SigFit
An SBIR success story

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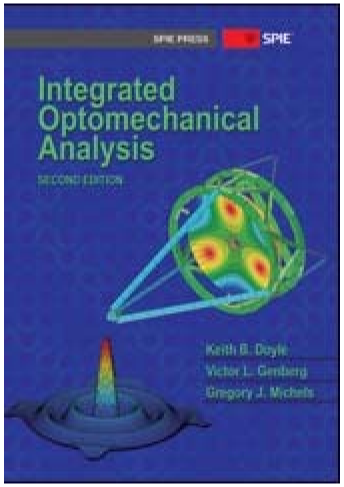
Outline

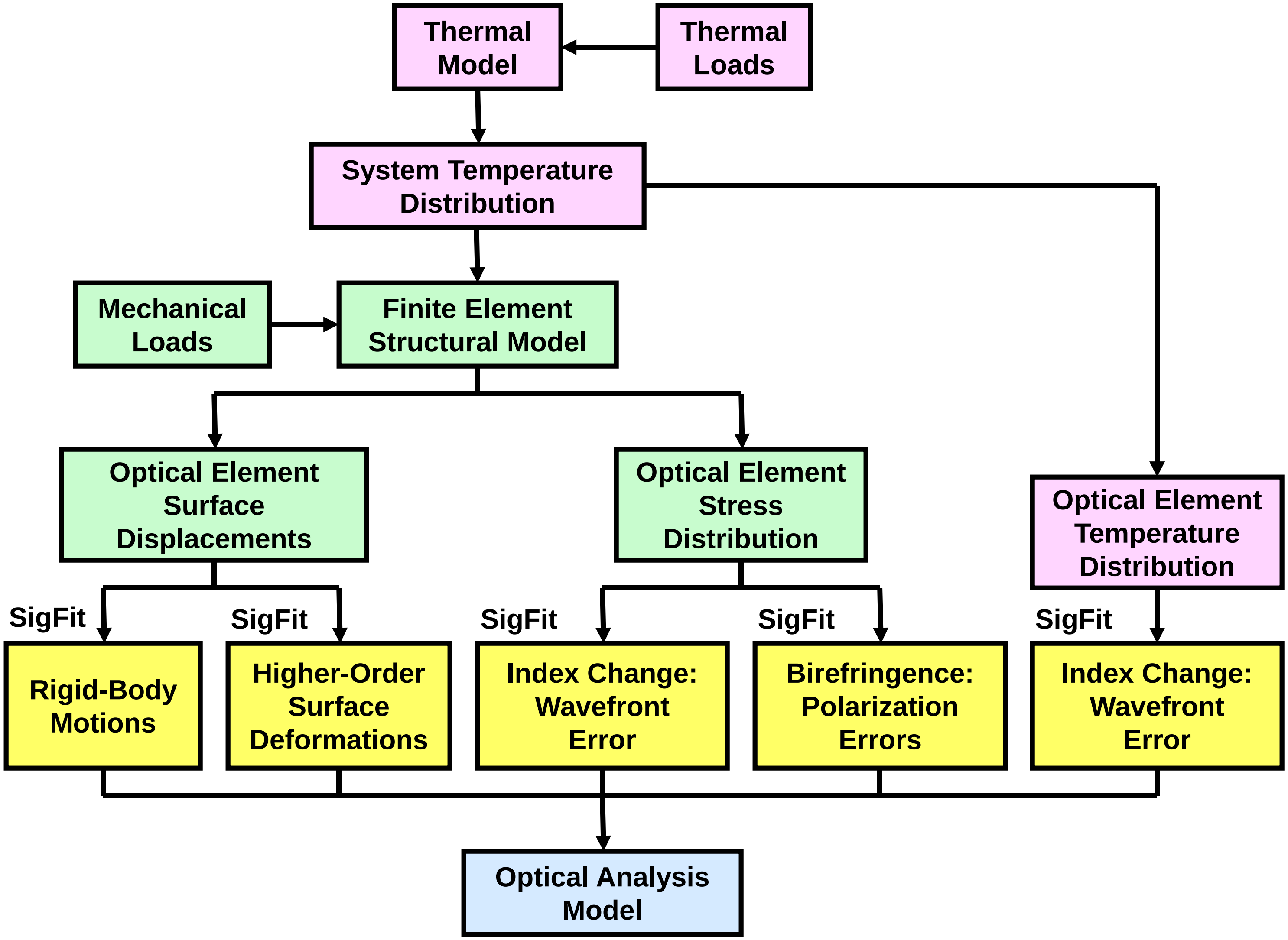
- Introduction
- SBIR history
- Commercialization
- Customers
- Current Capabilities
- New Features

Sigmadyne, Inc. (Rochester, NY)

- Engineering Consultants in Integrated Optomechanical Analysis & Design
- Specializing in Optimum Design of Precision Optomechanical Systems
- Finite Element Analysis in support of Design, Fabrication, and Test
- Predict optomechanical performance over operational environment
- **SigFit** optomechanical analysis software
- Teach “Integrated Optomechanical Analysis”, “FEA of Optics”short courses
- Authors: Integrated Optomechanical Analysis 2nd Ed., SPIE Press, 2012



SigFit Software for Integrated Modeling (STOP analysis)



SBIR History

- SigFit is an outgrowth of a NASA GSFC SBIR

- Prime: Cullimore-Ring Technology (Brent Cullimore)
- Subcontract: Sigmadyne (Vic Genberg)

- Purpose: Integrated analysis in a single software (OptiOpt) combining Thermal Desktop, Nastran, Nascode, CodeV, Isight (optimization)

- Nascode subroutine read Nastran results, fit Zernikes and wrote to CodeV.

