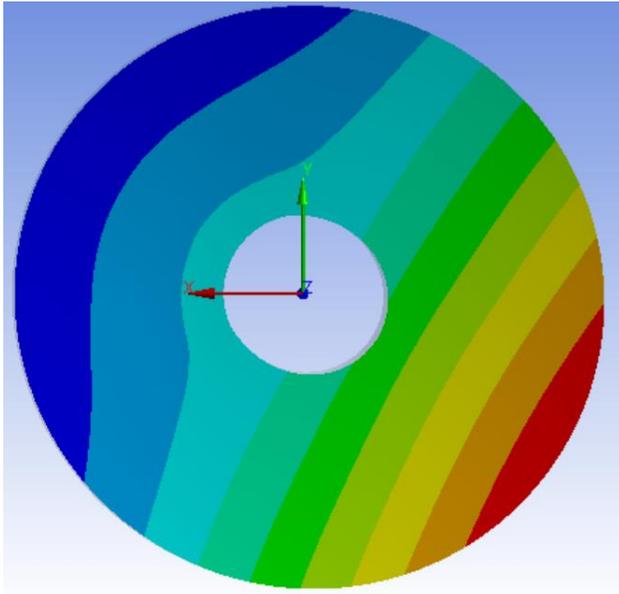
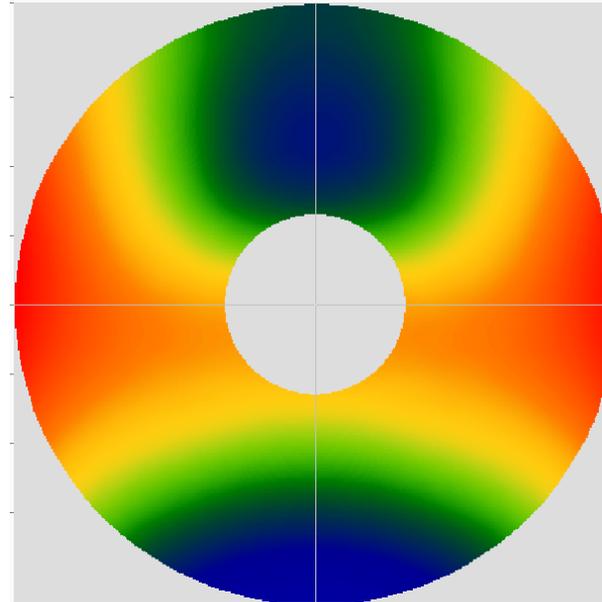


Finite Element Model
Deformation



Surface Aberration
Zernike fit



Bridging the Gap Between Finite Element Modeling and Wavefront Analysis for Streamlined Optical System Design

Jagan Ranganathan, NASA MSFC – ES23

Zernike Polynomials



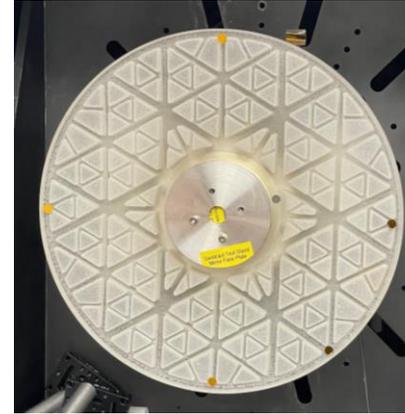
Zernike Polynomials:

- Orthogonal polynomial set defined over the unit circle
- Commonly used to describe wavefront aberrations in optical systems
- Each polynomial represents a specific type of aberration (Ex. Defocus, astigmatism, coma, spherical)
- Expressed in terms of radial and azimuthal components
- Characterized by two indices: n (order) and m (azimuthal frequency)

