# Critical Design Review

# FISH & CHIPS

FeatherCraft Integrated Structural Housing & Computer, Hardware Interface Processing Suite

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**Customer:** Michael Brown

**Advisor:** Joe Tanner

# PROJECT PURPOSE & OBJECTIVES

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# Project Motivation:

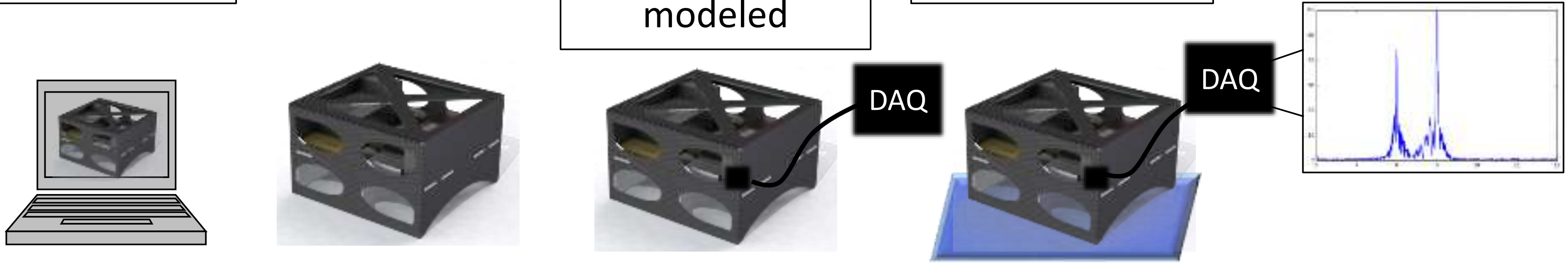
- Commercialization of International Space Station (ISS) provides a launch opportunity not only to cubesats but larger **100 kg spacecraft**
- Spacecraft are launched on ISS cargo resupply missions, allowing for soft-stowed configuration and less stress on structure in launch environment
- Surrey Satellite Technology US plans to offer the FeatherCraft system as a cost-effective platform for **payloads of 45 kg** or less.

# 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. Select suitable lightweight material and create design for structure → 2. Fabricate structural test model → 3. Design and build data acquisition system to verify structure's behavior is as modeled → 4. Test structural test model on a vibration table with mass loadings → 5. Analyze accelerometer data and verify requirements are met



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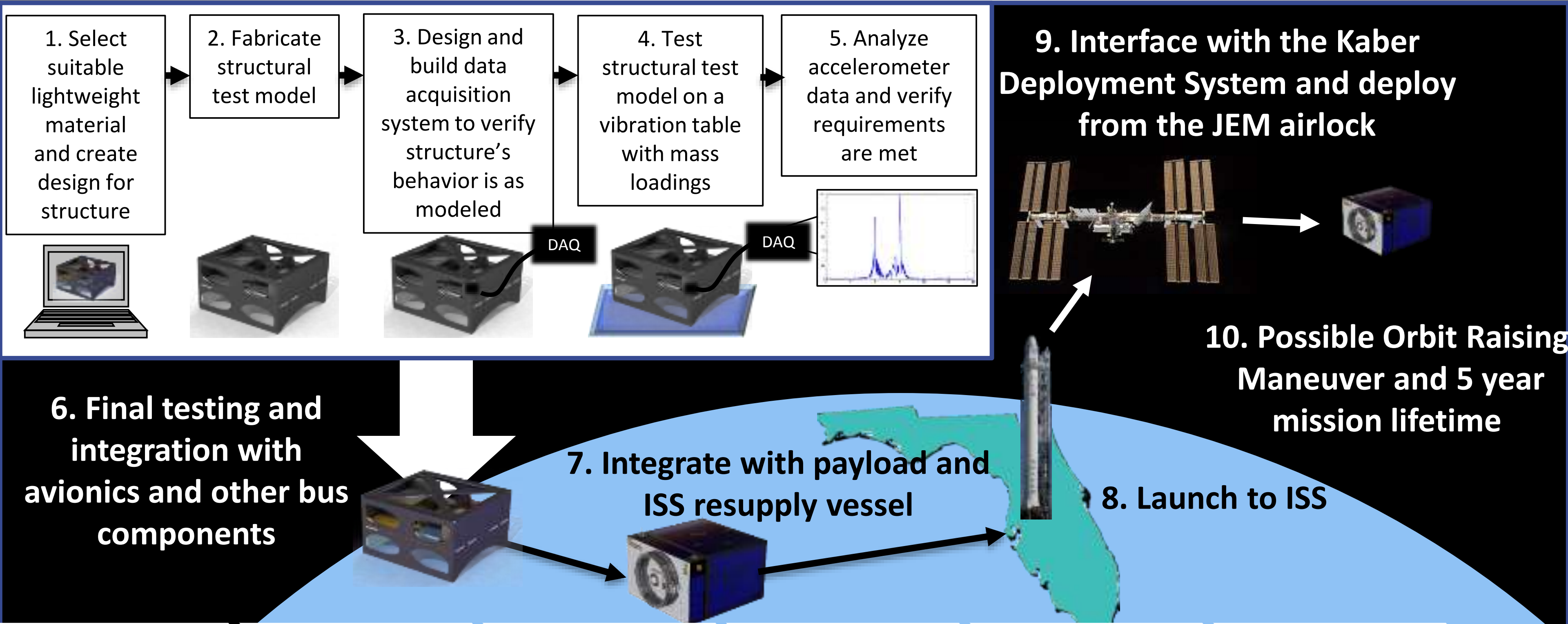
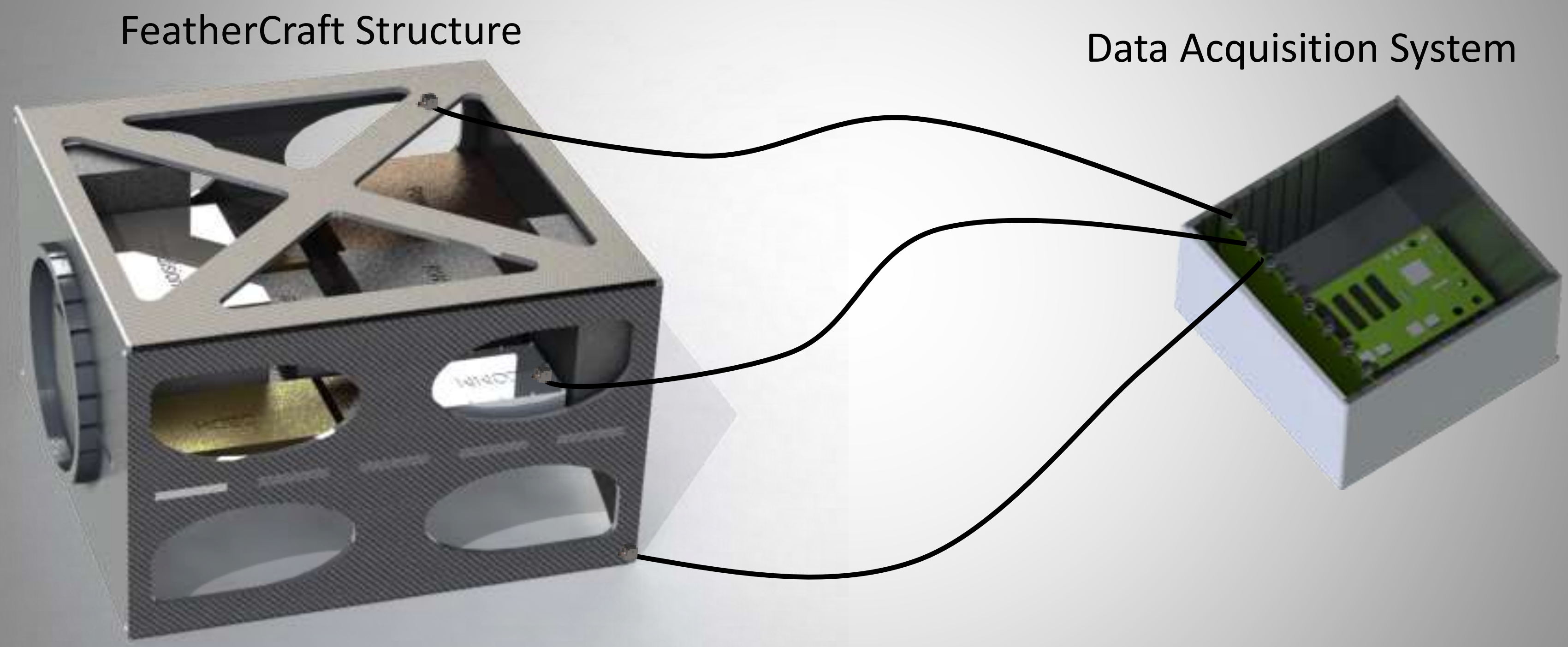
# CON OPS:

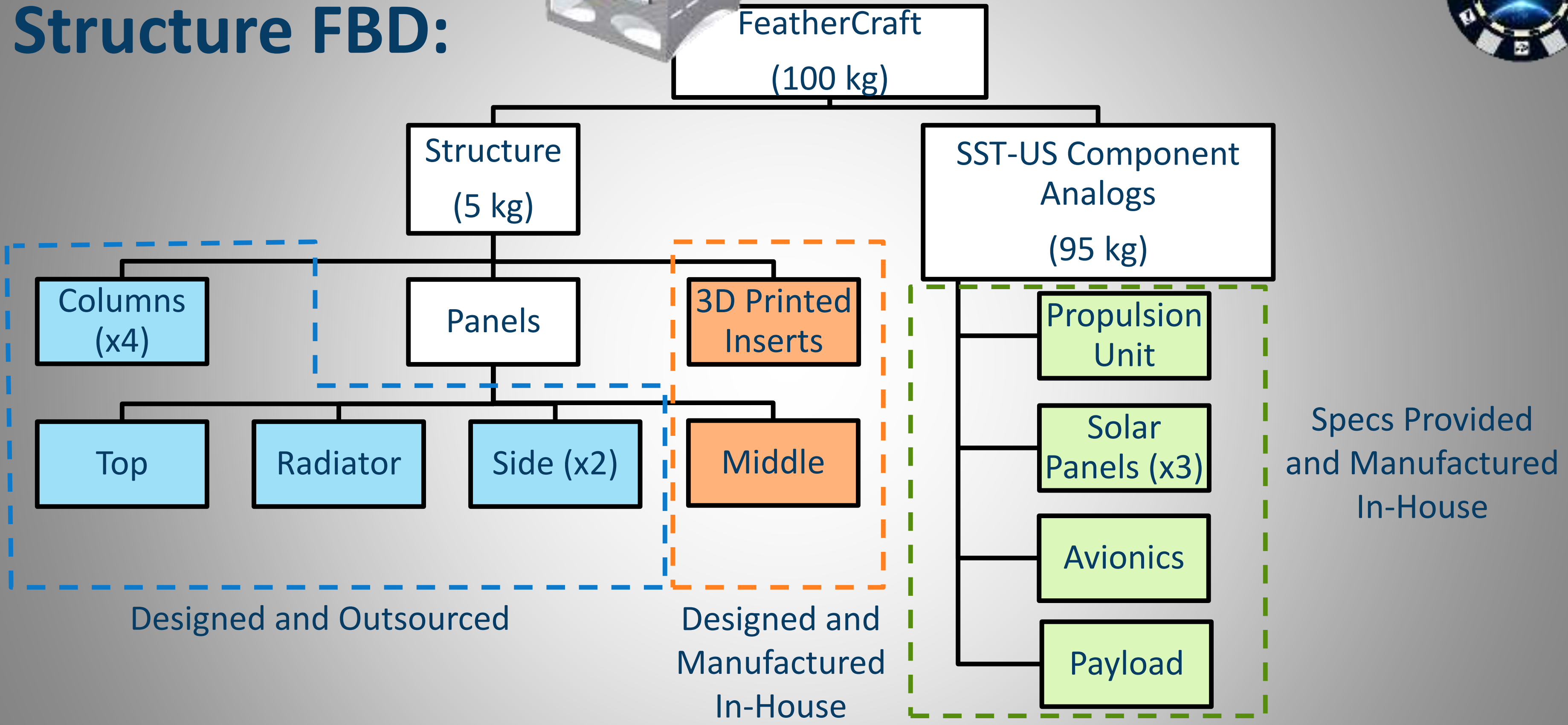


# DESIGN SOLUTION

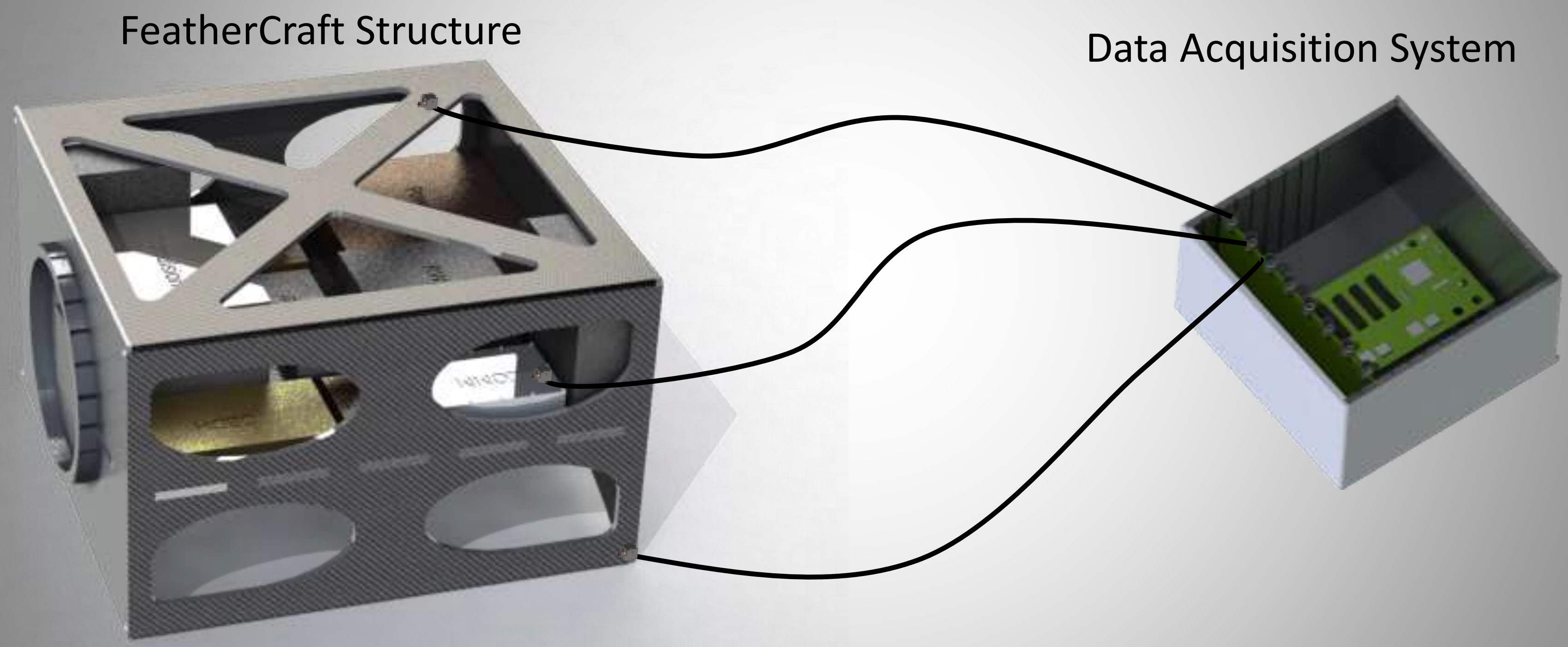
# FISH & CHIPS Design:



# Structure FBD:

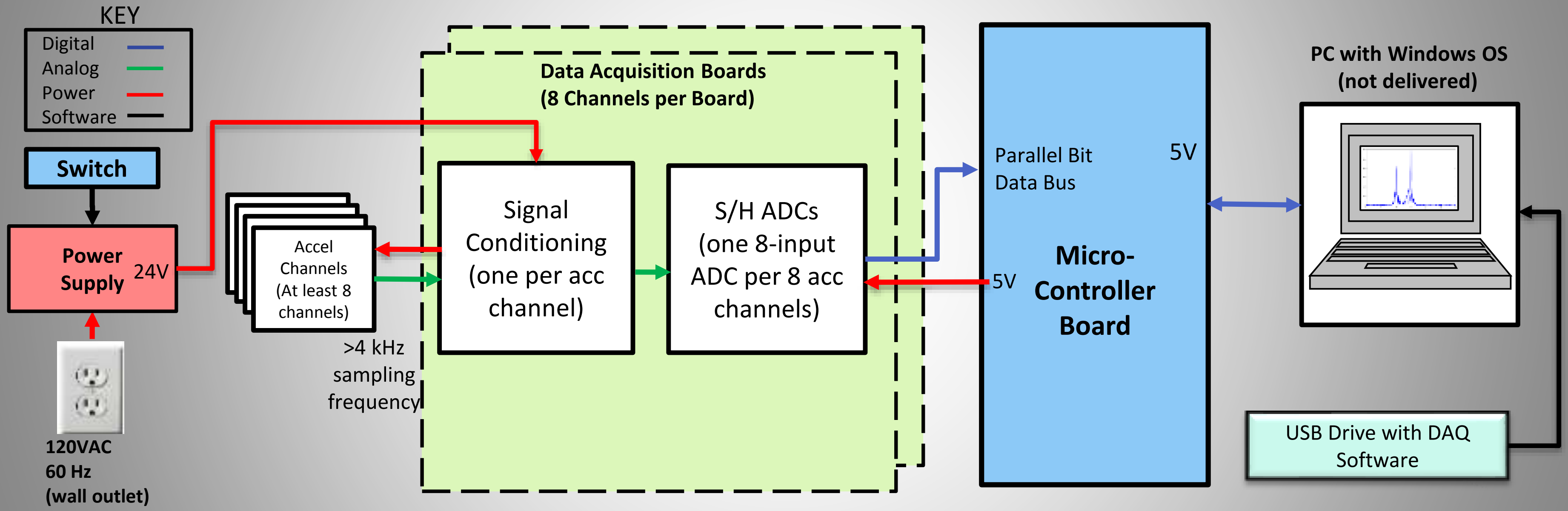


# FISH & CHIPS Design:



# DAQ Hardware FBD:

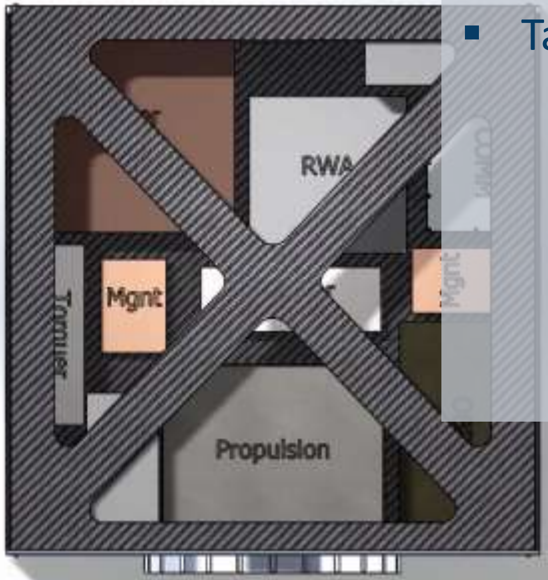
Detailed DAQ Design in Validation and Verification Section



# STRUCTURE DESIGN

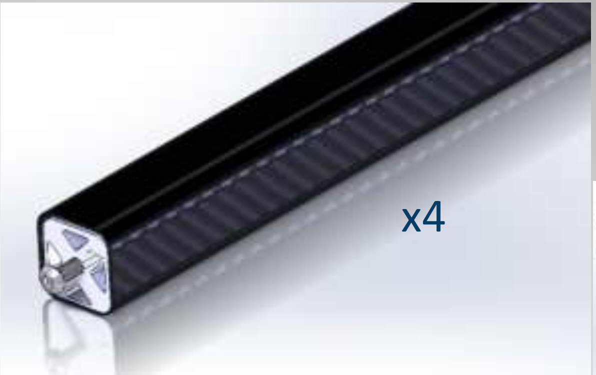
# Design Overview:

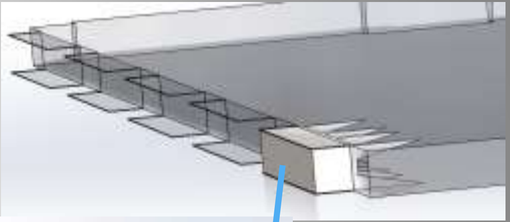
- Weight reliefs provide access to components after adhesives cure
- Proper component design allows total access
  - Clamshell cases
    - stress concentrations



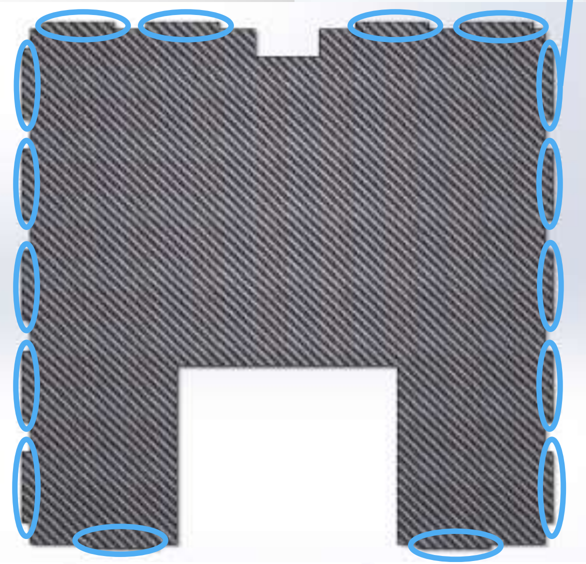

- Tab Inserts
  - 3D printed ABS plastic
  - Weight Relieved
  - Provide a strong tab/panel interface
  - Reduce stress concentrations

# Assembly Step 1:



- Columns
  - Inserts are bonded into columns
- Middle Plate
  - Inserts are bonded into tabs



Sub-assemblies are cured in thermal chamber

Edge close out is detailed in back-up slides

# Assembly Step 2:

Assemble frame

- Install Propulsion Plate and Radiator
- Install Middle Panel

# Assembly Step 3:

## Install Side Panels

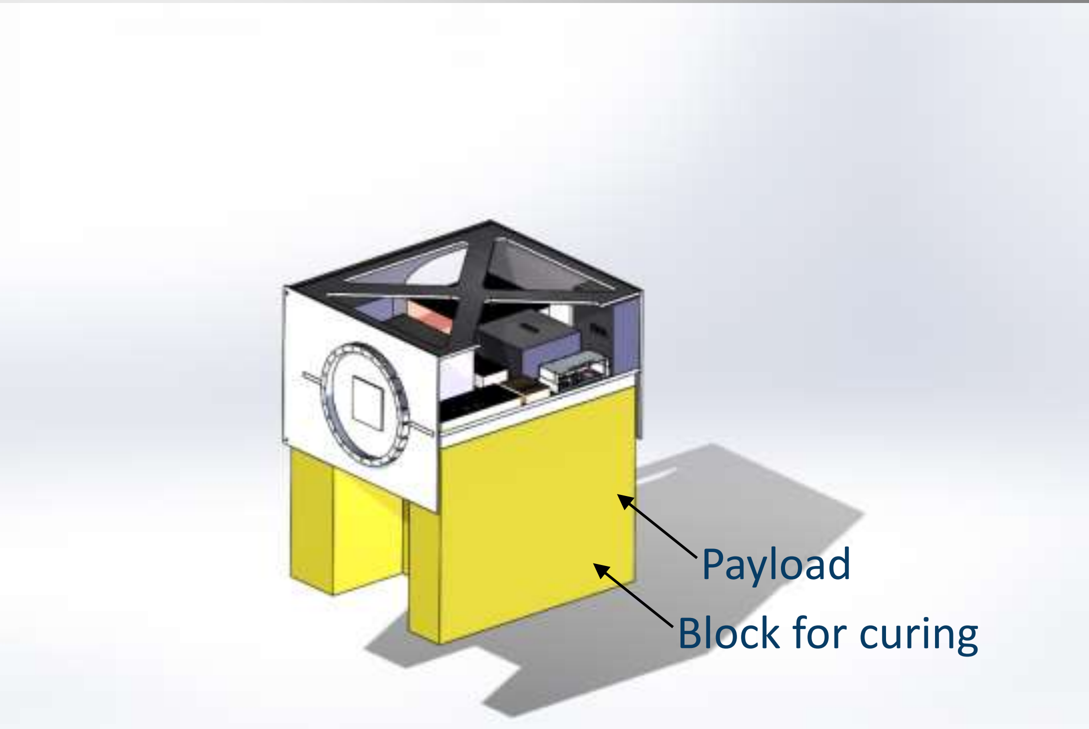
- Ensure proper alignment within structure
- Apply pressure on glued components

## Cure in thermal chamber

# Assembly Step 4:

- Integrate Payload
  - Assembly block configuration
  - Cure STM in thermal chamber

- Install avionics mass simulators
  - Gluing of mating surfaces
  - Install Top Panel with glue
  - Cure STM in thermal chamber



# Assembly Step 5:

- Install Solar Panels
  - Adhesive (Side)
  - Velcro (Top & Side)

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# CRITICAL PROJECT ELEMENTS

# Critical Project Elements:

| Critical Project Element | Component |
| --- | --- |
| Mass of structure below **5 kg** while **surviving launch** to the ISS (FR 1 and DR 3.1) | Structural |
| Support of up to **60 accelerometer** channels in DAQ system (DR 5.6.1.1) | Electronics and Software |
| Providing support and **mounting** positions for other **spacecraft components** (FR 4) | Structural |
| **Manufacturing time and cost** below required values and feasible in spring semester (FR 2) | Structural and Logistical |
| **Vibration test** table time acquisition (DR 5.2) | Logistical and Financial |

# DESIGN REQUIREMENTS

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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. |

# FR 1: Mass of less than 5 kg

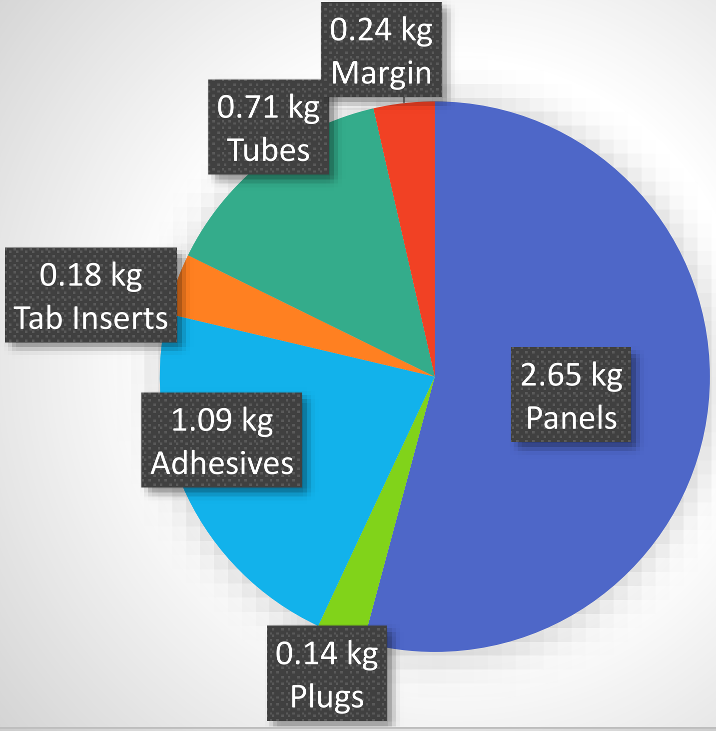
# Structure Mass below 5 kg:

- Structure consists of carbon fiber sheets, adhesive attachments, carbon fiber columns, column plugs, and tab inserts
- Analysis shows a current mass of 4.76kg
- All differences between design and STM will be noted and all components of STM weighed

| Requirement: | Required Value: | Current Value: | Margin: | |
|---|---|---|---|---|
| **FR 1:** Structure design must weigh less than 5 kg | 5 kg | 4.76 | 5% | Requirement Met |

# Mass Budget:

**Total Mass:**
**4.76 kg**



# FR 2: Reduce manufacturing time and material cost

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# Structure (space-grade) shall cost 50% less and take 50% less time than SST-US typical estimates:

**Assumptions:**

- All composites are space grade and manufactured by specialized composites companies.
- A team of 4 SST-US technicians making an average hourly wage assemble the spacecraft in house

| Requirement: | Required Value: | Current Value: | Percent Margin: | |
|---|---|---|---|---|
| **DR 2.1**: Material shall cost less than $20,000 | $20,000 | $7744 | 61% | Requirement Met |
| **DR 2.2**: Manufacturing and assembly shall take 9 months | 9 months | 3 months | 67% | Requirement Met |
| **DR 2.3**: Manufacturing and assembly labor shall cost less than $80,000 | $80,000 | $21,120[14] | 74% | Requirement Met |

# FR 3: Launch to the ISS and deploy from the Kaber system on the ISS

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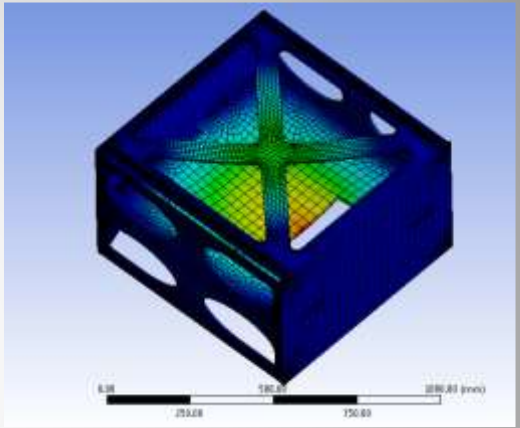
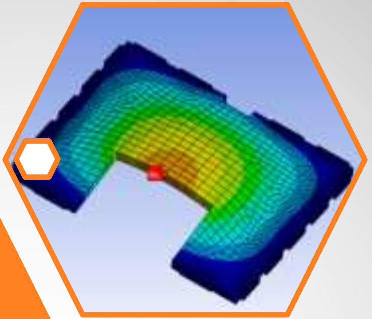
# Structure Shall Survive Launch to the ISS :

- ANSYS model created assuming worst case spacecraft component loading
- Next slides show more detail on creation of FEA



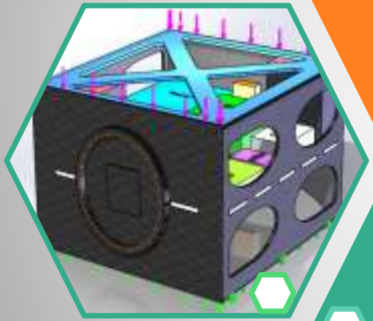
| Requirement: | Required Value: | Lowest Margin (Above FOS): | |
|---|---|---|---|
| **DR 3.1.1:** Structure design components will not show visible damage after simulating vibration profile | Positive margins on all critical components | 1.7% | Requirement Met |

# Analysis Overview:



ANSYS

(Whole Structure)

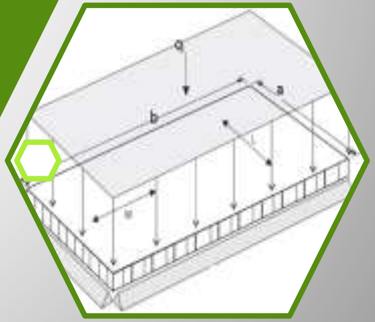


First Principles

(Worst-Case Bond Loads)

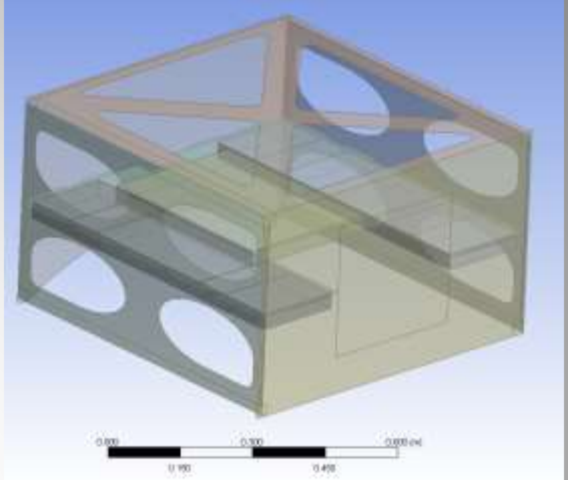
Solidworks

(FEA Check)



# ANSYS Overview:

- ANSYS
  - 2D Shell elements
  - Layered Sections
- 2 Analysis cases
  - Random Vibration Loading (3-axis)
    - Used conservative static loads
  - Modal Sweep

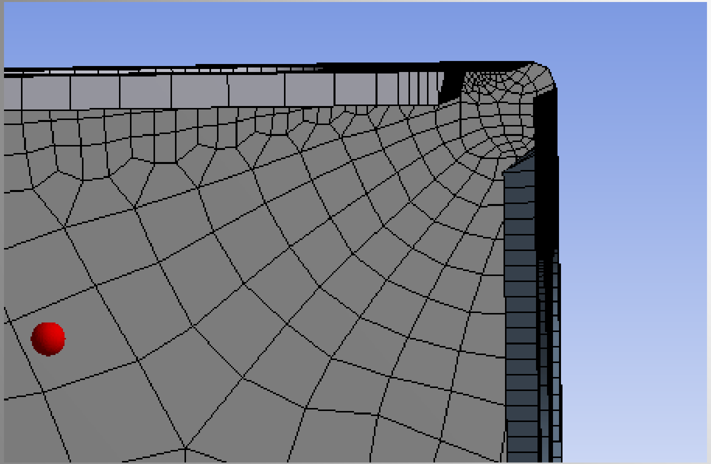


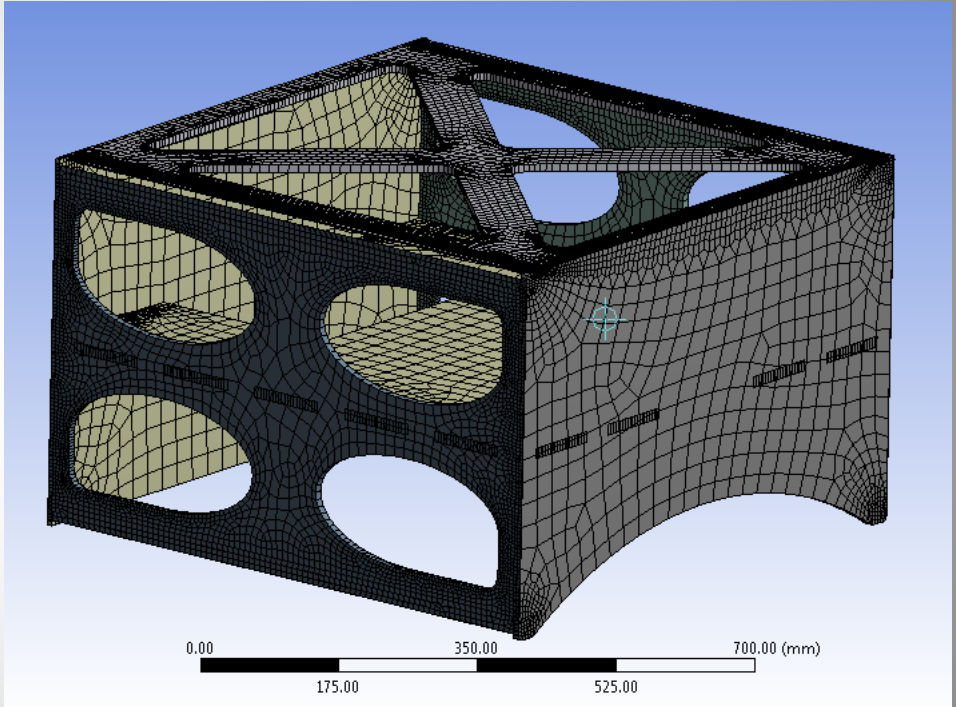
## 0.5” Middle Panel Layers:

| Layer | Material | Thickness (mm) |
|---|---|---|
| (+Z) | | |
| 5 | M55J 0/90 Fabric | 0.3 |
| 4 | M55J 45/-45 Fabric | 0.3 |
| 3 | Aluminum Core Material (5056 1/8" 72) | 12.7 |
| 2 | M55J 45/-45 Fabric | 0.3 |
| 1 | M55J 0/90 Fabric | 0.3 |
| (-Z) | | |