- Phase 1: 1998
- Phase 2: 1999
- OptiOpt delivered to GSFC in 2001

SBIR value

- The SBIR contract was crucial to getting Sigmadyne through our first 2 years
  - Allowed us to reach a commercialization phase

- The SBIR laid important groundwork for SigFit
  - Reading Nastran model data & Nastran results output
  - Polynomial fitting
  - Writing Zernike polynomials to CodeV

- The SBIR allowed CRT to incorporate temperature mapping
  - Thermal models to structural modes in Thermal Desktop
  - Using FE shape functions for 3D interpolation

Commercialization

- OptiOpt was not actively pursued as a commercial product.

- SigFit was written as standalone version of Nascode
  - Released as commercial product in 2001
  - New releases every year since.

- Commercialization of software is a significant task
  - Make it user friendly with easy-to-use GUI interface.
  - Prevent user blunders – bullet proof as much as possible
  - Provide good customer support and training
  - Complete, up-to-date documentation
  - Useful example problems
  - Document new features and error corrections
  - Code verification

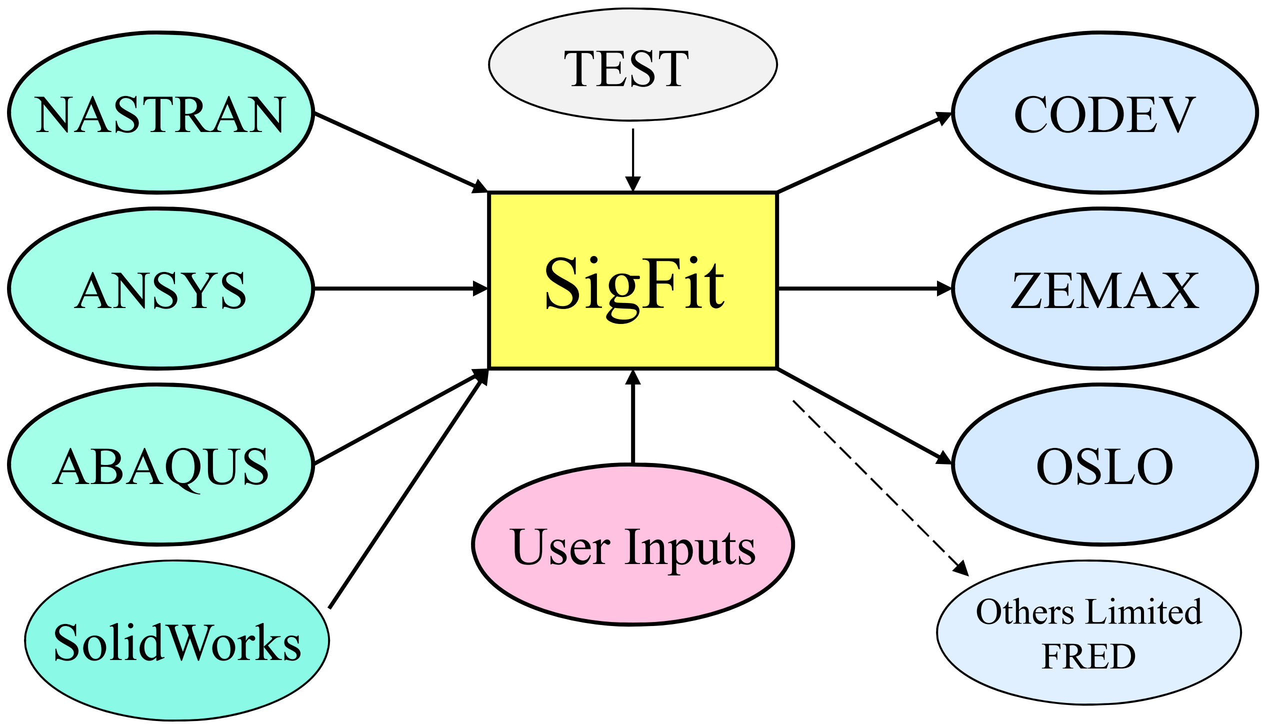
Customers

- Current customers include
  - NASA centers
  - National labs
  - Aerospace companies
  - Optics and photonics companies
  - Universities
  - International

- Our customers find it much cheaper to buy good commercial software than to develop, document, maintain and enhance in-house software.

- As very active users of SigFit in our consulting business, we continue to add new, useful features (not just glitzy features). The best software is written by users - not programmers working in a vacuum.

Current: Interfacing Multiple FEA Codes to Multiple Optical Codes



<u>Finite Element Model Data</u>
Node Locations
Element Connectivity
Coordinate Systems

<u>Finite Element Model Results</u>
Nodal Displacements
Nodal Temperatures
Element Stresses

Always Adding More I/Fs

<u>Displacement Results</u>
Rigid Body Motions
Normal Surface Deformations
Sag Surface Deformations

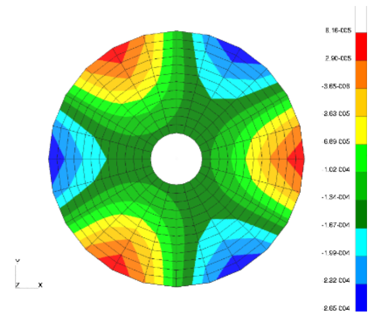
<u>Optical Path Difference Results</u>
OPD Maps

