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Fabrication of a lightweight CTE matched optical structure from Be/BeO Metal Matrix Composite

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Why X-Ray Telescopes

- To enable new discoveries in astrophysics by building lightweight high angular resolution X-ray optics
- Goal to achieve high resolution of Chandra with mass/cost of Suzaku
  - Low Mass- 50% Glass and 50% Structure
  - High Resolution
    - Near term - 5" to 10”
    - Long term < 1”
  - Large mirror area required for modest effective collecting area
    - 160 m^2 of mirror area required for 1.0 m^2 of effective area at 1.0 keV
- Science was identified as high priority by the Decadal Survey
- Technology scalable for any mission size
  - Sounding rocket (OGRE), Explorer (WHIMeX), Flagship (Athena)

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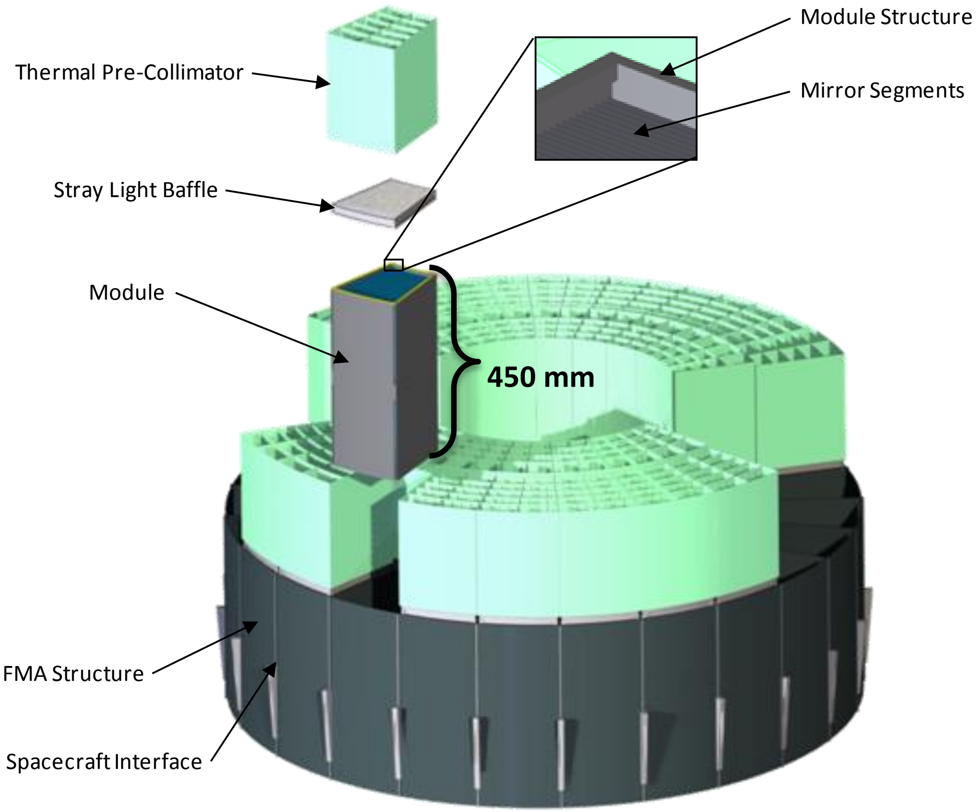
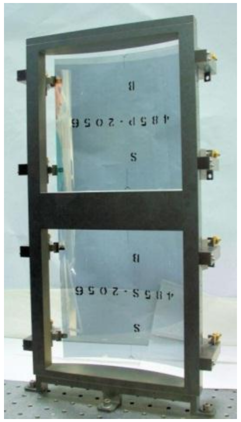
FMA and Module Overview

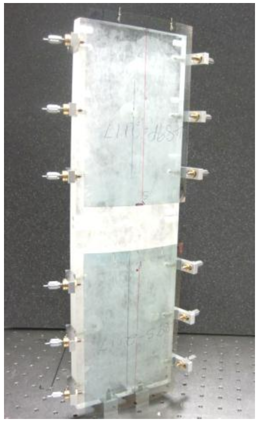
- Flight Mirror Assembly (FMA) holds dozens of modules
- Module holds hundreds of mirror segments
- Modular construction scalable to various mission sizes and objectives



