CFE Services

Lightweight Stable Optical Structures using Silicon Carbide

B. Catanzaro, November 15, 2017
bcatanza@alumni.caltech.edu

NASA Mirror Technology Days – 2017 / NASA SBIR
PM: Ron Eng / NNX17CM24P

Over Arching Goal of SBIR

Reduce the Mass, Time and Cost of
Optical Structures Made from Silicon Carbide

- Approach
  - Bonded Structures
  - Single Gauge Thickness
- Results from Case Studies
  - SiC Structures are Competitive Stiffness, Weight Ratios
  - Thermo-Elastic Analysis in Progress
  - Inspiration Enough to Want to Build H/W

Why Choose This Approach?

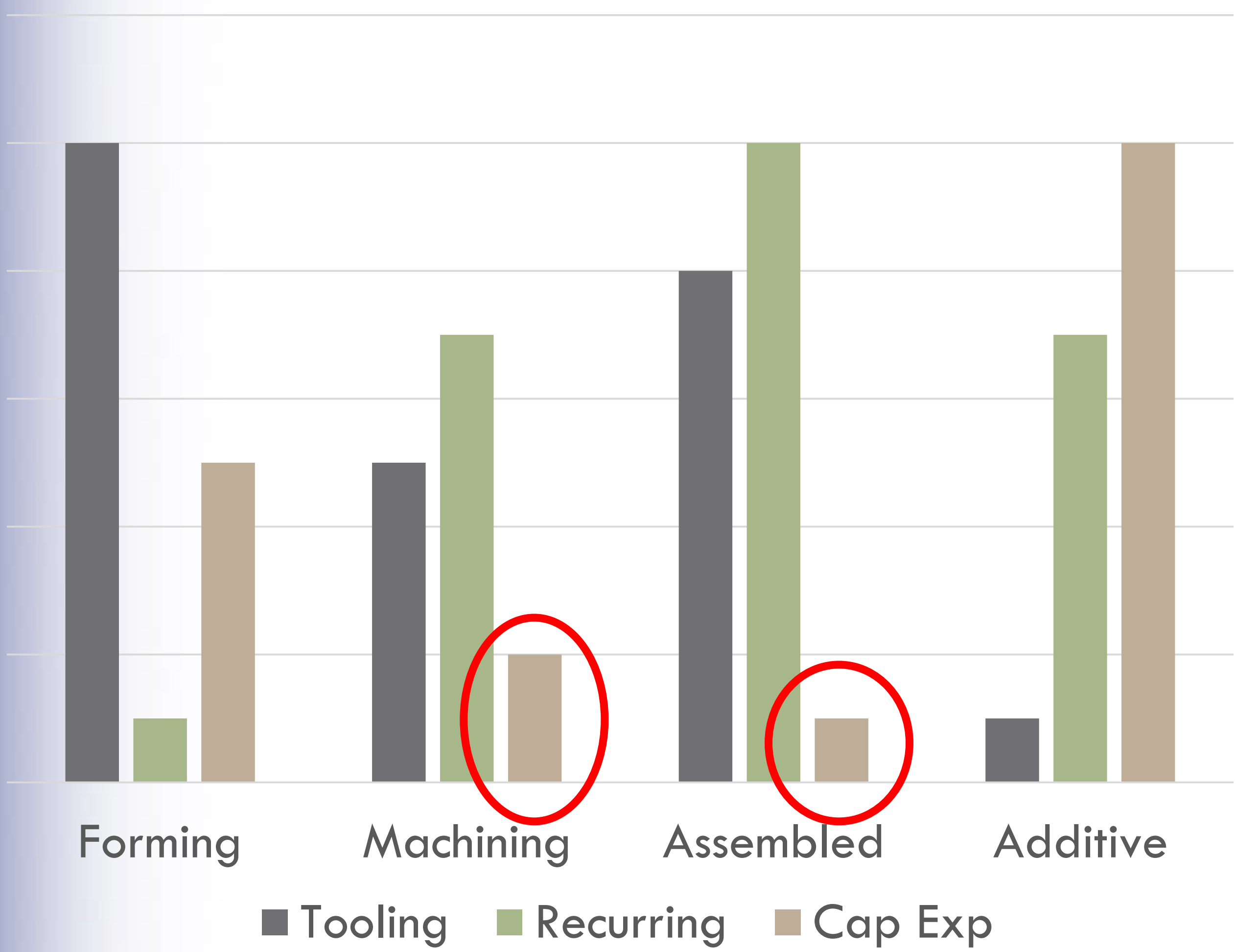
BACKGROUND

Access to Advanced Materials

- How Can a Small Business Gain Access to Advanced Materials?

