Optical Interface for MSC.Nastran

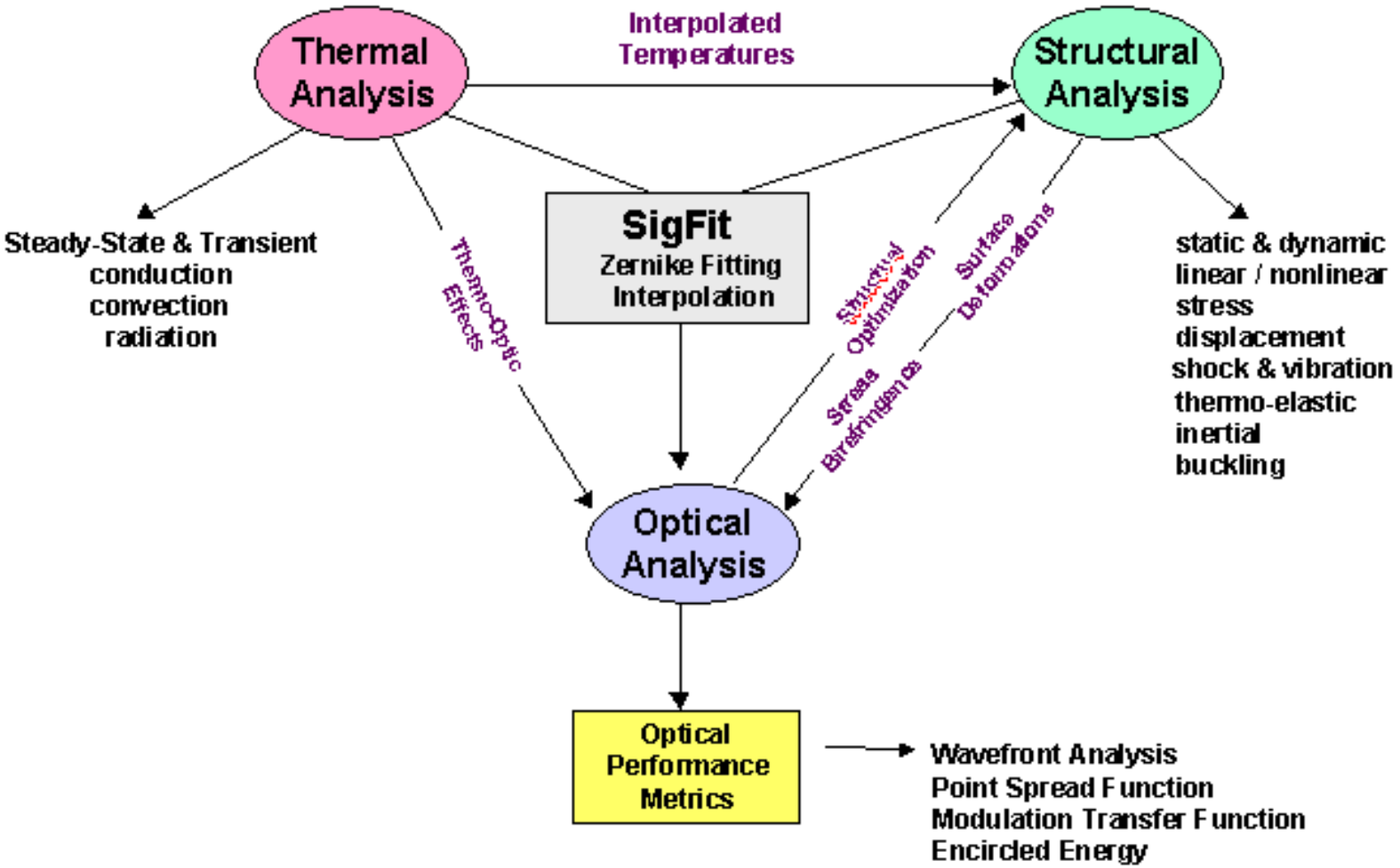
Victor Genberg, Keith Doyle, Gregory Michels
Sigmadyne, Inc