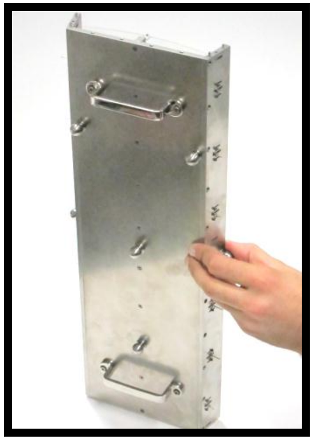
NGXO Technology Development Modules



TDM 1



TDM 2



TDM 3-8

TDM 9-10

Flight-like module

- TDM progressing from a breadboard platform using Kovar to a lightweight flight-like module
- TDM9 is a bridge between TDM5 and a flight-like TRL6 demonstration module
  - Number of mirrors
  - Axial size
  - Structural Mass

Material Options

Material	Density (kg/m^3)	Young's Modulus (GPa)	Specific Stiffness ($10^6 m^2/s^2$)	CTE (ppm/°C)	CTE Mismatch Error (arc-sec HPD)
M55J/954-3 CFRP	1688	104	62	-0.23	9.8
AF45 Glass	2720	66	24	4.18	3.2
Alloy 42 (Fe Ni Alloy)	8110	145	18	4.48	2.7
TiSiC MMC	3930	200	51	5.90	0.6
D263 Glass	2510	73	29	6.28	0.0
T300/E-Glass composite	1700	32	19	6.28	0.0
Custom Fe Ni Alloy	8359	138	17	6.28	0.0
E-60 Beryllium MMC	2513	331	131	6.68	0.4
Kovar F15 (Fe Ni alloy)	8359	138	17	6.67	0.6
Ti6Al4V Titanium	4430	114	26	8.88	3.9
410 Series Stainless Steel	7800	200	26	9.90	5.4
Beryllium S-200FH	1850	303	164	11.4	7.7
Aluminum 6061-T6	2700	69	26	22.6	24.5

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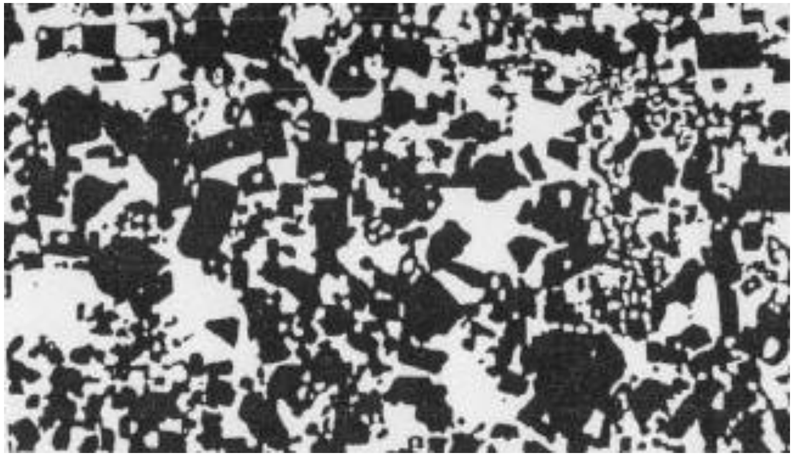
Kovar to E-60 Be/BeO Material Comparison

- Kovar 15 has been the baseline material
  - CTE close to D263 Glass
  - Low cost material
  - Easy to machine
  - But it is very heavy

- E-60 Composite Material
  - CTE close to the D263 glass
  - High Specific Stiffness
  - High thermal conductivity
  - Low density meets mass budget

E- Material Be/BeO Metal Matrix Composite

- E-Material is a Beryllium metal matrix composites that consists of a fine single crystal Beryllium Oxide(BeO) platelet surrounded by a continuous Beryllium(Be) matrix.
- The volume fraction of the BeO in the matrix can be altered, 20-60%, to tailor the thermal and mechanical properties
- Machining techniques
  - EDM
    - Wire and plunge
  - Diamond abrasive grinding
  - PCD machining



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E-60 Background

- E-Materials have been used extensively in low CTE thermal management applications
  - Iridium
  - F-16 and F-22 Avionics
- Materion has partnered with NASA to use E-60 as structural material for NGXO
  - Expands usage from electronic packaging to structural applications
  - Independent testing by NASA leads to space qualification of material and new applications

