SATELLITE TECHNOLOGY US

Spring Final Review

FISH & CHIPS

FeatherCraft **I**ntegrated **S**tructural **H**ousing & **C**omputer, **H**ardware **I**nterface **P**rocessing **S**uite

Team: Larry Burkey, Jorge Cervantes, Lewis Gillis, Evan Graser, Megan Howard, Andrei Iskra, Taylor Maurer, Davis Peterson, Maggie Williams

Customer: Michael Brown

Advisor: Joe Tanner

Executive Summary:

Project Overview

Structure

- Design Overview
- STM Modeling
- Vibration Test Results

DAQ

- Design Overview
- Component Testing Results

Systems

Project Management

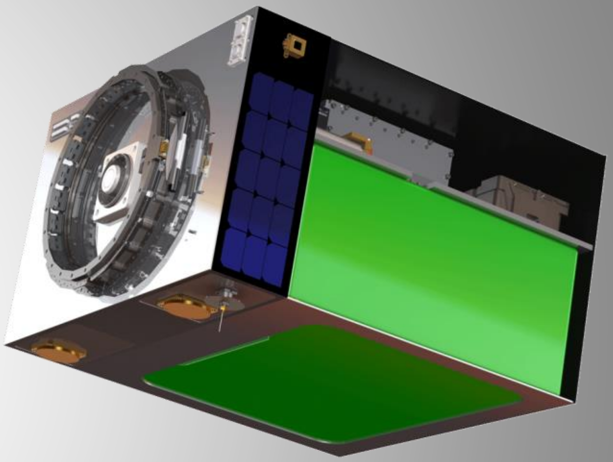
PURPOSE & OBJECTIVES

Project Motivation:

- Commercialization of International Space Station provides a launch opportunity not only to cubesats but larger **100 kg spacecraft**

- Spacecraft are launched on ISS cargo resupply missions, allowing for soft-stowed configuration and less stress on structure in launch environment

- Surrey Satellite Technology US plans to offer the FeatherCraft system as a cost-effective platform for **payloads of 45 kg** or less.



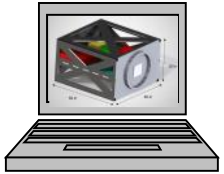
Surrey's FeatherCraft Illustration

Project Statement:

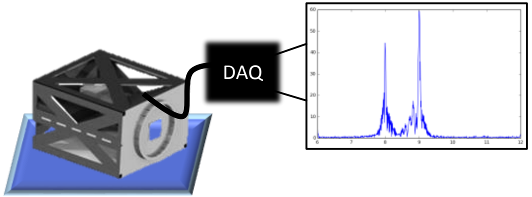
The **5 kg FeatherCraft structure** shall provide support for a **100 kg total mass** commercial spacecraft with reduced structural manufacturing time and materials cost, and enable the spacecraft to **survive launch** to and **deployment from the ISS** for a nadir facing mission.

CON OPS:

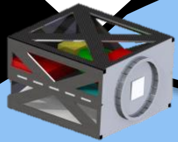
1. Design structure to meet all requirements, manufacture STM, design and create DAQ system



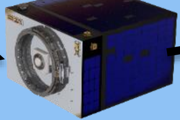
2. Perform vibration test and analyze accelerometer data

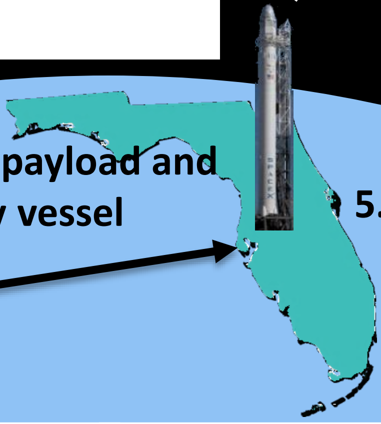


3. Final testing and integration with avionics and other bus components



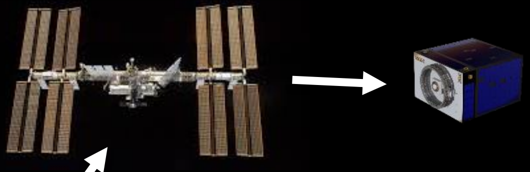
4. Integrate with payload and ISS resupply vessel





5. Launch to ISS

6. Interface with the Kaber Deployment System and deploy from the JEM airlock



7. Possible Orbit Raising Maneuver and 5 year mission lifetime

Levels of Success:

	Structure Design:	Vibration Testing:	Data Acquisition System:	Software:
Level 1	Design meets all physical requirements	Structural Test Model (STM) undergoes vibration test	Data can be collected for up to one hour	Saves CSVs for Excel analysis
Level 2	Design meets 50% reduction requirement	STM shows no failure		Software outputs PSD plots
Level 3		STM exhibits predicted modes within 10%	Real time PSD plotting	GUI allows control of test settings and analysis

Successful Unsuccessful

Levels of Success:

- Designed System:
  - Supports 4+ accels
  - Functional Charge Amplifier
  - Functional low pass filter
  - Functional ADC
  - Data faster than 4 kHz
  - Real-time PSD plots
- NI DAQ was used to due to non-functional ADC
  - Level 1 functionality
  - No PSD capabilities

Data Acquisition System:
Data can be collected for up to one hour
Real time PSD plotting

CPEs:

Critical Project Element	Achieved
Mass of structure below **5 kg** while **surviving launch** to the ISS (FR 1 and DR 3.1)	Yes, 4.16 kg structure survived launch vibrations
Support of up to **60 accelerometer** channels in DAQ system (DR 5.6.1.1)	No, but used back-up DAQ
Providing support and **mounting** positions for other **spacecraft components** (FR 4)	Yes
Manufacturing time and cost below required values and feasible in spring semester (FR 2)	Yes
Vibration test table time acquisition (DR 5.2)	Yes

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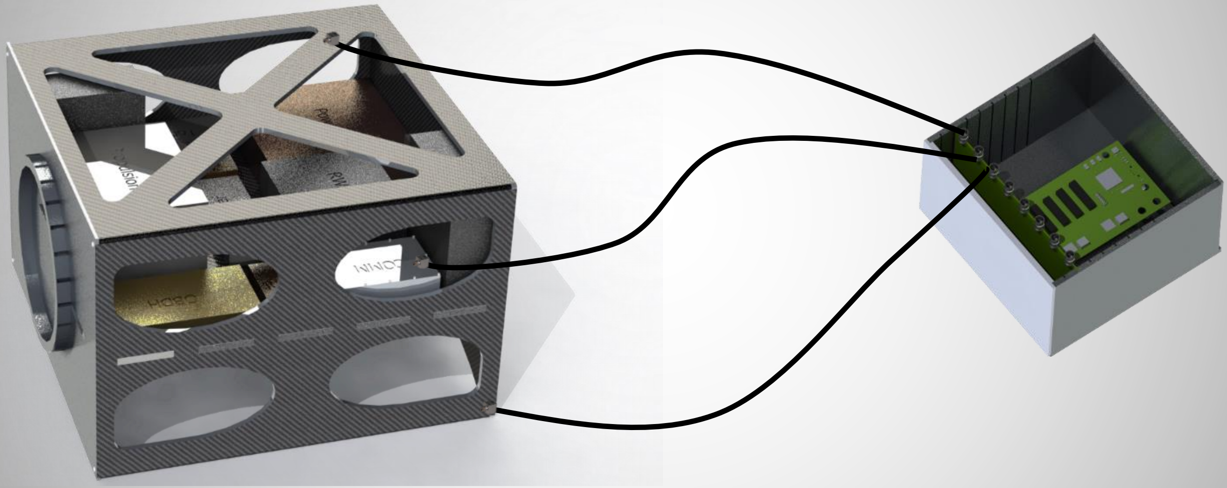
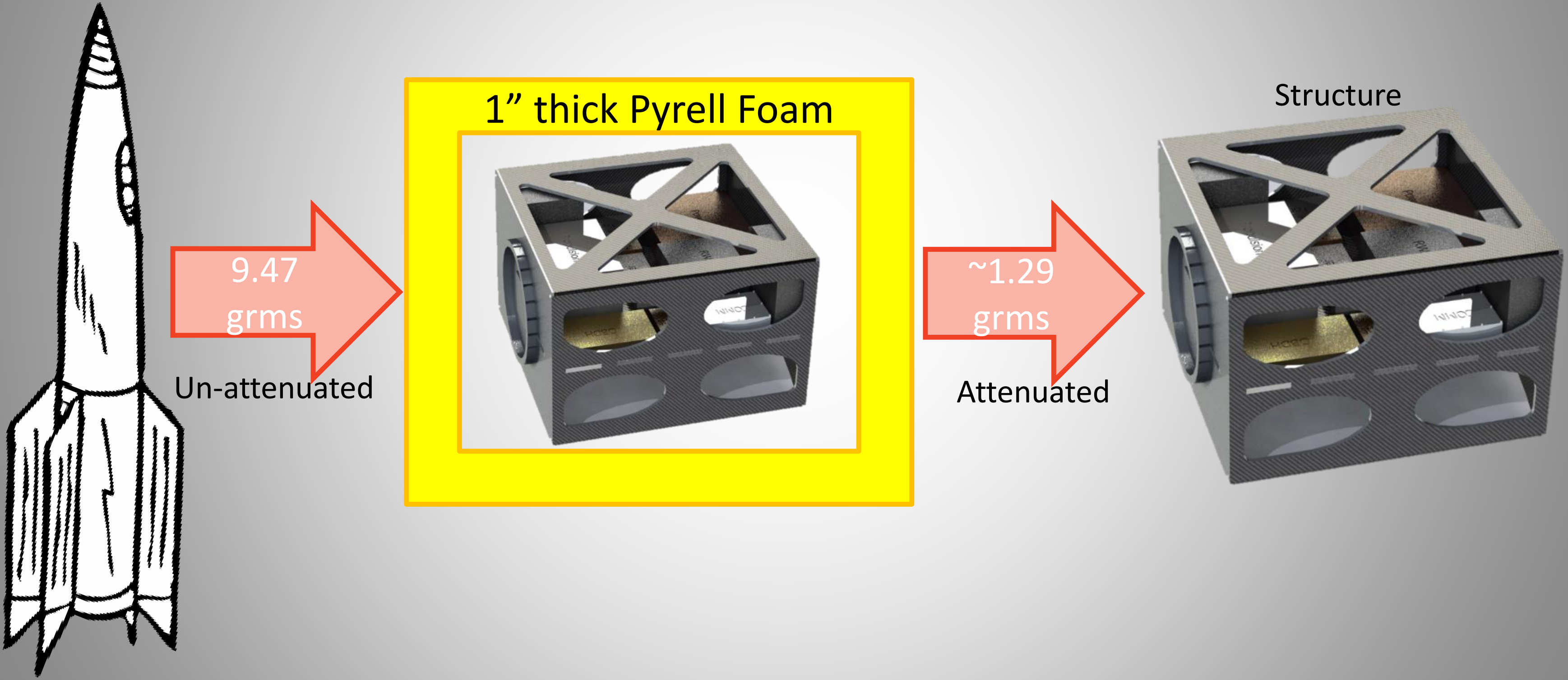


STRUCTURE

DESIGN

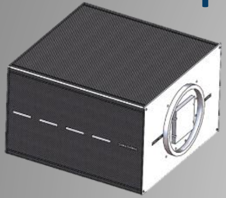
Launch Configuration:

ISS Resupply Vehicle

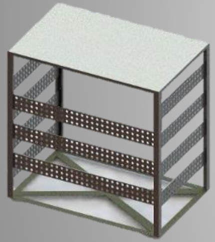


Design Evolution:

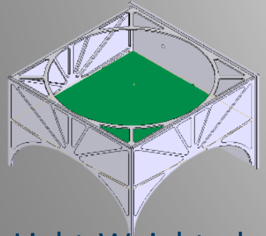
Initial Concepts:



Composite Panels

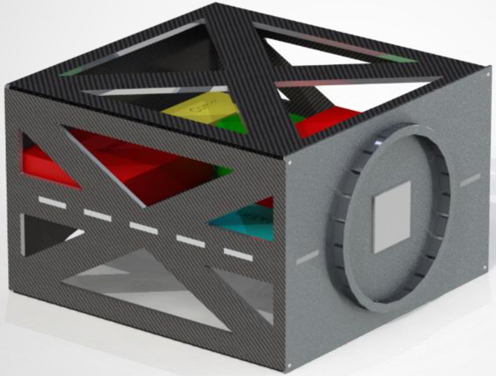


Skeleton Structure



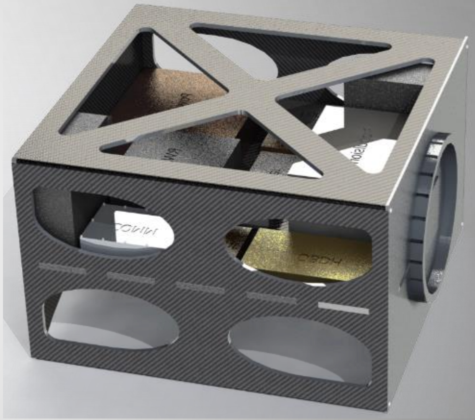
Light-Weighted

Preliminary Design:



Light-weighted composite panels with internal columns for stiffness

Final Design:



Weight relief radii optimized to reduce stress concentrations

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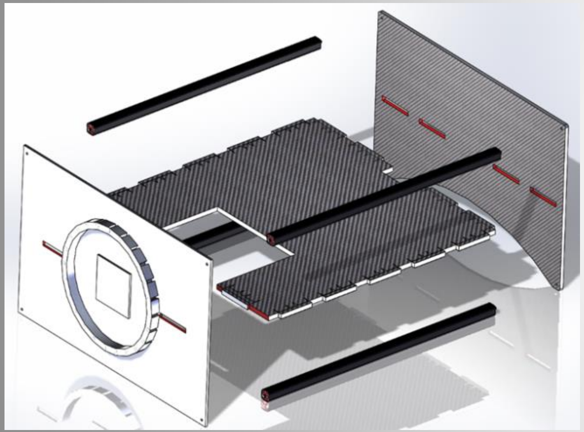
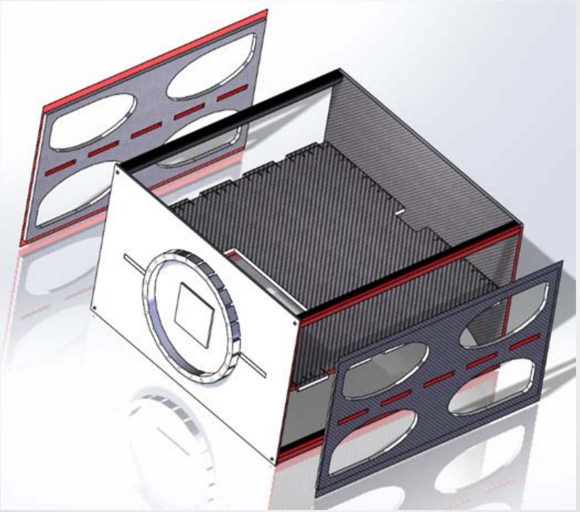
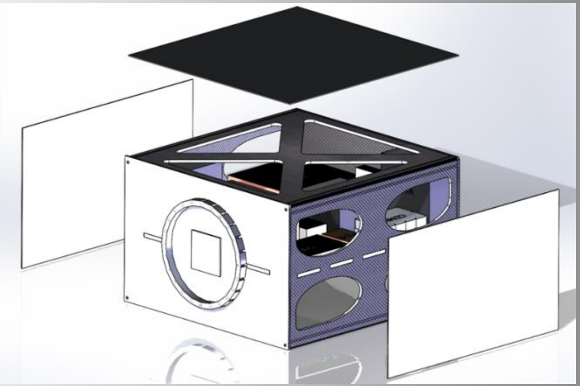
Baseline Design – Structure:

30"x 30"x 19" structure. Designed mass of 4.48 kg







Components are assembled with Scotchweld 2216 epoxy and 8 steel fasteners, with washers and helicoils.

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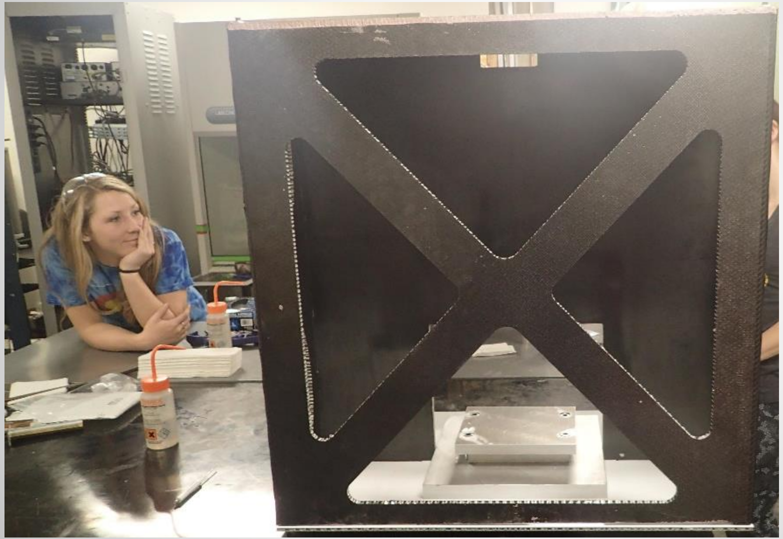
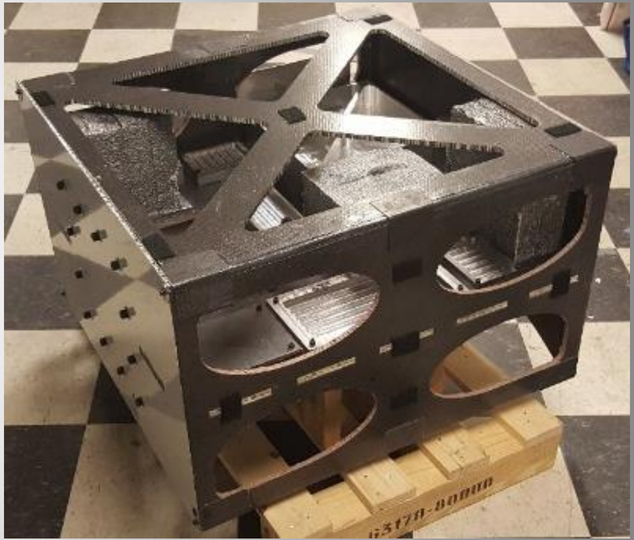
Structural Test Model:

30.5”x29.25”x19” STM. Final Mass: 4.16 kg





Components assembled with Scotchweld 2216 epoxy and 8 steel fasteners.

Mass-dummies of payload and avionics are adhered with the same epoxy.

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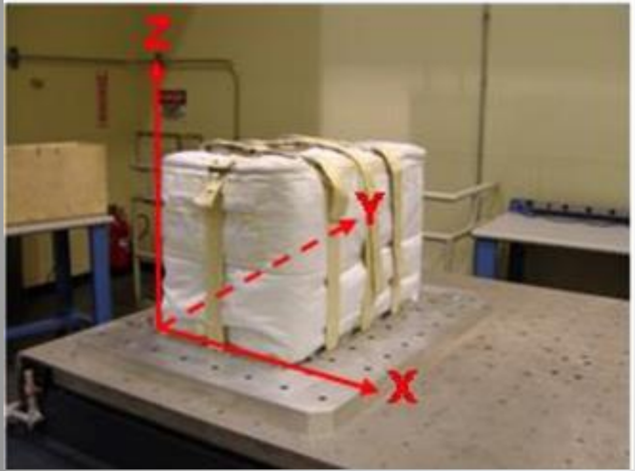
TESTING OVERVIEW

Purpose of Testing:

1. Determine if the structure can survive ISS launch conditions

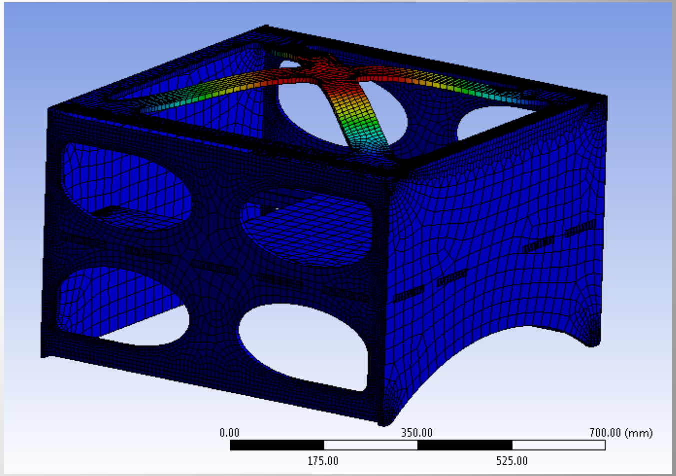
2. Determine if the natural modes of the structure are the modes predicted by FEA model

Validates STM



Example of Soft-Stowed Item
(from NASA GEVS)

Validates Design Analysis



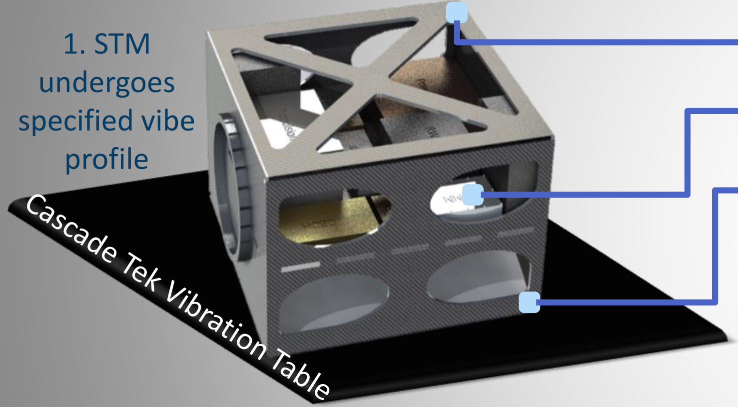
Mode 1 Deflection [mm]

Structure Testing FBD:

On 3/18

1. STM undergoes specified vibe profile

2. Accelerometers gather analog acceleration data



3. Analog signal converted to digital and sent to the PC

NI DAQ

PC with Windows OS (not delivered)

4. Software saves data and produces real time temporal plots

USB Drive – Transfers Data to PC with Analysis Software

After 3/18

5. Post Processing: Validate model and verify requirements

Were the modes what ANSYS predicted?

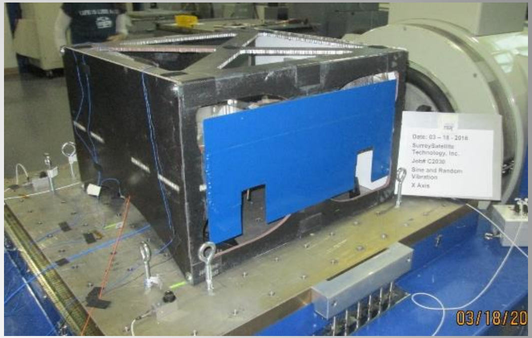
Will structure survive launch?

- Analog
- Digital
- Software
- DAQ Hardware
- DAQ Software

Vibration Test Facility:

- 3/17 – 3/18 at Cascade Tek Front Range
- One 8-hour test day
  - Sponsored by SST

Required Capabilities:	Facility Capabilities (SR16):
20 Hz – 2000 Hz frequency range	0 - 10000 Hz frequency range
Support 100 kg (~10 kN force output)	70 kN force output
> 32" x 32" bolt pattern	44" x 44" bolt pattern



Above: Slip Table (48" x 48")

Below: Expander Plate (44" x 44")

Types of Tests:

- **Modal Sweep – Unwrapped**
  - Identify **unwrapped** natural modes before & after random vibration
  - ≥±10% modal shift indicative of structural failure/alteration
  - Validate Structural Model
- **Modal Sweep – Wrapped**
  - Identify **wrapped** natural modes before & after random vibration
- **Random Vibration – Wrapped**
  - Simulate expected flight conditions to verify structure survivability
  - Visual inspection failure identification

Modal Sweep Specifications	
Frequency Range	20 Hz. – 2 kHz.
Sweep Rate	2.5 oct/min

Random Vibration Profile: 20 Hz. – 2000 Hz.	
Maximum Un-Attenuated	9.47 grms
Maximum Attenuated	1.29 grms

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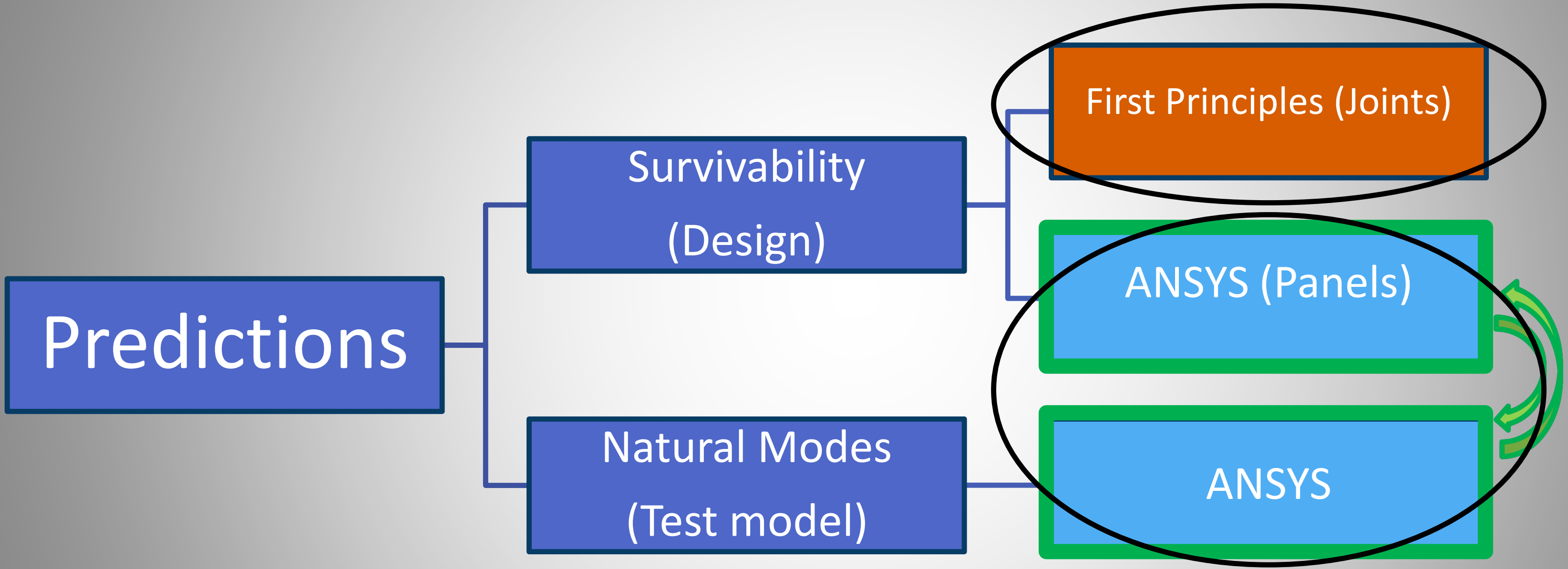
Analysis and Validation: Overview



1ST PRINCIPLES ANALYSIS

Margins:

Assumptions:

- 0.25 effective area for bonded interfaces
- Worst case loading (ignore reduction in stress due to interconnectedness of system)

Modeling:

- Linear analysis of 22 interfaces / failure cases are evaluated.
- Margins are calculated above Factor of Safety (FOS): 1.9 on composites, 1.25 metallic (per NASA GEVS)

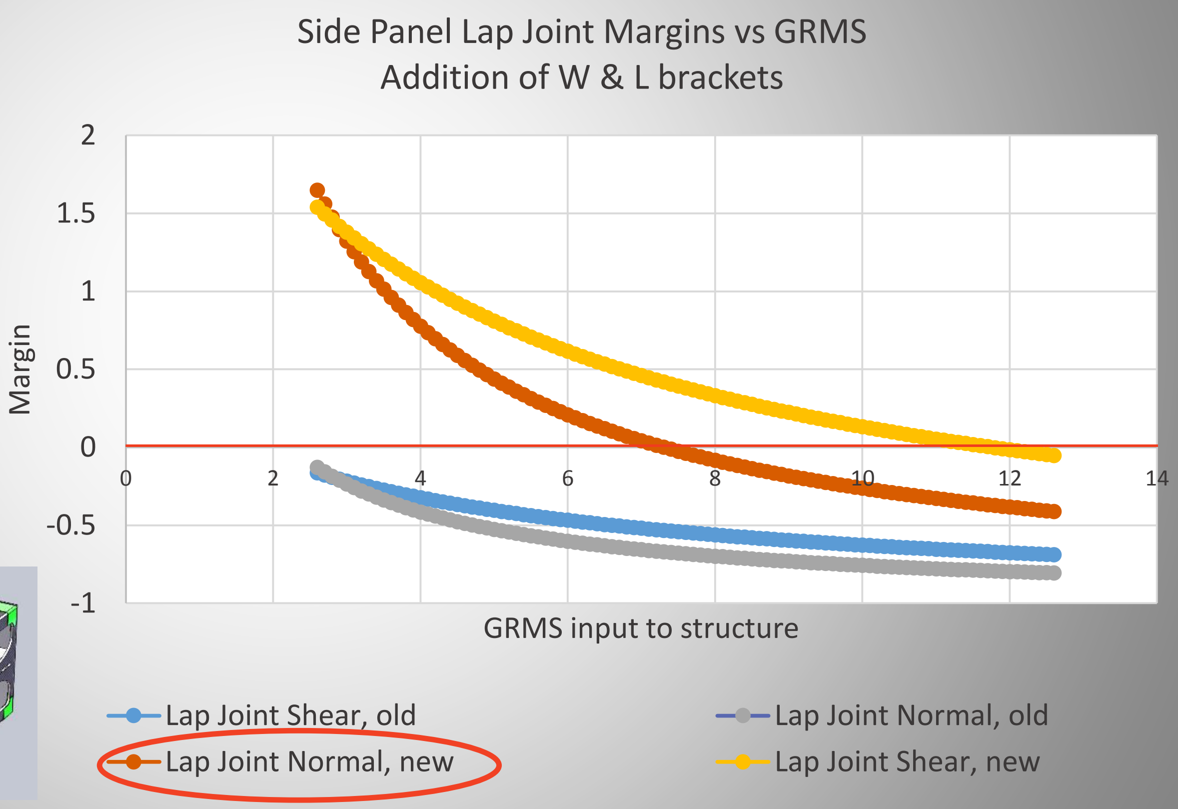
Interface:	Margin (above FOS):	Expected Failure (grms):
Mid-Panel Principal Stress	0.4	3.8
Mid-Panel Tab Shear	2.6	14.3
Lap Joint Normal, W brackets	1.7	7.5

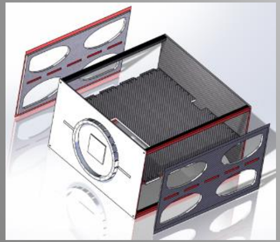
Side Panel Lap Joints:

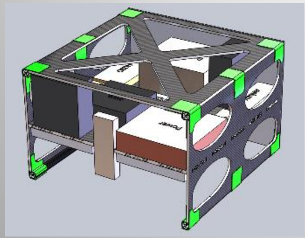
- Normal and Shear stresses in Side Panel Lap Joints
- Failure expected below design levels

Solution: addition of W & L brackets to the structure.