- Requirements
  - Affordable Material Configuration
  - Simple Manufacturing Process

Cost Structure



Assembled Structures

- Drive Down the Cost of Materials by Standardizing Thickness
  - Minimize Machining
  - Minimize Wasted Material
  - Maximize Stiffness / Weight Ratio

- Architectures for Assembled Structures
  - Aluminum Honeycomb Sandwich
  - Rib Stiffened Sandwich

Aluminum Honeycomb Sandwich

- Carbon Fiber Laminates on Aluminum Honeycomb
  - Very Simple Manufacturing Process
  - Generally Considered Less Stable than Rib Stiffened Structures

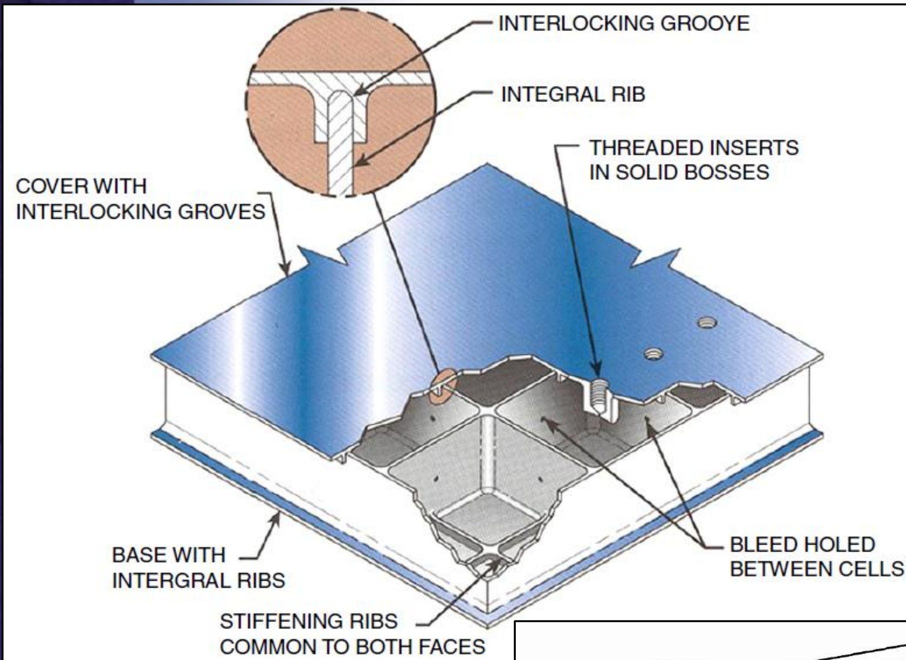
- Why Is It Less Stable?
  1. Orthotropic Materials

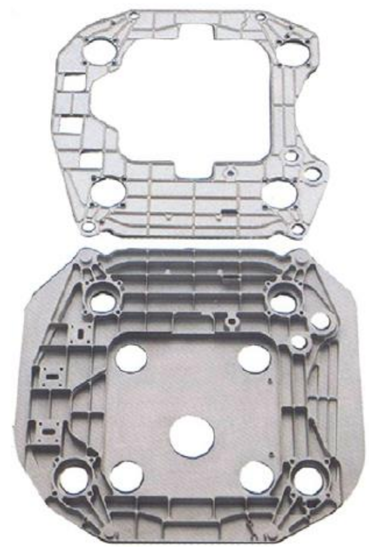
     Through Thickness is Resin Dominated
  2. CTE Mismatch

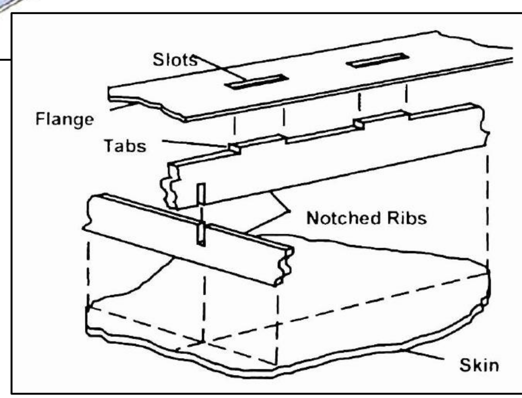
     Fittings / Adhesive

Can These Shortcomings be Overcome?

Rib Stiffened Structure







Krumweide, 1991

Pandurangan, 2007

Catanzaro, 2000

?