<u>Birefringence Results</u>
BIR and CAO Maps

SigFit's Surface Fitting and Grid Arrays

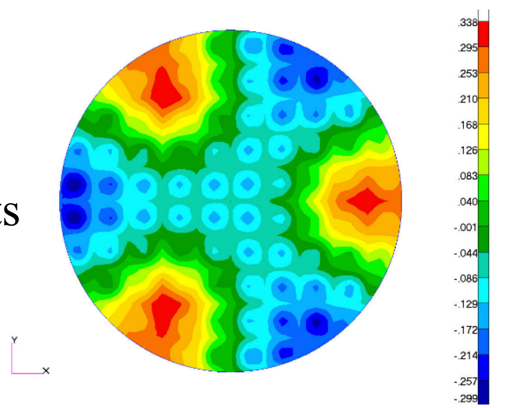
- Surface Fitting used to study mirror performance and optimize mirror design
  - in-use environments and test conditions (1-g backouts)

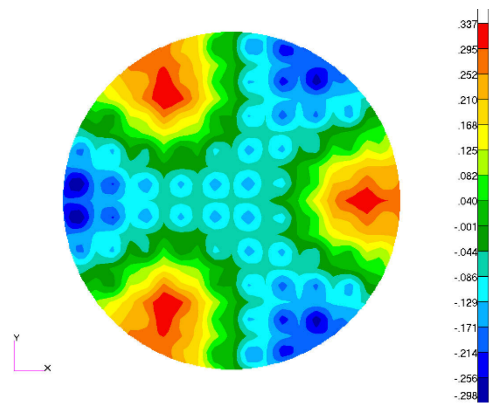
- Fit deformed shapes (FE results) with polynomials to pass to optics codes
  - Conventional: Zernikes (Standard & Fringe), Asphere, XY
    - Normalization and order to match optics code
  - X-ray: Fourier Legendre or Legendre in Z-Θ



- Interpolate to grid arrays if polynomials a poor fit

FE results



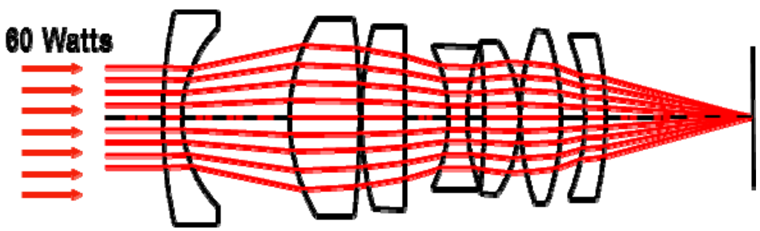


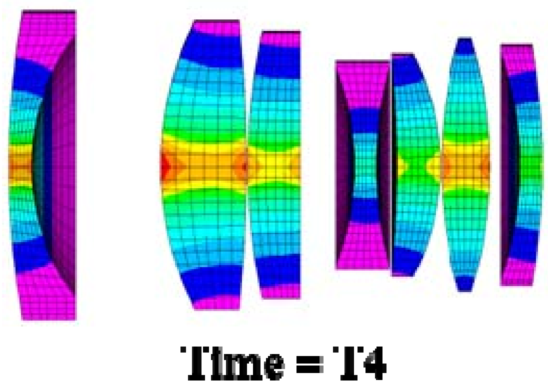
401 x 401 Array

SigFit is useful for Lens systems analysis

- Surface Distortions to Optics program
- Thermo-optic index change with temperature to optics program
- Stress index change & birefringence effects to optics program

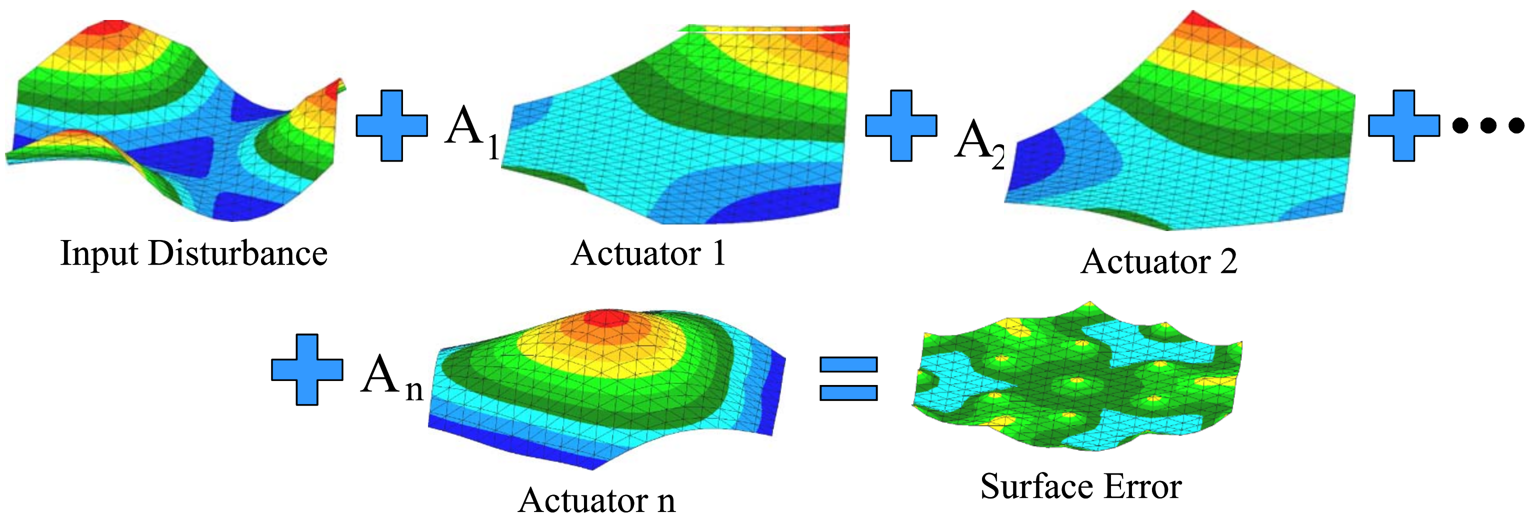
- All 3 effects written to optics codes





SigFit's Adaptive Optics Simulation

Adaptive/Active Performance Can Be Simulated With Finite Element Analysis
Solve for actuator inputs, $A_1, A_2, A_3 \ldots A_n$, to minimize surface error, E