- Total of 24 brackets added
- Failure is expected at **7.5** GRMS for normal stress







ANSYS ANALYSIS

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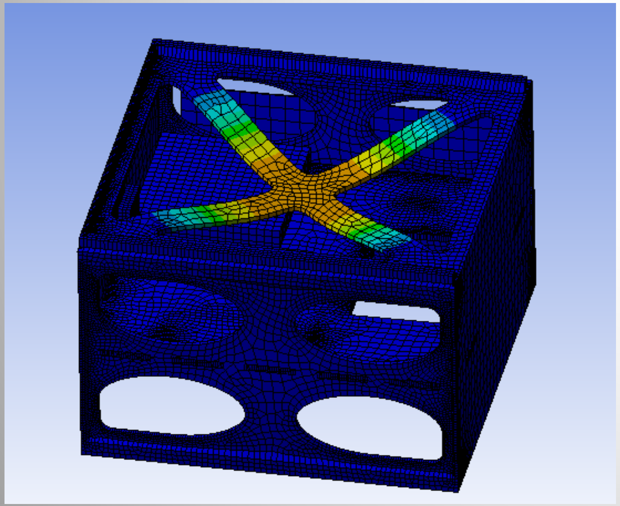
Models Developed:

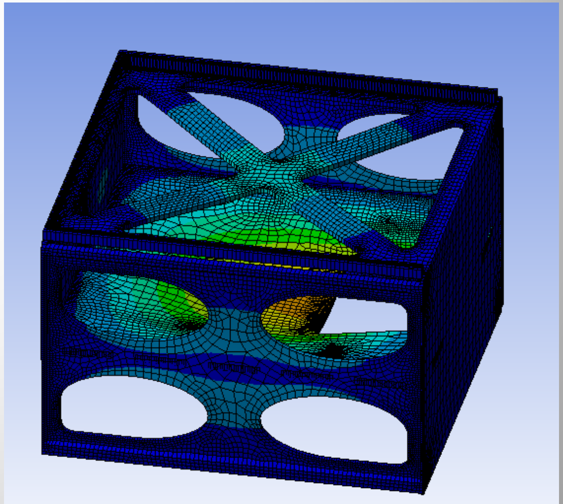
Two models developed:

One for detailed predictions of test model

One designing for an arbitrary payload



Test Model



Design model

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Predictions:

What are its **natural modes**?

Test Model Expected Modes:		
Mode:	Freq [Hz]:	Location [Orientation]:
1	51	Top
2,3	140	Top
4	149	Top, Radiator
5-6	~160	Radiator, Side
8	222	Radiator
9	266	Top

Will the structure **survive** launch loading?

Model Survival:		
Model:	Margin [%]:	Expected Failure [grms]:
Design	55	3.8
Test	140	6

TESTING RESULTS

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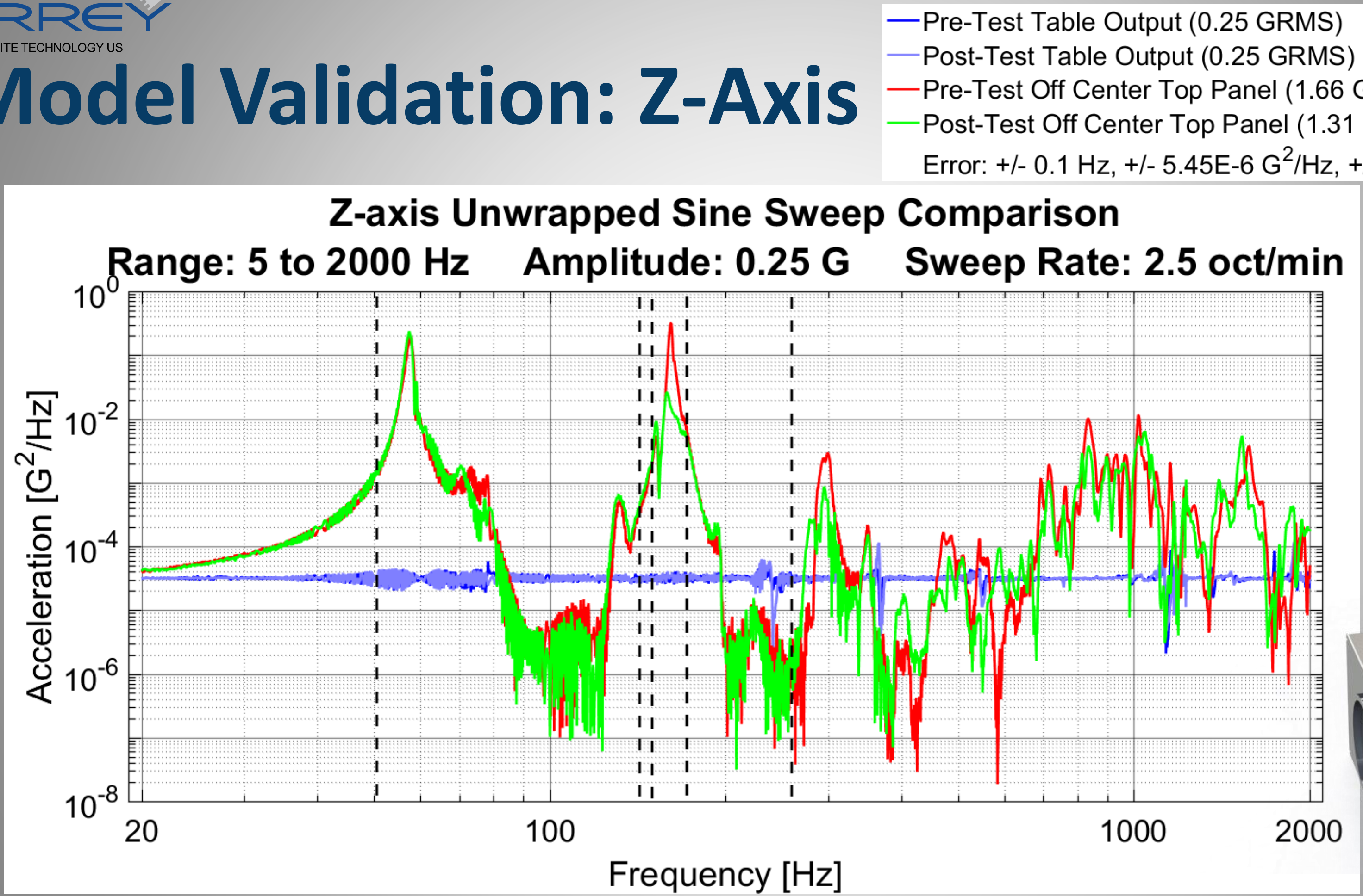
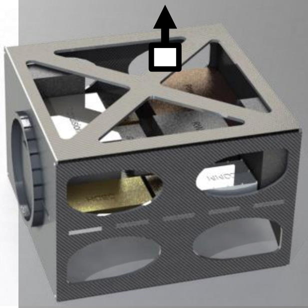
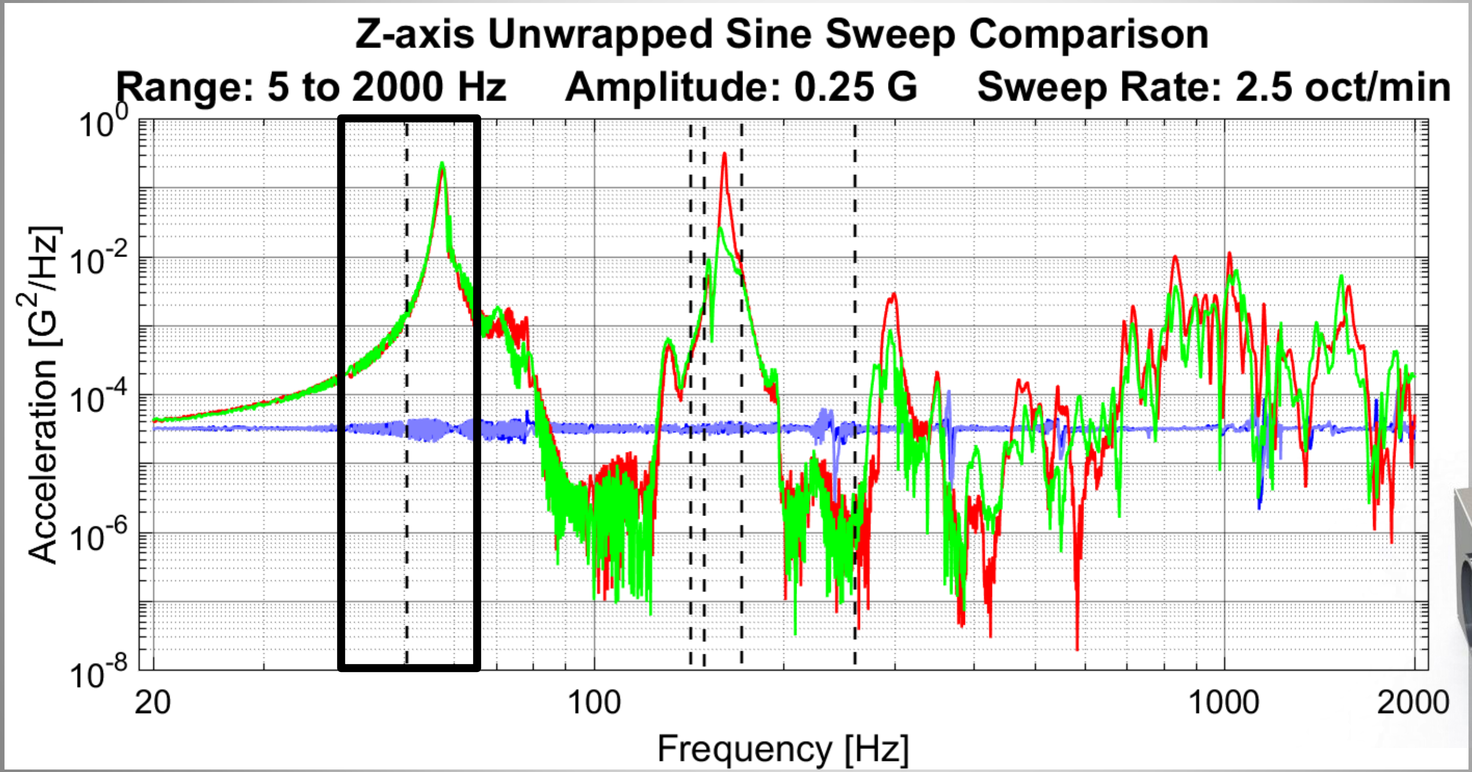
Were the natural modes of the STM what ANSYS predicted?

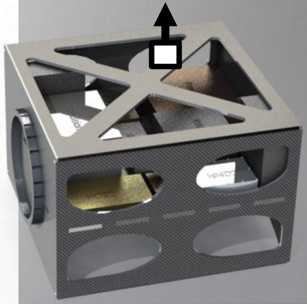
Model Validation: Z-Axis



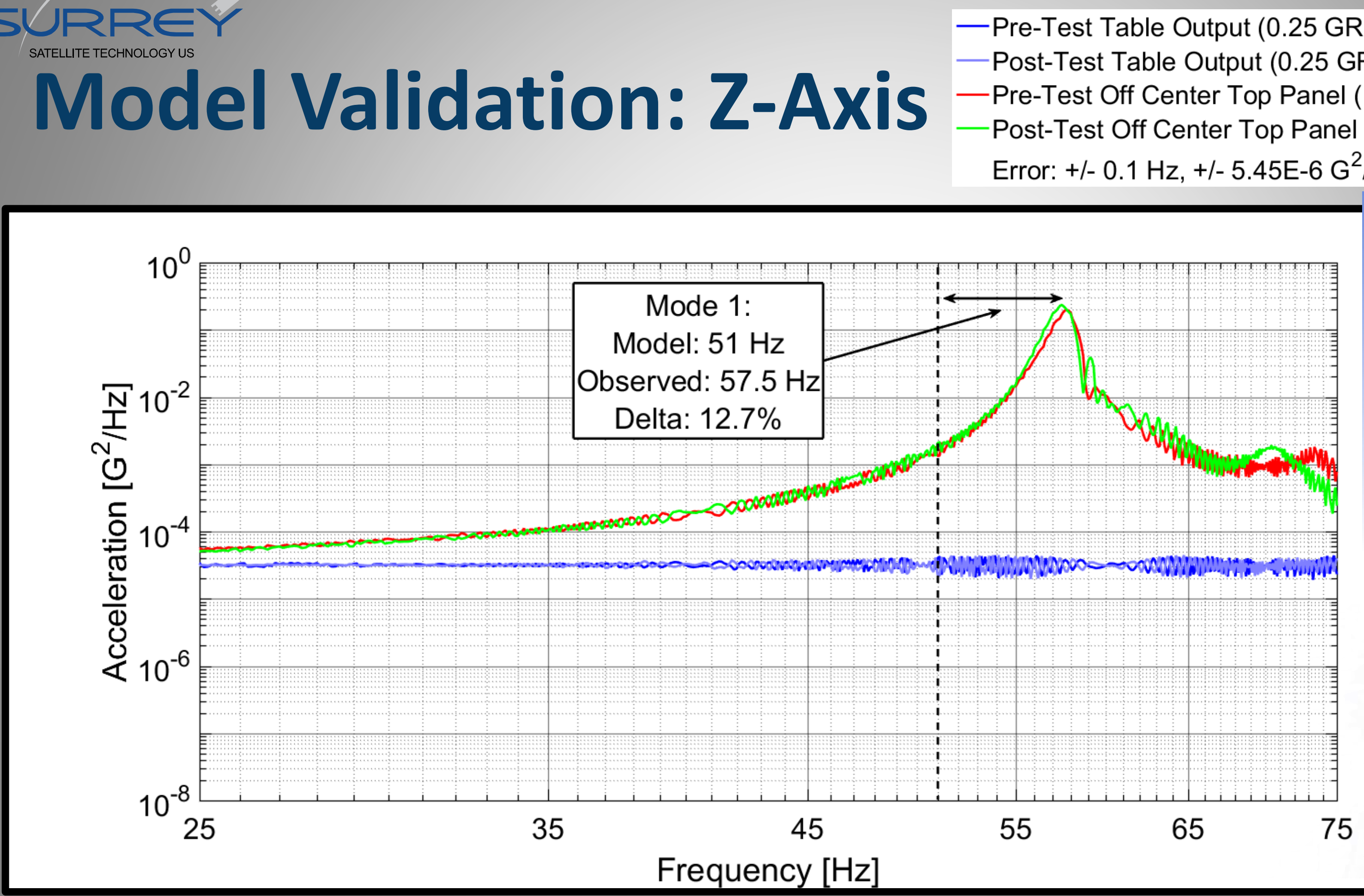


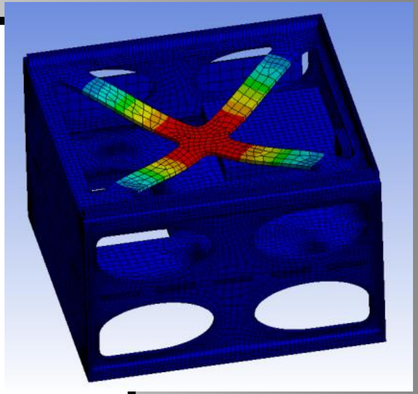
Model Validation: Z-Axis

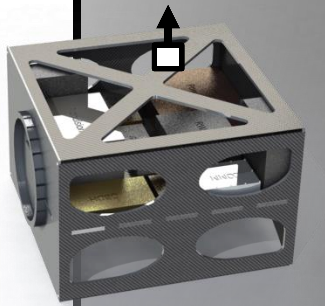




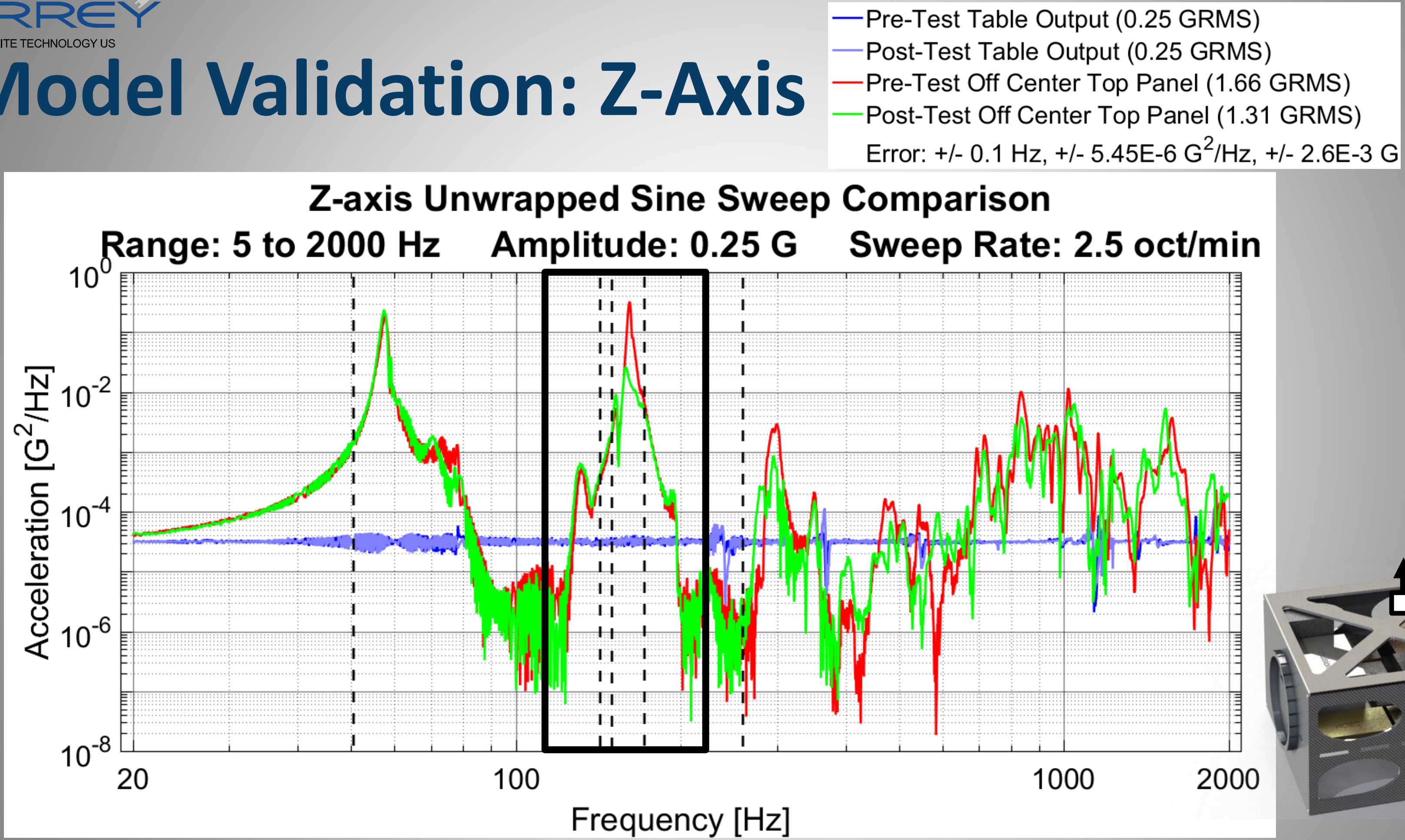
Model Validation: Z-Axis

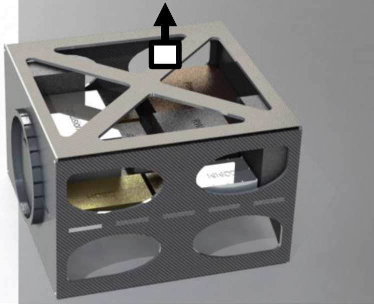




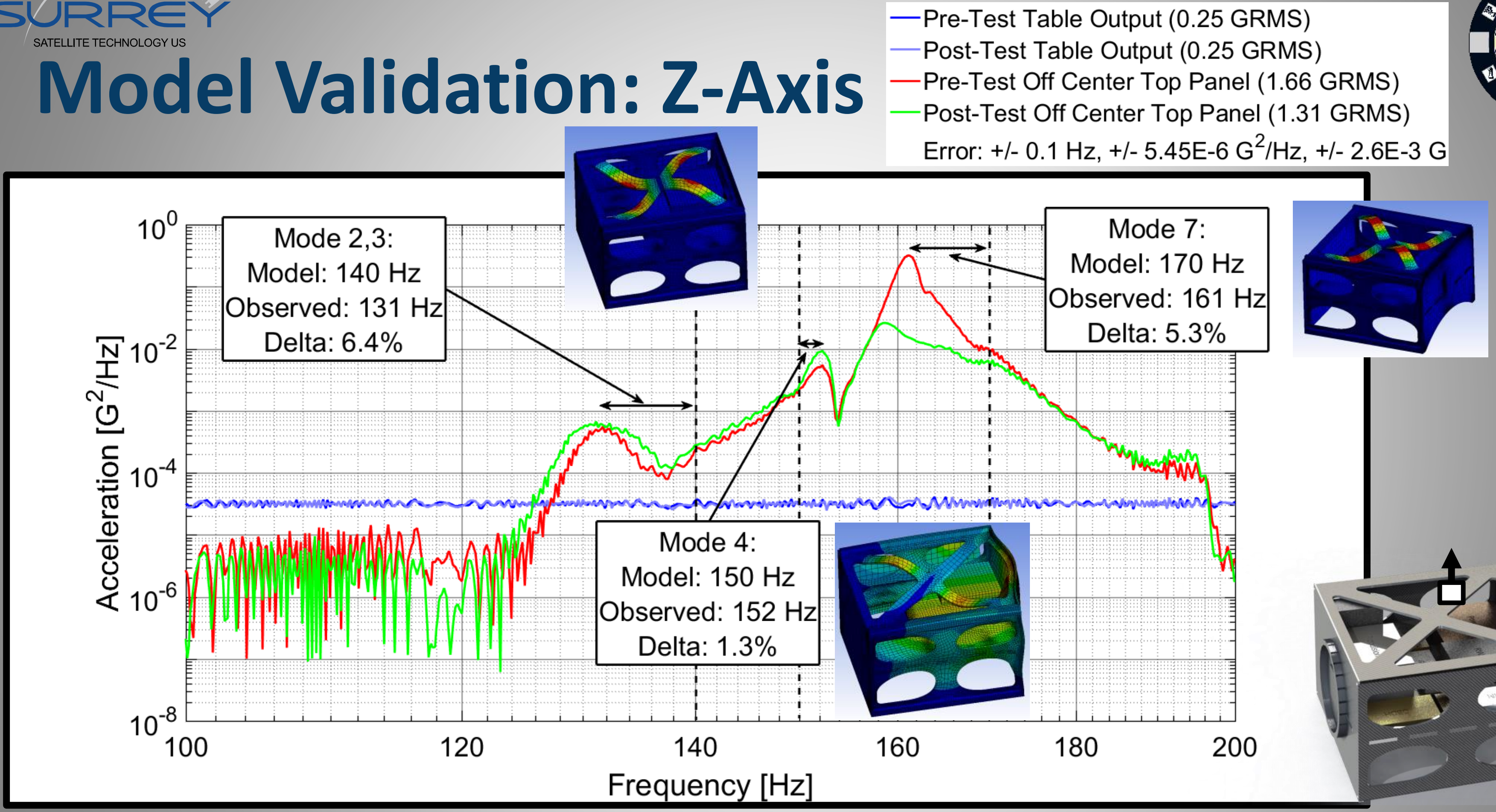


Model Validation: Z-Axis





Model Validation: Z-Axis



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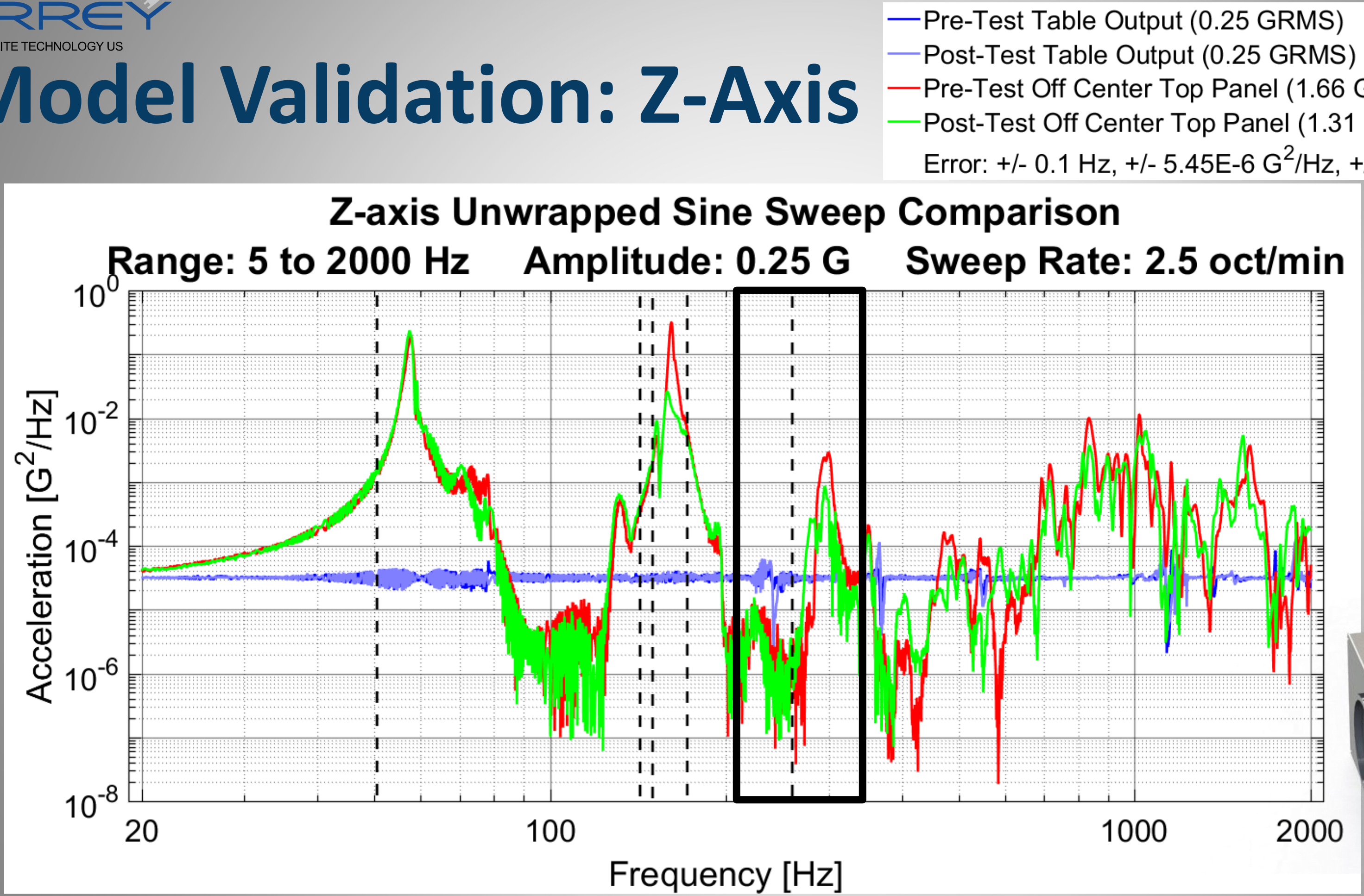
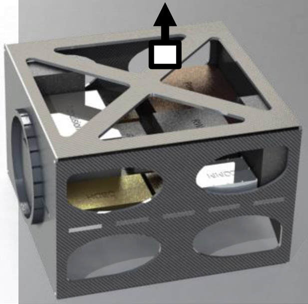
Model Validation: Z-Axis





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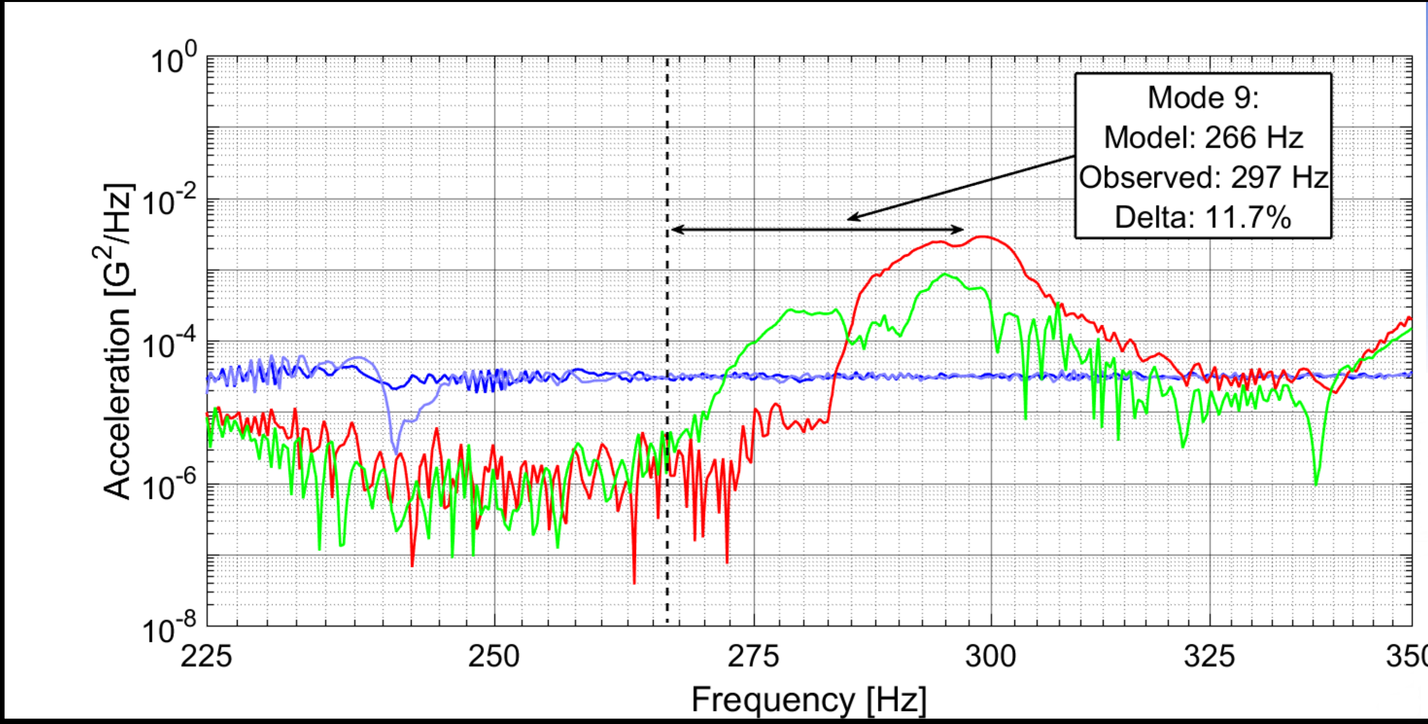
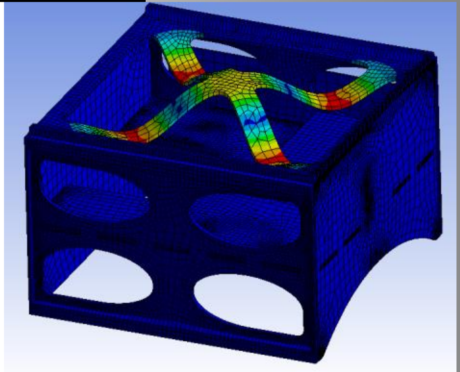
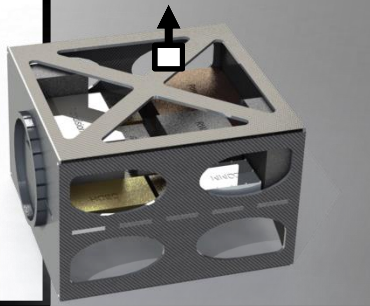
Model Validation: Z-Axis

Pre-Test Table Output (0.25 GRMS)
Post-Test Table Output (0.25 GRMS)
Pre-Test Off Center Top Panel (1.66 GRMS)
Post-Test Off Center Top Panel (1.31 GRMS)
Error: +/- 0.1 Hz, +/- 5.45E-6 G^2/Hz, +/- 2.6E-3 G







Modeling – Design validation:

- Predicting modes requires correct:
  - Material properties (stiffness, density)
  - Mass & Material distribution
  - Bonded connections
  - Boundary conditions
- 12% maximum error on predictions

Design Model Validated

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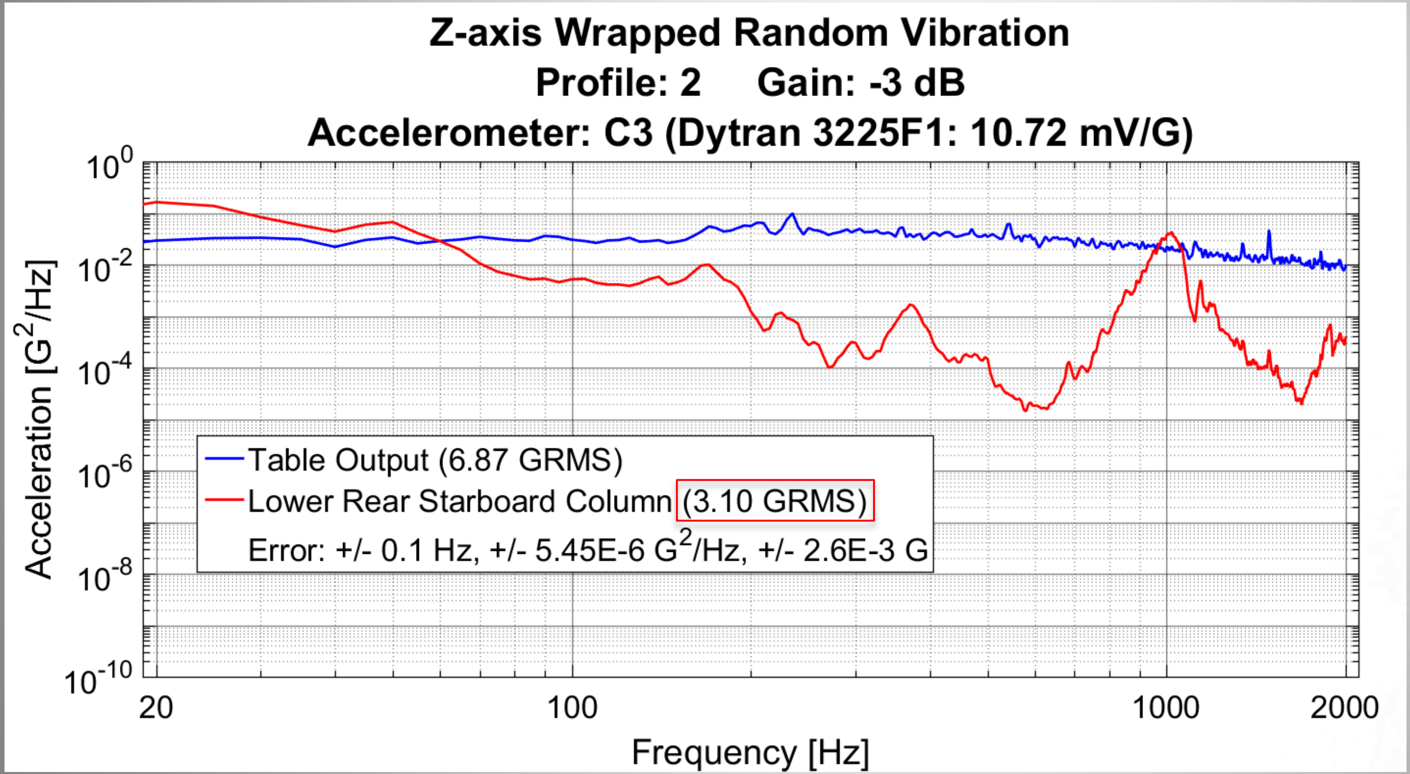
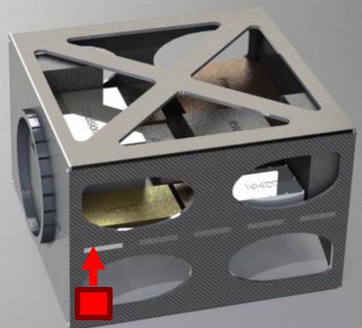
Will the structure survive launch to the ISS?