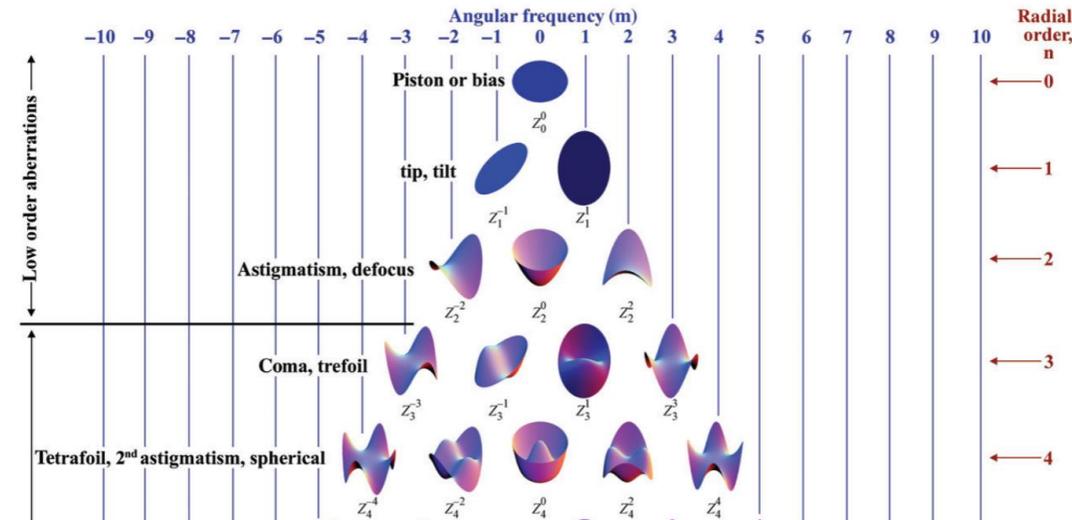
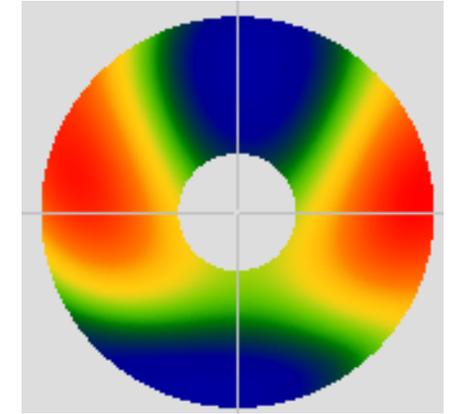
Why use Zernike Polynomial:

- Efficiently describe complex wavefronts with a small number of coefficients
- Directly relate coefficients to specific optical aberrations
- Orthogonality: Independent coefficients simplify analysis and calculations
- Standardization: Widely adopted in the optics community, facilitating data exchange.

