Test Readiness Review

FISH & CHIPS

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

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

Customer: Michael Brown

Advisor: Joe Tanner

OVERVIEW

Outline:

- **Project Overview**
- **Schedule**
- **Testing Status**
  - Testing Motivation
  - Test Procedure and Configuration
- **DAQ Status**
  - Final population of boards is complete
  - 100 hours of testing left
- **Structure Status**
  - Assembly successful so far
  - 20 hours left of assembly, 28 hours planned for test rehearsals
- **Budget**
  - $364.02 left and no further procurements planned

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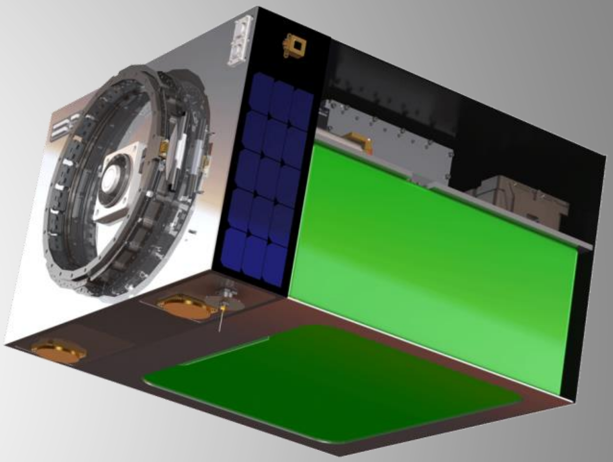
Project Motivation:

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

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

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



Surrey's FeatherCraft Illustration

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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.

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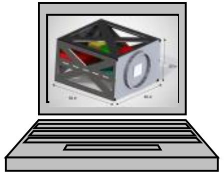
Levels of Success:

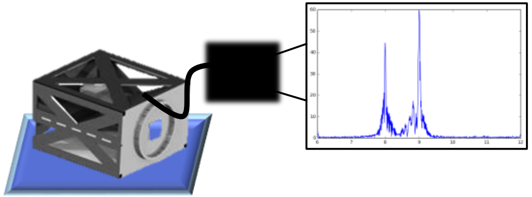
	Structure Design:	Vibration Testing:	Data Acquisition System:	Software:
Level 1	Design meets all physical requirements	Structural Test Model (STM) undergoes vibration test	Data can be collected for up to one hour	Saves CSVs for Excel analysis
Level 2	Design meets 50% reduction requirement	STM shows no failure		Software outputs PSD plots
Level 3		STM exhibits predicted modes within 10%	Real time PSD plotting	GUI allows control of test settings and analysis
	Completed	To be completed on 3/18	To be completed by 3/11	Completed

CON OPS:

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

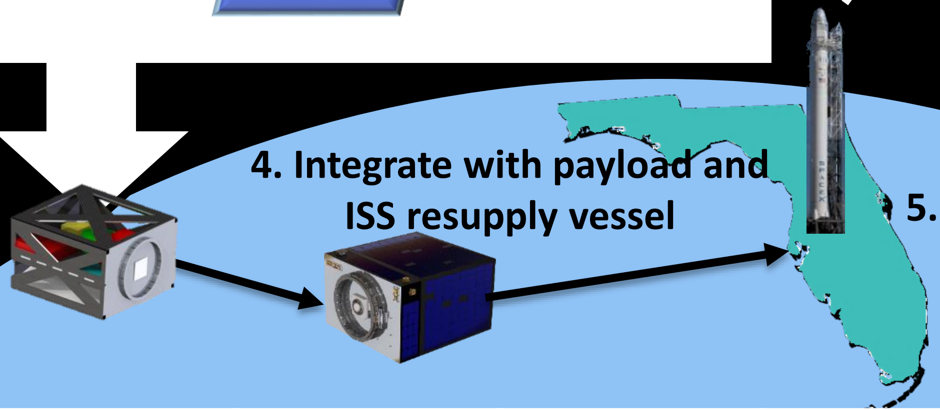


2. Perform vibration test and analyze accelerometer data



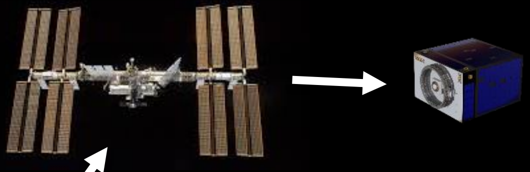
3. Final testing and integration with avionics and other bus components

