CFE Services

Rib Stiffened Sandwich Panels using Aluminum, Silicon Carbide, and Beryllium for Lightweight Telescope Structures

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Over Arching Goal of SBIR

Reduce the Time and Cost of Deployment of Lightweight Telescopes

- Prior Presentations – Wavefront Coding
- Stretch Goal – Rapid Fabrication of Lightweight Structures from Advanced Materials

Theme…

- How Can I Gain Access to Advanced Materials?
- How Do I Reduce Cost / Schedule without Sacrificing (too) Much Performance?

What Are the Manufacturing Methods?

What Materials?

What Are Some Cost Drivers?

Grouped by α

Which Materials?

	ρ	E	α (20C)	K	Cp
CFRC	1.78	93	0.02	35	800
ULE	2.21	67	0.03	1.31	766
Zerodur	2.53	91	0.05	1.64	821
Super Invar	8.13	148	0.3	10.5	515
Invar 36	8.05	141	1	10.4	515
SiC	3.21	456	2.3	186	680
Pyrex	2.23	63	3.3	1.13	1050
Kovar	8.35	138	5	17	439
Titanium	4.43	215	8.8	7.3	560
Beryllium	1.85	287	11.3	216	1925
SS 304	8.00	193	14.7	16.2	500

Handbook of Optomechanical Engineering, Ahmad
Opto-mechanical Systems Design, Yoder

General Processing Methodologies

CFRC

- Mandrel / Mold
- Unitape Layup
- Cure
- Machine
- Bond

SiC

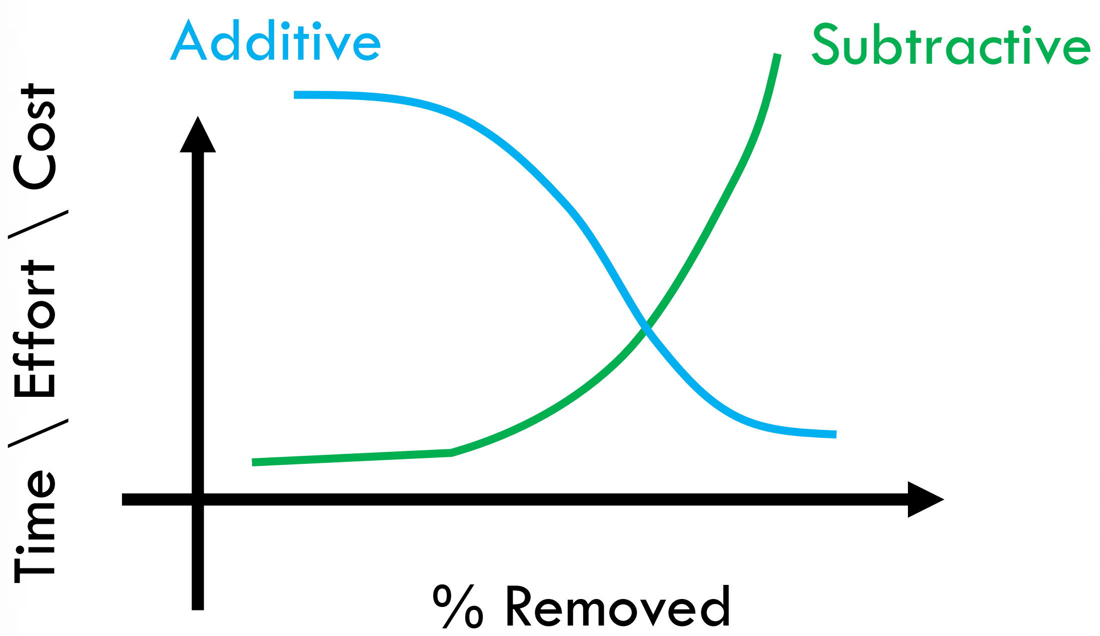
- Mandrel / Mold
- Convert
  - Greenbody + Fire
  - Deposit
  - Infiltrate
- Machine
- Braze / Bond