Optical Interface for MSC.Nastran

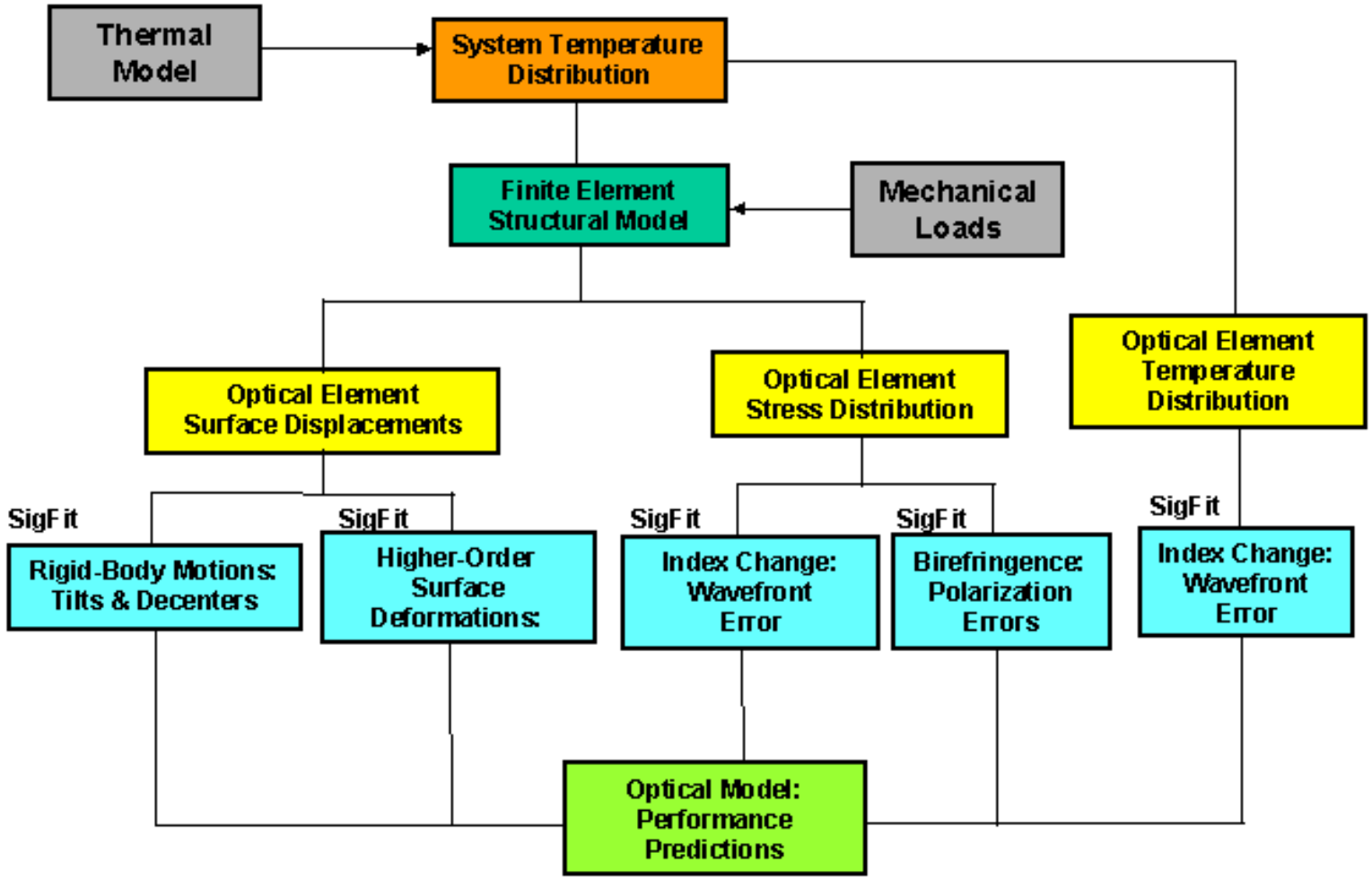
Outline of Presentation

- Integrated analysis procedure
- Surface distortions
- Thermo-optic effects
- Stress-optic effects
- Random response
- Adaptive (deformable) optic analysis
- System analysis
- Opto-Mechanical Optimization
- Summary

Integrated Analysis of Optical Systems



Analysis Flow for Optical Performance



Input to Optics Programs

Can NOT import FE results directly

- displacements, temperature, stress

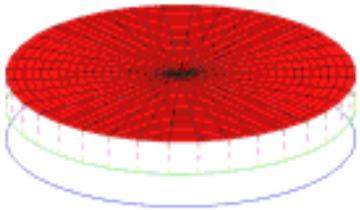
Can pass FE results only as

- “rigid body” motion (6 DOF per surface)
- Zernike/other polynomials (fit to results)
- Interferogram rectangular array (Hit Map)