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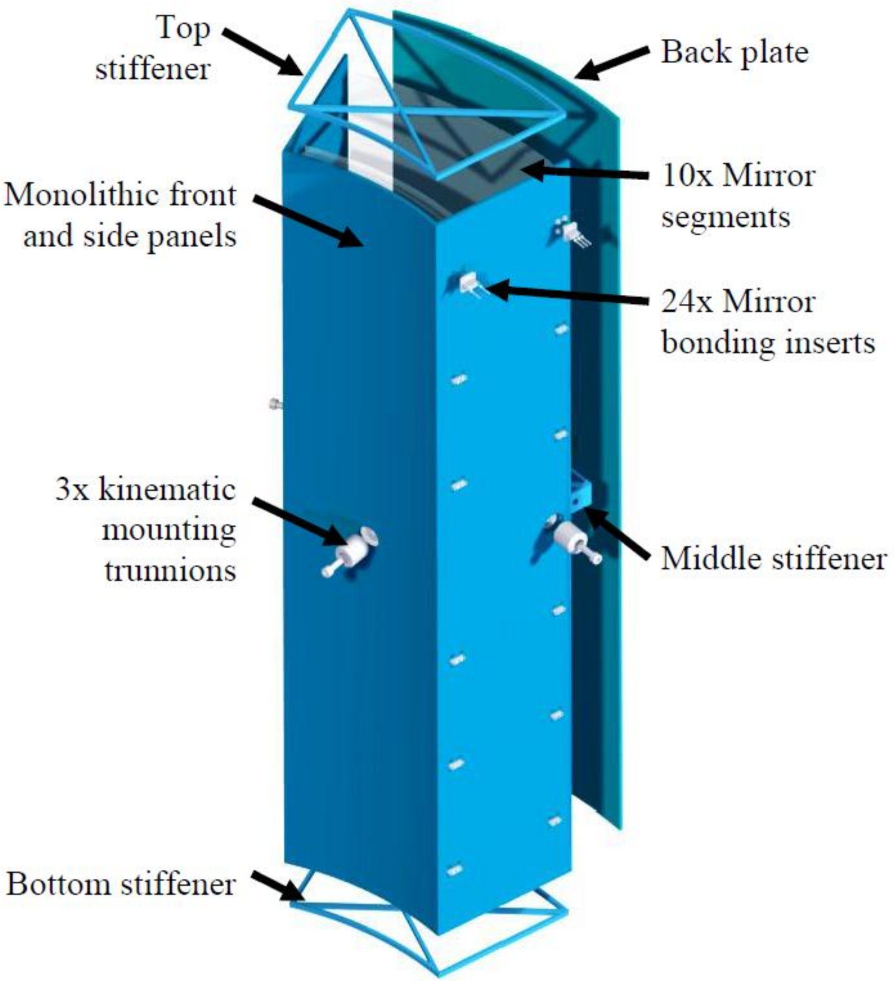
E-60 TDM 9 Design

- E-60 components designed to minimize cost and risk
  - Designed for nesting components to maximize material usage
  - All E-60 parts are 2D flat patterns for wire EDM
  - Only two E-60 parts require ram EDM
- Achieves mirror to structure mass ratio of 1.5 if fully populated
- Bonded together with Hysol 9309.3 epoxy



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TDM 9 Analysis Results

3.2 Analysis of next generation Technology Development Modules

In addition to being larger and lighter than the current TDMs, the next generation will also be significantly stiffer which reduces self-weight distortion, low frequency vibration amplification, and mirror/bond stress. Figure 10 illustrates the 849 Hz first mode of the E-60 TDM structure. The mode falls to 319 Hz when a Kovar structure is assumed. Figure 10 also shows the expected distortion due to gravity in the horizontal X-ray test configuration.