Mirror

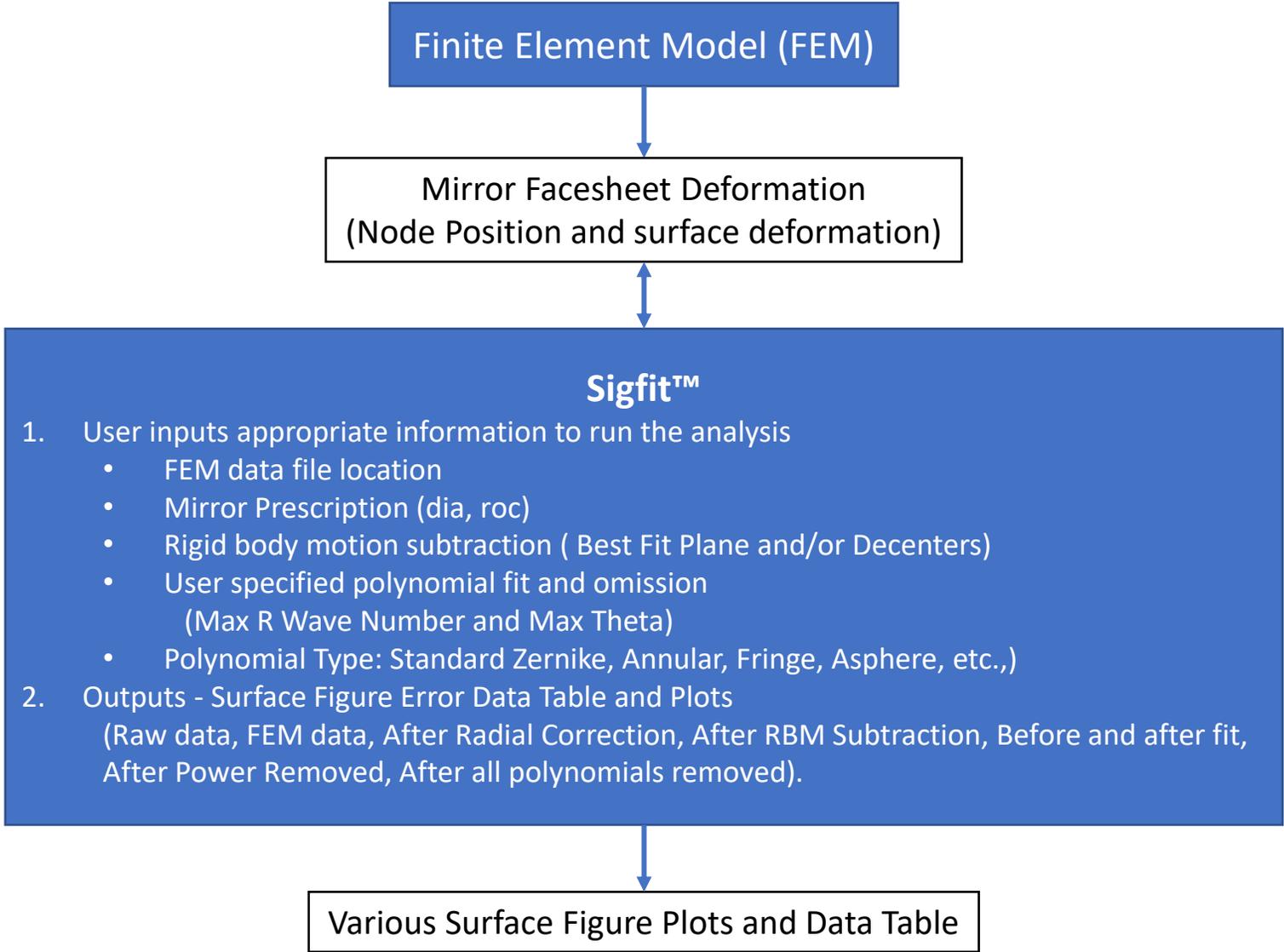


Zernike fit

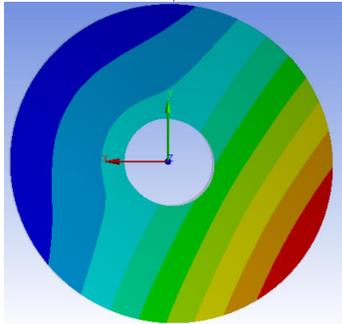


Offers significant advantages for representing finite element analysis (FEA) deformations of optical surfaces
Enable substantial data compression and seamless integration with optical analysis software.

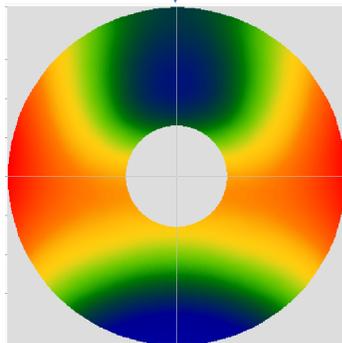
Standard Process flow for calculating Zernike coefficients



FEM



Deformation

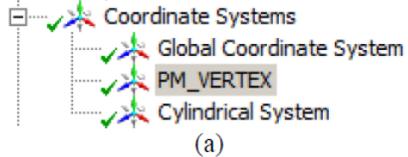
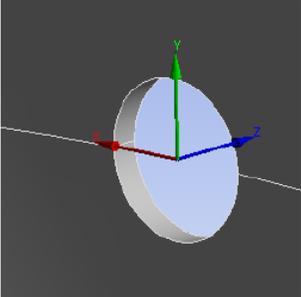


Surface figure Zernike fit

Preparing a model in ANSYS™ for analysis in Sigfit



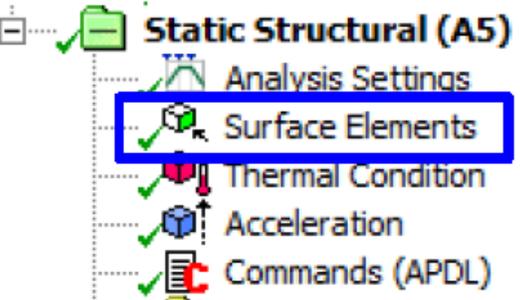
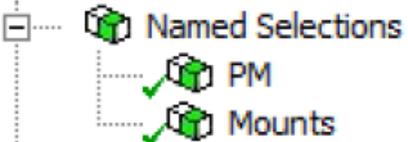
Defining the coordinate system on the mirror surface