4. Integrate with payload and ISS resupply vessel



5. Launch to ISS

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



7. Possible Orbit Raising Maneuver and 5 year mission lifetime

CPEs:

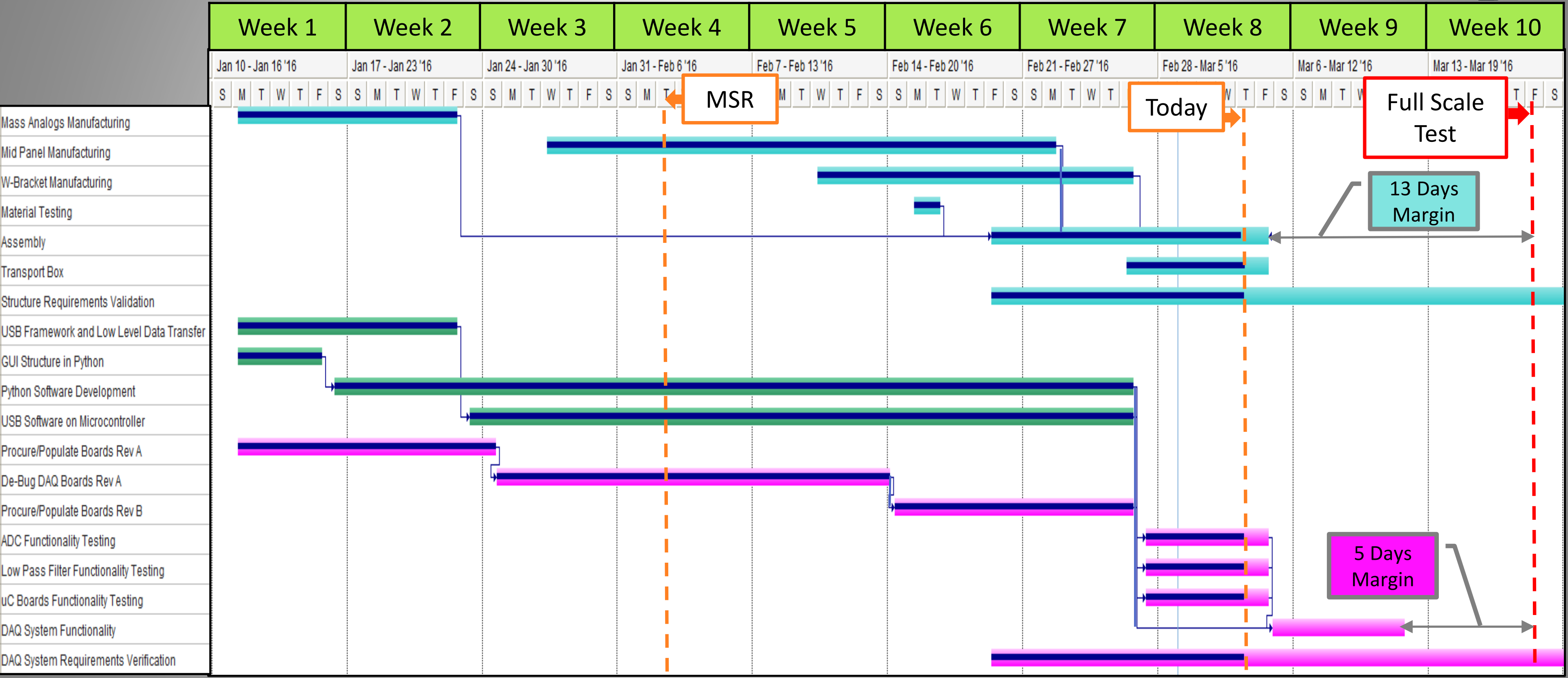
Critical Project Element	Testing Tasks
Mass of structure below **5 kg** while **surviving launch** to the ISS (FR 1 and DR 3.1)	- Composite and adhesive testing complete - Preparing for final vibration test
Support of up to **60 accelerometer** channels in DAQ system (DR 5.6.1.1)	- Functionality testing each component - Preparing for ITLL DAQ Comparison test

Other CPEs (time and cost of material and vibration test) no longer as critical

SCHEDULE

Schedule:

- Structure	- DAQ Software
- DAQ Hardware	- Percent Complete



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Schedule:

- Structure	- DAQ Software
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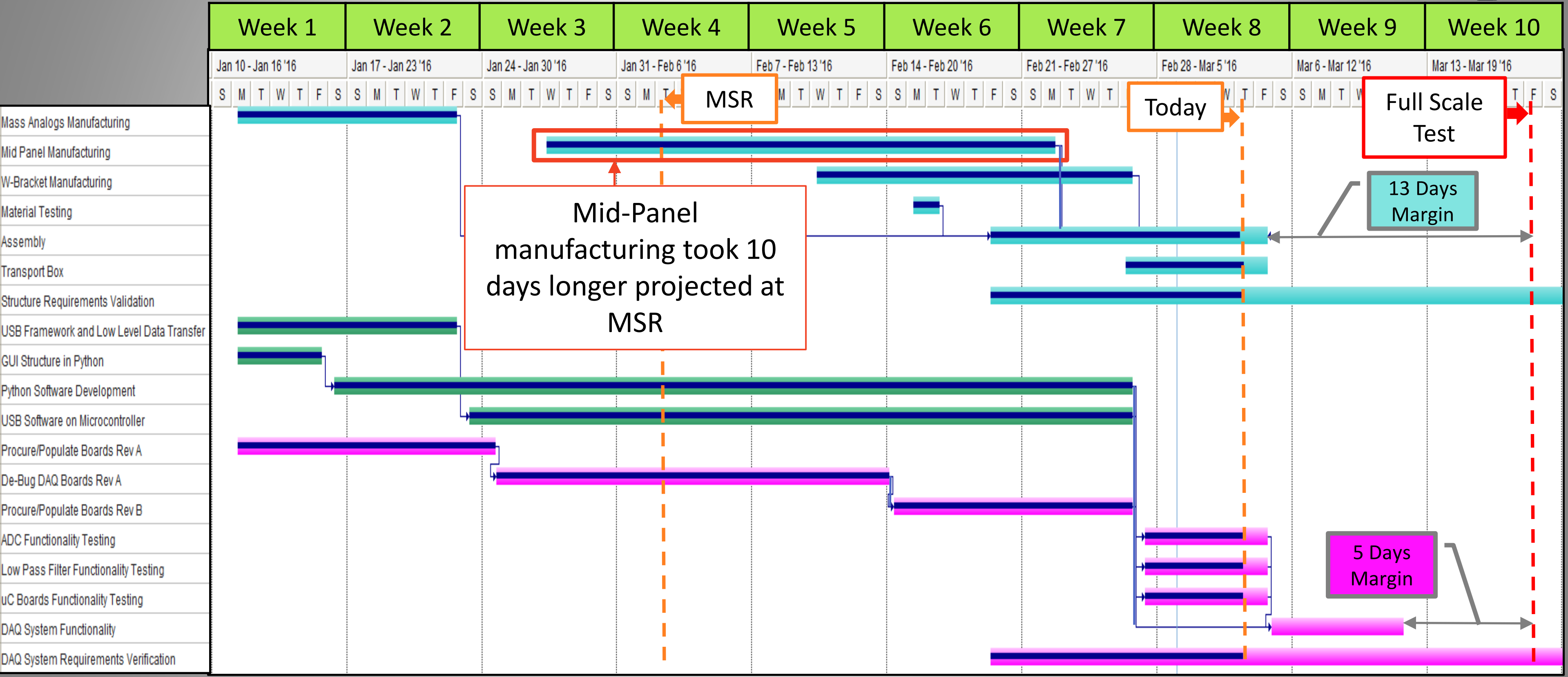