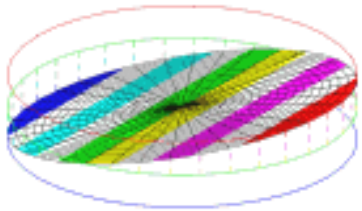
SigFit supports all above forms

- Code V, Oslo, Zemax formats

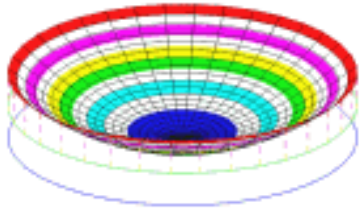
Zernike Polynomials



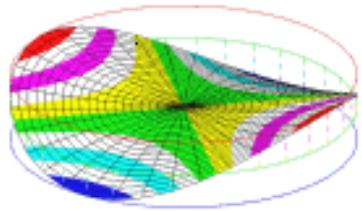
Bias/Piston



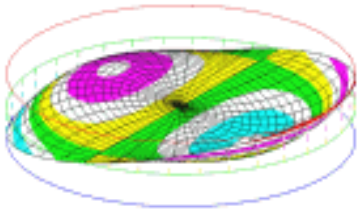
Tilt



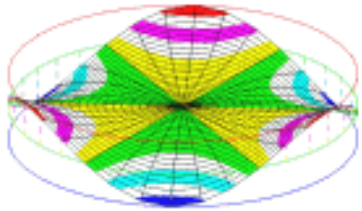
Power/Defocus



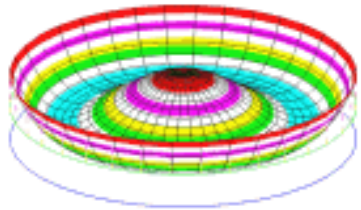
Pri-Astigmatism



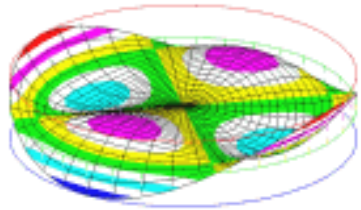
Pri-Coma



Pri-Trefoil



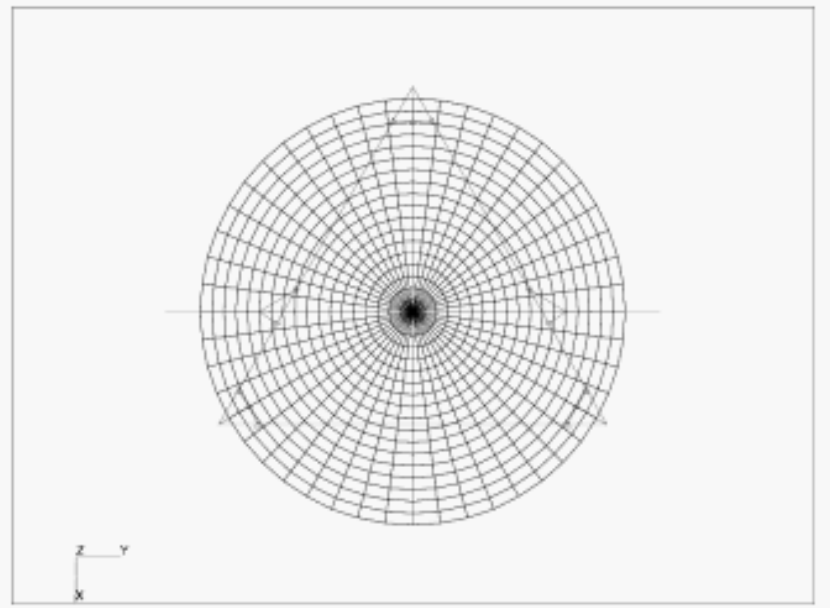
Pri-Spherical



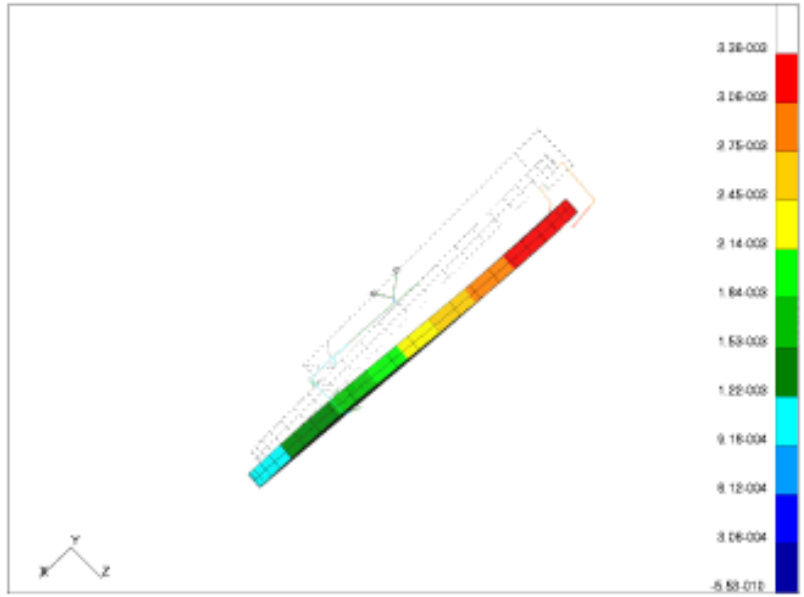
Sec-Astigmatism

$$\Delta Z(\rho,\Theta) = A_{00} + \sum_{N=2}^{\infty} A_{N0} R_0^N(\rho) + \sum_{N=1}^{\infty}\sum_{M=1}^{\infty} R_M^N\left[A_{NM}\cos(M\Theta) + B_{NM}\sin(M\Theta)\right]$$

Structural Distortion



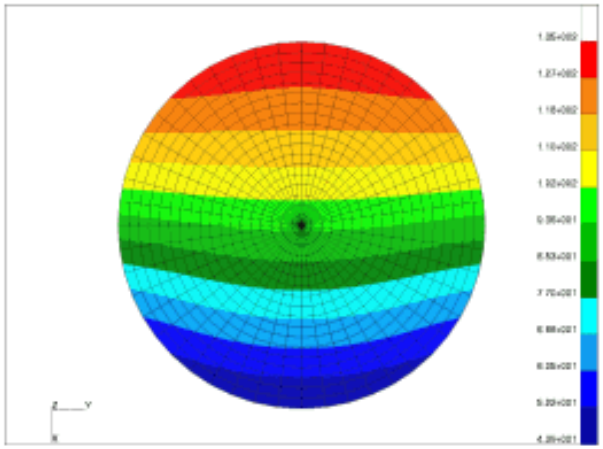
Mirror on Delta Frame



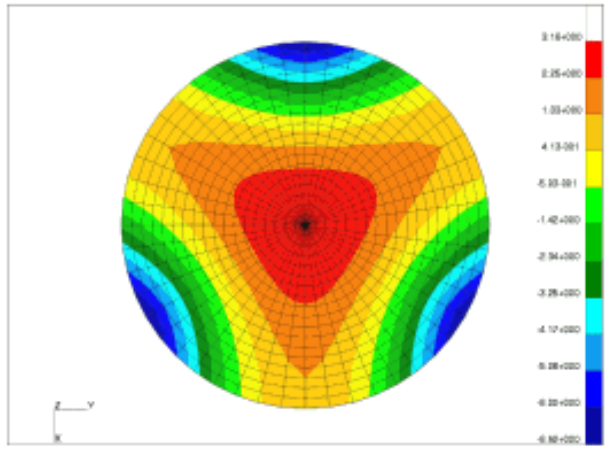
Deformed in 1g

FE deformation dominated by “rigid body” motion
which will be aligned out of the system