Apply the Architectures to Existing

CASE STUDIES

Balloon Based Optical Instrument Bench

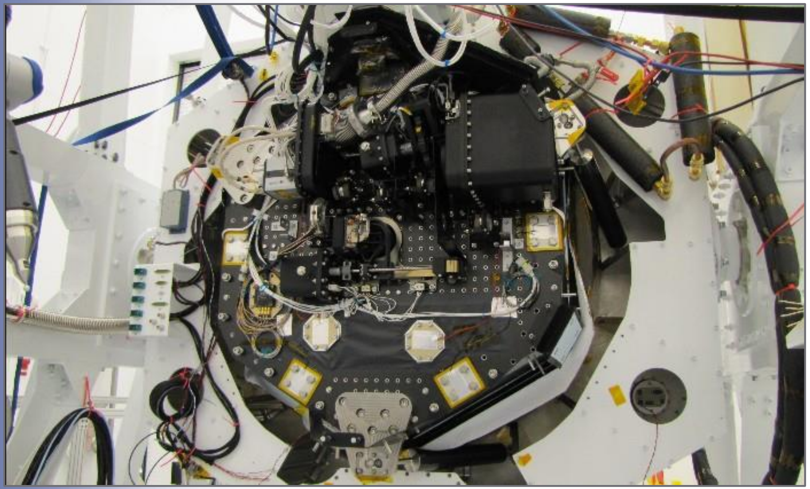
CASE STUDY – HONEYCOMB SANDWICH

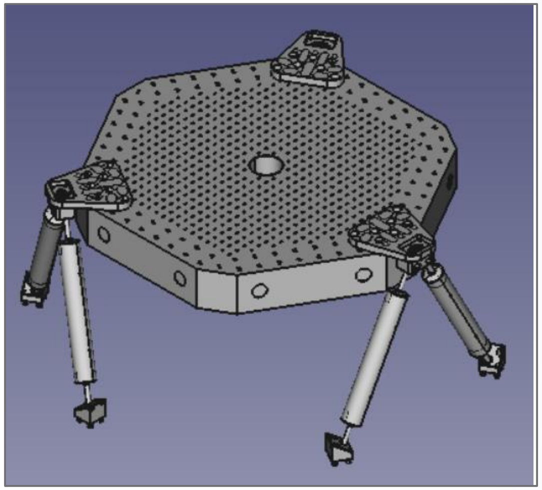
General Requirements

- Ballooning Environment
  - Temperature: 270 K to 310 K
- Types of Instruments
  - Imaging
  - Spectrometer (Point)
- Low Mass
  - Desire for Large Apertures Leaves Less Mass for Instrument
- High Stiffness
  - Vibration from Cryo-Coolers
  - Vibration / Settling from Pointing System

Heritage Mission: BRRISON

- BIRC + ISON = BRRISON
  - Rapid Response Designed to Observe ISON Comet
- Design Solution
  - 850 mm Flat-to-Flat
  - 100 mm Thick





Details of CFRC Bench Design

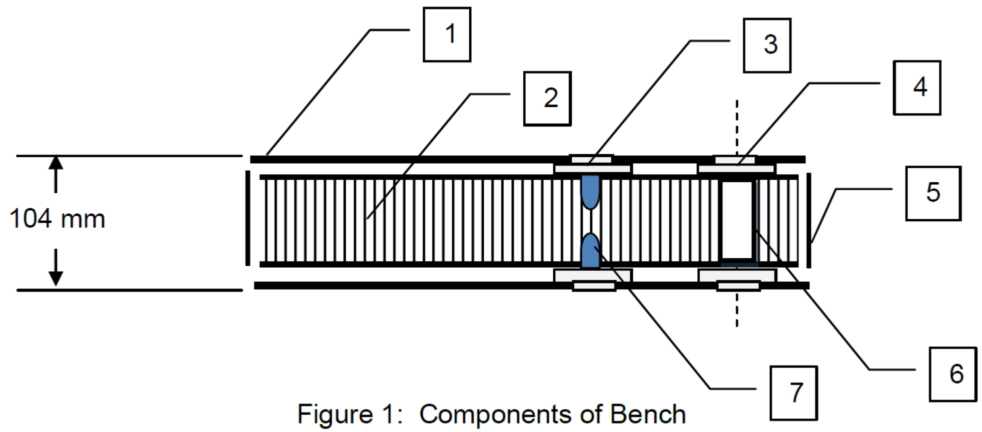


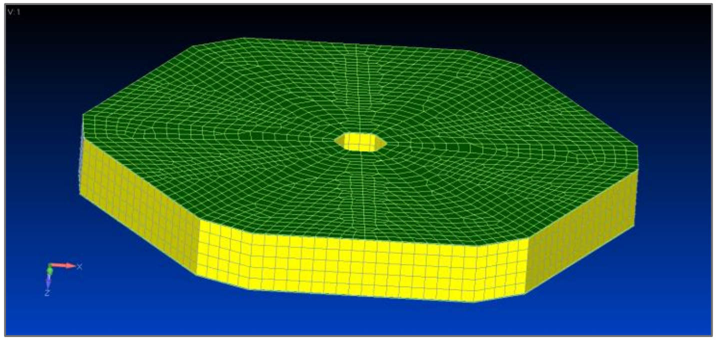
Figure 1: Components of Bench

1. Laminate (B)
2. Aluminum Honeycomb w/Laminate (A)
3. M4 Insert
4. M6 Insert
5. Close-Out Skins
6. Support Tube

SiC Bench Solution

- Modeled Honeycomb Using Effective Properties
  - Verified Effective Properties with Shell Model of Honeycomb

- Compared BRRISON Design and SiC Design
  - Stiffness / Mass



Heavy Gauge SiC is Stiffer / Lower Mass

BRRISON Baseline	SiC (1 mm thick)	SiC (2 mm thick)
16.7 kg	8.94 kg	12.9 kg

BRRISON Baseline	SiC (1 mm thick)	SiC (2 mm thick)
568 Hz	1130 Hz	1070 Hz
568 Hz	1140 Hz	1070 Hz
987 Hz	1650 Hz	1530 Hz
1080 Hz	1730 Hz	1550 Hz
1330 Hz	2010 Hz	1760 Hz

What Do I Do With Extra Stiffness? Jitter Suppression

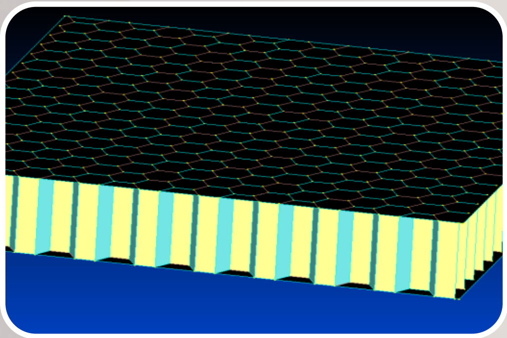
$$F = kx, \nu = \sqrt{\frac{k}{m}} \rightarrow$$