If focus compensation exists elsewhere, terms like $2r^2-1$ or DR can be added as *augment* actuator by polynomial

SigFit's adaptive analysis

Disturbance types
FE model analysis cases
Test interferogram arrays
Polynomials and ΔRoC
Vector data
Linear combinations

Influence function types
FE model analysis cases
Test interferogram arrays
Polynomials and ΔRoC
Vector data
Linear Combinations

Options
Stroke limits
Actuator failure
Placement optimization
Actuator resolution

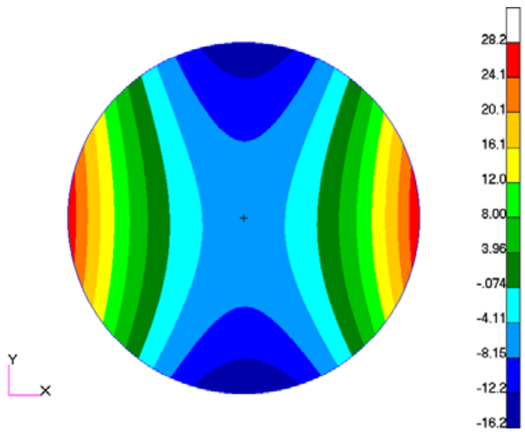
Find the linear combination of actuator influence functions to minimize error in disturbance

Adaptive correction

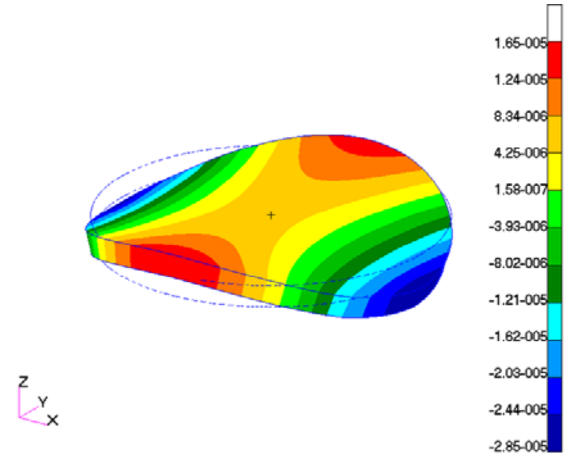
Results
Correctability
Actuator strokes
Contour plots
Surface polynomials
Surface grid array
Monte Carlo statistics

Can be used to solve a variety of non-adaptive problems

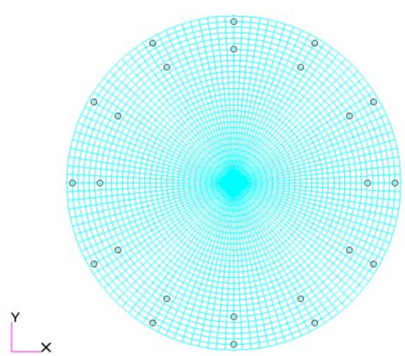
SigFit is used in Stressed-optic polishing