Definition	
Type	Cartesian
Coordinate System	Manual
Coordinate System ID	Manual
Suppressed	No

Definition	
Type	Cartesian
Coordinate System	Manual
Coordinate System ID	13.
Suppressed	No

Defining Surface Elements on optical surface



Creates a Sigfit compatible file (*.asig)

Calling the macro script to extract the displacement of the optical surface

```
sigout,'displacements',1,,0
```

Sigfit™ Analysis Process Flow (Polynomial fitting)



Solution Geometry Fitting Disturbance System Data Output Parameters

Solution Options (SOL)
Wavelength:
Surf Def Direction:
Surf Def Calculation:

Symmetry Options (SYMM)
Symmetry Condition:
Number of Segments:

FE Analysis Options (FEAPROG)
FEA Program:
FEA Length Units:
Graphics Program:

Optics Analysis Options (OPTPROG)
Optics Program:
Optics Length Units:

FE Model File Name:

Output Name (OUTNAME)
Manually Specify Output Filename:
Output File Name:

Analysis Setup

Solution Geometry Fitting Disturbance System Data

Coordinate Systems Medium Materials Surfaces

Coord Systems

CoordSystem 13

Csys Id: 13 Ref Id: 0 Type:

Origin
A1: A2: A3:

Point on Z Axis
B1: B2: B3:

Point in XZ Plane
C1: C2: C3:

Coordinate System Definition

Solution Geometry Fitting Disturbance Monte Carlo System Data Output Param

Coordinate Systems Medium Materials Surfaces Segments

Surface

Surface 1 (Surface)

Surface Definition (SURFACE)
Surface Id: 1
Surface Name: Surface
Define Surface By: Property

ID Ranges (SURDEF)
Lower Bound Upper Bound
15001

Vertex CID: 13
Optic SID: 2
Sign Convention:
Material Id: 0
Material CID:

Optical Prescription (SURGEOM)
Note: Use FEA Units for Radii of Curv and Norm Radius.
Conventional/Grazing:
Surface Type:
Amplitude Norm Type:
Radius of Curv X:
Conic KX:
Radius of Curv Y:
Conic KY:
Norm Radius:
Norm Radius:

Units for Surface Polynomials:
Surface Poly (SURPOLY)

Surface Definition

Solution Geometry Fitting Disturbance System Data Output Parameters

Output File Requests Output Interpolation

Summary Files
Summary File #1 (OUTSUM1):
Summary File #2 (OUTSUM2):

Nodal Files
Nodal Files (OUTNOD):
Extra Nodal Files (OUTNOEX):

Displacement Files
Displacement Files (OUTDIS):
Residual Displacement Files (OUTRSD):

Coefficient Files
Coefficient Table #1 (OUTCOF1):
Coefficient Table #2 (OUTCOF2):
Coefficient Table #3 (OUTCOF3):

Adaptive Control Files
Actuator Stroke File (OUTACT):
Correctability File #1 (OUTCOR1):
Correctability File #2 (OUTCOR2):

Optical Files
Optical Files (OUTOPT):
Dynamics Files
Dynamic Response Files (OUTDYN):

Output Options

Solution Geometry Fitting Disturbance Monte Carlo System Data Output Parameters

FEA Vector Polynomial Hit Map Zernike INT Linear Comb

FEA Disturbances:

FEA Disturbance Subcase Ranges (DFCASE1)

Step Selection Type:

FEA Disturbance Step Ranges (DFCASE1)

Disturbance Step Default
Step Selection Type:

FEA Disturbance Step Default Ranges (DFSTPD1)

FEA Disturbances File Name:

FEA Deformation file input

Solution Geometry Fitting Disturbance Monte Carlo System

Surface Fitting Segment Fitting

Surface

Surface 1 (Surface)

Subtraction (SUBT)
Rigid Body Motion:
ROC/Power:
Global/Local RBM Optical Output:
Global Coord Sys Id: 0

Polynomial Fitting of Surface Deformation (FITPOLY)
Polynomial Type:
Amplitude Norm Type:
Max R Wave Number:
Max Theta Wave Number:
R Normalization (FE Units)
Obstruction Ratio

Omitted Terms (NOFIT)

N	M

Surface Fitting

Standard Process flow for calculating Zernike coefficients



Finite Element Model (FEM)

