Modular Mirror Assembly Systems Engineering

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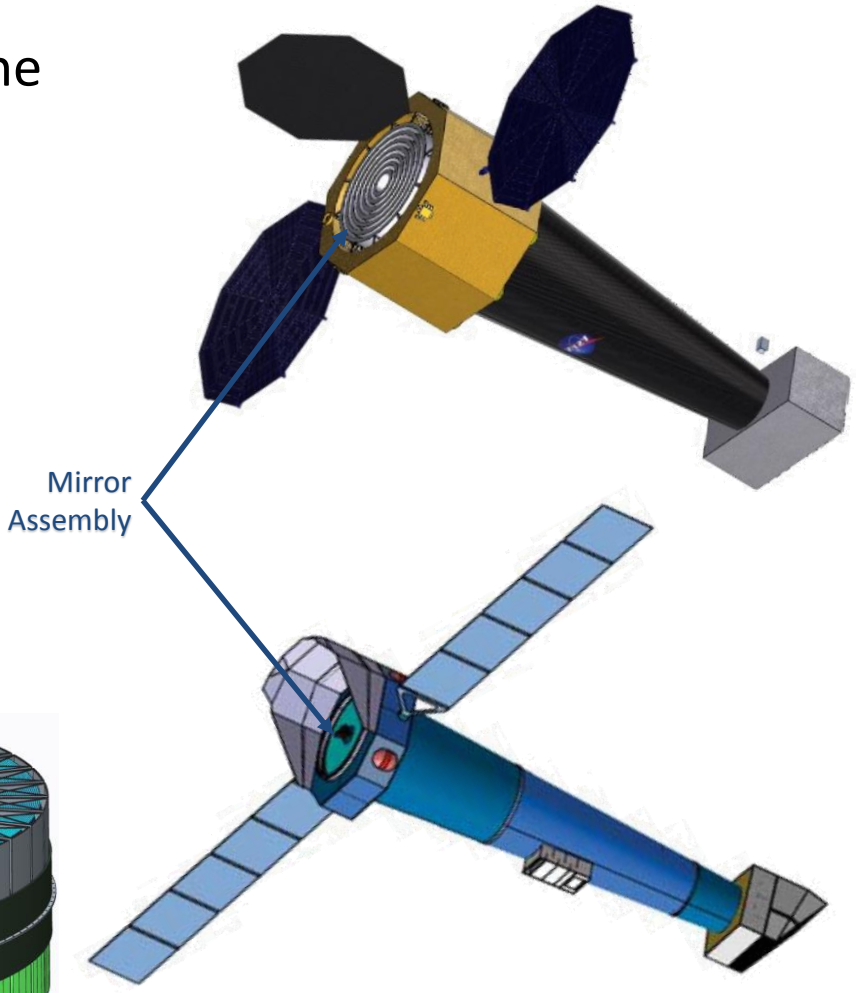
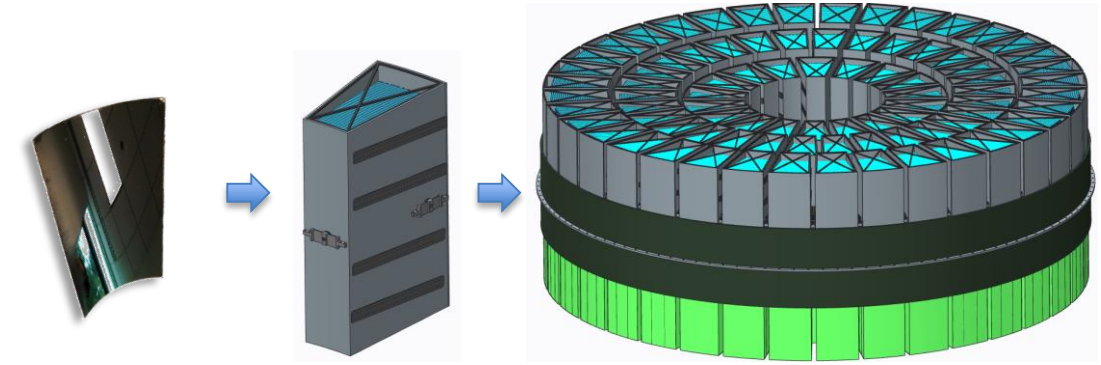
Overview

- Goal: Consider design challenges for X-Ray Surveyor beyond mirror segment fabrication and mounting
  - Unique challenges for modular Mirror Assembly
- Example 5” Mirror Assembly design
- Error budget for a 5” Mirror Assembly
- Error budget for a 0.5” Mirror Assembly
- Analysis of error budget terms
  - Design drivers for 5” Mirror Assembly
  - Pathway to 0.5” Mirror Assembly