Random Vibration: Z



- 60 seconds at or above launch level survived in all 3 axes



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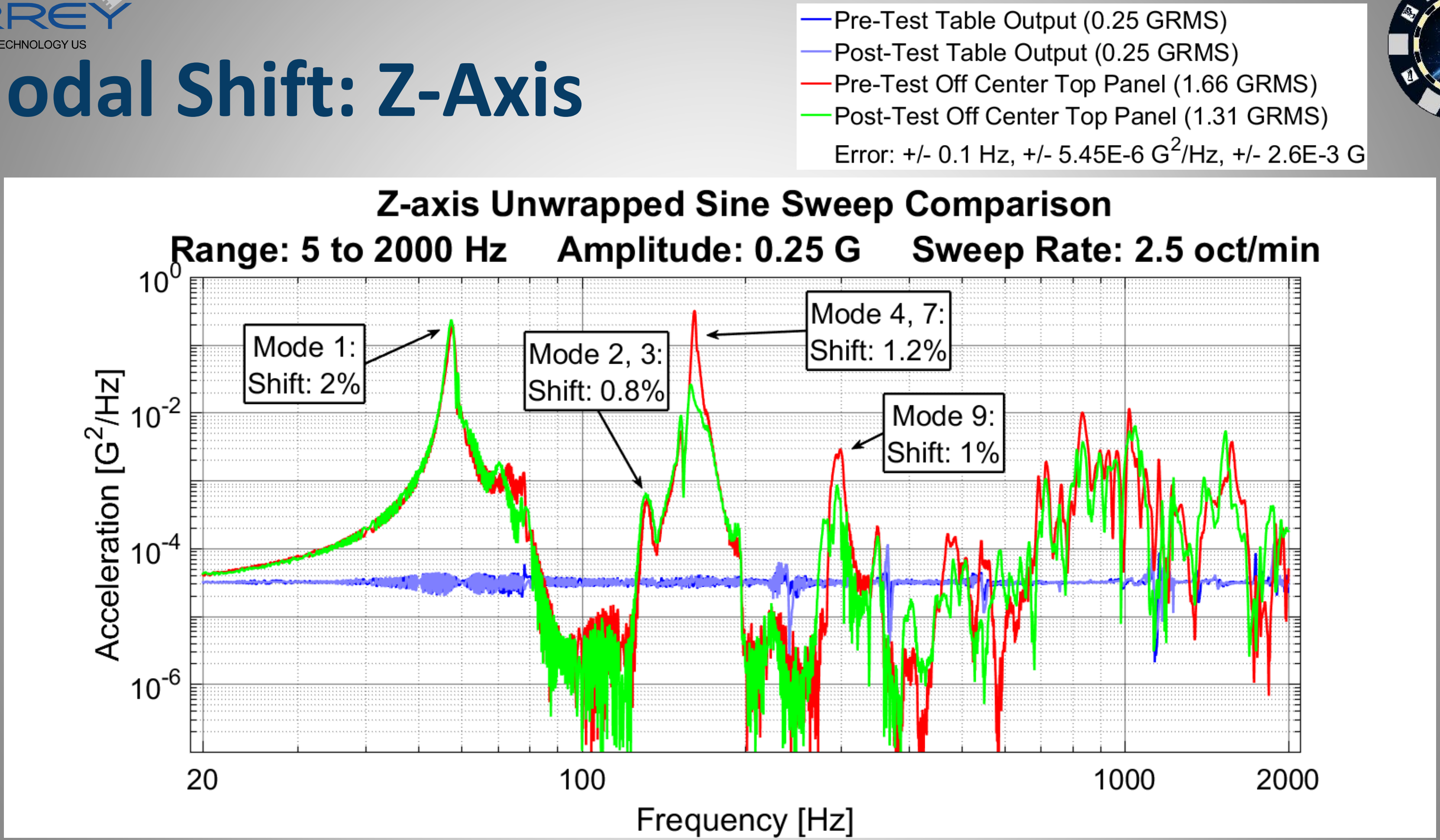
Modal Shift: Z-Axis



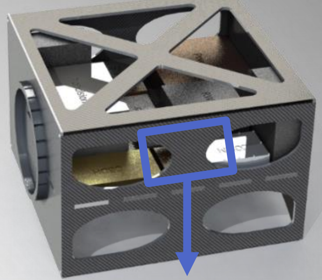
Survival & Failure Test:

- Random Vibration Loads
  - ≥ 1.29grms in all axes
- Failure Test: Z-axis
  - 4.7 grms for 60s
  - 9 grms max

STM survived launch qualification (DR 3.1)

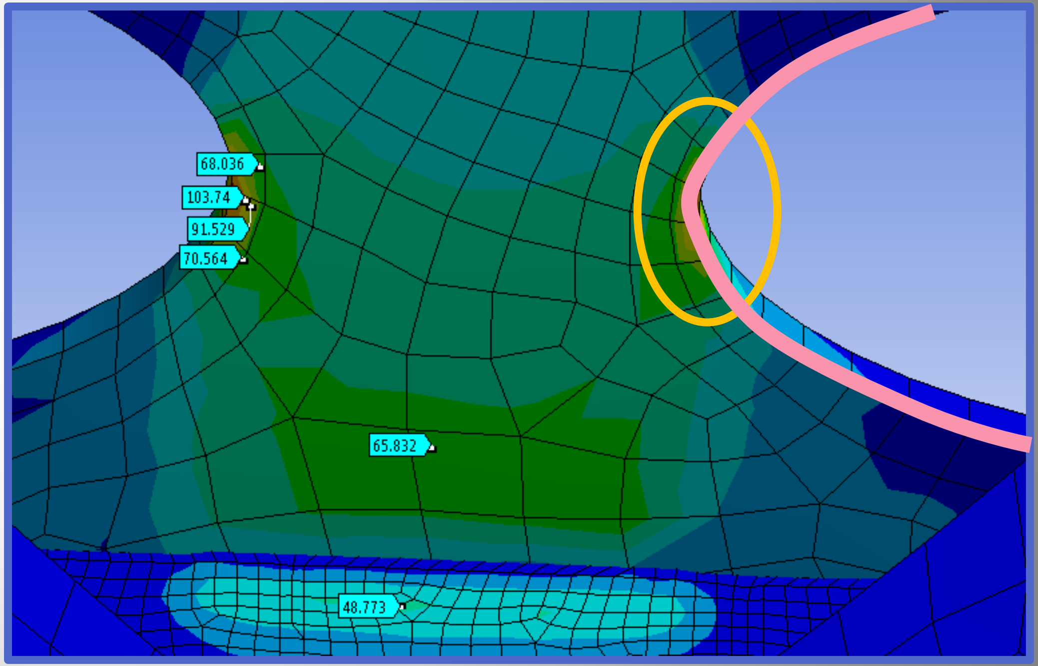
Why did the STM survive?

Explanation for Survival:



Survival at 9 grms:

- **1st Principles Analysis** is worst-case scenario.
- **Potting material** supports areas with concentrated stresses



Modeled stresses in side panel. Units in Mpa.
Failure Stress ~75MPa

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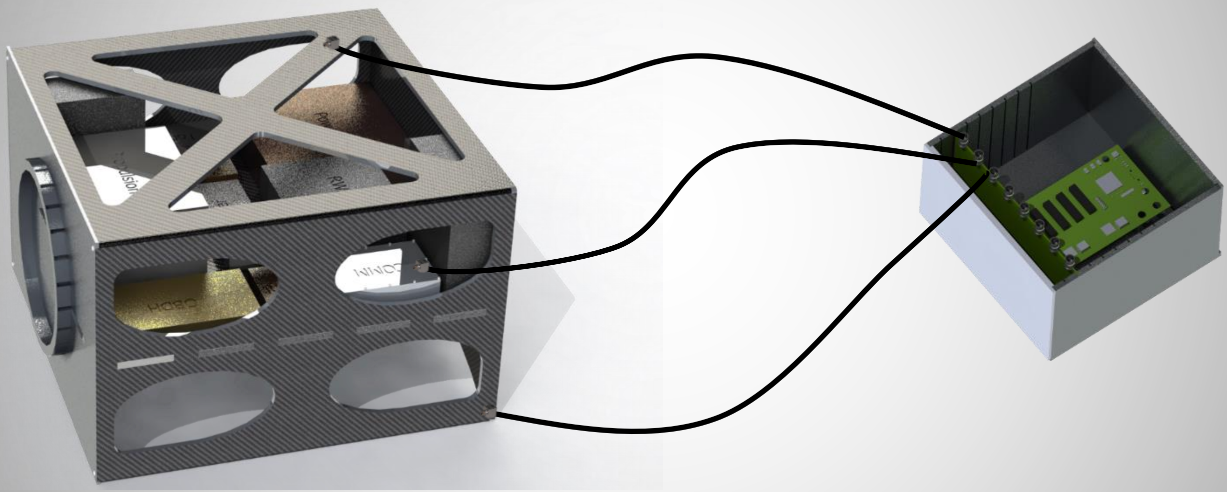
Vibration Test:

- **Model Correlation**
  - Max error 12%
- **STM Survived Launch Loads**
  - Max modal shift 4%
- **TRL of 4-5**



DAQ

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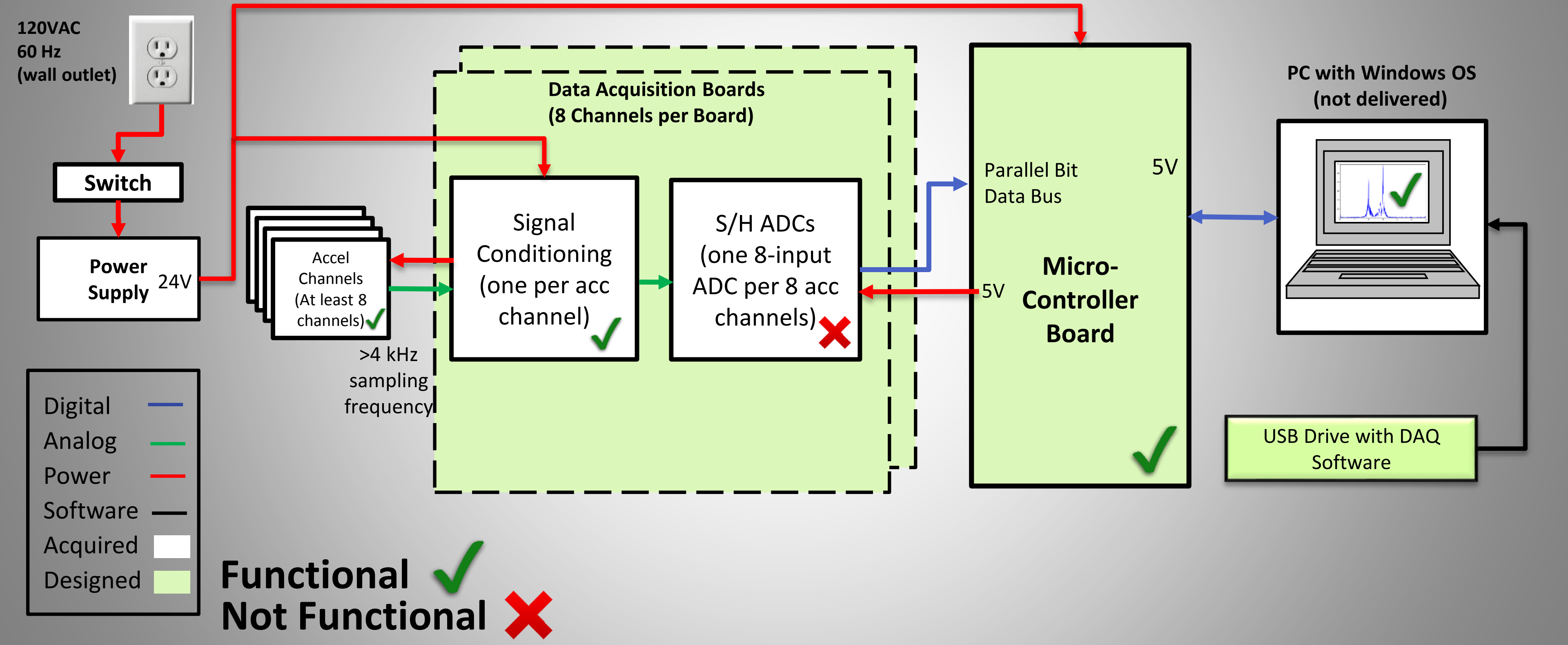
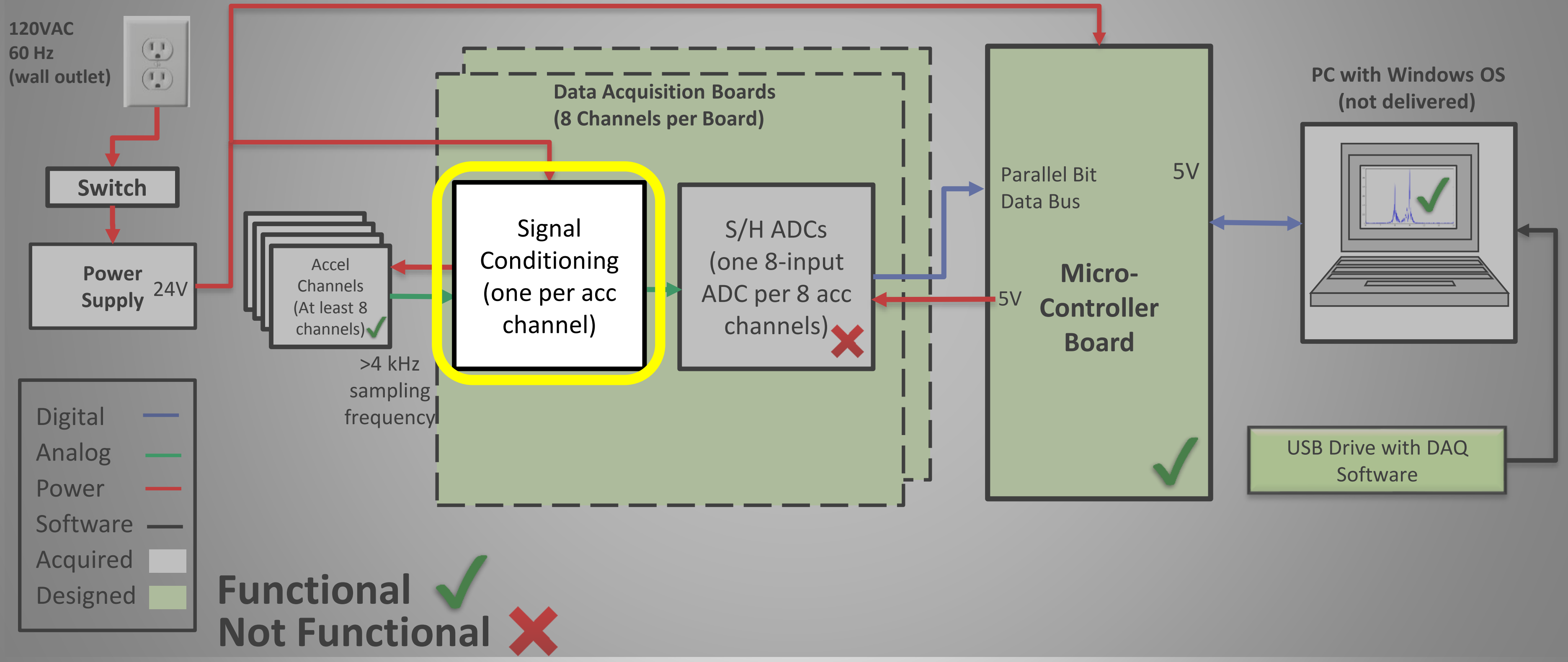
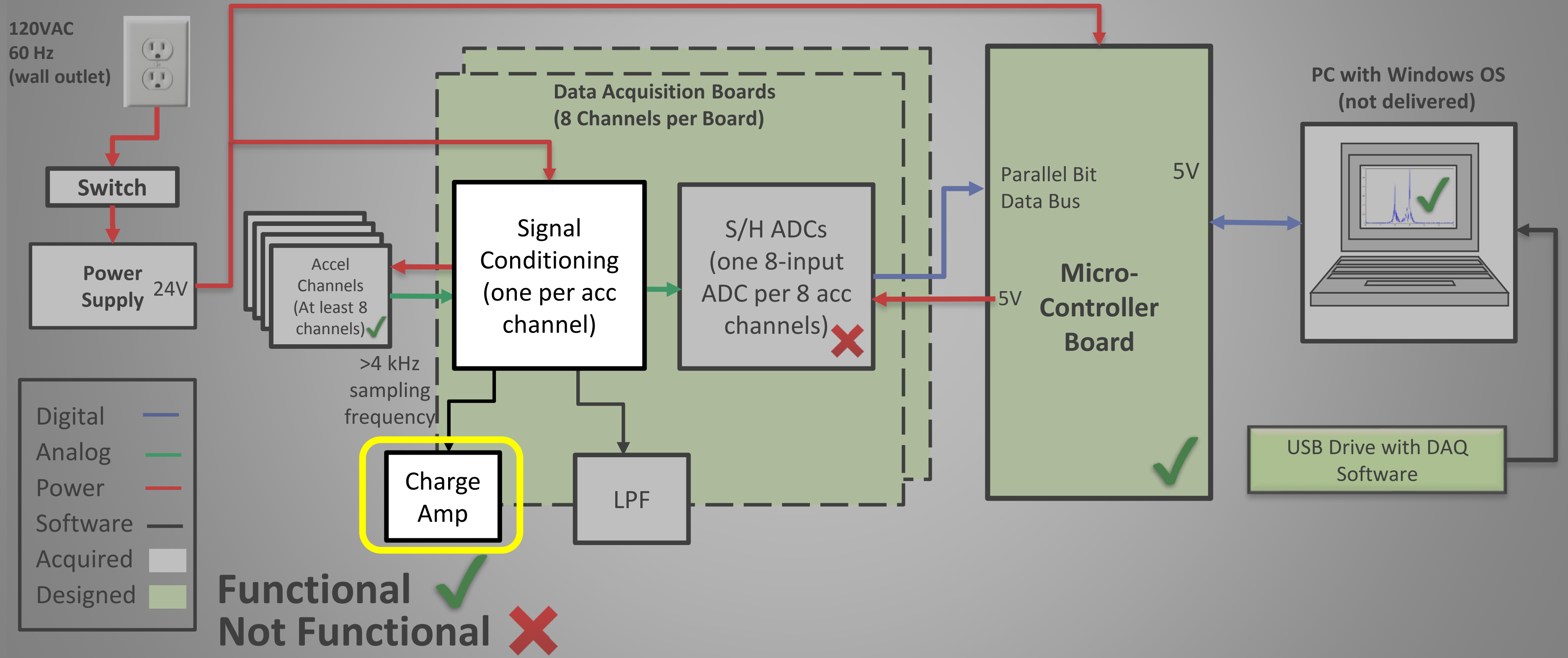
DESIGN

DAQ Hardware FBD:



TESTING OVERVIEW


120VAC
60 Hz
(wall outlet)
Switch
Power Supply
24V
Accel Channels (At least 8 channels)
>4 kHz sampling frequency
Data Acquisition Boards
(8 Channels per Board)
Signal Conditioning (one per acc channel)
S/H ADCs (one 8-input ADC per 8 acc channels)
Parallel Bit Data Bus
5V
5V
Micro-Controller Board
PC with Windows OS
(not delivered)
USB Drive with DAQ Software
Digital
Analog
Power
Software
Acquired
Designed
Functional
Not Functional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Charge Amp
LPF
Parallel Bit Data Bus
5V
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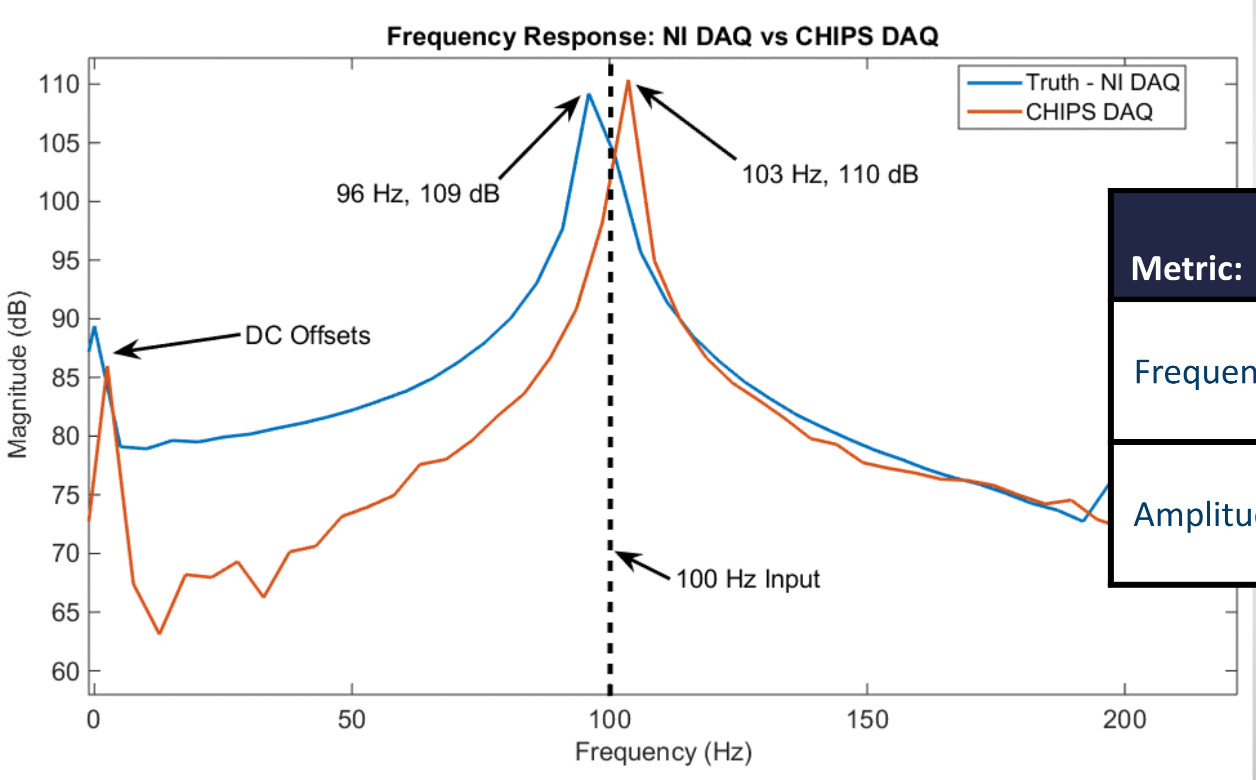
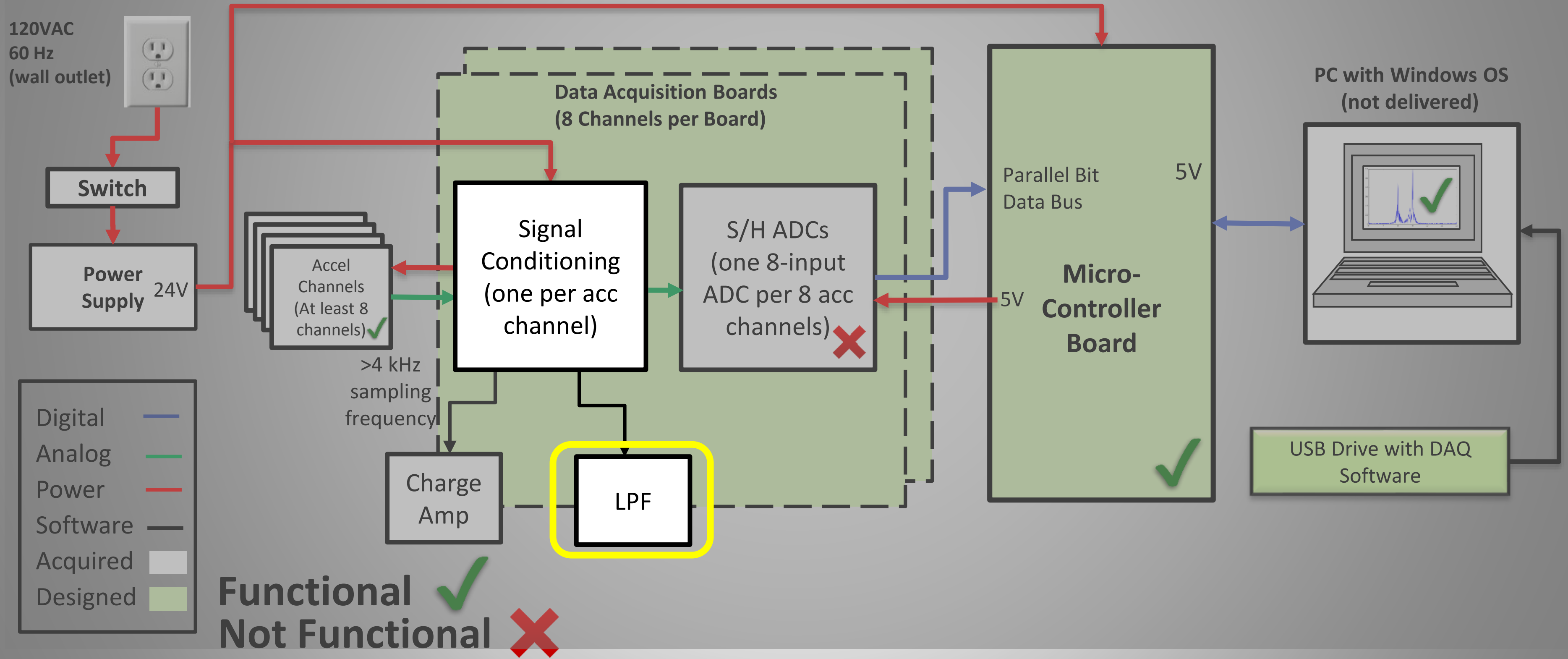
Charge Amplifier Output:



Metric:	Error:	% Error:	Within tolerances?
Frequency	7 HZ	~ 7%	Accounted for in error analysis (DR 5.6.3.1)
Amplitude	1 dB	~ 0.9 %	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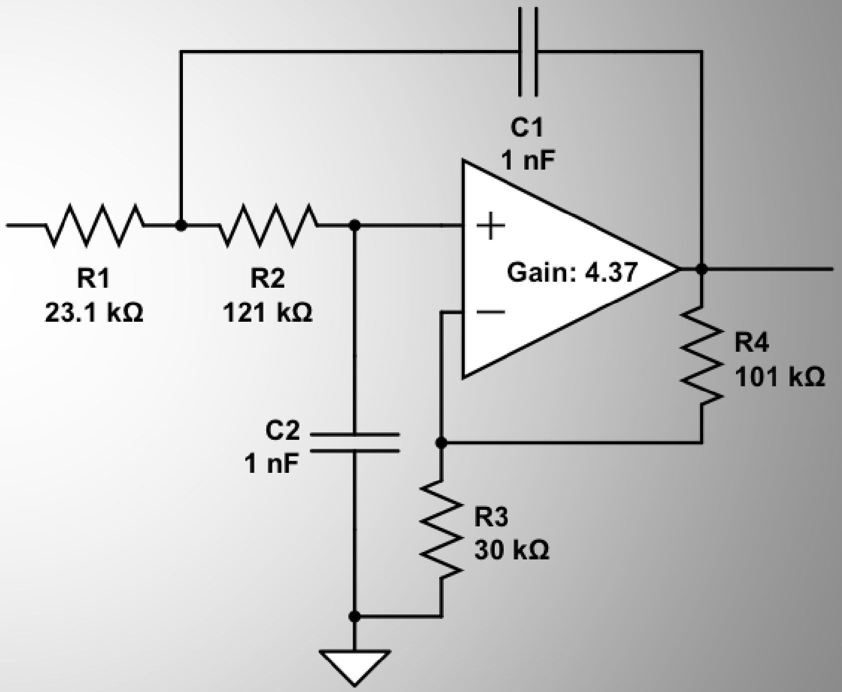
Low Pass Filter – Expected:

- Anti-aliasing
- **Gain: 4.37x**
- **f_{cutoff} = 3010 Hz**
    - Assumed infinite impedance
- 4 circuit op-amp