Beryllium

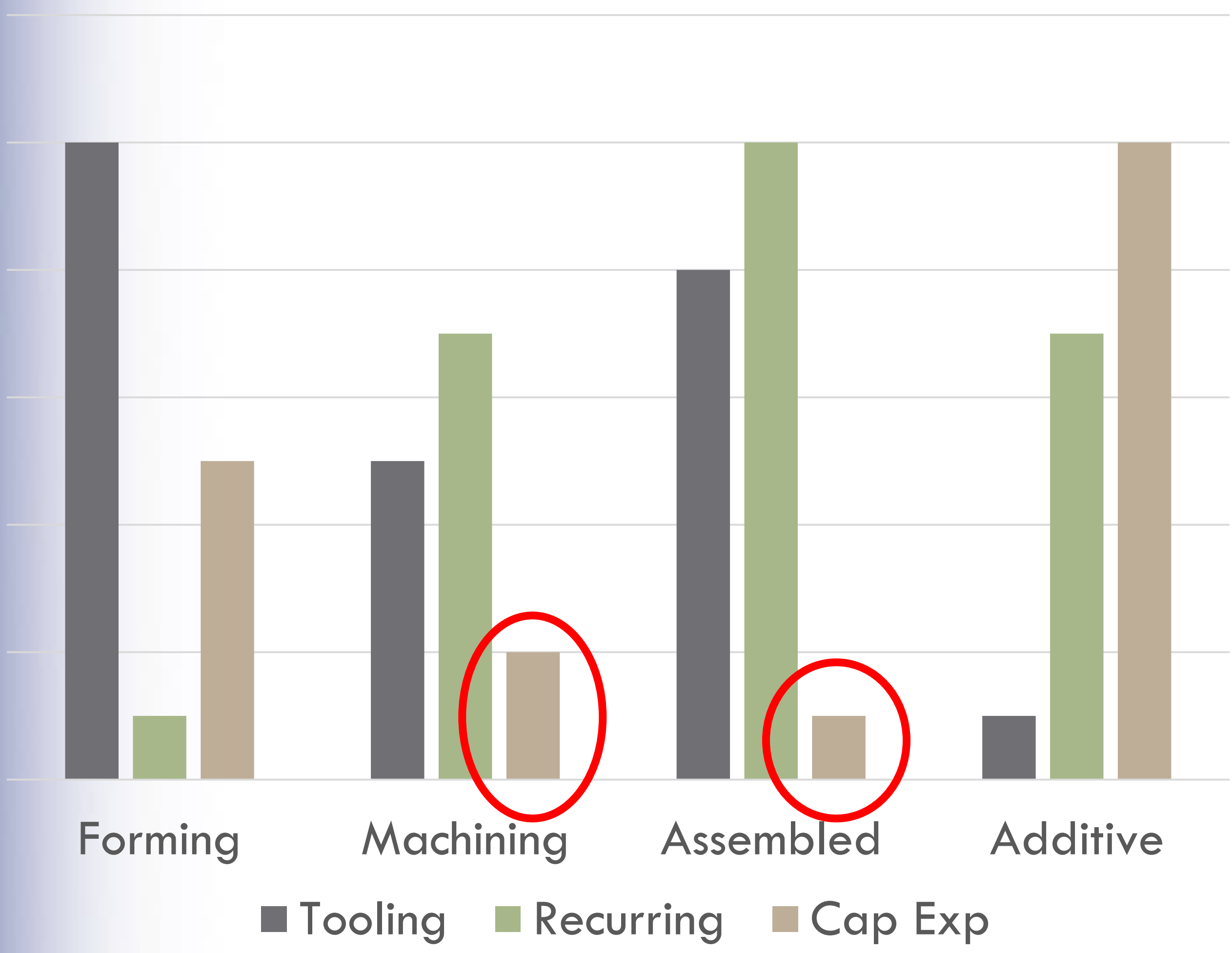
- HIP / Treat
- Machine
- Braze / Bond

Intuitive Trade-Off

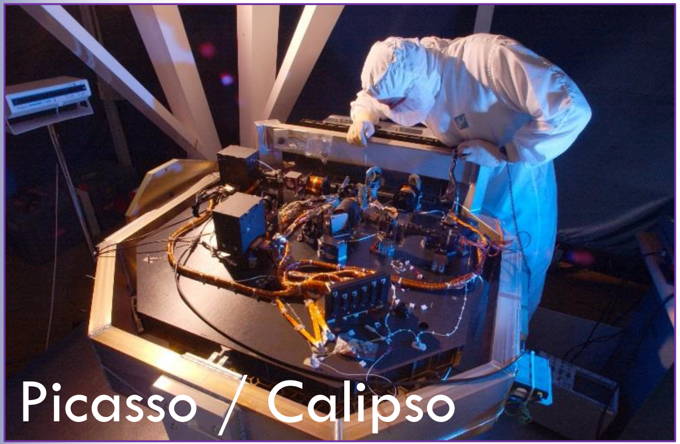
- Lots of Enthusiasm Regarding 3D Printing
  - Can (Should?) Advanced Materials Be 3D Printed?

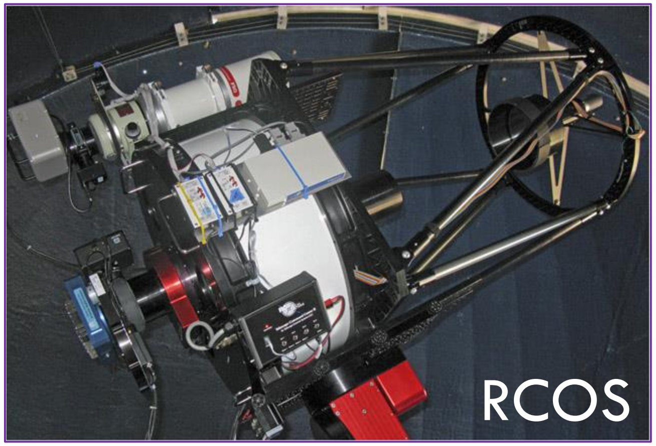


Cost Structure

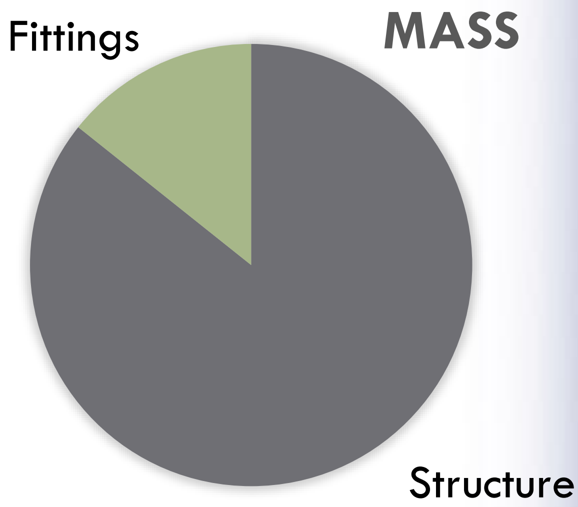


Inspired by Assembled CFRC



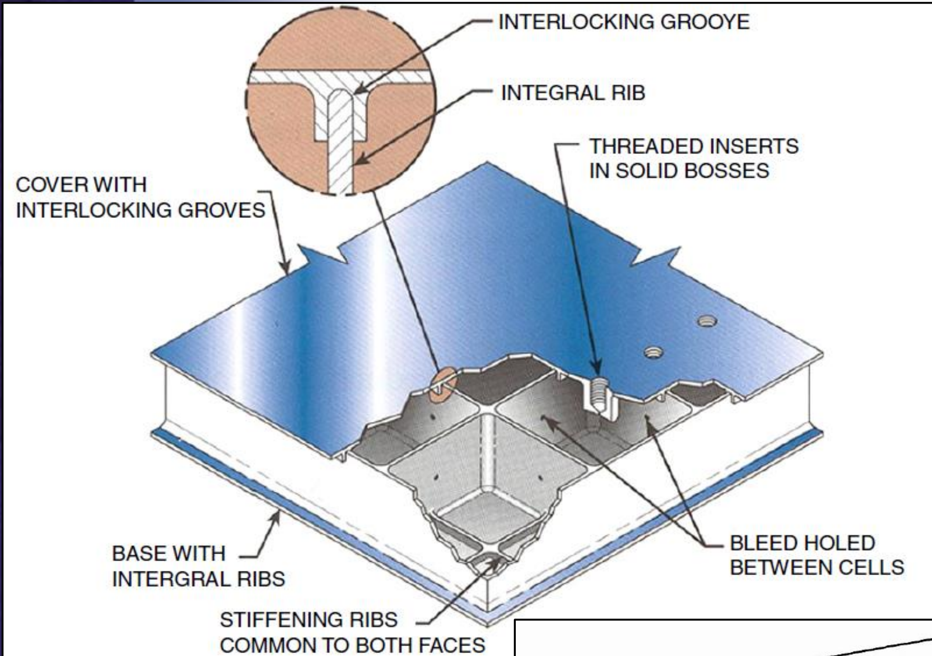


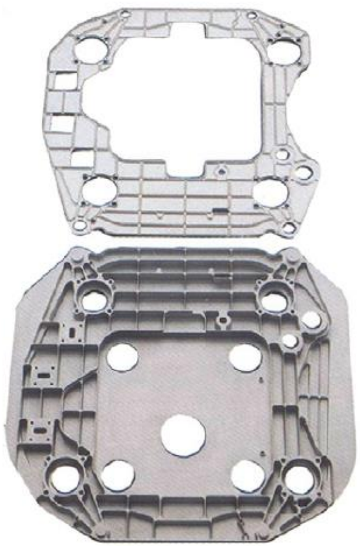
- Tube / Truss
- Panel
  - Honeycomb
  - Rib Stiffened
    - Open Back
    - Closed Back

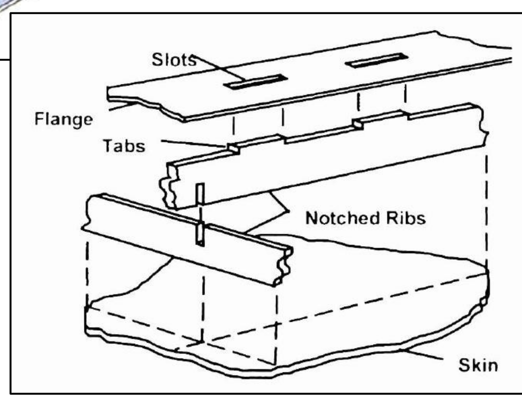


Personal Bias: Tend to Favor Panel to Reduce Fitting Mass

Rib Stiffened Structure Examples







Krumweide, 1991

Pandurangan, 2007

Catanzaro, 2000

Manufacturing Process Concept

Create Flat Stock	• Practical Thicknesses Likely Known • Inventoried, Optimize for Manufacturing
Design Structure / Fittings	• Mortise / Tenon • Metallic Threaded Fittings
Cut Flat Stock	• Waterjet • Wire EDM
Assemble	• EA9394, 3M 2216 (et al. adhesives) • Tooling for Precision Fittings