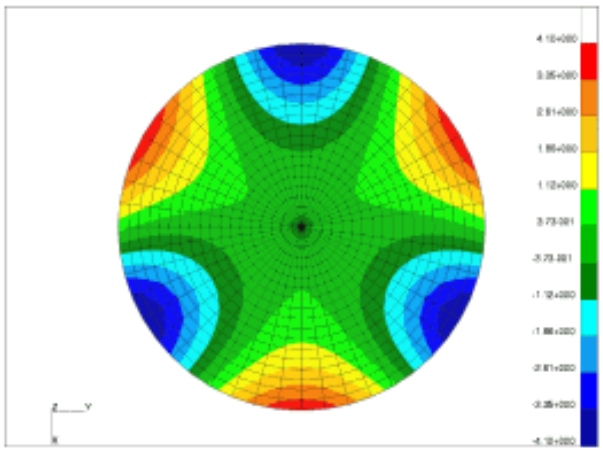
Structural Distortion



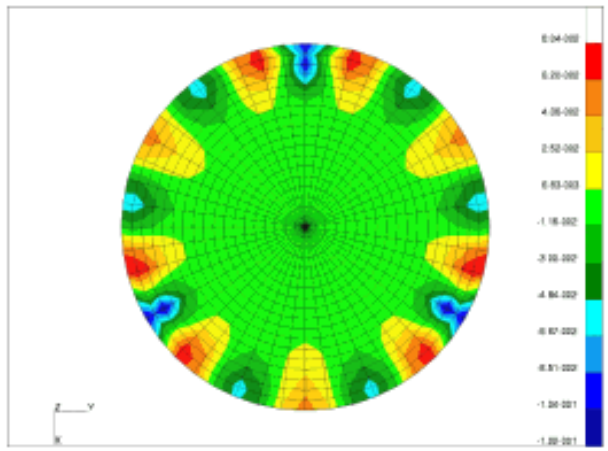
FE Raw Displacement (Normal) RMS=95λ



Best-Fit Plane Removed in SigFit RMS=2.3λ



BFP and Power Removed in SigFit RMS=1.6λ



All Terms Removed in SigFit RMS=0.03λ

Structural Distortion

Sigmadyne, Inc. SigFit Version=v2003-r1

Order K	N	M	Aberration	Magnitude (Waves)	Phi (Deg)	Residual RMS	Residual P-V
			Input(wrt zero)			95.6034	91.1636
1	0	0	Bias	92.29817	.0	24.9243	91.1636
2	1	1	Tilt	49.61448	179.9	2.2775	10.0795
3	2	0	Power (Defocus)	-2.81611	.0	1.5887	8.1731
4	2	2	Pri Astigmatism	.03751	89.8	1.5886	8.1791
5	3	1	Pri Coma	.01434	-180.0	1.5886	8.1862
6	3	3	Pri Trefoil	4.43376	0.0	.2369	1.3379
7	4	0	Pri Spherical	.33960	.0	.1782	1.1849
8	4	2	Sec Astigmatism	.00891	0.0	.1781	1.1890
9	4	4	Pri Tetrafoil	.01092	0.0	.1781	1.1760
10	5	1	Sec Coma	.00038	0.0	.1781	1.1764
11	5	3	Sec Trefoil	.43847	-60.0	.1203	.7565
12	5	5	Pri Pentafoil	.00226	-.1	.1203	.7596
13	6	0	Sec Spherical	-.00403	.0	.1203	.7596
14	6	2	Ter Astigmatism	.00037	-90.0	.1203	.7599
15	6	4	Sec Tetrafoil	.00124	0.0	.1203	.7599
16	6	6	Pri Hexafoil	.42821	-30.0	.0379	.3101

Structural Distortion

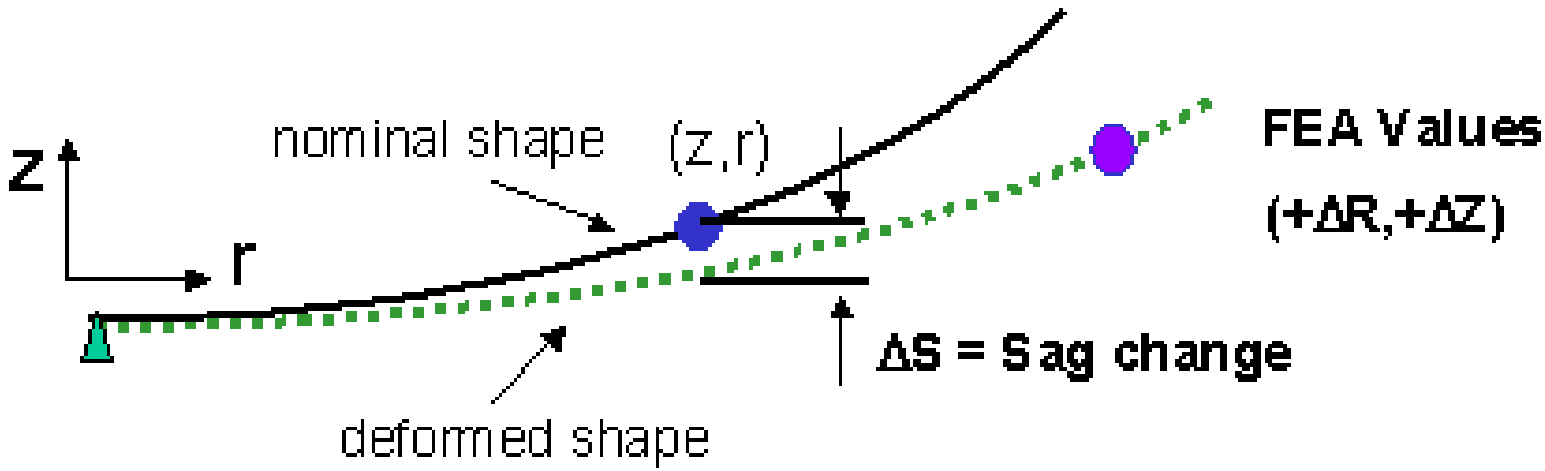
SigFit separates FE displacements:

- Pointing error (corrected by repointing)
  - if system has alignment capability
- Focus error (corrected by refocusing)
  - if systems has focus capability
- Elastic wavefront error (uncorrectable)
  - requires adaptive mirror to correct

SigFit passes FE displacements to optic code

- Writes Zernikes in optic code's format
- Using optic code's ordering and normalization

Radial Correction



FEA ΔZ displacement does NOT represent surface Sag

SigFit calculates Sag as the combined effect of ΔZ and ΔR

Interpolation Hit Map <=> FE Model

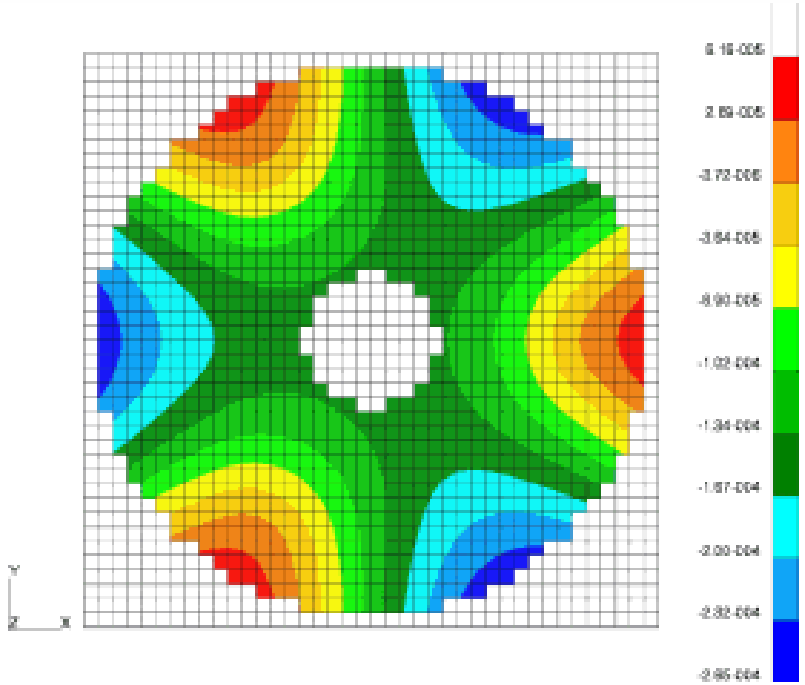
Interferometric testing creates Hit Maps