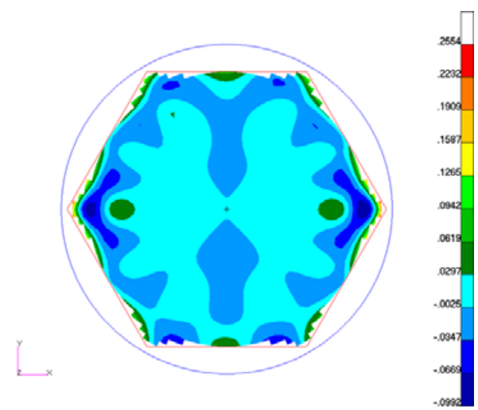
Desired shape RMS=9.5 micron



Bend to reverse shape & polish flat

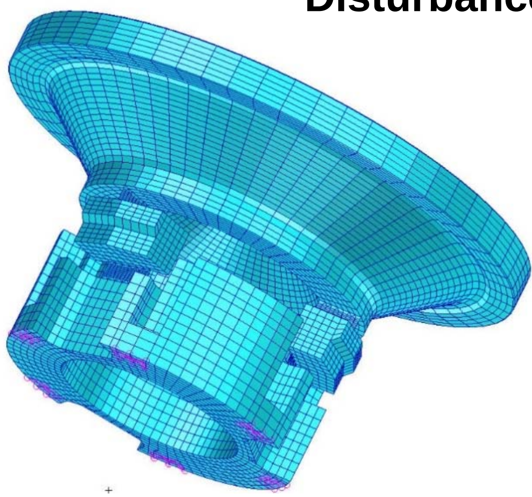


SigFit finds Best Actuator location
For ALL segment geometries

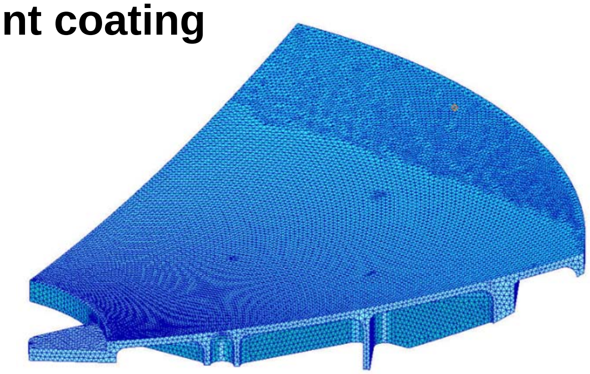


SigFit calculates Best actuator forces
Residual error   RMS=0.02 micron

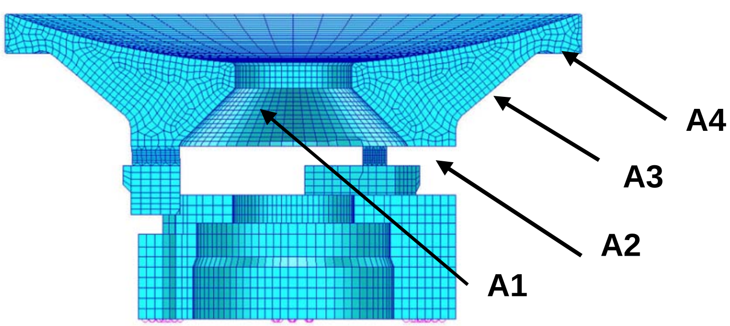
SigFit’s Adaptive Analysis used to find backside eNi coating thickness to minimize surface error on Lightweight mirrors

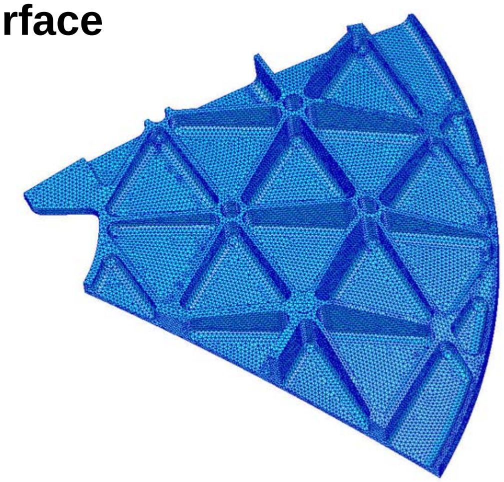


Disturbance = Surface error for front coating



4 Actuators = eNi thickness on various portions of back surface





SigFit used to determine Backside eNi coating thickness to minimize surface error on Lightweight mirrors

	All 4	1,3,4	limit 1,3,4	limit 3,4
	Thick	Thick	Thick	Thick
Coating	(mil)	(mil)	(mil)	(mil)
1	1.49	7.12	5.00	
2	4.58			
3	2.85	2.73	2.96	3.77
4	2.92	2.72	0.00	0.00
%corr	99.6	96.4	95.2	81.5
with Tol	96.6	93.7	92.4	78.9

Correctability for isothermal temperature change

Tolerance of 0.1 mil on thickness control

Limits on coating thickness 0.0 < thick < 5.0

Use adaptive to find thickness.

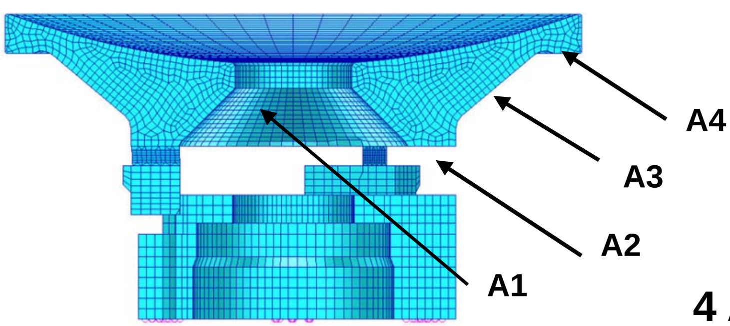
- One pass Linear solution (iterative trade study NOT required)

Easy to do other trade studies:

- Delete coating section
  - Ignore that subcase
- Limit coating thickness
  - Mfg bounds and >0

Easy to put tolerance on thickness

- Tolerance of 10% thick control

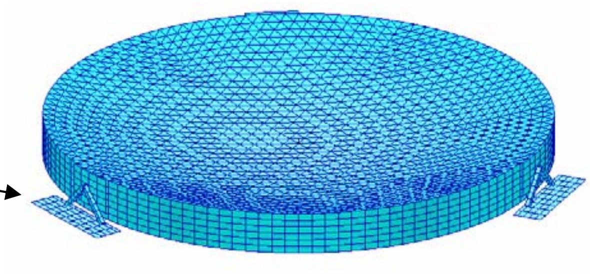


4 Actuators = eNi thickness on various portions of back surface

SigFit's Tolerancing capability

- Monte Carlo techniques to create tolerances based on optical performance
  - Each quantity treated as random variable with distribution
  - User specifies number analyses and confidence level
  - SigFit calculates variations of BFP, polynomials, surface RMS, LoS

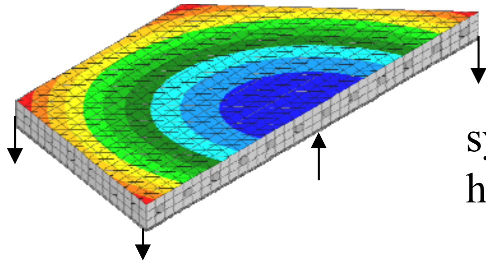
- Mount flatness requirements
  - flatness and coplanarity



Mirror on flexures bolted to support structure

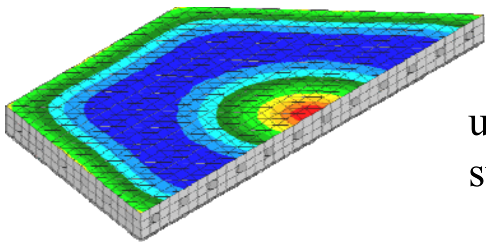
- Other examples
  - Substrate CTE variation
  - Coating thickness variation
  - Actuator resolution