Low Pass Filter – Results:

f_{cutoff} = 3937 Hz

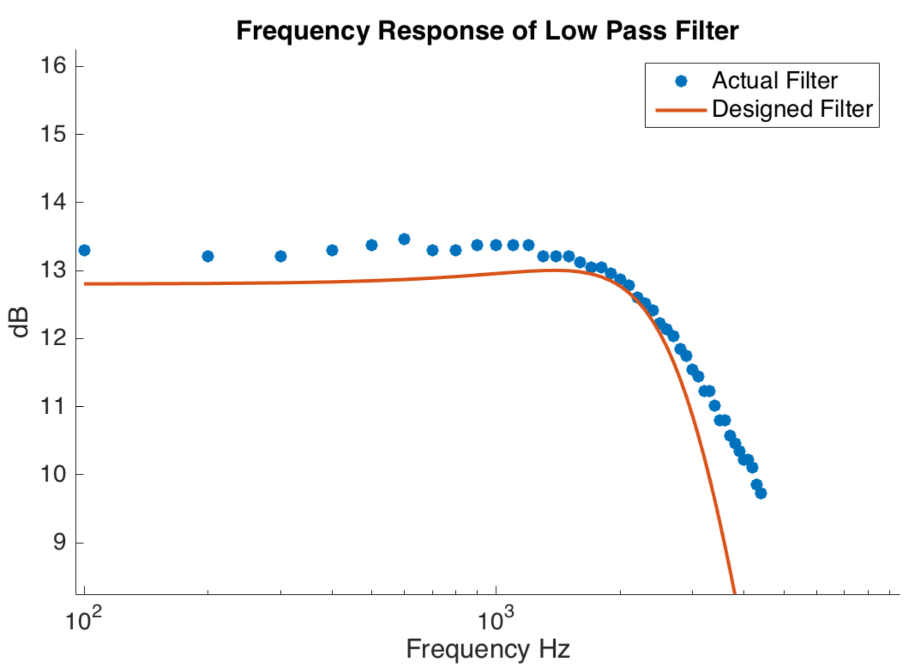
- Difference of 30.7%

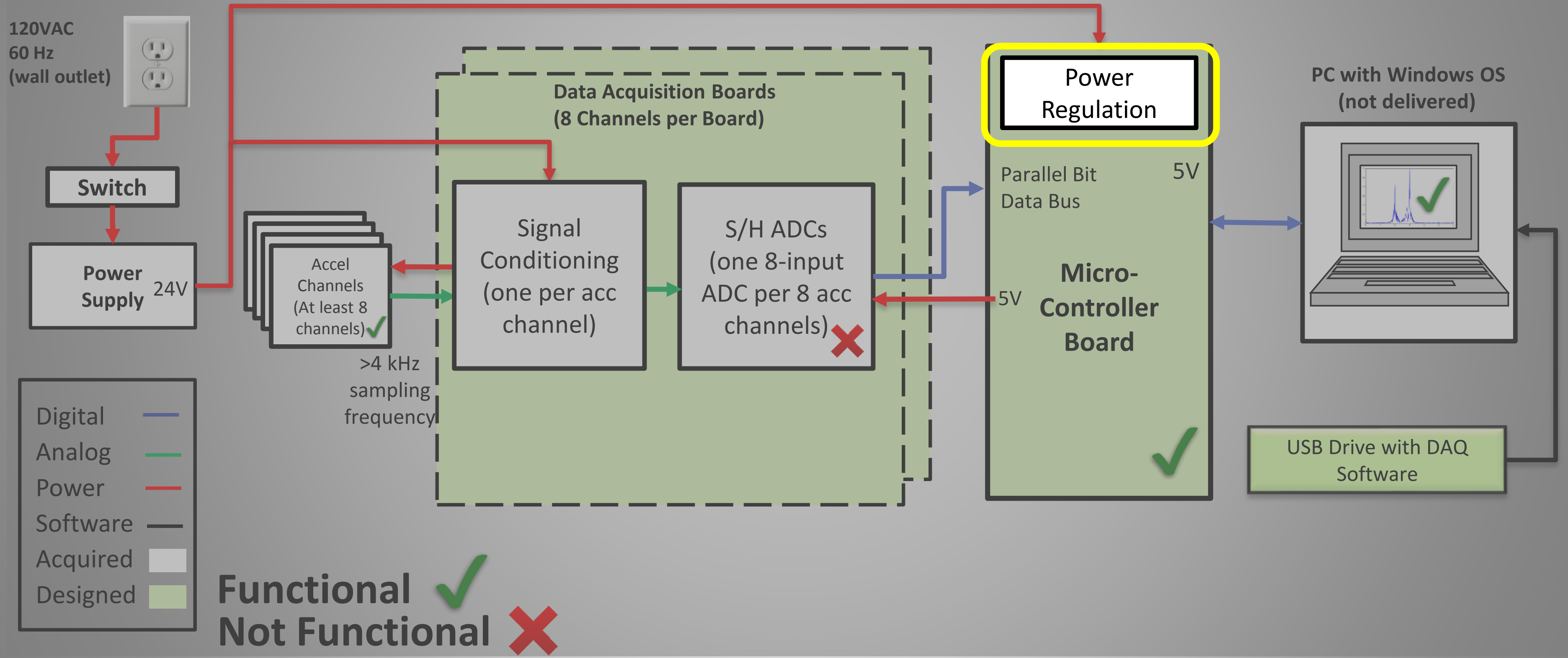
Handled with software

Gain: 4.62

- Difference of 5.72%
- DAQ will be able to measure up to 10.8 g

1.29 grms ≈ 6 g max
6 g < 10.8 g
(DR 5.6.3.2)





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60 Hz
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Power Supply
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Power Regulation
Parallel Bit Data Bus
5V
5V
Micro-Controller Board
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(not delivered)
USB Drive with DAQ Software
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Power
Software
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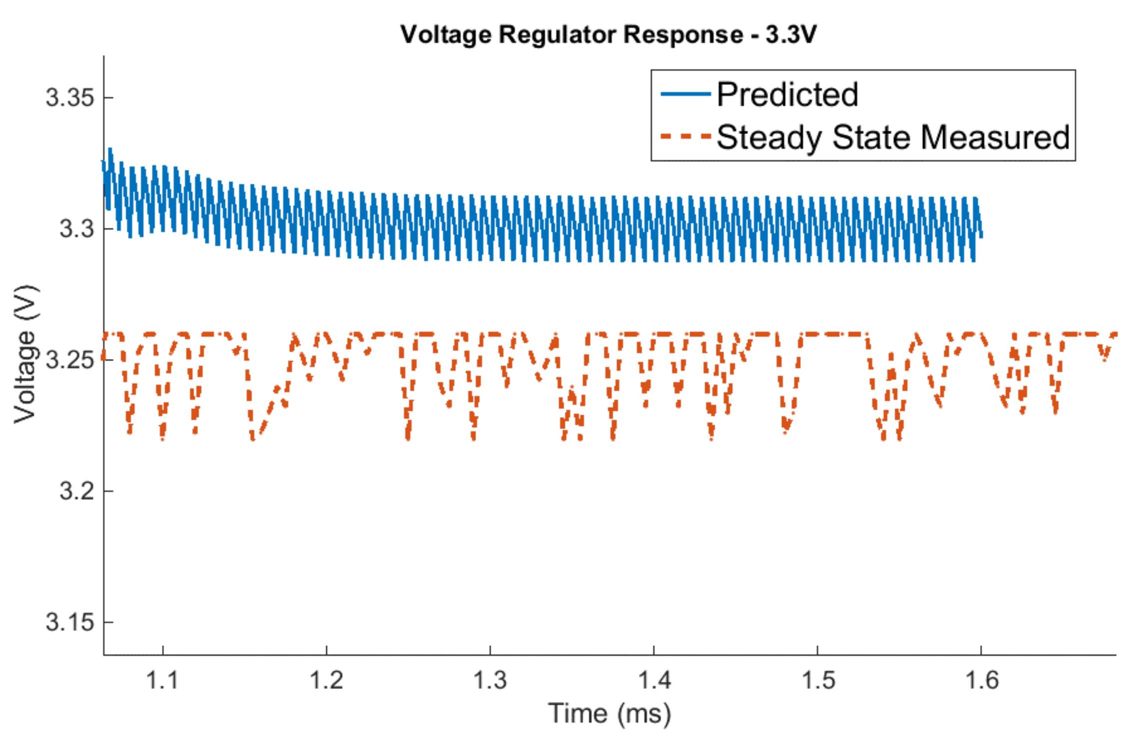
Not Functional

Power Regulation – 3.3V:



Component Metric:	Metric Value:	Within tolerance?
PIC32 Power	2.3 - 3.6 V	✓
ADC Logic Voltage	2.3 - 5.25V	✓

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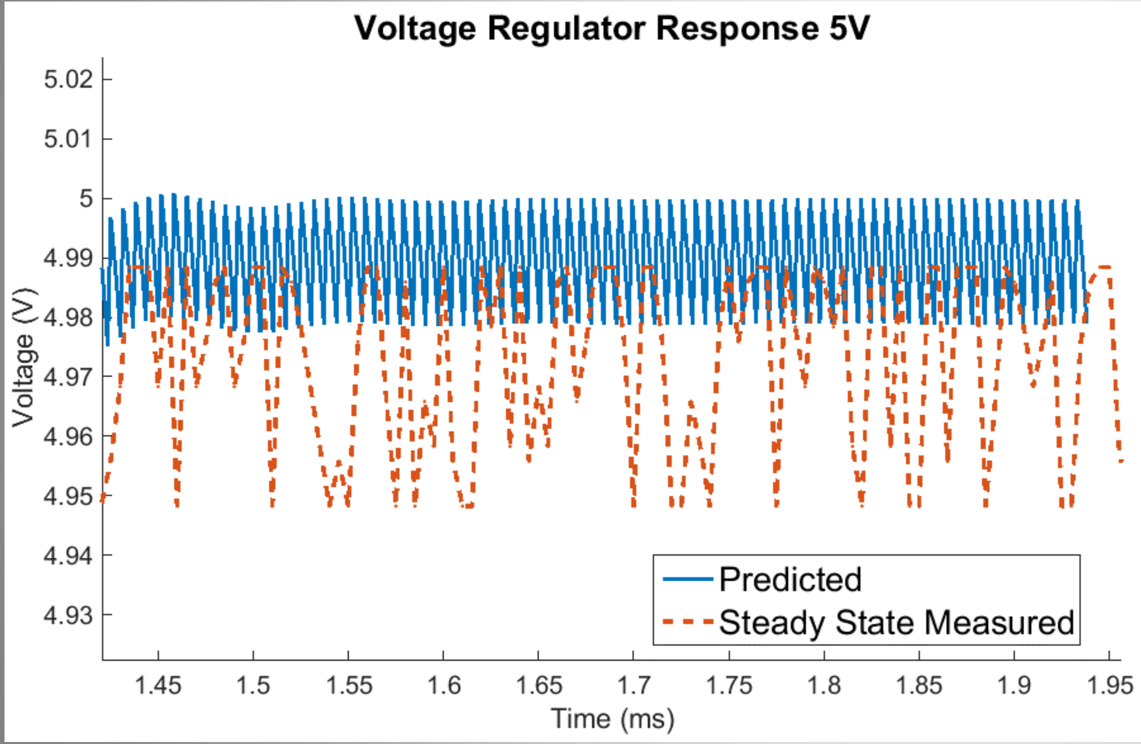
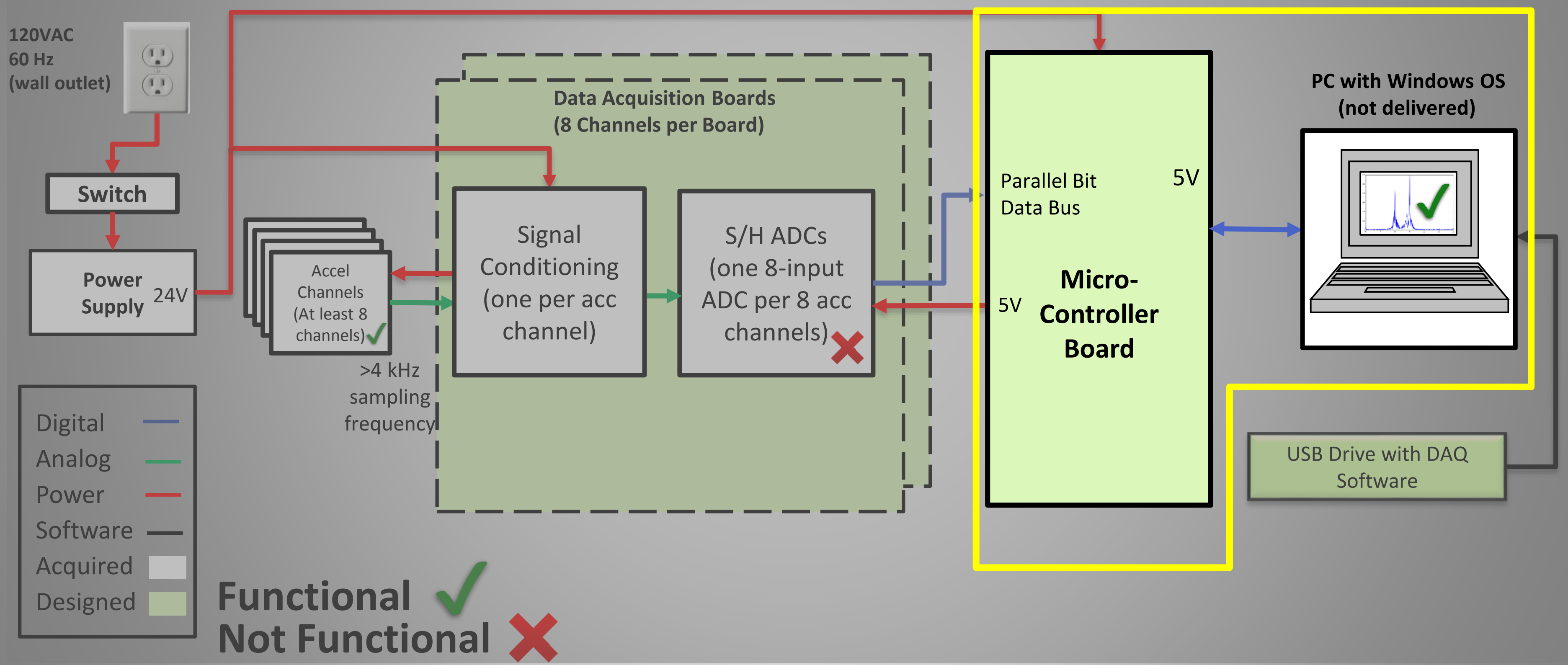
Power Regulation – 5V:



Component Metric:	Metric Value:	Within tolerance?:
ADC Power	4.75 - 5.25 V	✓
Op Amp Power	2.7 – 5.5 V	✓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Analog
Power
Software
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Functional
Not Functional

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DAQ Results: Data TX between µC and PC:

```
int main
{
        SYS_Initialize();
        while(true)
        {
            SYS_Tasks();
            if(time to sample)
            {
                  Tell ADC to Convert and hold
                  for each DAQ Board (8x)
                  {
                        for each channel on ADC (8x)
                        {
                              read and store data into a temporary buffer
                        }
                  }
                  store temporary buffer into alternating data buffers that
                  will be sent to the USB endpoints where PC polls for the data
            }
        }
}
```

4.4 µs

Sample every 50µs (20kHz)

4.28 µs

0.34 µs

45.4 µs

38.5 µs

4.1 µs

0.098 µs

- ADC sampling routine: 45.4 µs
- System Tasks: 4.4 µs
- 49.8 µs total loop time
- Maximum sampling rate is <u>**20080 Hz**</u>

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DAQ Results: Data TX between μC and PC

```
int main
{
        SYS_Initialize();
        while(true)
        {
            SYS_Tasks();
            if(time to sample)
            {
                  Tell ADC to Convert and hold
                  for each DAQ Board (8x)
                  {
                        for each channel on ADC (8x)
                        {
                              read and store data into a temporary buffer
                        }
                  }
                  store temporary buffer into alternating data buffers that
                  will be sent to the USB endpoints where PC polls for the data
            }
        }
}
```

4.4 μs

Sample every 200μs (5kHz)

4.28 μs

0.34 μs

45.4 μs

38.5 μs

4.1 μs

0.098 μs

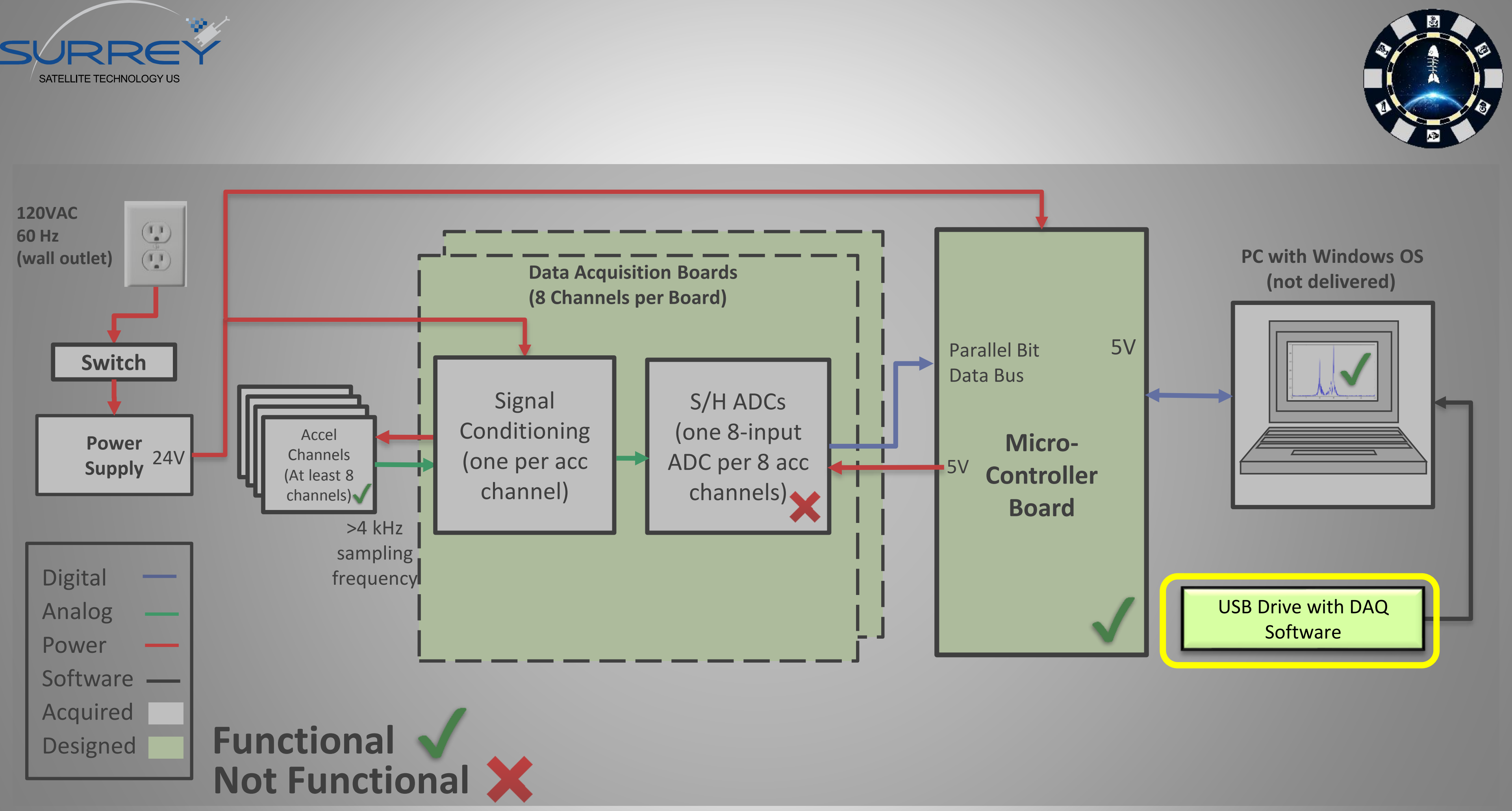
Limited by PC processing so sampling rate is set to 5000 Hz.

Data TX between µC and PC

- Minimum required sampling rate based on Nyquist Theorem: 250µs, **4 kHz**
- Initial calculation of effective sampling time: every 83 µs, 12 kHz
- Due to PC memory limitations, maximum sampling rate with PC is 200µs, **5 kHz**

DAQ System Timing Specifications

Metric:	Required (DR 5.6.3.5)	Predicted:	Actual:
Sampling Time	250 µs	83 µs	200 µs
Sampling Rate	4 kHz	12 kHz	5kHz ✓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DAQ SW Results:

Component:	Requirement:	Observed:
Real-Time-Plot Refresh Rate [Hz] (DR 5.6.4)	0.2 to 2	1
Data Capacity [# of double precision pairs] (DR 5.6.3.5)	19.2E6	48E6

Non-numeric capabilities:

- Excel compatible reports (DR 5.6.5)
- Single file executable
- Conversion from temporal data to frequency domain PSD (DR 5.5.2)
- Optional notch filtering
- Graphical User Interface (GUI)
- Limits checking per channel

SYSTEMS

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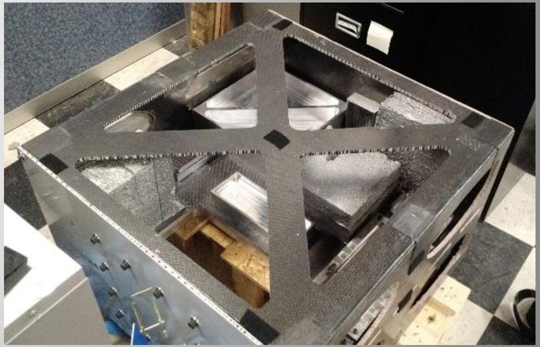
Systems Engineering Approach

- Structure and DAQ were developed separately
  - **Requirements** defined early and had no major changes
  - Structure explored **trade space** and used a hybrid of designs from CDD
  - DAQ determined **key components** (microcontroller, accelerometers, and software) first and designed boards and integration next
- **ICDs** used for Surrey Components
  - Mass and size of **component analogs** and their placement
  - Not as necessary within subsystems
- Communication with Customer
  - Change in vibration profile did not affect our levels of success
  - DAQ functionality can be completed after structure test



Mass analogs integrated with structure

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Risk:

CDR Risk Matrix

Severity

Likelihood	1	2	3	4	5
5					
4					
3	1,7,12				
2		16	4,17		8
1	3, 9	5,6,13,15		10,11,18, 19	2,14

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Risk:

CDR Risk Matrix

Severity

Likelihood	1	2	3	4	5
5					
4					
3	1,7,12				
2		16	4,17		8
1	3, 9	5,6,13,15		10,11,18, 19	**2** 14

2. Structure Fails on the way to vibration test – Did not consider transport in and out of car

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Risk:

CDR Risk Matrix

Severity

Likelihood	1	2	3	4	5
5					
4					
3	1,7,12				2
2		16	4,17		8
1	3, 9	5,6,13,15		10,11, **18** **19**	**14**

14. USB Protocol is not fast enough
18. Power distribution fails or destroys components
19. Microcontroller cannot be programmed
All reduced in severity because of NI DAQ

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Risk:

CDR Risk Matrix

Severity

Likelihood	1	2	3	4	5
5					
4					
3	1,7,12		**20**		2
2		16	4,17		8
1	3, 9	5,6,13,15	14, 18, 19	10,11	

20. Integration between boards -
Should have been identified earlier

Lessons Learned:

- Manufacturing and **integration process** must be taken into account when designing
  - Difficulty in DAQ soldering
  - Gluing hard-to-reach parts of structure
- Requirements should be explicit about **subsystem dependencies** – did the DAQ need to be verified through our vibration test or afterwards?
- Every person should be a part of **multiple teams** to spread out work to alleviate the burden on one person for an entire subsystem

PROJECT MANAGEMENT

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Approach:

Advisor: Joe Tanner

Customer: Michael Brown, SST-US

Management

Project Manager: Megan Howard

Systems: Maggie Williams

Financial: Taylor Maurer

Structure

- Lewis Gillis – Modeling Lead
- Andrei Iskra – Structure Lead
- Evan Graser – Testing Lead
- Megan Howard
- Maggie Williams

DAQ

- Jorge Cervantes – Electrical Lead
- Larry Burkey – Software Lead
- Davis Peterson
- Taylor Maurer

3 sub-teams:

- Management
- Structure
- DAQ

Weekly Meetings:

- Team – update status/allocate work load
- Customer – update
- Advisor – update

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Lessons Learned:

Structure

- Seemingly small design changes have cascading effects

DAQ

- Scheduling for de-bugging time is very difficult
- There is a trade off between cost and heritage/quality in a DAQ.

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Budget:

Category:		CDR:	Final:	Difference:
Available	ASEN Budget	$5000		--
	EEF Budget	$2000		--
	Total	**$7000**		--
Spent	Structure	$4114	$3968	-$146
	DAQ	$1912	$1928	+$16
	Built in Margin/Shipping/Printing	$250	$414	+ $164
	Testing	$389	$389	$0
	Total	**$6665**	**$6699**	**+$34**

- Only $34 above CDR estimate
- Margin built in at CDR helped offset shipping cost

$301 under budget

Industry Cost:

Assumptions:

- Salary of $65,000 for 2080 hours of work
- Overhead cost is 200% of cost of labor

Team average per Week:	171 hours
Total Hours:	4459 hours
Labor Cost:	$139, 336
Overhead Cost:	$278, 672
Materials & Testing Cost:	$10,226
Total Industry Cost:	**$428,234**

Material & Testing Details:

STM:	$4030
DAQ:	$2007
Testing:	$2189
Mass Analogs*	$2000

*Mass analogs based on material cost estimate for aluminum and steel found in Aerospace Shop

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Acknowledgements:

Engineering Excellence Fund

CASCADE TEK™
FRONT RANGE

Aerospace Engineering
CU

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QUESTIONS?

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References:

[1] Materion Coroporation. AlBeMet Property Datasheet. Elmore, OH: Beryllium & Composites, n.d. Print.

[2] Sandwich Panel Fabrication Technology. N.p.: Hexcel Composites, 2001. Print.

[3] Honeycomb Sandwich Design Technology. N.p.: Hexcel Composites, 2000. Print.

[4] Roark, Raymond J., and Warren C. Young. Formulas for Stress and Strain. New York: McGraw-Hill, 1975. Print.

[5] Microchip. PIC32MZ Embedded Connectivity with Floating Point Unit (EF) Family. Phoenix AZ: Microchip, n.d. PDF.

[6] PCB Piezotronics. Aerospace Ground Test. Depew, NY: PCB Piezotronics, n.d. PDF.

[7] ST Microelectronics. MEMS digital output motion sensor ultra low-power high performance 3-axes “nano” accelerometer. n.p.: ST Microelectronics, 2010. PDF.

[8] PCB Piezotronics. Quote: SGL11887. Depew, NY: PCB Piezotronics, 2015. PDF.

[9] “ Alloy A286” Delta Fastner Corp. Web. 27 Sept. 2015.. <http://www.deltafastener.com/a286.html>

[10]“The Use of Silicone Adhesives in Space Applications” Adhesives and Sealant Industry. Web. 27 Sept 2015. <http://www.adhesivesag.com/articles/85082-the-use-of-silicone-adhesives-in-space-applications>

[11] “Kaber Small Satellite Deployment System” NanoRacks. Web. 26 Sept 2015. http://nanoracks.com/wp-content/uploads/Kaber-Small-Satellite-Deployment-System-Presentation.pdf

[12] “Sandwich Panels”. ACP Composites. Web. 22 Sept 2015. < http://www.acpsales.com/Carbon-Fiber-Sandwich-Panels.html>

[13] “Spacecraft Thermal Control – Chapter 6” 2011. Print.

[14] “Salary of Aerospace Technicians”. Glass Door. Wed. 15 Nov 2015 https://www.glassdoor.com/Salaries/aerospace-technician-salary-SRCH_KO0,20.htm

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Slide Index:

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Back-Up Slide Index:

BACK-UP SLIDES

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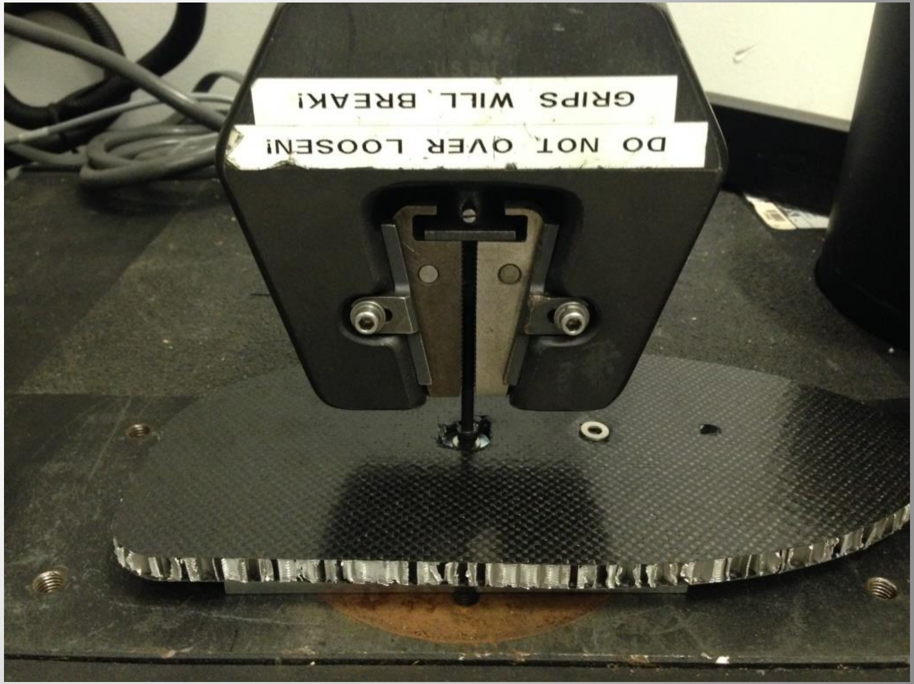
Compression of Radiator Panel at the Tube to Panel Interface:

Purpose: Determines if a compression sleeve is necessary (maximum expected load 4300 N)

Results: compression sleeve may be added to the assembly to carry preload and vibrational loads through the interface (panel fails at 1600 N with 1” washer)



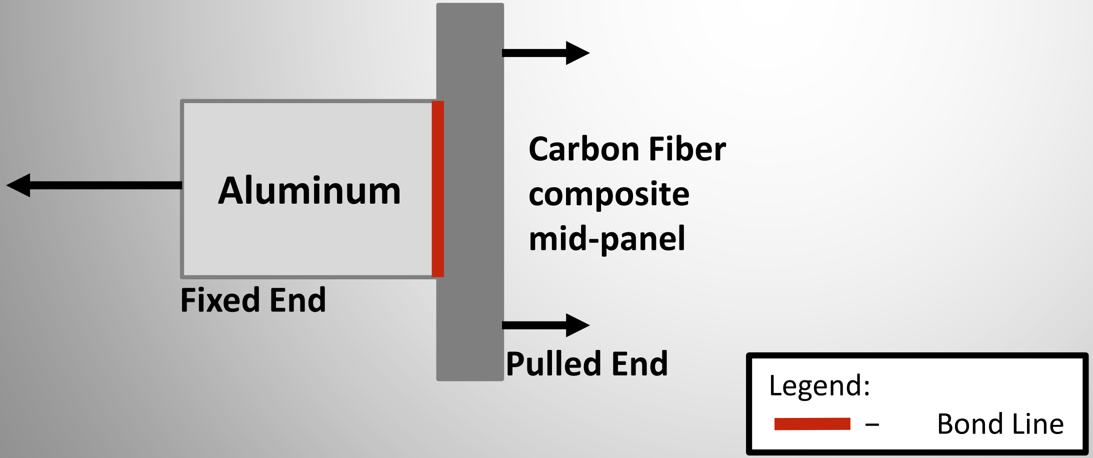
Tube Inserts Bonding Line Test:

Purpose: Quantify the performance of tube insert, and find failure load for the design.