- rectangular array of data

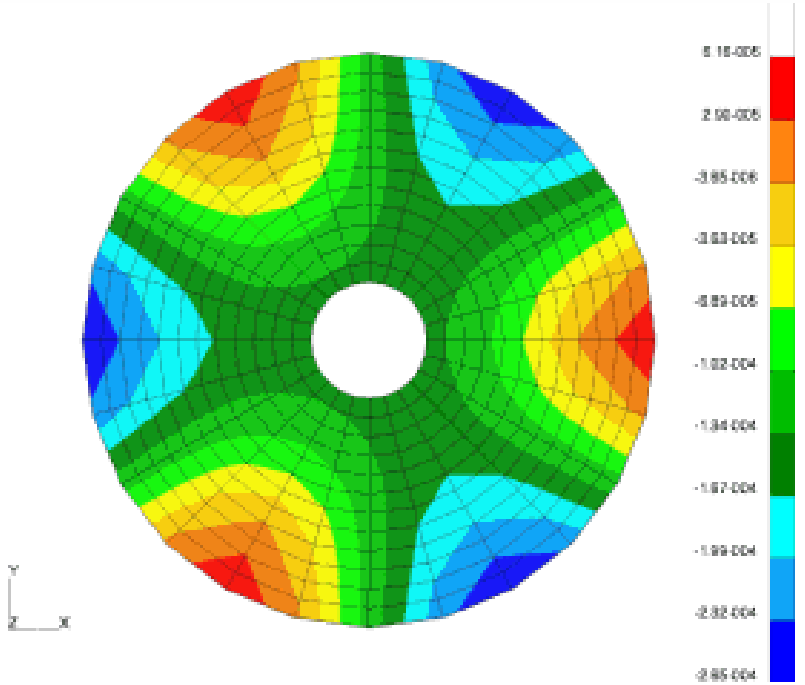
SigFit interpolates between FE Models and Interferogram Arrays (Hit Maps)

- Output FE analysis data to test systems
- Compare test and analysis (point-to-point)
- Create analysis backouts for ground tests
- Import test data for adaptive correction
- Used when Zernikes are a poor fit to deformations

Interpolation Hit Map <=> FE Model



HitMap Contours



FE Model Contours

SigFit passes data between test interferograms and FE models using FE shape functions for interpolation

Thermo-Optic Effect

Temperature causes change in index (n)

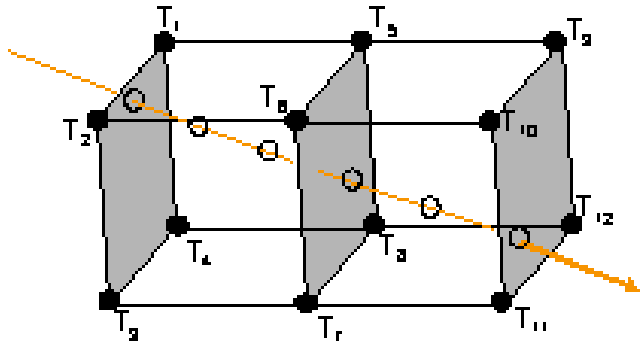
- index changes cause optical pathlength changes
- OPD = Optical Path Difference

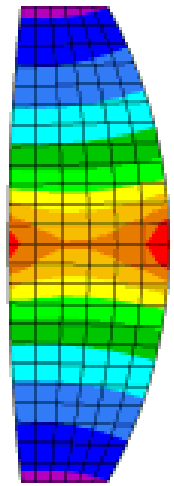
SigFit calculates OPD due to dn/dT

- Reads MSC.Nastran thermal results
- Integrate through the optic along ray paths
- Calculates OPD
  - Fit Zernikes to OPD, write in optics format
  - Interpolate to HitMap, write in optics format
  - Supports CodeV, Zemax, Oslo formats

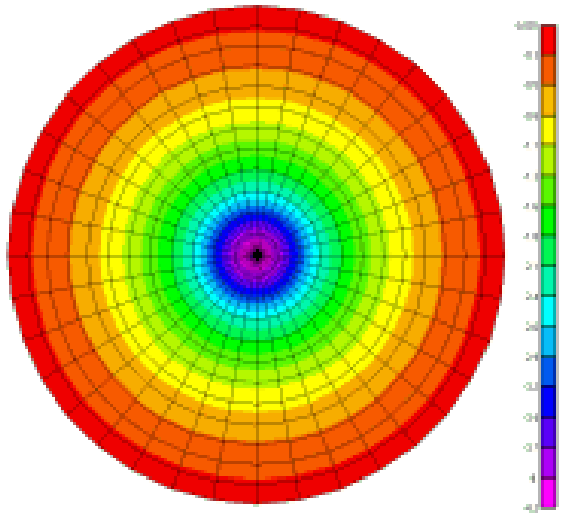
Thermo-Optic Effect

$$OPD = \sum_{n=1}^{n=total} \frac{Dn}{Dt} \Delta T_n L_n$$





Lens Temperature Distribution



Lens OPD Map

Stress-Optic Effects

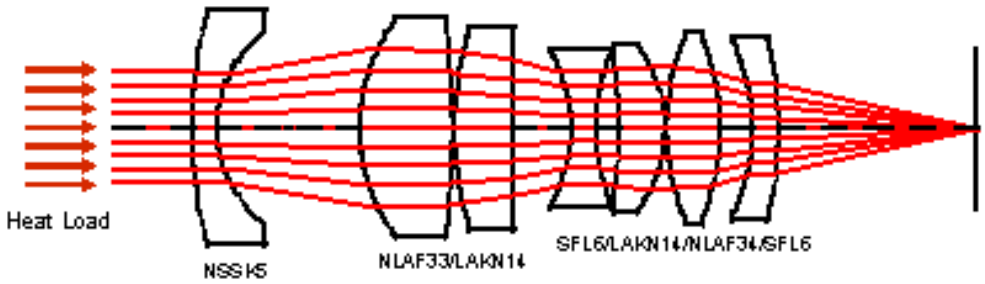
Stress causes changes in index ($dn/d\sigma$)

- index changes cause pathlength changes (OPD)
- birefringence cause polarization changes (ΔOPD)