Modular Mirror Assembly

- Mirror Assembly – the optics
  - Includes the system that holds the optics and provides mounting to the telescope or spacecraft
  - Eg Chandra HRMA, IXO FMA
- Segmented mirrors lend themselves to a modular approach
  - Hitomi/Astro-H
  - Athena





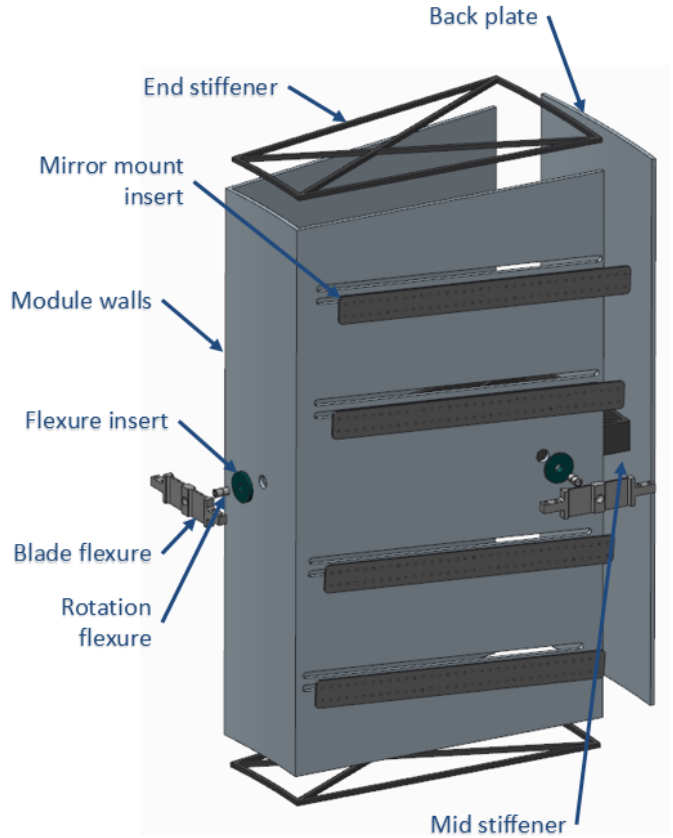
Mirror Segment (hundreds)

Mirror Module (dozens)

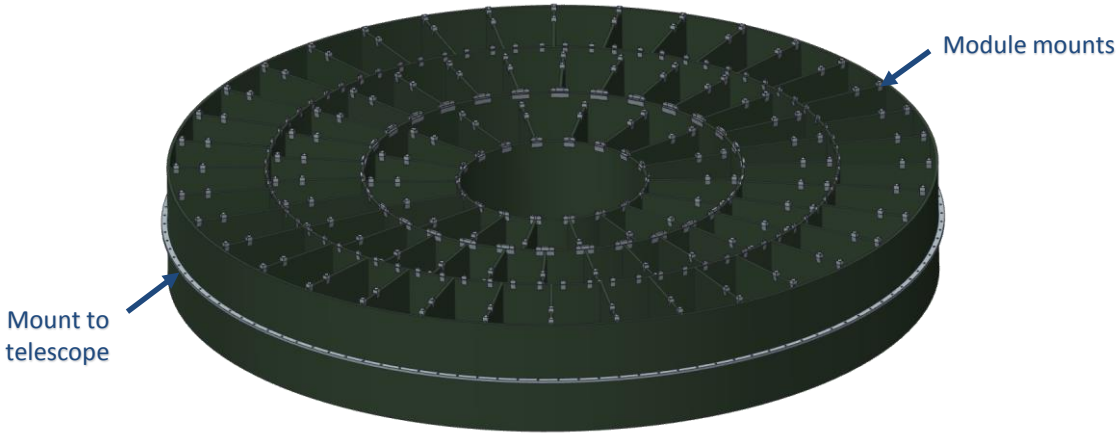
Mirror Assembly

Example 5” Mirror Assembly Design

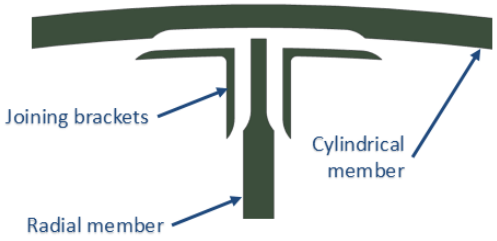
- GSFC recently undertook a detailed design and analysis of a 5” Mirror Assembly
  - CAD and FEM of every part
  - Based on Silicon mirrors with edge-bonding mount
    - Silicon module structure with Invar interfaces
    - Flexure mounted to Module Support Structure
  - CFRP Module Support Structure
    - Bolts onto telescope assembly