Stiffness / Density Suggests Unique Design

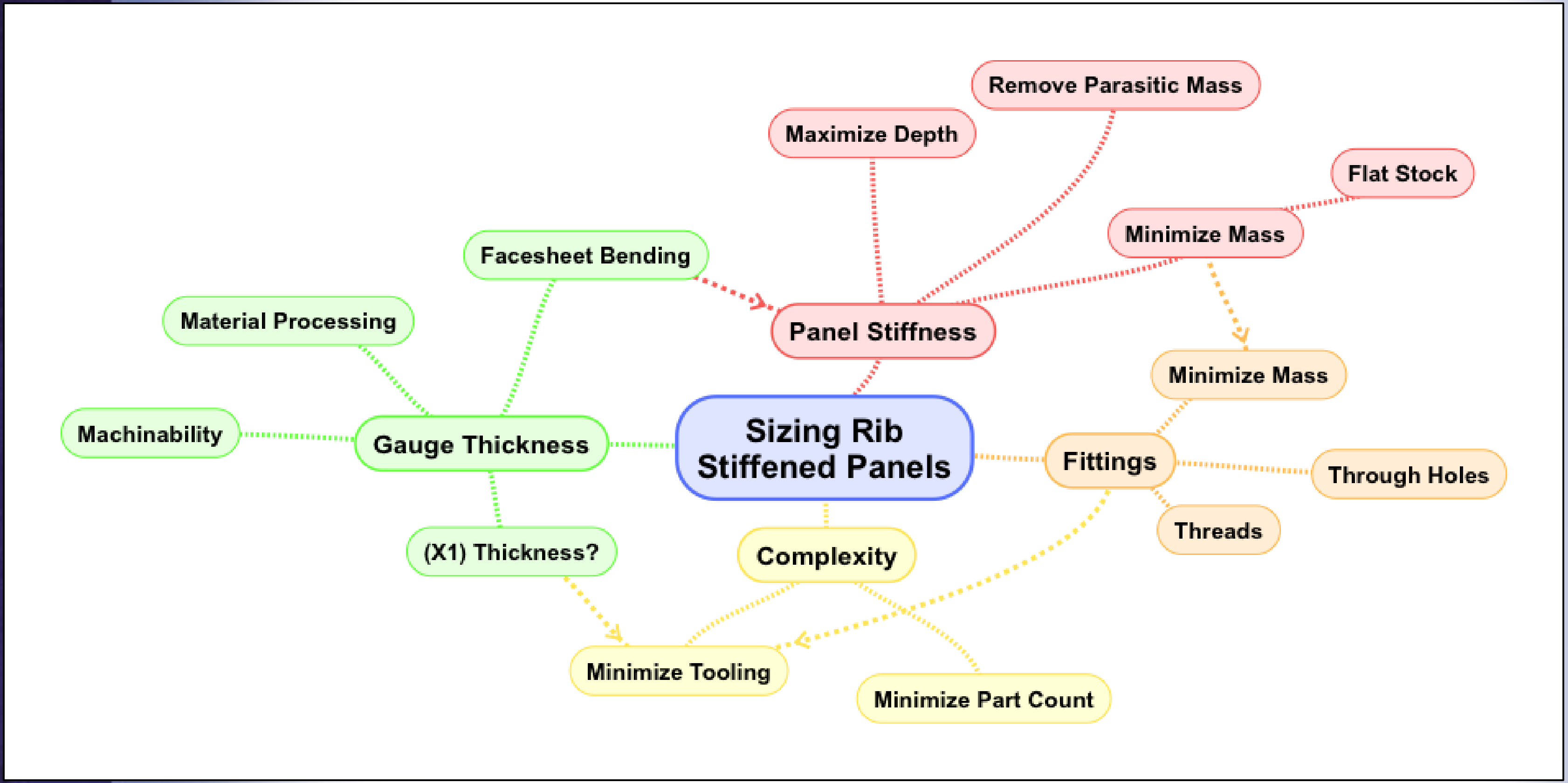
	ρ	E	$(E/\rho)^{1/2}$	α (20C)
CFRC	1.78	93	7.2	0.02
Invar 36	8.05	141	4.2	1
SiC	3.21	456	11.9	2.3
Titanium	4.43	215	7.0	8.8
Beryllium	1.85	287	12.5	11.3