Mirror Facesheet Deformation
(Node Position and surface deformation)

Sigfit™

1. User inputs appropriate information to run the analysis

- FEM data file location
- Mirror Prescription (dia, roc)
- Rigid body motion subtraction (Best Fit Plane and/or Decenters)
- User specified polynomial fit and omission (Max R Wave Number and Max Theta)
- Polynomial Type: Standard Zernike, Annular, Fringe, Asphere, etc.,)

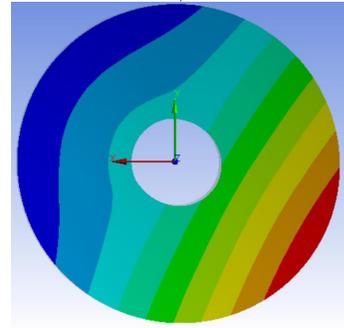
2. Outputs - Surface Figure Error Data Table and Plots
(Raw data, FEM data, After Radial Correction, After RBM Subtraction, Before and after fit, After Power Removed, After all polynomials removed).

Analysis setup can be labor intense (~10 min)

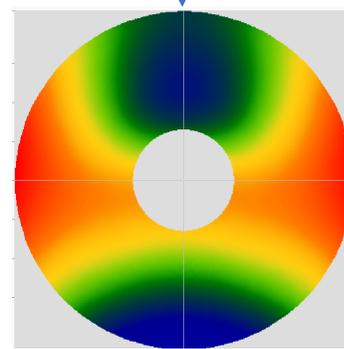
Various Surface Figure Plots and Data Table