Module Exploded View



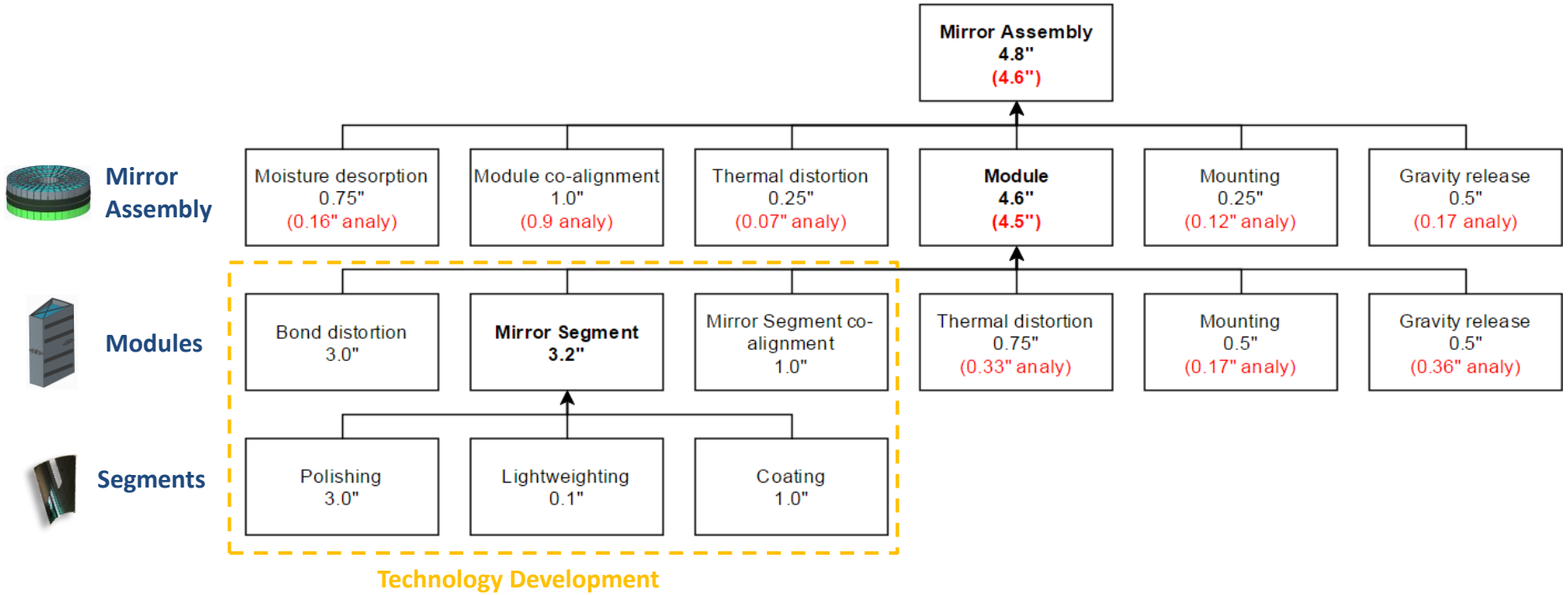
Module Support Structure



Module Support Structure Detail

Error Budget for 5” Mirror Assembly

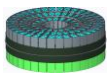
- 5” Half-Power Diameter (HPD) on-orbit
  - 1” allocated to Telescope Assembly = 4.8” for Mirror Assembly



- For 0.5” Mirror Assembly, reduce every term by an order of magnitude
  - In reality, errors may be redistributed