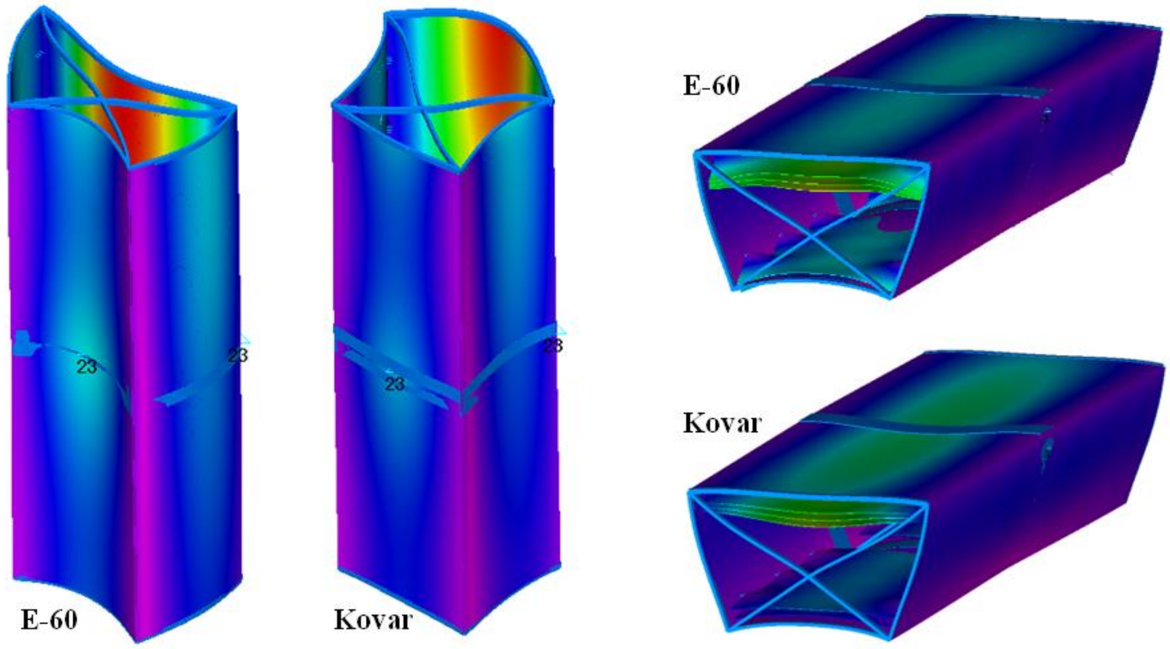

Figure 10. First mode of next generation TDM structure is 849 Hz when fabricated from E-60 and 319 Hz when fabricated from Kovar (left). The gravity distortion figure error in the horizontal X-ray configuration is 2.2 arc-seconds HPD with an E-60 structure and 5.8 arc-seconds HPD with a Kovar structure (right).

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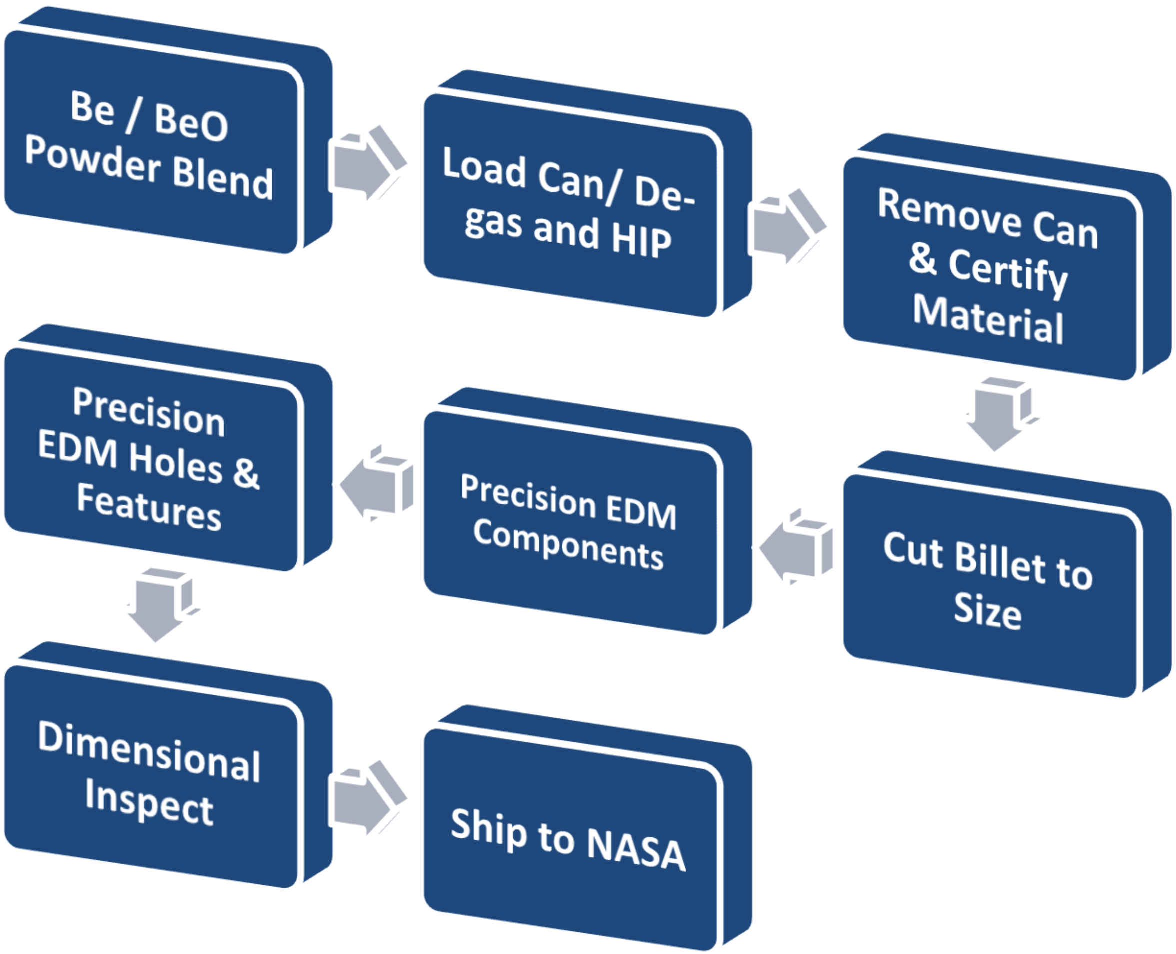
E-60 TDM9 Manufacturing Flow