# ANSYS Geometry:

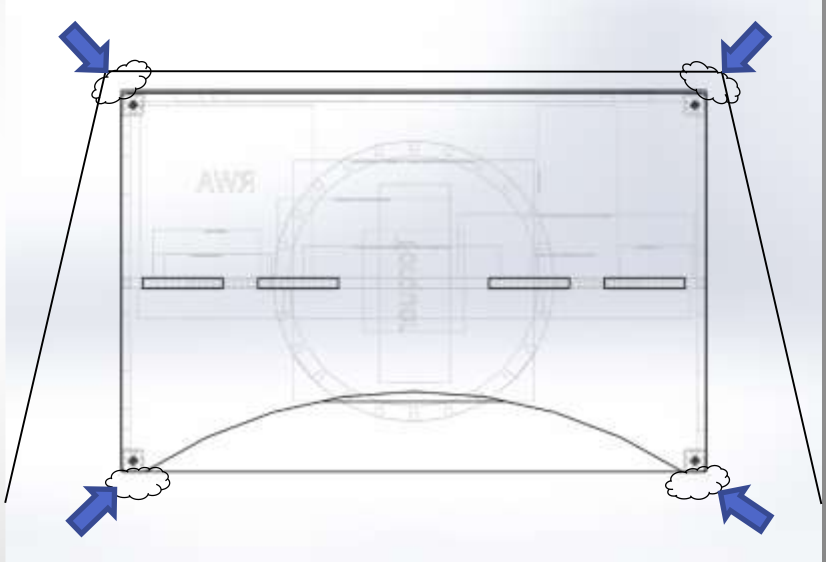
- Limited number of elements
- Columns omitted from model





# ANSYS Boundary Conditions:

- Columns treated as fixed – acceleration will act on structure through these members.
- Columns extremely rigid compared to structure.
- In modal, only fix lower columns
    - Toe clamps



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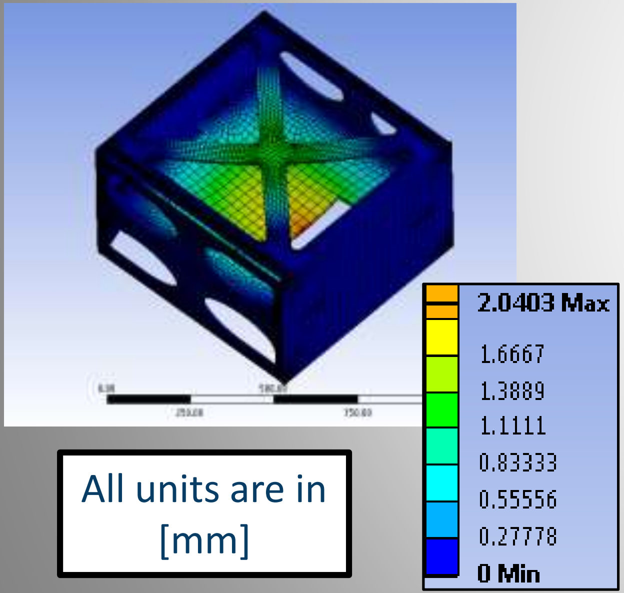
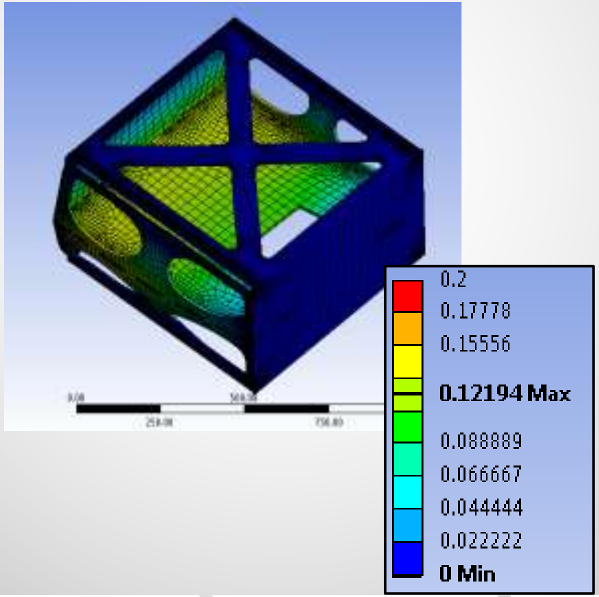
# ANSYS Design Model Results:

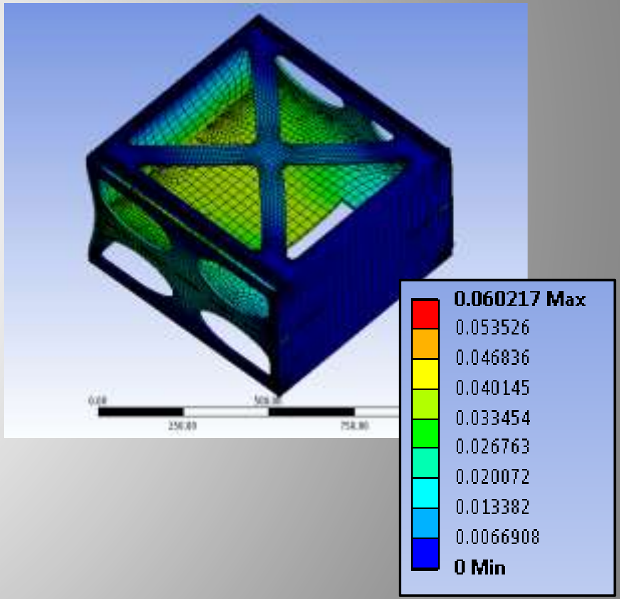
Zenith Acceleration-
Worst case: **middle panel**




Port/Starboard Acceleration-
Worst case: **side panels**



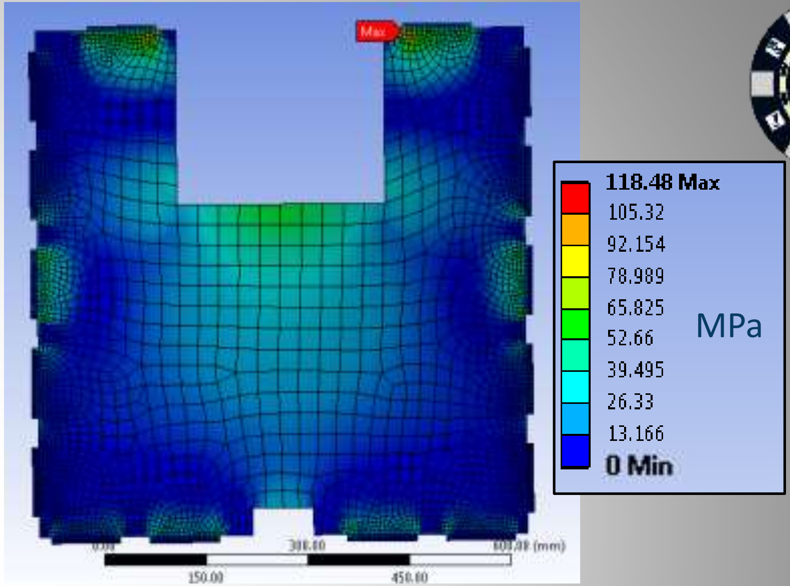

Ram/Wake Acceleration-
Worst case: **bolted joints**



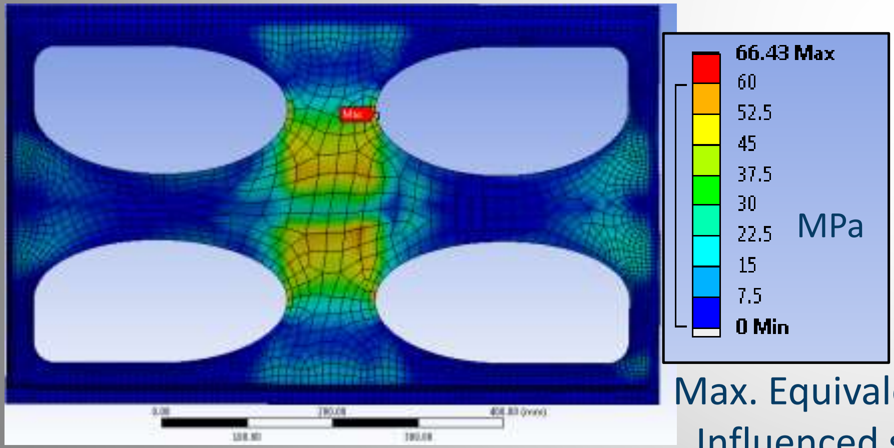

All units are in [mm]

# Zenith Acceleration:

- Influenced layout and size of tabs
- Central tabs bear greatest load
  - Due to distributed mass
- $\sigma_{Ult} = 750MPa$




Max. Equivalent stress in middle panel (experienced by face sheets)




Max. Equivalent stress in side panels
Influenced shape of weight reliefs

**Margin above FOS: 30%**

# Joint Survivability: Adhesives

## Structural Epoxy:

Scotch Weld EC-2216


## Potting Epoxy:

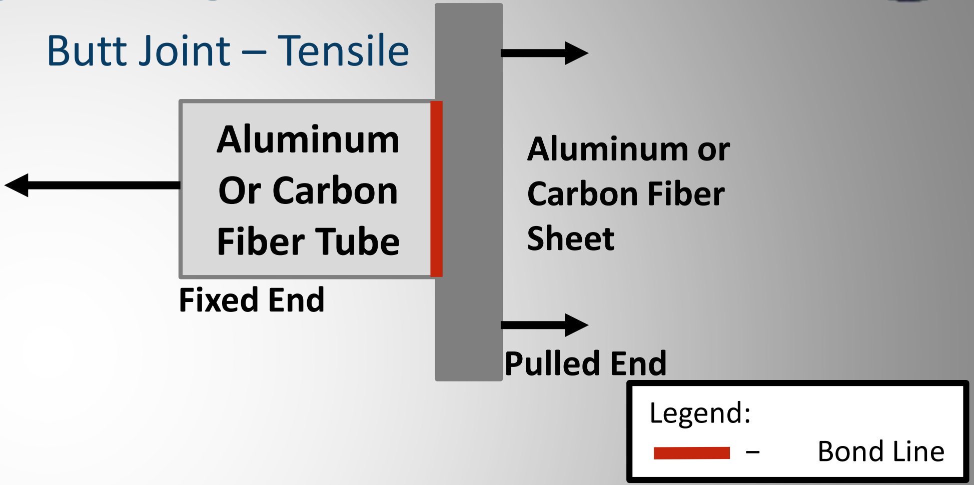
Scotch Weld 3550


Edge Close Out Example

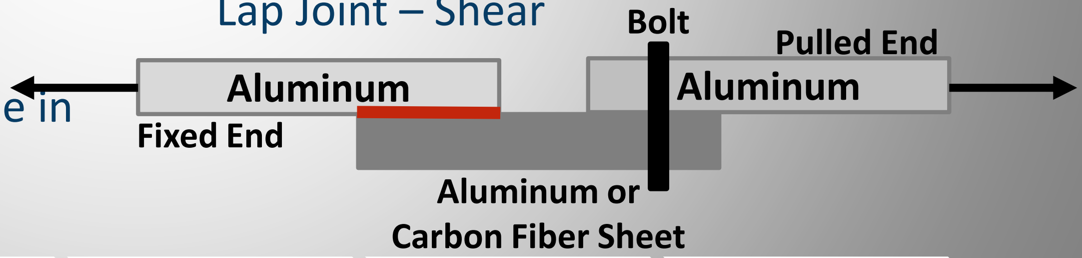
# Small Scale Adhesive Testing Configuration:

- Tensile Tests
  - Aluminum to Aluminum (FR 4)
  - Aluminum to Carbon Fiber Sheet (FR 4)
  - Carbon Fiber Tube to Carbon Fiber Sheet (FR 3)
- Shear Tests
  - Aluminum to Aluminum (FR 4)
  - Aluminum to Carbon Fiber Sheet (FR 4)

Butt Joint – Tensile




Lap Joint – Shear

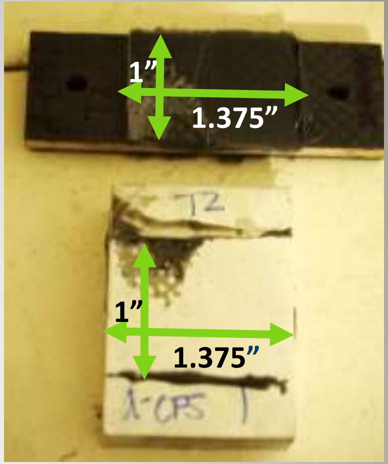


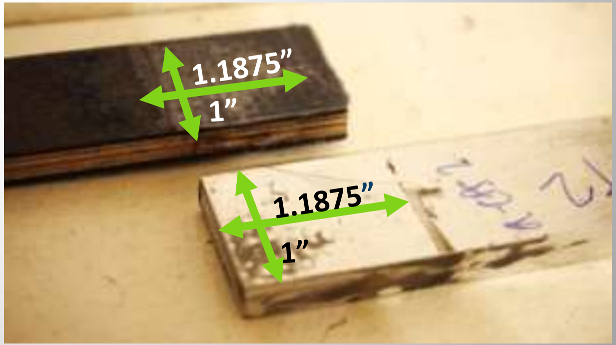

Tests performed using INSTRON machine in ITLL

# Small Scale Adhesive Testing Procedure:

- Surface Preparation
  - Wiped surface with **acetone**
  - Sanded surface with **sandpaper**
  - Wiped with **acetone and isopropyl alcohol**
  - Performed this with aluminum (tests 1-6), carbon fiber (tests 4-6)
- Gluing
  - Epoxy stirred in recommended ratio with stick and applied to both surfaces
  - **Bond thickness (0.005”)** controlled with wires laid on one surface and other surface pressed on top
- Curing
  - Held with clamps for weights for 12-24 hours
  - Cured in small oven at 200 degrees F about 2 hours

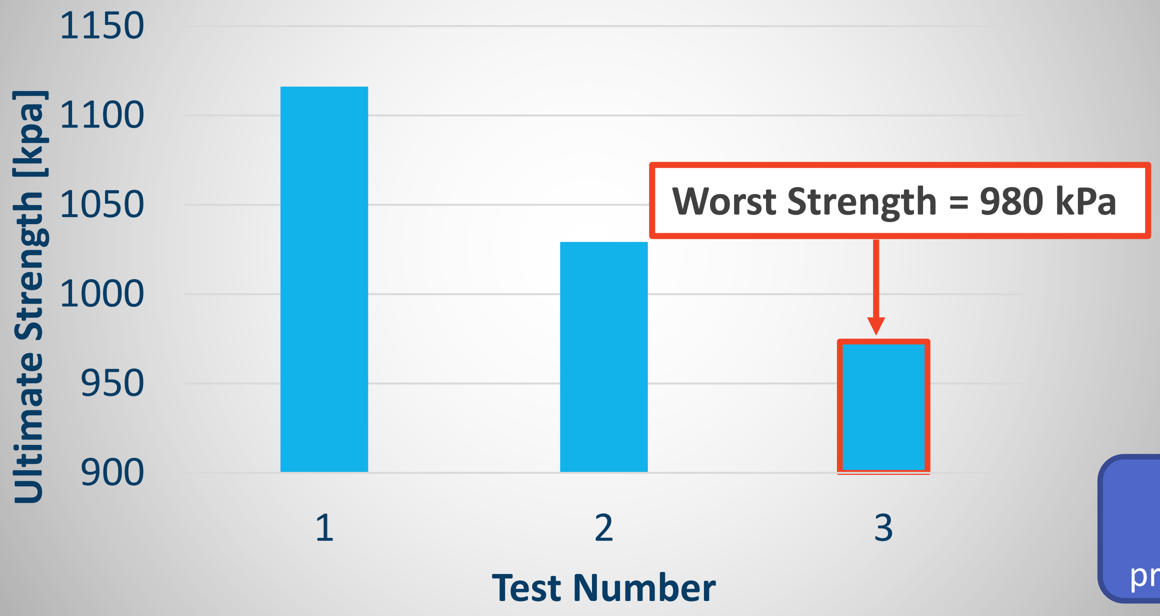
Tensile Test




Shear Test

# Carbon Fiber Tube to Carbon Fiber Sheet Adhesive Testing Results:




Results of other Adhesives Tests presented on slide 43

# Adhesives Analysis:

## Assumptions:

- Factor Of Safety: 4
- Allowable strength of adhesive σ = 980 kPa (lowest observed in testing)

| Areas Considered: | Percent Margin: |
|---|---|
| Side Panel - Tube | 38 % |
| Top Panel - Tube | 12.5 % |
| Tube Inserts - Tube | 1.7 % |

# FR 4: Interface SST-US spacecraft components.

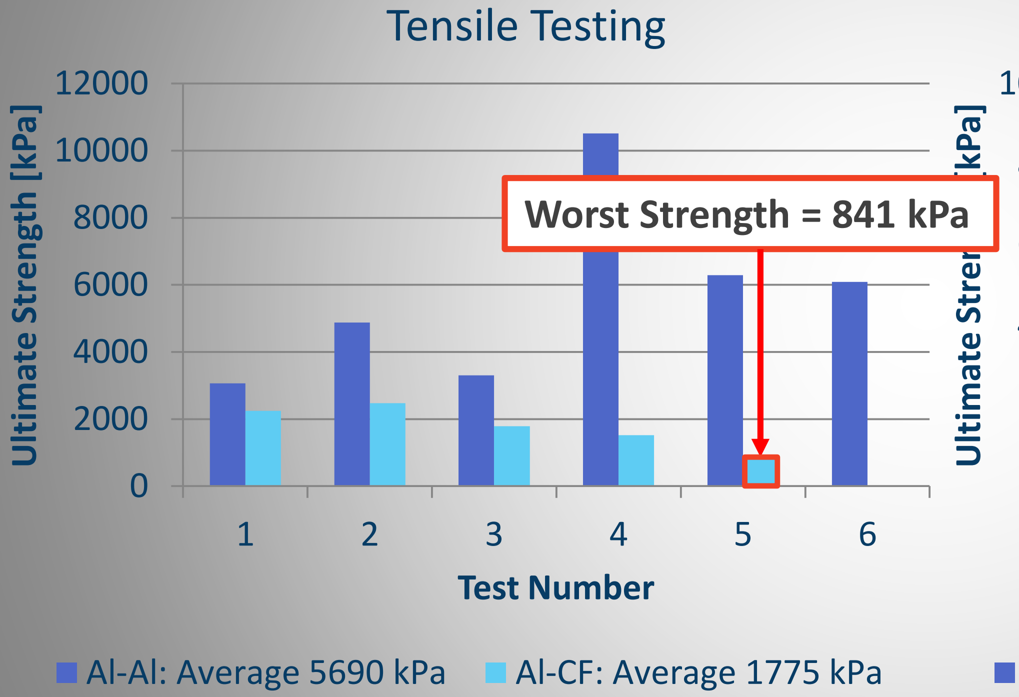
# Components will be Mounted on Structure:

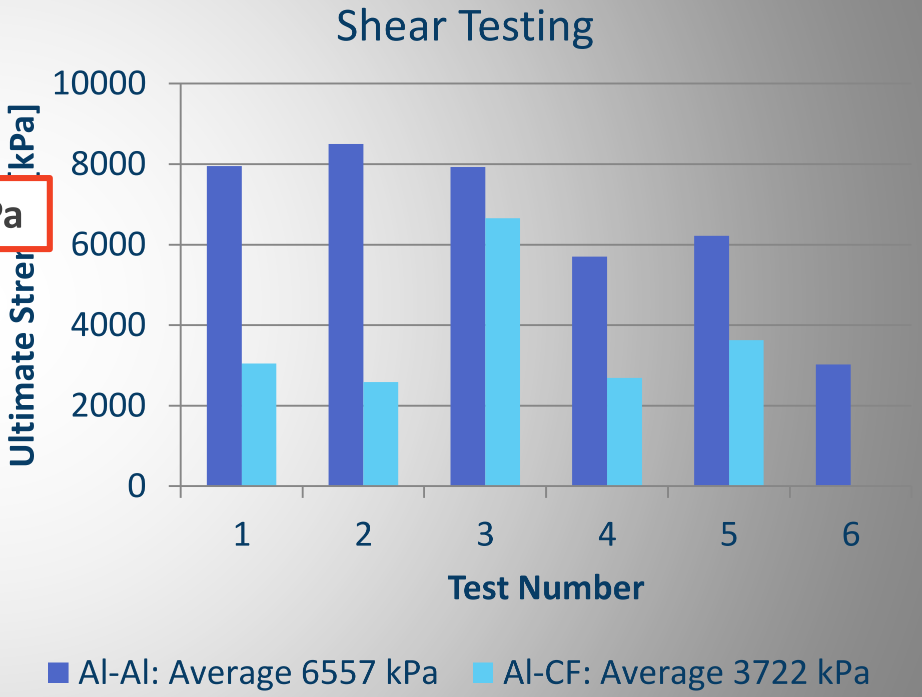
- Epoxy 2216 will be used to mount avionics analog, payload analog, and one solar panel analog
- Current strength from small-scale tests performed on aluminum and carbon fiber in shear and pull
- Assumes 25% adhesive area and additional FOS = 1.9 on required strength

All components shown in back-up slides

| Requirement: | Required Value: | Current Value: | Design Margin: | |
|---|---|---|---|---|
| **DR 4.1-4.5:** Structure design shall mount all spacecraft components | 94.2 kPa (max, COMM) | 841 kPa (Lowest Observed) | 78.7 % | Requirement Met |

# Small Scale Component Adhesive Testing Results:



# FR 5: Demonstrate structural integrity through a random vibration test.

# Acquiring Time on a Vibration Table :

- Facility: Cascade Tek
  - DS16 Shaker, slip table, and head expander
  - Contact: Greg Matthews – Test & Dynamics Technician
- Test funded by Surrey Satellite Technologies- US
  - $1800 per day

| Requirement: | Required Capabilities: | Facility Capabilities: | |
|---|---|---|---|
| **DR 5.2:** Structural test model shall be tested on vibration table. | 20 Hz – 2000 Hz random vibe | 0 - 10000 Hz random vibe | Requirement Met |
| | Support 100 kg (~10 kN force output) | 70 kN force output | |
| | > 32” x 32” bolt pattern | 44” x 44” bolt pattern | |

# Transferring Data from Accelerometers Through DAQ at above 4 kHz:

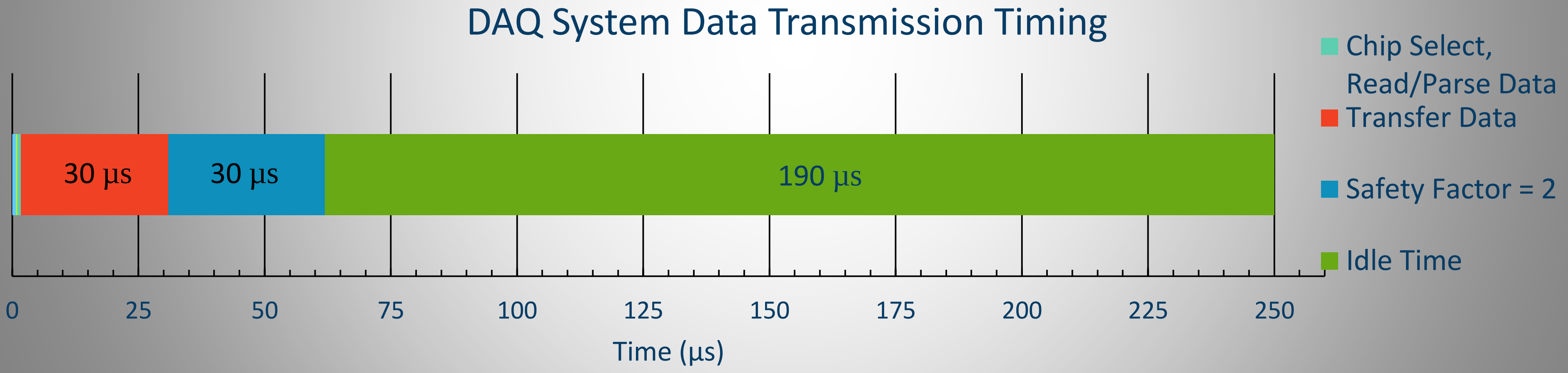
- Most critical element is timing of data collection within microcontroller and from microcontroller to computer

Detailed DAQ system design on slide 57

| Requirement: | Required capabilities: | Current Capabilities: | Margin: | |
|---|---|---|---|---|
| **DR 5.6.3.5.1:** µC shall be capable of acquiring data from 60 channels at faster than 4 kHz sampling rate | 60 channels<br>4 kHz | 64 channels<br>16 KHz | 4 channels and 12 KHz in data rate | Requirement Met |

# Transferring Data from Accelerometers Through DAQ at above 4 kHz:

- Assuming
  - Microcontroller operates at maximum 200 mega instruction cycles/sec
  - High-Speed USB module throughput rate is 35 Mbps (400 Mbps data rate)
  - Computer speed runs at much greater speed (GHz) than microcontroller (MHz)
- 4 kHz sampling rate corresponds to sampling faster than every **250 µs**



# PROJECT RISK:

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# Pre-Mitigation Risk Matrix:

Severity

Likelihood

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

- 8: Adhesive does not perform as expected
- 14-19: DAQ system components are not functional
- 2: Structure fails while transporting to vibration test
- 10: Vibration testing takes over 8 hours

# 8 - Adhesive Underperforms:

- Severity: 5 Likelihood: 3 **Total: 15**
- Despite high margin, adhesive are least predictable and most critical component
- Mitigation Before:
  - Test adhesive on carbon fiber in small scale (completed)
  - Test adhesive on larger masses similar to payload analog
  - Purchase extra glue, extra VELCRO, and other fast adhesive methods
- Response After:
  - Experiment with different bond lines and attempt to use more glue
  - Remove component and continue testing
- Post-mitigation Severity: 5 Likelihood: 2 **Total: 10**

Other risks detailed in back-up slides

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# Post-Mitigation Risk Matrix:

Severity

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

8: Adhesive does not perform as expected

14-19: DAQ system components are not functional

2: Structure fails while transporting to vibration test

10: Vibration testing takes over 8 hours

Other risks detailed in back-up slides

# VERIFICATION AND VALIDATION

# Verification and Validation Overview:

## ANSYS model will be verified by performing a vibration test on fabricated STM and collecting accelerometer data

- Vibration Test Plan
- Expected modes and frequencies in model generated by ANSYS
- Designed DAQ system to collect acceleration data and create PSD plots

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# Model Validation and Design Feasibility:

- **Modal Sweep – Unwrapped**
  - Identify natural modes before & after random vibration
  - ≥±10% modal shift indicative of structural failure/alteration
- **Random Vibration – Foam Wrapped**
  - Simulate expected flight conditions
  - Failure Identification:
    - Visual inspection of structure
    - Modal shifts

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

**Validates DR 5.2 and DR 5.4**

**NASA GEVS Vibration Profile in backup slides**

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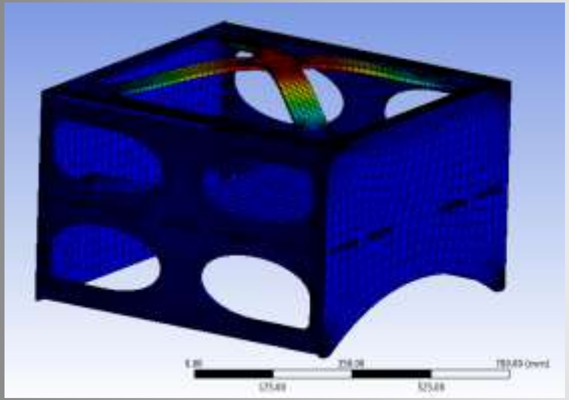
# Predictions for Modal Sweep:

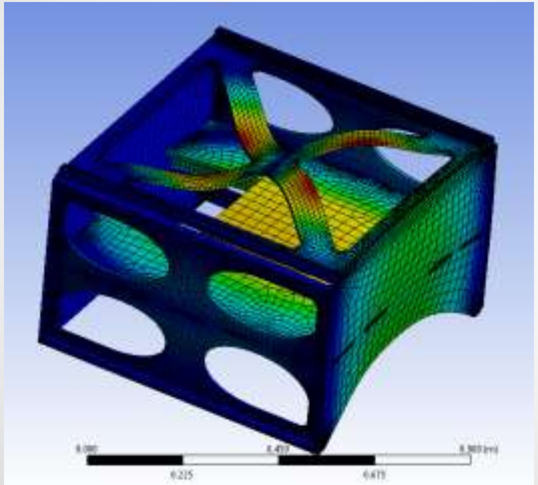
Small-Scale modelling test in back-up slides

- Mass Dummies add significant stiffening

**Mode 1: 39Hz**



**Mode 2: 104Hz**



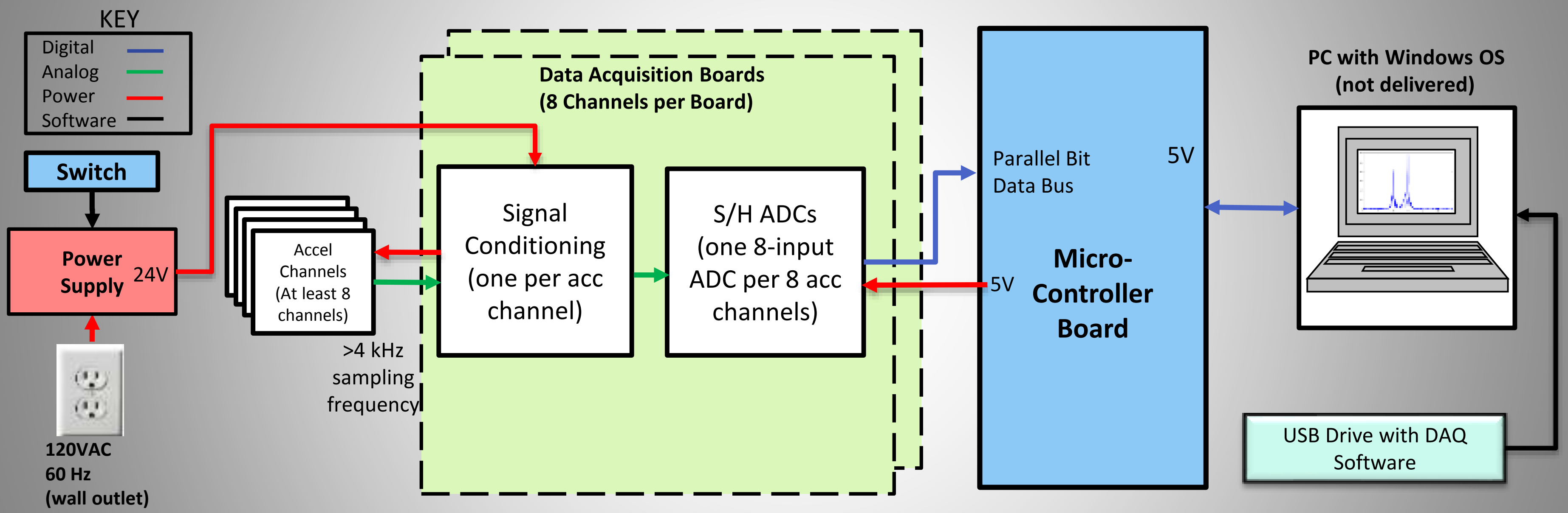
Note: Deformations are **not to scale**

**Validates DR 5.2**

| Expected Modes | | |
|---|---|---|
| Mode | Freq (Hz) | Location (Orientation) |
| 1 | 39 | Top (Zenith) |
| 2 | 104 | Top, Mid (Zenith) |
| 3,4 | 111 | Top (Zenith) |
| 6 | 185 | Radiator (Port) |
| 7 | 185 | Mid (Zenith) |
| 16 | 392 | Radiator (RAM) |

# DATA ACQUISITION OVERVIEW

# DAQ Hardware FBD:



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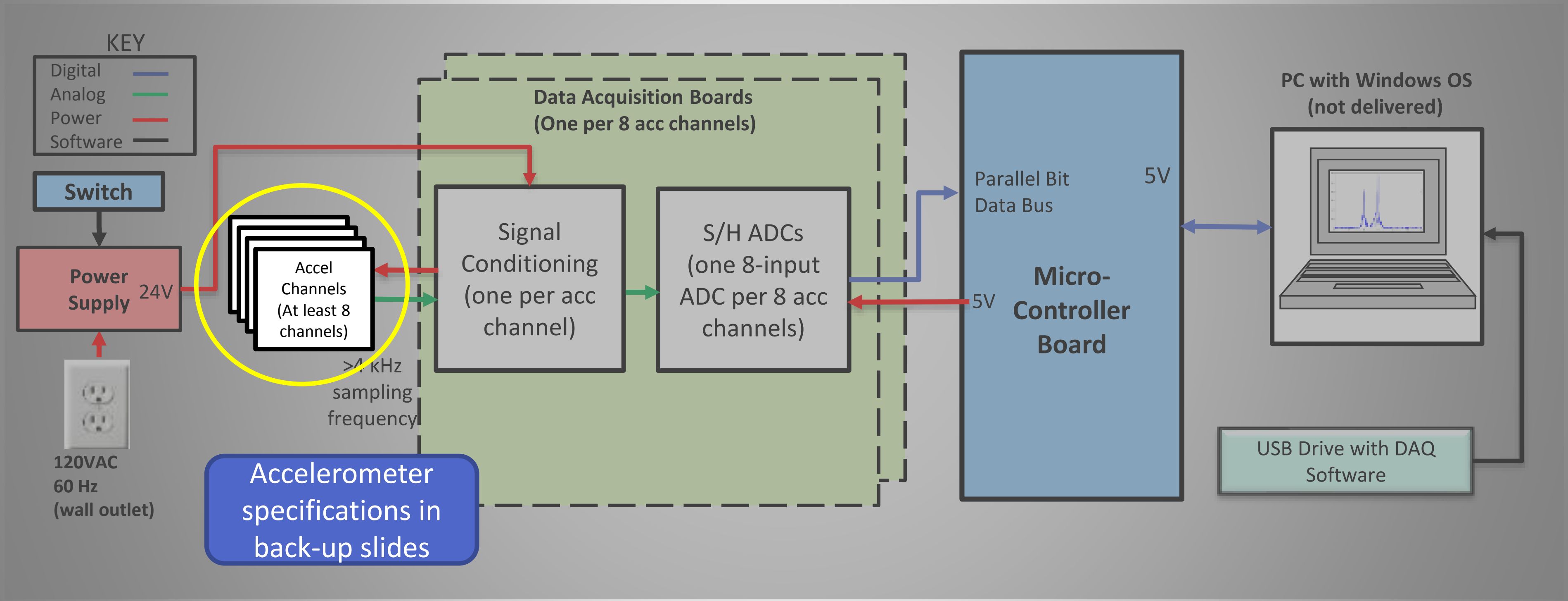
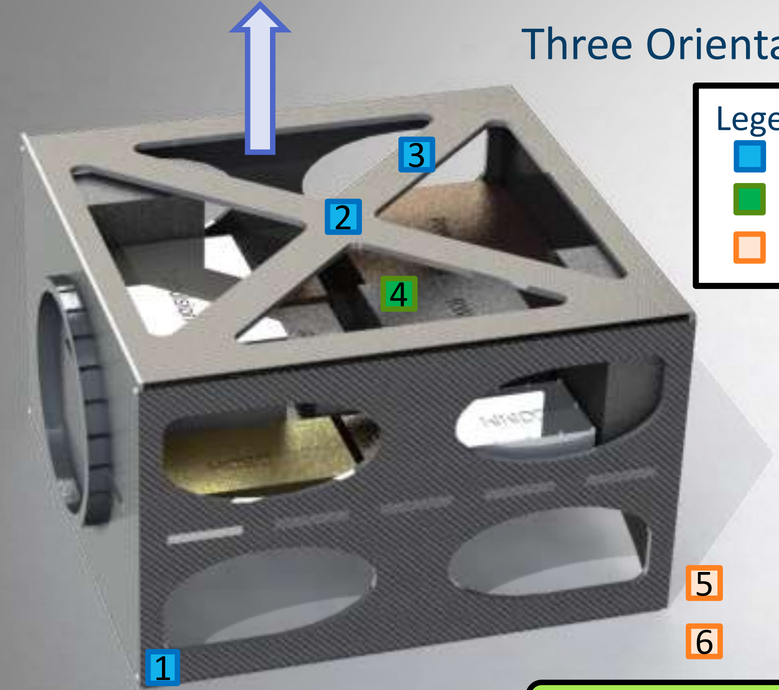
# Accelerometers:




Accelerometer specifications in back-up slides

# Accelerometer Locations:

Three Orientations – Only Two Shown

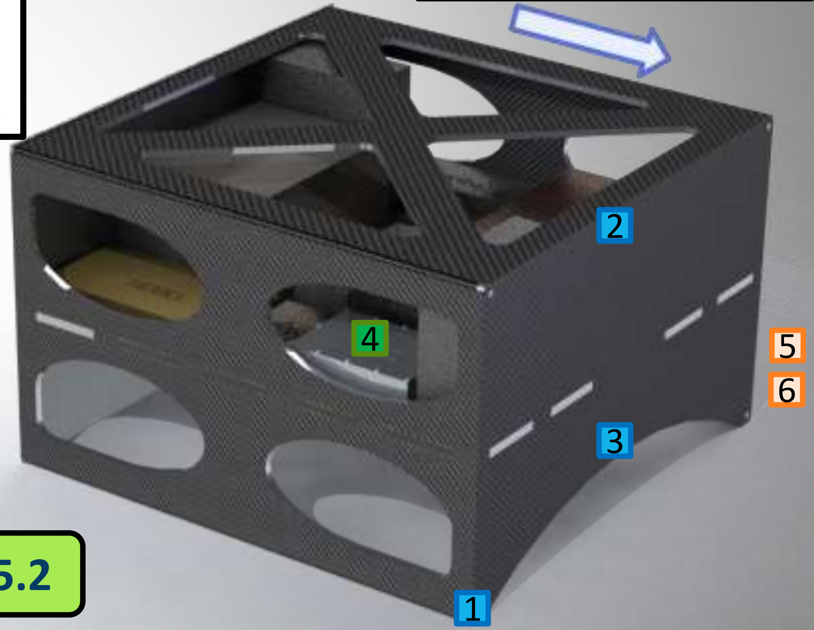



Zenith Acceleration

Legend:

- ■ – Single Axis
- ■ – Tri-axial
- ■ – Cascade Tek

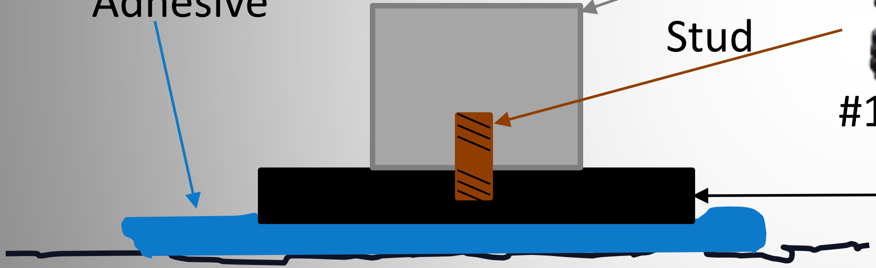
Ram Acceleration




**Validates DR 3.1 and DR 5.2**

# Accelerometer Mounting:

Loctite 454
Adhesive



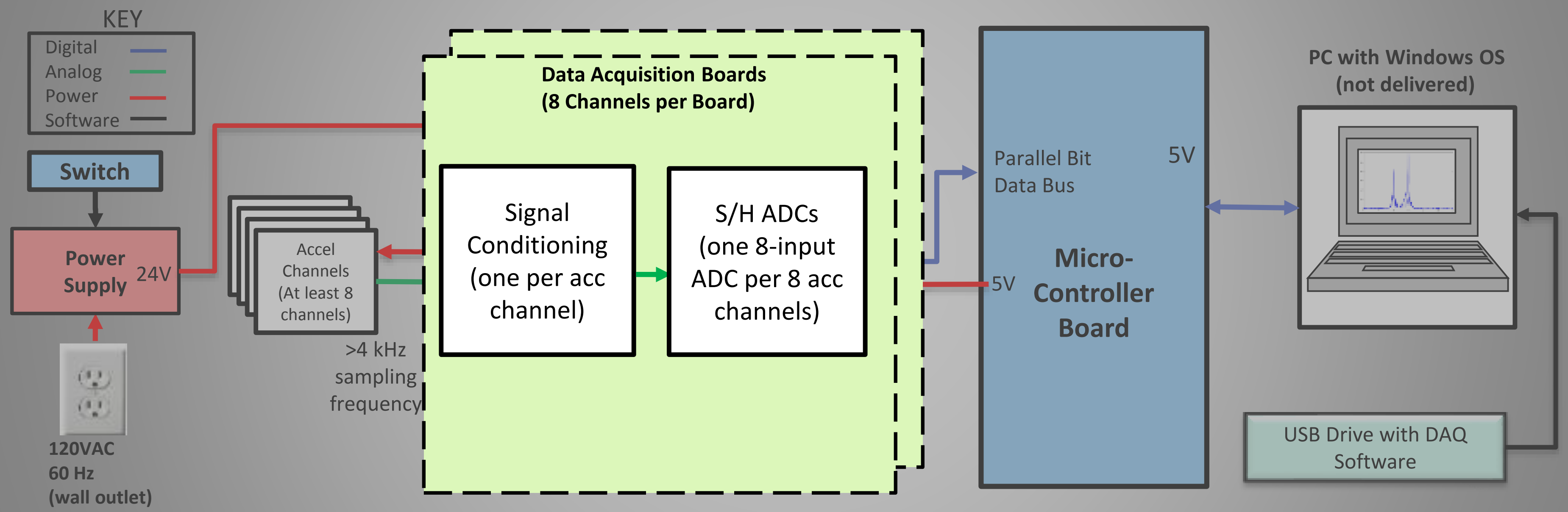

#10-32


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


Images from PCB.com

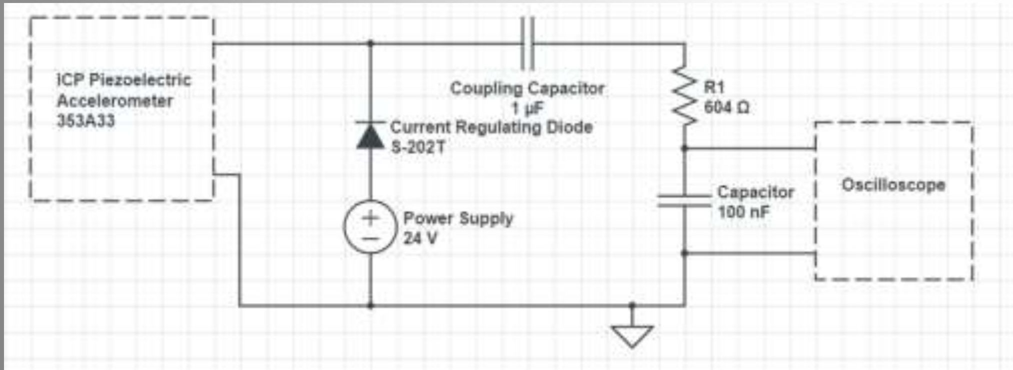
**Validates DR 5.5.1**

# Data Acquisition Board:

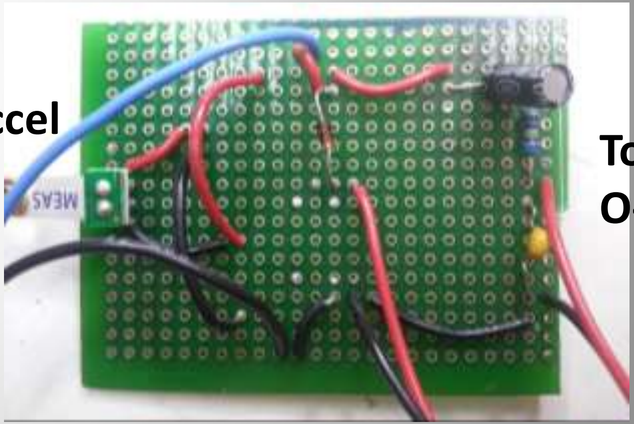


# Data Acquisition Board: Charge Amplifier Test

- **Goal:** To verify our charge amplifier circuit is correct for the ICP accelerometers.
- **Procedure:** Built a prototype charge amplifier to supply a constant current and 24V to an accelerometer.




To Accel

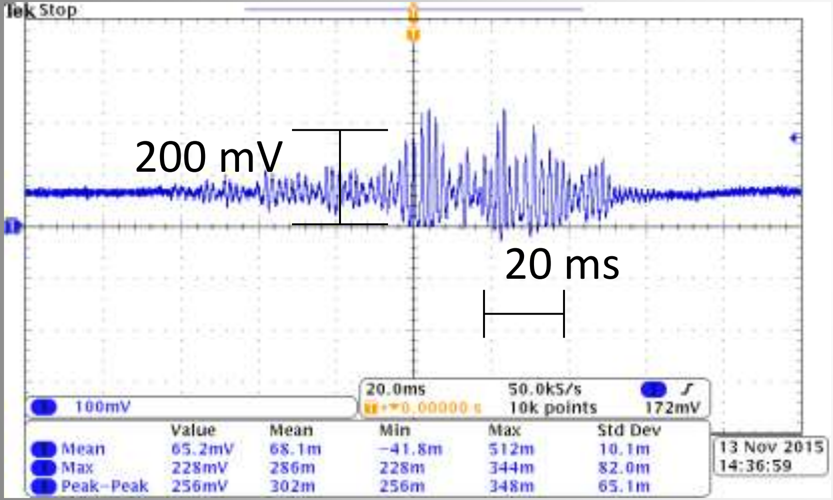


To O-scope

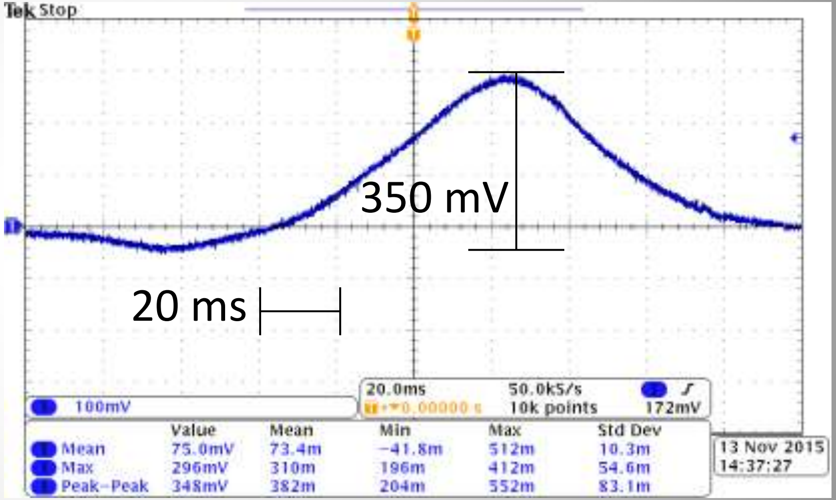
To Power Supply

# Data Acquisition Board: Test Charge Amplifier

## Impulse Response

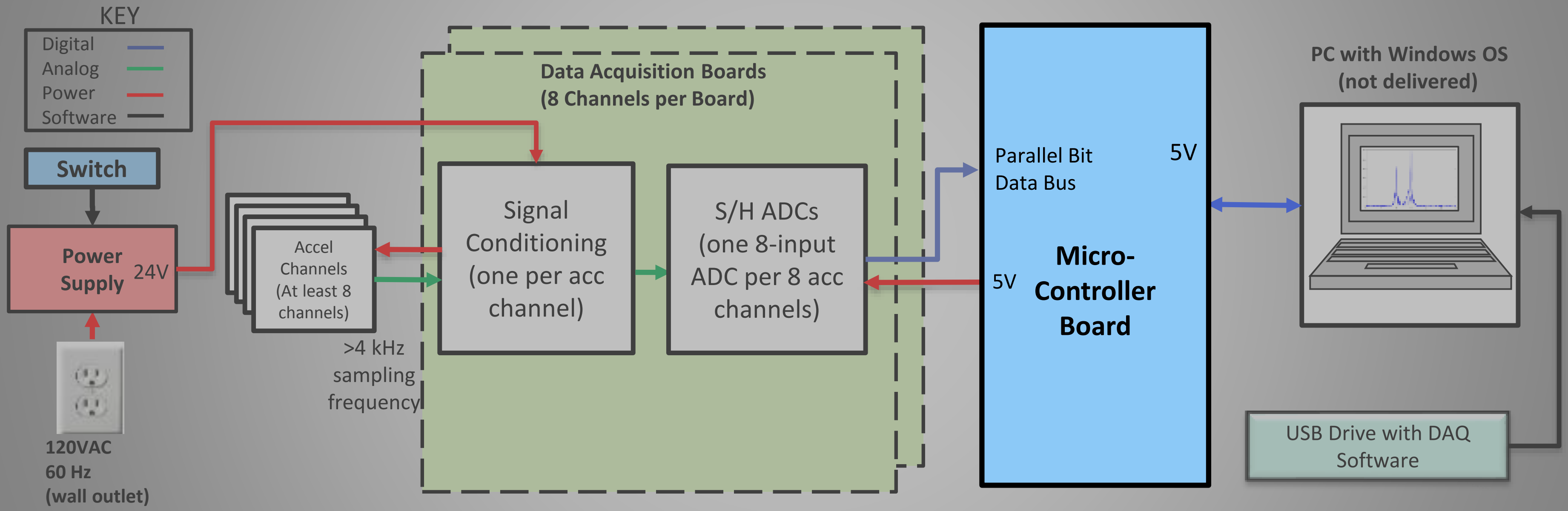



## Shake Response




**Validates DR 5.6.3**

# Microcontroller Board:



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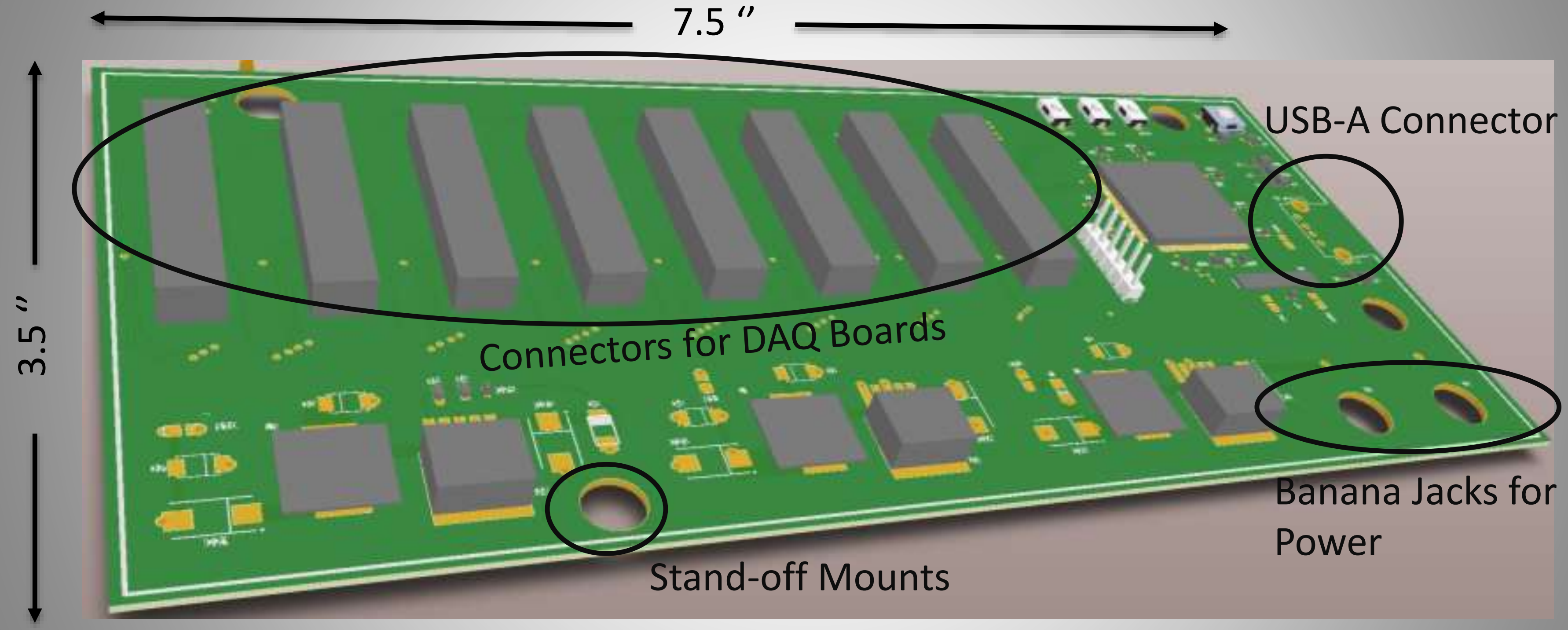
# Microcontroller Board:



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# Microcontroller: PIC32MZ

- High Speed USB Communication
  - 35 Mbps Data Rate
- Parallel bit data transfer
  - 32 bit data registers
- Primary Oscillator – 24 MHz
  - Instructions pipe = occur every clock cycle
  - PLL Module allows for 200MHz operating frequency
    - Instruction takes 5 ns


**Validates DR 5.6.3.5**

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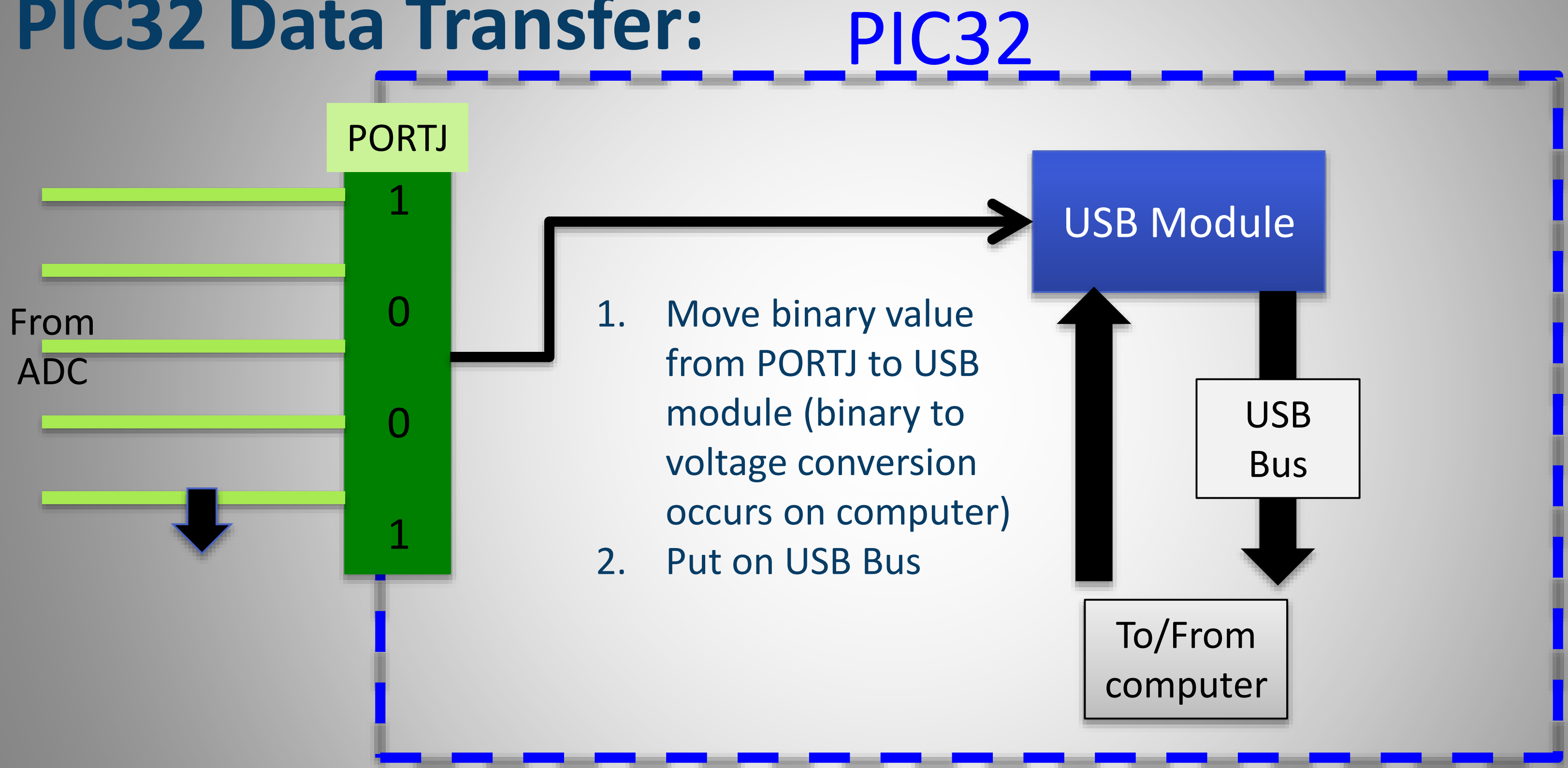
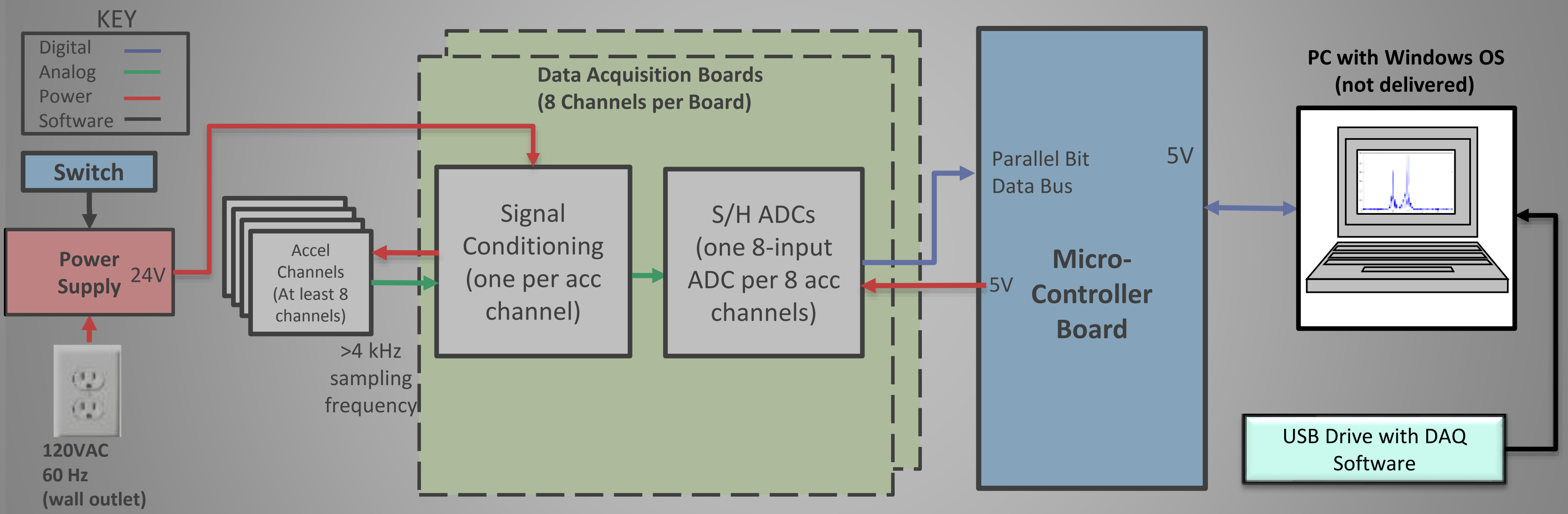
# PIC32 Data Transfer:

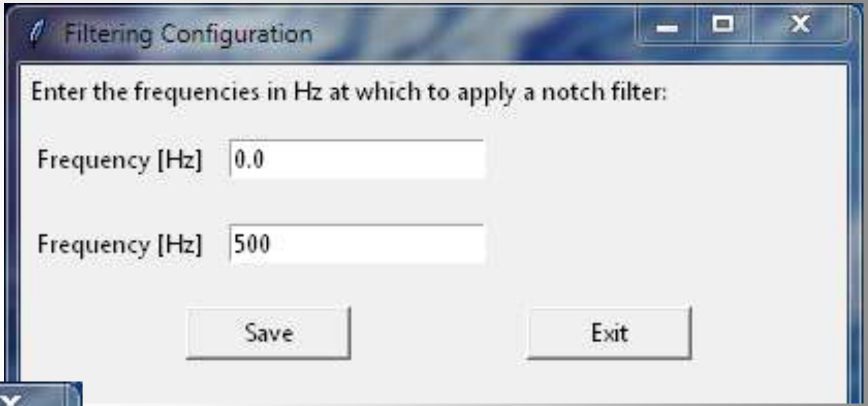


# Software:


KEY
Digital
Analog
Power
Software
Switch
Power Supply
24V
120VAC
60 Hz
(wall outlet)
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

# Software: Functionality Testing

- GUI developed
- Executable generated
- Power Spectral Density algorithm demonstrated
- **Filter configuration complete**






**Validates DR 5.6.3 and DR 5.6.4**

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# PROJECT PLANNING

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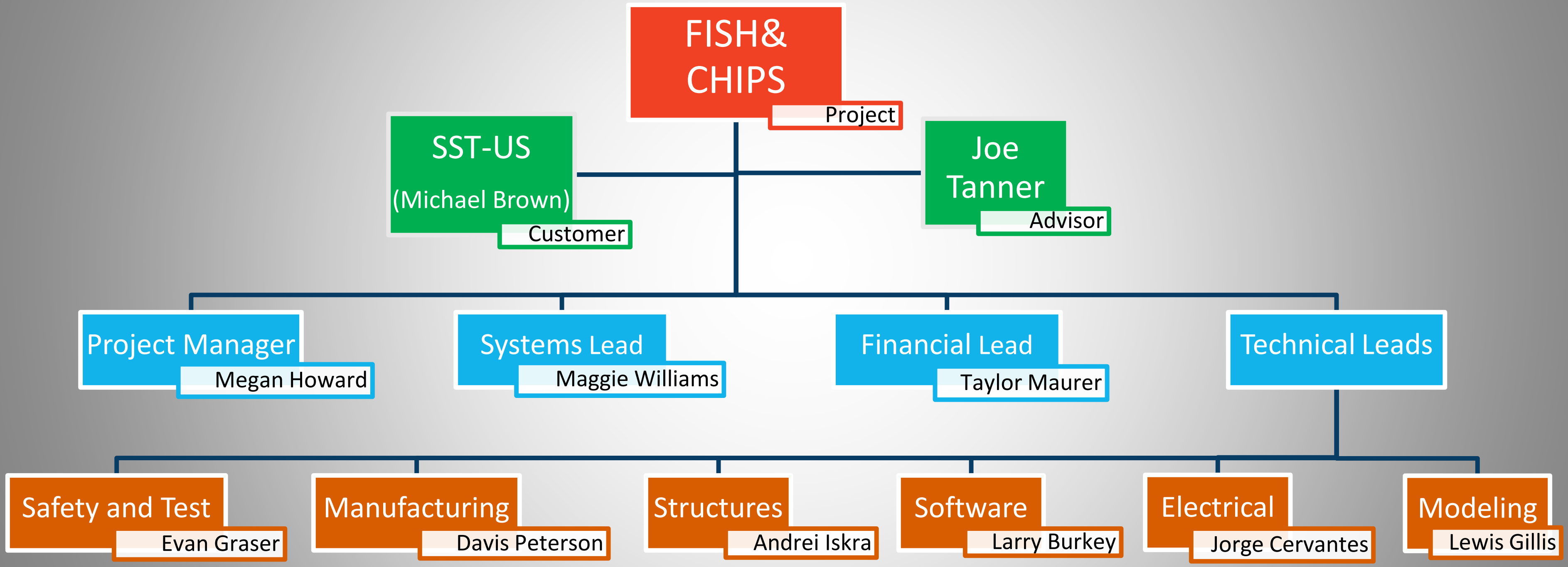
# Organization Chart:



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# Work Breakdown Structure:

## FISH & CHIPS

- **Management & Systems**
  - Requirements
  - Schedule
  - Risk Matrix
  - WBS
  - Acquired Components
- **Structure**
  - CAD Model
  - ANSYS Model
  - GSE for Adhesives
  - FeatherCraft
  - Transport Box
- **Data Acquisition**
  - Data Acquisition Board Layout
  - $\mu$C Board Layout
  - Software Flow Chart
  - 2 Printed Data Acquisition Boards
  - $\mu$C Board
  - Software Executable
  - Data transfer via USB
- **Testing**
  - V&V Plan
  - Mass Analogs
  - Modal Data
- **Deliverables**
  - CDR
  - FFR
  - MSR
  - TRR
  - AIAA
  - SDS
  - SFR
  - PFR

Legend:
- (light green) – Complete as of CDR
- (dark grey) – Incomplete as of CDR

Complete as of CDR: Requirements, Schedule, Risk Matrix, WBS, CAD Model, ANSYS Model, Data Acquisition Board Layout, $\mu$C Board Layout, Software Flow Chart, V&V Plan, CDR.

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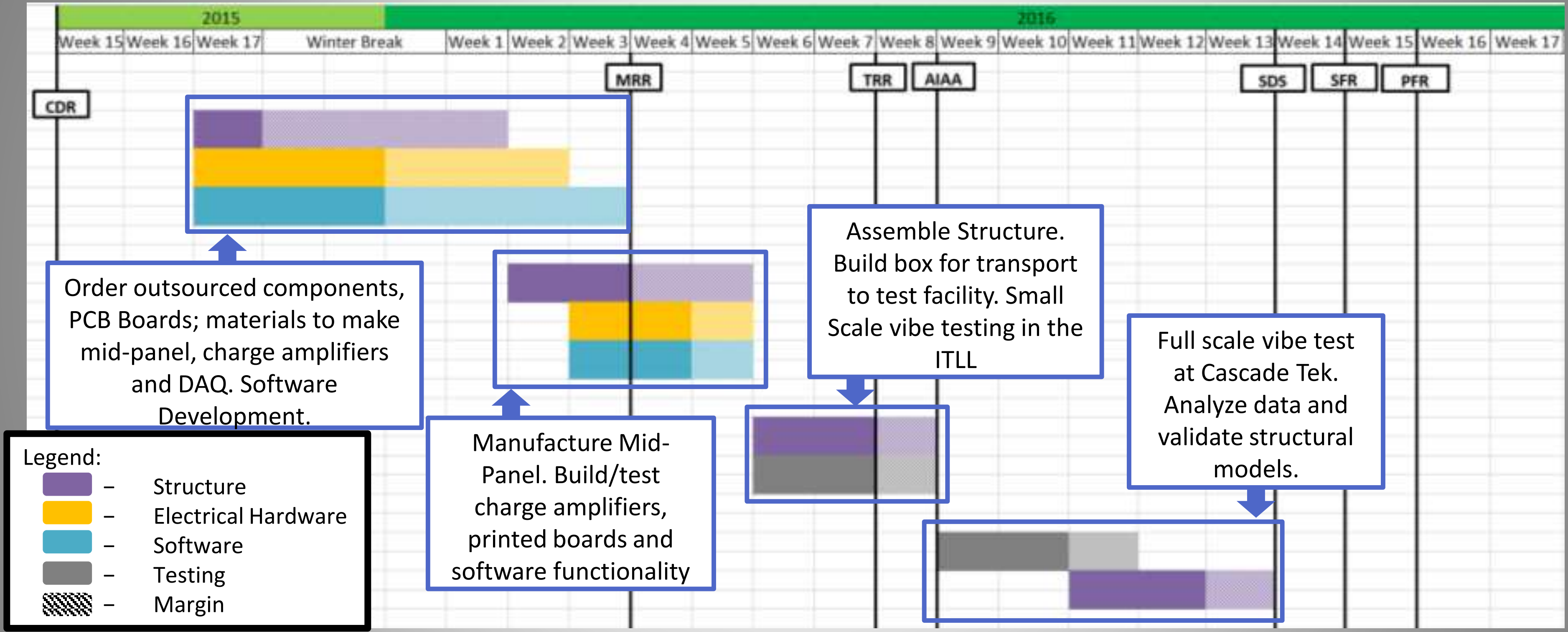
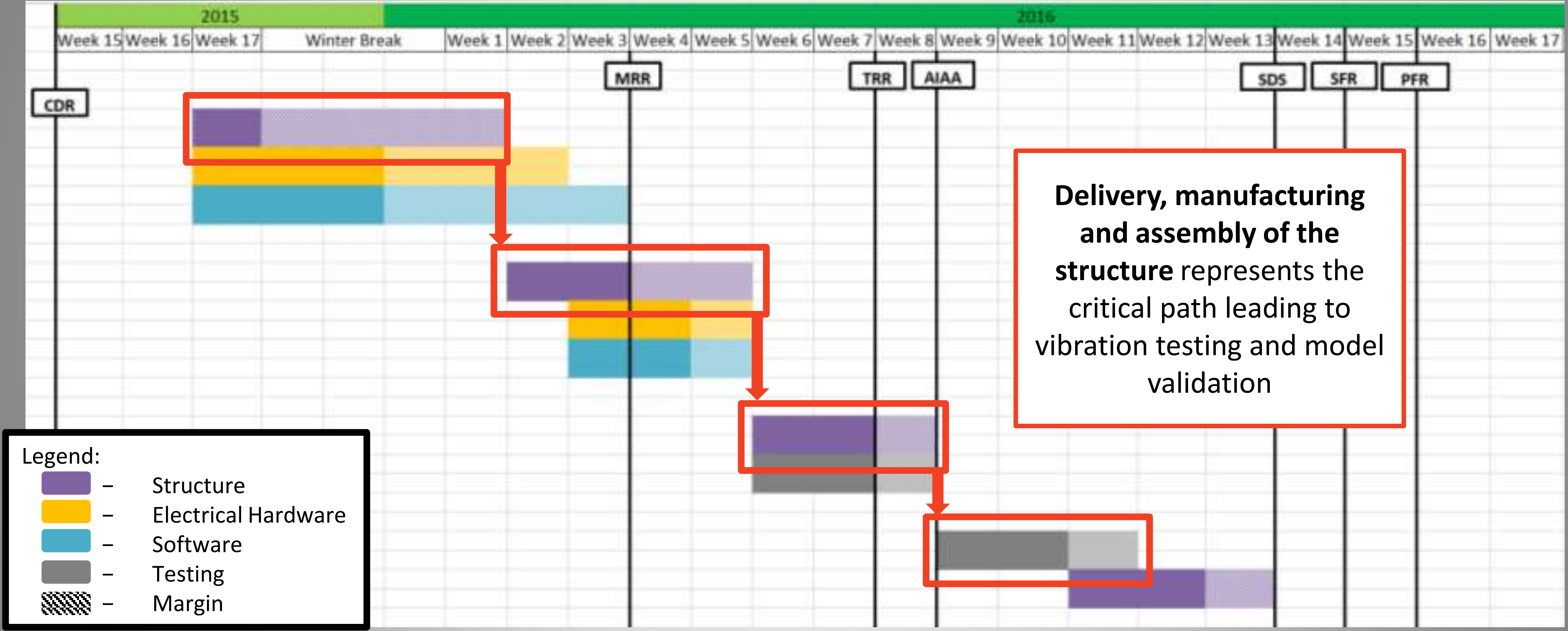
# Work Plan:

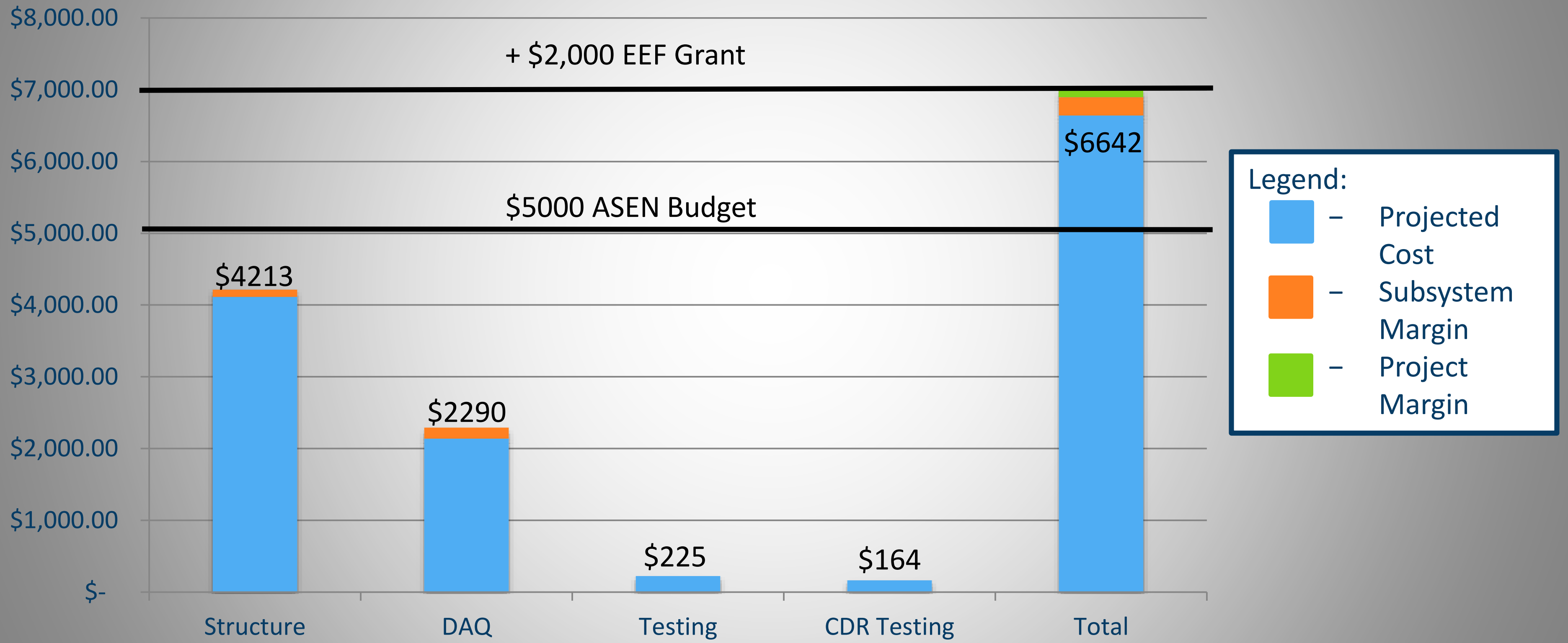


# Critical Path:




**Delivery, manufacturing and assembly of the structure** represents the critical path leading to vibration testing and model validation

# Cost Plan – Overall Budget:



# Build and Test Plan:

| Week: | Testing Goals: | Key Dates: |
|---|---|---|
| 1-2 (1/11 – 1/24) | Mechanical and Adhesive tests, mid-panel and 3D printed inserts manufacturing, acquiring ordered parts | |
| 3-4 (1/25 – 2/07) | TRR & **Checklist** Development, Test Structural Inserts, manufacture transportation box | 2/1 (MSR Due) |
| 5-6 (2/8 – 2/21) | DAQ Functionality Testing, Small Scale **Vibration** Tests with **Foam,** structural **assembly** with avionics and payload | 2/1 MSR Due |
| 7 (2/22 – 2/29) | Complete **TRR, rent accelerometers** and **integrate** full system | |
| 8 (2/29 - 3/06) | Submit and perform **TRR,** test **Rehearsals** (Transport, wrapping, accelerometer placement, CHIPS setup) | 2/29 TRR Due |
| 9 (3/07 - 3/13) | Full Test **Rehearsal** | 3/7 AIAA Report Due<br>3/12 Full Test Rehearsal |
| 10 (3/14 – 3/20) | Transportation Preparation, **Vibration Testing at Cascade Tek** | **3/18 – Vibration Test** |

# Acknowledgements:

Engineering Excellence Fund

CASCADE TEK™ FRONT RANGE

Aerospace Engineering CU

# References:

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# QUESTIONS?