FEM

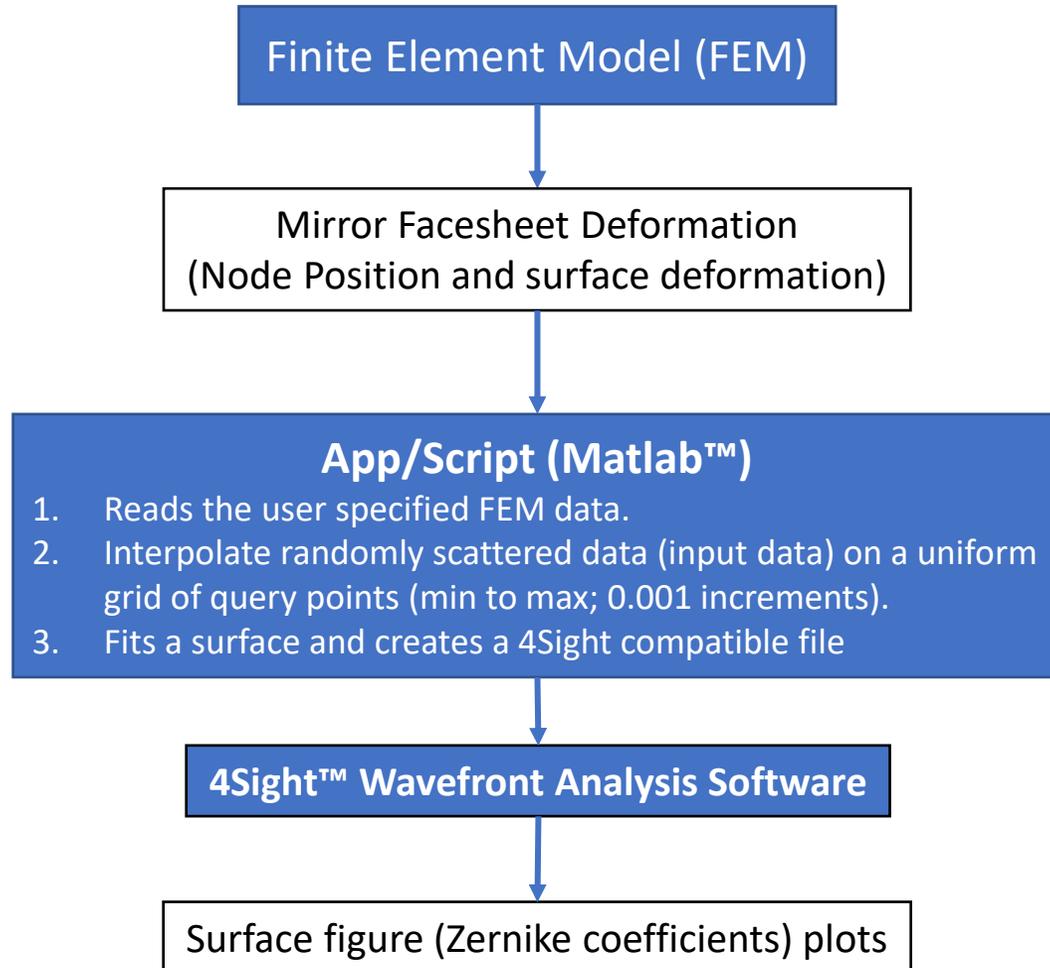


Deformation

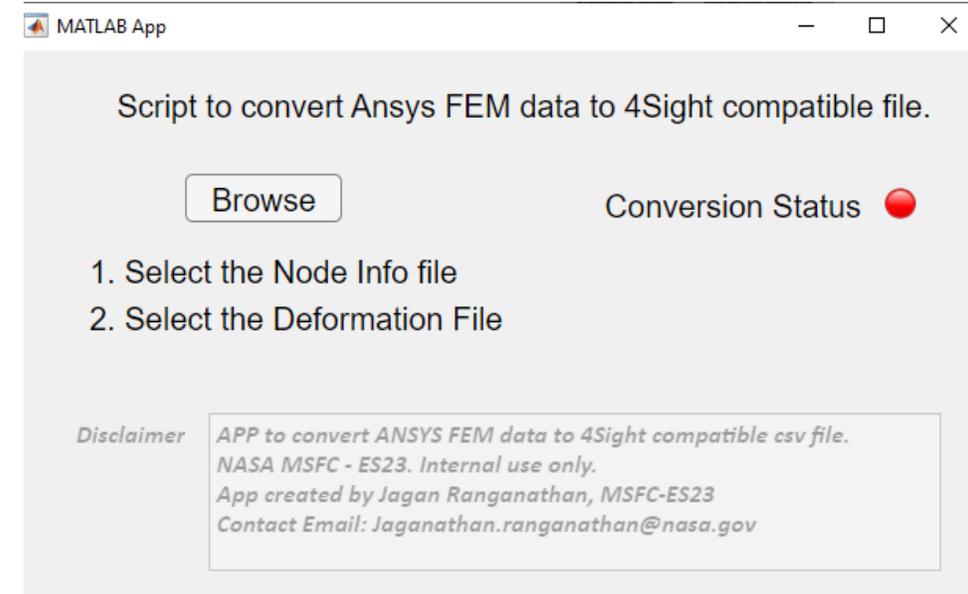


Surface figure
Zernike fit

New Process flow for calculating Zernike coefficients

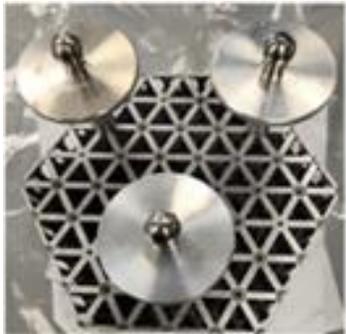


FEM

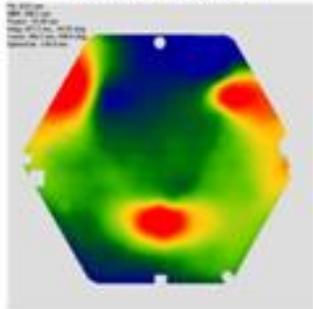


User need <5 seconds to convert the FEA data to view the surface figure plot

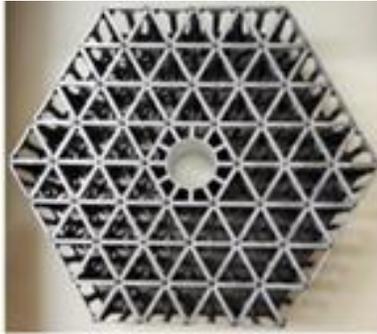
Process Validation



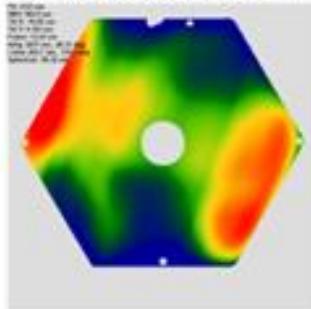
24-cm Al Mirror on
Tooling Ball Mount



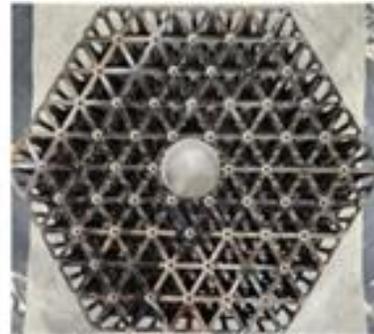
21K - 292K
2573 nm PV
248 nm RMS



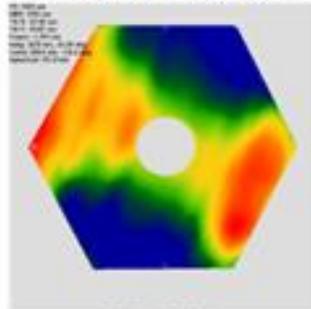
39-cm, 7 ribs support,
areal density: 32.4 kg/m²



25K - 291K
5337 nm PV
903 nm RMS



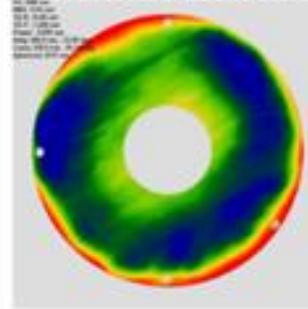
39-cm, 9 ribs support,
areal density: 21.5 kg/m²



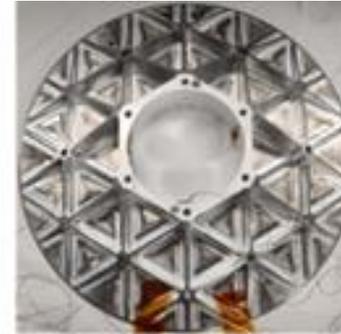
25K - 293K
5165 nm PV
1183 nm RMS



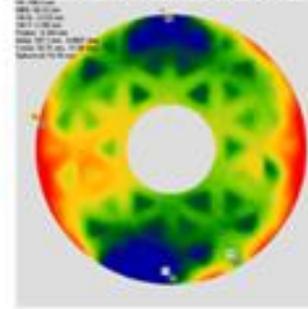