X8 Variation

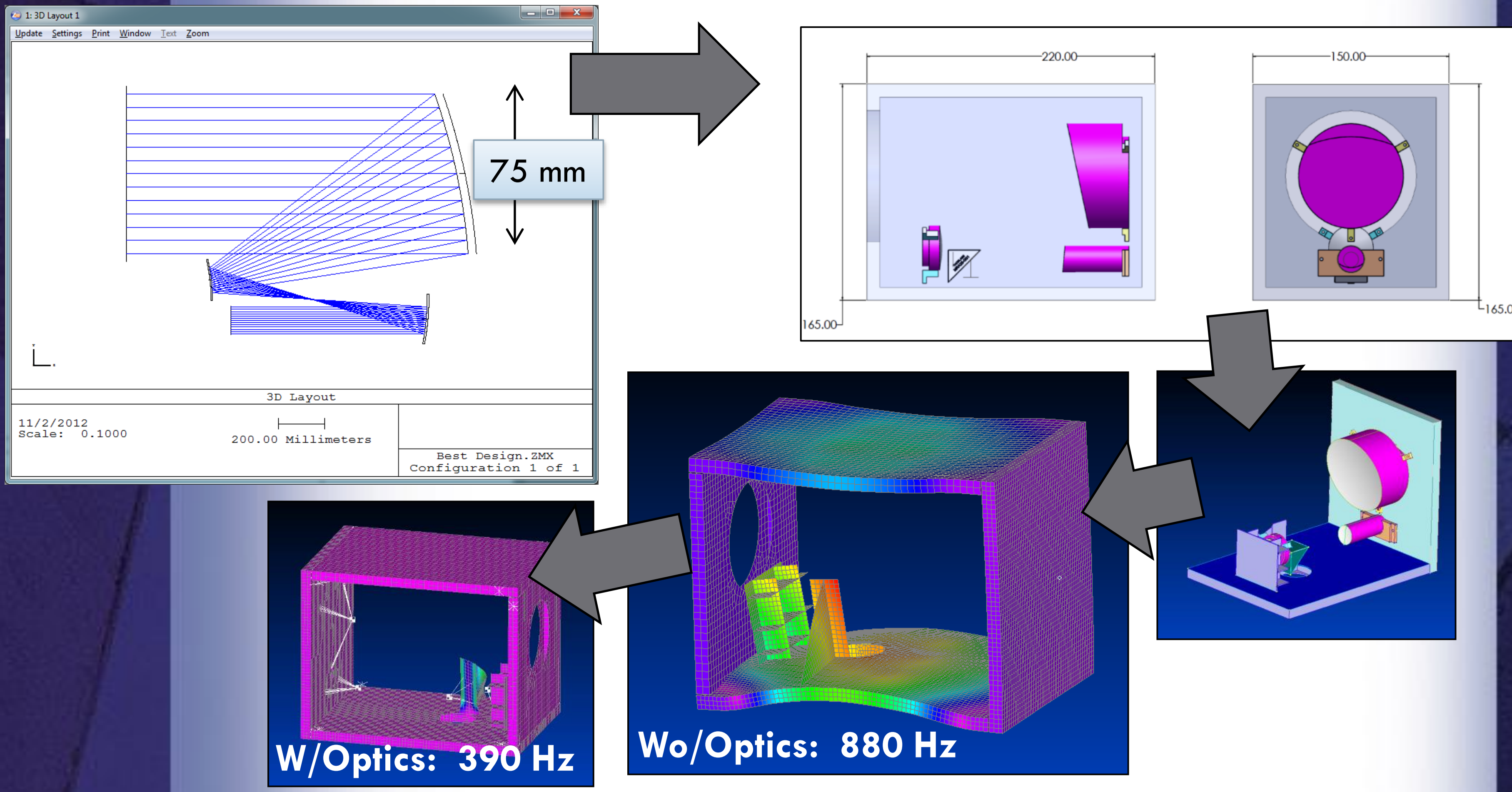
X5 Variation

- How Could These Result in Similar Designs?

Optimize Sizing



Develop Guidelines with Reference Design



- Three Mirror Telescope Studied Previously

Practical Sizing of Structure

- Frequency Goal > 500 Hz (System)
- Mass
  - Attempt Best Lightweighting of Panels
  - Overall Mass Driven by Existing Optics
- Conclusion
  - Panels Should be Approx. f_0 = 1000 Hz
  - Facesheet Approx. Thick = 1 mm

Is This Optimal or
Just a Guess?

Rib Density vs. Depth

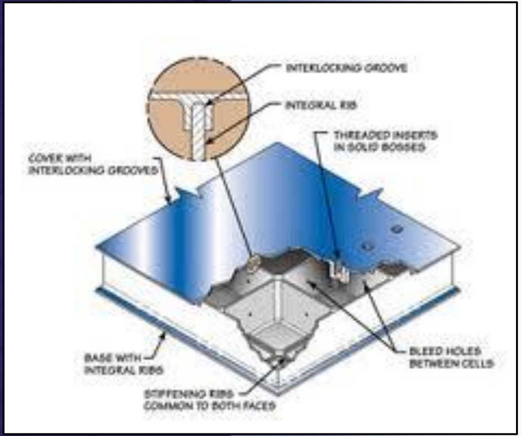
- Assume a Square Rib Pattern
  - Ribs Likely Need to be As Stiff as Facesheet
  - Stiffness Tied to Moment of Inertia

$$I = \frac{1}{12} b \cdot h^3$$

$$\frac{1}{12} t_{rib} \cdot h^3 = I_{rib} = 2 \cdot I_{cell} = 2 \cdot \frac{1}{12} R \cdot t_{face}{}^3$$

$$t_{rib} \cdot h^3 = 2R \cdot t_{face}{}^3 \rightarrow R = \frac{t_{rib}}{2} \cdot \left(\frac{h}{t_{face}} \right)^3$$

$$\text{for } \; t_{rib} = t_{face} \rightarrow R = \frac{h^3}{2t^2}$$



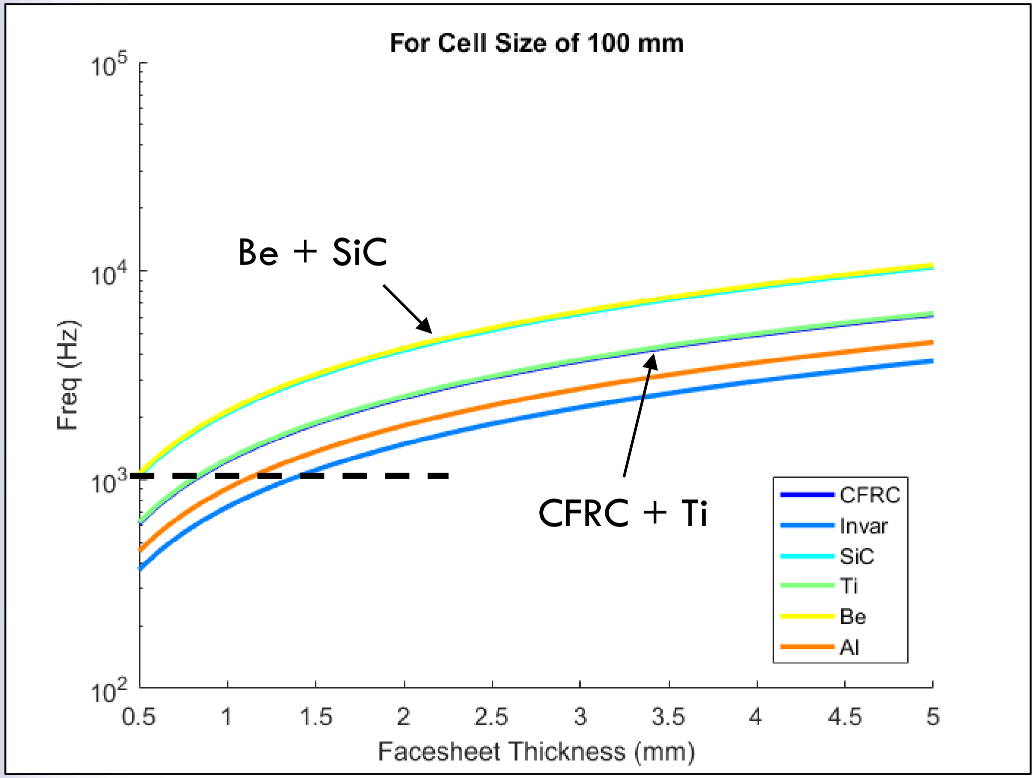
Need to Pick Gauge Thickness

- Gauge Thickness affects Frequency
  - Effect on Rib Stiffness Minimal
  - Effect on Facesheet Thickness Dramatic
- Imagine Each Cell is a Plate with Fixed Edges

$$f_{cell} = \frac{\pi}{1.5}\sqrt{\frac{D}{\gamma}\left(\frac{3}{a^4} + \frac{2}{a^2 b^2} + \frac{3}{b^4}\right)}, \gamma = \frac{A}{m} = \rho \cdot t_{facesheet}$$