Error Budget for 0.5” Mirror Assembly

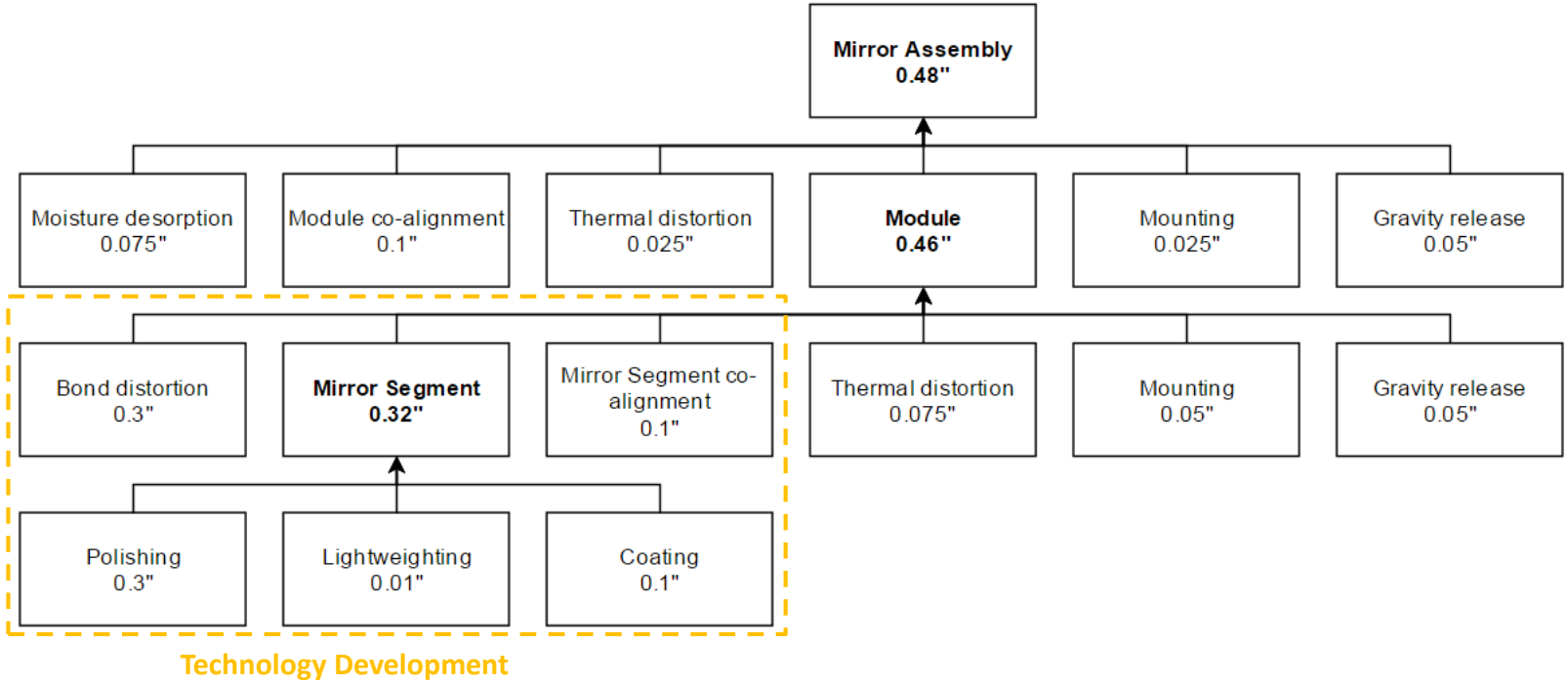
- 0.5” Half-Power Diameter (HPD) on-orbit
  - 0.1” allocated to Telescope Assembly = 0.48” for Mirror Assembly