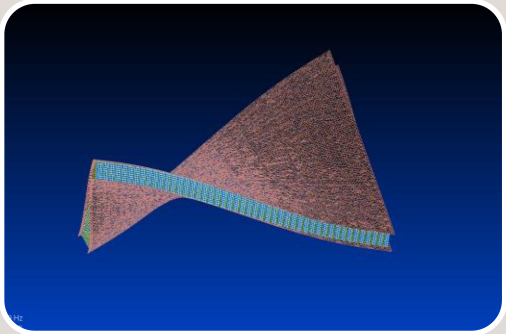
$$\delta x = \frac{F}{m \cdot \nu^2}$$

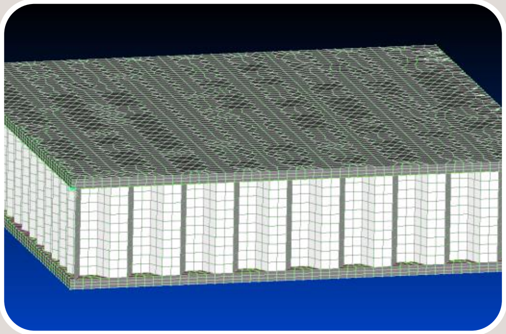
Thermo-Elastic Stability

- Does the CTE Mismatch between Core and Facesheet Case Warpage?
- Does CTE Mismatch of Adhesive Cause Warpage?

Build a More Detailed Model







Build Honeycomb Core Automatically

- Use FEMAP API
- C# Code to Automate Geom, Mesh, Materials

Correlate to Effective Properties

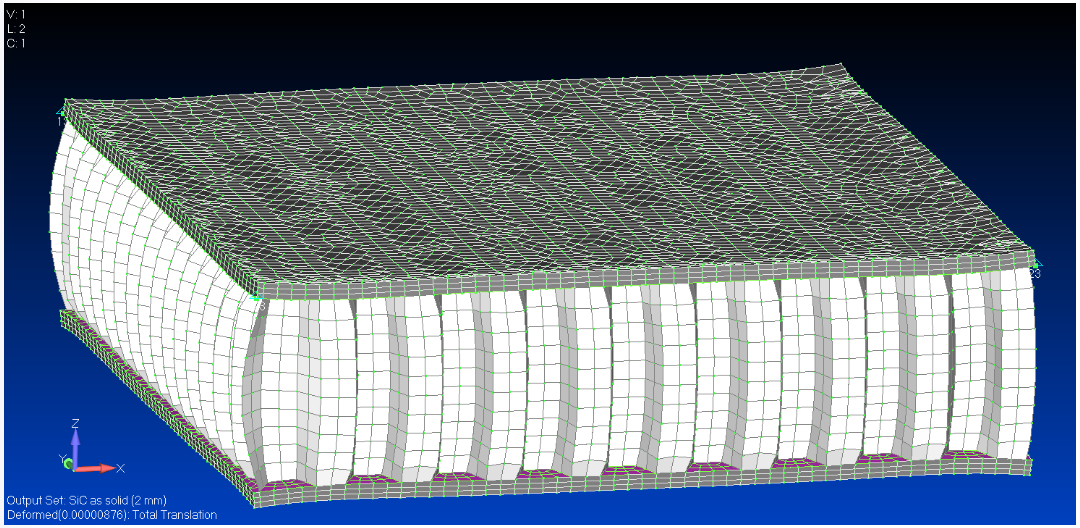
- Compare Stiffness of Detailed Model to Effective Properties Model
- Compared w/ASTM Tests

Explore Thermo-Elastic Stability

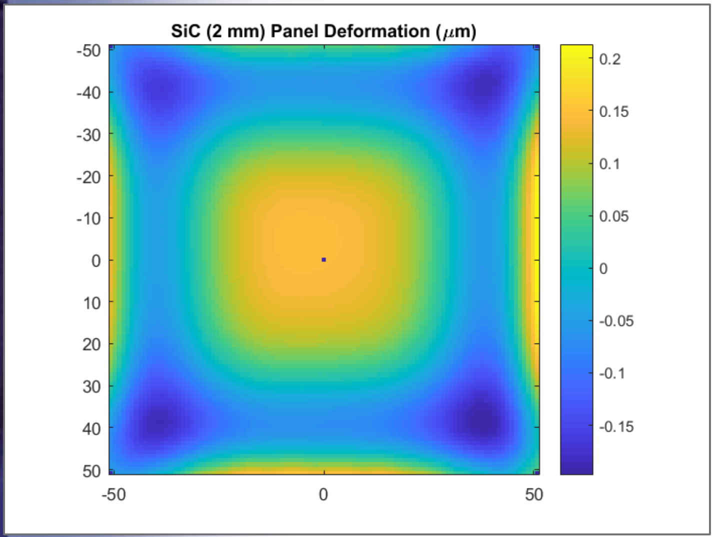
- Vary Facesheet Thickness
- Vary Adhesive Thickness