SigFit’s Mirror optimization capability



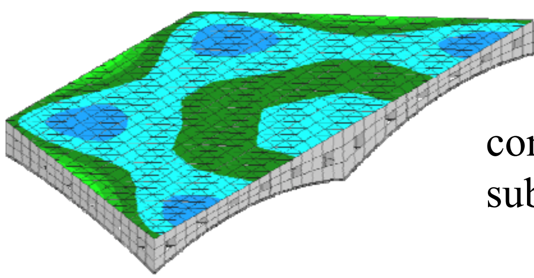
symmetric
half model

Adaptive mirror thermal distortion



uniform
substrate

Adaptively corrected surface error



contoured
substrate

Optimized design (3x improvement)

SigFit writes optical performance
measures as FE model input data
for use as design objective
or as design constraints

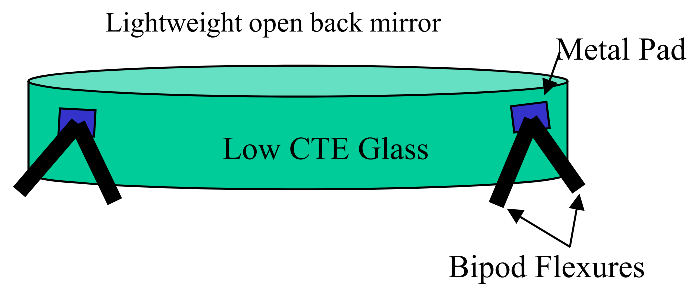
Polynomial coefficients

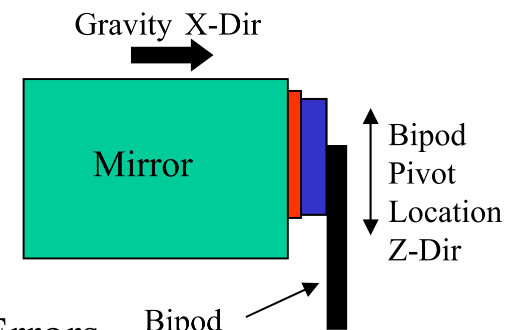
Surface error (RMS and P-V)
with BFP and polynomials removed

Line-of-sight equations

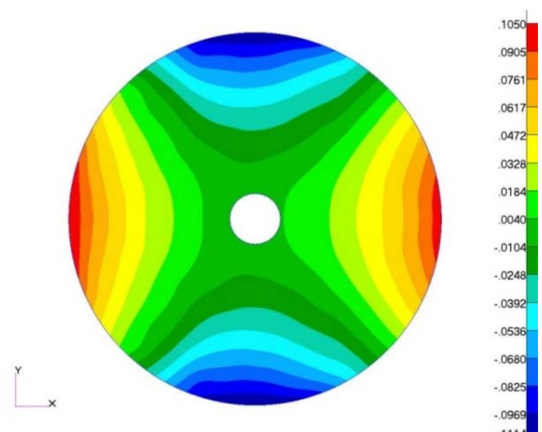
SigFit's optimization used to find best mount design

- Structural optimization techniques employed to minimize optical surface distortions
- Example: mirror mounted on three bipods subject to gravity acting in the in-plane x-direction
  - Design variables: bipod vertical pivot location
  - SigFit wrote Nastran Equations for RMS after BFP removed
  - RMS surface error reduced by ~ 10x for gravity x-direction

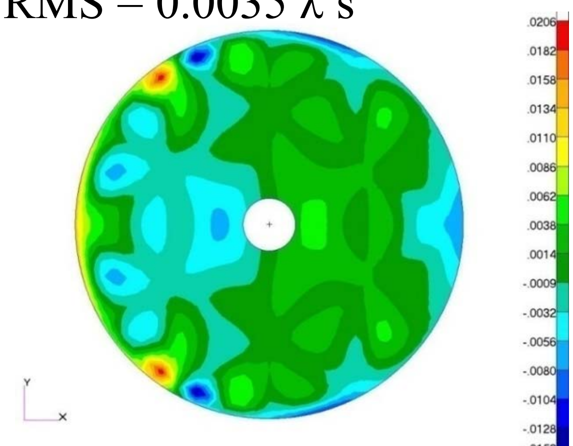




Nominal Design Surface Errors
RMS = 0.04 λ's



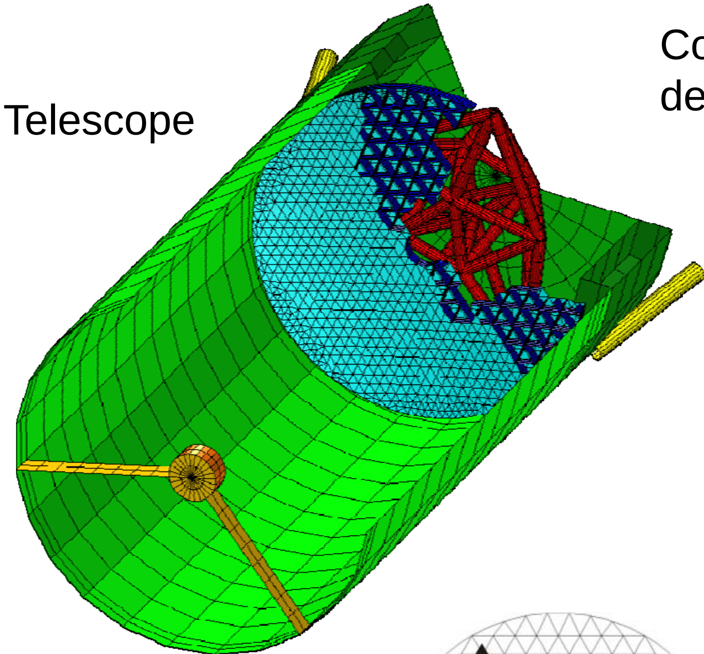
Optimized Design Surface Errors
RMS = 0.0035 λ's