Mirror Assembly

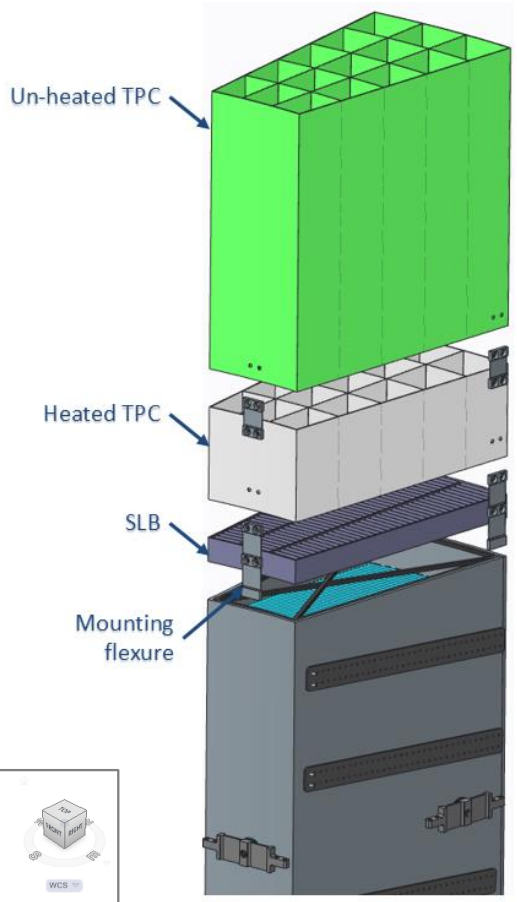
Modules

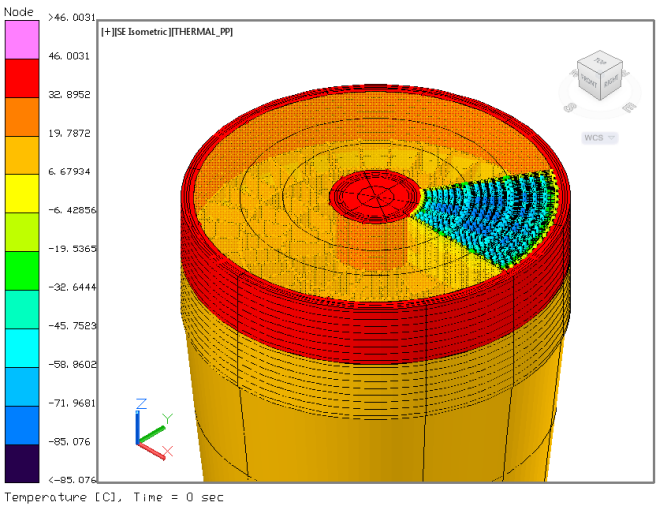
Segments

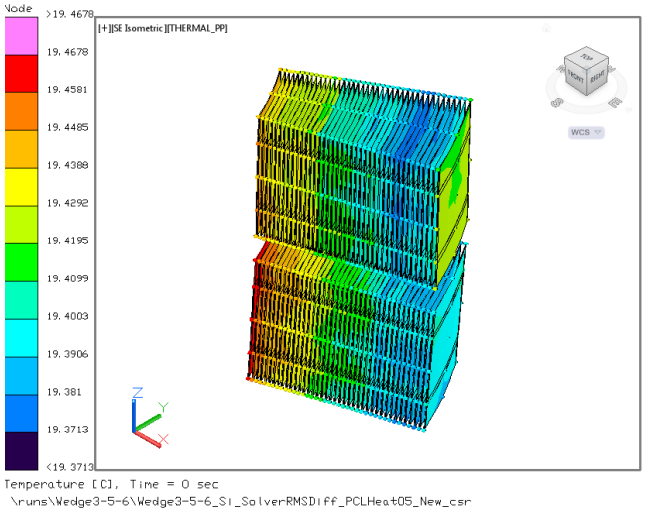


Module Thermal Distortion - Design

- Performed Structural Thermal Optical Performance (STOP) analysis of the mirror assembly
  - Hundreds of mirror segments modeled at correct prescription in structure and thermal models
- Thermal design limits view of mirrors to space and replaces lost heat
  - 20°C Mirror Assembly
  - Module Support Structure heated at ID and OD
  - First ~1 m of metering tube heated
  - Heated stray light baffle
  - Partially heated thermal pre-collimator
  - Temperature set points numerically optimized







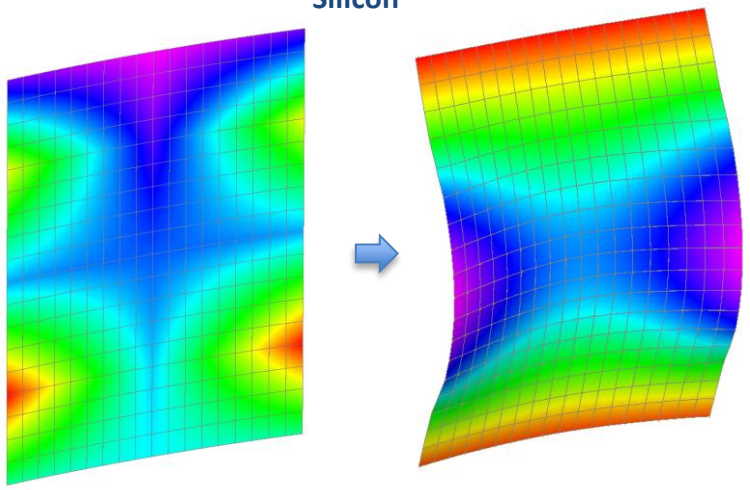
Module Thermal Distortion – STOP results

- Distortion within 0.75” requirement once optimized
- Distortion is driven by gradient over a mirror segment
- D263 glass distortion is ~10x worse
  - CTE 2x higher than silicon
  - Thermal conductivity 100x lower

Thermal distortion 0.75" (0.33" analy) → Thermal distortion 0.075"

- Pathway to 0.075” (4.4x)
  - Use low CTE and/or high conductivity materials
  - Avoid hot spots at mounting interfaces
  - Use more complex heating – more heater zones