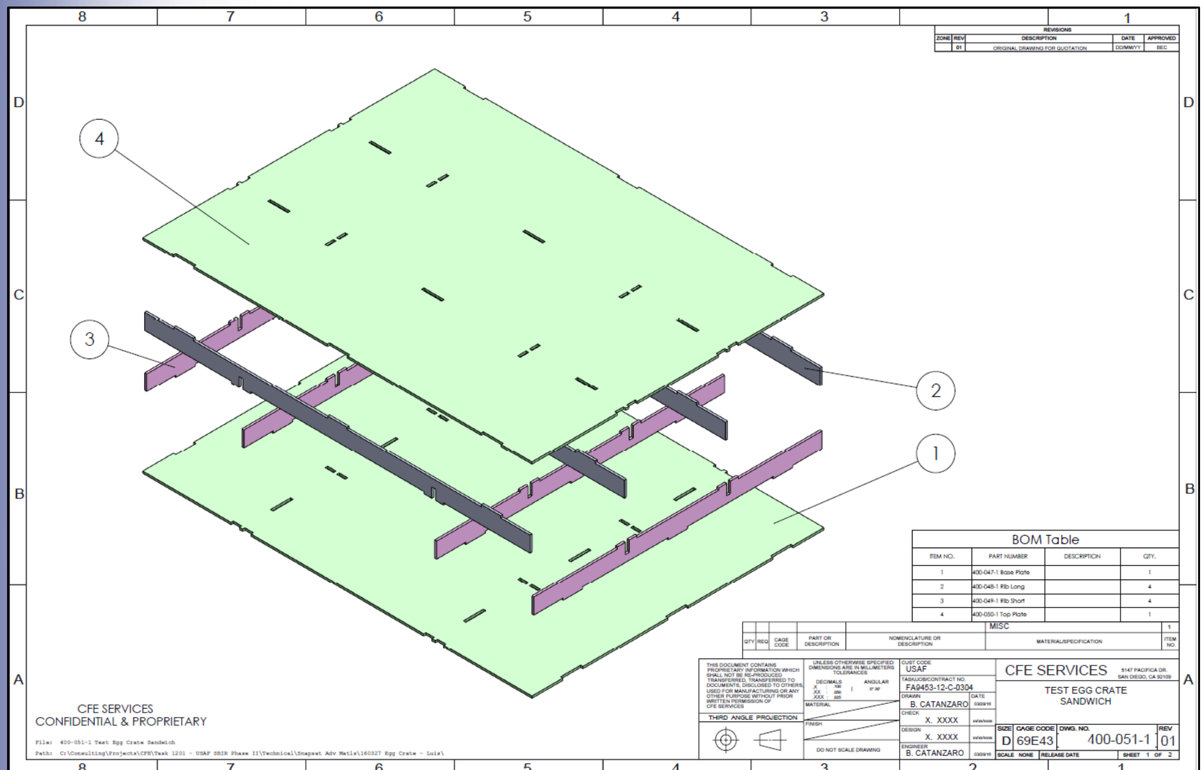
$$a = b = R \rightarrow f_{cell} = \frac{2\pi}{1.5R^2}\sqrt{2\frac{D}{\gamma}}$$

Gauge Thickness vs. Material



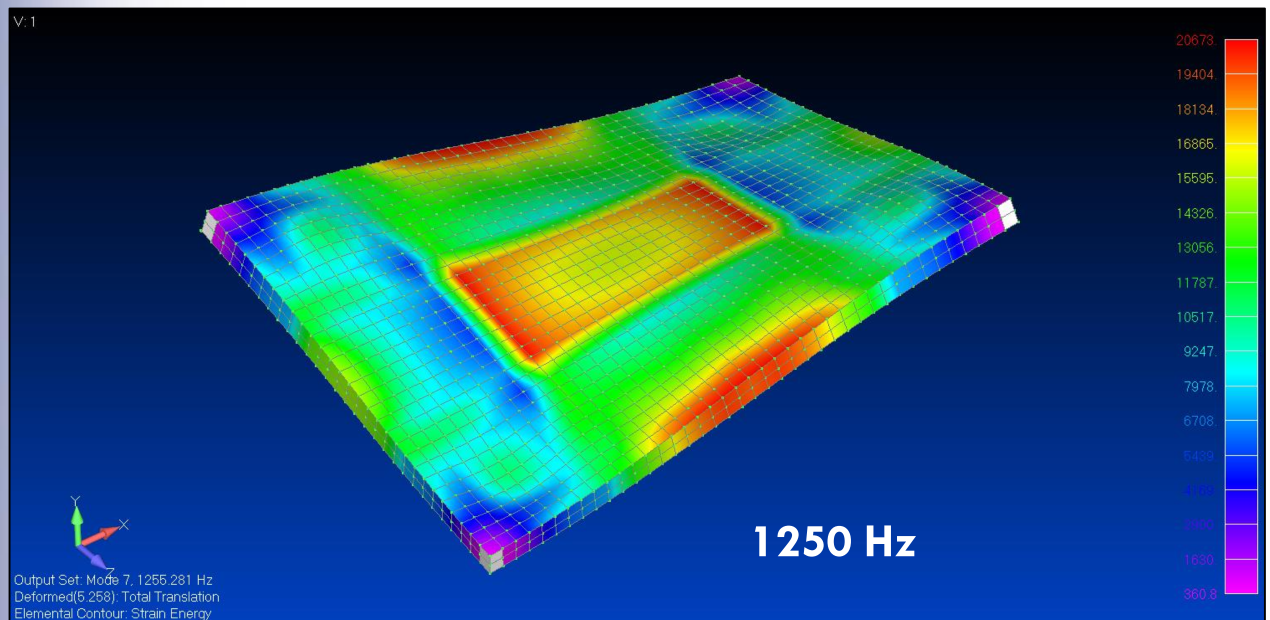
- Aluminum to 1 kHz at 1 mm
- Be + SiC at 1mm Exceed 1kHz… too thick!

Sandwich Panel Reference



- Size: 150 mm x 200 mm
- Goal: f = 1000 Hz with Aluminum
- Optimize Design for Adv. Materials

Aluminum Design



$$f_{panel} = \frac{\pi}{2}\sqrt{\frac{D}{\gamma}\left(\frac{2.08}{a^2 b^2}\right)}$$

$$f' = f_{panel}\sqrt{\frac{m}{m + m_{parasitic}}}$$

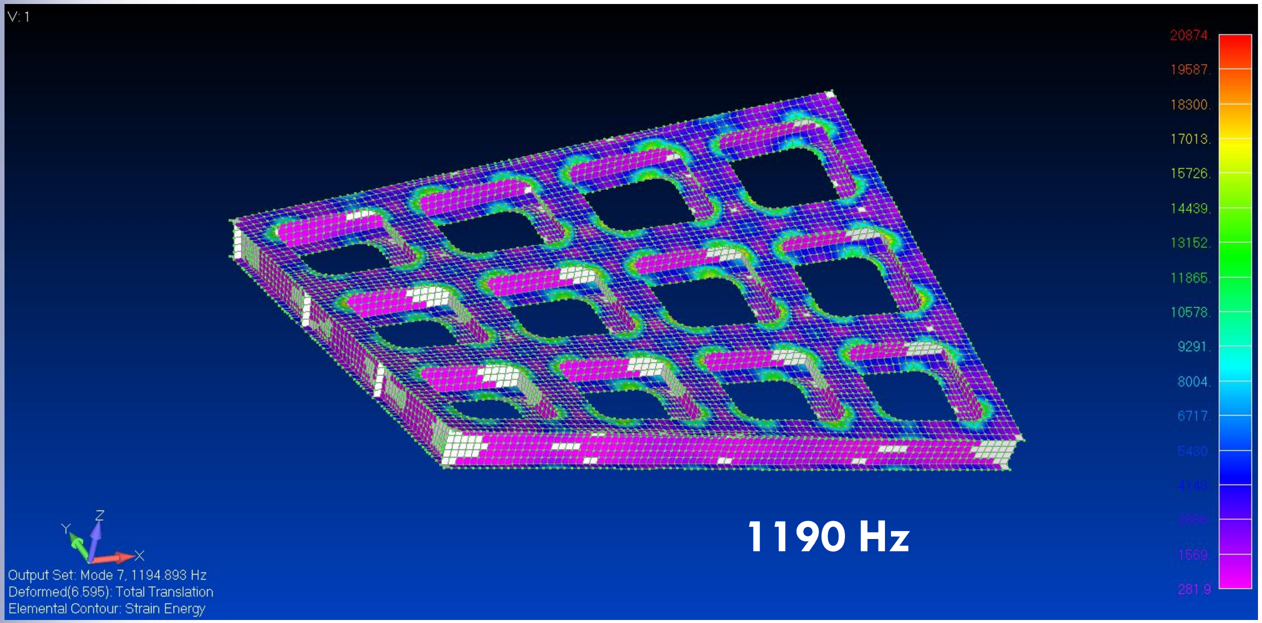
f = 1300 Hz

FEA Results

Material	Free-Free 1st Freq.	Mass
Aluminum	1250 Hz	0.19 kg
Silicon Carbide	3130 Hz	0.23 kg
Beryllium	2880 Hz	0.13 kg
Invar	1070 Hz	0.58 kg