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# Presentation Appendix:

# Back-Up Slides Appendix:

| REQ: | | | FR 1 | FR 2 | FR 3 | FR 4 | | FR 5 | |
|---|---|---|---|---|---|---|---|---|---|
| FR 1 | DR 4.7 | DR 5.5.2 | Mass Break | Cost | Kaber Vol. | Velcro | Aperture | Cutting Panels | Vibe Profile Table |
| FR 2 | DR 4.8 | DR 5.6.1 | Avionics | 9 months | Mid Panel | Adh SS Test | | Make Mass Dum | Vibe Contingency |
| FR 3 | FR 5 | DR 5.6.2 | Panels | Labor | Facing Str | Adh BOTE Ana | | Acc. Met 5.6.2.4 | GRMS Definition |
| DR 3.1 | DR 5.2 | DR 5.6.3 | Adhesives | | Core Shear | Tensile Test | | Transfer via USB | GRMS Method |
| DR 3.2 | DR 5.3 | DR 5.6.3.5 | Columns | | Local Comp. | Shear Test | | Vibe Facility | DR 5.4 Foam |
| FR 4 | DR 5.4 | DR 5.6.4 | Plugs | | Tab Shear | Adh. Results | | Vibe Increments | Wrap/Mount |
| DR 4.3 | DR 5.5 | DR 5.6.5 | Tabs | | SS Adh. Res | Adh Knowledge | | Vibe Profile Des | |
| DR 4.6 | | | Margin | | Tube Insert | Radiator | | | |

| FR 5 Cont. | | RISK: | | | SS Testing: | FEM: | |
|---|---|---|---|---|---|---|---|
| Acq. Foam | Acc. Loc Rand Vibe | 1 Foam Attenuation | 9 Slow Manufac | 16 CA Corr. Data | Model Val | ANA Loads | Fastners |
| Data Qual. CA | Acc. Loc Modal Port | 2 Fail In-Rout | 10 Vibe > 8 hrs | 17 ADC | ANA Bkgrd | Port Acc | |
| Data Qual. A/D | | 3 Fit Thru Door | 11 MA not Prep | 18 Power Sys | CB Set Up | Ram Acc | |
| DAQ Timing | | 4 Materials Late | 12 Modes | 19 uC | CB Results | ANA Loading | |
| Timing Calc | | 5 Noisy DAQ | 13 Adh. Fail Assy | | GUPPY Result | Load Cases | |
| Acc. Specs | | 6 DAQ Can't Save | 14 USB Slow | | Adh. Analysis | HoneyComb | |
| | | 7 CF is Frayed | 15 LPS Corr. | | | HC Anay | |

| Budget : | V & V: | Software Flow: | | Joints: | |
|---|---|---|---|---|---|
| Sub-System | LPF | 500 Hz | GUI Structure | Edge Close | |
| Uncertainties | LPF Response Curve | Signal w/ Noise | Saved Report | Potting | |
| | A/D | 500 Hz removed | Configure | Tube Inserts | |
| | Power 5V | Filtering | Reset Test | Tab Inserts | |
| | Power 5V | Exe. Devlopment | Start Test | Column-Side | |
| | Power 3.3V | Data Output | Stop Test | Column-Rad | |
| | | | PSD | | |

# BACK-UP SLIDES

# FR 1 Breakdown

**FR 1:** The FeatherCraft structure design shall be less than 5 kg.
*Source:* Customer requirement. Increasing the structural mass beyond 5 kg would prevent SST-US from integrating with a profitable weight class of payloads.
Verification: Analysis, modeling, and comparison with demonstration of STM.

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# FR 2 Breakdown

**FR 2:** The Feathercraft structure design shall reduce manufacturing time and material cost from SST-US's typical spacecraft estimates.
*Source:* Surrey would like to reduce the cost of the structure and project overall.
Verification; Analysis, fulfillment of subsequent DRs.

- DR 2.1: Structure design material cost shall be less than $20,000.
  *Source:* Customer requirement, SST-US typically expends $40,000 on a spacecraft material and this design shall reduce that metric by 50%.
  Verification: Budget analysis
- DR 2.2: Structure design manufacturing and assembling shall take less than 9 months.
  *Source:* Customer requirement, SST-US typically spends 18 months on spacecraft manufacturing and assembling and this design shall reduce that metric by 50%.
  Verification: Manufacturing estimates and analysis
- DR 2.3: Structure design manufacturing and building labor shall cost less than $80,000.
  *Source:* Customer requirement. This is a 50% reduction of SST-US's typical manufacturing and building cost of $160,000 and will help the company meet the goal total price of $6 million.
  Verification: Budget estimates and analysis

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# FR 3 Breakdown

**FR 3:** FeatherCraft Structure shall be designed to deploy from the Kaber Deployment System on the ISS.

*Source:* The basis of the satellite is to launch in a foam-wrapped configuration, enabling it to be lightweight, and then deploy from the new Nanoracks Kaber system on the ISS. Therefore, the structure must survive there and fit within the Kaber volume. The Kaber deployment forces will be negligible compared to launch forces.

Verification: Analysis and demonstration in DR 5.3

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# FR 3 Breakdown

- DR 3.1: FeatherCraft structure in launch configuration shall be designed to not be damaged by simulated attenuated launch environment of up to 1.29 grms random vibration with safety factors as outlined in the GEVS ISS Pressured Volume Hardware Common Interface Requirements Document Rev C.
  *Source* : Customer requirement. To remain profitable, the FeatherCraft package needs to be reliable and provide a robust platform for their customers, as well as meet all NASA requirements for launch to the ISS.
  Verification: Vibration test executed on STM in FR 5 and measurement of STM before and after vibration test
  - DR 3.1.1 FeatherCraft structure design components shall not experience visible damage after vibration testing.
    *Source:* Structure must not deform to outside the allowed Kaber volume. The margin on known dimensions are about 2 inches, but larger deformations can cause other failures such as adhesive detachment.
    Verification: Analysis, Inspection after DR 5.2

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# FR 3 Breakdown

- DR 3.2 FeatherCraft structure design including mounted components shall fit within the volume of 30"x30"x19" to interface with the Kaber Deployment System.
  *Source:* The spacecraft as a whole must be placed within the Kaber volume to be deployed and begin its mission. This volume ensures at least 2'' of space between the spacecraft volume and the edge of the JEM airlock.
  Verification: Inspection of drawings, demonstration with measurement

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# FR 4 Breakdown

**FR 4:** FeatherCraft structure design shall interface with SST-US-provided spacecraft components and mission design.

*Source:* Because the structure is the base of the satellite, it must be able to support already-existing SST-US components.

Verification: Demonstration of DR 4.1-4.7 and DR 5.3.

- DR 4.1: FeatherCraft structure design shall provide mounting position on Side 3 for one 30’’x30’’x0.125’’ solar panel of mass 2 kg.
  *Source*: Customer requirement, this side is the largest covered side and as such needs to mount a solar array panel.
  Verification: STM demonstration in FR 5, modelling and analysis
- DR 4.2: FeatherCraft structure design shall provide mounting positions on Side 2 and Side 4 for two 30’’x18.976’’x0.125’’ solar panels of mass 2 kg each.
  *Source*: Customer requirement, this side is the largest covered side and as such needs to mount a solar array panel.
  Verification: STM demonstration in FR 5, modelling and analysis

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# FR 4 Breakdown

- DR 4.3: FeatherCraft structure design shall provide a mounting position for a 29.094’’x18.976’’x0.125’’ propulsion plate of mass 2 kg on Side 1.
  *Source:* Customer requirement. The propulsion plate design has been finalized, and its dimensions necessitate its mounting location.
  Verification: modeling and inspection of drawings, STM demonstration in FR 5
- DR 4.4: FeatherCraft structure design shall provide a space for a 12x12x10 in propulsion subsystem of mass 10 kg on the internal side of Side 1.
  Source: Customer requirement. The propulsion subsystem must be attached to the propulsion plate and the space it takes in the bisecting plate must be accounted for.
  Verification: modeling and inspection of drawings, STM demonstration in FR 5
- DR 4.5 FeatherCraft structure design shall have an internal structural component equally bisecting the 19’’ height dimension to provide mounting capabilities to the avionics components and payload components.
  *Source:* Customer requirement. The mounting capabilities are necessary for the customer to assemble the spacecraft easily and safely. This bisecting structural component defines a payload bay and avionics bay so that a payload volume is defined for potential customers.
  Verification: Inspection of drawings, Test (measure STM)

# FR 4 Breakdown

- DR 4.6 FeatherCraft structure design shall provide mounting capabilities on bisecting sheet for the avionics components and payload components.
  *Source:* Customer requirement. The mounting capabilities are necessary for the customer to assemble the spacecraft easily and safely. This bisecting structural component defines a payload bay and avionics bay so that a payload volume is defined for potential customers.
  <u>Verification:</u> Inspection of drawings, Test with STM
  - DR 4.6.1: FeatherCraft structure design shall provide mounting capabilities for a mass of 32 kg of aluminum.
    *Source:* Customer component as part of DR 4.5, simulating avionics
    <u>Verification:</u> Inspection of drawings, test with STM
  - DR 4.6.2: FeatherCraft structure design shall provide mounting capabilities for a mass of 45 kg of aluminum.
    *Source:* Customer component as part of DR 4.5, simulating payload
    <u>Verification:</u> Inspection of drawings, test with STM

# FR 4 Breakdown

- DR 4.7 FeatherCraft structure design shall dissipate up to 100 W of heat generated equally by avionics and payload bays at an internal operating temperature of -20 to 50 degrees C.
  *Source:* Customer requirement. The maximum power output is estimated by the customer to remain below 100W. The specifics of this analysis are presented in Section 4.1.4.
  Verification: Analysis
  - DR 4.7.1: FeatherCraft structure design shall have a radiative material on Side 6.
    *Source:* Customer requirement, derived from DR 4.6. This solution is used to satisfy DR 4.6 for simplicity.
    Verification: Inspection of model

# FR 4 Breakdown

- DR 4.8 FeatherCraft structure design shall have an open aperture of at least 12’’x12’’ on Side 5.
  *Source:* Customer requirement, payload use and space for antenna(s) facing nadir.
  Verification: modeling, inspection in STM
- DR 4.9 FeatherCraft structure design shall remain operational for five years in a space environment.
  *Source:* Customer requirement, the spacecraft bus will be advertised as a five-year mission.
  Verification: Analysis of structure material and assembly method for similarity to previous missions’ material heritage.

# FR 5 Breakdown

**FR 5:** A manufactured STM of the FeatherCraft structure design shall be used to validate the design through a modal vibration sweep and a random vibration test to the requirements of SSP 50835.
*Source*: SSP 50835 dictates the stress that a structure should expect to experience during launch. Performing a test under these expected vibration conditions validates FR 3.
Verification: Demonstration of subsequent DRs.

- DR 5.1: STM shall be manufactured with sufficient similarity to the structural design such that it can be used for validation of the designed structure.
  *Source:* Customer requirement. A physical test must be performed to provide a baseline of feasibility; this can only be proved if the STM is similar to the design. However, the materials of the STM are constrained to the FeatherCraft team budget.
  Verification: Analysis of materials
  - DR 5.1.1: STM shall be manufactured to all specifications in FR 4 and FR 2.
    *Source:* STM must mount mass analogs of all spacecraft components specified in FR4, and the STM may not exceed the parameters specified in FR 2 due to course budget and time restraints.
    Verification: Testing, inspection of mounting positions, cost, and time

# FR 5 Breakdown

- DR 5.2: STM shall be tested on a vibration table for a vibration profile of 20-2000 Hz and up to an experienced vibration of 1.29 grms with each test lasting 60 seconds.
  *Source:* GEVS table 3.1.1.2.1.2.3.2-1 (Page 3-17 of ISS Pressured Volume Hardware Common Interface Requirements Document Rev C.) It is estimated by this document that with a vibration table setting of 9.47 grms, the foam-wrapped structure should experience 1.29 grms. This will simulate launch load conditions and prove feasibility of FR 3.
  Verification: Inspection of test plan, test
  - DR 5.2.1: STM shall undergo a modal sweep preceding and after every random vibration test to identify loads.
    *Source:* A change in mode of over 10% after random vibration is an indication of structure change and subsequent instability.
    Verification: Demonstration

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# FR 5 Breakdown

- DR 5.3 STM shall support loads through vibration testing that are equivalent to the required loading of the designed structure.
  *Source:* Validation of FR 3 and FR 4
  Verification: Demonstration
  - DR 5.3.1 STM shall support the mass analog aluminum propulsion plate of mass and size specified in DR 4.3 mounted to Side 1.
  *Source:* Validation of DR 4.3 and FR 5.
  Verification: Inspection, mass measurement
  - DR 5.3.2 STM shall support the solar panel mass analog aluminum plates mounted on sides as specified in DR 4.1 -4.2.
    *Source:* Validation of DR 4.1, DR 4.2 and FR 5.
    Verification: Inspection, mass measurement
  - DR 5.3.3 STM shall have an internal load simulating the avionics subsystem mass as described in DR 4.5.1.
    *Source:* Validation of DR 4.5 and FR 5. The shape of these components can be split between components of created as one large mass; the only requirement is that it must incorporate all the required masses.
    Verification: Inspection, mass measurement
  - DR 5.3.4 STM shall have an internal load simulating the payload as specified in DR 4.5.2.
    *Source:* Validation of DR 4.5 and FR 5. This is the SST-US provided estimate it will allow for payload mass.
    Verification: Inspection, mass measurement
  - DR 5.3.5 STM shall have a mass analog of the propulsion box as specified in DR 4.4 bolted to the propulsion plate.
    *Source:* Validation of DR 4.4 and FR 5. While this component is not adhered by the team, for testing purposes the mass analogs must be created and bolted to the mass analog of the propulsion plate.
    Verification: Inspection, mass measurement

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# FR 5 Breakdown

- DR 5.4: STM shall be wrapped in 0.5-2’’ thick Pyrell foam prior to vibration testing.
  *Source:* Customer Requirement stemming from ISS Pressured Volume Hardware Common Interface Requirements Document Rev C. The test shall be performed with the STM in the flight configuration.
  <u>Verification:</u> Demonstration, inspection

# FR 5 Breakdown

- DR 5.5 FEM model shall be verified with structural accelerometer information.
  *Source:* Provides evidence for completion of FR 5 and allows data collection for later correlation to designed structure. The number of accelerometers necessary and their positions is determined by the modes exhibited in the FEM model.
  Verification: Analysis of FEM model, inspection of drawings of vibration test configuration, creation of DR 5.6.
  - DR 5.5.1: STM shall have at least 4 accelerometers mounted on it during a vibration test, with accelerometers moved and data collected at each FEM position specified in the Vibration Test Plan.
    *Source*: The FEM model shows possible fluctuations at certain points in the structure specified in the Vibration test plan, and four accelerometers will allow verification of DR5.6.1 as well as speed up the process of verifying the FEM model.
    Verification: Inspection
    - DR 5.5.1.1: Accelerometers shall be able to attach and reattach to STM.
      *Source:* Because the budget may not allow for the number of accelerometers necessary to validate the model, available accelerometers must be moved.
      Verification: Demonstration
    - DR 5.5.1.2: One tri-axial accelerometer shall be attached to the mid-panel.
      *Source:* Customer requirement, the acceleration that the components experience during launch is critical to the spacecraft design.
      Verification: Inspection
    - DR 5.5.1.3: One accelerometer shall be attached to a solar panel adhered with VELCRO.
      *Source:* Customer requirement, the VELCRO adhesion is difficult to model and the acceleration measurement of this panel is desired.
      Verification: Inspection

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# FR 5 Breakdown

- DR 5.5.2: Accelerometer data shall be saved in the form of power spectral density plots.
  *Source:* Customer requirement, DR 5.5
  Verification: Demonstration of DR 5.6.4
  - DR 5.5.2.1: Software must create final power spectral density plots at the end of each test.
    *Source:* FEM comparison will not take place in realtime, but will occur after each test and after all tests are complete. This method will be used to compare ANSYS plots and test data.
    Verification: Inspection
- DR 5.6 A data acquisition and analysis system shall be designed and created for testing of STM to validate structural properties.
  *Source:* Customer requirement, it will save the project money to own a data acquisition system, and this can be used for custom data collection and future tests.
  Verification: Demonstration

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# FR 5 Breakdown

- DR 5.6.1 DAQ system design shall be capable of transferring data from 20 tri-axial accelerometers into the DAQ system during one test.
  *Source:* Customer estimate, it will be desired to obtain acceleration data at about 20 points on the structure in all three directions depending on the developed FEM model.
  <u>Verification:</u> Analysis of DAQ system
  - DR 5.6.1.1 DAQ system design shall provide capabilities for 60 channels of accelerometer data.
    *Source:* DR 5.6.1, each tri-axial accelerometer will create 3 channels of accelerometer data which must be transferred simultaneously.
    <u>Verification:</u> Analysis of DAQ system
    - DR 5.6.1.1.1 DAQ system shall contain a microcontroller capable of receiving 60 channels of accelerometer data.
      *Source:* DR 5.6.1, each tri-axial accelerometer will create 3 channels of accelerometer data which must be transferred simultaneously.
      <u>Verification:</u> Inspection of microcontroller
    - DR 5.6.1.1.2 DAQ system design shall include 8 boards capable of transferring 8 channels of accelerometer data each.
      *Source:* DR 5.6.1, 8 boards with 8 channels each yields the possibility 64 channels, exceeding the 60 channel requirement in DR 5.6.1.1.
      <u>Verification:</u> Inspection of system design

# FR 5 Breakdown

- DR 5.6.2 DAQ system shall contain at least 1 tri-axial and 1 single-axis accelerometers.
  *Source:* To keep costs low but validate two boards in the DAQ system, one tri-axial and one single axis accelerometer will be used on each board.
  Verification: Inspection of system
  - DR 5.6.2.1 Manufactured DAQ shall contain 16 accelerometer channels.
    *Source:* To validate a multiple-board system, two full boards will be manufactured with eight channels on each for redundancy and the possibility of 16 accelerometer channels.
    Verification: Inspection of system

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# FR 5 Breakdown

- DR 5.6.3 DAQ system hardware shall collect accurate accelerometer data to complete DR 5.5.
  *Source:* DR 5.5, in order to collect useful accelerometer data, the subsequent components are necessary.
  Verification: Inspection of system and subsequent DRs.
  - DR 5.6.3.1 Each accelerometer channel shall include a charge amplifier.
    *Source:* DR 5.5, to provide amplified data to the software
    Verification: Inspection
  - DR 5.6.3.2 Each accelerometer channel shall include a low pass filter.
    *Source:* DR 5.5, accelerometer data needs to be filtered and the simplest way to do this is with a low pass filter before entering the software system. More filtering can be executed in the software as well.
    Verification: Inspection
  - DR 5.6.3.3 Each accelerometer channel shall pass through an analog to digital converter.
    *Source:* DR 5.5, to provide the software system with digital data transferrable via USB.
    Verification: Inspection
  - DR 5.6.3.4 Accelerometers shall be rated to 2 kHz or above.
    *Source:* DR 5.6.3, the highest vibration frequency tested at is 2 kHz. This accelerometer rating drives the accelerometer selection.
    Verification: Inspection

# FR 5 Breakdown

- DR 5.6.3.5 Accelerometer data shall be sampled by the DAQ system faster than 4 kHz.
  *Source:* DR 5.6.3, the highest vibration rate will be 2 kHz thus the Nyquist frequency minimum sampling rate is 4 kHz.
  Verification: Demonstration
  - DR 5.6.3.5.1 Data from 60 accelerometer channels shall be sampled, packetized, and transmitted faster than 4 kHz.
    *Source:* DR 5.6.3.5, the microcontroller will not be saving data so it must sample data and transfer it back out above the Nyquist frequency.
    Verification: Demonstration
  - DR 5.6.3.5.2 The DAQ computer shall receive data above the microcontroller's output rate with accelerometer data sampled at 4 kHz.
    *Source:* DR 5.6.3.5, the microcontroller will not be saving data so it must sample data and transfer it back out above the Nyquist frequency.
    Verification: Demonstration

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# FR 5 Breakdown

- DR 5.6.4: Accelerometer data shall display in the form of power spectral density plots during each test.
  *Source:* Customer requirement, safety for structure during test, real-time performance analysis
  Verification: Demonstration
  - DR 5.6.4.1: DAQ software executable file shall be downloaded and run on any Windows computer.
    *Source:* To display power spectral density plots in real-time, a computer software is necessary to interface with data. This operation is necessary because all operations are assumed on any Windows computer (also see DR 5.6.6).
    Verification: Demonstration
  - DR 5.6.4.2: Accelerometer data shall be transferred during each vibration test.
    *Source:* Power spectral density plots require accelerometer data, and will perform a calculation to display this accelerometer data in quasi-realtime.
    Verification: Demonstration

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# FR 5 Breakdown

- DR 5.6.5 Accelerometer raw data and PSD data shall be saved during each test in an Excel-compatible format.
  *Source:* Customer requirement for fast post-test analysis on any Windows computer.
  <u>Verification:</u> Demonstration
- DR 5.6.6 Accelerometer data shall be transferable via USB from the data collection computer to any Windows computer.
  *Source:* Customer Requirement. To prevent errors and wasted time, data should be easy to transfer to any of SST-US' computers.
  <u>Verification:</u> Demonstration

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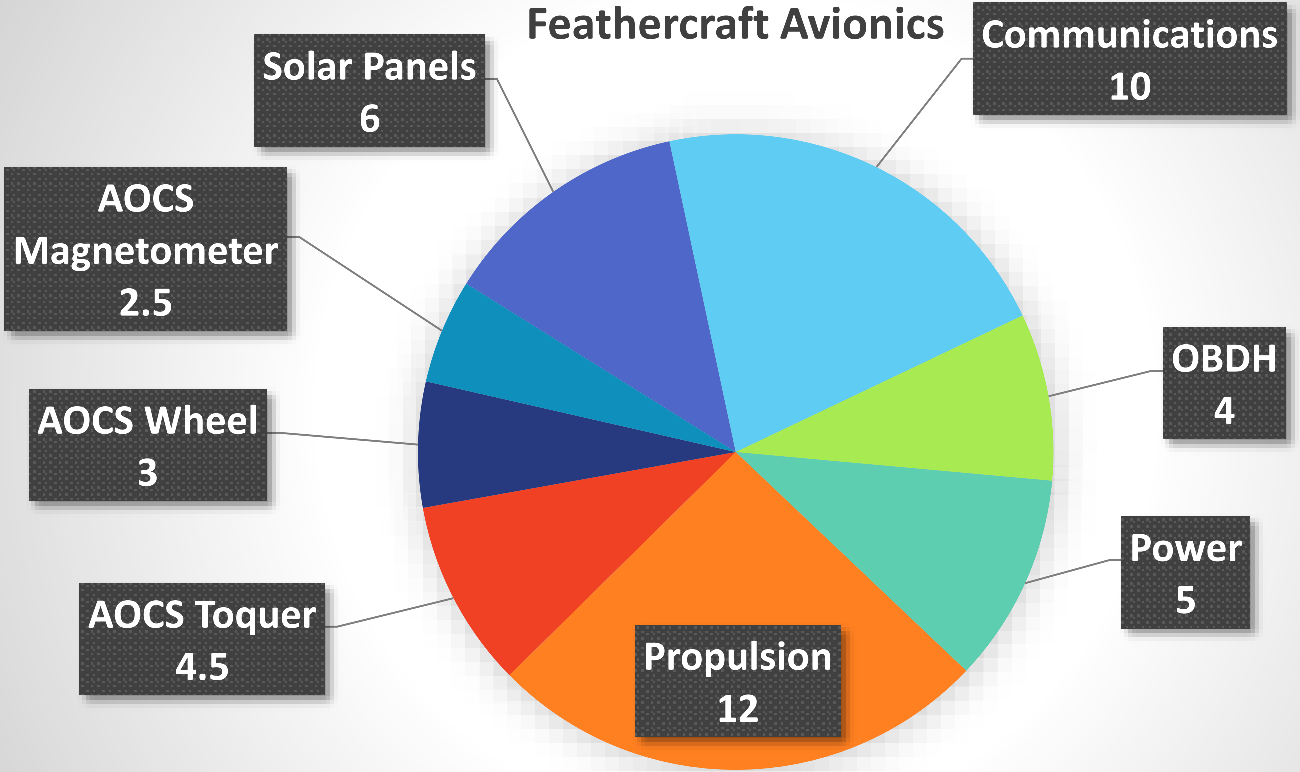
# Mass Breakdown

- 100kg Total
  - 5kg – Structure
  - 45kg – Payload
  - 32kg – Avionics
  - 6kg – Three solar panels
  - 12kg – Propulsion box and plate

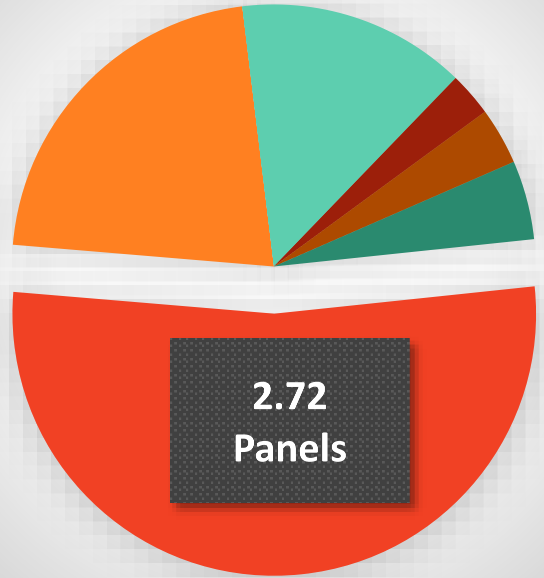
# Avionics



Feathercraft Avionics
Solar Panels 6
Communications 10
AOCS Magnetometer 2.5
OBDH 4
AOCS Wheel 3
Power 5
AOCS Toquer 4.5
Propulsion 12

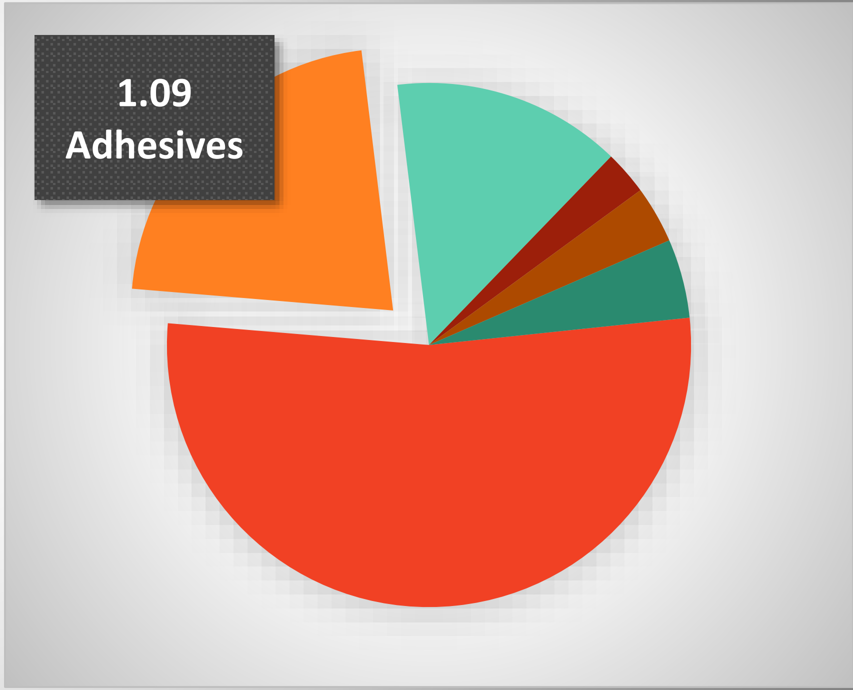
# Panels – 2.72kg

- Purchased Panels
  - 1ply, .375”
  - Waterjet Cut
- Manufactured Panels
  - 2ply, .5”
  - Waterjet Cut



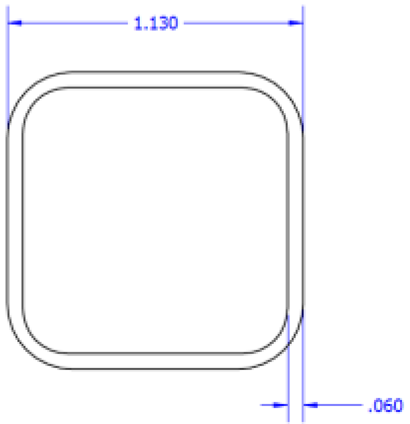
# Adhesives – 1.09kg

- ScotchWeld 2216 (220g)
  - Epoxy for bonding components, structural members.
  - Assumed 200% bond thickness, 120% bond area
- ScotchWeld E3550 (867g)
  - Void-filler for edges of panels
  - Not used on weight-relief

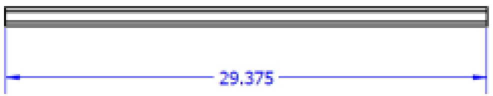


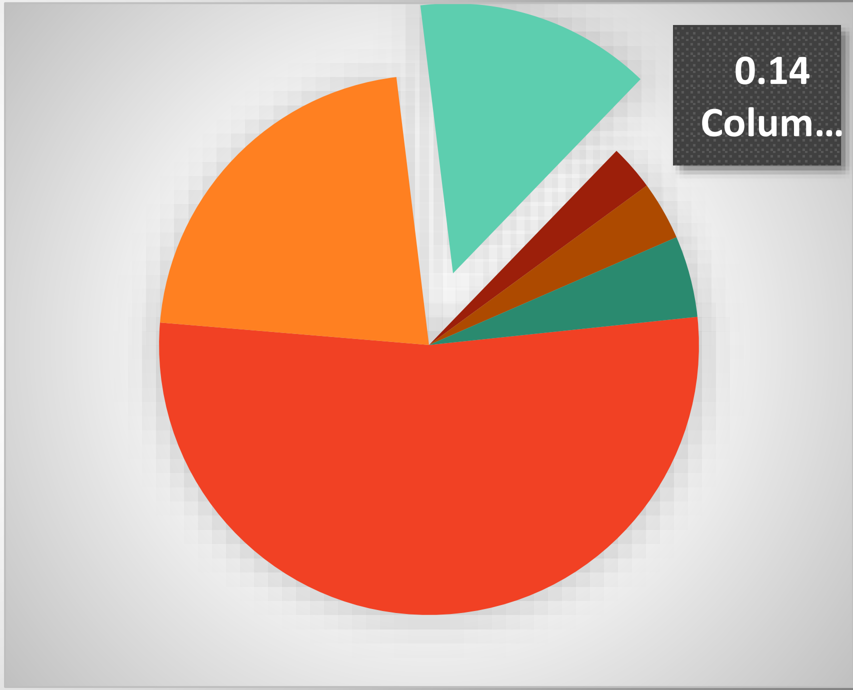
# Columns – 0.14kg

- High Modulus Carbon Fiber square tubing




4x



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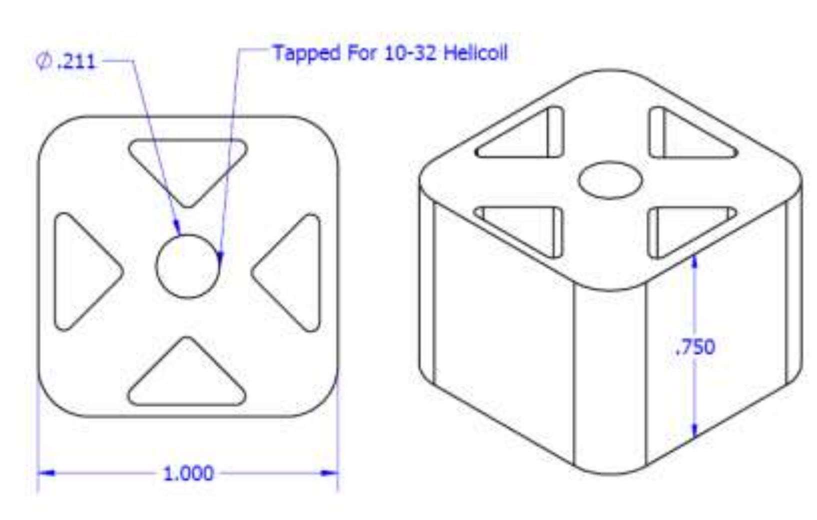
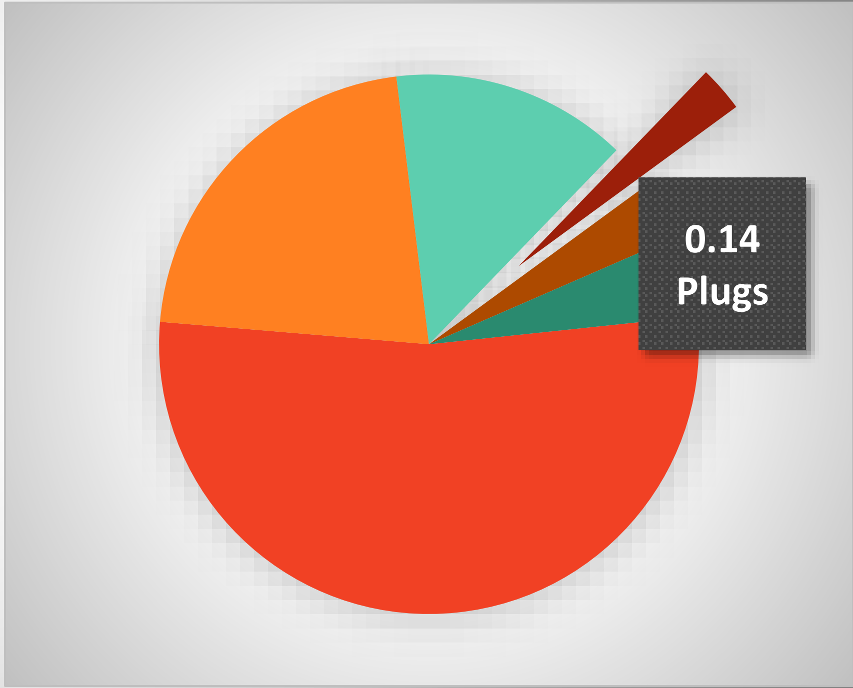
# Plugs – 0.14kg

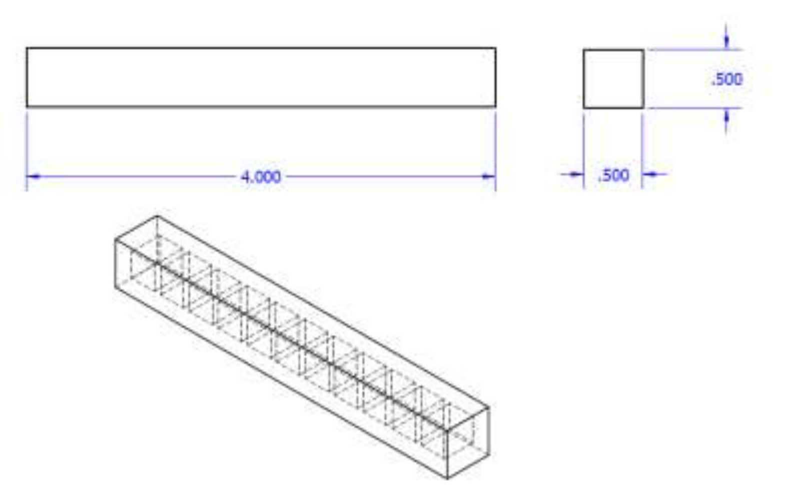
- Veriwhite Plastic, 3D Printed Insert
  - Supports Column/Endplate interface
  - Allows for initial fastening and removal of propulsion plate and radiator.

