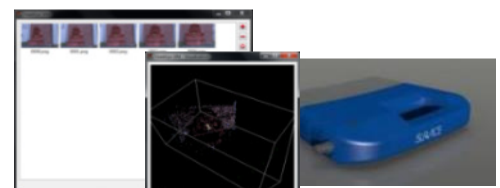
VSL (Visual Sim Lab)

High performance V/L analyses to be part of next AJEM release.



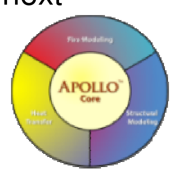
P&W (Pratt & Whitney) FAST *II*

Custom H/W & S/W solution for **F-22** engine exhaust duct data collection



HAWKEYE

SURVICE-developed 3D scanning hardware & software



Apollo™

CFD running NVIDIA's CUDA on GPU

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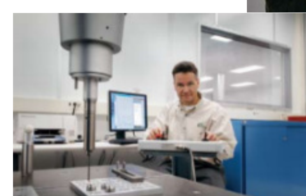
Subcontractor: UNC Charlotte
Center for Precision Metrology (CPM)



- Research: Development and integration of precision metrology as applied to manufacturing
- Facilities:
  - 4,000 sq. ft. of controlled environment for metrology and instrument development
  - 1,500 sq. ft. controlled environment, 20± 0.1º C, class 10,000 metrology laboratory
  - 33,000 sq. ft. laboratories & offices Duke Centennial Hall
- Extensive capabilities
  - Metrology
  - Precision manufacturing
- CPM Affiliates: B&W Y-12, Zeiss, Caterpillar, Corning Cable, Cummins, GE Energy, General Dynamics, Intel, LLNL, Micro Encoder, NIST, Renishaw, United Technologies

~ Recap ~

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