- Sandwich Structure Far Exceeds Goals for Advanced Materials
- Remove Unnecessary Mass

Lightweighted Sandwich (SiC)



- Similar Performance with Be

FEA Results

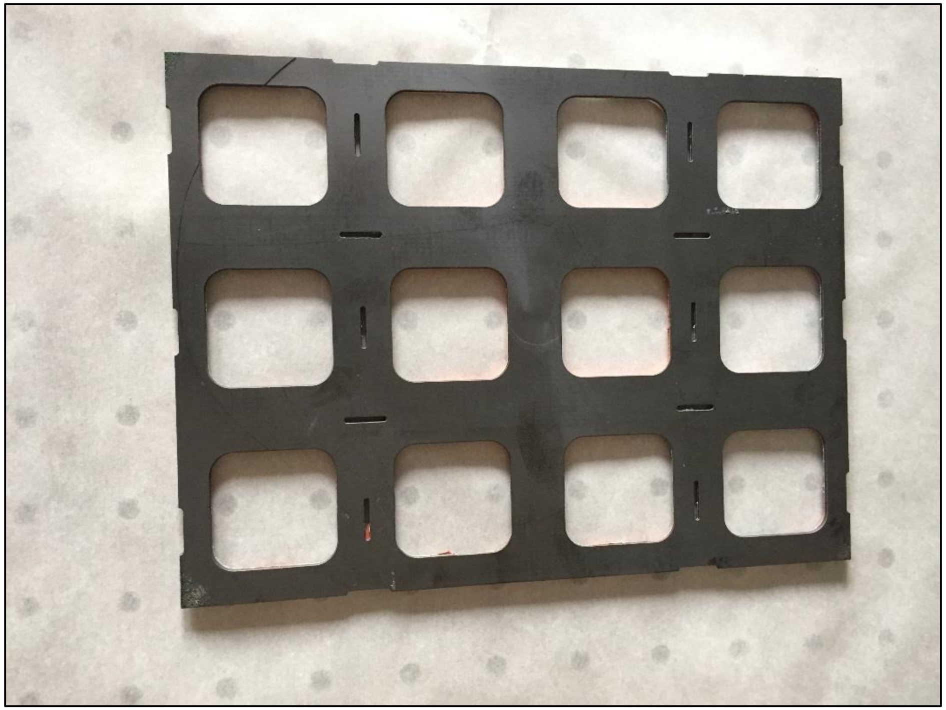
Material	Free-Free 1st Freq.	Mass
Aluminum	500 Hz	0.13 kg
Silicon Carbide	1190 Hz	0.15 kg
Beryllium	1050 Hz	0.089 kg
Invar	420 Hz	0.39 kg

Manufacturing Panels

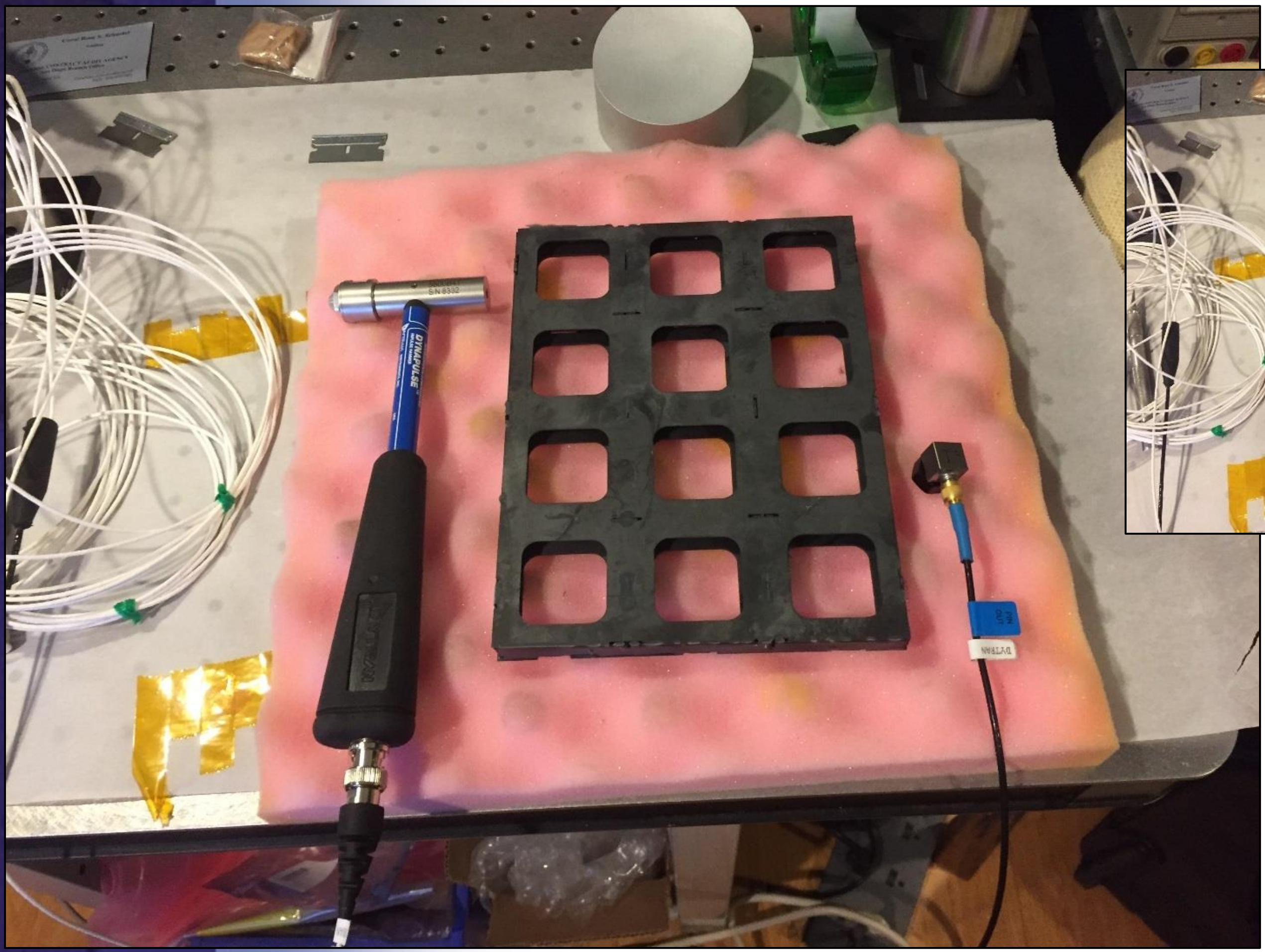
- **Aluminum, Invar**
  - Purchased Commercial Flat Stock
  - Industrial Waterjet — CalWaterjet
  - Bonded 3M 2216
- **Beryllium (SR200)**
  - Materion:
    - Cut from Vacuum Hot Pressed
    - Rolled to Uniform Properties
    - Heat Treat / Test
    - Grind / Trim
  - Precision Waterjet — WessDel
  - Bond 3M 2216
- **Silicon Carbide**
  - CVC Deposition — Fantom
  - Grind — Chand
  - Optimized Waterjet — Bear
  - Bond 3M 2216