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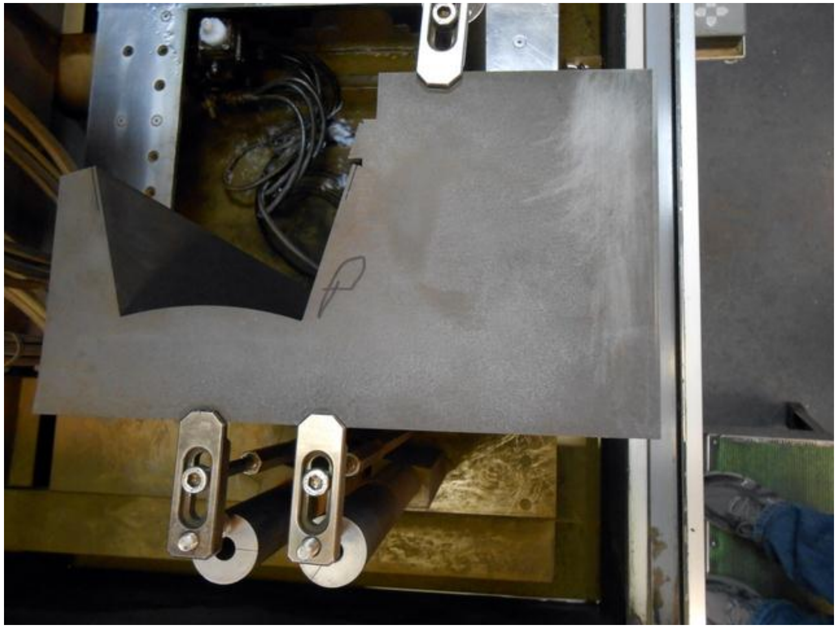
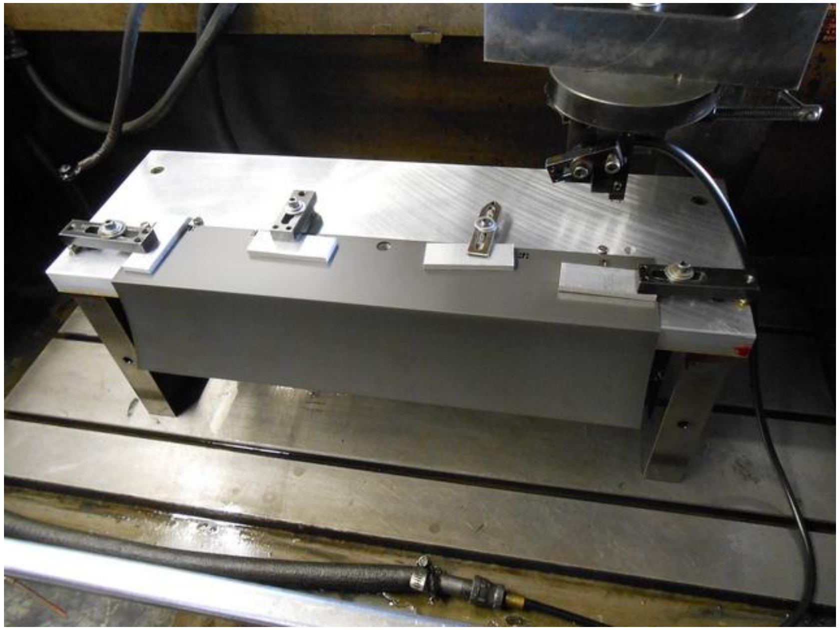
Billet EDM