31-cm AlSiC Ni Overcoat,
areal density: 25 kg/m²



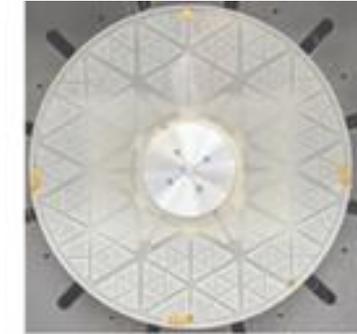
20K - 292K
7888 nm PV
1110 nm RMS



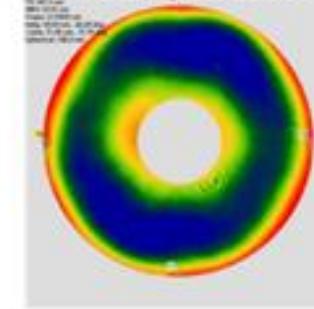
31-cm bare Al-6061,
areal density: 21.5 kg/m²



19K - 293K
700 nm PV
67 nm RMS



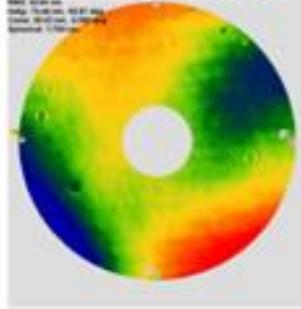
43-cm Wangness Bk7 Cast
Mirror on Center Hub Mount



110K - 293K
468 nm PV
63 nm RMS



50-cm Kyocera Cordierite
Mirror with 3 Inserts



33K - 291K
413 nm PV
41 nm RMS

Verified the process flow on multiple mirror geometry and its experimental test data (Gravity and Cryo Deformation)

Summary



- Simplified the FEA deformation data conversion process using custom script/app.
- 99% reduction in labor time (from 600 seconds to 5 seconds)
- Validated on multiple mirror geometry
- Enables rapid evaluation of design trade study and its influence on optical performance due to gravity and/or temperature