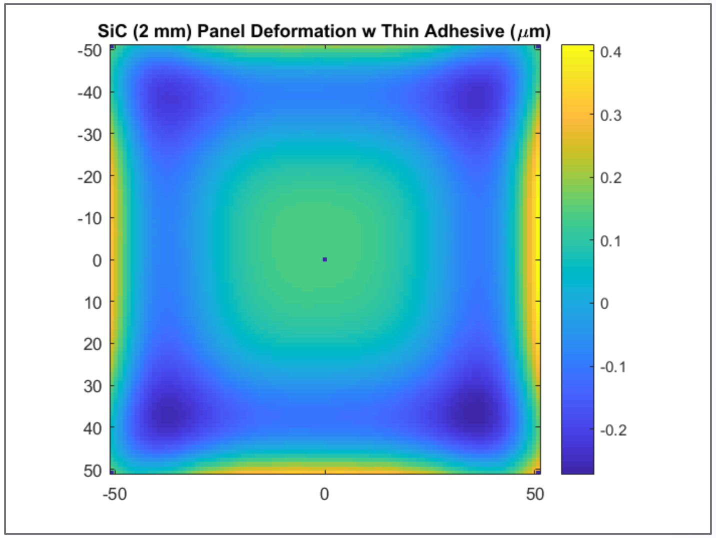
Simple Test Cases

- Load Case
  - Isothermal Load ($\Delta T = 10$ C)
  - Kinematic Conditions
- Facesheet: SiC = 1 mm or 2 mm
- Adhesive: EA9394 = 0.1 mm or 1.0 mm



Adhesive has Greatest Impact

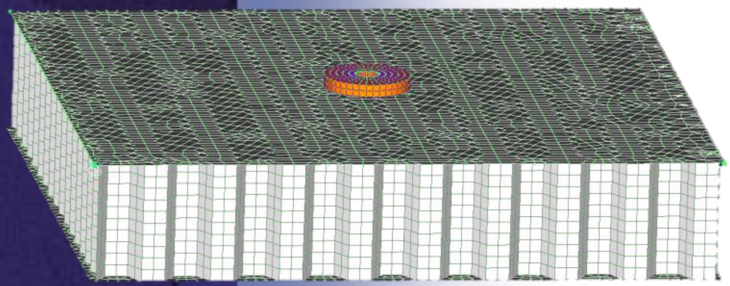


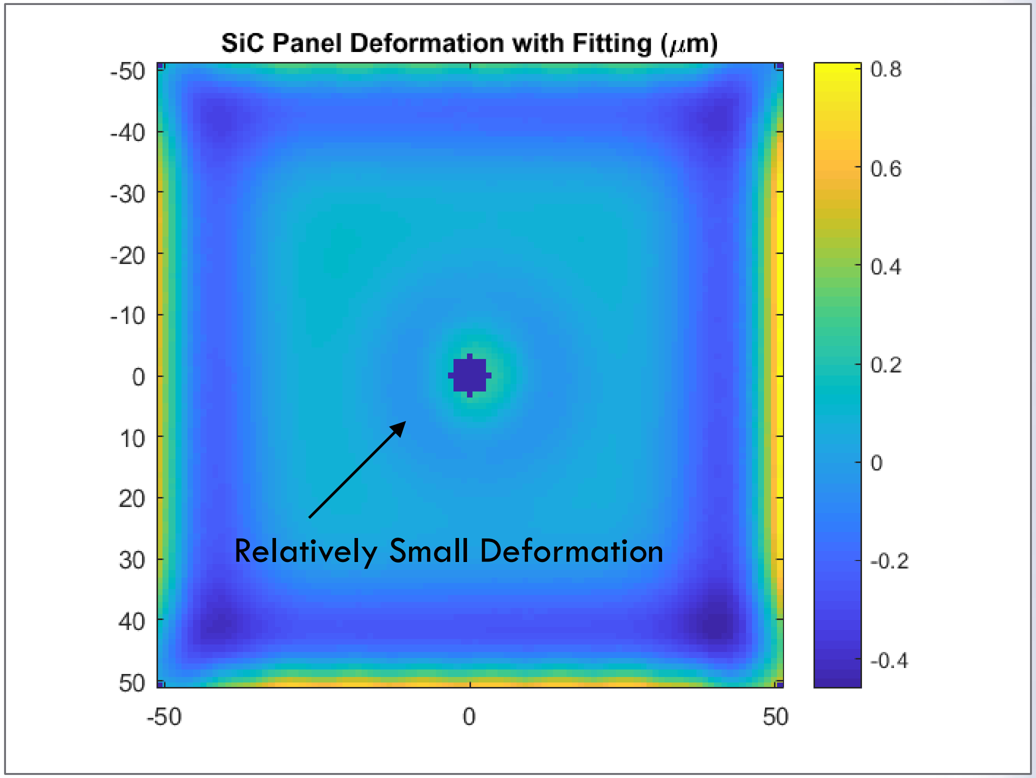


	Skin	Adhesive	Max Deformation
Skins / Core	2 mm	0 mm	0.4 um
Skins / Adhesive / Core	1 mm	1 mm	3.0 um
	2 mm	1 mm	1.6 um
	2 mm	0.1 mm	0.7 um

Do Fittings Warp Facesheet?