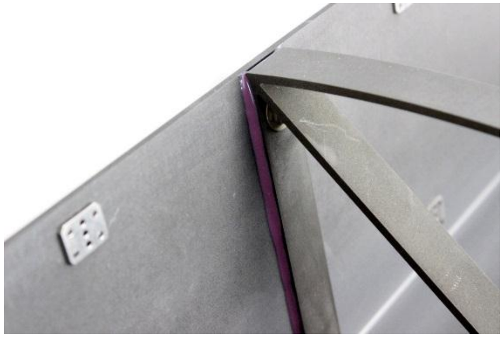
Main Shell EDM Setup
(Wire EDM)



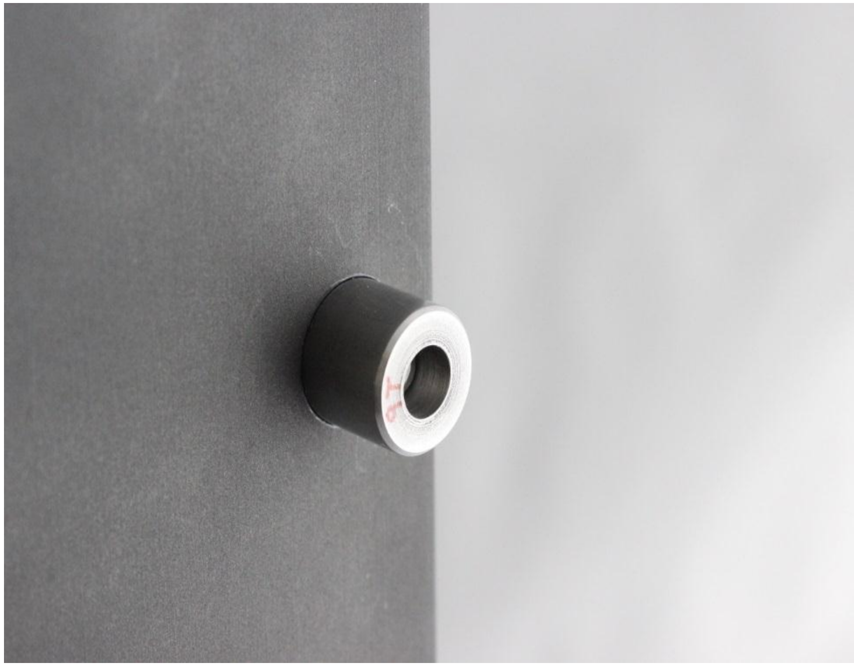
Mounting Feature EDM Setup
(Plunge EDM)