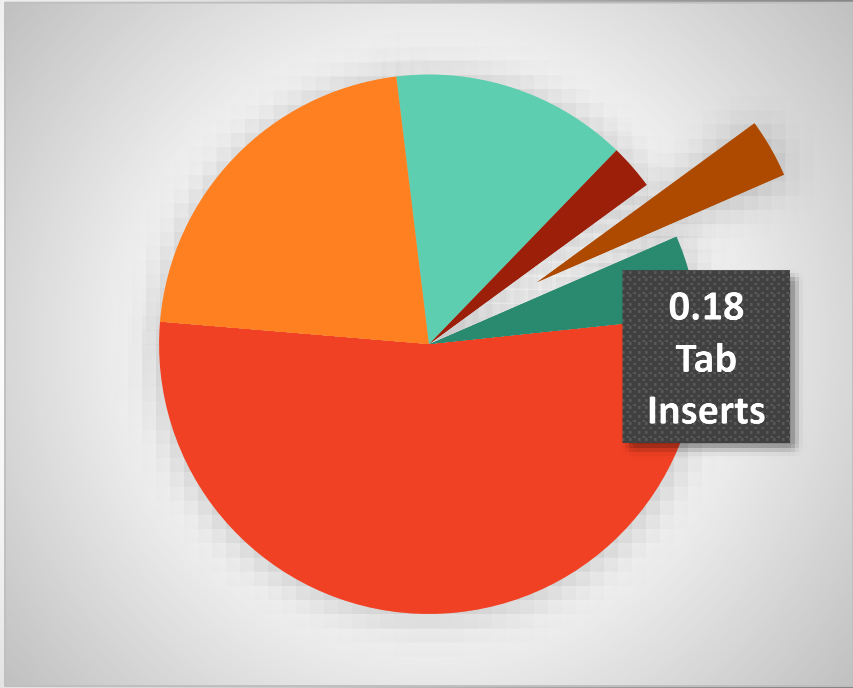


# Tab Inserts – 0.18kg

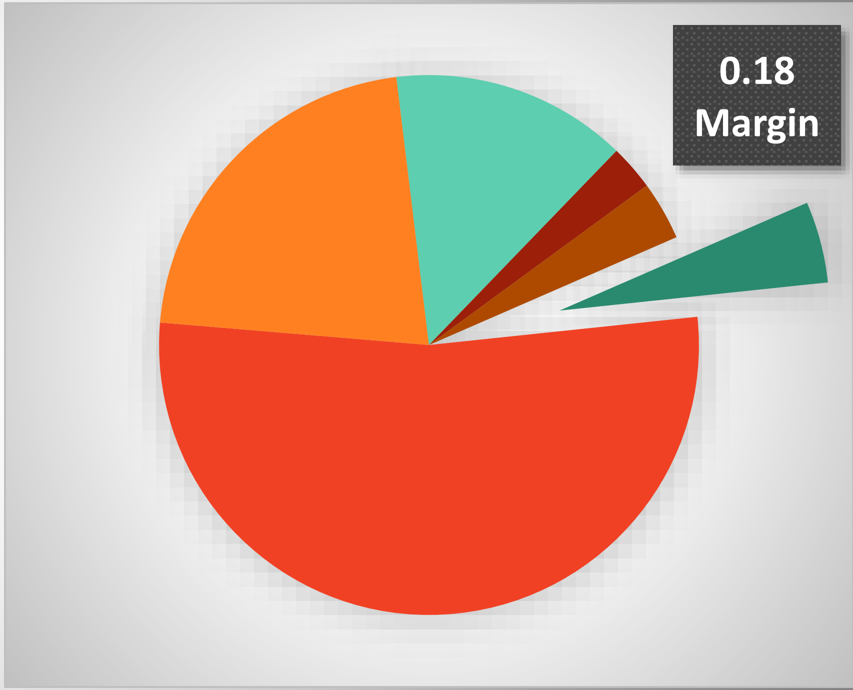
- Tab Insert – Universal between tabs
- Supports local compression of middle plate



# Margin – 0.18kg

- 5% Margin
- Little room for error
  - Too much glue
  - In-house panels



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# Cost:

| Supplier: | Cost: | Units: | Total: |
|---|---|---|---|
| ACP Composites | $6,730.00 | 1 | $6,730.00 |
| Ellsworth | $ 140.00 | 1 | $ 140.00 |
| Hillas | $ 16.14 | 5 | $ 80.70 |
| RockWest Composites | $ 170.00 | 2 | $ 340.00 |
| 3D Additive Fabrication Inc. | $ 26.00 | 4 | $ 104.00 |
| 3D Additive Fabrication Inc. | $ 24.00 | 17 | $ 408.00 |
| Velcro | $ 22.00 | 1 | $ 22.00 |
| | | Total: | $7,824.70 |

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# DR 2.2: Manufacturing and Assembly shall take less than 9 months

- Lead time for custom panels from ACP Composites is 4 weeks
- Lead time for 3D printed inserts in 3-5 days (negligible)
- Full adhesive cure takes 7 days, assume 4 glue cycles = 1 month

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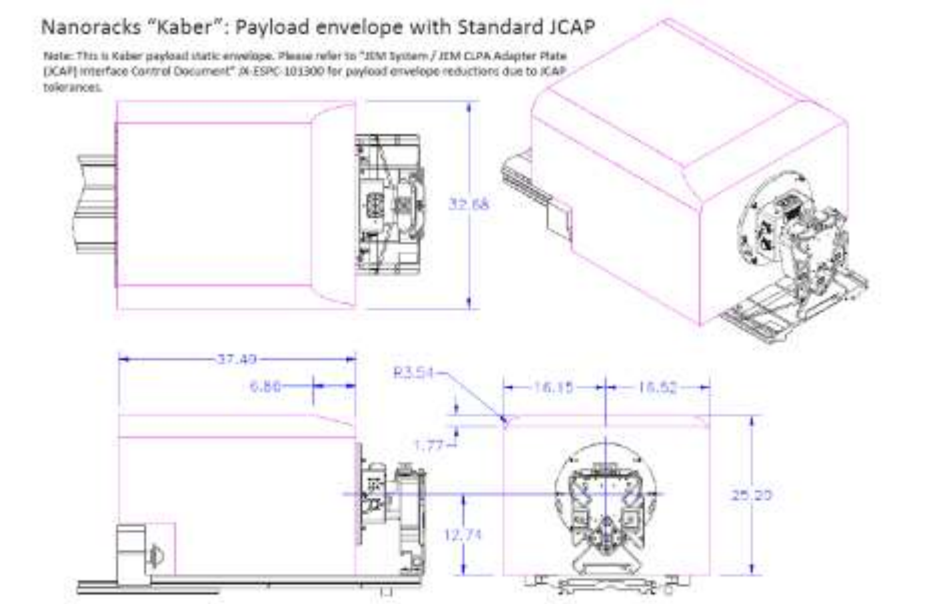
# DR 2.3: Manufacturing and assembly labor shall cost less than $80,000

- By deferring composites manufacturing to dedicated companies SST-US avoids all manufacturing labor cost
- Assembly labor cost was estimated using an Aerospace Technicians average salary as $30.66/hour.  One month for assembly of the spacecraft. Four person team.

# DR 3.2 - Structure will fit in Kaber Volume

- Structure Max Dimensions:
  - 30.000”x29.138”
  - Height: 18.976”




| Requirement: | Required Value: | Current Value: | Margin: | |
|---|---|---|---|---|
| **DR 3.2 Structure design shall fit within volume of Kaber system** | 30’’x30’’x19’’ | 30’’ x 29.138’’ x 18.976’’ | SST-US built in margin | Requirement Met |

# Middle Panel Deflection:

- Determine K values (1, 2, 3)
- Determine λ parameter

```
νa = 0.33; (*Poisson's Ratio*)
λ = 1 - νa^2 ; (*Additional term introduced*)
```

- Determine maximum deflection of the Middle Plate

```
δm = 2 * K1 * q * b^4 * λ / (En * tf * hm^2) (*m*)
0.00418266
```

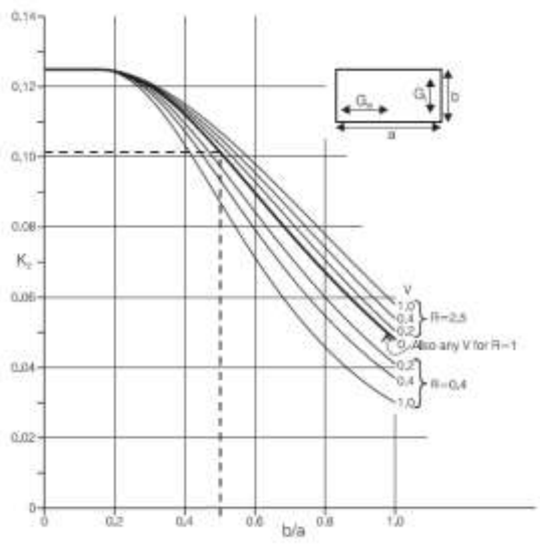


Figure 2 - $K_2$ for determining facing stress σ

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# Facing Stress:

- The core compressive strength must be adequate to resist local loads on the panel surface

**Facing stress** (compare to yeild 79 MPa)

$\sigma fm = K2 * q * b \wedge 2 / (hm * tf)$ (*Pa*)

$3.16495 \times 10^{7}$

$M\sigma fm = \sigma y / \sigma fm - 1$ (*Marging on facing stress*)

1.49443

# Core Shear:

- The core must resist shear stress due to loading

- hm – height of the middle plate

**Core Shear** (compare to $\sigma u$ = 750*10^6 Pa)

```
τc = K3 * q * b / hm (*Pa*)
173 487.

Mτc = σu / τc - 1 (*Margin on core shear*)
4322.08
```

# Local Compression:

- The core compressive strength must be adequate to resist local loads on the panel surface

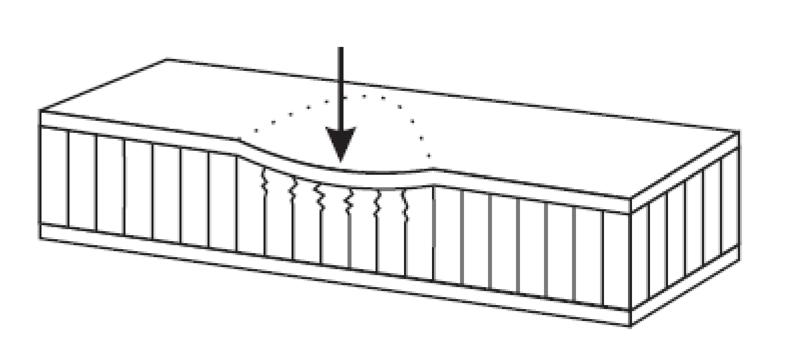
**Local Compression** (compare to $\sigma ca$ = 4.7 *10^6 Pa)

$\sigma c = q$ (*Pa - Pressure on surface*)

8742.17

$M\sigma c = \sigma ca / \sigma c - 1$ (*Margin on local compression*)

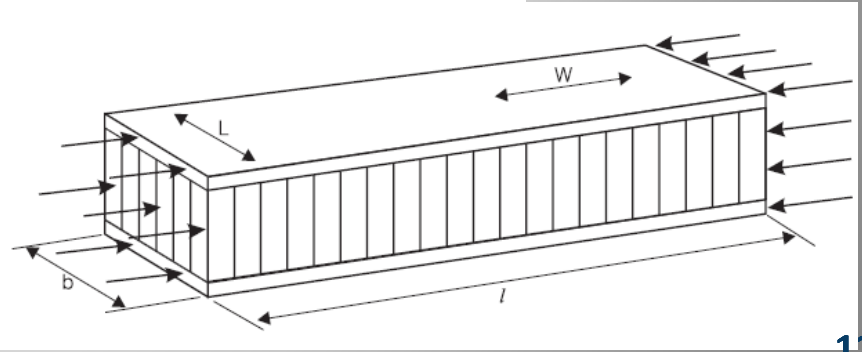
536.624



# Tab Shear:

- Tabs carry shear during dynamic loading

```
a2 = 0.01397 * tf * 2 (*m^2 - contact area of 1 tab*)

0.000016764

n = {10, 6}; (*number of tabs involved depending on direction of *)
τt2 = (F1 / b) / (n * a2) (*Pa - Shear stress*)

{3.97371×10^7, 6.62285×10^7}

Mτt2 = σy / τt2 - 1

{0.986741, 0.192045}
```



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# Adhesive Small Scale Testing Results:

| Carbon Tube-Carbon Fiber Face Sheet | | Adhesion Area |
|---|---|---|
| **Round 1** | | 1'x1' = 1 in^2 |
| Test #: | Force [N]: | |
| 1 | 720 | |
| 2 | 664 | |
| 3 | 628 | |
| Avg. Force [N]: | 674 | |
| Avg. Pressure [MPa]: | 1.044702089 | |

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# Tube-Insert Interface

>>> >>> >>>**Insert**: Interface between columns and plates - total of 8 bonding places >>> >>> >> >> >>> >

Analysis shows that glue interface is critical - loss of 1 is catastrophic

```
σ2216 = 1 * 10 ^ 6; (* Pa - Critical value: lowest experimental result*)

tw = 1 / 16 * 0.0254; (*m - thickness of tube wall*)
n3 = {8, 7}; (*number of bonding areas*)
w3 = 1 * 0.0254; (*m - inside width*)
l3 = 1 * 0.0254; (*length of glue-in insert for tube 2 plate mount*)
A3 = w3 * l3 * 4 * 0.25; (*assuming 25% effective bonding area*)
τ3 = F1 / (A3 * n3); (*Pa - Shear stress in glue joint*)
Mτ3 = σ2216 / τ3 - 1

{0.0167833, -0.110315}

Pm3 = (1 - τ3 / σ2216) * 100

{1.65063, -12.3993}
```

Margin above FOS

# Why VELCRO?

- Customer request for experimentation on the top and a side solar panels, will also be used for another side solar panel for ease of use during vibration testing
- Utilizing Industrial-Strength Extreme Velcro
- Not anticipating danger of failure during test because structure will be foam-wrapped
- Total mass added ~4.8 oz = 136 g for large 10’x1’’ (0.0774 m^2) strip
- Small scale testing will be done to verify the strength [illegible]LCRO

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# Adhesive Small Scale Testing:

## Round 1

- Surface Preparation
  - Prepared aluminum and left carbon fiber alone
  - Wiped with acetone
  - Sanded with fine sandpaper
  - Wiped with acetone and isopropyl alcohol
- Gluing
  - Epoxy pushed equally out of tube and stirred with stick
  - Applied conservatively with sticks on both sides
  - Thin wires laid on one surface and other surface pressed on top
- Curing
  - Left held with clamps or weights for 12-24 hours to handling strength
  - Cured in small oven at 200 degrees F for 30-120 minutes

## Round 2 Changes

- Surface Preparation
  - Prepared both aluminum and carbon fiber
  - Etched crossed lines into both surfaces
  - Sanded with coarser sandpaper
- Gluing
  - Applied thickly on both sides and excess epoxy more carefully removed
- Curing
  - Held all samples with clamps for 12-24 hours
  - Cured in small oven at 200 degrees F for 2 hours and 10 minutes

# Full Adhesives BOTE Analysis

| Component: | Mass: | Quasi-static load: | 25 % of Available Area: | Required Strength: | Percent Margin: |
|---|---|---|---|---|---|
| Payload | 45 kg | 2719 N | 0.12 $m^2$ | 23.4 kPa | 94.7% |
| COMM | 10 kg | 604.3 N | 0.0064 $m^2$ | 94.2 kPa | 78.7% |
| OBD | 4 kg | 241.7 N | 0.0113 $m^2$ | 21.5 kPa | 95.1% |
| POWER | 11 kg | 664.7 N | 0.0251 $m^2$ | 26.4 kPa | 94.0% |
| Torquer | 1.5 kg | 90.6 N | 0.00563 $m^2$ | 16.1 kPa | 96.4% |
| Wheel | 1 kg | 60.4 N | 0.00297 $m^2$ | 20.3 kPa | 95.4% |
| Magnetometer | 1.25 kg | 75.5 N | 0.000975 $m^2$ | 77.5 kPa | 82.5% |
| Small Solar Panel | 2 kg | 120.9 N | 0.051 $m^2$ | 2.39 kPa | 99.6% |
| Large Solar Panel | 2 kg | 120.9 N | 0.065 $m^2$ | 1.846 kPa | 99.5% |

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# Adhesive Small Scale Testing Results:

| Aluminum-Carbon Fiber Face Sheet | | | |
|---|---|---|---|
| **Round 1** | | **Round 2** | |
| Test #: | Force [N]: | Test #: | Force [N]: |
| 1 | 1992 | 1 | 1590 |
| 2 | N/A | 2 | 1351 |
| 3 | 2194 | 3 | 746 |
| Avg. Force [N] | 2093 | Avg. Force [N] | 1229 |
| Avg. Pressure [MPa]: | 2.359386537 | Avg. Pressure [MPa]: | 1.385420953 |

Overall avg [Mpa] 1.872403745

Adhesion Area

1'x1.375'=1.375 in^2

Adhesive generally stuck to CF instead of Al.

Percent difference between Round 1 and Round 2 averages

-58.72%

| Aluminum-Aluminum | | | |
|---|---|---|---|
| **Round 1** | | **Round 2** | |
| Test #: | Force [N]: | Test #: | Force [N]: |
| 1 | 5095 | 1 | 17479 |
| 2 | 8107 | 2 | 10463 |
| 3 | 5494 | 3 | 10117 |
| Avg Force [N]: | 6232 | Avg Force [N]: | 12686.33333 |
| Avg. Pressure [MPa]: | 3.468250415 | Avg. Pressure [MPa]: | 7.06023441 |

Adhesion Area

1.9375'x1.4375'=2.78515625 in^2

about 30%

Percent difference between Round 1 and Round 2

49.12%

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# Adhesive Small Scale Testing Results:

## Shear Testing

| Aluminum-Carbon Fiber Face Sheet | | | |
|---|---|---|---|
| **Round 1** | | **Round 2** | |
| Test #: | Force [N]: | Test #: | Force [N]: |
| 1 | 2336 | 1 | 5099 |
| 2 | 118 | 2 | 2061 |
| 3 | 1983 | 3 | 2780 |
| Avg Force [N]: | 2159.5 | Avg Force [N]: | 3313.333333 |
| Avg. Pressure [MPa]: | 2.818721427 | Avg. Pressure [MPa]: | 4.324780579 |
| | Overall avg [Mpa] | 3.571751003 | |

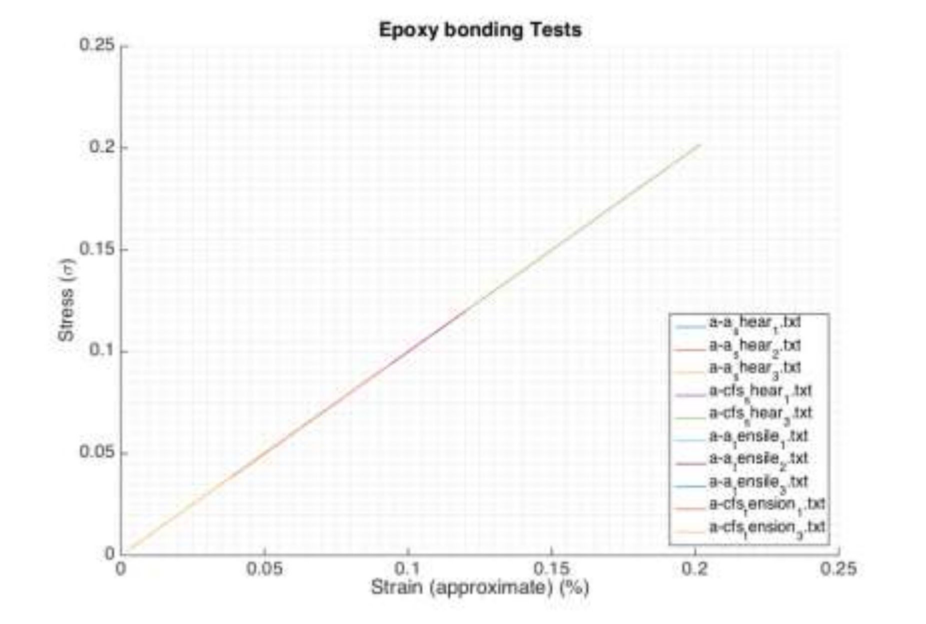
Adhesion Area
1'x1.1875' = 1.1875 in^2
Adhesive generally stuck to CF instead of Al.
Round 1 Test 2 not included in average.
Percent difference between Round 1 and Round 2 averages
65.18%

| Aluminum-Aluminum | | | |
|---|---|---|---|
| **Round 1** | | **Round 2** | |
| Test #: | Force [N]: | Test #: | Force [N]: |
| 1 | 5534 | 1 | 3964 |
| 2 | 5914 | 2 | 4328 |
| 3 | 5517 | 3 | 2106 |
| Avg Force [N]: | 5655 | Avg Force [N]: | 3466 |
| Avg. Pressure [MPa]: | 8.130103217 | Avg. Pressure [MPa]: | 4.983012865 |

Adhesion Area
1.4375'x0.75' = 1.078125 in^2
Equal amount of adhesive stuck to both samples after failure.
Percent difference between Round 1 and Round 2 averages
-61.29%

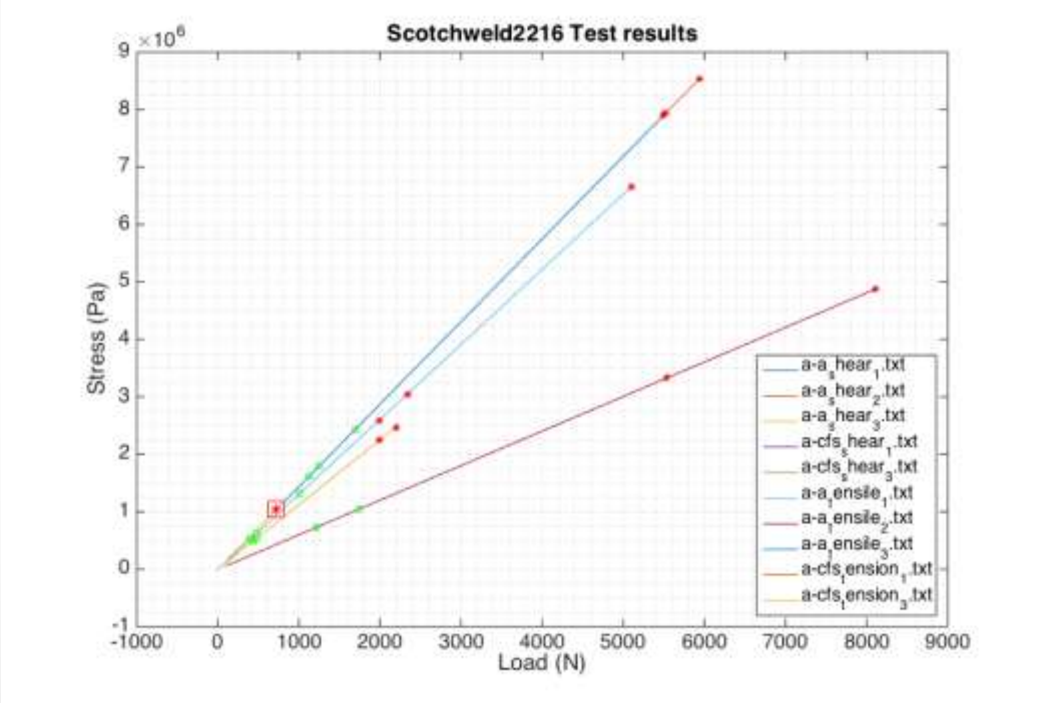
# Adhesive Testing Results:

- Linear portion of elastic curve exceptional match in stress – strain.
- Shows **consistent mixing ratios**
- Modulus is 306 MPa



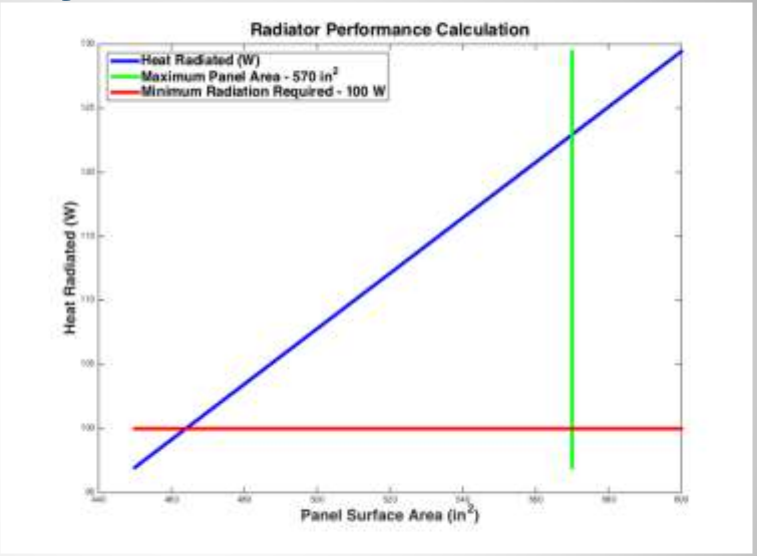
# Adhesive Testing Knowledge:

- Justification by test for FOS = 4
- Variation in maximum stress due to surface prep and curing time/temp
- Maximum allowable stress 841 kPa



# DR 4.6 Met through Analysis

- One 19” x 30” allocated for thermal radiation
- Detailed thermal design not required by Surrey
- Key Assumptions:
    - 100 W of radiation at standard operating temperature ~25 C
    - Radiator positioned to face deep space (T = 4 K)
    - Carbon emissivity ~0.75
    - Thermal pathways will be added to Feathercraft design in later stages of the project




- Feasible under assumed conditions for 460 -570 square inches

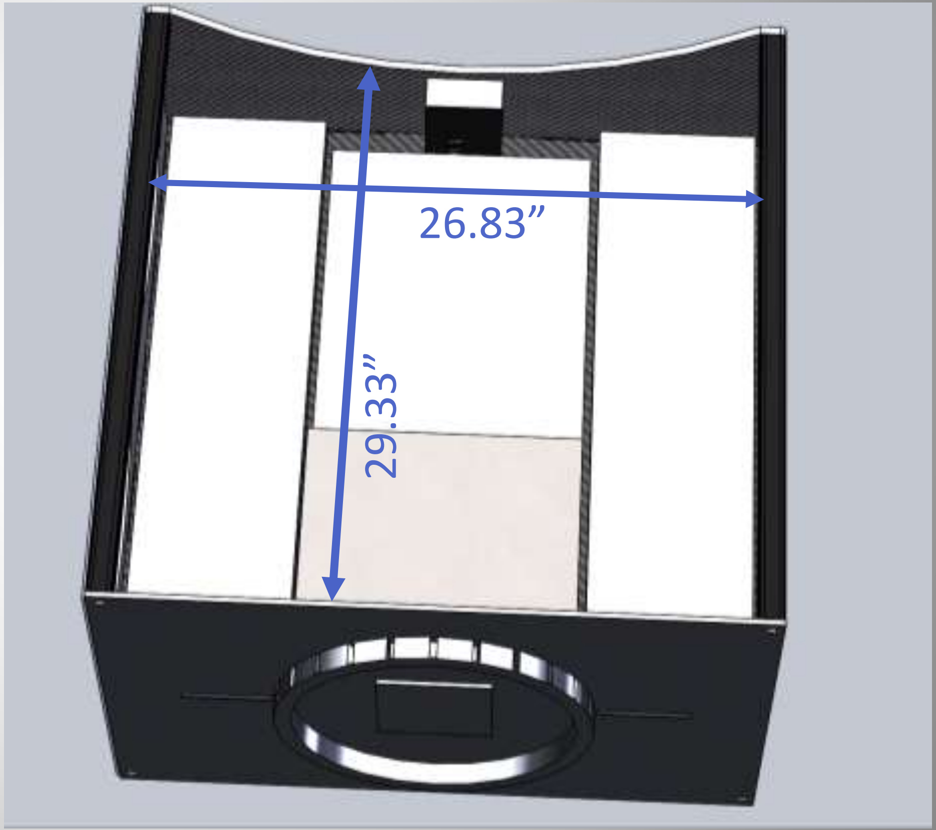
- Given nature of requirement, 460 used in design to help meet target 5kg mass

| Requirement: | Required Value: | Current Value: | |
|---|---|---|---|
| **DR 4.6:** Radiator shall dissipate 100 W of heat | 100 W | 100 W (option to increase area to add margin) | Requirement Met |

# DR 4.7 Met Through Analysis:

**DR 4.7:** FeatherCraft design shall have an open aperture of at least 12”x12” inches on side 5

| Require d Value: | Current Value: | Margin: | |
|---|---|---|---|
| 12”x12” | 29.33”x26 .83” | 82% | Requirement Met |



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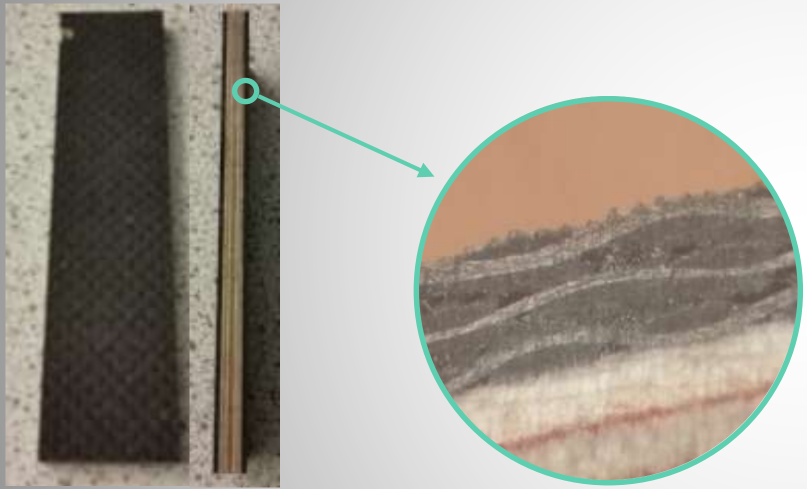
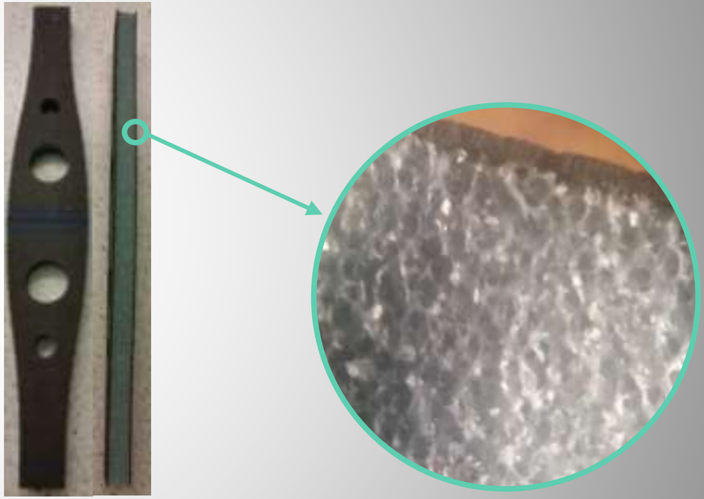
# Cutting Carbon Fiber Sandwich Panels:

**DR 5.1:** Structural test model (STM) shall be created

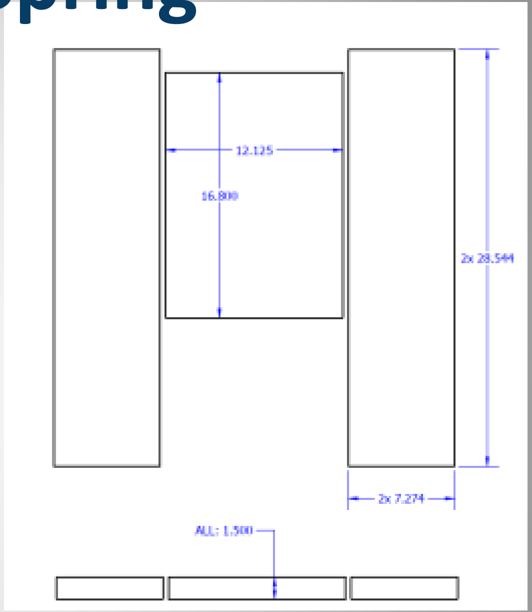




Both CNC routing and water-jet cutting proved to be effective methods of cutting sandwich panels without delamination.