Challenges in Waterjet

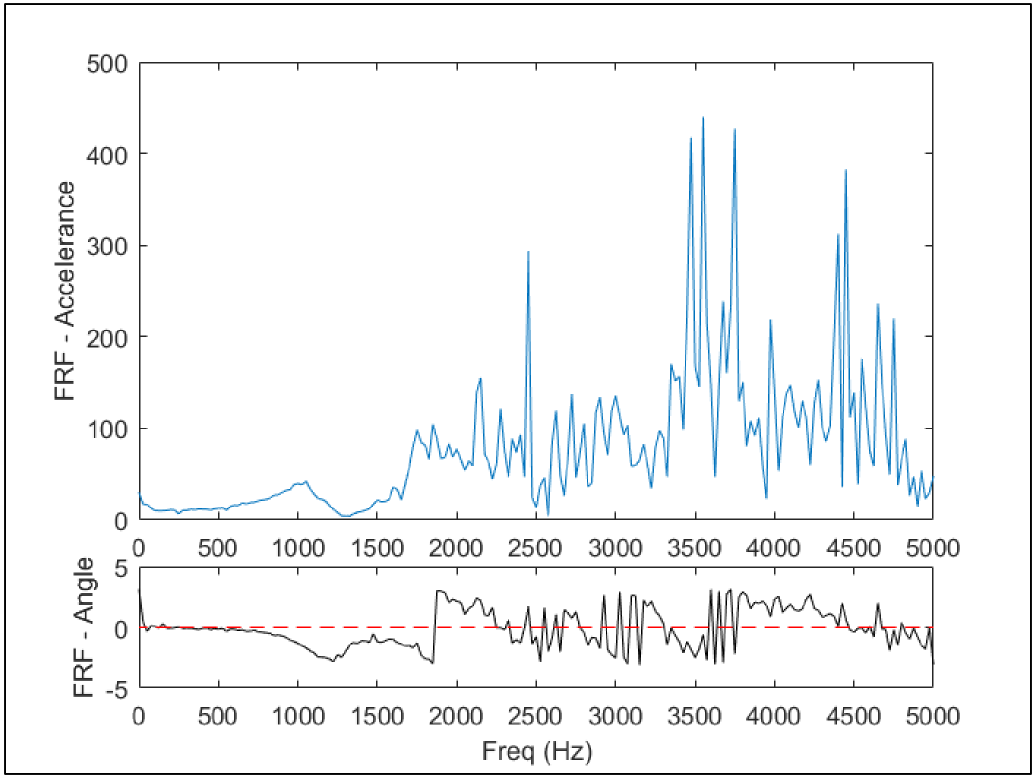
- Silicon Carbide Robust to Grinding
- Waterjet Processing Left Cracks