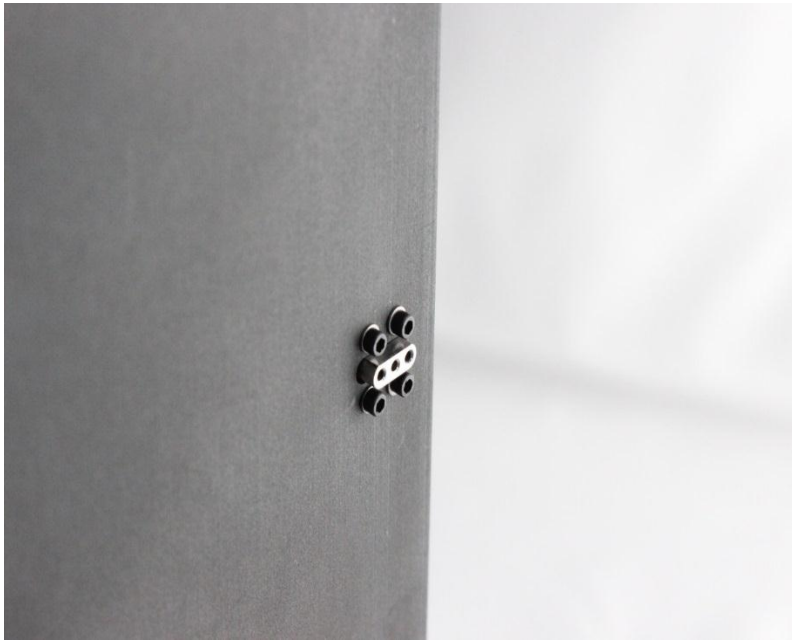
TDM 9 Fabrication

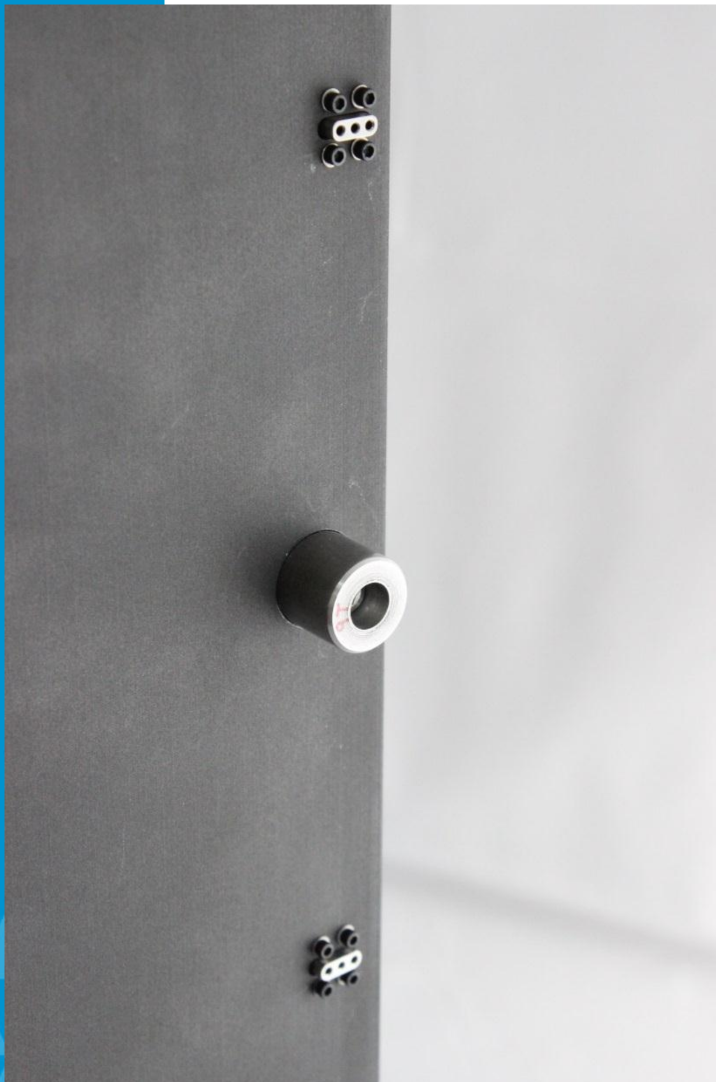
- E-60 block fab
  - CTE ave from 25 C - 100 C was 7.3 PPM/C
  - Instantaneous CTE @ 20 C (based on 2nd order regression analysis was 6.7 PPM/C
- Approx 16 weeks lead time for E-60 billet and another 12 weeks to EDM components
- Approx module cost is $30k-$40k
- EDM lessons learned
  - Sharp external radii issue
  - Wire breaking issues due to height of block, special wire needed
  - The taller the module, the worse the wire bow leading to stiffener fit issue