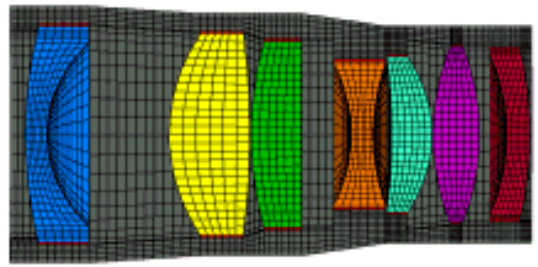
SigFit calculates OPD & birefringence

- Reads MSC.Nastran stress results
- Integrates through the optic
  - shape function interpolation through elements
- Calculates OPD & Birefringence
  - Fit Zernikes to OPD, write in optics format
  - Interpolate to HitMap, write in optics format
  - Supports CodeV, Zemax, Oslo formats

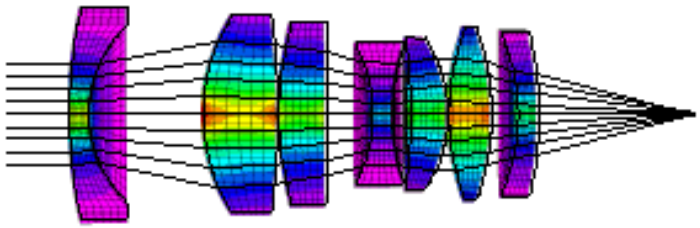
Combined Stress & Thermal effects



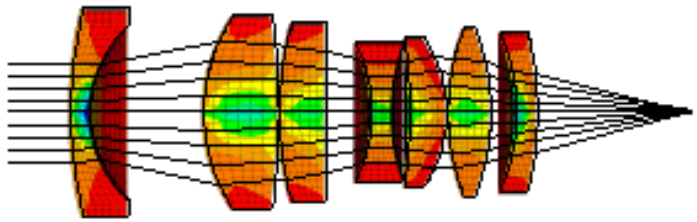
Optical Model



FEA Model



Temperature Field

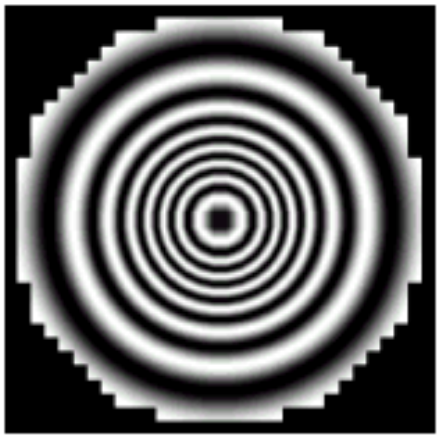


Stress Field

SigFit calculates the OPD effect for dn/dT and dn/dσ which can be combined with surface distortions and passed to an optics code

Combined Stress & Thermal effects

Thermo-Elastic Interferogram Map



rms = 1.7
p-v = 7.6

Stress-Induced Interferogram Map

rms = 0.4
p-v = 1.2

Thermo-Optic Interferogram Map

rms = 1.9
p-v = 8.5

SigFit data passed to Code V. Above results from Code V

Dynamic Analysis

FEA random response results

- optical surface responses are all RMS values (>0)
- cannot distinguish rigid-body from elastic motion
- cannot differentiate pointing from wavefront errors

All RB motion, No elastic distortion

No RB motion, All elastic distortion

Dynamic Analysis

SigFit calculates dynamic response

- reads MSC.Nastran mode shapes
- decomposes mode shapes into
  - rigid body and elastic components
- calculates harmonic & random response
  - uses modal analysis methods
  - reports pointing error (rigid body) response
  - reports wavefront error (elastic) response

Adaptive (Deformable) Optic Analysis

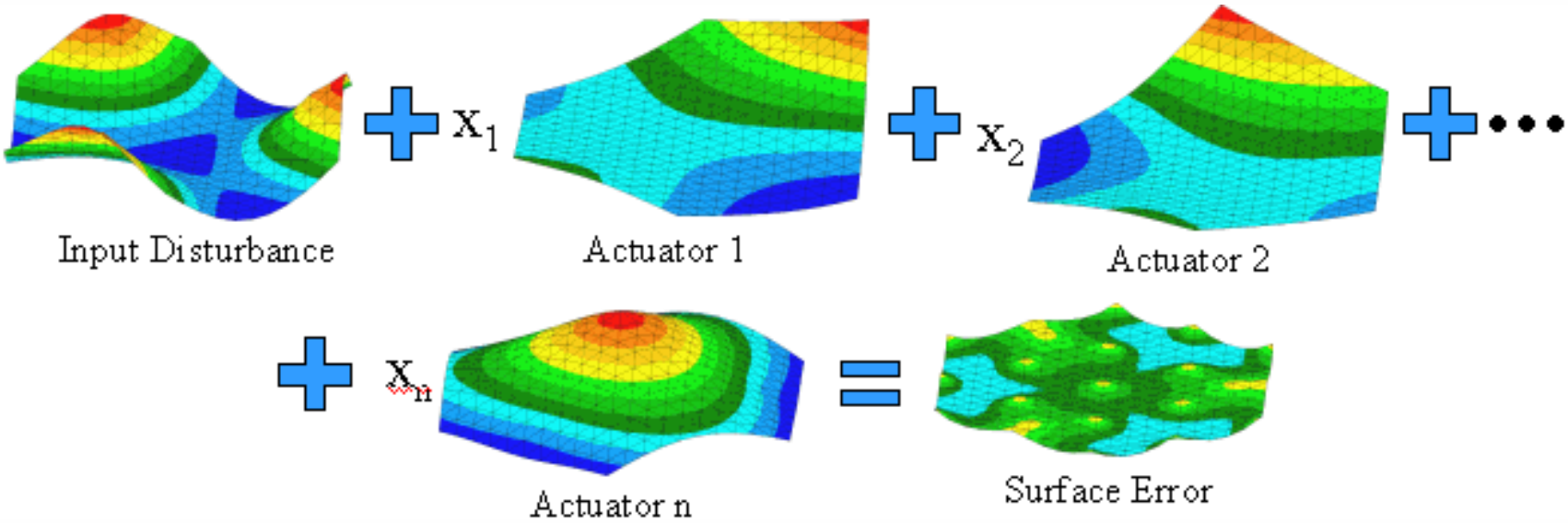
Adaptive optics used to improve performance

- Cancel atmospheric turbulance
- Correct fabrication / mounting errors
- Correct for thermal distortions
- Correct for mechanical distortions