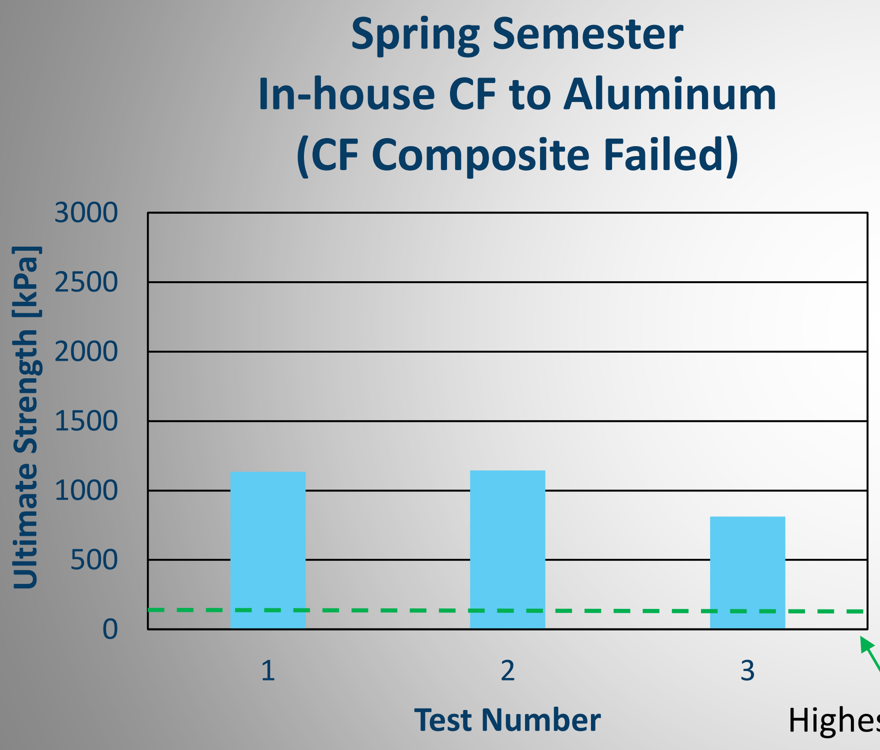
Result: Qualified the interface to twice the maximum expected load (8800 N)

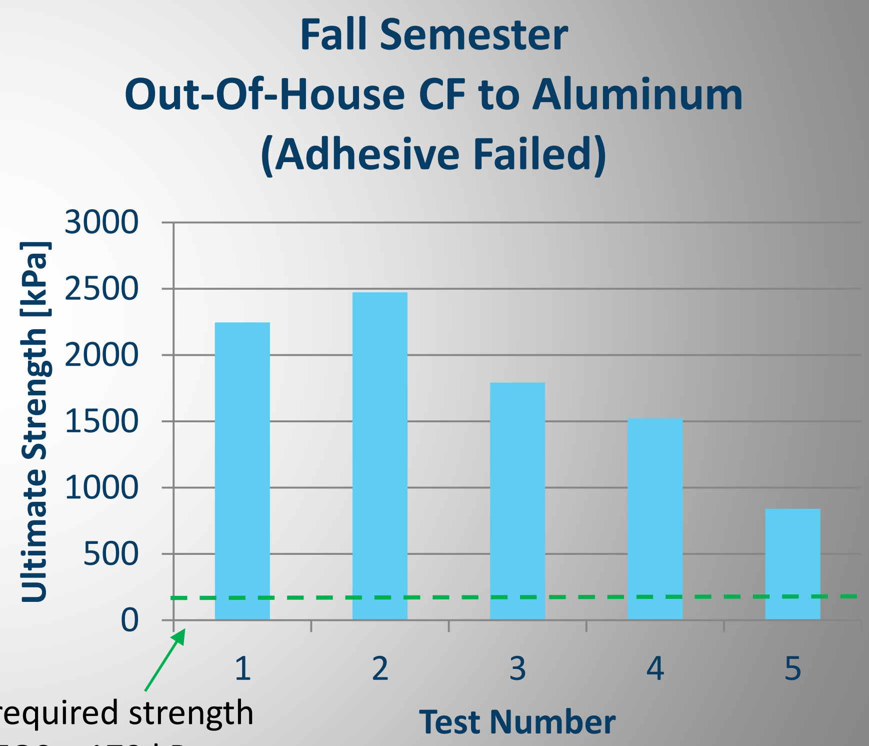
Adhesive Test Results:

- Tested mid-panel to aluminum bond in tension
  - Purpose: Verify expected glue strength can be achieved with manufactured carbon fiber
  - **Results: mid-panel deflected or failed before glue showed any failure. Still at 78% margin**



Adhesive Tension Test Results:

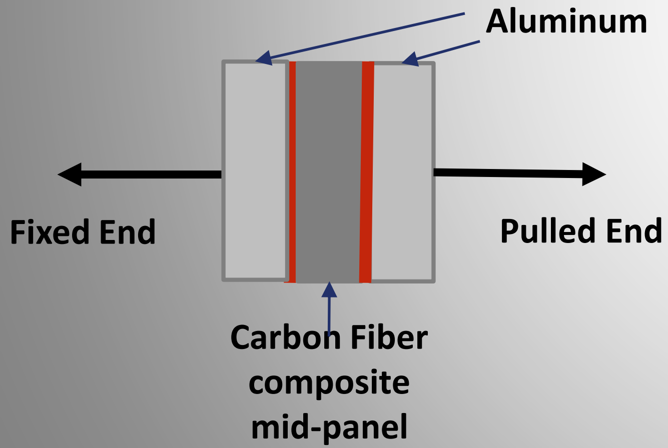




Highest required strength
with FOS = 179 kPa

Delamination Test Results:

- Tested aluminum to mid-panel to aluminum bond in tension
  - Purpose: Determine the expected mode of failure between the interfaces on the mid-panel
  - **Results: bond between aluminum honeycomb and carbon fiber failed but still higher margin than adhesives**



Legend:
– Bond Line

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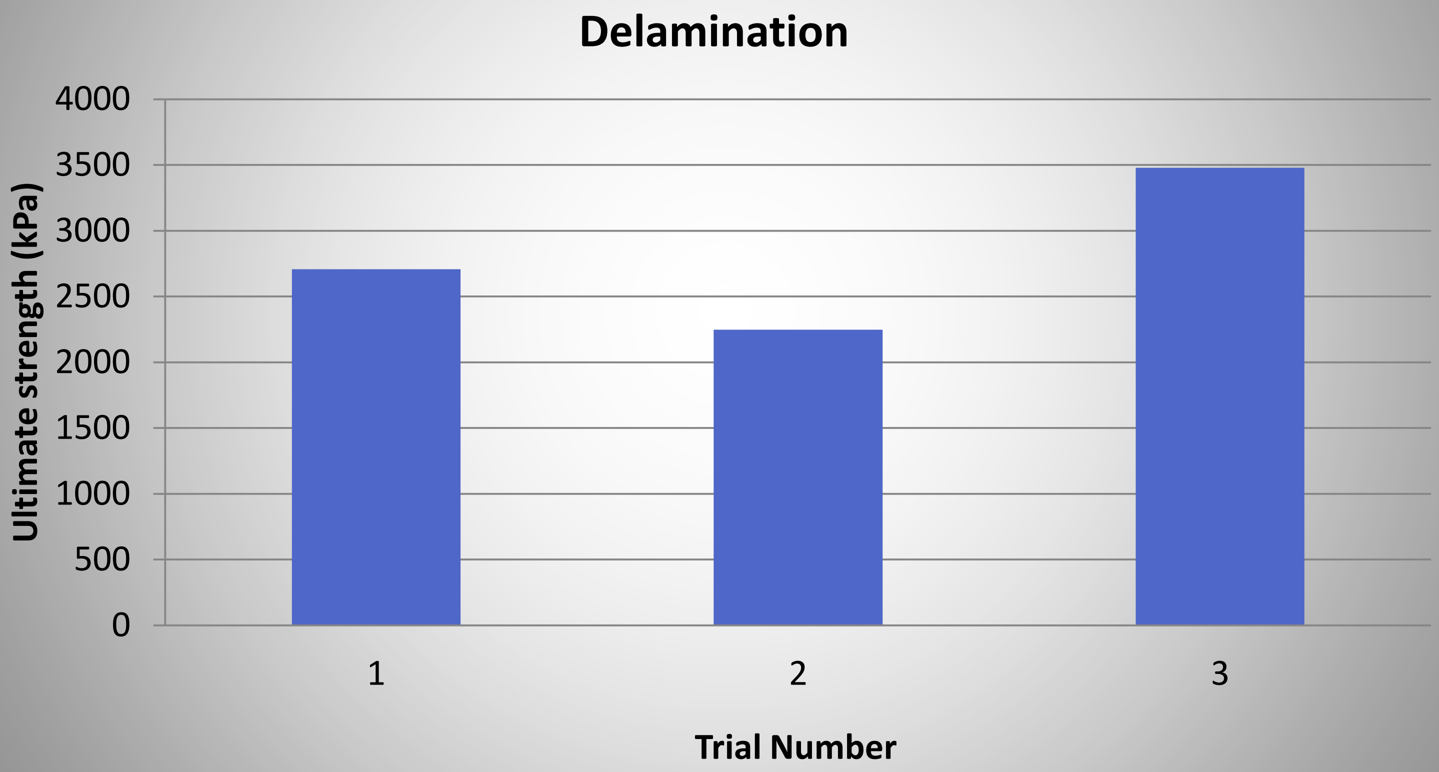
Delamination Test Results:



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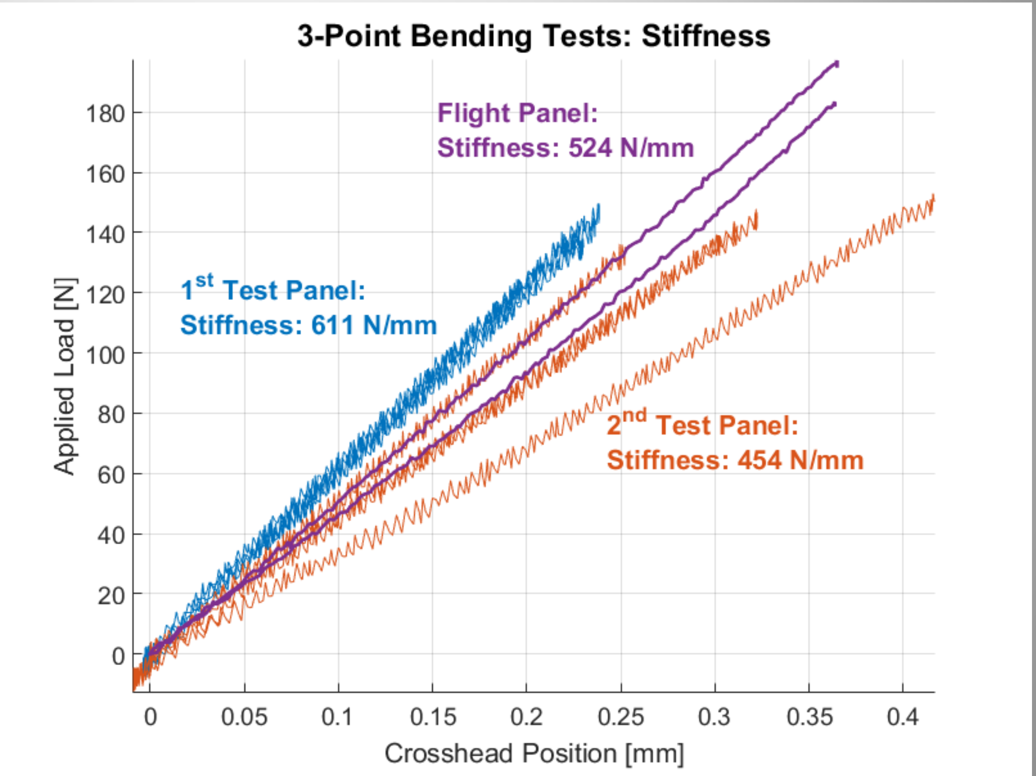
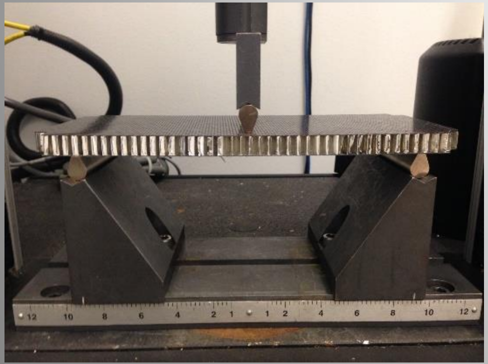
3-Point Bending Test:

Purpose: determine modulus of mid-plate sandwich panel manufactured in-house.

Results: ~ 524 N/mm

Input for modeling of natural frequencies of the Structural Test Model

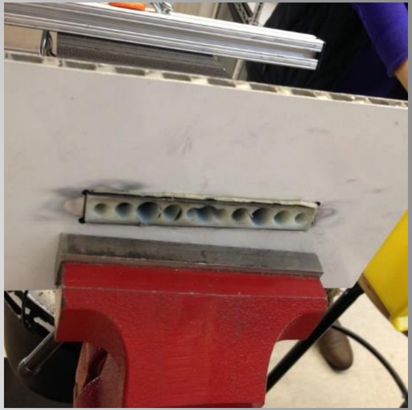




Tab Insert Interface Bending Test:

Purpose: Determine effectiveness of the inserts by performing bending test on propulsion to mid-panel tab interface

Results: 3.8x improvement in strength over panel without an insert



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Functional Requirements:

FR 1	The Feathercraft structure design shall have a **mass of less than 5 kg.**
FR 2	The Feathercraft structure design shall **reduce manufacturing time and material cost** from SST-US's typical spacecraft estimates.
FR 3	FeatherCraft Structure shall be designed to **deploy from Kaber Deployment System on the ISS.**
FR 4	FeatherCraft structure design shall **interface with SST-US-provided spacecraft components and mission design**.
FR 5	An **equivalent manufactured STM** of the FeatherCraft structure design shall be used to **demonstrate the feasibility of the FeatherCraft structure** through a **random vibration test** to the requirements of NASA GEVS documentation.

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Structure Requirements

Completed

1	Structure design shall have a mass < 5 kg	Analysis & Demonstration
2.1	Structure design shall cost < $20,000	Analysis
2.2	Structure design shall take less than 9 months to manufacture	Analysis & Demonstration
2.3	Structure design shall require less than $80,000 labor	Analysis
3.1	Structure design shall exhibit no visual deformation on vibration	Test
3.2	Design shall be less than 30''x30''x19''	Inspection
4.1-4.3	Design shall hold solar panels and prop plate	Test & Demonstration
4.4	Design shall have prop box	Demonstration
4.5	Design shall have mid-plate	Inspection
4.6.1	Designed mid-plate supports 32 kg on top	Demonstration & Test
4.6.2	Designed mid-plate supports 45 kg on bottom	Demonstration & Test
4.7	Radiator panel shall dissipate 100 W heat	Analysis
4.8	Design shall have open aperture on nadir side	Inspection
4.9	Components shall have space heritage	Analysis
5.1	STM shall be made to above specs	Inspection
5.2	Vibration test shall be performed correctly	Inspection
5.3	STM shall support all required weight	Demonstration
5.4	STM shall be foam-wrapped during vibration test	Inspection

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DAQ Requirements

Completed

5.5.1	Shall 4 accelerometers on structure during test	Inspection
5.5.1.1	Accelerometers shall be movable during test	Demonstration
5.5.1.2	Tri-axial accelerometer on mid-panel	Inspection
5.5.1.3	Accelerometer on Velcro-ed panel	Inspection
5.5.2	PSD plots shall be saved	Demonstration
5.6.1	DAQ design shall be capable of 20 accelerometers data transfer	Analysis
5.6.2	DAQ system shall include at least 1 tri-axis and one single axis accel	Inspection
5.6.2.1	DAQ system shall include 2 boards with 8 accel channels each	Inspection
5.6.3.1-5.6.3.4	DAQ system has charge amplifier, low pass filter, and ADC for each channel and 2 kHz accels	Inspection
5.6.3.5	Microcontroller/SW shall transfer data faster than 4 kHz	Demonstration
5.6.4	Software shall display PSD plots realtime	Demonstration
5.6.4.1	Shall be able to run DAQ SW on any Windows computer	Demonstration
5.6.5	SW shall save data as Excel files	Demonstration
5.6.6	Data shall be transferred via USB after test	Demonstration

Accelerometer Placement and Validation

Ram/Wake (X) Vibration			
Accelerometer	Location	Torque	Purpose
A1 (Single)	X1 – Outer face of lower right prop plate	5 in-lb	“Input” accelerometer 1. Placed at a stiff point on the bottom of the structure to capture the acceleration being put into the structure. Used to measure random grms values.
A2 (Single)	X2 – Outer face of upper right radiator	5 in-lb	Solar Panel Accelerometer. Placed on the outer face of the zenith solar panel at the radiator/starboard corner above the Velcro interface to measure acceleration at this point of interest.
A3 (Single)	X3 – Outer face of middle lower radiator	5 in-lb	Capture Modes 5 & 7 during modal sweeps and random vibration. Expected at ~175Hz.
T4 (Triaxial)	X4 – Ram side of avionics torquer, mid panel	10 in-lb	Placed on mid panel to capture acceleration seen by avionics components.
C1 (Single)	X1	N/A	Placed with A1. Used to correlate data with CHIPS. Serves as a backup to A1 in the event of functionality issues.
C2	Slip Table	N/A	Placed on the slip table, measures the output of the vibration table.

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Accelerometer Placement and Validation

Port/Starboard (Y) Vibration			
Accelerometer	Location	Torque	Purpose
A1 (Single)	Y1 – Outer face of lower left starboard plate	5 in-lb	"Input" accelerometer 1. Placed at a stiff point on the bottom of the structure to capture the acceleration being put into the structure. Used to measure random grms values.
A2 (Single)	Y2 – Outer face of upper left port plate	5 in-lb	Solar Panel Accelerometer. Placed on the outer face of the zenith solar panel at the radiator/starboard corner above the Velcro interface to measure acceleration at this point of interest.
A3 (Single)	Y3 – Outer face starboard panel, off center	5 in-lb	Capture Mode 6 during modal sweeps and random vibration. Expected at 170 Hz.
T4 (Triaxial)	Y4 – Starboard side of avionics torquer, mid panel	10 in-lb	Placed on mid panel to capture acceleration seen by avionics components.
C1 (Single)	Y1	N/A	Placed with A1. Used to correlate data with CHIPS. Serves as a backup to A1 in the event of functionality issues.
C2	Slip Table	N/A	Placed on the slip table, measures the output of the vibration table.

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Accelerometer Placement and Validation

Zenith (Z) Vibration			
Accelerometer	Location	Torque	Purpose
A1 (Single)	Z1 – Lower right prop plate, top of column	5 in-lb	"Input" accelerometer 1. Placed at a stiff point on the bottom of the structure to capture the acceleration being put into the structure. Used to measure random grms values.
A2 (Single)	Z2 – Upper right radiator, on top panel	5 in-lb	Solar Panel Accelerometer. Placed on the outer face of the zenith solar panel at the radiator/starboard corner above the Velcro interface to measure acceleration at this point of interest.
A3 (Single)	Z3 – Outer face of top panel, off center	5 in-lb	Capture Modes 1-4 during modal sweeps and random vibration. Expected values at 34 Hz., 104 Hz., and 111 Hz.
T4 (Triaxial)	Z4 – On top of avionics torquer, mid panel	10 in-lb	Placed on mid panel to capture Modes 2 and 7, expected at 104 Hz. and 185 Hz. Respectively.
C1 (Single)	Z1	N/A	Placed with A1. Used to correlate data with CHIPS. Serves as a backup to A1 in the event of functionality issues.
C2	Head Expander Plate	N/A	Placed on the plate, measures the output of the vibration table.

Accelerometer Mounting:

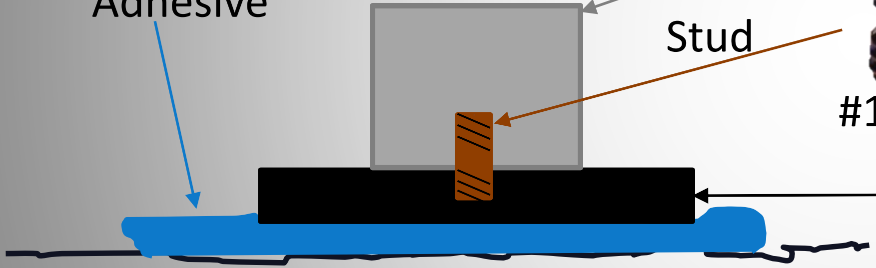
Loctite 454 Adhesive

(PCB-333B30) & (PCB-356A16)

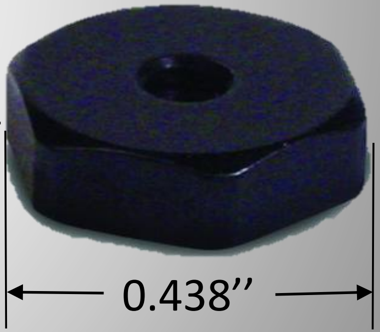
Accelerometer

Stud

#10-32



Mounting Pad



Surface

Validates DR 5.5.1

Images from PCB.com

Random Vibration Profile

- Gives Random Vibration (RV) max envelopes for different frequencies and ranges of frequencies in g^2/Hz.
- Specifies RV max envelopes for unattenuated and attenuated environments
  - Unattenuated (9.47 grms): RV experienced by unwrapped cargo i.e. the input to the vibration table
  - Attenuated: RV experienced by cargo wrapped in this specific configuration – ½" to 2" Pyrell Foam. This is what FISH will experience in flight and what it is being designed to survive.

Test Concept

- Limited ability to model testing conditions & predict foam attenuation
- Risk: Attenuation will be insufficient to reduce full 9.47grms output to 1.29grms
- Mitigation: Multiple random vibration tests, gradually increasing intensity
  - Cascade Tek has software to adjust profile (reference Greg Matthews)
  - Start at Profile – 12 dB, increase intensity until the structure is seeing the required 1.29 grms
- Modal sweeps will be done with a 2 oct/min sweep rate

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Random Vibration Profile 1 – Primary Profile

TABLE 3.1.1.2.1.2.3.2-1 UNATTENUATED AND ATTENUATED RANDOM VIBRATION ENVIRONMENTS FOR END ITEMS SOFT-STOWED IN A SINGLE CTB, X/Y/Z AXIS

Frequency (Hz)	Max. Flight RV Env[1]	20 lb ORU in Pyrell in a Single CTB
20	0.057 (g^2/Hz)	0.1465 (g^2/Hz)
20-153	0 (dB/oct)	-9.76 (dB/oct)
153	0.057 (g^2/Hz)	0.0002 (g^2/Hz)
153-190	+7.67 (dB/oct)	0 (dB/oct)
190	0.099 (g^2/Hz)	0.0002 (g^2/Hz)
190-250	0 (dB/oct)	0 (dB/oct)
250	0.099 (g^2/Hz)	0.0002 (g^2/Hz)
250-750	-1.61 (dB/oct)	0 (dB/oct)
750	0.055 (g^2/Hz)	0.0002 (g^2/Hz)
750-2000	-3.43 (dB/oct)	0 (dB/oct)
2000	0.018 (g^2/Hz)	0.0002 (g^2/Hz)
OA (grms)	**9.47**	**1.29**

Note:

1) Unattenuated RV levels are from Table 3.1.1.2.1.2.1-1.

Random Vibration Profile 1 – Primary Profile

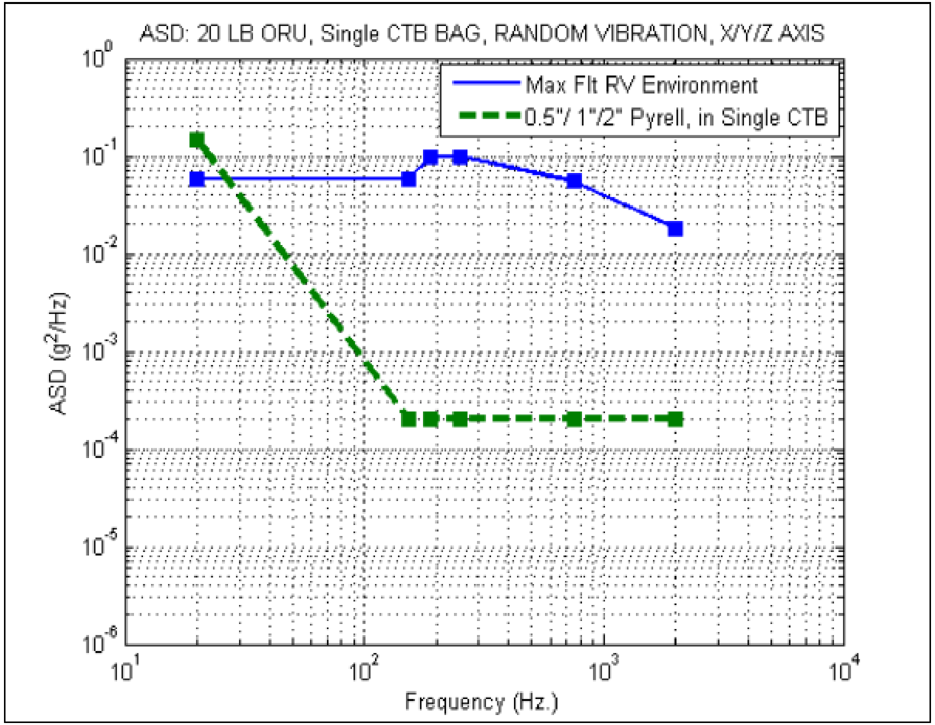

FIGURE 3.1.1.2.1.2.3.2-1 ATTENUATED RANDOM VIBRATION ENVIRONMENT FOR END ITEMS PACKED IN PYRELL AND SOFT-STOWED IN A SINGLE CTB, X/Y/Z AXIS

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Random Vibration Profile 2 – Flight Profile

TABLE 3.1.1.2.1.2.3.2-2 UNATTENUATED AND ATTENUATED RANDOM VIBRATION ENVIRONMENTS FOR END ITEMS SOFT-STOWED IN AN M01 BAG

Frequency (Hz)	Max. Flight RV Env[1]	150 lb ORU in 1.0" Pyrell, in an M01 Bag	150 lb ORU in 1.0" Pyrell, in an M01 Bag	150 lb ORU in 1.0" Pyrell, in an M01 Bag
		X-Axis	Y-Axis	Z-Axis
20	0.057 (g^2/Hz)	0.002 (g^2/Hz)	0.0001 (g^2/Hz)	0.1 (g^2/Hz)
20-40	0 (dB/oct)	-6.99 (dB/oct)	-6.99 (dB/oct)	+2.43 (dB/oct)
40	0.057 (g^2/Hz)	0.0004 (g^2/Hz)	2.0e-5 (g^2/Hz)	0.175 (g^2/Hz)
40-153	0 (dB/oct)	0 (dB/oct)	0 (dB/oct)	-8.25 (dB/oct)
153	0.057 (g^2/Hz)	0.0004 (g^2/Hz)	2.0e-5 (g^2/Hz)	4.4e-3 (g^2/Hz)
153-190	+7.67 (dB/oct)	0 (dB/oct)	0 (dB/oct)	-1.06 (dB/oct)
190	0.099 (g^2/Hz)	0.0004 (g^2/Hz)	2.0e-5 (g^2/Hz)	0.004 (g^2/Hz)
190-250	0 (dB/oct)	0 (dB/oct)	0 (dB/oct)	-8.36 (dB/oct)
250	0.099 (g^2/Hz)	0.0004 (g^2/Hz)	2.0e-5 (g^2/Hz)	1.9e-3 (g^2/Hz)
250-750	-1.61 (dB/oct)	-16.42 (dB/oct)	-6.31 (dB/oct)	-9.52 (dB/oct)
750	0.055 (g^2/Hz)	1.0e-6 (g^2/Hz)	2.0e-6 (g^2/Hz)	5.9e-5 (g^2/Hz)
750-2000	-3.43 (dB/oct)	0 (dB/oct)	0 (dB/oct)	-11.26 (dB/oct)
2000	0.018 (g^2/Hz)	1.0e-6 (g^2/Hz)	2.0e-6 (g^2/Hz)	1.5e-6 (g^2/Hz)
OA grms	**9.47**	**0.35**	**0.1**	**2.63**

Note:
1) Unattenuated RV levels are from Table 3.1.1.2.1.2.1-1.