# DR 5.3- Verified by Inspection in Spring

- Now manufacturing all spacecraft components out of aluminum except for aluminum honeycomb propulsion plate
- Payload Dummy
  - 42.5kg plates (right)
  - 5kg in variable additions
    - Allow 100kg total weight
- Avionics Dummies
  - 12 ‘components’
  - Simulate size, CG, and material to be adhered (Al)




| Requirement: | Required Value: | Current Value: | Design Margin: | |
|---|---|---|---|---|
| **DR 5.3:** Manufacture aluminum mass analogs with provided masses and sizes | 1450 in^3 | 1450 in^3 | N/A | Requirement Met |

# DR 5.6.2.4 Met through inspection of datasheet

- Piezoelectric accelerometers are manufactured to sample data during vibrations at higher frequencies
- Frequency range for single-axis accelerometer is 0.5 to 3000 Hz

| Requirement: | Required Value: | Current Value: | Design Margin: | |
|---|---|---|---|---|
| **DR 5.6.2.4** Accelerometers shall be rated to above testing frequencies | 20-2000 Hz | 0.5-3000 Hz | 15 Hz | Requirement Met |

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# DR 5.6.6 Met through design analysis

- Files will be transferrable after each test with USB thumb drive.
- Files can be transferred one at a time in between tests.

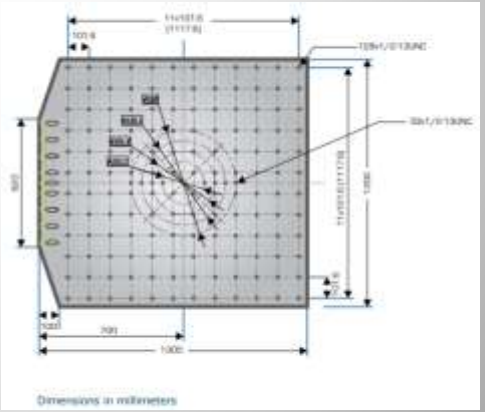
| Requirement: | Required Value: | Current Value: | Percent Margin: | |
|---|---|---|---|---|
| **DR 5.6.6:** Files shall be transferrable via USB. | 8 GB | 38.4 MB (at 5 kHz) | 96.6% | Requirement Met |

# 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.

# Vibration Test: Facility and Equipment

- Cascade Tek (Longmont)
  - SR16 Shaker, slip table, and head expander
- Cost: $1800 - covered by SST-US
- Reference: Greg Matthews, Test & Dynamics Technician



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# Vibration Testing – Incremental 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

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# Random Vibration 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.

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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<br>-Either postpone or proceed with test depending on nature of failure |
| -Structural Failure during Random Vibration | -Unwrap and document failure, TRB<br>-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)

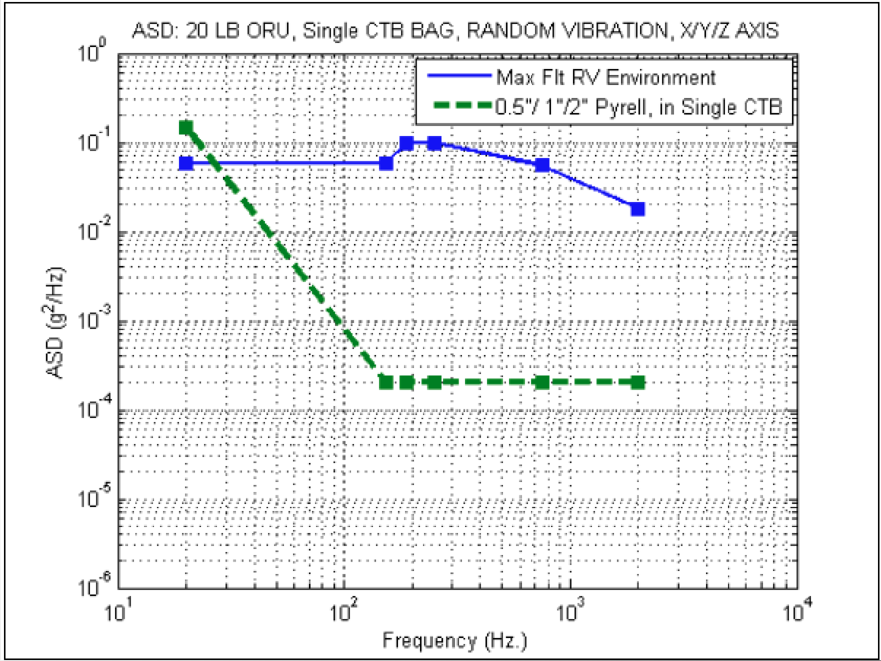
# GRMS

- 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

# GRMS Methodology

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

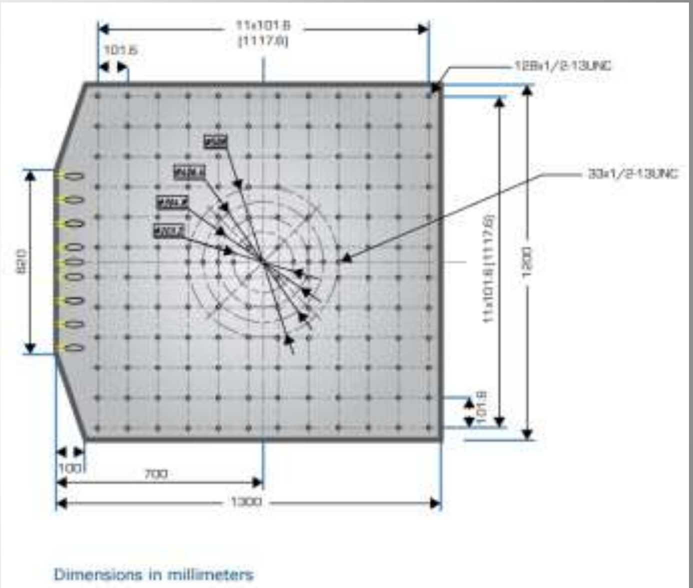
$$grms = \sqrt{\int_0^{2000} ASD(f)\, df}$$




Sample ASD Plot for unattenuated and attenuated random vibration

# 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 | |

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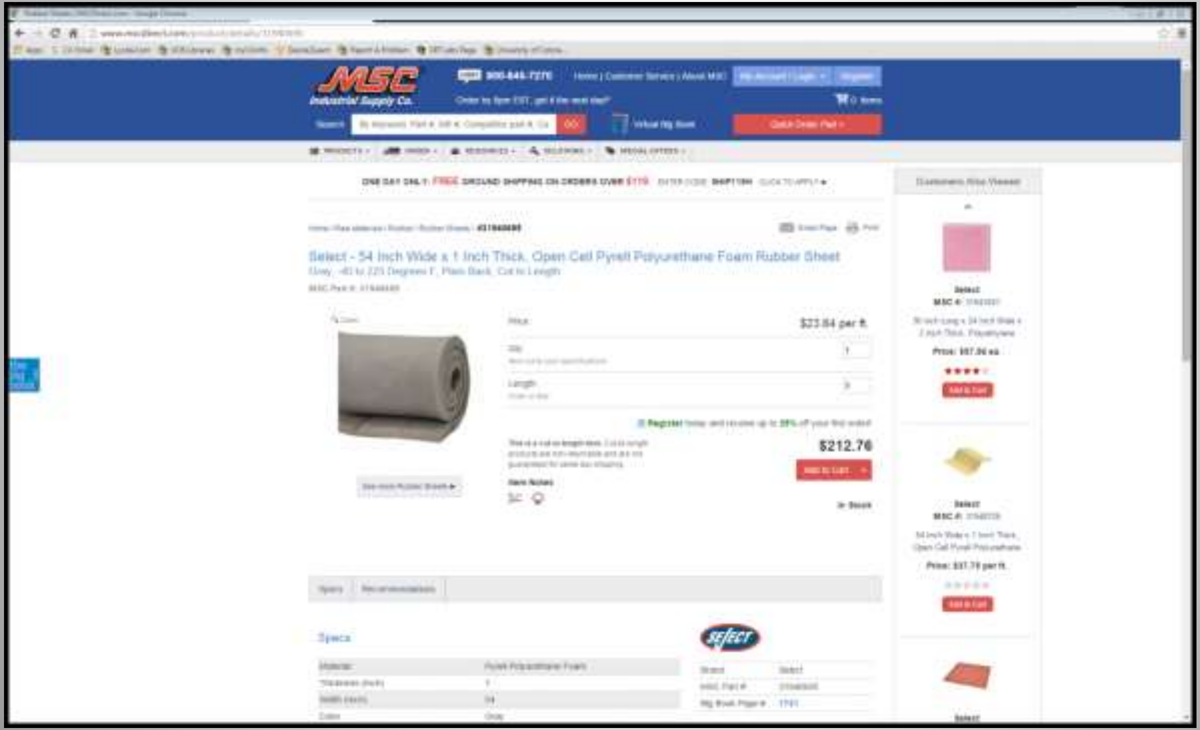
# DR 5.4 – Acquiring Foam

MSC is a trusted and fast resource which stocks the Pyrell foam



# 5.6.3: DAQ System – Providing Quality Data

- The charge amplifiers will add a constant 2mA current to the charge output of the accelerometer.
- Frequencies above 2.5kHz will be filtered out by the Active Low Pass filter. This will remove higher harmonics to protect the ADC.

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# 5.6.3: DAQ System – Providing Quality Data

- Analog to Digital Converter converts the analog voltage output to a binary number.
- The microcontroller pulls the binary number and relays it to the computer.
- The software removes any DC bias seen through the charge amplifier and plots the final result.

# Transferring Data from Accelerometers Through DAQ at above 4 kHz:

- Calculated sampling time: every 31 μs
- Results are summarized in table below

**DAQ System Timing Specifications**

| Description: | Value: |
|---|---|
| Minimum Required Sampling Rate | 4 kHz |
| Calculated effective sampling rate | 32.1 kHz |
| With FOS = 2 | 16 kHz |
| Margin | 12 kHz |

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# DAQ System Timing Calculations

| Step | Process | Instruction Cycles/count | Count # | Required Time (µs) | Total Required Time (µs) |
|---|---|---|---|---|---|
| 1 | Toggle Chip Select (x2) | 2 | 8 | 0.08 | 0.08 |
| 2 | Toggle Read Pin (x2) | 2 | 64 | 0.64 | 0.72 |
| 3 | Read Data from Port | 1 | 64 | 0.32 | 1.04 |
| 4 | Store Data in Local Memory | 2 | 64 | 0.64 | 1.68 |
| 5 | Transfer Data to USB Module | 4 | 1 | 0.02 | 1.70 |
| 6 | Transfer Data to PC via USB | 35 Mbps | 1024 bits | 29.3 | 31 |
| 7 | Toggle AD Convert Pin(x2) | 2 | 1 | 0.01 | 31.1 |
| REPEAT | | | | | |

$$Required\ Time = \frac{Instruction\ Cycles\ * Count\ \#}{Operating\ Frequency}$$

$$Effective\ sampling\ rate = 32.1\ kHz$$

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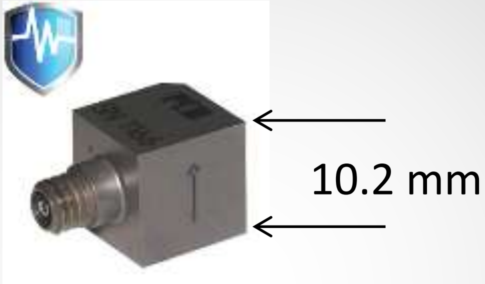
# ACCELEROMETERS:

**Resources:**

- Trudy Schwartz
- Christine Buckler (ITLL) for borrowing accelerometers and cables
- The Modal Shop for renting accelerometers for 30 days




Single Axis (PCB-333B30)


Tri-axial (PCB-356A16)

| Accelerometer | Buy Price | Rent Price | Mass | Size |
| --- | --- | --- | --- | --- |
| Single axis | $297 | $60/ month | 4 grams | 10.2x16.0x10.2 mm |
| Tri-axial | $931.50 | $200/ month | 7.4 grams | 14.0x20.3x14.0 mm |

# Accelerometer Locations: Random Vibe

**Structure is wrapped in foam**

1 - Hard Point on structure (1-axis)

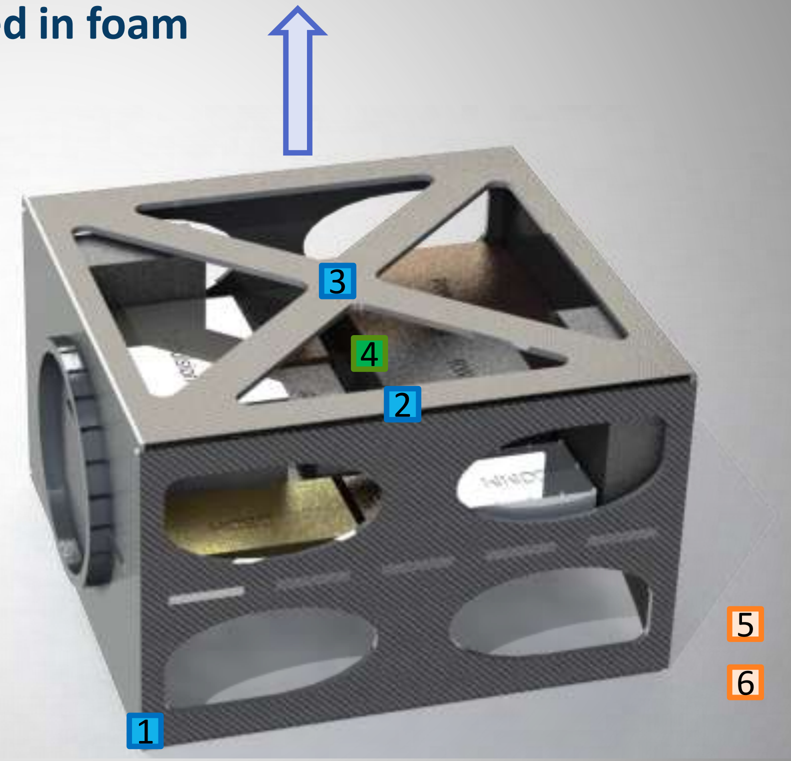
2&3 - Panel normal to acceleration

- Middle (1-axis)
- Offset (1-axis)

4 - Components/Masses (Tri-axial)

Legend:

- Single Axis (blue)
- Tri-axial (green)
- Cascade Tek (orange)



# Accelerometer Locations: Modal

1 - Hard Point on structure (1-axis)

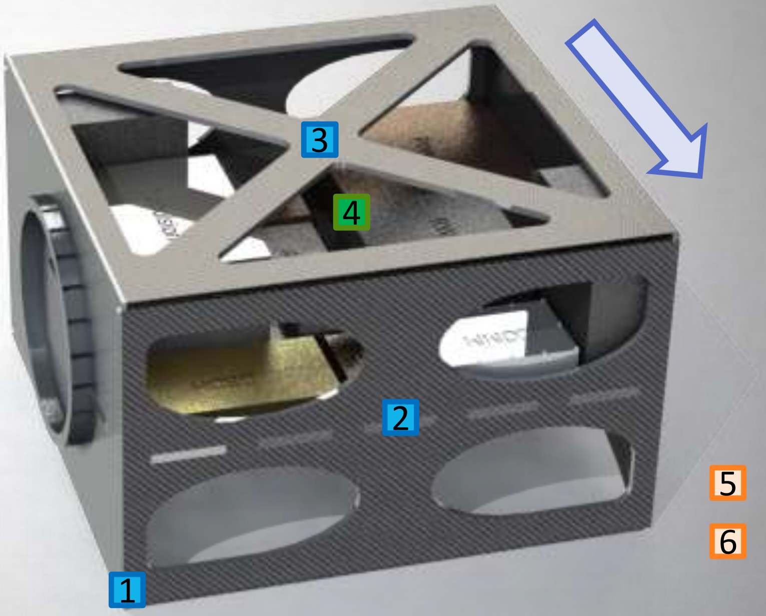
2&3 - Panel normal to acceleration

- Middle (1-axis)
- Offset (1-axis)

4 - Components/Masses (Tri-axial)

Legend:
- Blue – Single Axis
- Green – Tri-axial
- Orange – Cascade Tek

Port/Starboard



# 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**

# 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

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# 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**

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# 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**

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# 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

# 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

# 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

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# 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

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# 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**

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# 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

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# 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**

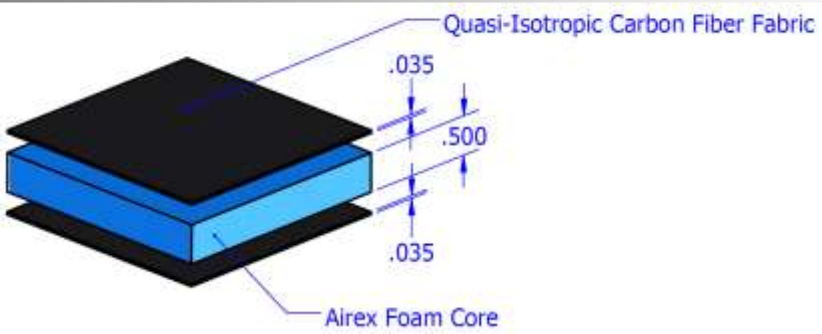
# Background for ANSYS Model

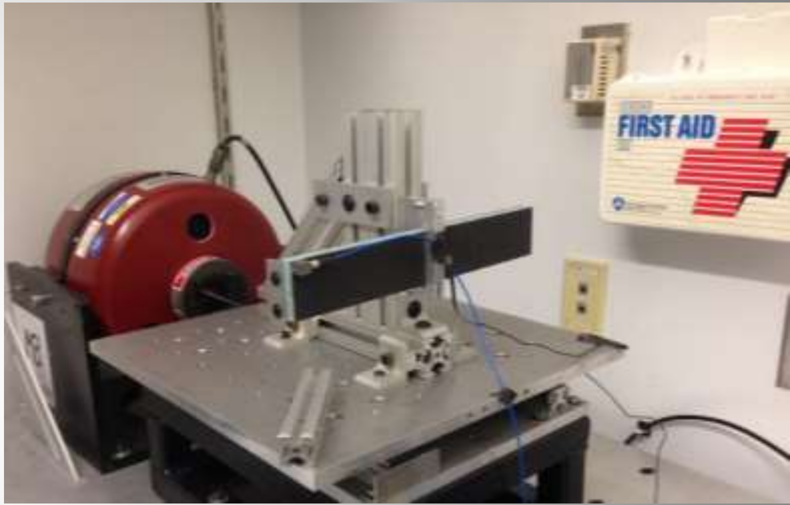
- Composite beams
  - Bending Tests (refine material properties)
  - Modal Sweep (confirm modelling capability)
- Validation of complex-geometry predictions

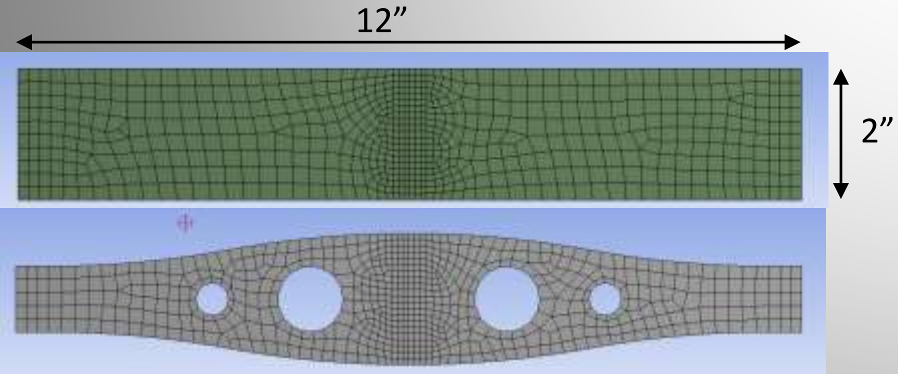
# Model Validation: Preliminary Tests

| Test: | Purpose: | Facility & Equipment: |
|---|---|---|
| **3 Point Panel Bending** | Refine model material properties based on experimental material properties | ITLL: Instron Machine |
| **Face-Sheet Column Interface Failure** | Characterize types of failure at interface<br>Experimentally quantify stresses for each failure | ITLL: Instron Machine & E-Red Shaker |
| **Mass Testing** | Experimentally quantify the mass of all materials (adhesive, filler, panels) | CU Composites Lab |
| **Small Scale Vibration** | Determine modal prediction accuracy<br>Adhesive fatigue testing | ITLL: E-Red Shaker, accelerometers, and DAQ |

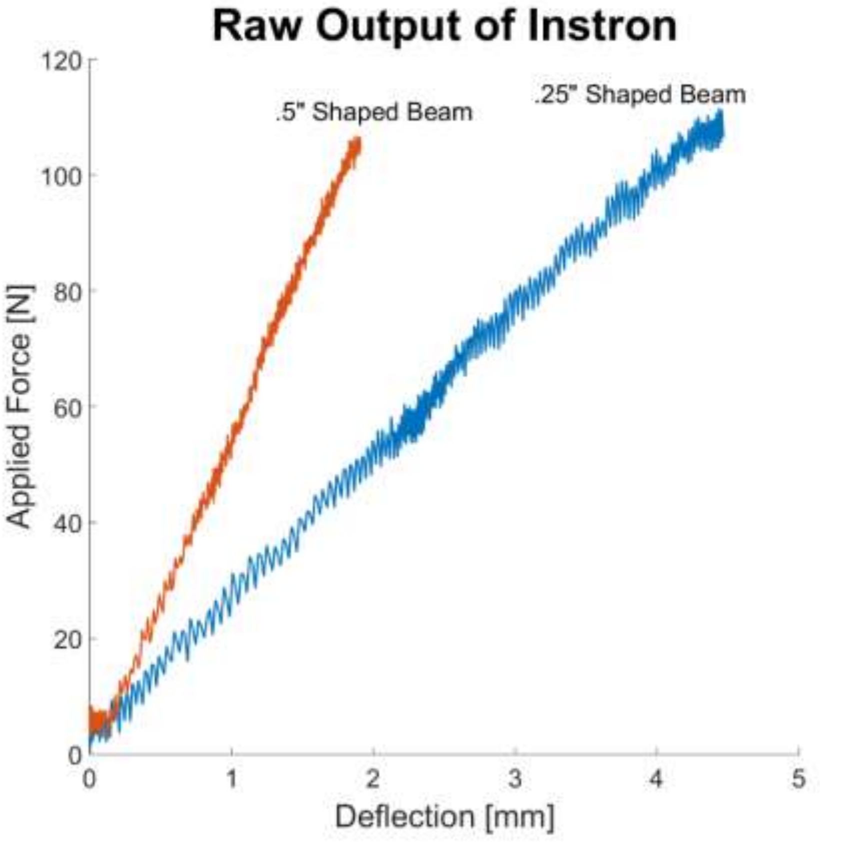
# Composite Beam Tests

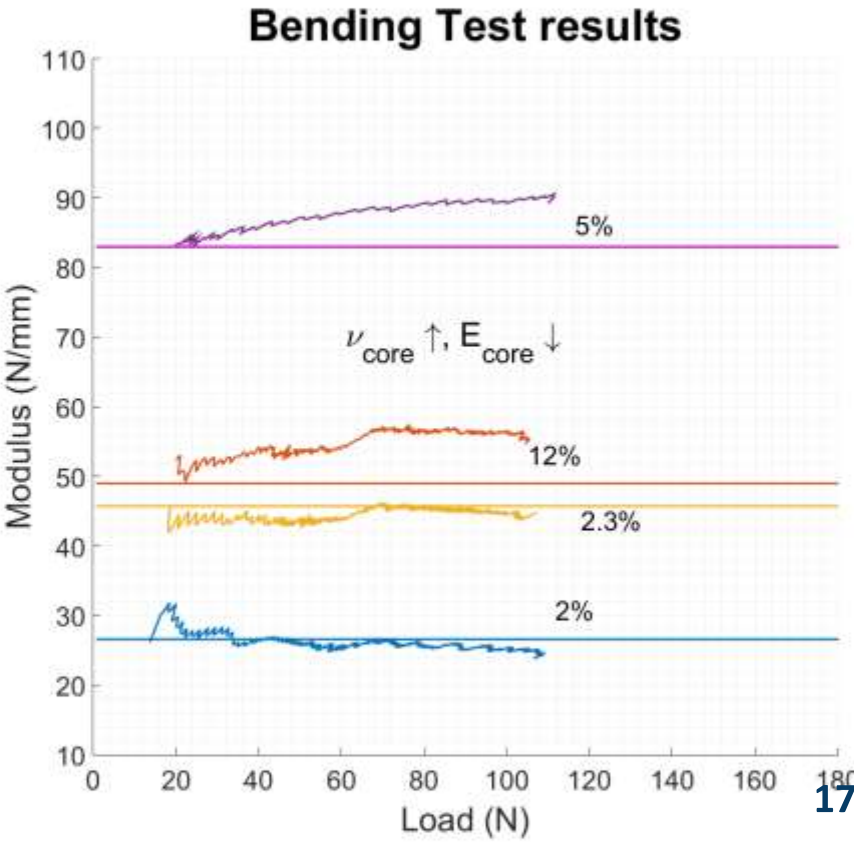


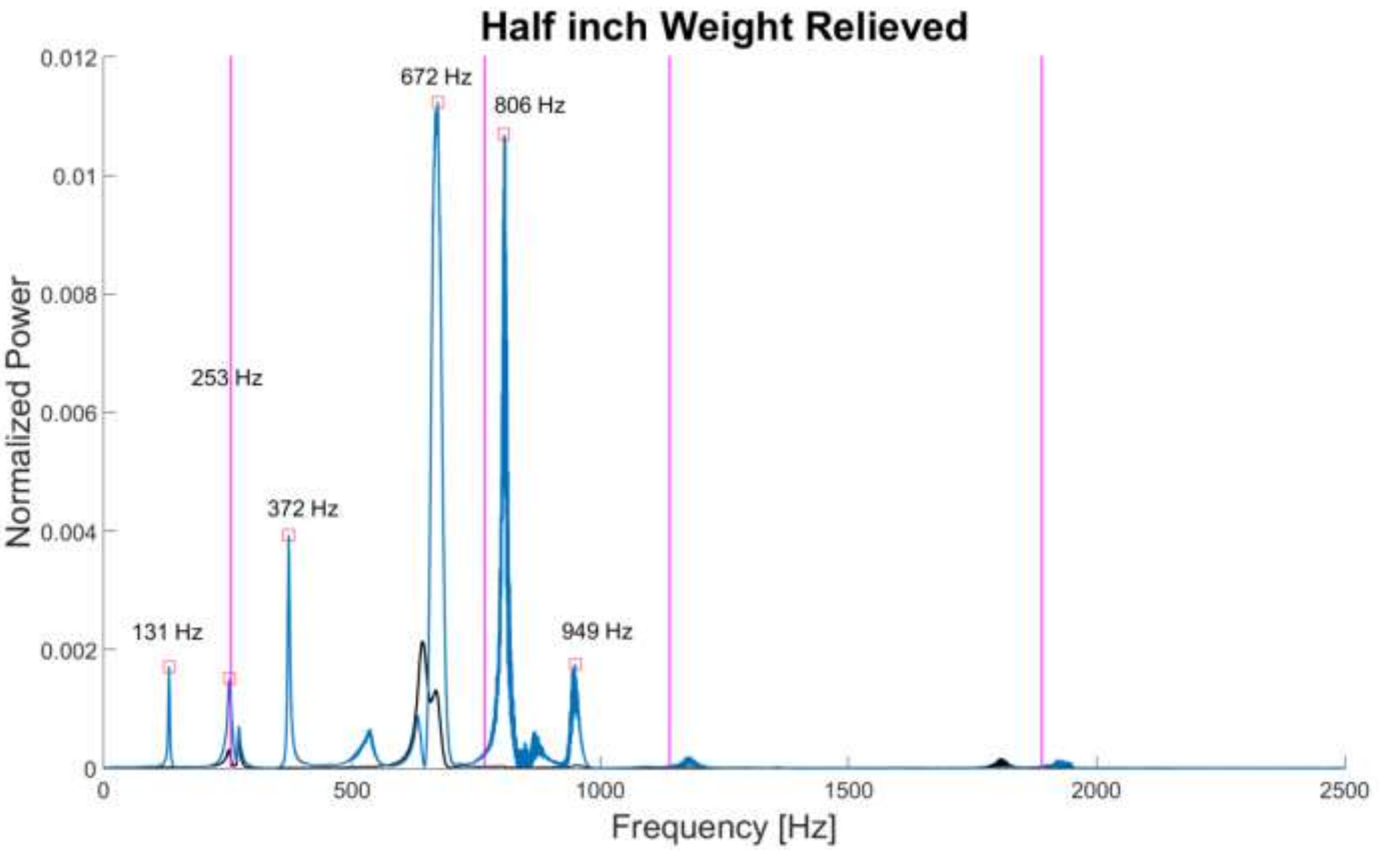




# Composite Beam Tests (cont)

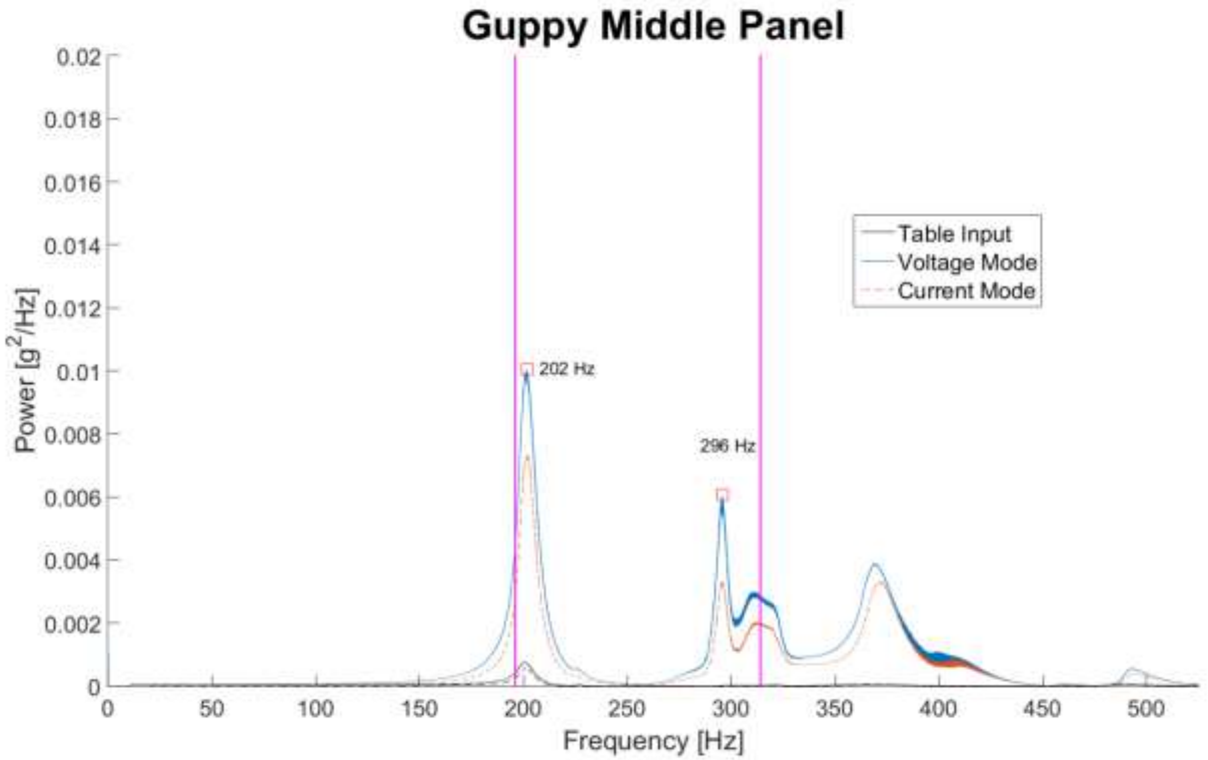


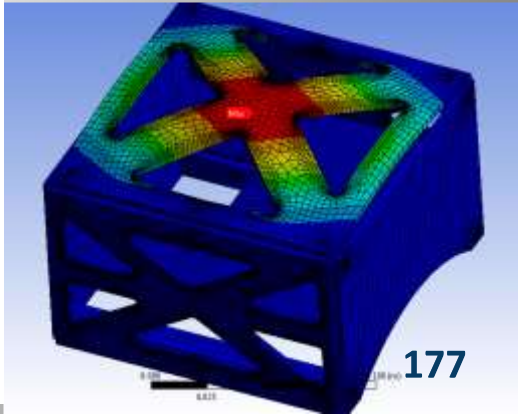



# Composite Beam Tests



# GUPPY Vibration Test



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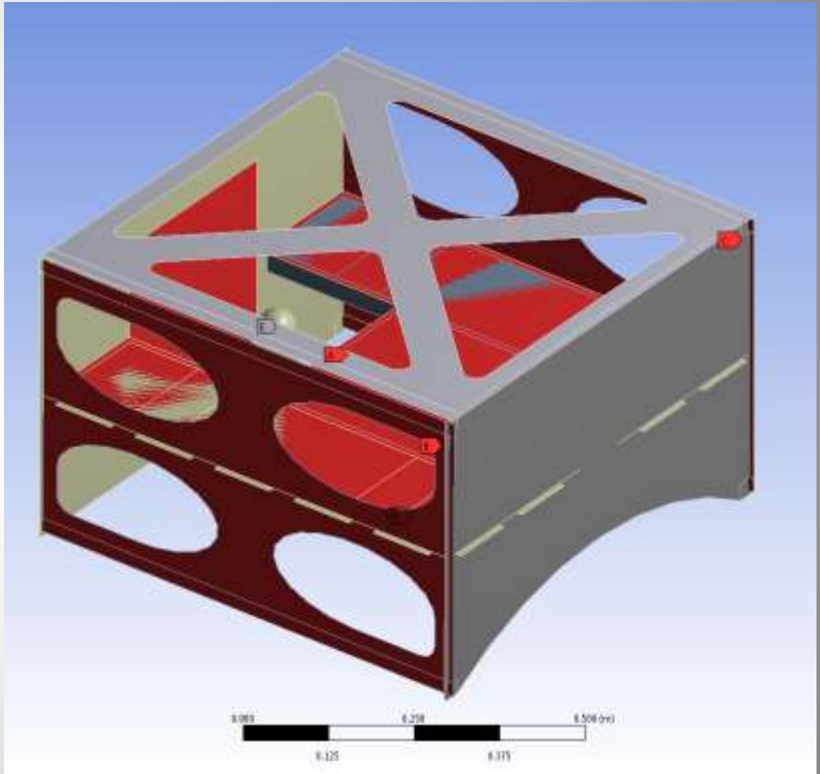
# Adhesive Small Scale Testing Analysis:

- Assumptions in calculations
  - 25% available area effectively adhered
  - Quasi-static load of 1g + 4σ = 6.16 g (σ = 1.29 grms vibration experienced)
- Because vibration will occur in all three axis, the same strength is required in shear and tensile modes

| Component: | Mass: | Quasi-static load: | 25 % of Available Area: | Required Strength: | Minimum Glue Strength: | Percent Margin: |
|---|---|---|---|---|---|---|
| Payload | 45 kg | 2719 N | 0.12 $m^2$ | 23.4 kPa | 841 kPa | 97% |
| COMM | 10 kg | 604.3 N | 0.026 $m^2$ | 94.2 kPa | 841 kPa | 89% |
| Solar Panel | 2 kg | 121 N | 0.051 $m^2$ | 2.39 kPa | 841 kPa | 99% |

# ANSYS Loads and Contacts:

- Solar Panels act as distributed masses
  - 6kg
- Components modeled as:
  - Design model
    - Distributed & Point masses
    - 32kg Avionics
    - 45kg Payload
  - Test model
    - Distributed avionics mass
    - Aluminum blocks – Payload



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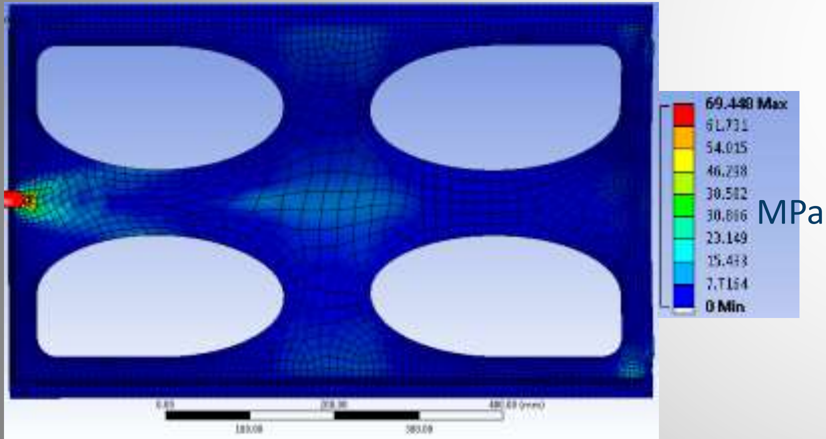
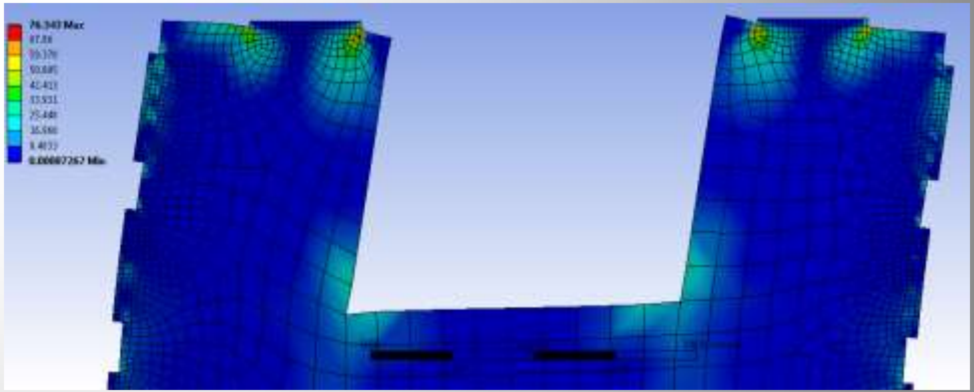
# Port/Starboard Acceleration:

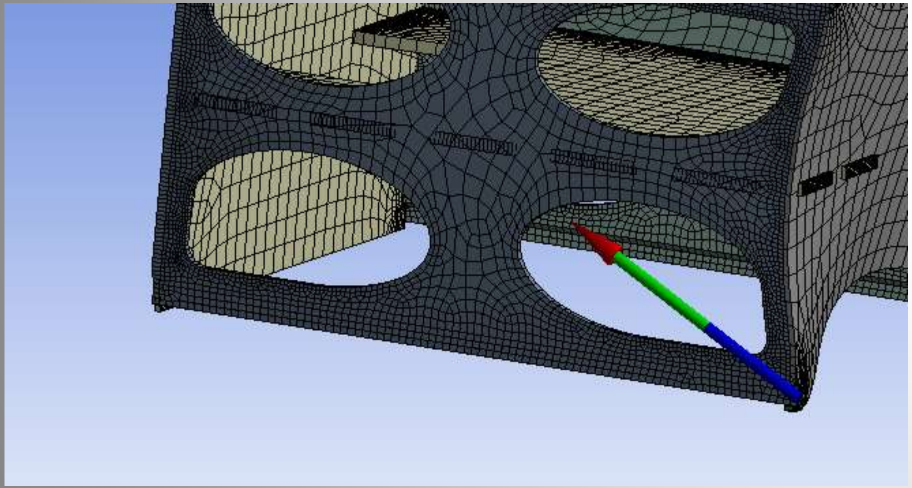
- Largest concern: Delamination of panels from column interface:
- ~3kN distributed along both strips
  - Testing necessary

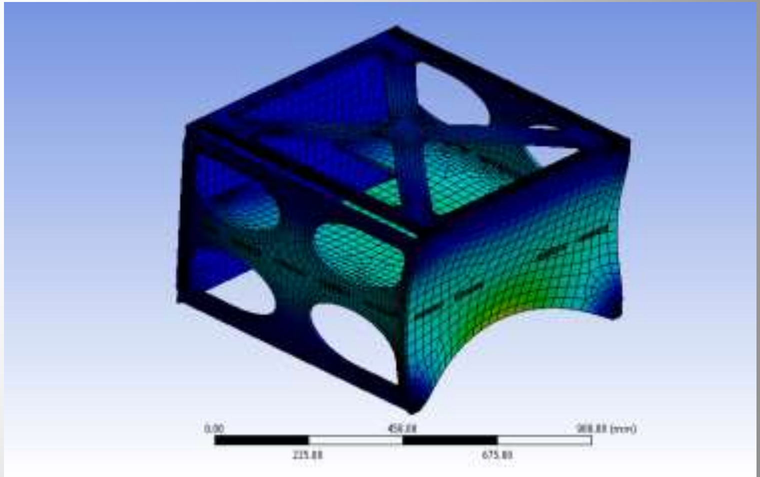


# Ram/Wake Acceleration:

- Largest danger on Bolted column interface
- 1.9kN in normal force





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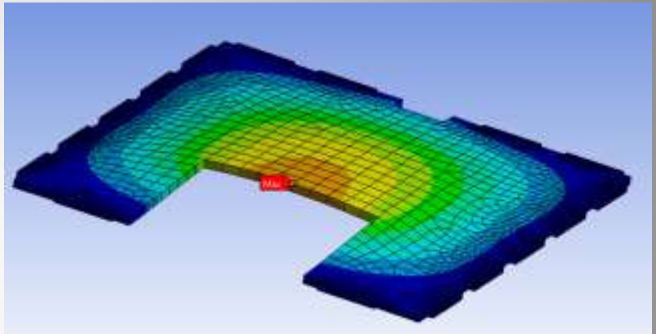
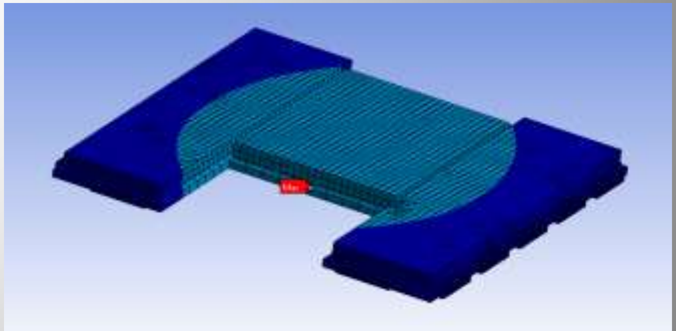
# ANSYS Loading:

## 2 Models -

- Design case – worst case loading to ensure structural strength
  - Panel allowed to flex
- Testing case – same loading case as will be used in test
  - Panel stiffened by dummy masses

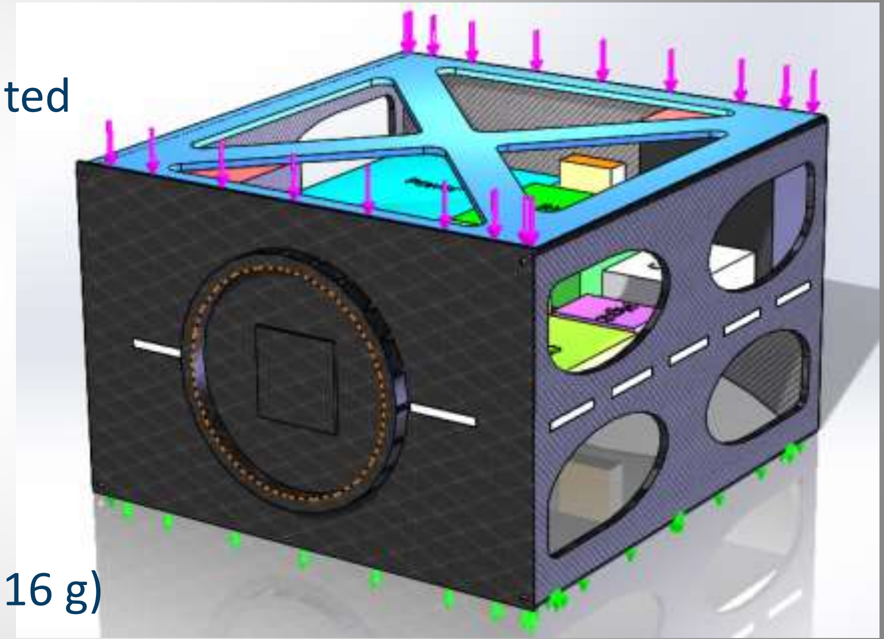
View of middle panel: deformations are **exaggerated**





# Load Cases

- Assumptions
  - Payload and Avionics mass is distributed on Middle Panel
- Launch Configuration
  - Holding straps
  - Foam Dampeners
- Static equivalent Stress analysis
  - Equivalent load of 5.1 kN (84 kg @ 6.16 g)
  - Consider acceleration in X, Y, Z
  - Major modes of vibration act on structure



Start

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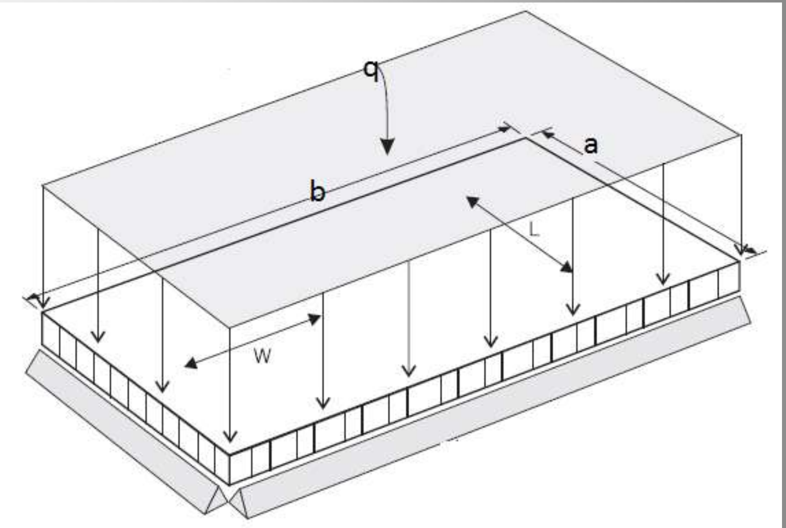
# Honeycomb

- **Assumptions**
  - Middle Plate is loaded in simply supported configuration
  - Factor of Safety 1.9 applied to material strengths

  - Allowable strengths of Epoxy Woven Fabric
    - $\sigma_u$ = 750 MPa ultimate along fiber
    - $\sigma_y$ = 79 MPa transverse yield
  - Modulus in fiber direction
    - E = 65 GPa

  - Allowable strengths of Aluminum Core (5056)
    - $\sigma_c$ = 4.7 MPa compression strength
    - $\tau_w$ = 1.7 MPa plate shear (w direction)
  - Modulus
    - $E_w$ = 193 MPa in w direction
    - $E_l$ = 483 MPa in L direction

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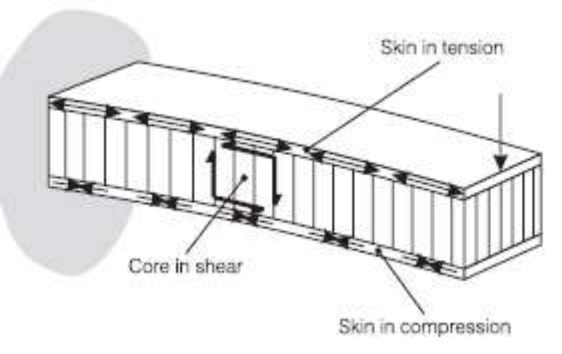
# Honeycomb Analysis

| Middle Panel | Value | Margin Above FOS |
|---|---|---|
| Deflection at center | 4 mm | n/a |
| Facing Stress | 31.6 MPa | 1.49 |
| Core Shear | 0.17 MPa | big |
| Local Compression | 0.009 MPa | big |
| Principal in-plane stress | 31.6 MPa | 1.49 |
| Tab Shear | 39.7 MPa | 0.99 |
| Tab Buckling Limit | 0.6 MPa | 11 |
| Shear Crimping | 13 MPa | big |
| Skin Wrinkling | 1.3 GPa | n/a |
| Intra-cell Buckling | 1.1 GPa | n/a |




Start

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# Fasteners

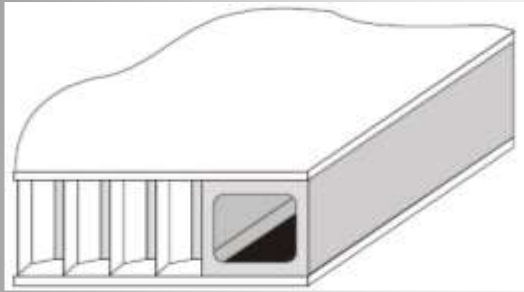
- Assumptions
  - Factor of Safety 1.9 on ultimate
  - Low profile Hardened Alloy Steel 10-32 thread
  - Tensile Ultimate strength 1 GPa
  - Installed with thread locking compound (Locktite)

- Loading Considered
  - Combination of shear and normal stresses
  - Pre-load due to Installation Torque of 30 in-lb

```
σaf = 999.7 * 10 ^ 6 / fs(*526 MPa - Normal allowable strength of hardened steel alloy*)
5.26158 × 10^8

k = 0.5; (*Ratio of allowable shear to normal strenghts*)

τaf = k * σaf(*263 MPa - Shear Allowable strength of hardened steel alloy*)
2.63079 × 10^8

af = 0.0187045 * 0.0254 ^ 2 (*m^2 - Cross sectional area of minor diameter*)
0.0000120674

σf = (F1 / 4) / af(*Pa - Normal Stress*)
1.05161 × 10^8

τf = (F1 / 4) / af;(*Pa - Shear Stress*)

σmaxf = σf / 2 + ((σf / 2) ^ 2 + τf ^ 2) ^ 0.5(*Pa - Principal Stress*)
1.70154 × 10^8

Mtf = σaf / σmaxf - 1(*Margin on Principal Stress*)
2.09224

τmaxf = ((σf / 2) ^ 2 + τf ^ 2) ^ 0.5(*Pa - Principal Shear*)
1.17574 × 10^8

Msf = τaf / τmaxf - 1(*Margin on Principal Shear*)
1.23756
```

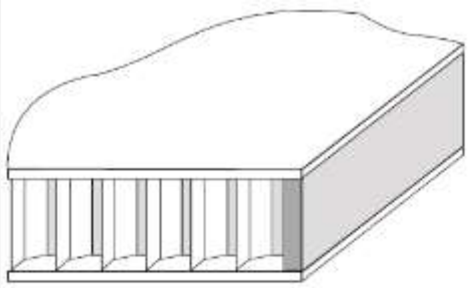
# EDGE CLOSE OUT:

## Box Extrusion Method - Tabs:



- Use end mill or router table with a fly cutter to clear core
- Used where panels interface with columns

## Epoxy Fill In Method– Where Core in Exposed:



- Use block to push core back from edge
- Fill with Hysol EA-9321

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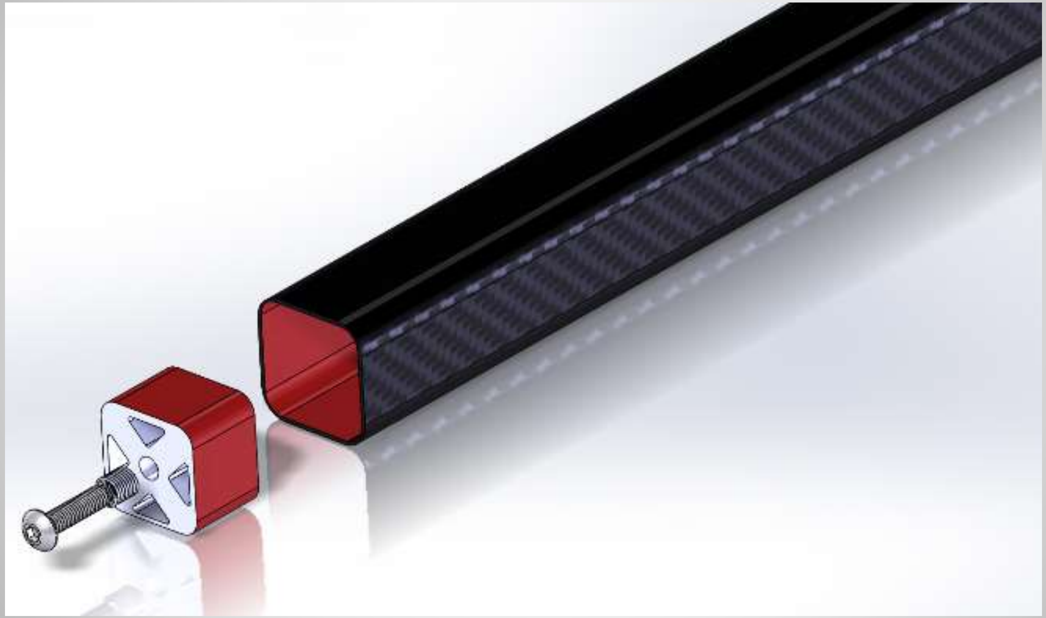
# Scotch Weld 3350:

- Epoxy Paste Adhesive
- Potting Heritage
- Testing will be done to determine effectiveness of Scotch Weld 3350 ScotchWeld EC-2216 bond

# Tube Inserts:



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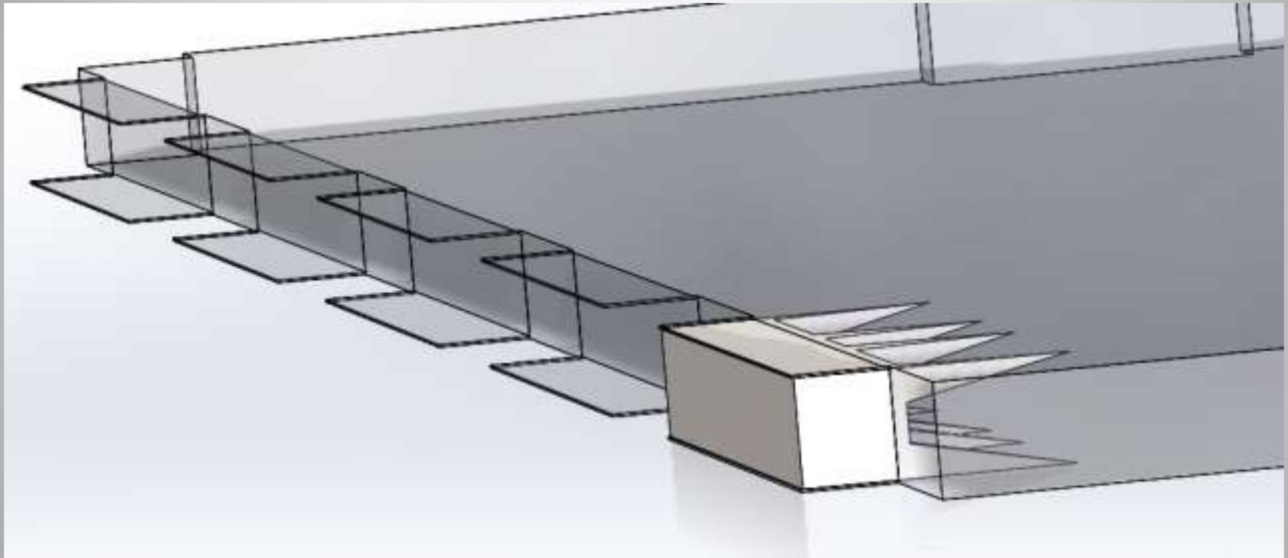
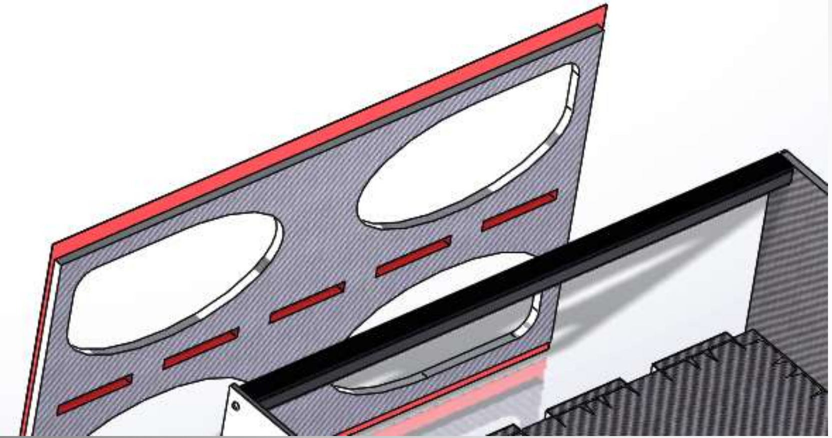
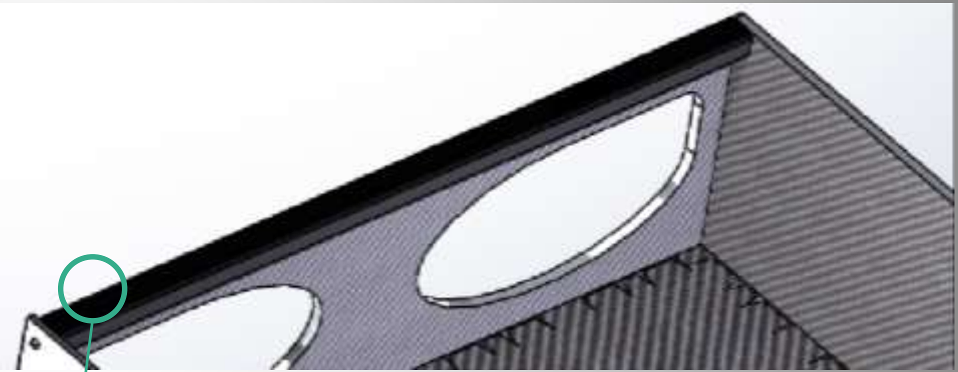
# Tab Inserts:



# Column-Side

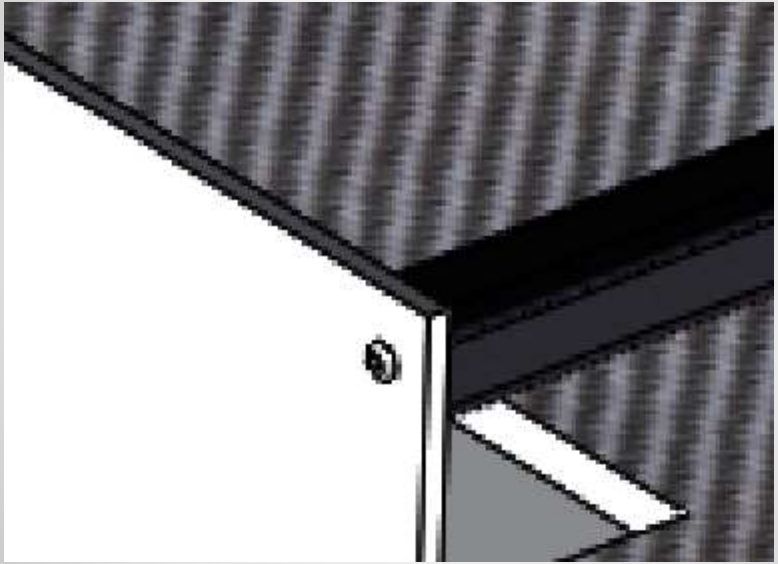


Before Bonding



After Bonding

# Column – Propulsion Plate and Radiator



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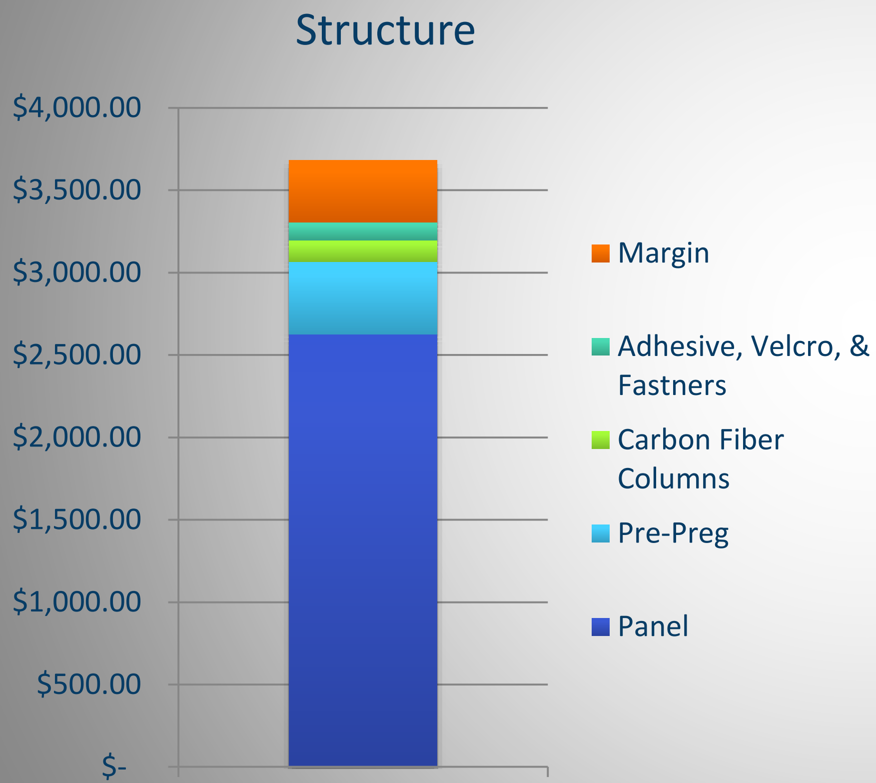
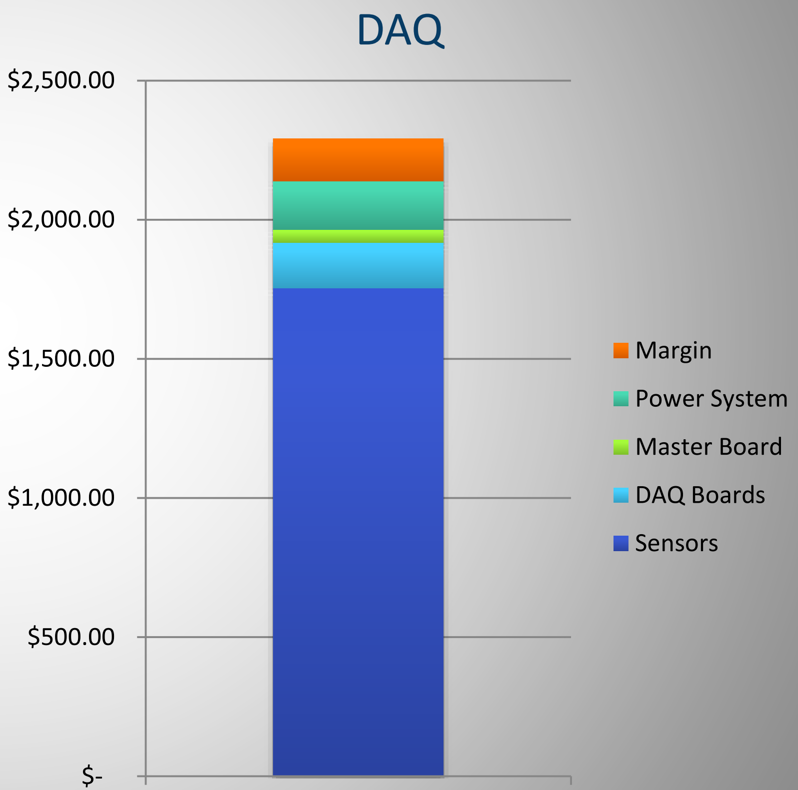
# Cost Plan – Subsystem Budgets:

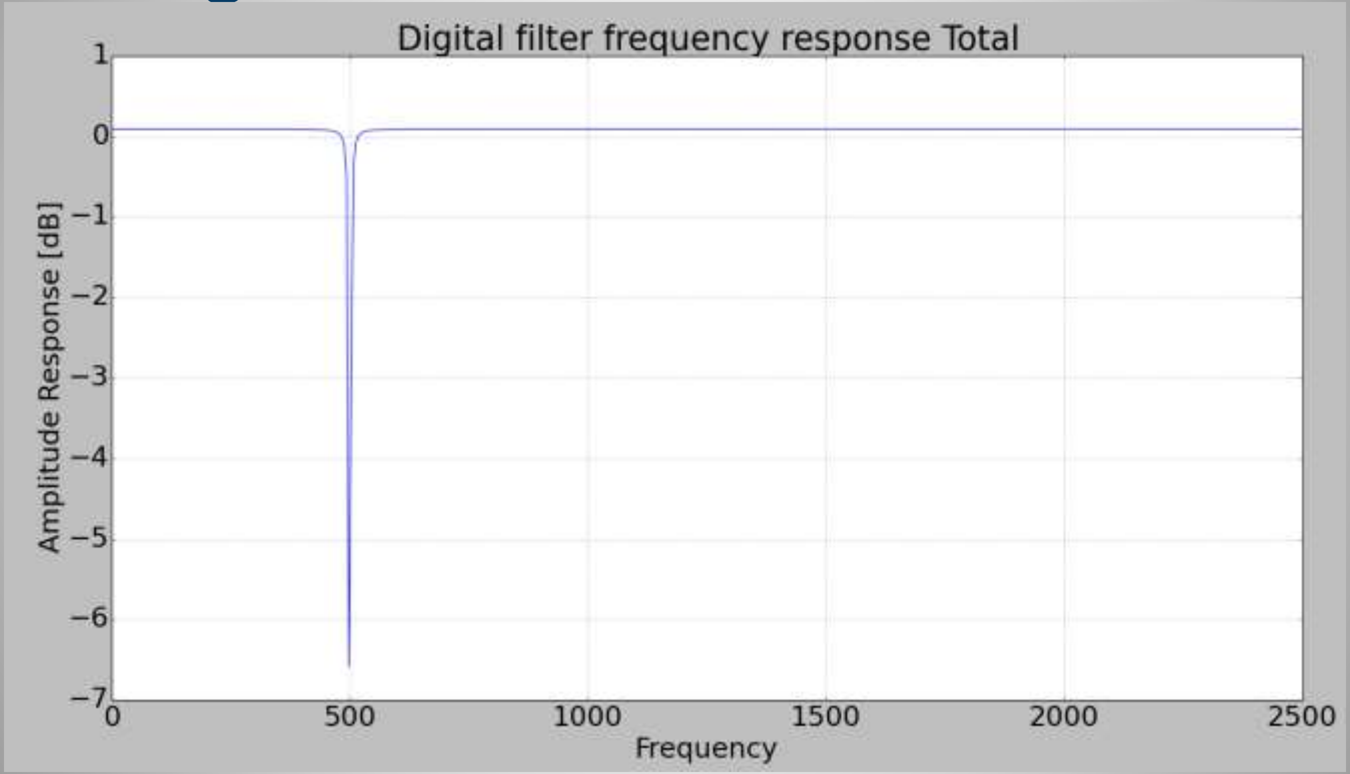


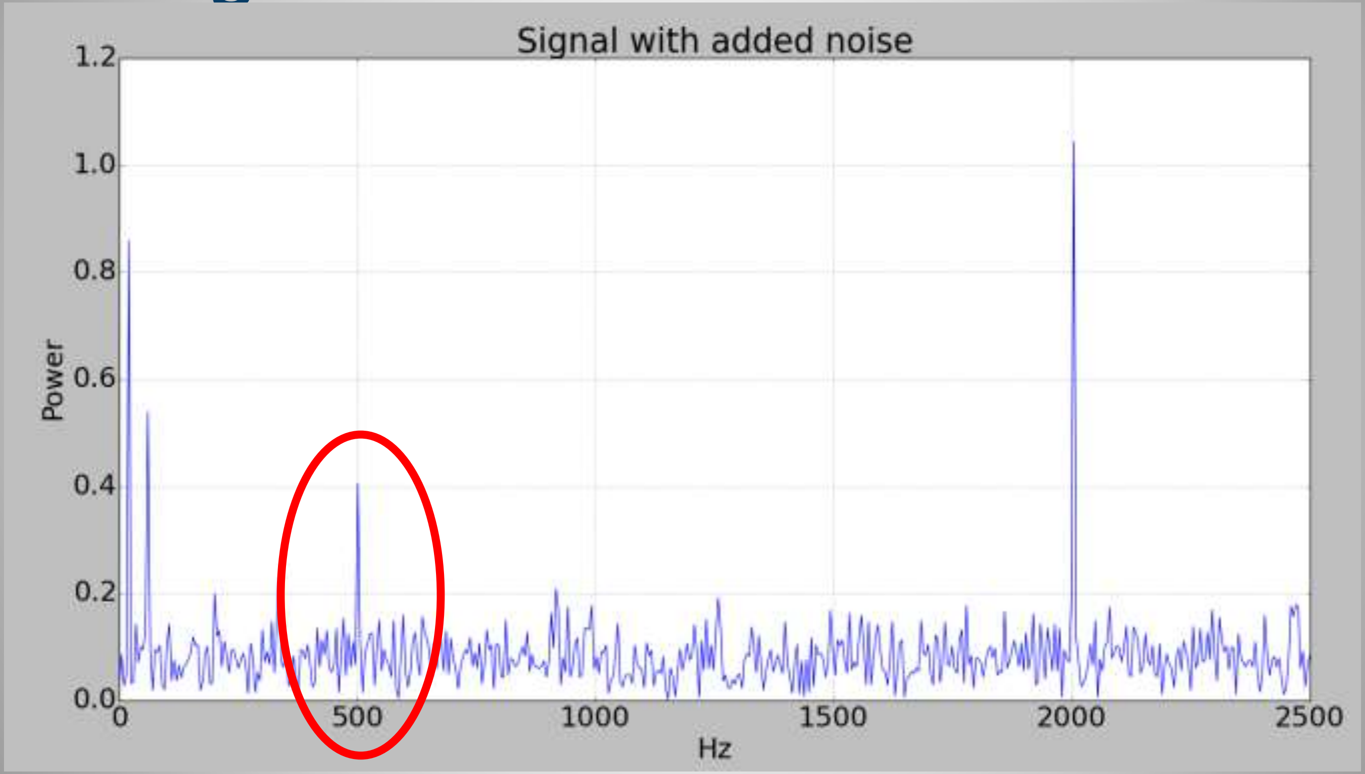
# Uncertainties and Margin Breakdown

- DAQ:
  - PCB – need multiple attempts at printing ($33.00)
  - Extra parts – redundancy
    - Coax Connectors – design cycle:
      - Choosing -> validating design -> re-choosing
- Structure:
  - Free Aluminum Core
  - Adhesive Reliability
  - Free and available mass analogs