SigFit calculates adaptive correction

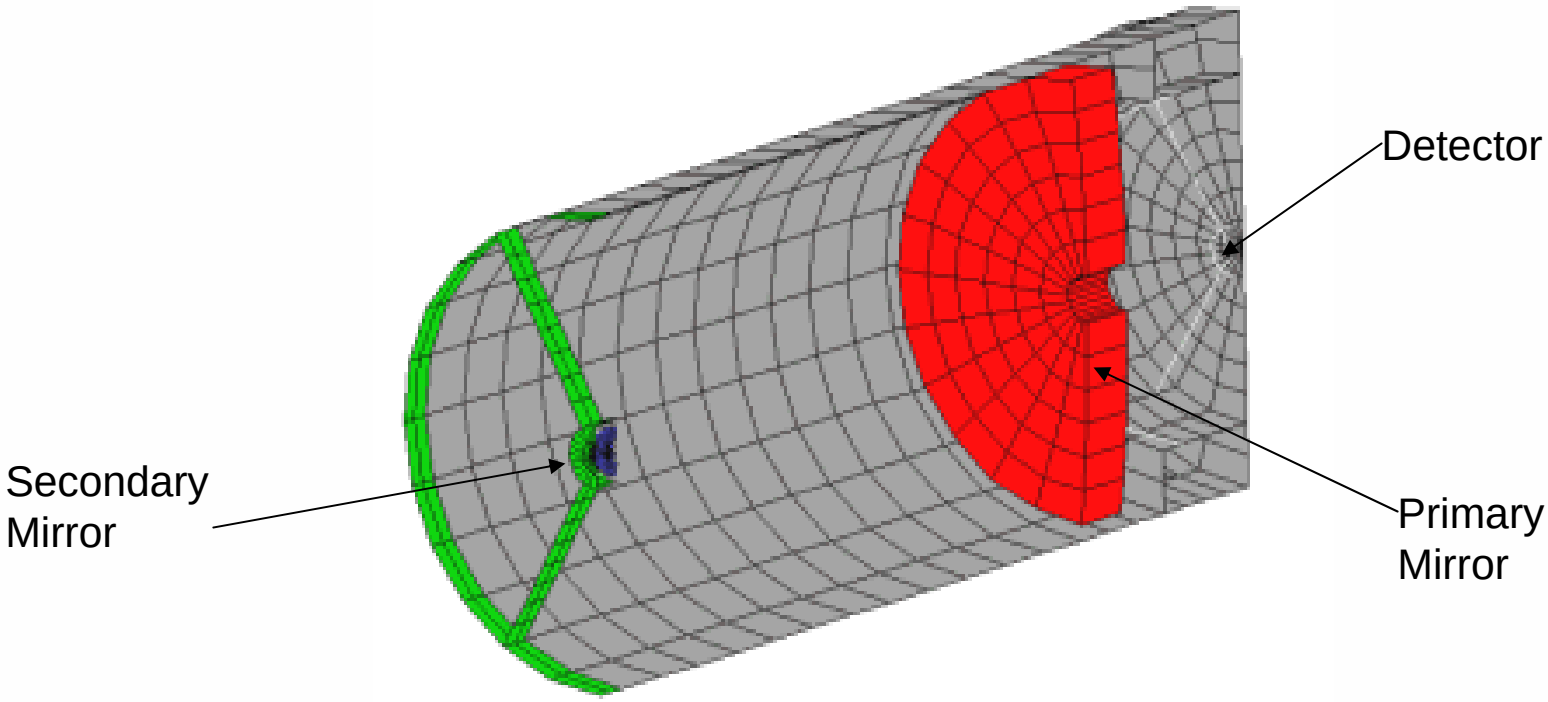
- Finds actuator motions required to minimize RMS
- Calculates corrected surface and actuation forces
- Outputs resulting surface in optics format

Adaptive (Deformable) Optic Analysis



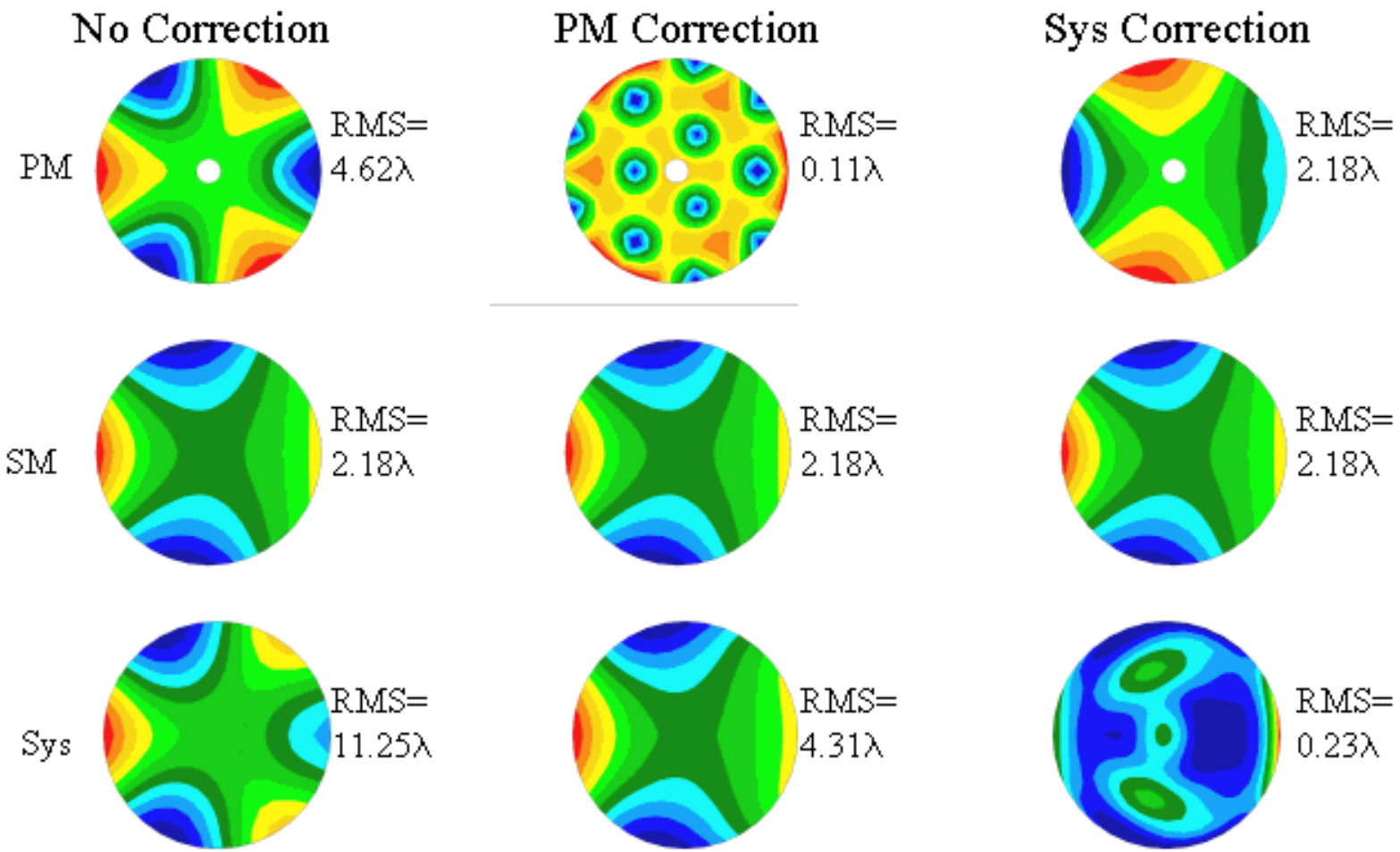
- SigFit supports a very general adaptive analysis capability
  - force and/or displacement actuators
  - test and/or analysis input disturbance
  - bounded or unbounded solutions (actuator limits)