- Invar39 Fitting Bonded to Facesheet
  - Isothermal Load: 10 C





Forward Looking Work

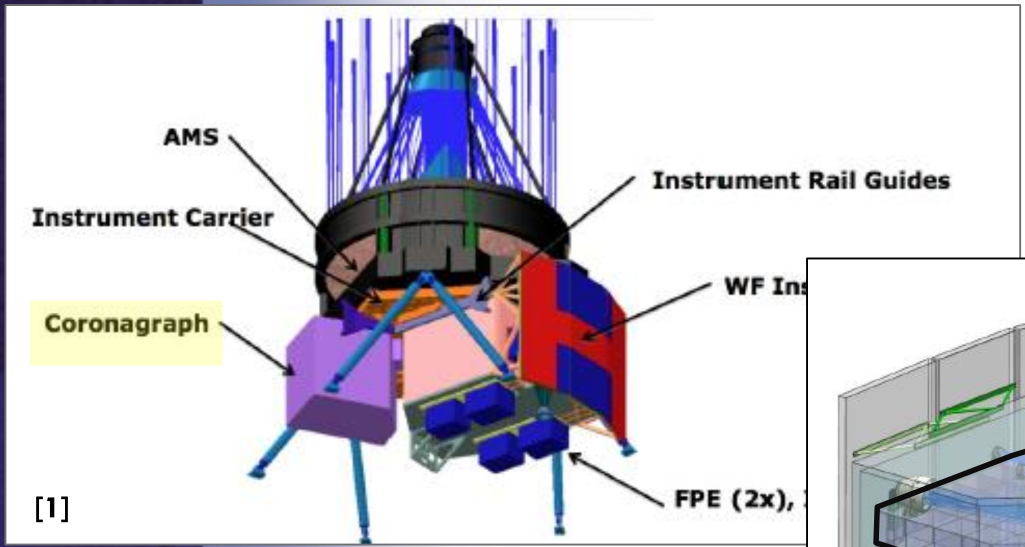
- Thermo-Elastic Model
  - Optical Table of Fittings
  - Adhesive

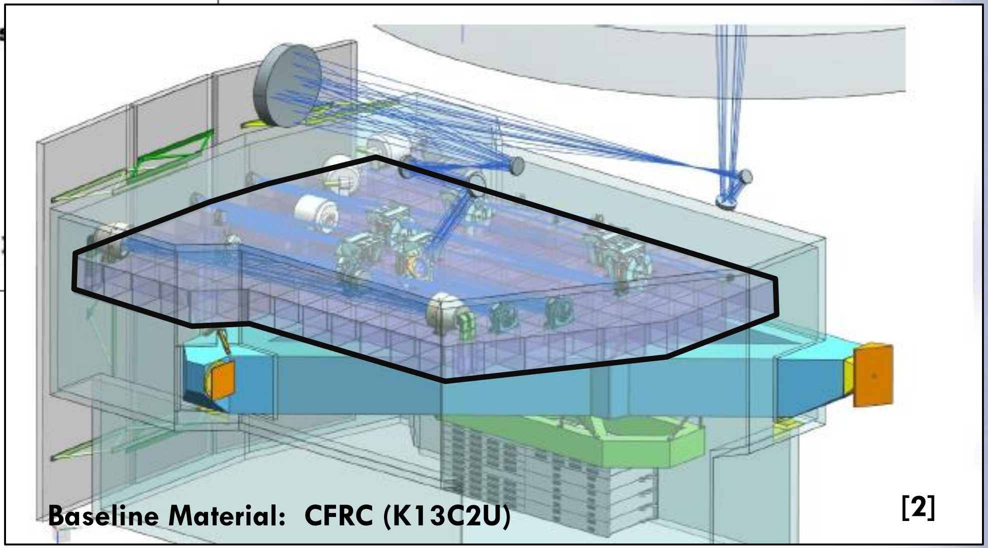
- Detailed Model / Evaluate Against
  - Isothermal Change
  - Thermal Gradient