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Random Vibration Profile 2 – Flight Profile

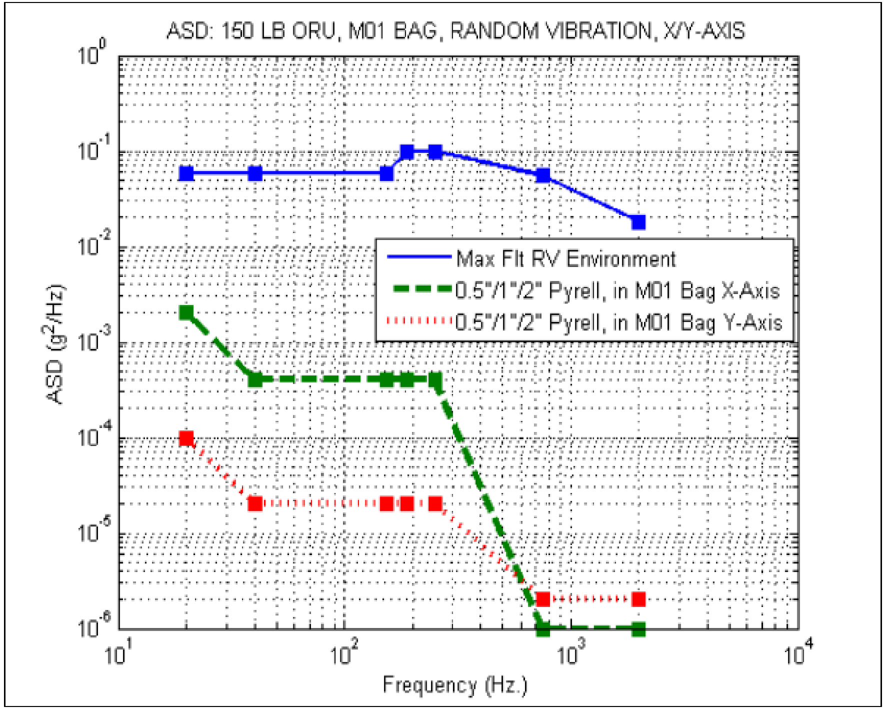

FIGURE 3.1.1.2.1.2.3.2-2 ATTENUATED RANDOM VIBRATION ENVIRONMENTS FOR END ITEMS SOFT-STOWED IN AN M01 BAG, X/Y AXIS

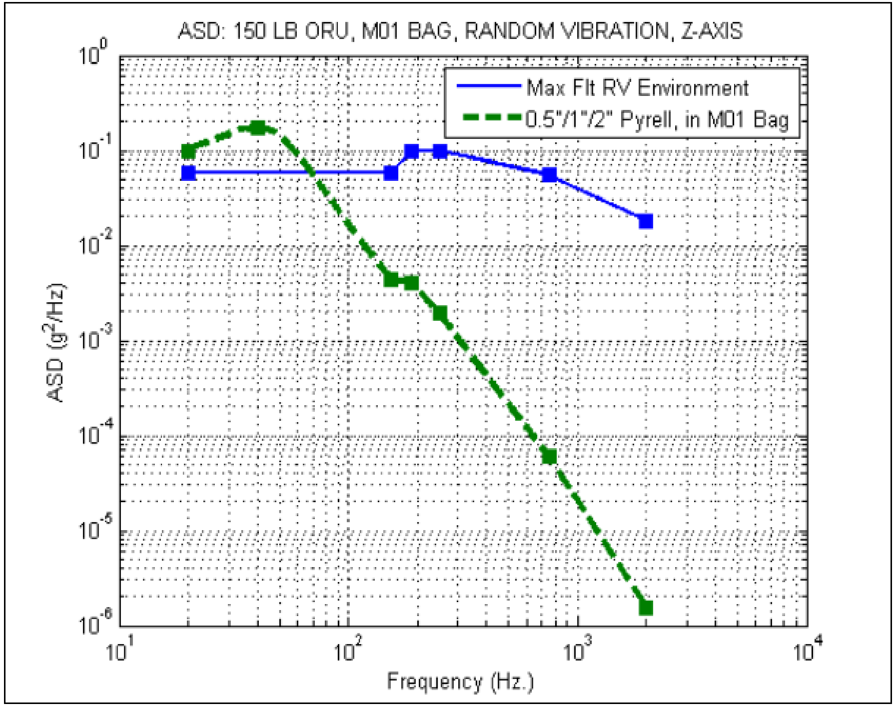

FIGURE 3.1.1.2.1.2.3.2-3 ATTENUATED COMPOSITE RANDOM VIBRATION ENVIRONMENTS FOR END ITEMS SOFT-STOWED IN AN M01 BAG, Z-AXIS

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Vibration Testing – Contingencies

Contingency	Mitigation or Testing Change
-Attenuation insufficient to reduce full 9.47 grms output to 1.29 grms	-Random Vibration conducted in incremental stages starting at -24 dB
-Attenuation is too great to achieve 1.29 grms at full 9.47 grms output	-Incrementally increase above max flight envelope until structure sees 1.29 grms
-Structural Failure before Random Vibration (transportation or sine sweep)	-Document failure & convene TRB -Either postpone or proceed with test depending on nature of failure
-Structural Failure during Random Vibration	-Unwrap and document failure, TRB -Either suspend or proceed with test depending on nature of the failure

*All testing done with professional assistance of Cascade Tek engineers and Surrey's Michael Brown and Jon Miller. All testing changes will ultimately be made at the discretion of the professionals after a Test Review Board (TRB)

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GRMS

- grms is the “Root Mean Square” of acceleration, and is the preferred method to characterize Random Vibration Loading
- Random Vibration response curves are plotted as Frequency (Hz.) vs. Acceleration Spectral Density (ASD, g^2/Hz.)
  - To calculate grms: Average the squared acceleration over frequency, and take the square root

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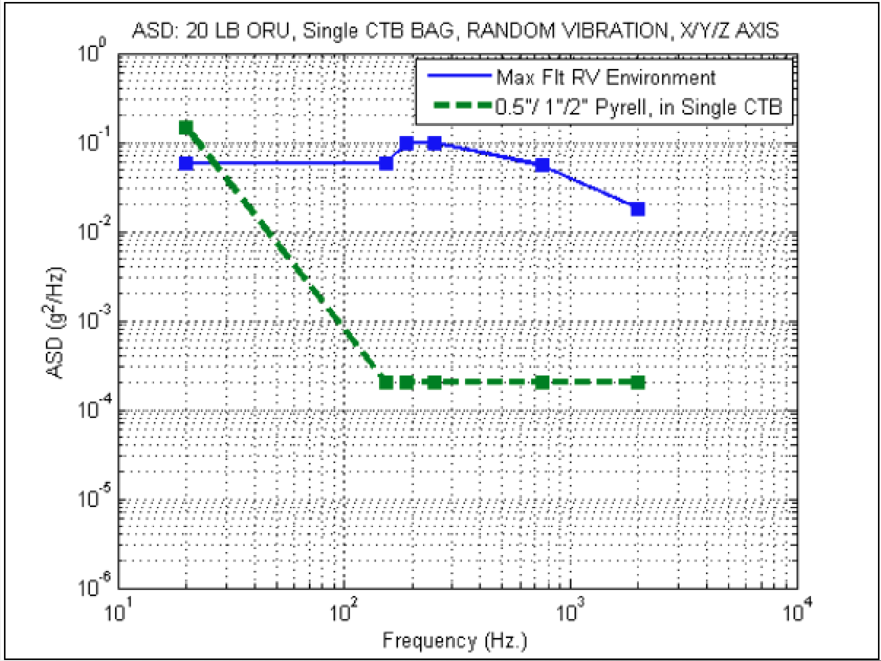
GRMS Methodology

- Calculation of grms for random vibration test (20 Hz. – 2 kHz.):

$$grms = \sqrt{\int_{0}^{2000} ASD(f)\, df}$$



Sample ASD Plot for unattenuated and attenuated random vibration

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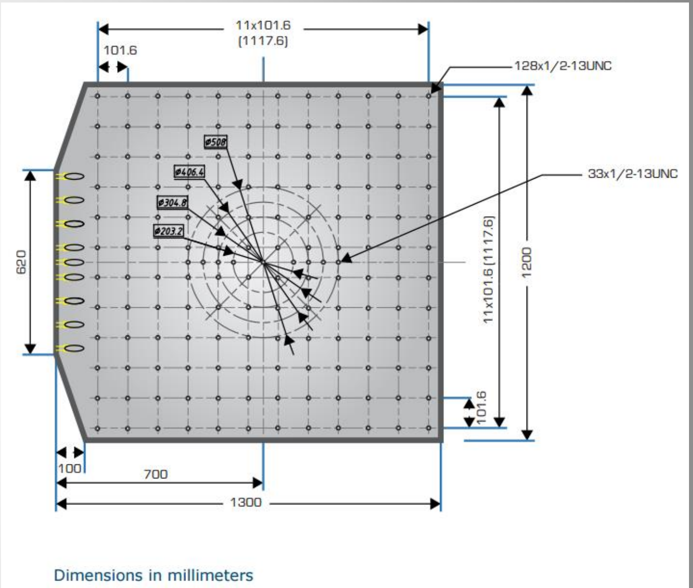
Wrapping & Mounting

- Sine Sweep: Clamp configuration
  - 6 toe clamps, columns to slip table
- Random Vibration: Wrap configuration
  - 1” Pyrell Foam
    - Available in 48” x ft (9 ft minimum required)
  - 4 ratchet straps hooked to eyebolts
  - Eyebolts attach to slip plate & head expander



-Slip Table: 4” bolt pattern (1/2” – 13)
-Head Expander: 4” bolt pattern (3/8” 16)

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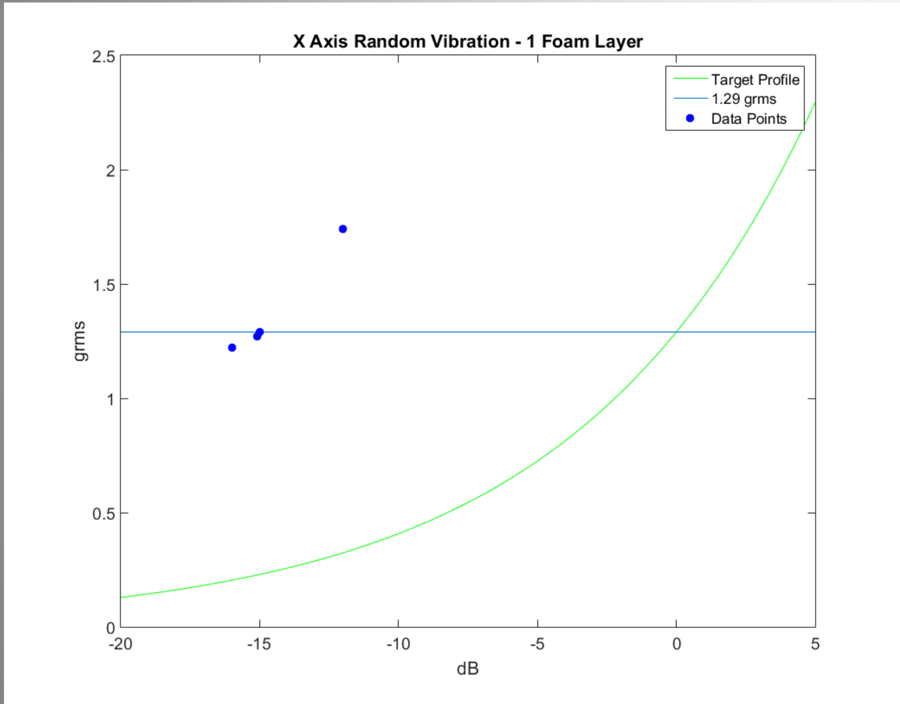
DR 5.4 – Foam Wrapping

- Specified flight condition: .5” to 2” thick Pyrell Foam wrap
  - ISS Pressured Volume Hardware Common Interface Requirements Document Rev C.
- Obtainable online for ~ $22 per ft. length (48” width, 1” thick)
  - 9 ft minimum needed for full wrap around testing axis
  - Included in project budget

Requirement:	Required Value:	Current Value:	
STM shall be wrapped in 0.5” – 2” thick Pyrell Foam prior to random vibration testing	> 20.42 ft^2	36 ft^2	Requirement Met
	0.5 in < t < 2 in	1.0 in	

Foam Attenuation: X-Axis



- Configuration: 1 layers of 1” Foam
- Poor attenuation of random vibration

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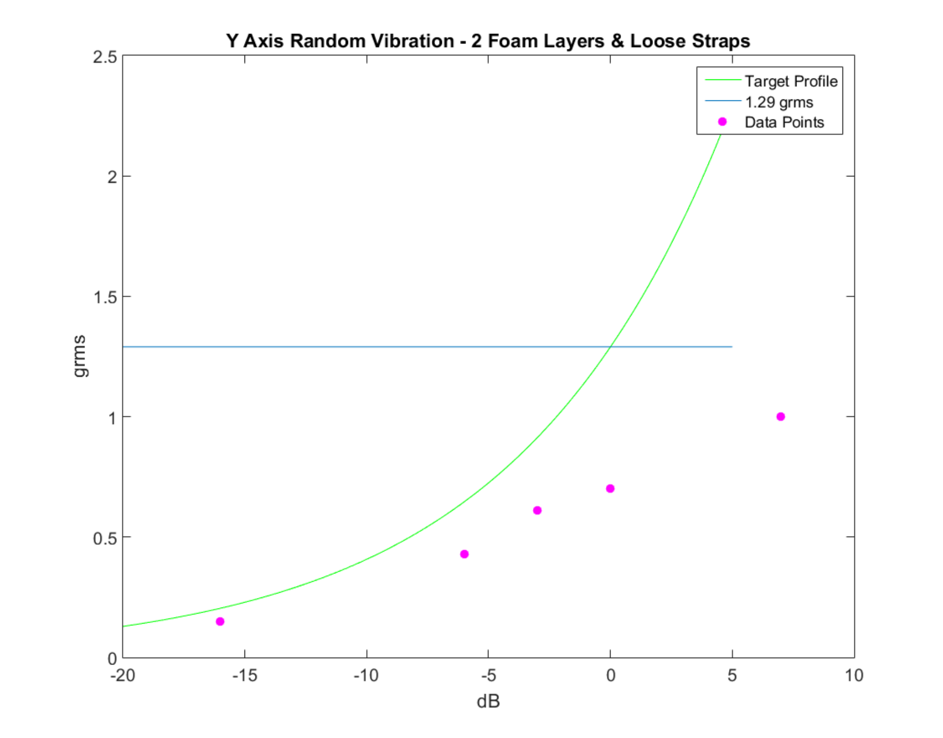
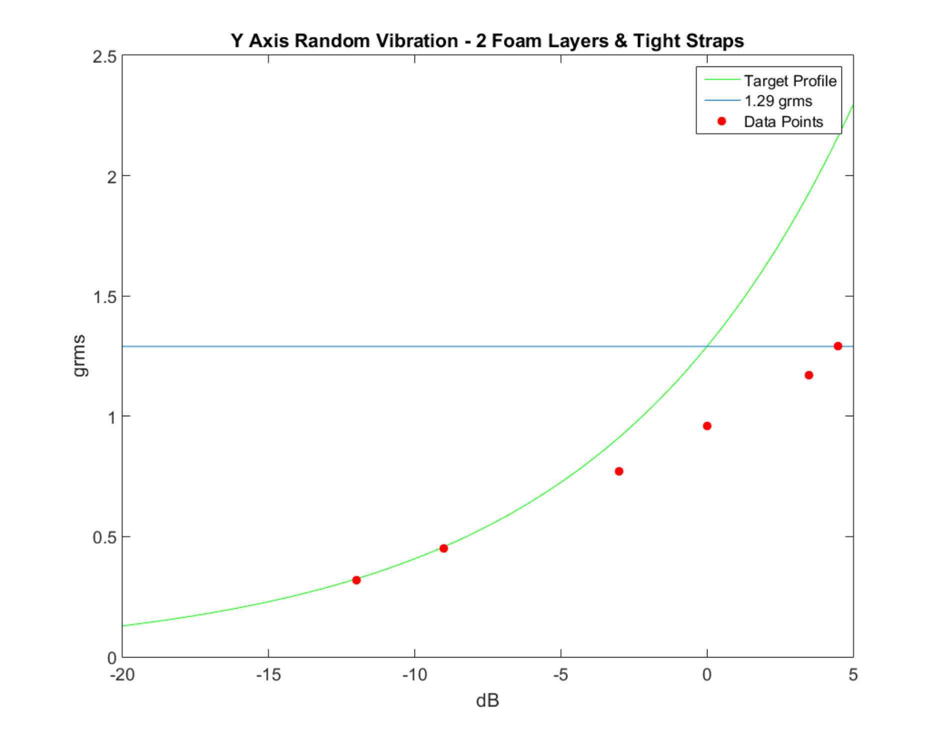
Foam Attenuation: Y Axis



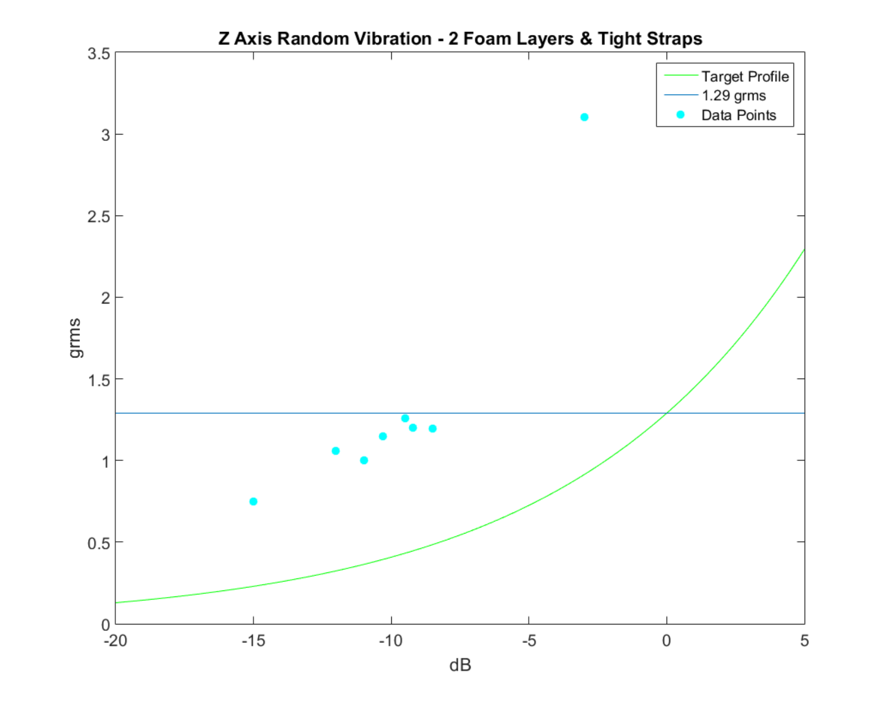
- Configuration: 2 layers of 1” Foam at contact points
- Addition of foam improves attenuation
- Reduced prediction accuracy as intensity increases

Foam Attenuation: Y Axis



- Configuration: 2 layers of 1” Foam at contact points
- Straps tightened from previous tests
- Improved prediction accuracy, still degrades over time

Foam Attenuation: Z Axis

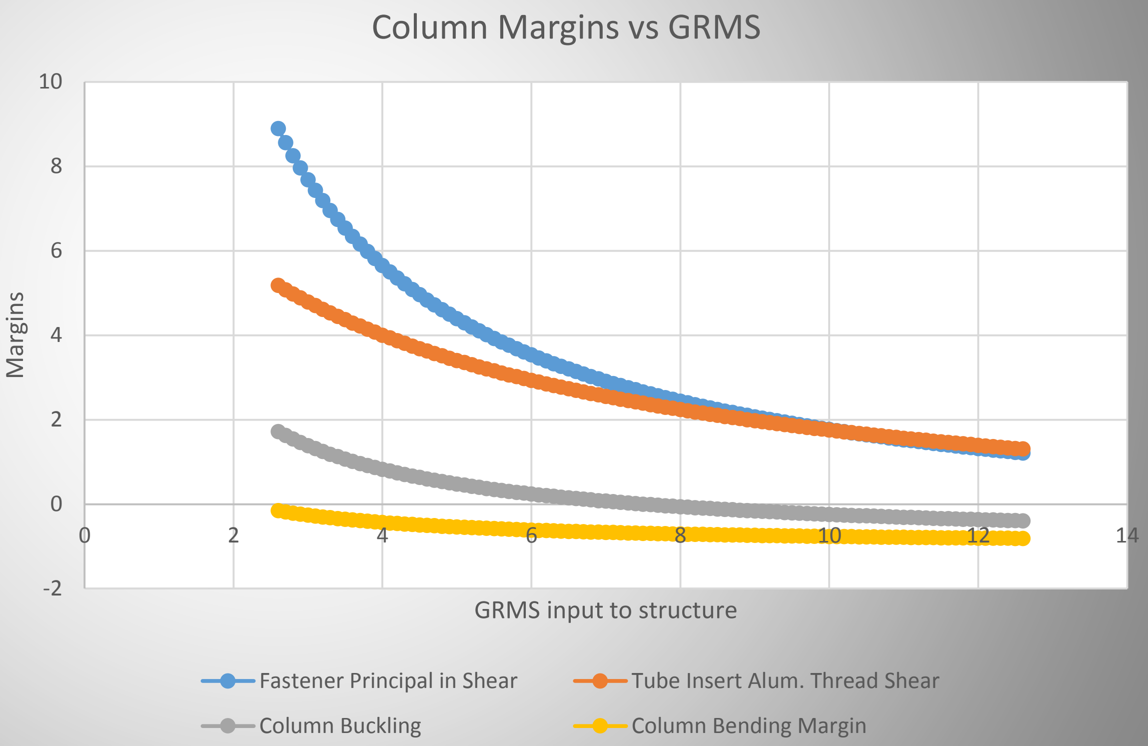


- Configuration: 2 layers of 1” Foam at contact points
- Poor attenuation compared to y-axis despite same configuration

Modeling – Column Margins:

- Fastener Shear is Safe
- Tube Insert thread Shear is Safe
- Column buckling is expected at 7 GRMS
- Column Bending Margin is insufficient (risk)

Solution: linear model does not capture structure's dynamics – passed test.



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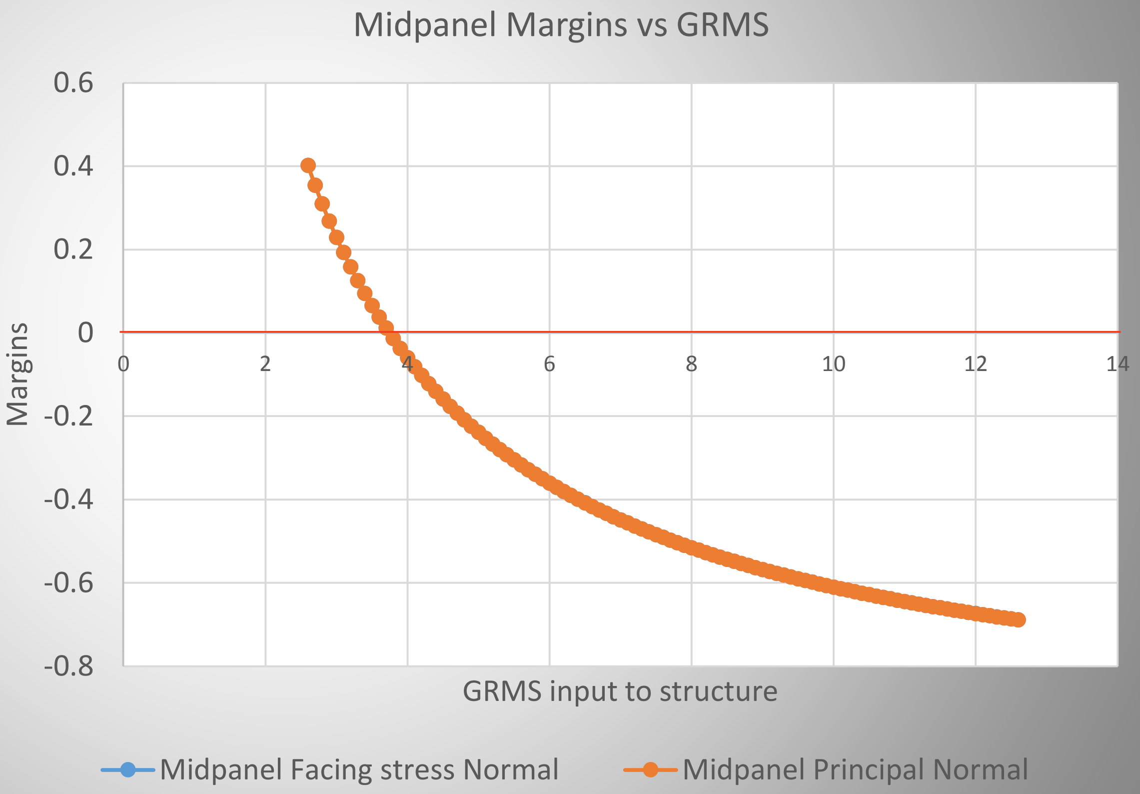
Modeling – Mid Panel Margins:

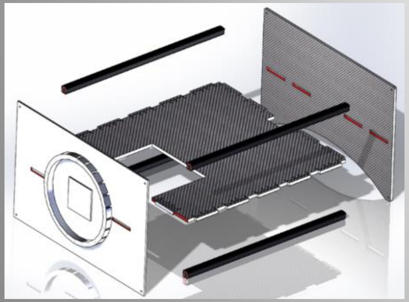
- Normal Stress due to bending is calculated in mid-panel.
- Failure is expected at 3.8 GRMS input to the structure

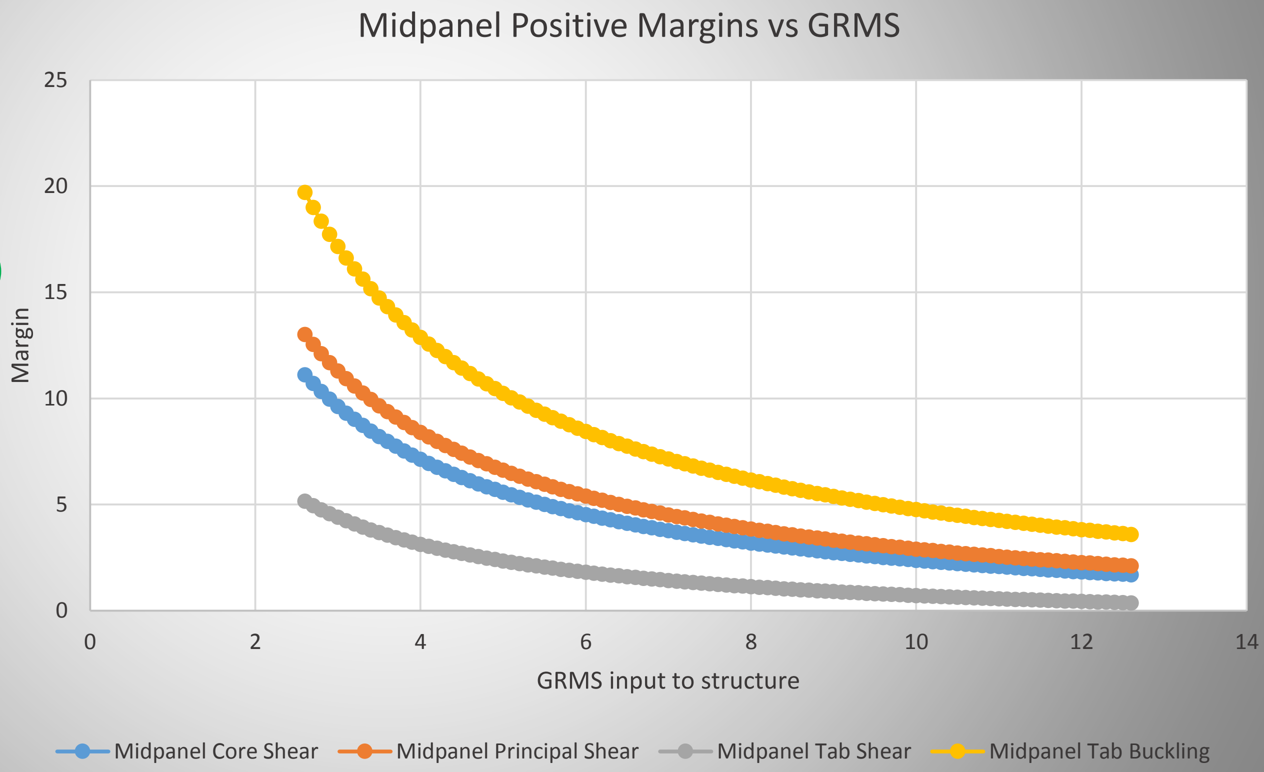
- Because of the distributed load condition, deflection of the mid-panel is negligible and stress is transferred to shear/torsion.



Modeling – Mid Panel Positive Margins:

- Shear due to loading is calculated in mid-panel.
- Failure is not expected within test limits.





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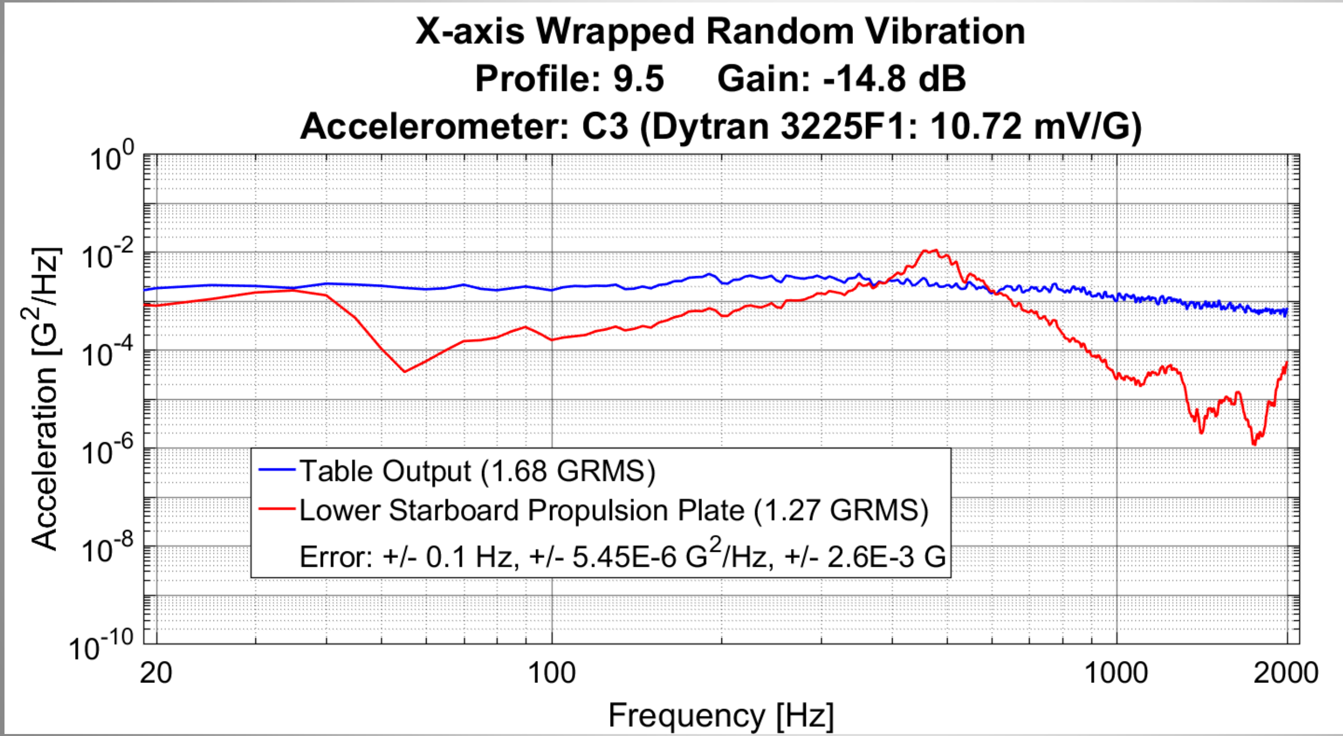
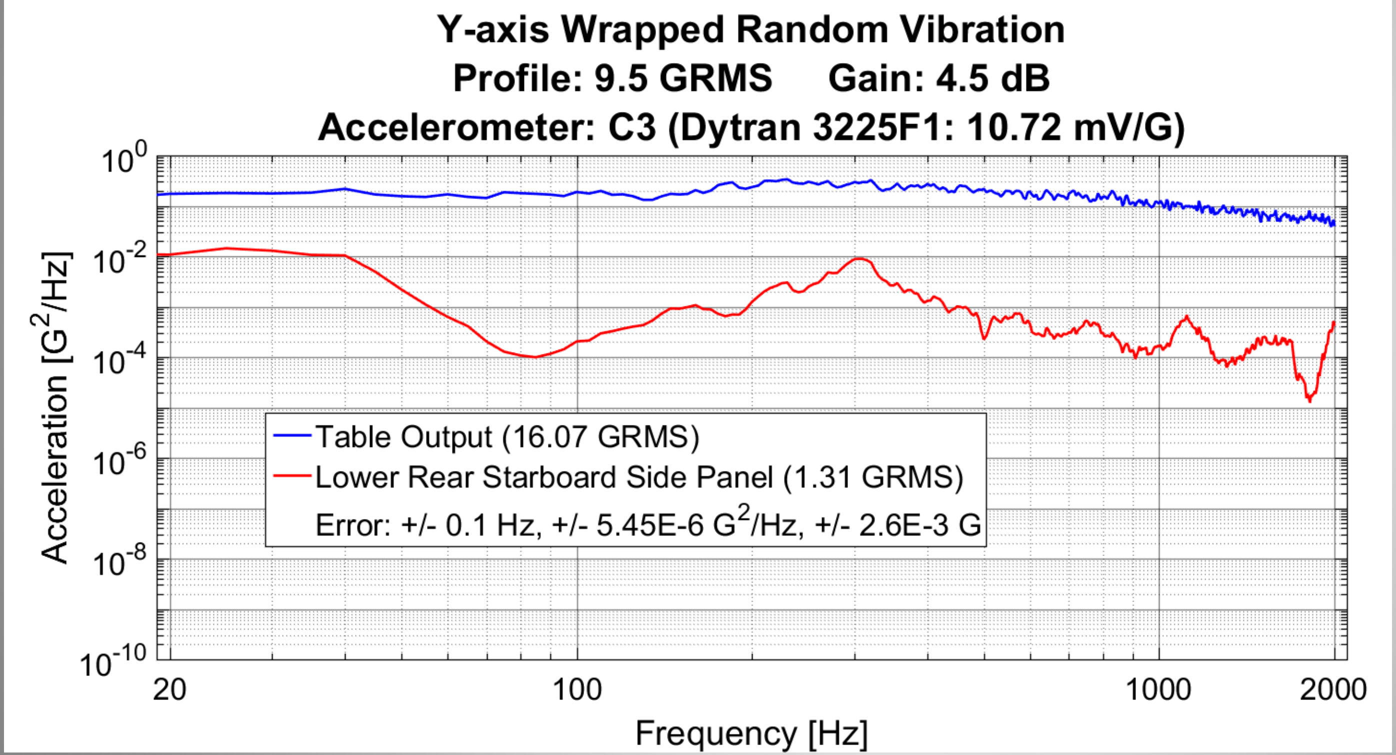
Random Vibration: X