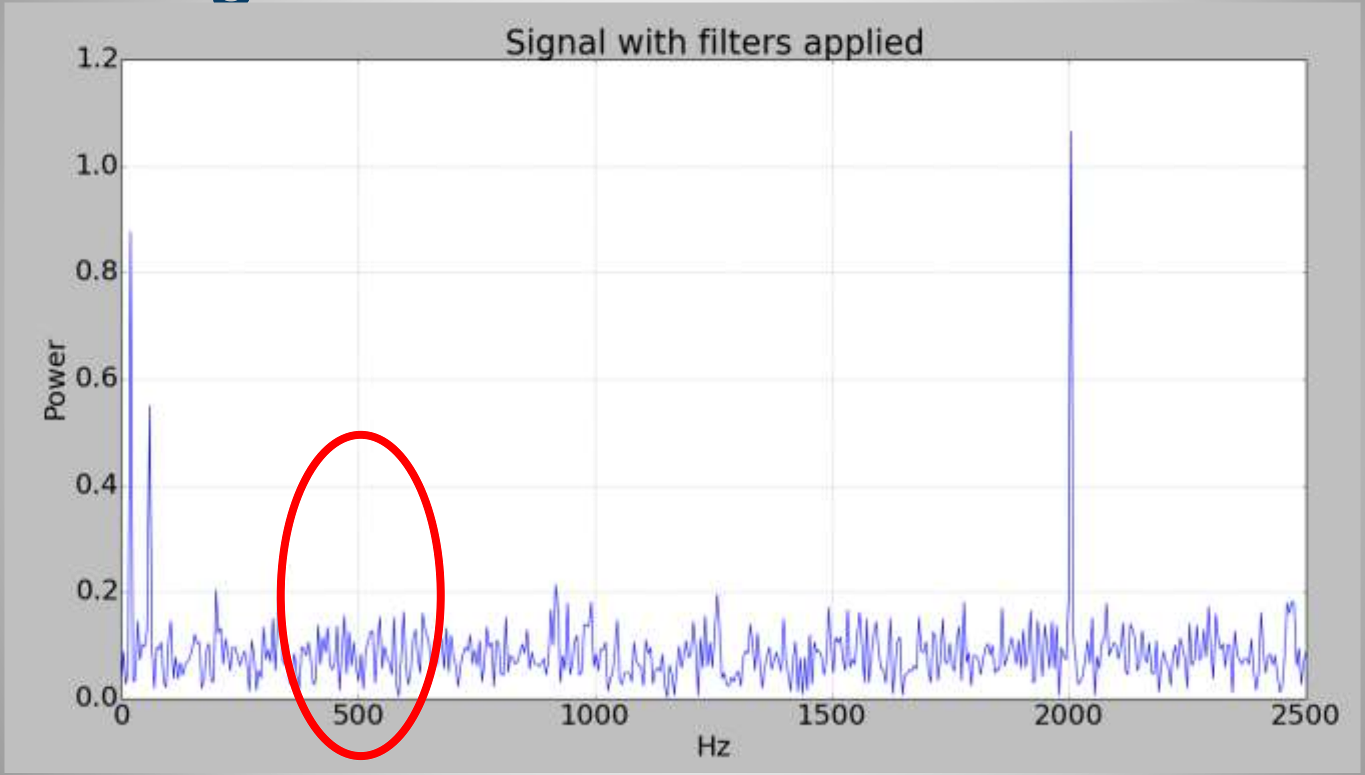
# Software: Digital Filter Demo



# Software: Digital Filter Demo



# Software: Digital Filter Demo



# Software: Filtering

- Infinite Impulse Response (IIR) Digital Notch Filters
- Transfer Function:

$$H(z) = \frac{1 - 2\cos(\omega_0)z^{-1} + z^{-2}}{1 - 2r\cos(\omega_0)z^{-1} + r^2 z^{-2}}$$

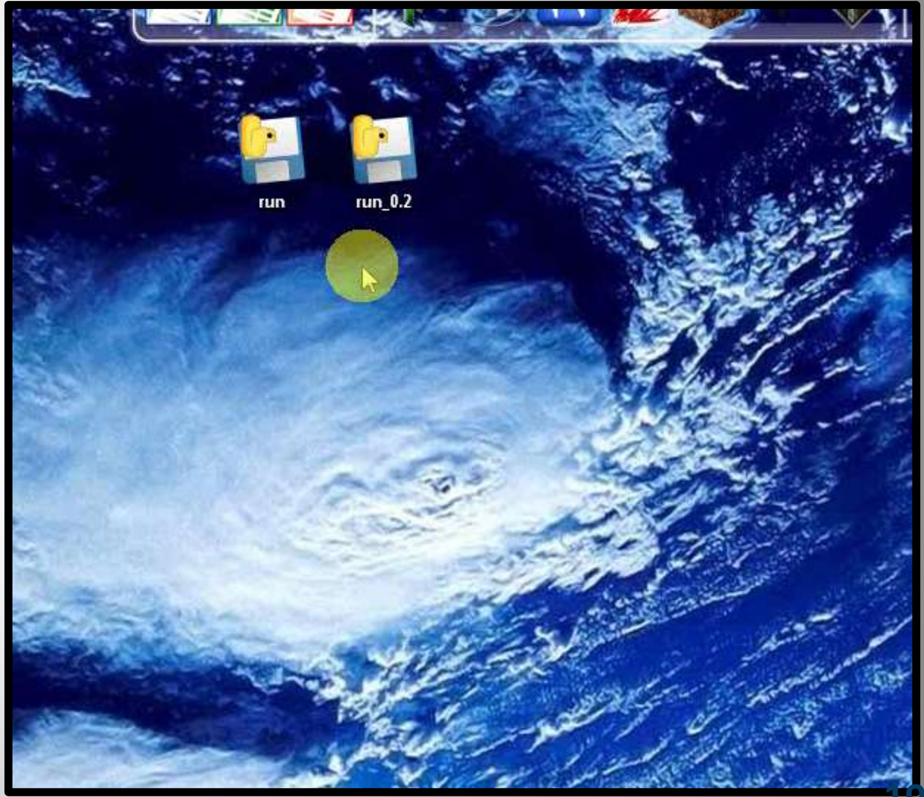
Where:

$\omega_0$ = Notch Frequency

$r$ = Order coefficient (0.99)

# Software: Executable Development

- Basic GUI created and converted to .exe
- Tested on various team computers
- All modules included



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# Software: Data and Report Output

- Excel module tested
- Data size too large for raw data in Excel
- Raw data will be saved as .csv and plots exported to Excel

| Sample Rate [Hz] | Test Duration [s] | Data Points [million] | Data Size [MB] |
|---|---|---|---|
| 5000 | 60 | 19.2 | 38.4 |
| 16000 | 60 | 61.44 | 122.88 |
| 32000 | 60 | 122.88 | 245.76 |

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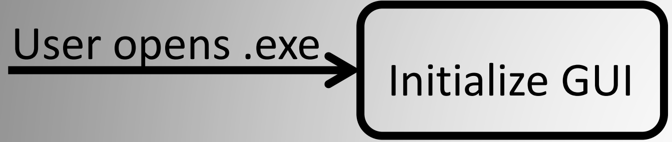
# Software: GUI Structure




## GUI Menu Structure

File:
- Save
- Save As
- Reset Test
- Start Test
- Stop Test
- Exit

Configure:
- Wizard
- Test
- Report
- Filtering
- Calibration

Help:
- About
- FAQ
- Tutorials

Buttons:

Reset | Start | Stop

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# Software: Saved Report Format

Tabs:
- Configuration
- Raw Data
- Filtered PSD Data
- PSD Plots 1 – Channel #
- Raw Plots 1 – Channel #

Filtered PSD Data Header:

Frequency [Hz] | Channel # Value [$g^2$] | ... | Channel # Value [$g^2$]

Raw Data Tab Header:

Time | Channel # Value [V] | ... | Channel # Value [V]

Configuration Tab:
- Date/Time
- Serial Port Used
- Sample Rate
- Version Info

Channels 1 - #:
- Name
- Calibration
- Warning/Alarm Limits
- Max-min values

Frequency:
- Filters
- Max-min values
- Warning/Alarm Limits

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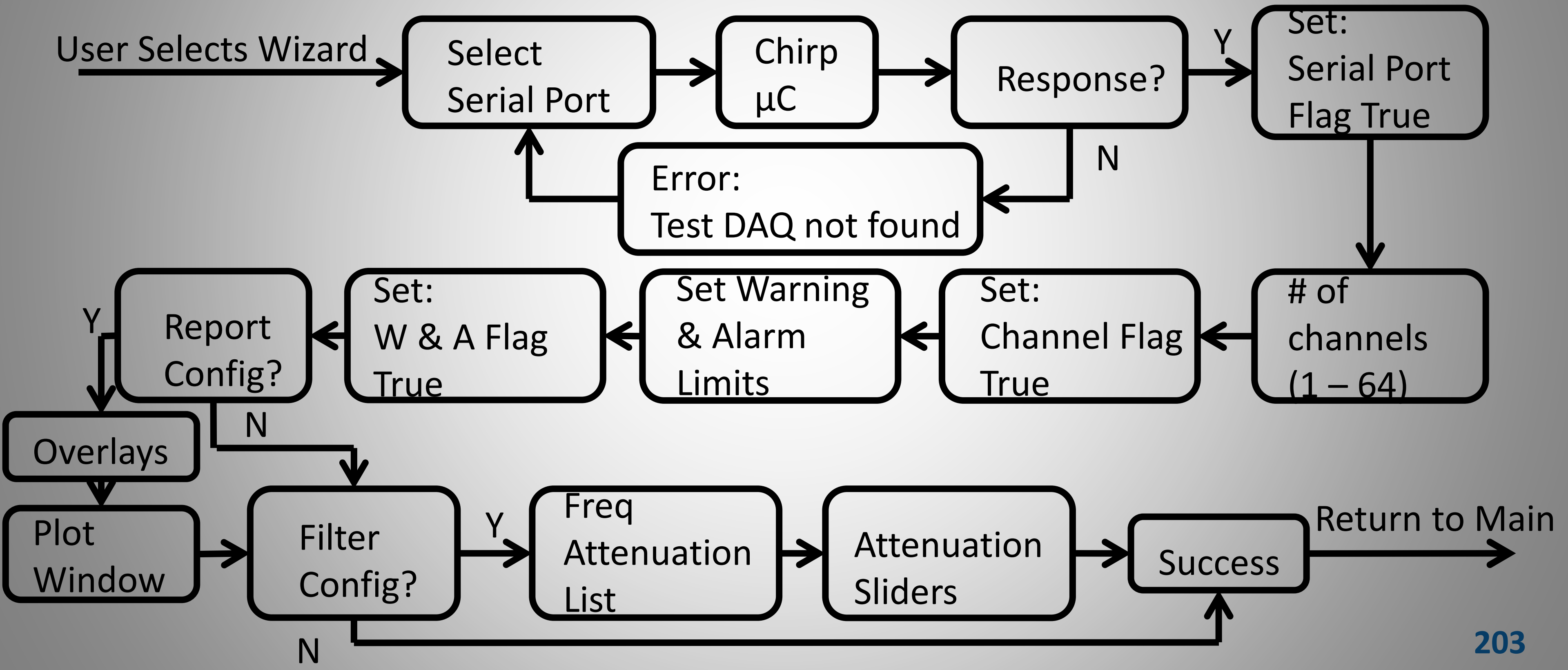
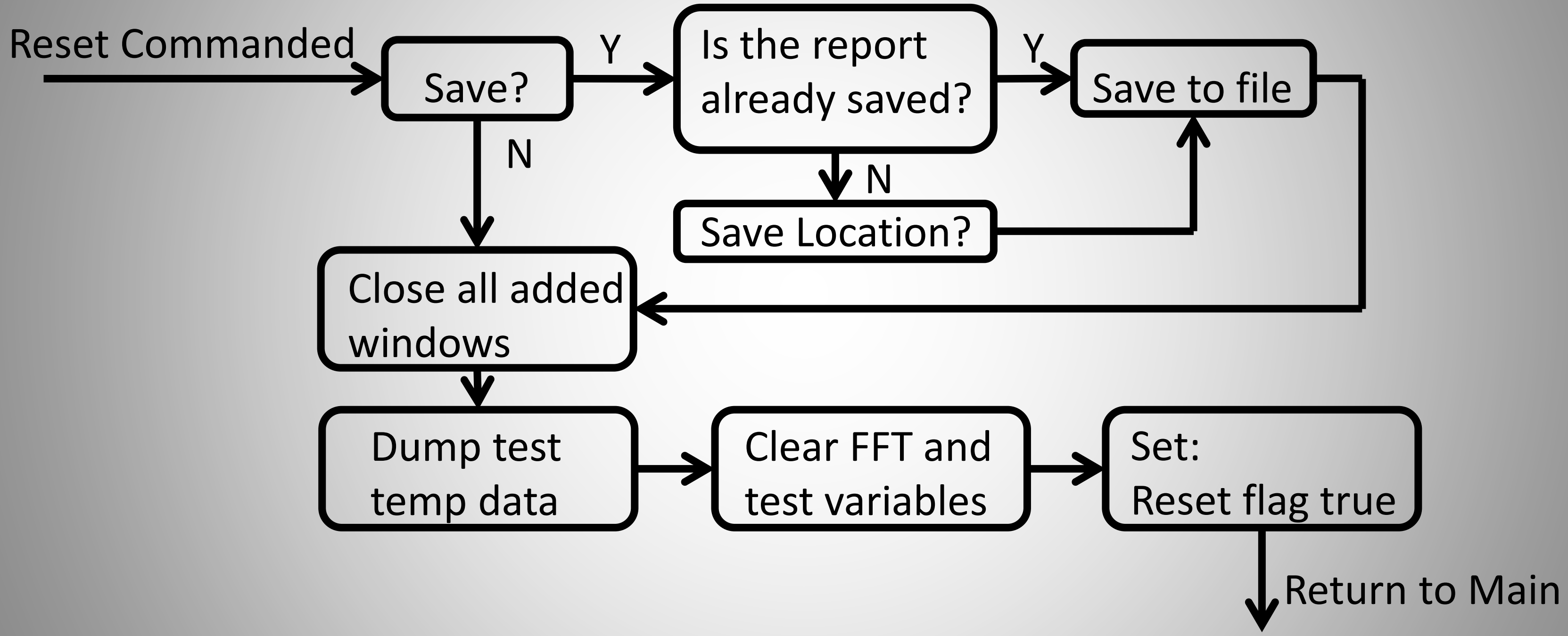
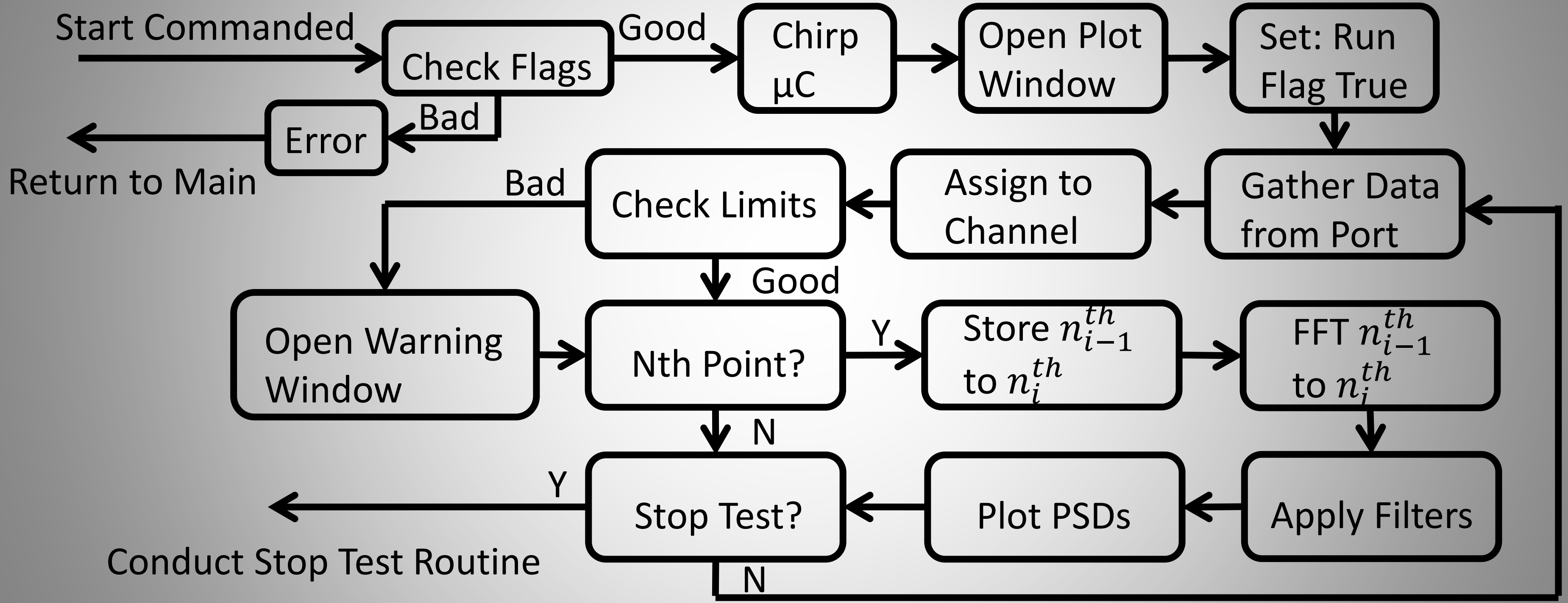
# Software: Configure Wizard



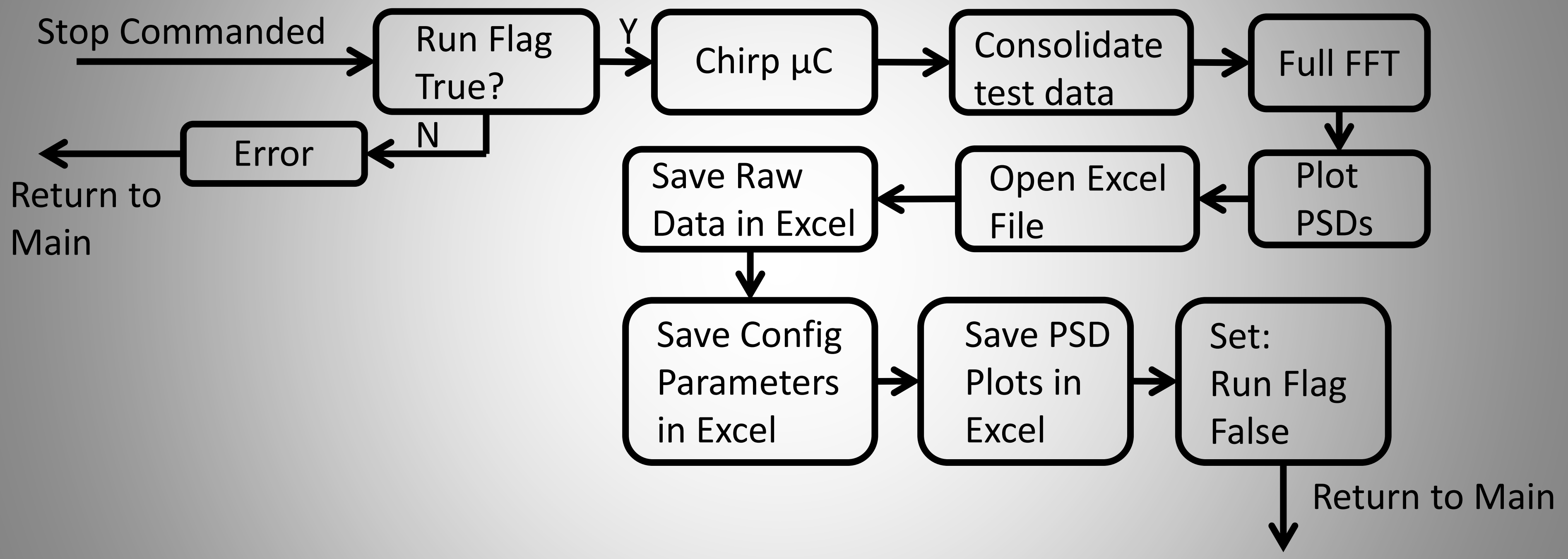
# Software: Reset Test



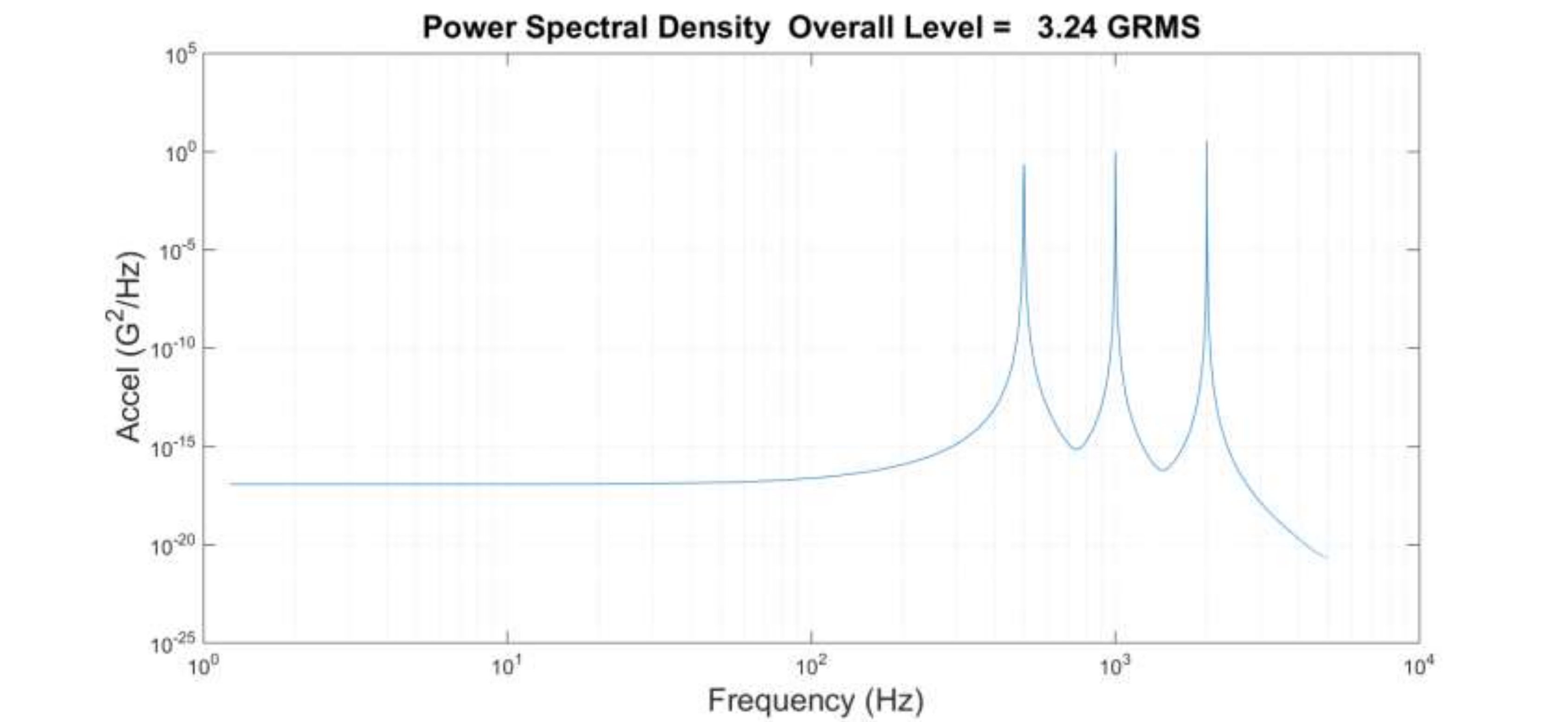
# Software: Start Test



# Software: Stop Test

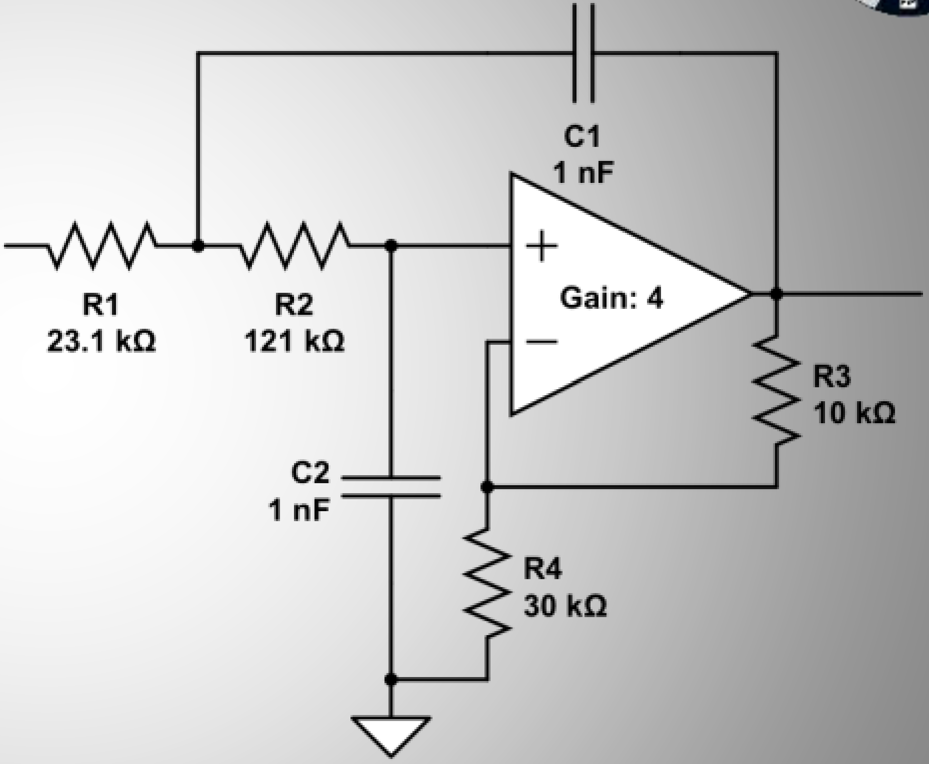


# Software: Power Spectral Density

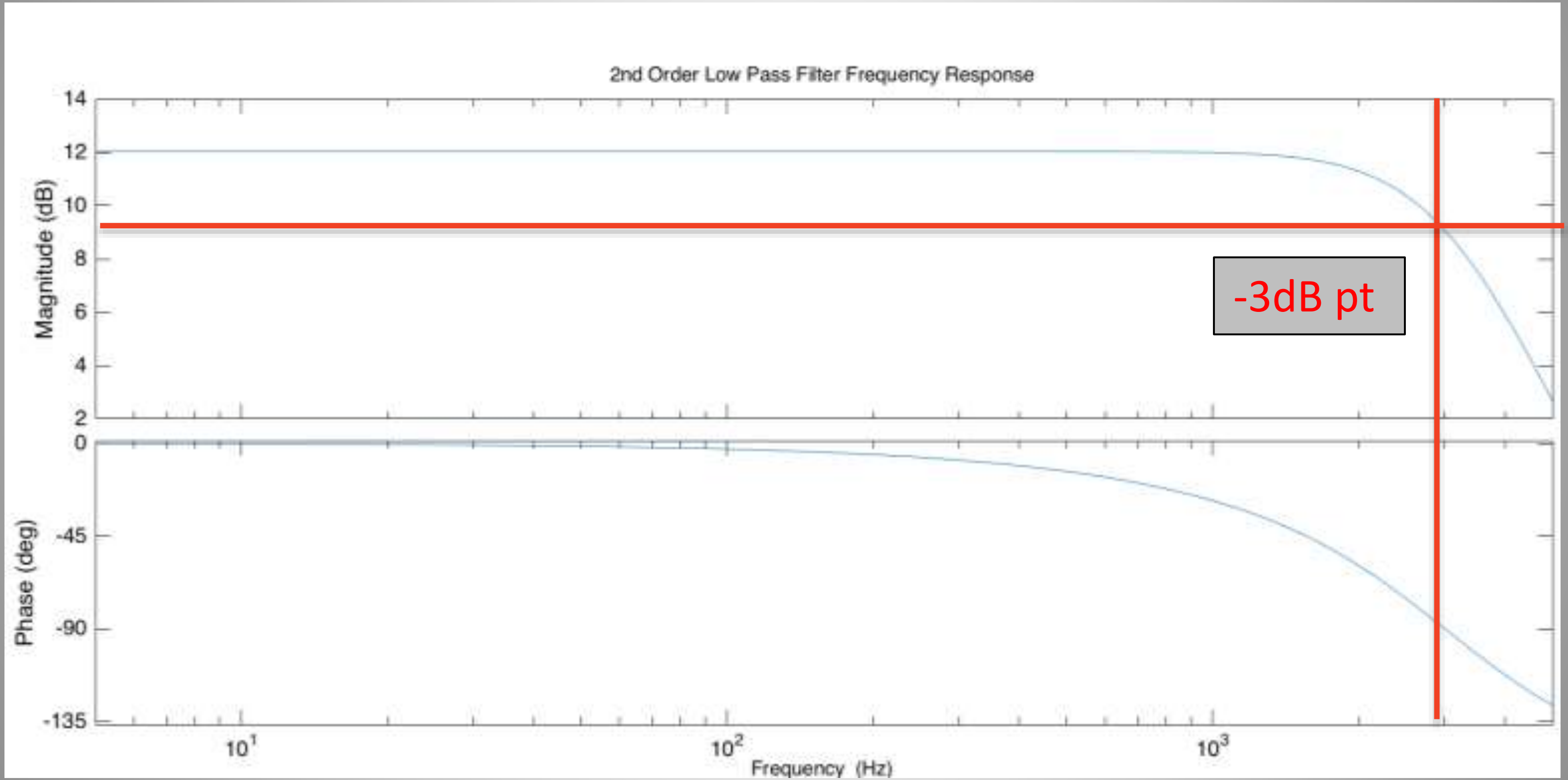


# Data Acquisition Board: Low Pass Filter

- Anti-aliasing
- Amplification: 4x
- $F_{cutoff}$ = 3000 Hz
- 4 circuit op-amp



# Low Pass Filter – Frequency Response Curve

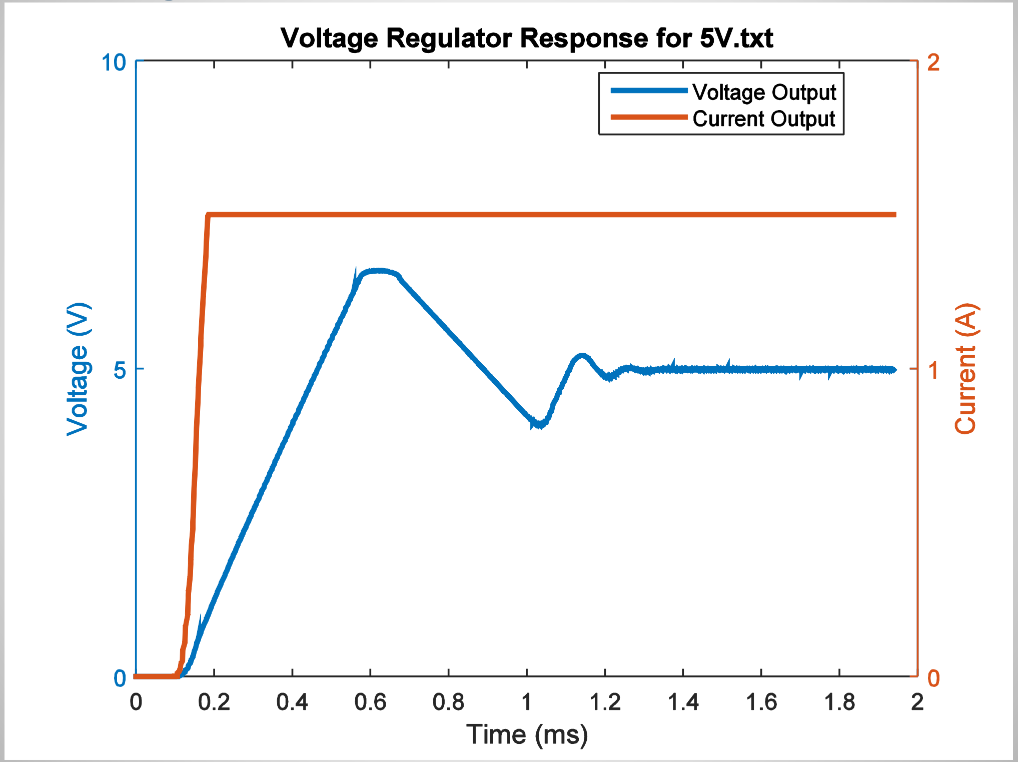


# Analog to Digital Converter: AD7606

- 16 bit A/D conversion
- 10V range (-5V to 5V)
  - Voltage resolution of 0.1526 mV/bit ($10V/2^{16}$)
  - Accelerometers have 100mv/g
  - g resolution of 0.001526g/bit

- 1 A/D converter per accelerometer meaning:
  - 8 A/D for our constructed DAQ
  - 64 A/D for our designed DAQ
    - Software written can handle 64 channels

# Power Section Spice Simulations 5V



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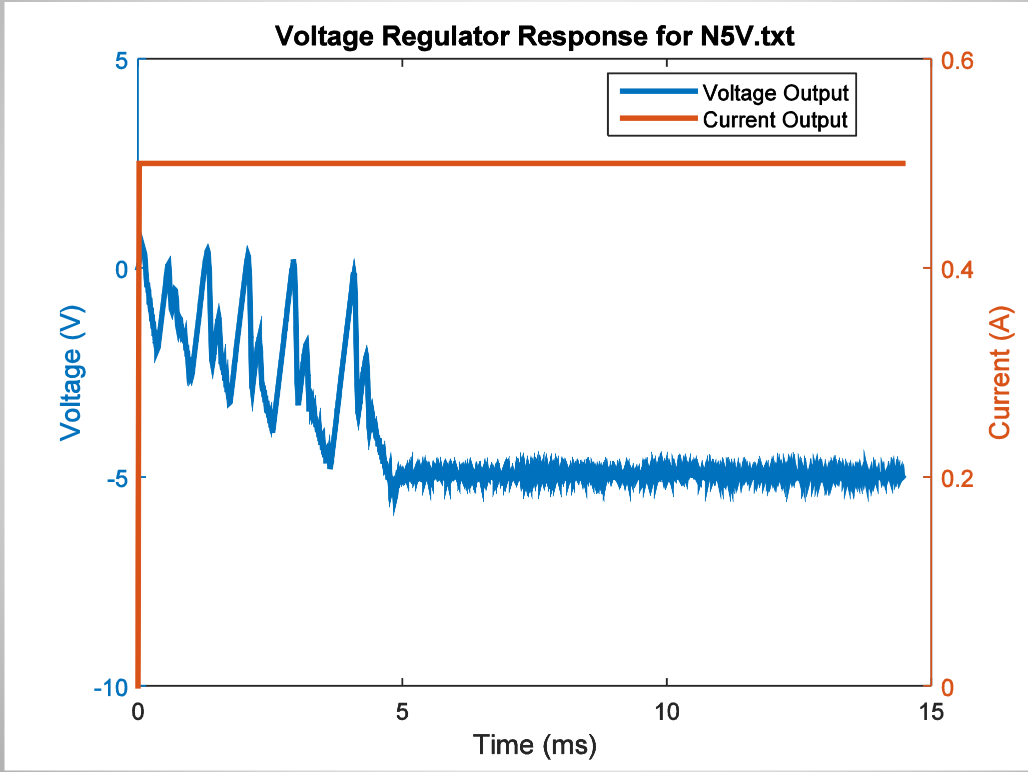
# Power Section Spice Simulations - 5V



# Power Section Spice Simulations - 3.3V