Stiffness Testing

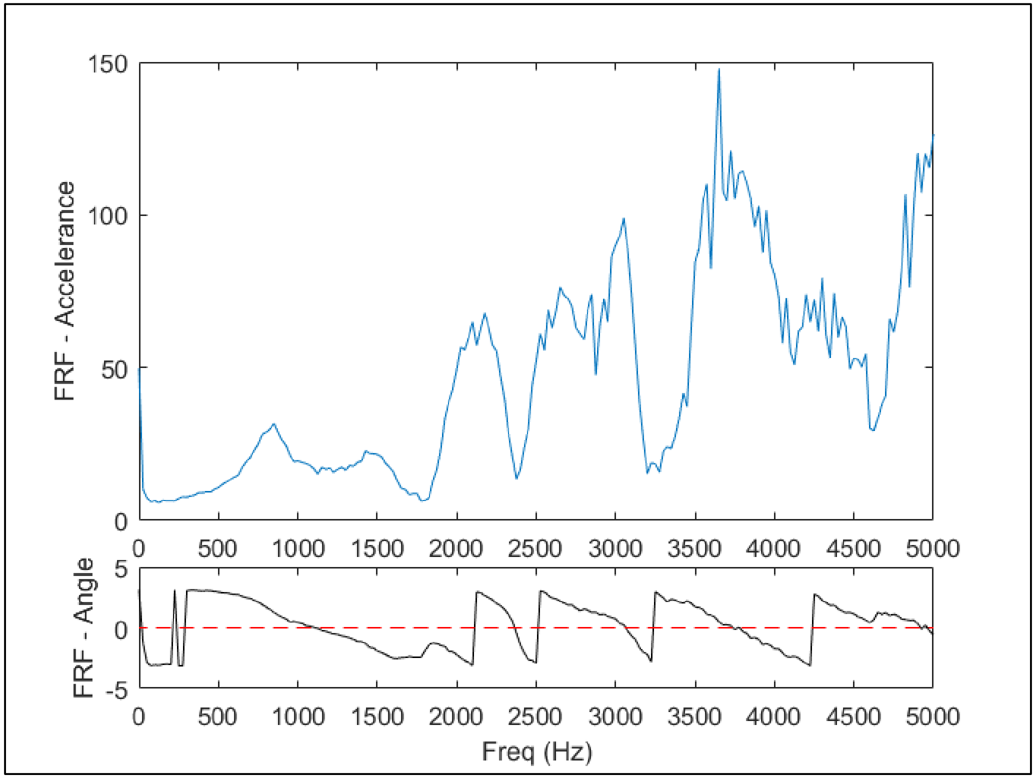


Frequency Response Function



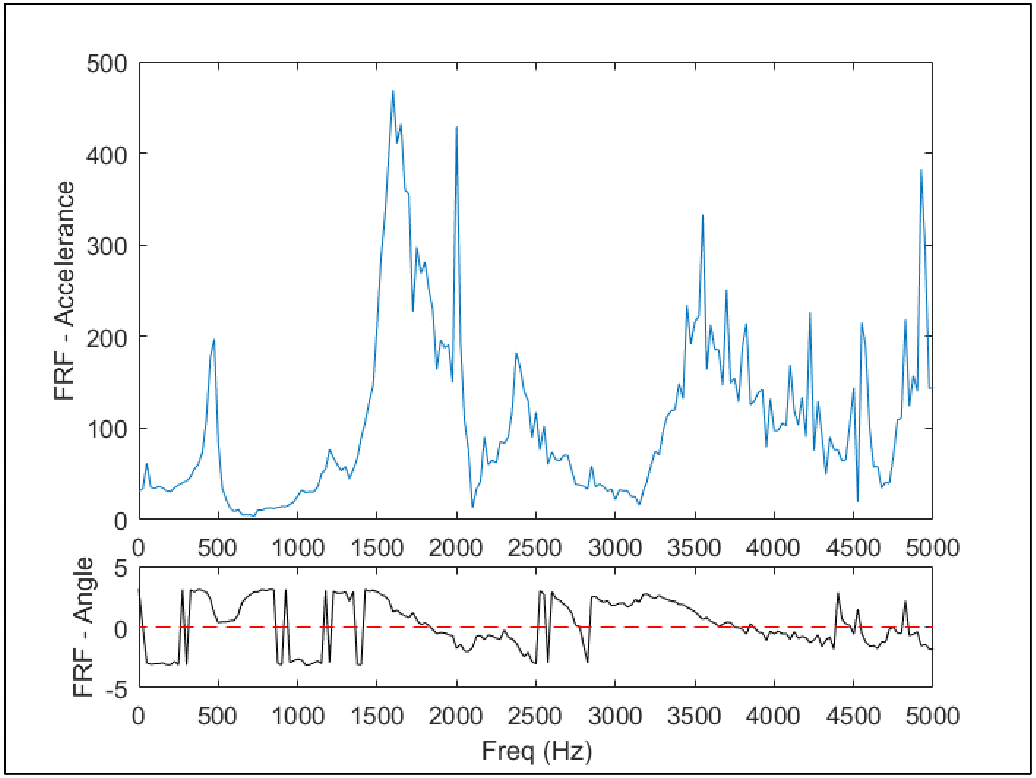
Aluminum Sandwich:1 kHz

FRF / Invar Sandwich



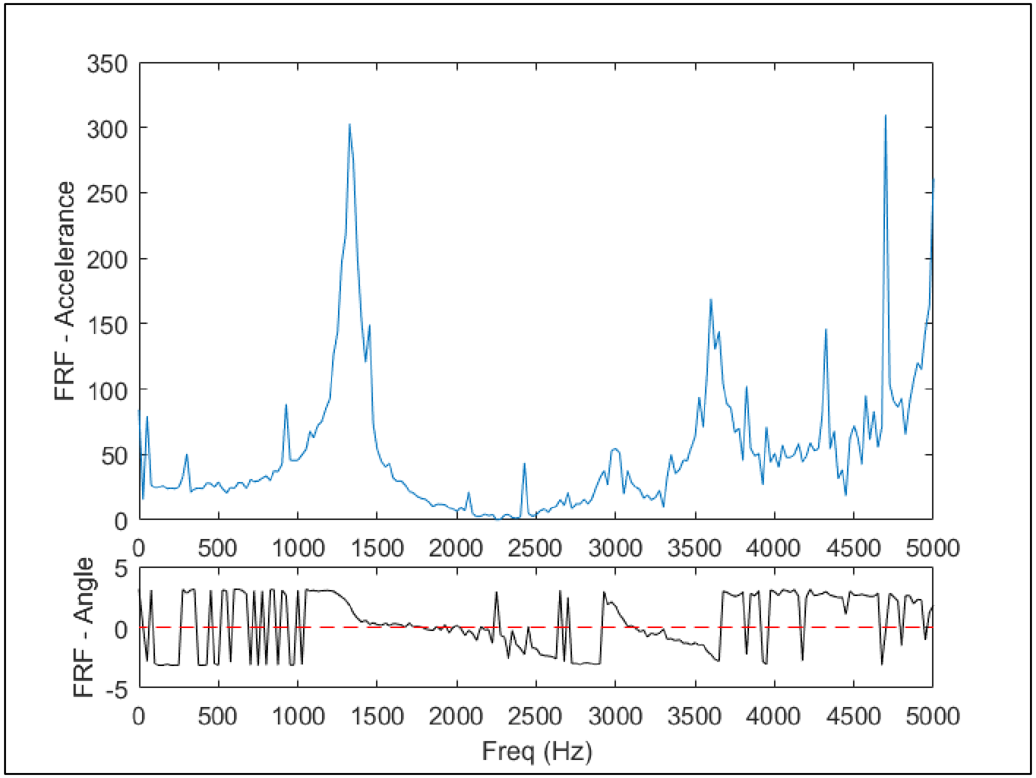
Invar: <900 Hz

FRF / Aluminum Pane



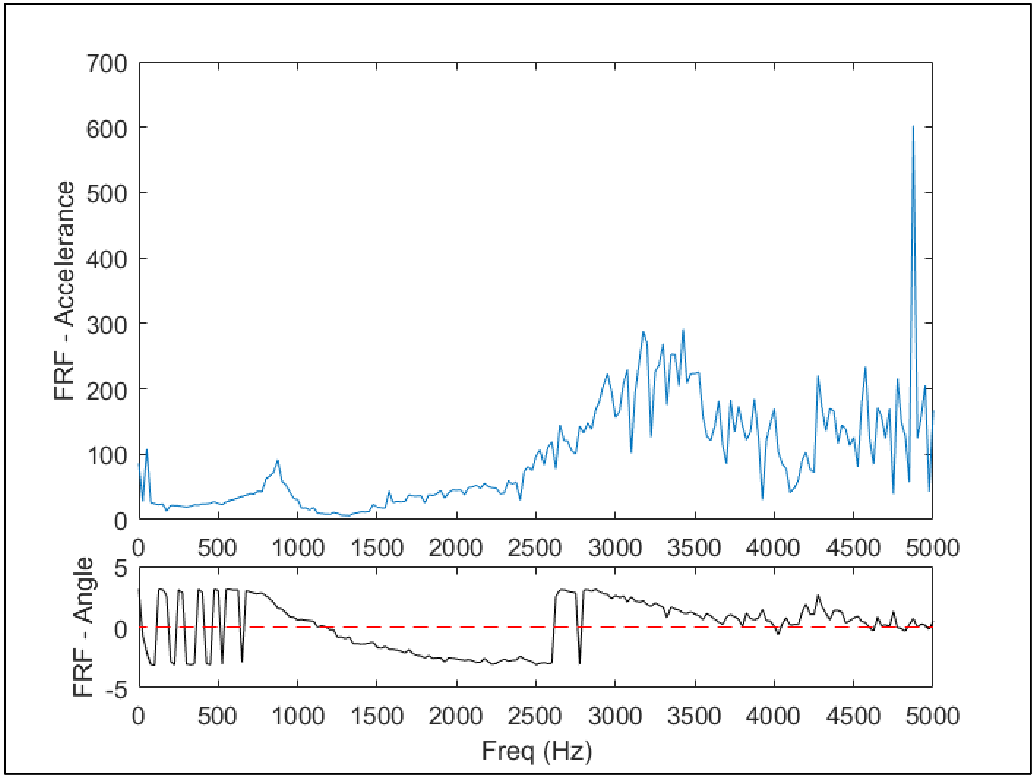
Aluminum Pane: <500 Hz

FRF / Beryllium Pane



Be Pane: 1300 Hz

FRF / Silicon Carbide Pane



SiC: 900 Hz*

*With Cracks

Lessons Learned

- Not Always Easy To Achieve Geometry that Optimizes Specific Stiffness
  – Facesheets for Panels must be Thin
  – Thickness Affects
    - Robustness, Grinding Costs
- Beryllium
  – Material and Processing Straightforward
- Silicon Carbide
  – Process Steps Known but Maturing
  – Material Much More Robust than Advised
- Costs… Just About the Same

Acknowledgements

- Materion
  - Rob Michel / Acquired Material Instantly
- WessDel
  - Rich Bernard / Outstanding Waterjet Processing
- Fantom
  - Fred Styer / Provided Material Instantly
- Bear Machining
  - Blair Stultz / Developed Waterjet Process