WFIRST Coronagraph Optical Bench

CASE STUDY – RIB STIFFENED

WFIRST-AFTA Coronagraph



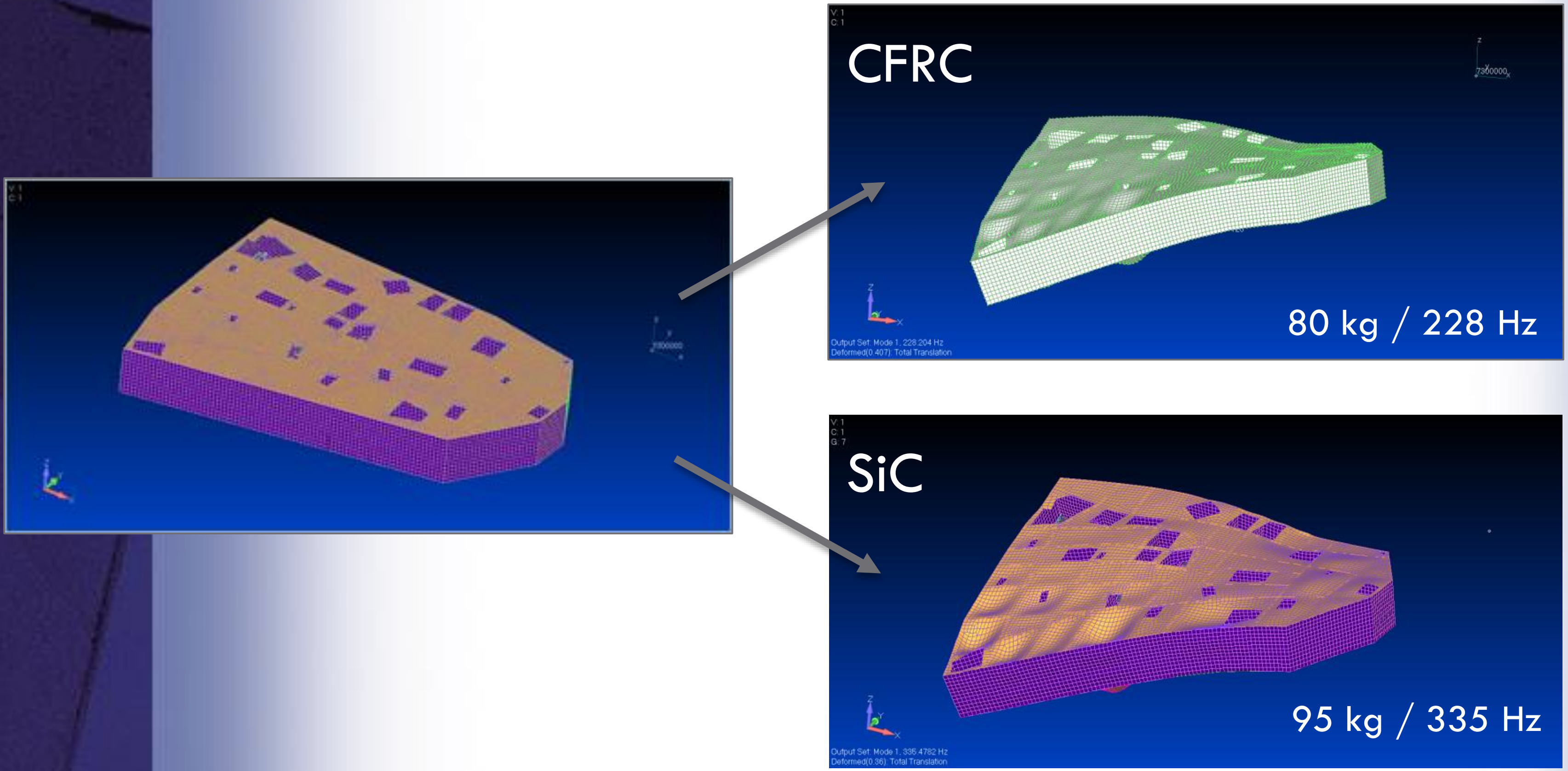


[1] B. Pasquale, "Optical Design of the WFIRST-AFTA Wide-Field Instrument" SPIE 2014
[2] R. Demers, "WFIRST-AFTA Coronagraph Instrument" 2015

Baseline Design Solution

- Design
  - Carbon Fiber Composite
  - Rib Stiffened
  - (x3) Facesheets for Additional Stiffness
- Mass / Stiffness
  - Structure = 40 kg / Attached Mass = 40 kg
  - First Mode < 230 Hz
- Issues with Optical Alignment
  - Maximizing Stiffness Includes Top Sheet
  - Top Sheet Limits Access to Adjusting Optics

First Cut Material Swap



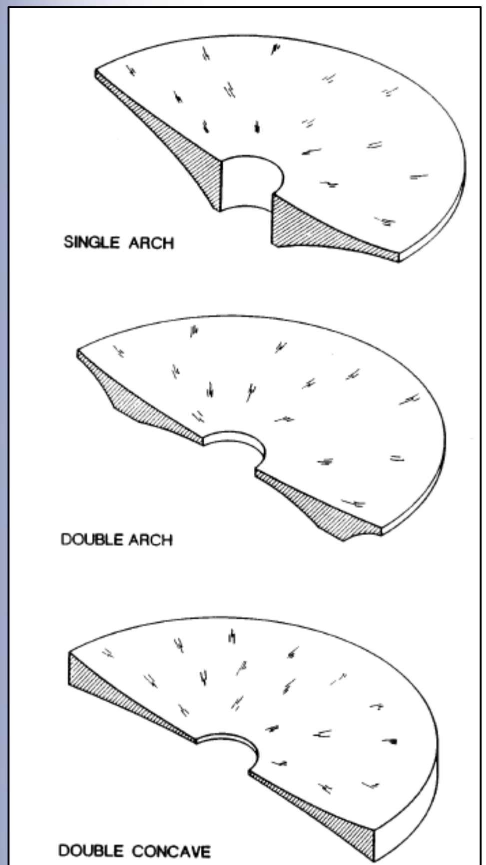
- Inadequate Performance
  – Parasitic Mass?