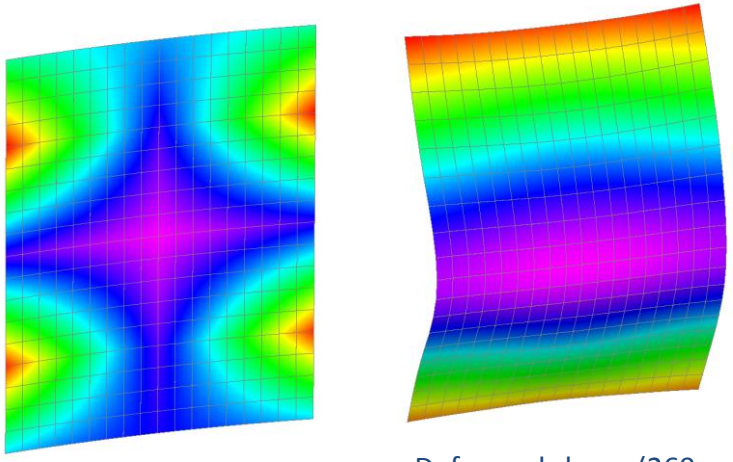
Silicon



Thermal gradient 0.2°C

Deformed shape (30 nm)
0.33” HPD

D263 Glass



Thermal gradient 0.7°C

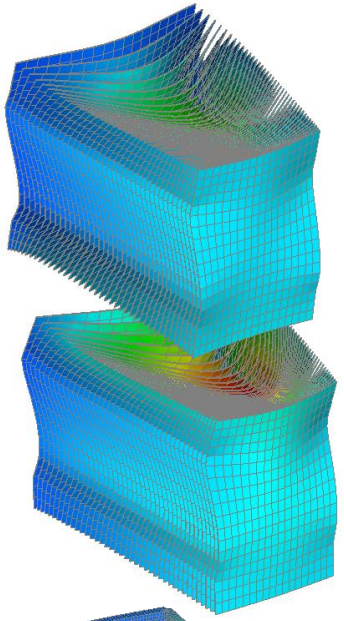
Deformed shape (260 nm)
3.4” HPD

Module Gravity Release

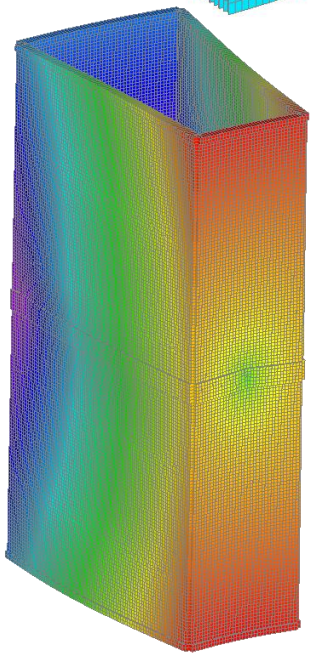
- Module is built, populated, and tested in 1 g but used in zero g
  - Thin lightweight mirrors distort
  - Module housing distorts

Gravity release
0.5"
(0.36" analy)

Gravity release
0.05"

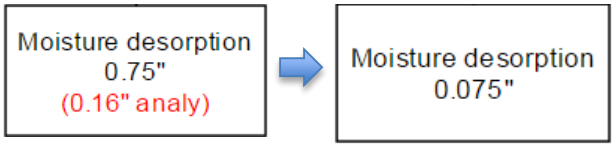


- Pathway to 0.05” (7.2x)
  - Use materials with high stiffness to weight ratio
    - Silicon is excellent, 2.2x better than D263 glass
  - Use thicker mirrors/structures
  - Add additional mirror segment constraints