Adaptive (Deformable) Optic Analysis



Simple Telescope with Adaptive Primary Mirror
Cut-away view showing inside

Adaptive (Deformable) Optic Analysis

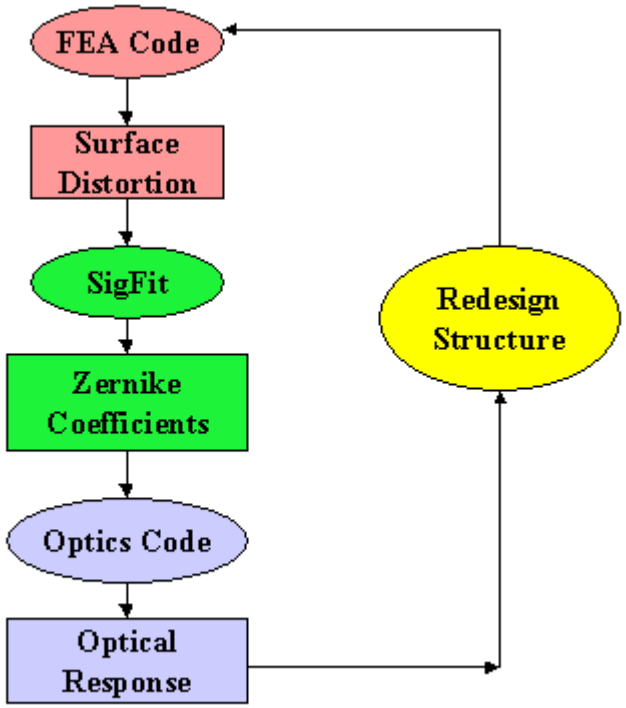


System Analysis

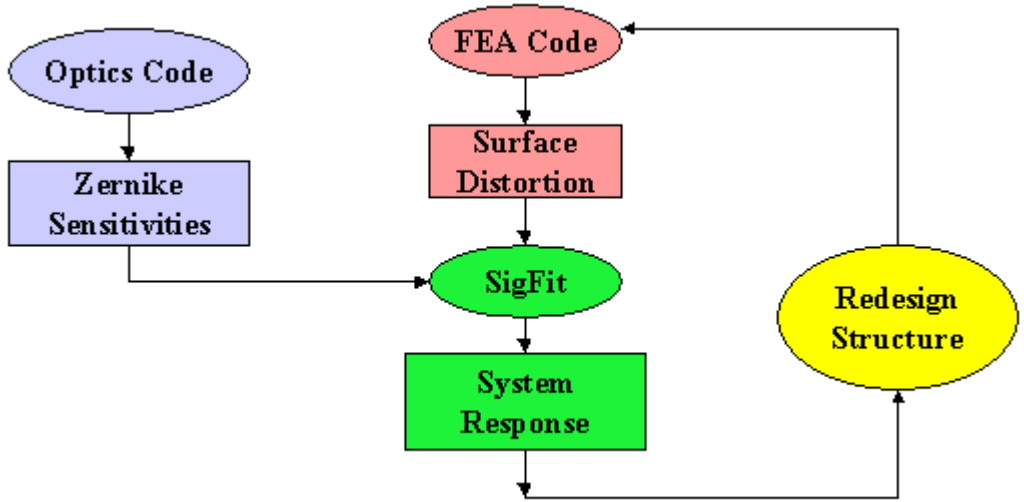
SigFit supports system analysis

- Uses Zernike sensitivities from optics program
  - Input unit Zernikes at each surface (use script)
  - Create Matrix of Zernike responses at exit pupil
- SigFit will calculate system response
  - Fit Zernikes on each surface to FE results
  - Multiply by sensitivity matrix to get resulting response
  - Used for system analysis/ adaptive/ dynamic response
- Provides much faster design iteration

System Analysis



Old Design Process



New Design Process

Mechanical design process involves only the mechanical engineer. There is no trading of data back and forth during design cycle

Opto-Mechanical Optimization

SigFit supports MSC.Nastran SOL 200

- Writes Surface RMS or Peak-to-Valley after Zernike fit as **DRESP2**
  - Can then be used as a constraint or as the objective in SOL 200
  - Especially useful in the optimum design of large light-weight mirrors
  - Well established and documented procedure
- Writes Surface/System wavefront response as **DRESP3**
  - Writes necessary DRESP1 and DRESP3 in a preprocessing step
  - Called by DRESP3 to calculate individual surface or total system response
  - Especially useful in system level optimization with adaptive control
  - New feature discussed in Greg Michels' paper
- Allows optical performance measures to be used in structural optimization

Optical Interface for MSC.Nastran

References at www.sigmadyne.com

- Several recent papers (download)
  - Technical details on all topics in this talk
- SigFit documentation (download)
  - Reference Manual
  - Examples Manual
  - Example I/O files

Short Course & Book from SPIE:

- **Integrated Optomechanical Analysis**