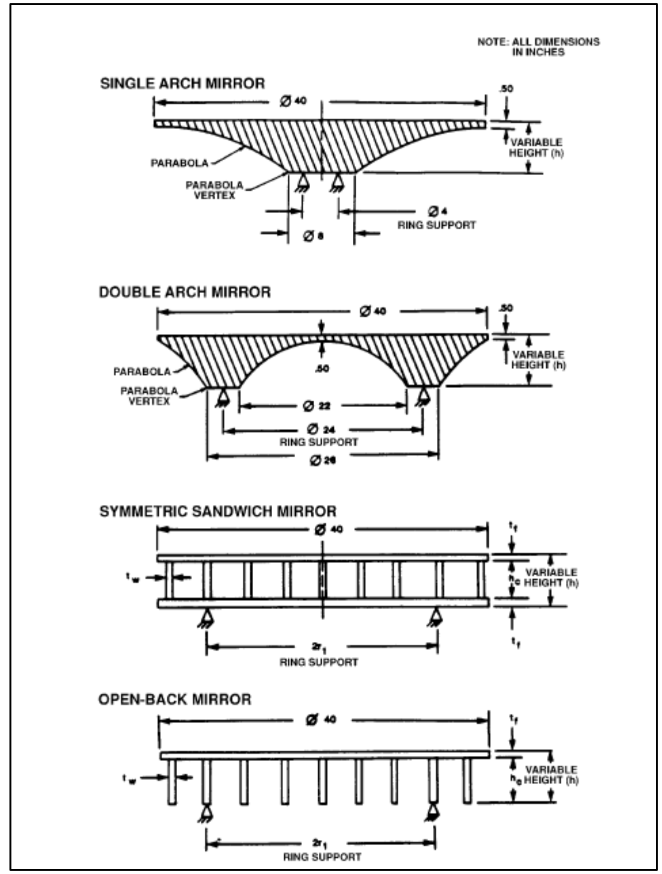
Inspirational Quote

The Optical Benches and Structures of the Future will Need to Look More Like the Lightweight Mirrors of Today – [Unknown]

I'm Looking for Somebody to Give Credit to this Quote

Variations on Mirror Design





[3] A. Ahmad, <u>Handbook of Optomechanical Engineering</u>
[4] P. Yoder, <u>Opto-mechanical Systems Design</u>

Apply Concepts to Bench

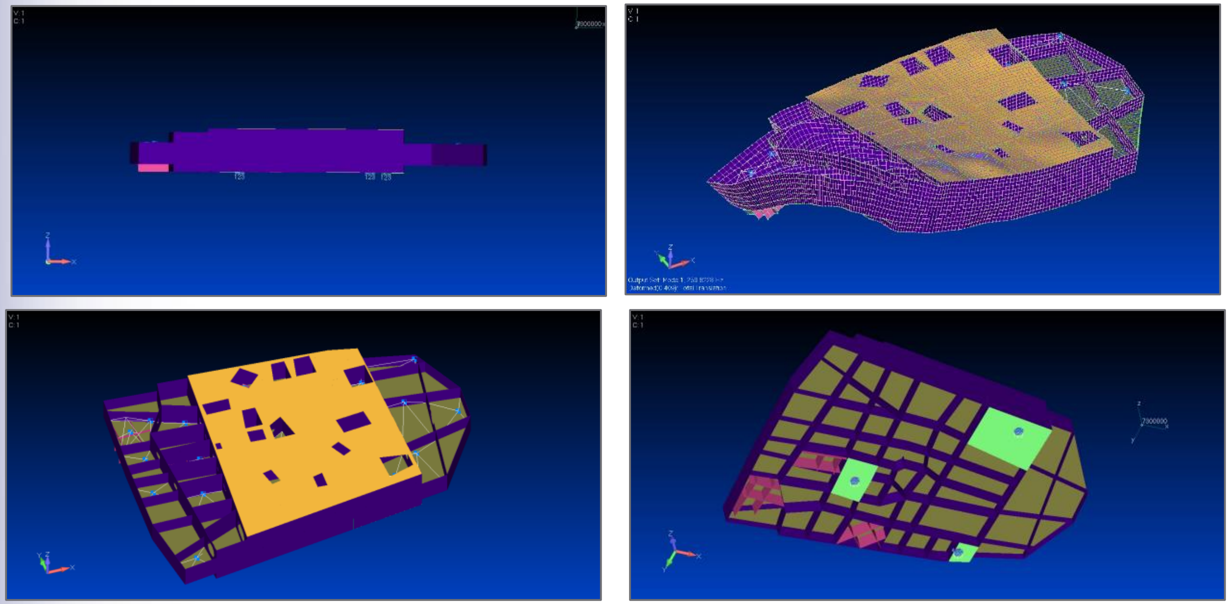
- Single Arch / Double Arch Design
  - Remove Mass from Areas that are Unsupported
  - Except Where there is a Mounted Component

- Sandwich Structure Provides Great Stiffness
  - Be Careful with Open Back Structures

- In Addition…
  - Let Strain Energy Be Your Guide

Current Iteration: 260 Hz / 78 kg

Baseline: 230 Hz / 80 kg



- Remove Top / Bottom Facesheets
  - Remove as if Tapering the Structure
  - Taper Ribs
  - Guided by Strain Energy

Future Work

- Add Details to Model
  - Fittings, Adhesive
- Thermo-Elastic Distortion
  - Isothermal Load ($\pm$ 3 K)
  - Lateral Gradient ($<$ 100 mK)
- Strength
  - Launch Loads

Lessons Learned

- SiC is Stiff Enough to Overcome Density
- SiC Can Be Competitive in Terms of Stiffness and Mass
- Effective Designs Can Be Created with Flat Stock
- It's Not So Much the Material as it is the System
- Forward Work
  - Thermo-Elastic Modeling
  - Demonstration Bench / Distortion Test

Acknowledgements: Monica Hoffmann (GRC), David Braun (JPL)