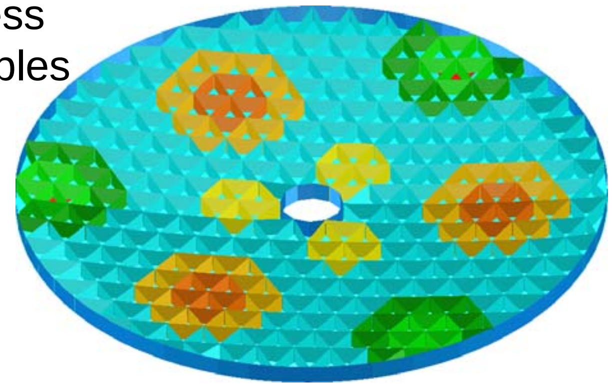
10X improvement

SigFit Optimization - System Level WFE performance constraints

Telescope

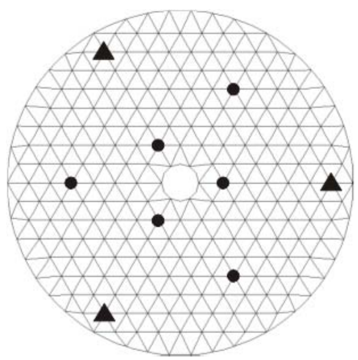


Core thickness
design variables



Adaptive Primary Mirror

Actuator
locations

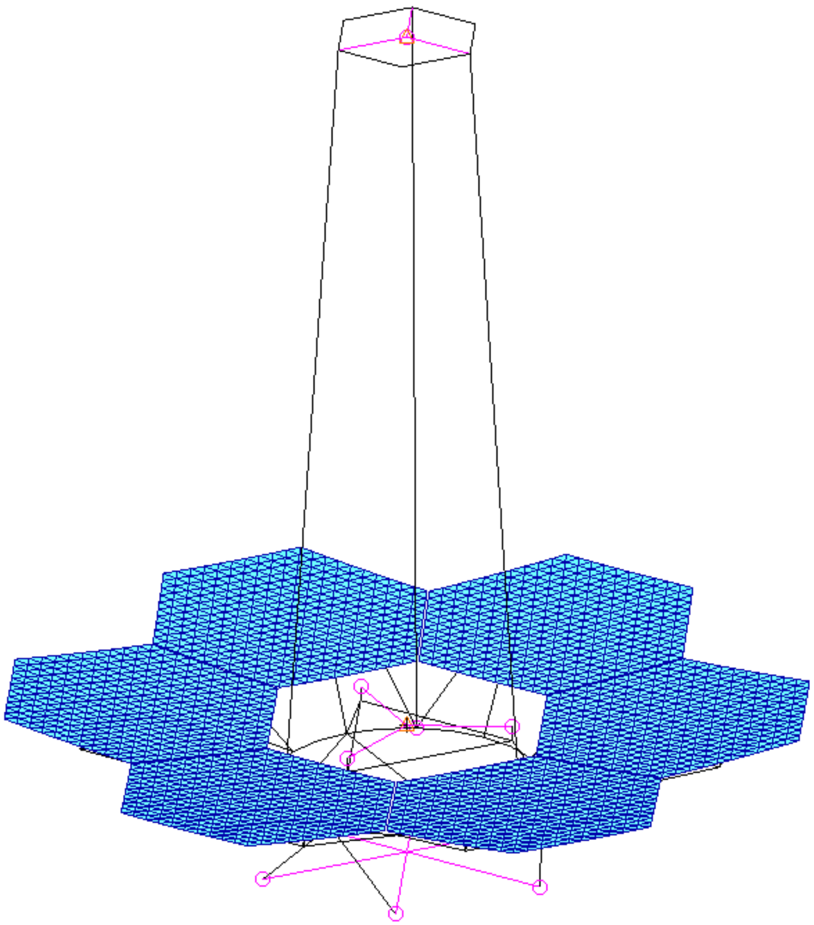


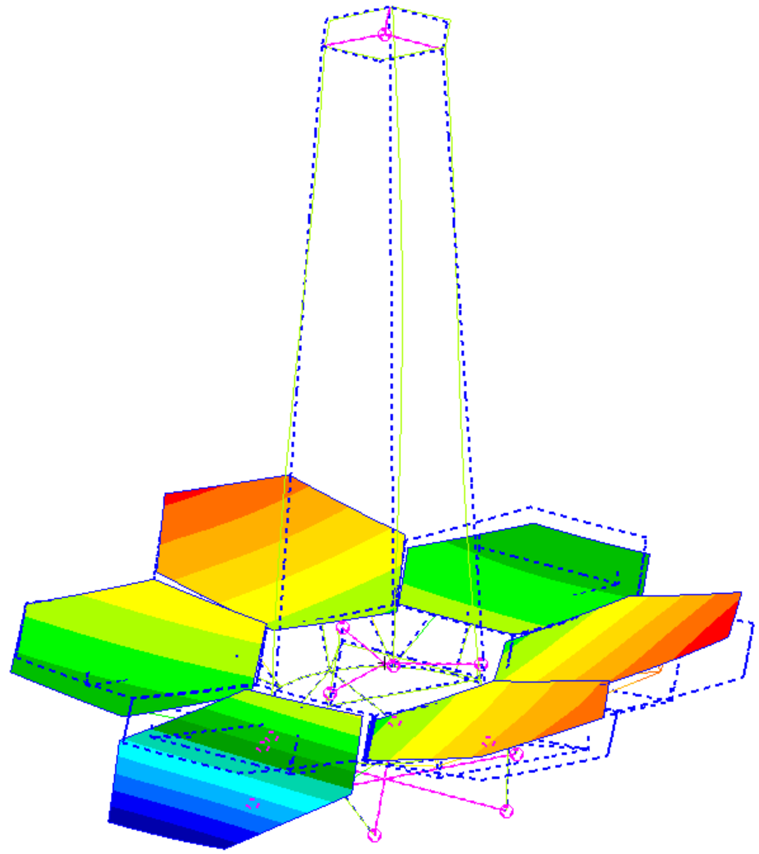
Response	Initial Design	Optimized Design	Requirement
Thermally Induced Wavefront Error	9 nm	20 nm	20 nm
Gravity Release Induced Wavefront Error	54 nm	60 nm	60 nm
Peak Launch Stresses	1000 psi	1000 psi	1000 psi
First Natural Frequency	231 Hz	221 Hz	200 Hz
Weight	20.8 kg	9.9 kg	Minimum
Areal Density	53.0 kg/m^2	25.2 kg/m^2	Minimum