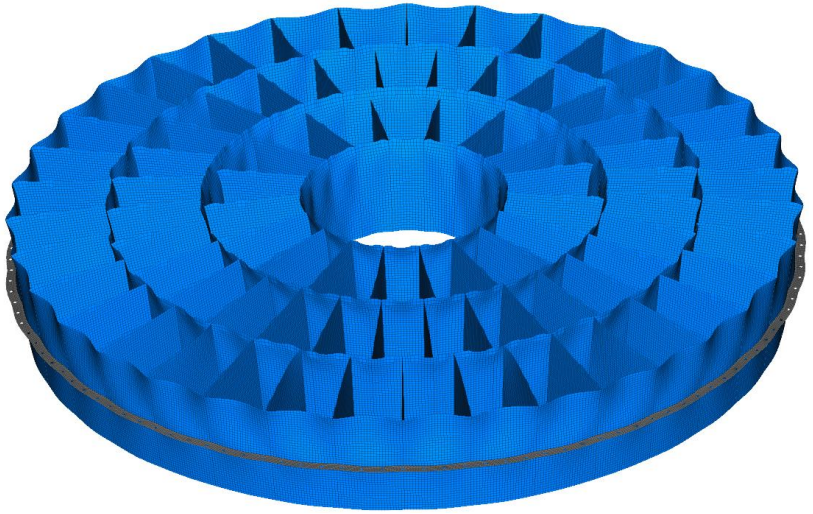


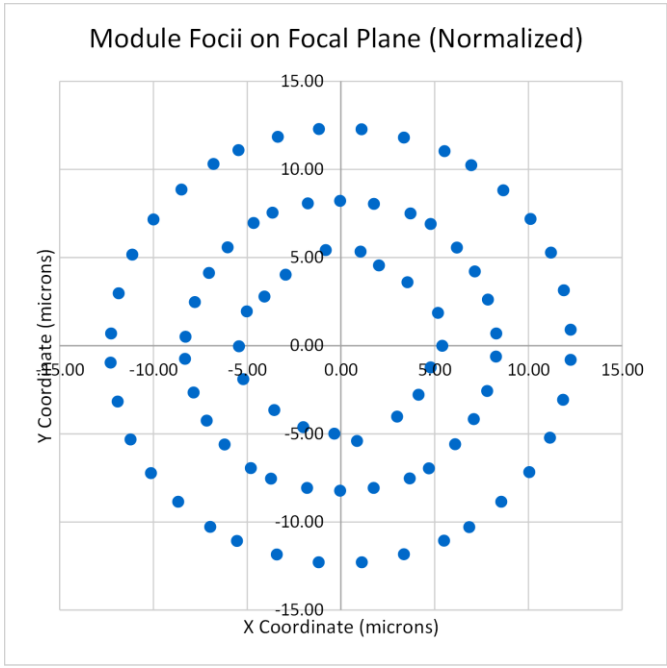
MSS – Moisture Desorption

- CFRP structure's main drawback
  - Moisture is absorbed on the ground and released in space
    - Strain = %mass loss (50%-0%RH) * CME (ppm/%)
  - Moves the module foci



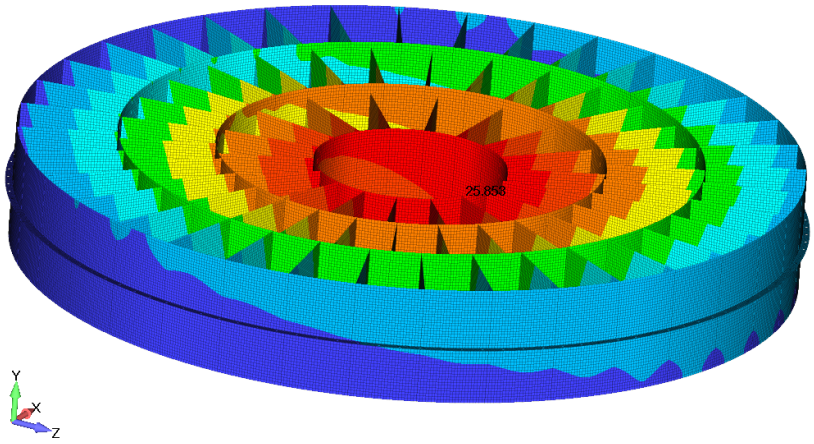
- Path to 0.075" (2.1x)
  - Use special low moisture saturation composite
  - Compensate for focal change during module alignment
  - Use a metallic structure





MSS – Thermal Distortion

- Composite structure CTE is low, but not zero
  - CTE (-0.13 ppm/°C)
  - Moves the module foci
  - Based on STOP analysis

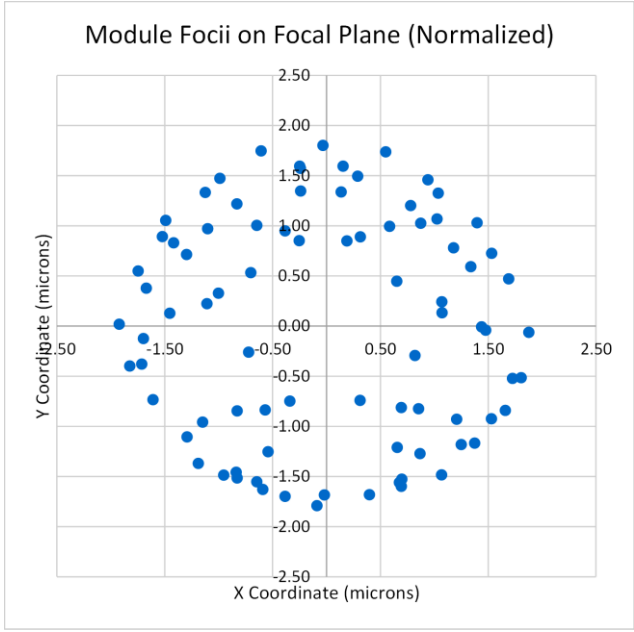


Thermal distortion
0.25"
(0.07" analy)

→

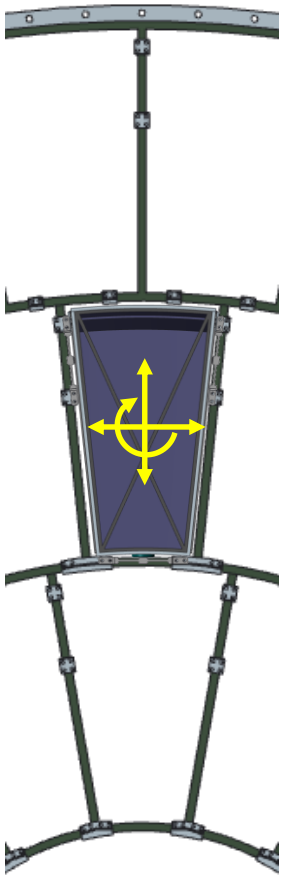
Thermal distortion
0.025"