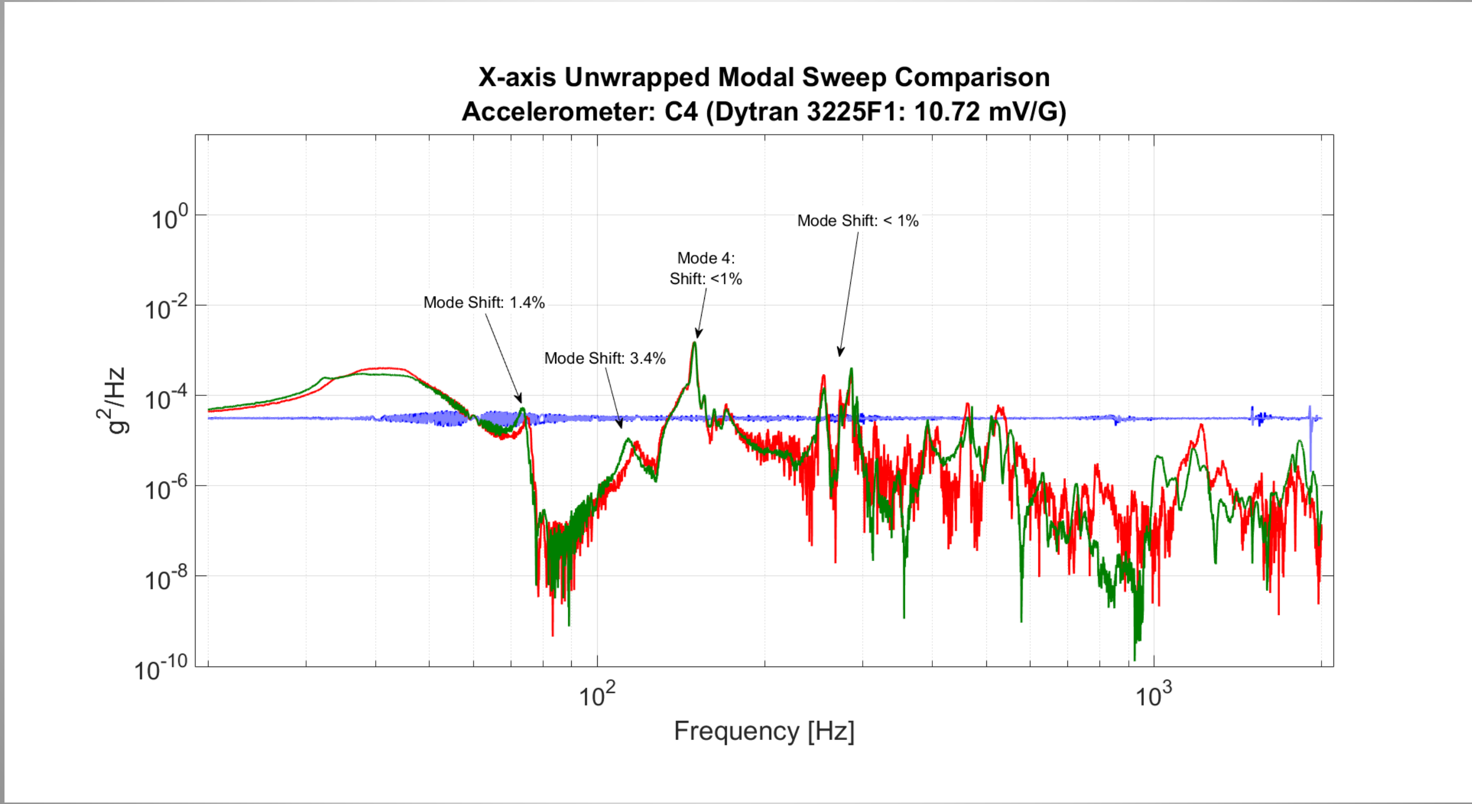
- 60 second test
- 1.27 grms

Random Vibration: Y

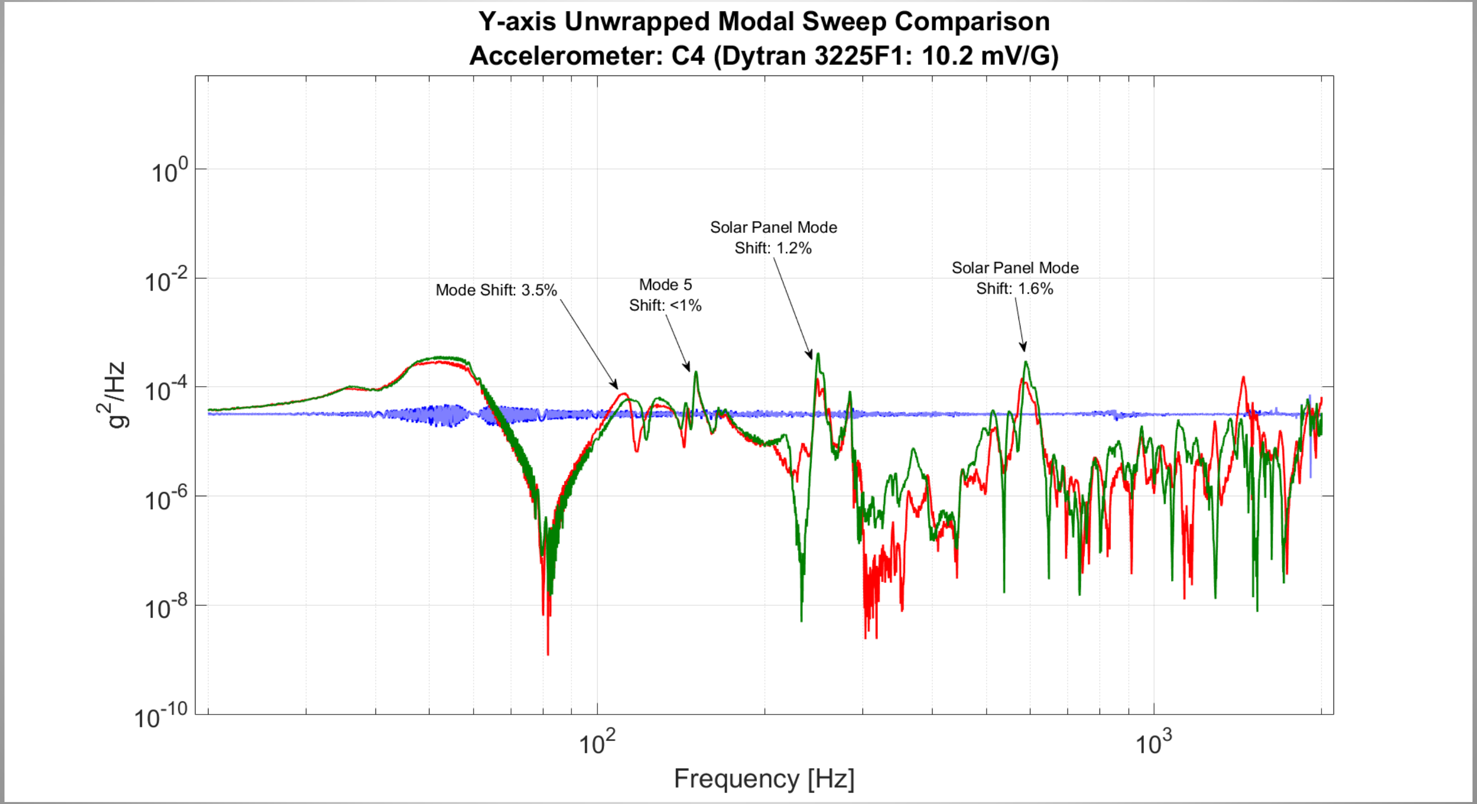


- 60 second test
- 1.31 grms

Modal Shift: X-Axis



Modal Shift: Y-Axis



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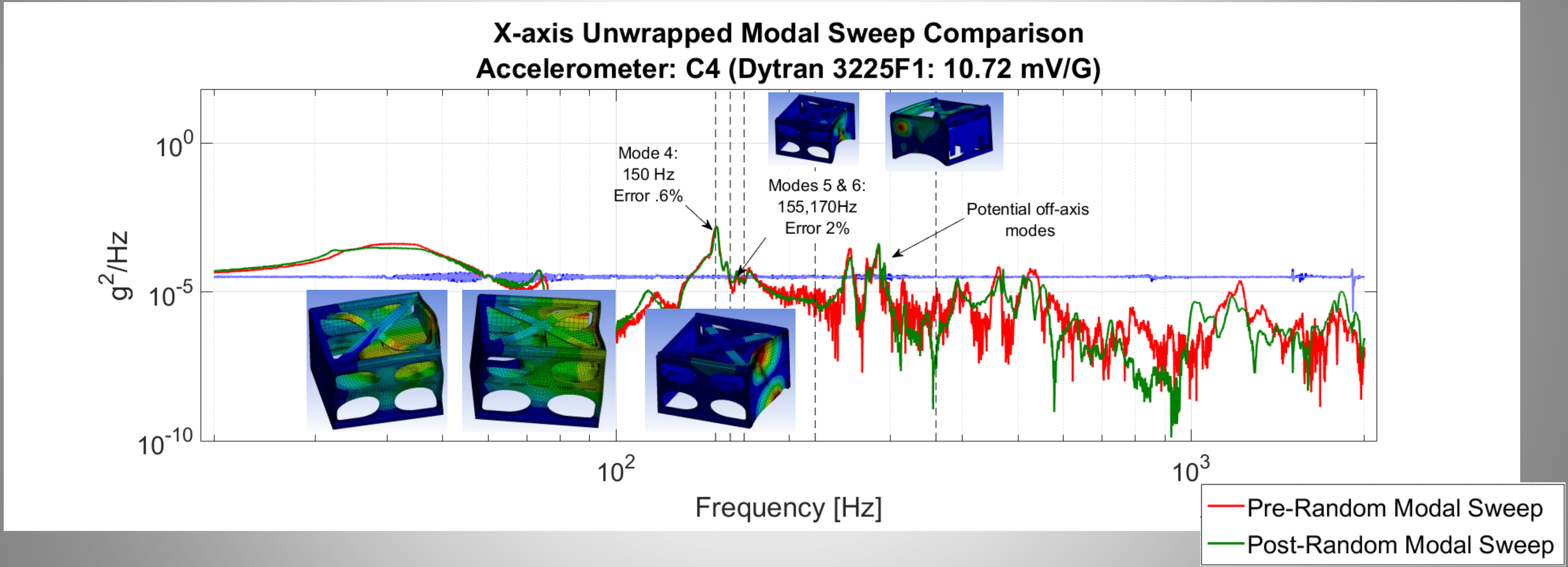
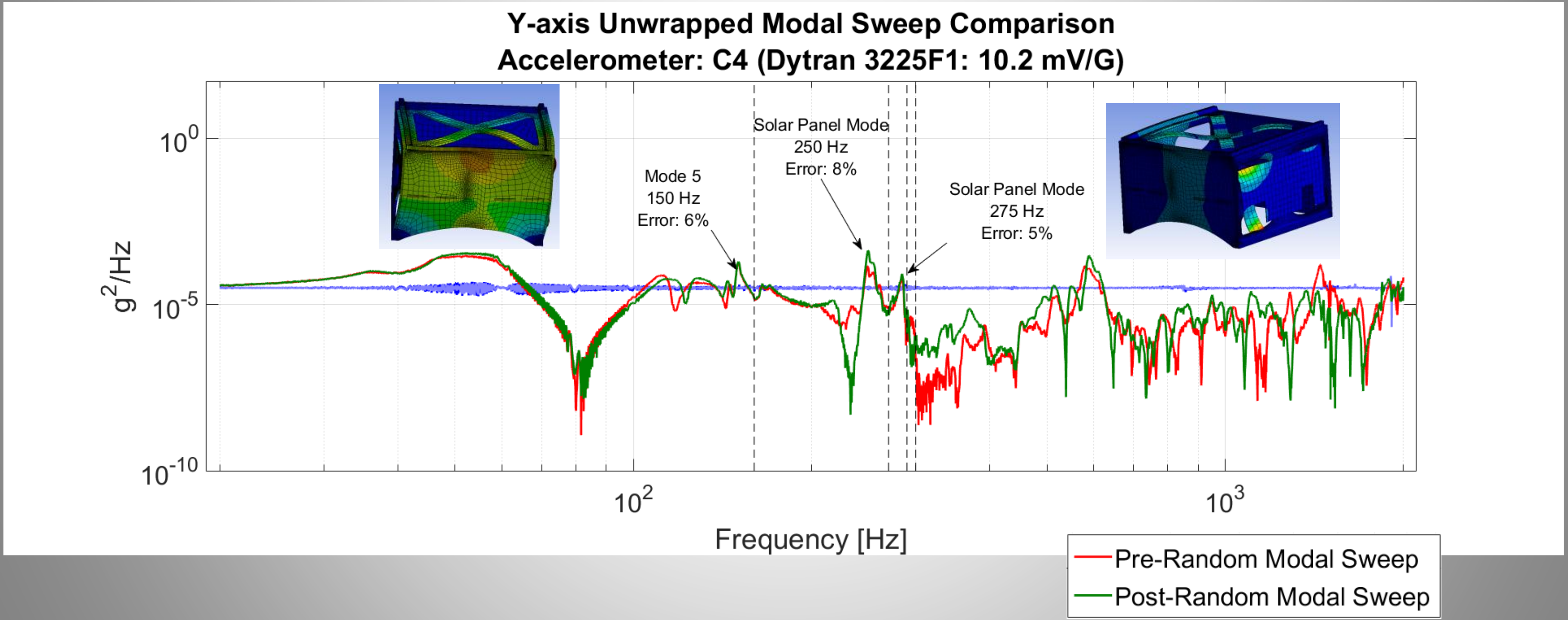
Model Validation: X-Axis

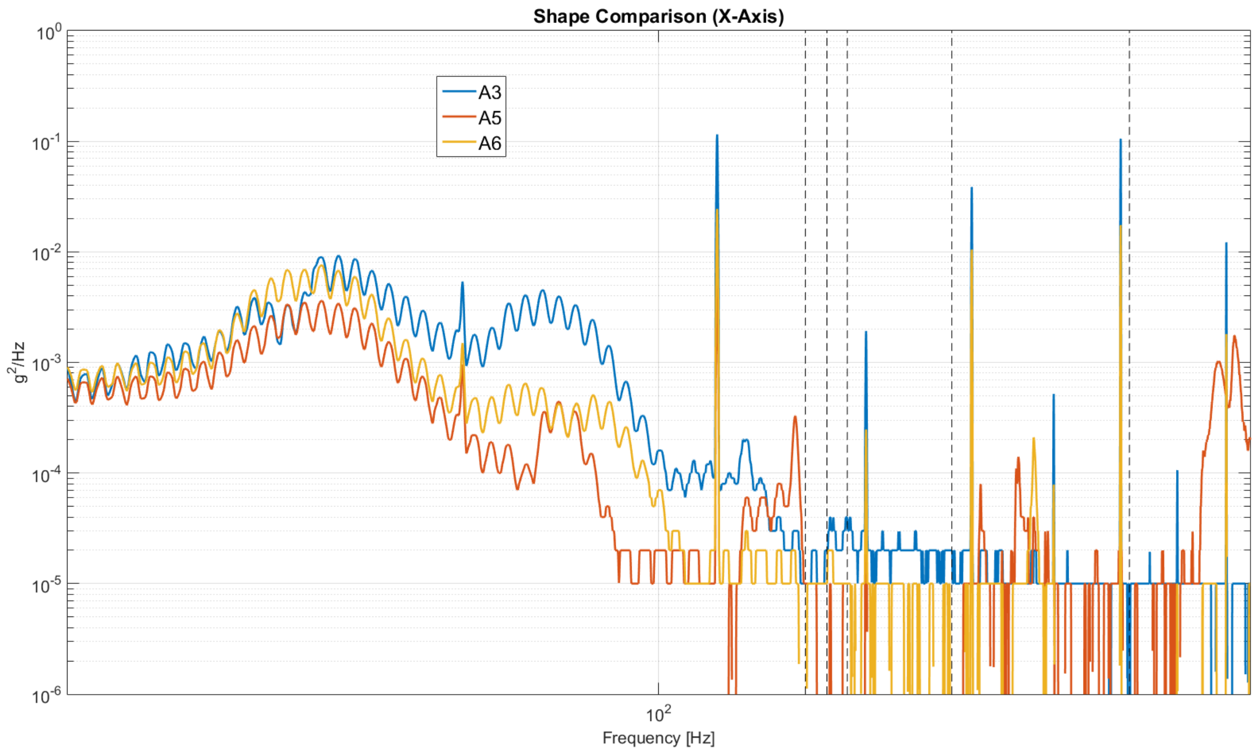


SURREY SATELLITE TECHNOLOGY US

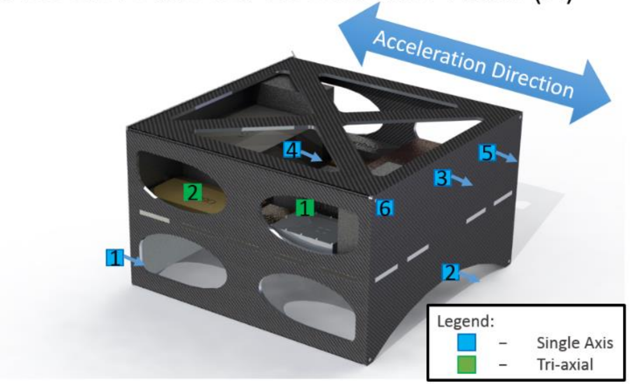
Model Validation: Y-Axis



Results: Shape Comparison (X)

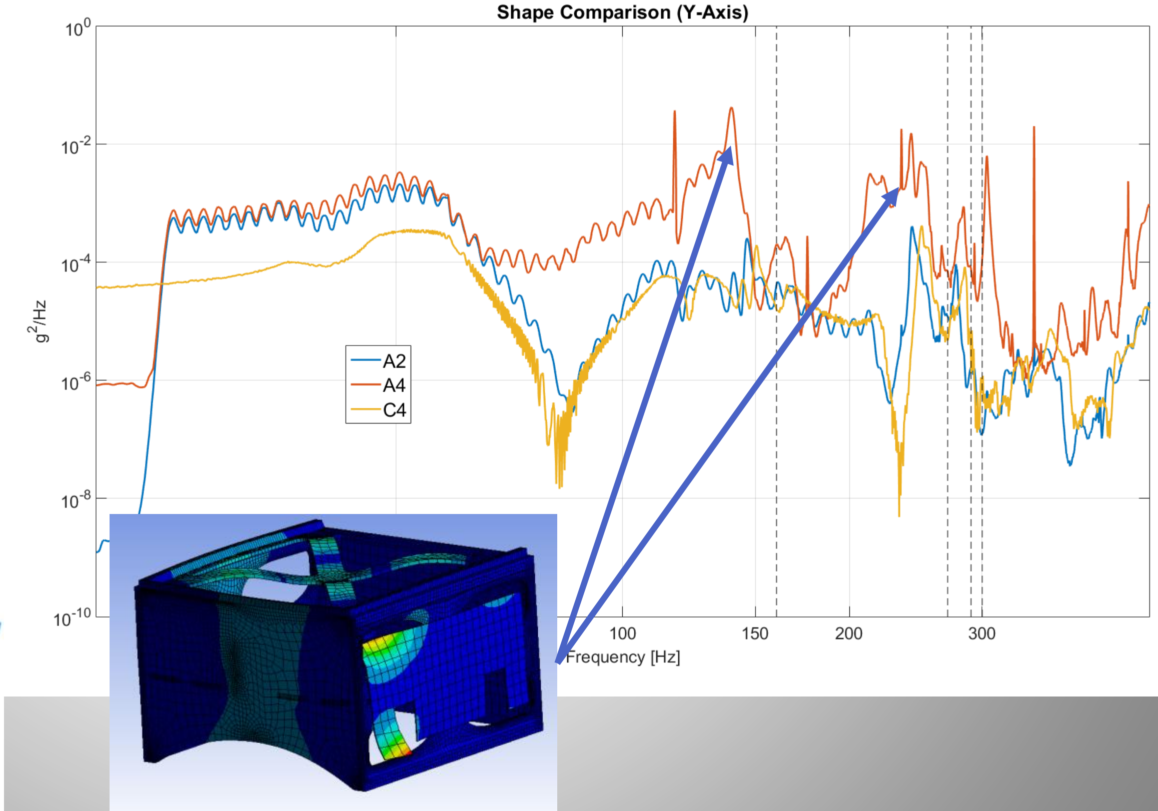


Accelerometer Locations: Ram (X)

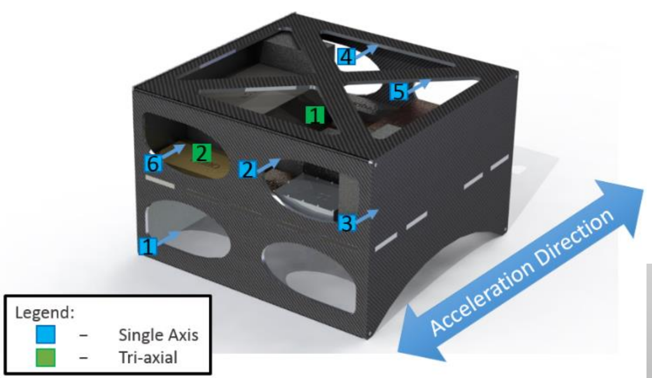


Results: Shape Comparison (Y)

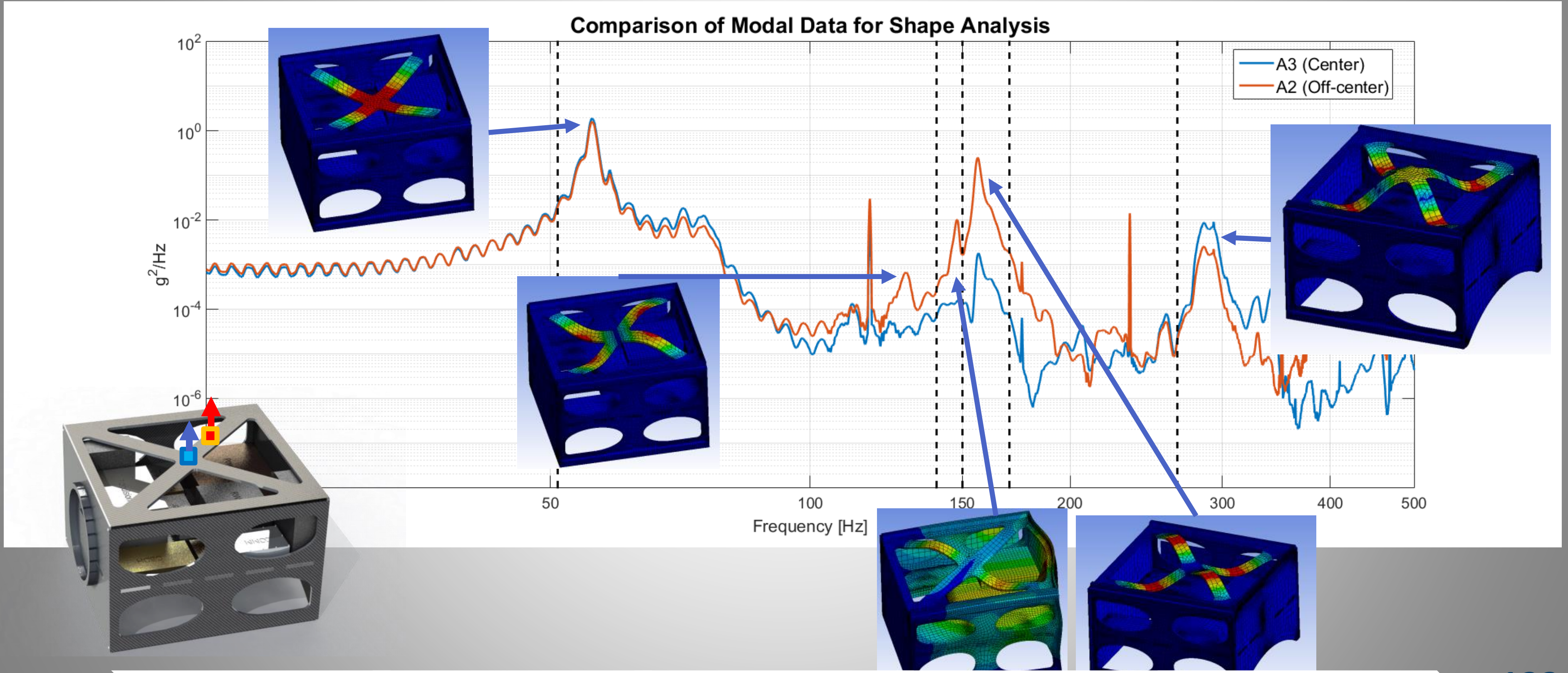
- Did not fully capture solar panel modes

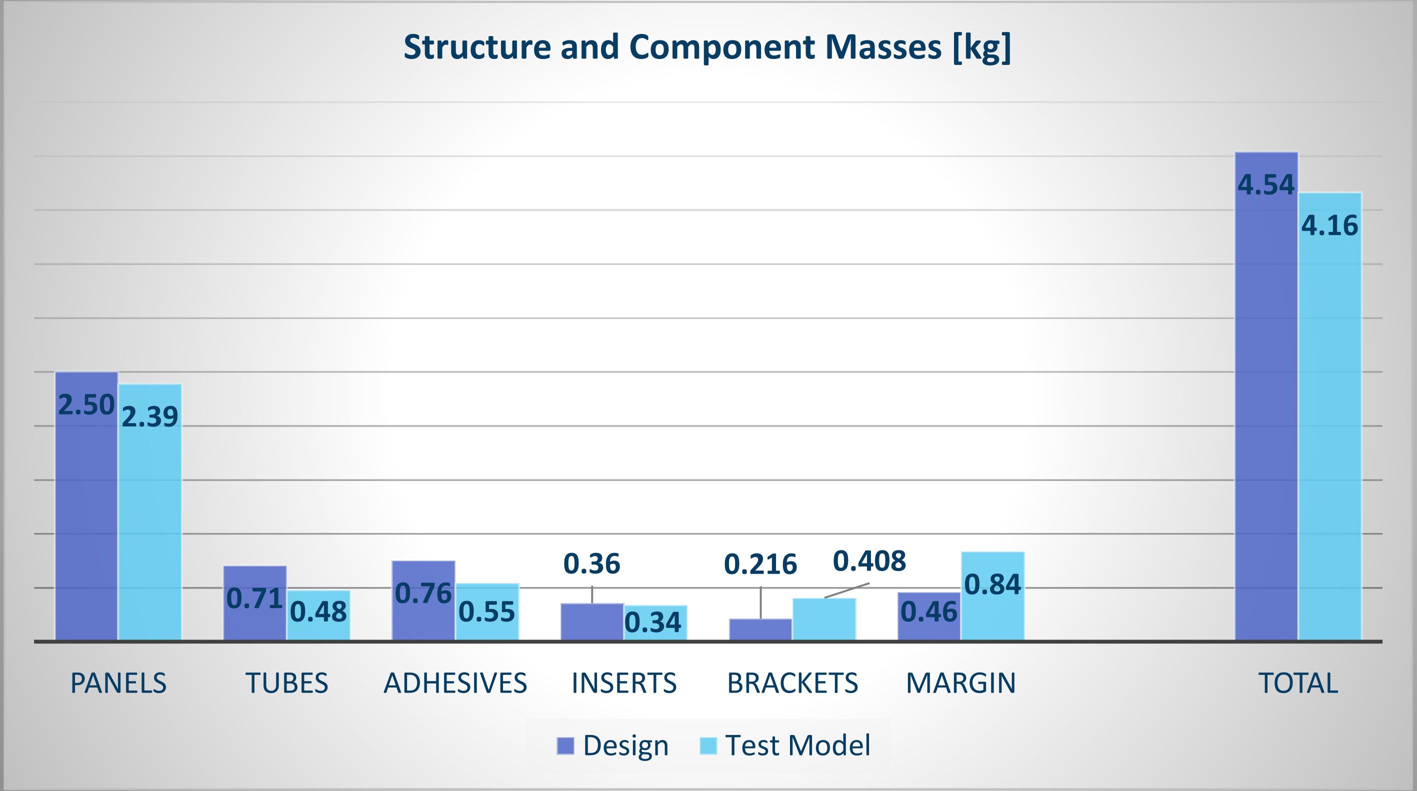


Accelerometer Locations: Side (Y)



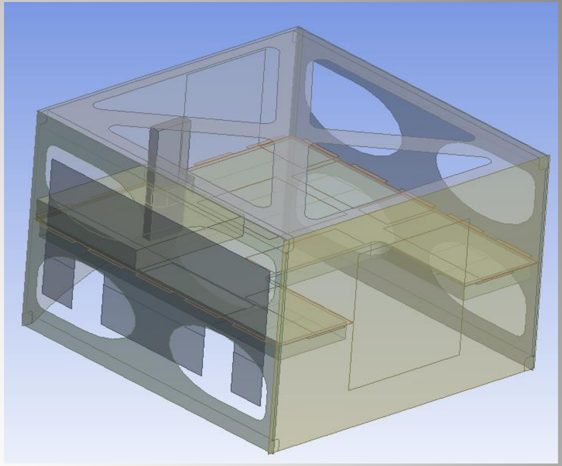
Results: Shape Comparison (Z)




Structure and Component Masses [kg]
2.50
2.39
0.71
0.48
0.76
0.55
0.36
0.34
0.216
0.408
0.46
0.84
4.54
4.16
PANELS
TUBES
ADHESIVES
INSERTS
BRACKETS
MARGIN
TOTAL
Design
Test Model

ANSYS Overview:

- ANSYS
  - 2D Shell elements
  - Layered Sections
- Loading
  - Point and distributed masses
  - Modeled large masses that add stiffness
    - Payload
    - Torque rod
    - Power box
    - Solar Panel

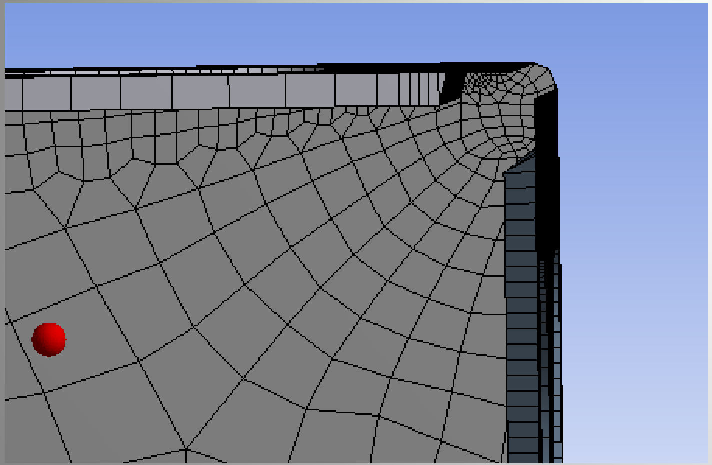


0.5” Middle Panel Layers:

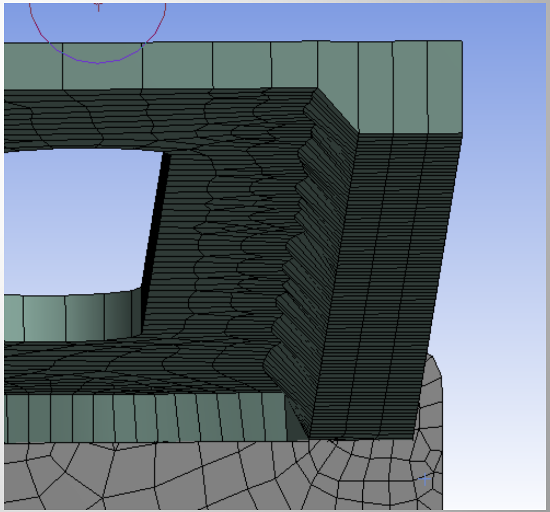
Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
3	ACP CF, 2ply	0.61	0
2	Aluminum Core Material (3003 1/4" 83)	12.7	0
1	ACP CF, 2ply	0.61	0
(-Z)			

ANSYS Geometry:

- Limited number of elements
- Columns omitted from model

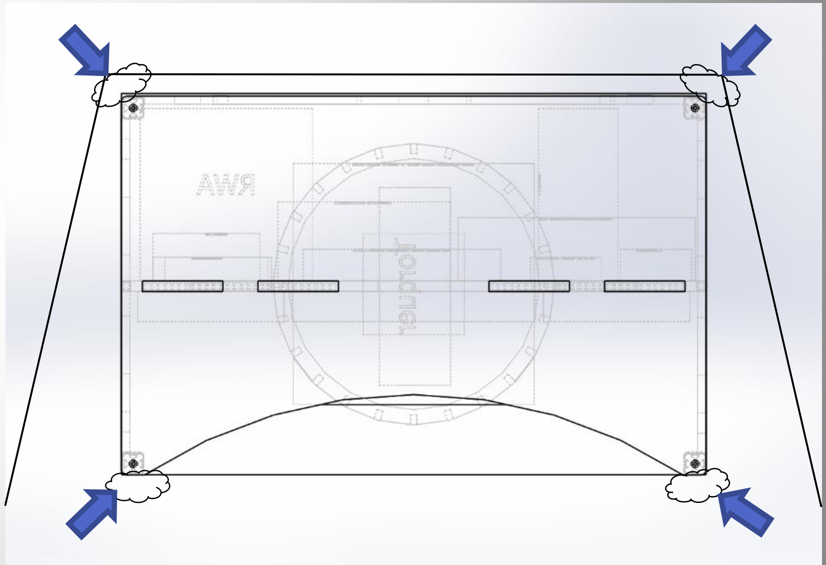


- Added stiffening section
- Removes necessary fixed boundary condition



ANSYS Boundary Conditions:

- Columns treated as fixed for wrapped modal.
- Columns extremely rigid compared to structure.
- In unwrapped modal, only fix lower columns
  - Toe clamps



Predicting Structure Survival

Modal Analysis

- 1g Static Load (gravity)
- **Modes** 1-50 to capture full mass fraction (~90%)

Random Vibration

- 9.47grms Flight Environment
- Solves for worst case **deflection** (99.7% confidence)

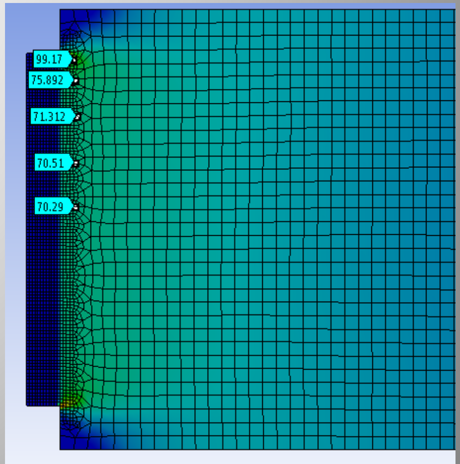
Quasi-Static Load

- Load determined by previous deflection
- Recovers (maximum) structural **stresses** experienced in vibration

- Max = 5.4mm (top panel)
- Quasi-static load of ~46g's (slightly larger than 4x9.47grms)
  - Due to modal amplification
  - Max stress in model: 111MPa
- Expected failure point: **6grms**

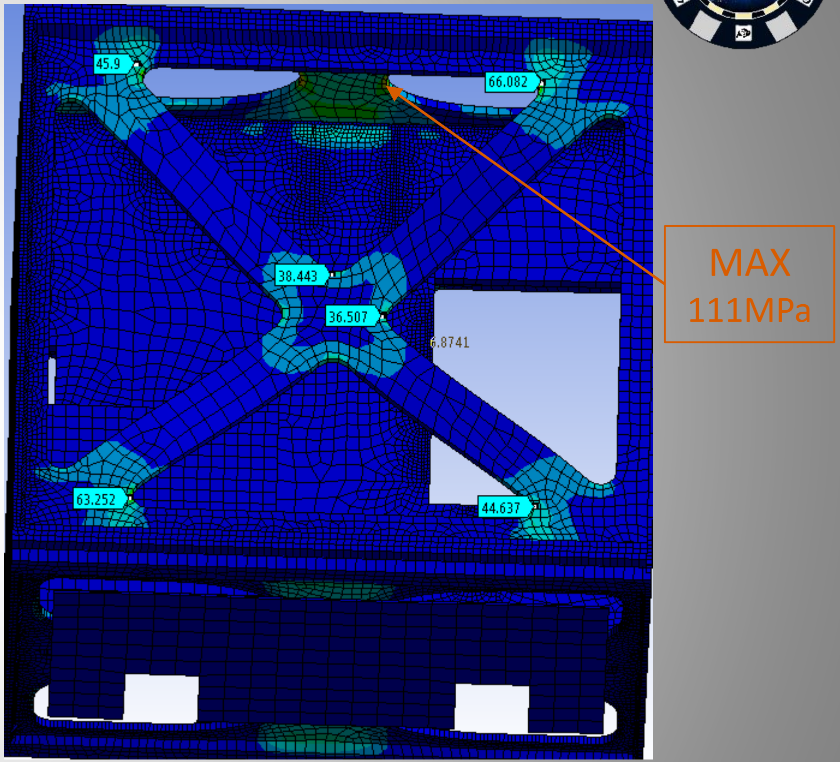
Applicability to Model

- Modeled in ANSYS
- Failed at loads ~26 kg applied to test panel tip.
- Translates to an expected equivalent stress of ~70 Mpa in face sheets
- Corroborated by BoTE model predicting 62.5MPa



Survivability: Test Model

- Max δ = 5.4mm (top panel)
- Quasi-static load of ~46g's (slightly larger than 4x9.47grms)
  - Due to modal amplification
  - Max stress in model: 111MPa
- Expected failure point: **6grms**



Equivalent stress under quasi-static load.
Units are in MPa

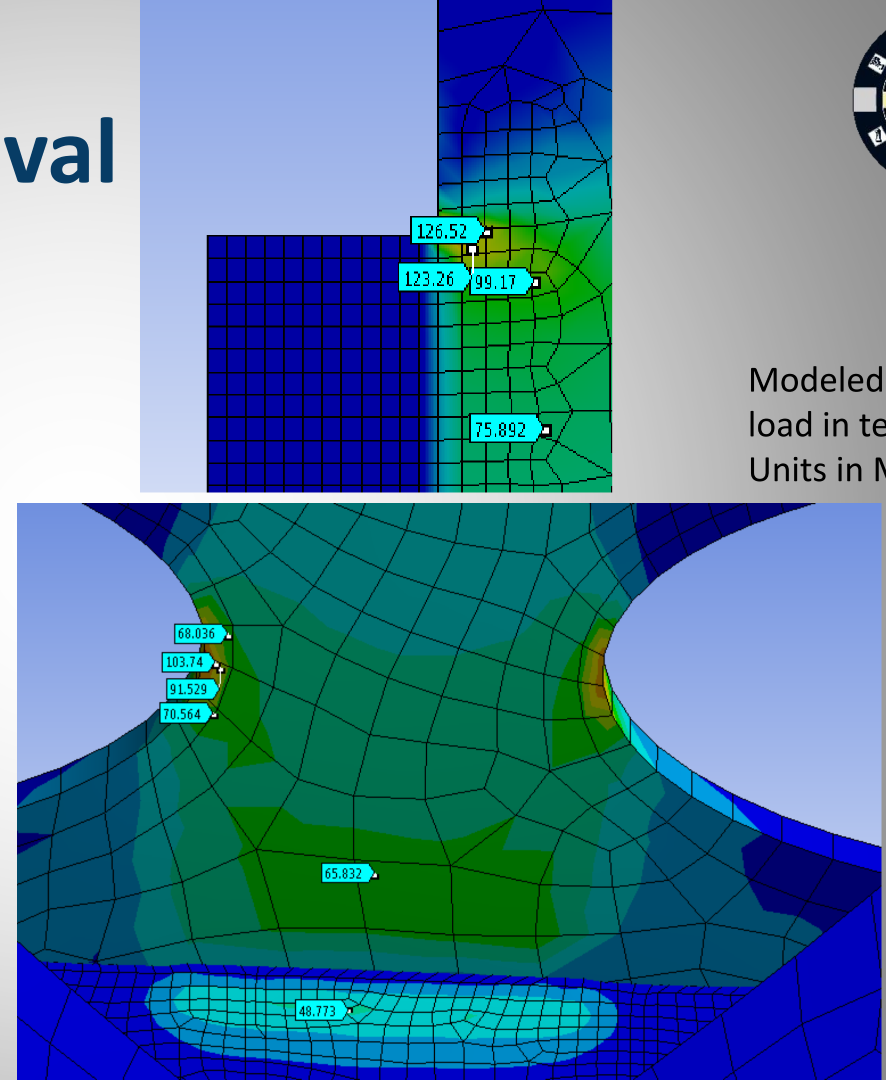
Expected strengths of both models

- In testing, foam-wrapping attenuated accelerations to ~.95grms
- Structure design is VIABLE

Property	Design Model	Test Model
Max [mm] -Vibe	10.3	5.4
Max load [Mpa] -Static	174.6	111
Expected Failure [grms]	3.8	6
Requirement	1.29	
Margin above FoS	55%	145%

Explanation for Survival

- Survival at 9grms:
  - **1st Principles Analysis** does not capture structure Dynamics
  - **Potting material** supports areas with concentrated stresses



Modeled failure load in test panel. Units in MPa

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1: Foam does not attenuate to 1.29 grms

- Severity: 1 Likelihood: 4 **Total: 4**
- Unexpected foam attenuation is not a failure in the design but a consequence of using an unfamiliar material
- Before Mitigation:
  - Develop fast method of computing modes with a change in attenuated vibration loads
  - Perform small-scale foam tests in ITLL and measure experienced acceleration
- Response After:
  - Stop test and continue at SST's discretion with either a new model or with the structure mounted directly to table and a vibration table setting of 1.29 grms
- Post-Mitigation Severity: 1 Likelihood: 3 **Total: 3**

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2 - Structure Fails on the Way to Vibration Test:

- Severity: 5 Likelihood: 2 Total: 10
- Structure will need to be fully assembled with adhesive before transferring to vibration test facility, and transfer will likely have more loads than the vibration test itself
- Before Mitigation:
  - Wrap structure at least as much as it will be wrapped during vibration testing
  - Drive slowly and carefully
  - Build box for transport
- Response After:
  - Bring emergency adhesives / tape
- Post Mitigation Severity: 5 Likelihood: 1 Total: 5

3: Structure does not fit through door

- Severity: 3 Likelihood: 1 Total: 3
- Extreme cautions will be taken so that this challenging inconvenience does not occur
- Before Mitigation:
  - Measure all doors and structures the STM must fit into and develop path to transfer vehicle before assembly
- Response After:
  - Carefully turn structure
  - Find another exit
- Post Mitigation Severity: 3 Likelihood: 0 Total: 0

4: Materials are not received on time

- Severity: 4 Likelihood: 2 **Total: 8**
- Timeline depends on having the panels early in the assembly process
- Before Mitigation:
  - Order materials as soon as possible after CDR
  - Contact manufacturing company frequently to verify delivery
- Response After:
  - Shorten timeline for the rest of manufacturing
  - Attempt to use similar material that is readily available for worst-case
- Post Mitigation Severity: 3 Likelihood: 2 **Total: 6**

5: DAQ System data is noisy

- Severity: 2 Likelihood: 3 Total: 6
- DAQ system has many complex systems that need to be integrated together and test for noise before going to vibration test where more unexpected noise can be incorporated
- Before Mitigation:
  - Test completed DAQ system on ITLL vibration table and analyze results
  - Communicate with CascadeTek about what signal effects to expect
- Response After:
  - Apply software filter to data after test day
- Post Mitigation Severity: 2 Likelihood: 1 Total: 2

6: DAQ system cannot save data

- Severity: 5 Likelihood: 1 Total: 5
- File sizes for test are large and also need to ensure permissions are correct for software to be used on any computer
- Before Mitigation:
  - Test software with fast data transfer on as many Windows computers as possible
- Response After:
  - Attempt to retest or use CascadeTek's data to complete requirements
- Post Mitigation Severity: 2 Likelihood: 1 Total: 2

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7: Manufactured Carbon Fiber panels are frayed

- Severity: 2 Likelihood: 3 Total: 6
- If edge-cutting is performed by team, many imperfections could be created
- Before Mitigation:
  - Manufacture test pieces
  - Develop metric to evaluate what imperfections are acceptable
- Response After:
  - Use spare pieces to manufacture again
  - Re-model the structure with these imperfections and test if the imperfections do not cause unexpected failure
- Post Mitigation Severity: 1 Likelihood: 3 Total: 3

9: Manufacturing takes longer than expected

- Severity: 4 Likelihood: 2 Total: 8
- Manufacturing needs to follow a fast-paced timeline and delays can quickly arise based on machine availability
- Before Mitigation:
  - Perform small-scale manufacturing to estimate time necessary for each piece
  - Reserve resources ahead of time if possible
- Response After:
  - Purchase components if this speeds up manufacturing process
  - Reduce necessary quality if margin allows
- Post Mitigation Severity: 1 Likelihood: 1 Total: 1

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10 - Vibration Testing Takes Longer Than 8 Hours:

- Severity: 5 Likelihood: 2 **Total: 10**
- Budget hinges on paying for an 8 hour testing day and if testing is not completed, measures will need to be taken to pay for another day or use table after hours
- Before Mitigation:
  - Practice entire process of moving accelerometers and unwrapping/rewrapping structure
  - Develop time estimates for each test and off-ramps to complete test more quickly while still meeting requirements
- Response After:
  - Attempt to finish test outside business hours or another day for a reduced rate
  - Attempt to finish required tests on smaller scale in ITLL
- Post Mitigation Severity: 4 Likelihood: 1 **Total: 4**

11: Mass analogs are not prepared in time for test

- Severity: 5 Likelihood: 1 Total: 5
- Mass analog creation will not be difficult but is essential to perform vibration test
- Before Mitigation:
  - Create specific plan to acquire each mass analog and manufacture it, similar to design plan
- Response After:
  - Create mass analog with scraps from shops or borrowed weights that may be reduced uniformity
- Post Mitigation Severity: 4 Likelihood: 1 Total: 4

12: Exhibited modes in vibration test do not match predicted model

- Severity: 1 Likelihood: 4 Total: 4
- Unexpected modes do not necessarily mean failure, but team model of structure must be validated
- Before Mitigation:
  - Create many possible profiles of structure modes based on calibrations and first tests
  - Consult PAB members and faculty to verify model should be correct
- Response After:
  - Attempt to match modes with prepared model profiles
  - If structure is not experiencing failure, continue with test and analyze results after test day
- Post Mitigation Severity: 1 Likelihood: 3 Total: 3

13: Adhesive bonds break during assembly

- Severity: 3 Likelihood: 1 Total: 3
- Adhesive strength is largest variable and may not withstand other elements of assembly
- Before Mitigation:
  - Analyze assembly plan with possible points of failure
  - Prepare schedule and budget for spare gluing time and spare glue
- Response After:
  - Re-glue failed components
- Post Mitigation Severity: 2 Likelihood: 1 Total: 2

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14: USB Communication protocol does not function at necessary speed

- Severity: 5 Likelihood: 3 Total: 15
- USB communication currently has large margin but fast data transfer must be achieved for quality data to be collected
- Before Mitigation:
  - Use development board to demonstrate USB protocol capabilities (In progress)
- Response After:
  - Explore different USB transmission schemes
  - Experiment with other protocols such as Ethernet
- Post Mitigation Severity: 5 Likelihood: 1 Total: 5

15: Low pass filter corrupts accelerometer data

- Severity: 4 Likelihood: 1 Total: 4
- Low pass filter is necessary to signal processing but adds complexity to design
- Before Mitigation:
  - Test low pass filter circuit and model frequency response
- Response After:
  - Perform digital filtering on circuit instead
  - Revise board and reorder
- Post Mitigation Severity: 2 Likelihood: 1 Total: 2

16: Charge Amplifier corrupts signal

- Severity: 4 Likelihood: 2 **Total: 8**
- Charge amplifier will be created by team and as such includes variability that cannot influence data
- Before Mitigation:
  - Test charge amplifier circuit and demonstrate its capabilities with accelerometer data
- Response After:
  - Rebuild circuit, revise board
- Post Mitigation Severity: 2 Likelihood: 2 **Total: 4**

17 - ADC Corrupts / Cannot Transfer Signal:

- Severity: 5 Likelihood: 2 **Total: 10**
- ADCs are essential to the transfer of data from sensor to microcontroller
- Before Mitigation:
  - Thoroughly familiarize with ADC specs
  - Review ADC schematic with PAB members
  - Utilize former team's knowledge and prior experience
- Response After:
  - Debug on board
  - Revise board and remanufacture
- Post Mitigation Severity: 3 Likelihood: 2 **Total: 5**

18: Power distribution fails or destroys components

- Severity: 5 Likelihood: 1 Total: 5
- All electronics are power-sensitive and all failures will be considered before test day
- Before Mitigation:
  - Include fuses, zero-ohm resistors, and voltage regulators for circuit protection
  - Create plan to verify functionality of power section before powering critical components
- Response After:
  - Remove damaged component and replace from available resources
  - Rework board design and remanufacture
- Post Mitigation Severity: 4 Likelihood: 1 Total: 4

19 - Microcontroller Cannot be Programmed:

- Severity: 5 Likelihood: 2 Total: 10
- Microcontroller required for data transfer speed is more complicated than boards previously used by team members
- Before Mitigation:
  - Use development board to program microcontroller (In progress)
  - Read literature and programming manuals
- Response After:
  - Utilize more team resources to debug and revise board
  - Use development board while designed board is in work
- Post Mitigation Severity: 4 Likelihood: 1 Total: 4

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Error Analysis:

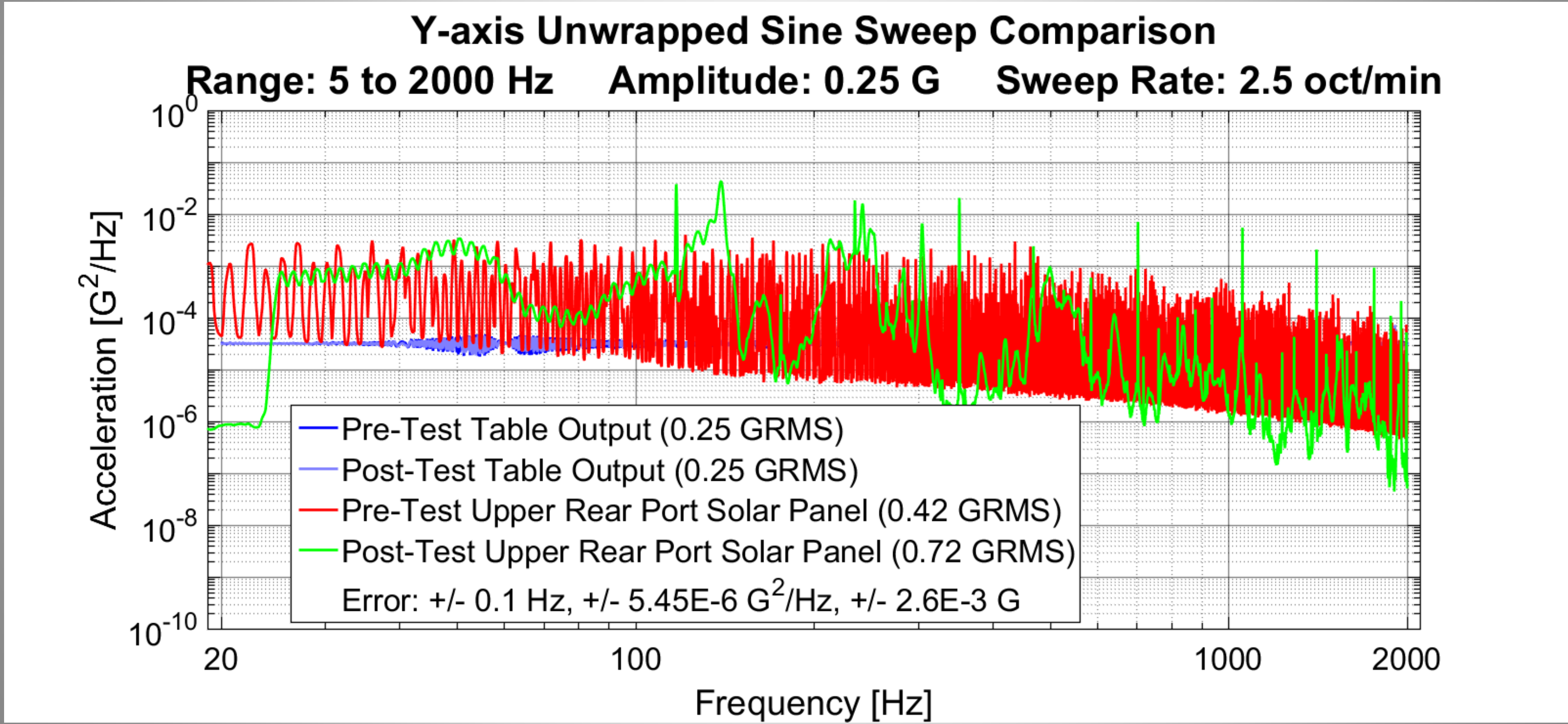
- Sources with known error: IE. NI DAQ
- Sources with unknown error: IE. Accelerometer mounting
- Error propagation formula:

$$\delta q = \sqrt{\left(\frac{\partial q}{\partial x} * \delta x\right)^2 + \left(\frac{\partial q}{\partial y} * \delta y\right)^2 + \cdots}$$

Component	Timing Error [± s]	Amplitude Error [± Volts]
NI 9234 DAQ	2.5E-8	2.5E-5
Cables	-	2.6E-4
Accelerometers	-	4.9E-7

Data Type	Error ±
Frequency [Hz]	0.1
Acceleration [G]	2.6E-3
Acceleration [G^2/Hz]	5.45E-6

Observed Errors:



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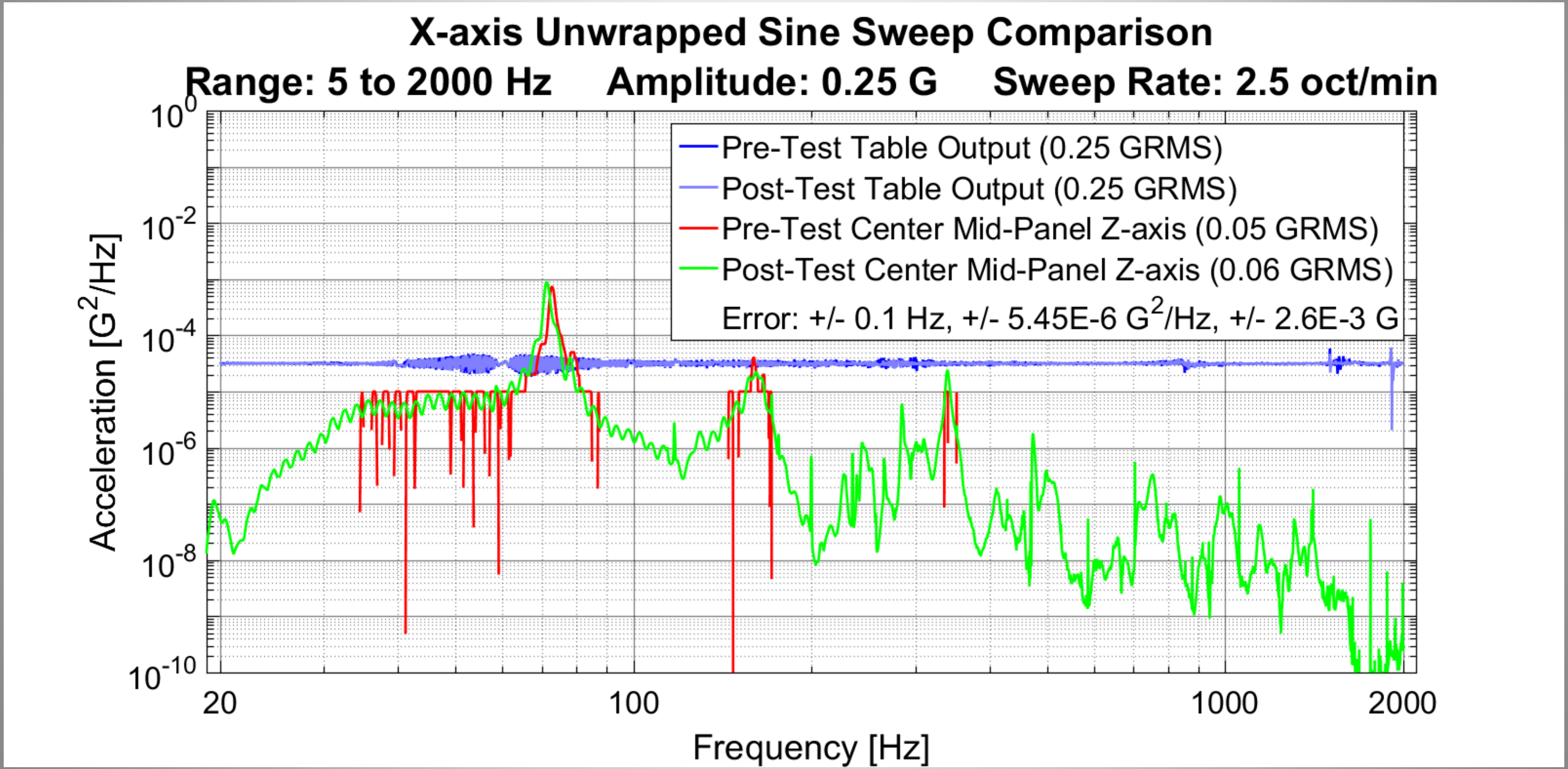
Observed Errors:



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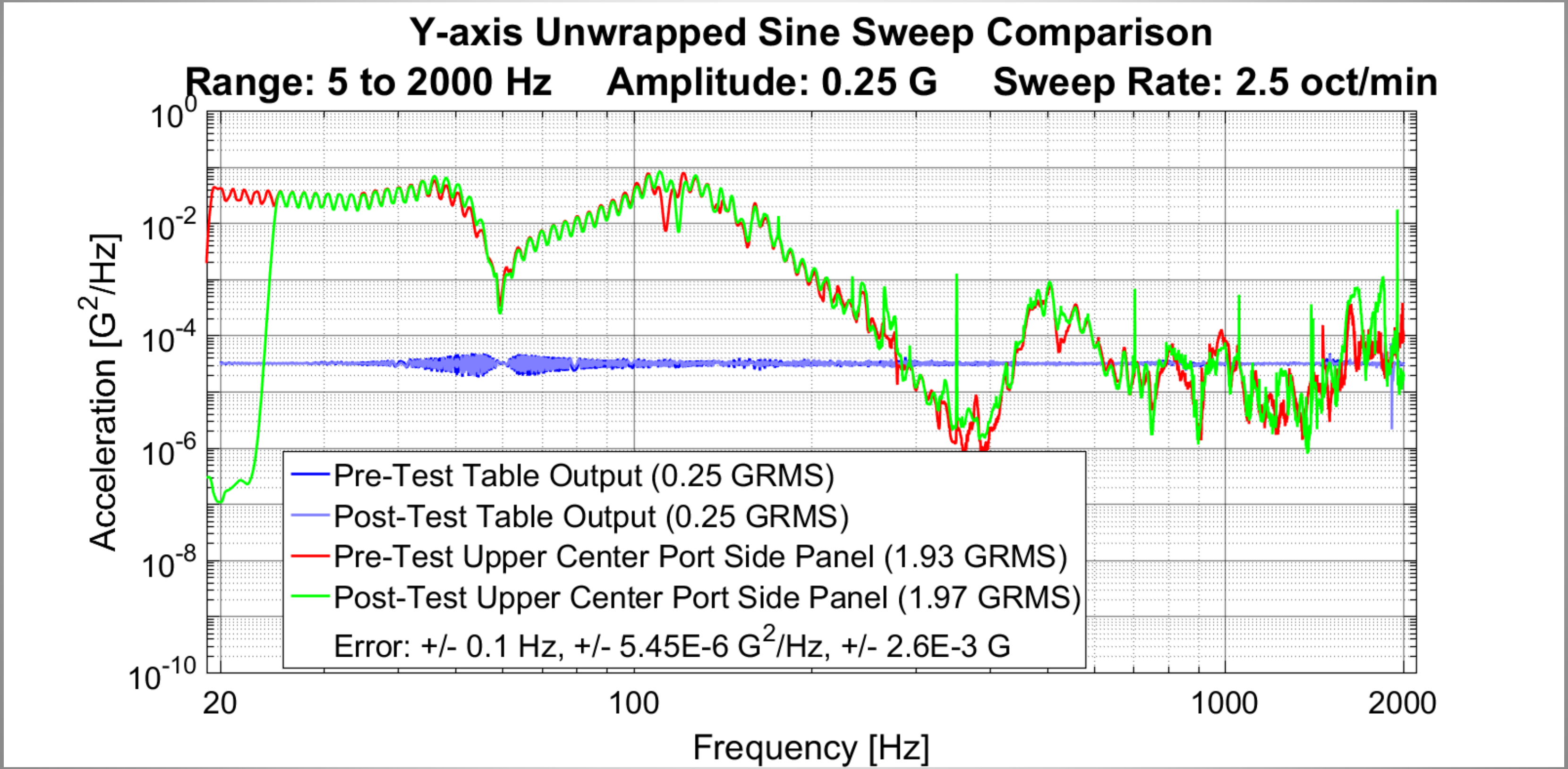
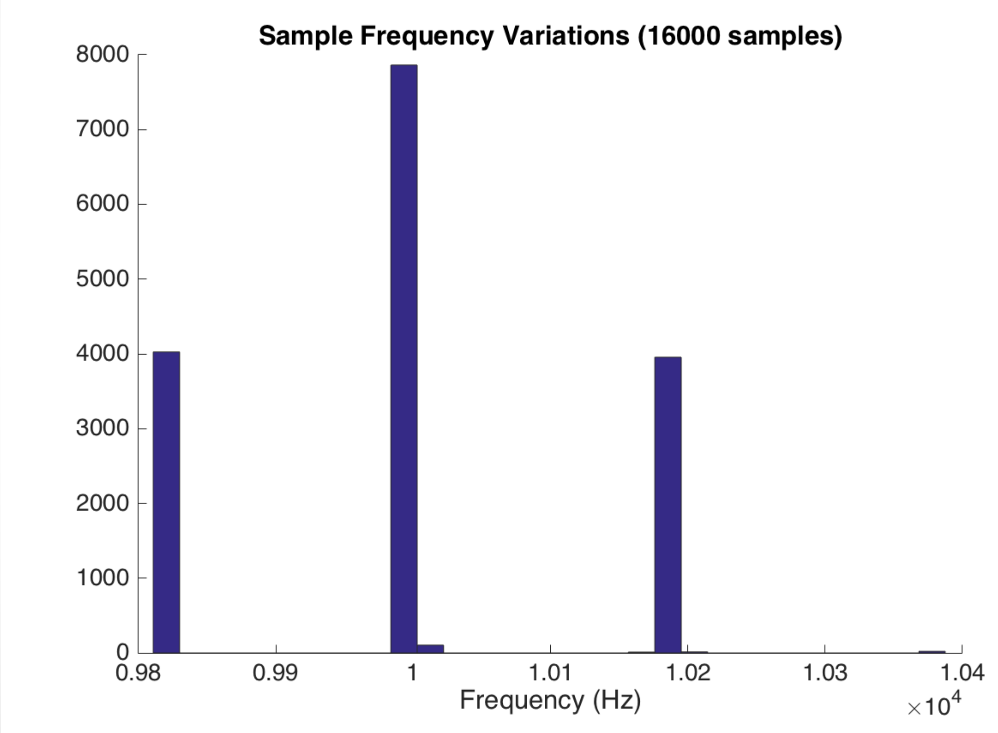
Observed Errors:



DAQ Results: Data TX between μC and PC

Metric:	Value [Hz]:	Error:
Mean Sample Rate	10.0018 kHz	0.0175%
Max. Sample Rate	10.387 kHz	3.87%
Min. Sample Rate	9.810 kHz	-1.89%
Standard Deviation	132.08 Hz	NA



Data TX between µC and PC – Results:

- Verified data rate accuracy
  - Used f_{sample} = 10 kHz
  - Ran bulk data transfer over USB bus
    - Sent timing information to verify data transfer
  - Handled within software through interpolation for the PSD calculation

Metric:	Value [Hz]:	Error:
Mean Sample Rate	10.0018 kHz	0.0175%
Max. Sample Rate	10.387 kHz	3.87%
Min. Sample Rate	9.810 kHz	-1.89%
Standard Deviation	132.08 Hz	NA

Why Is It Too Big?

- Compression of the radiator showed we needed a diameter larger washer to prevent crushing
  - Had to add two additional washers so the screw wouldn't slip through
- Screws head in design were unavailable
- Columns may be slightly longer than designed