linear optics model with Nastran's
DRESP3 call to SigFit

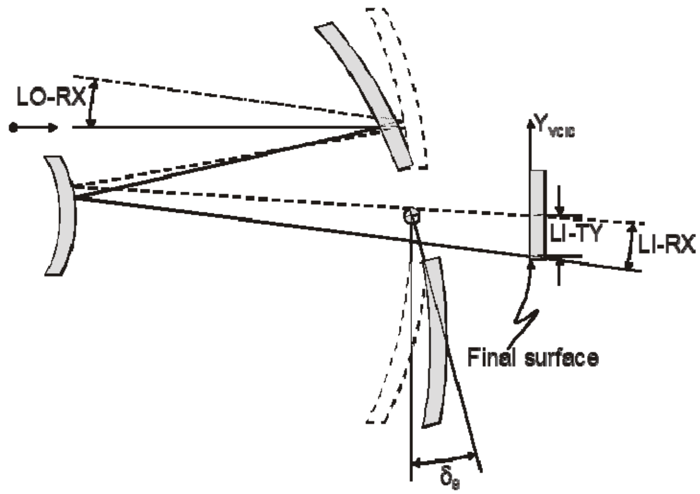
Optimized Primary Mirror Summary
Weight cut by 1/2

Telescope with segmented mirrors



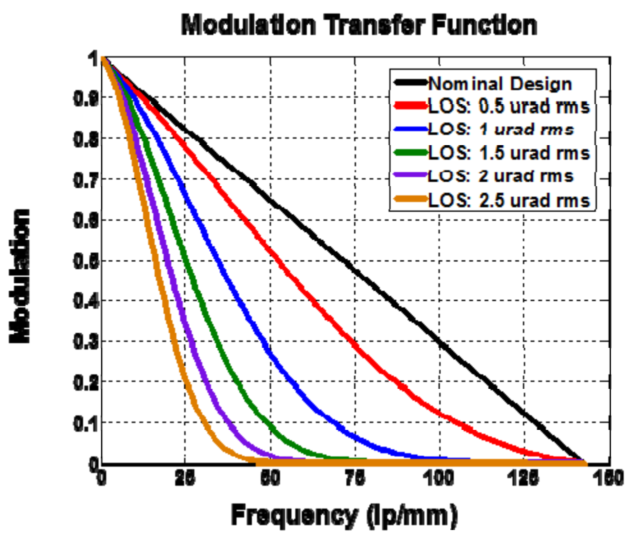


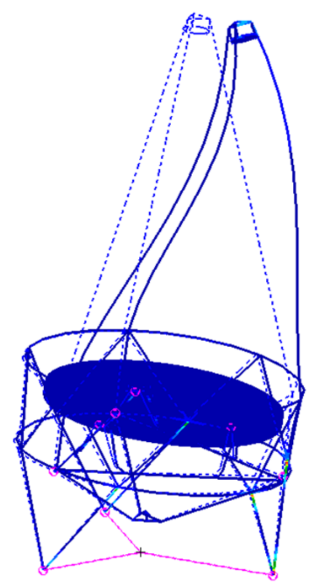
Telesope Line-of-Sight equations, Jitter MTF



SigFit calculates

- LOS equations
- Dynamic response, Jitter MTF.
- Surface RMS in Random
- Identifies key modes





SigFit v2016 has new Segmented optic analysis

Capabilities

- Fit Poly to Parent and Segments
- Calc RMS & P-V for Parent & Segments
- Calc Segment Relative motion in statics, dynamics (including random)
- Calc LoS of Parent & delta-LoS for each Segment
- Calc each modes contribution to LoS (Parent & Segment)
- Calc Segment racking = Segment RB – Parent RB
- Calc Node racking = mount strain effects
- Write spreadsheets of racking output (JWST assembly)

Summary – SigFit an SBIR success story.

- SigFit grew out of an SBIR program into a widely used commercial product
  - Without the SBIR, SigFit (and maybe Sigmadyne) might not exist

- SigFit is used for mirrors, lenses, gratings, and optics of all shapes
  - design, optimization, fabrication, testing

- Capabilities include
  - Surface fitting of several polynomial types and grid arrays
  - Adaptive/Active mirror analysis including actuator placement optimization
  - Mechanical Tolerancing using optical metrics
  - Calculation of LOS equations & dynamic response (including jitter MTF)
  - Mirror & mount Optimization using optical responses (LOS, SFE, WFE)

- Our papers are available from our website: **www.sigmadyne.com**

- **I am at a table in the exhibit area. Please stop by and chat.**