- Pathway to 0.025” (2.8x)
  - Improve thermal control of Module Support Structure



MSS – Module Co-alignment

- Modules must be aligned to a common focus in 6 dof
  - Performed sensitivity analysis
  - Relatively insensitive to yaw, pitch, and focus
  - Highly sensitive to module roll



5” Mirror Assembly

Term	Image Error Cont. (HPD arc-sec)	Mount tolerance required
Yaw (rx)*	0.25	375"
Pitch (ry)*	0.25	375"
Roll (rz)*	0.5	4.4"
Radial (x)	0.5	12.1 um
Azimuthal (y)	0.5	12.1 um
Focus (z)	0.25	125 um
RSS	**1.0**	

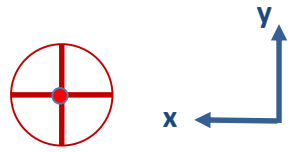
* rotations are about module center of gravity/area

0.5” Mirror Assembly

Term	Image Error Cont. (HPD arc-sec)	Mount tolerance required
Yaw (rx)*	0.025	37.5"
Pitch (ry)*	0.025	37.5"
Roll (rz)*	0.05	0.4"
Radial (x)	0.05	1.2 um
Azimuthal (y)	0.05	1.2 um
Focus (z)	0.025	12.5 um
RSS	**0.1**	

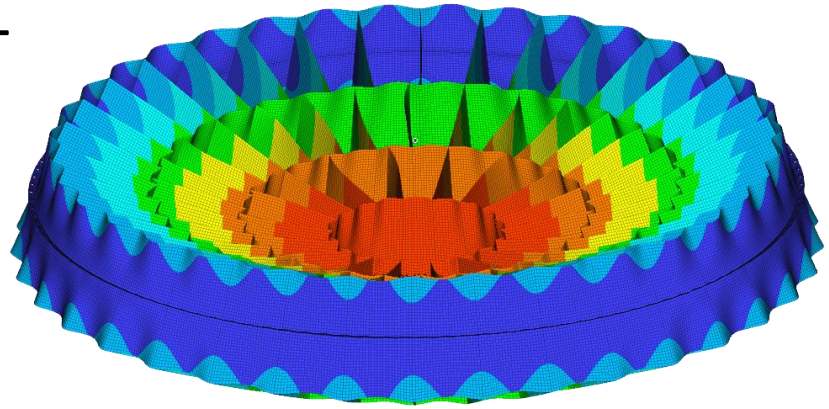
* rotations are about module center of gravity/area

- Pathway to 0.1” (10x)
  - Install mirror with precision hexapods
  - Bond flexures to Module Support Structure



MSS – Gravity Release

- Modules are integrated under 1 g loading but operate in zero g
  - Module Support Structure sags as modules are integrated
  - Moves the focal points of the modules

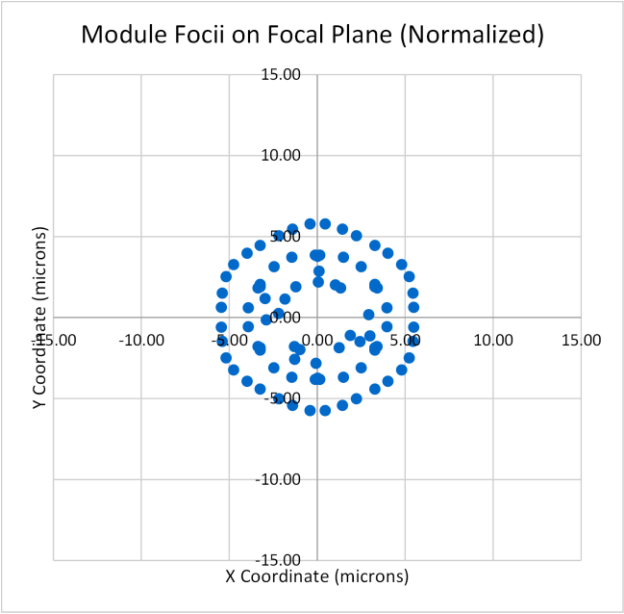


Maximum gravity sag 17 µm

Gravity release
0.5"
(0.17 analy)

Gravity release
0.05"

- Pathway to 0.05” (3.4x)
  - Thicken Module Support Structure
  - Compensate for gravity release during integration



Conclusions

- Designed and analyzed a 5” Mirror Assembly
  - Error budget can be met with good engineering
- Error budget adapted to X-Ray Surveyor 0.5” proposed requirement
- Modular approach to X-Ray Surveyor Mirror Assembly presents unique challenges beyond fabrication and mounting of mirror segments
  - Thermal distortion
  - Moisture desorption
  - Gravity release
  - Module co-alignment
- Full-shell approach has system level advantages
  - What if you could leverage these advantages while still using segmented mirrors…