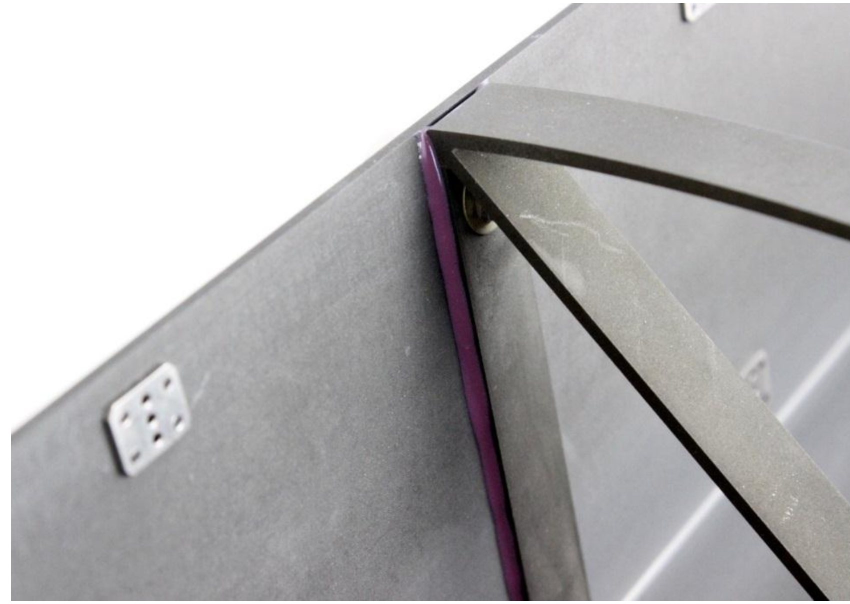


TDM9 Bonded Inserts









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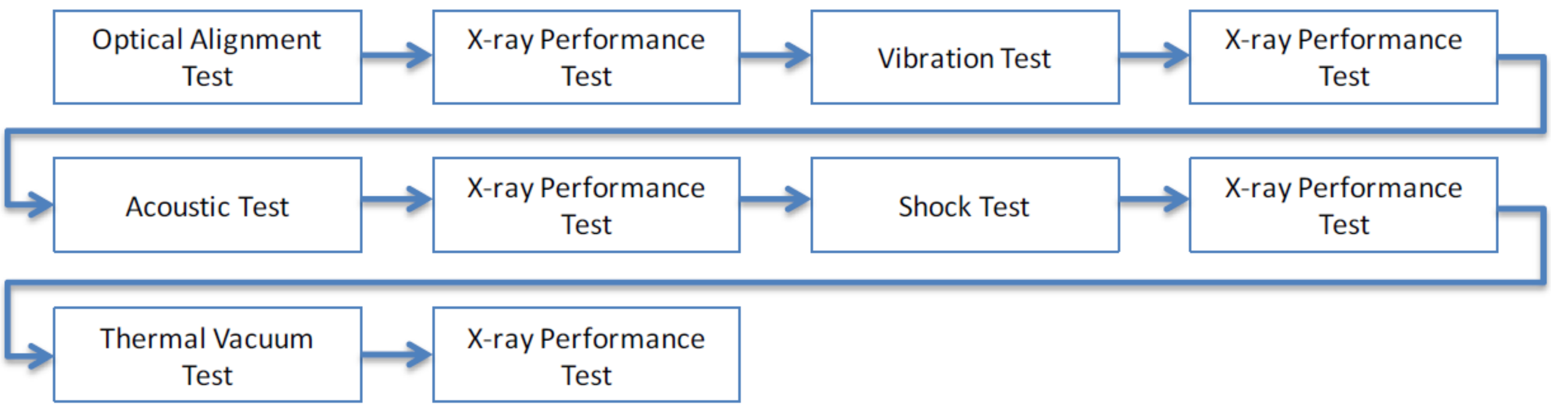
TDM9 Bonded Bulkheads

TDM 9 Test Flow

- Test to generic flight mission requirements
  - 6.8 G rms random vibration
  - 143.3 dB OASPL acoustic
  - 3,000g pyro-shock- Separation Load Test
  - 0°C-40°C thermal vacuum cycling
- Pre and post x-ray performance testing to verify stability



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Conclusion

- E-60 is a viable structural material for X-ray telescope modules
  - CTE very close to D263 glass which minimizes distortion due to thermal loading
  - May be able to modify Be/BeO ratio to make CTE a closer match
  - Low density meets mass target
  - Lots of lessons learned on EDM process
- Future work
  - Test and verify TDM 9 Module
  - Material characterization leading to space certification
  - Mission specific design and testing (eg OGRE)

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