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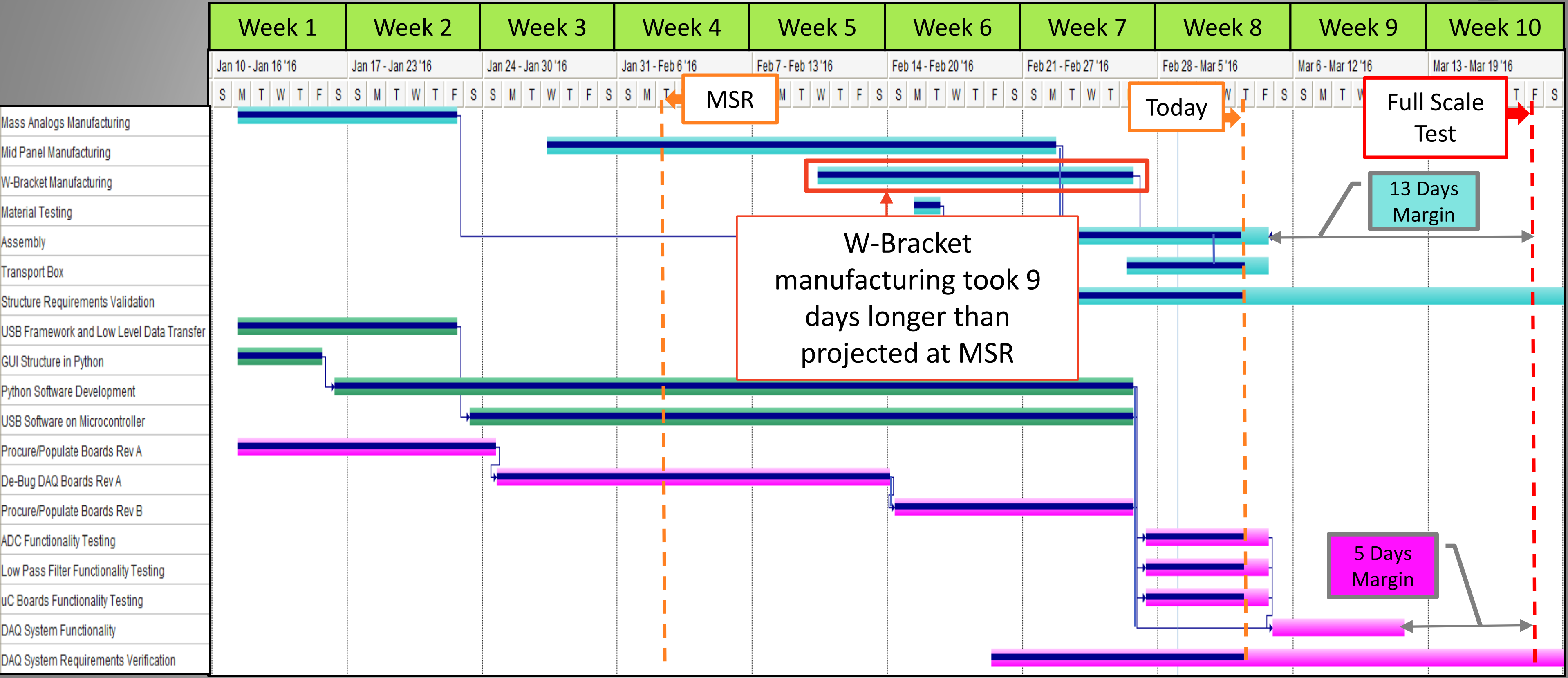
Schedule:



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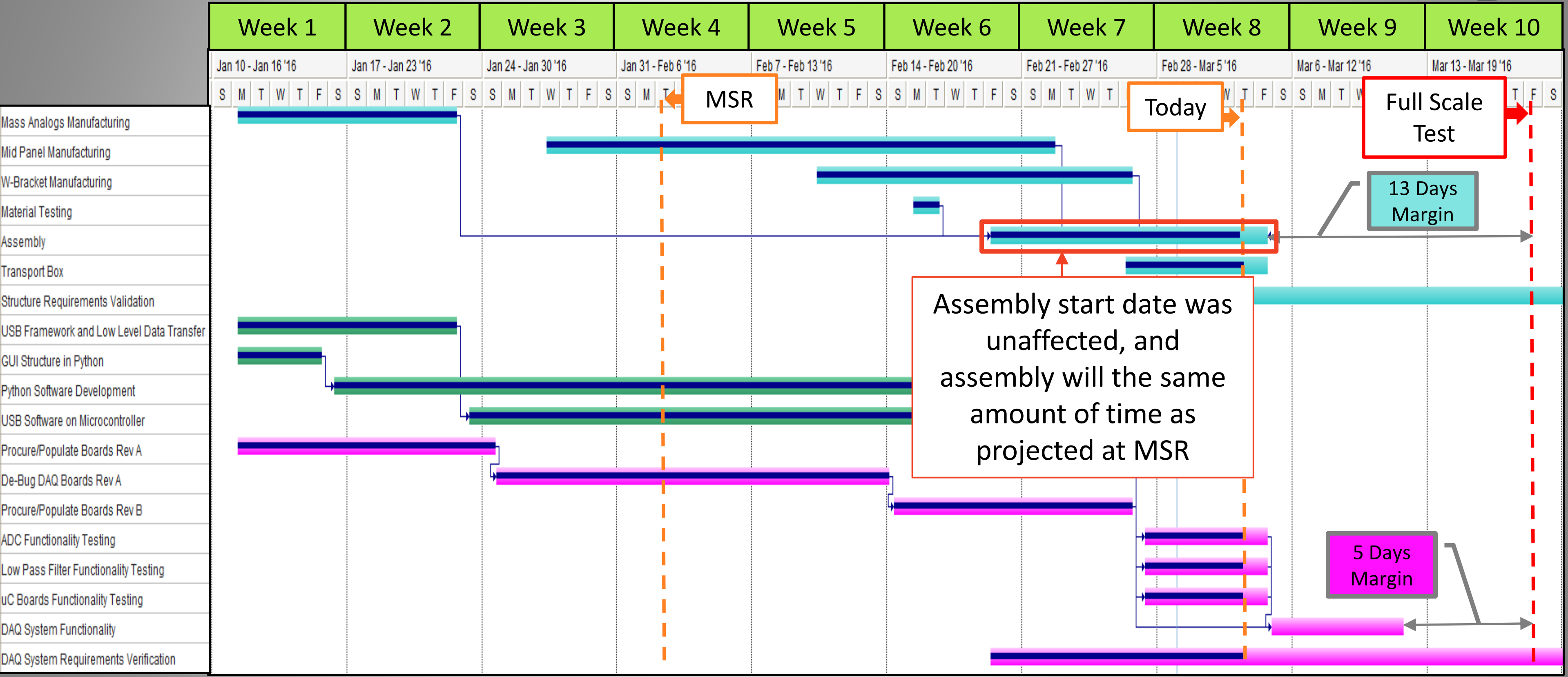
Schedule:

- Structure
- DAQ Software
- DAQ Hardware
- Percent Complete



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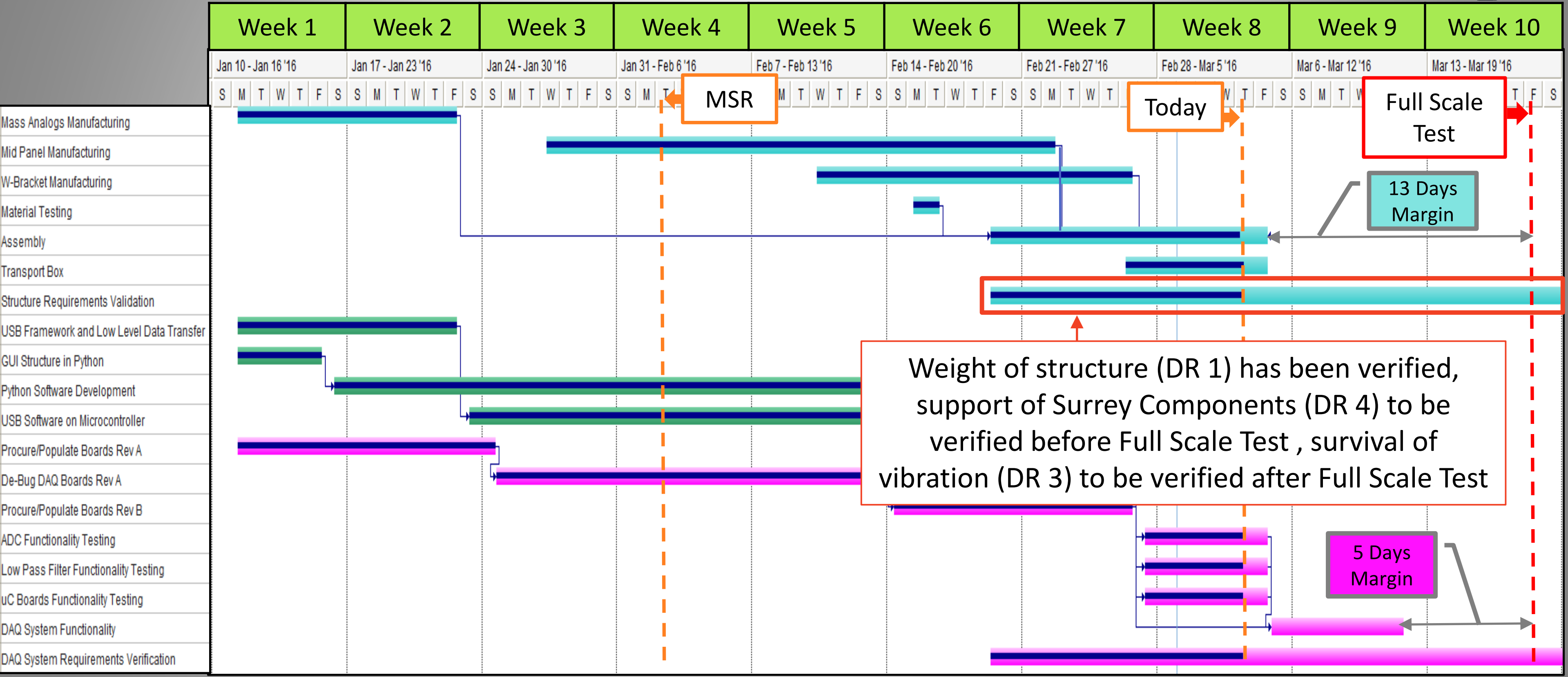
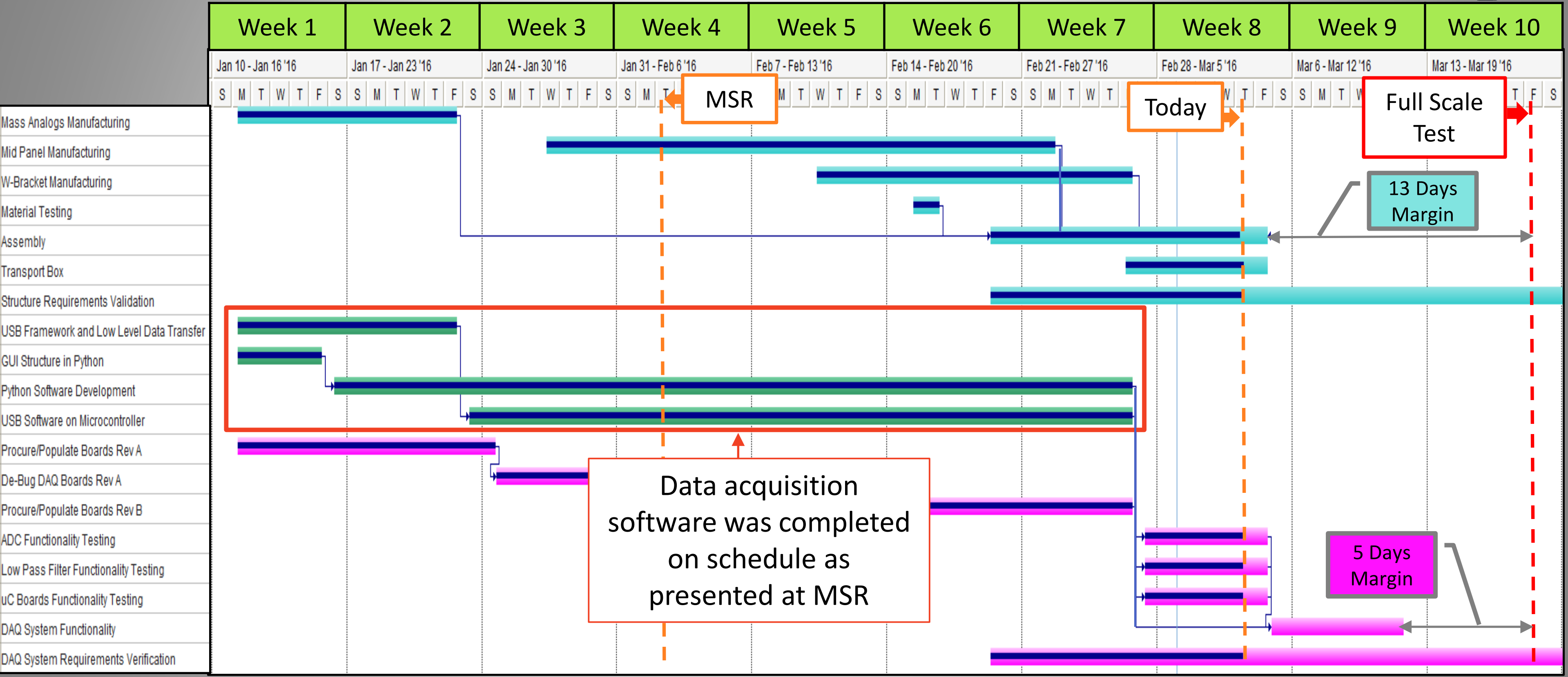
Schedule:



Schedule:

- Structure	- DAQ Software
- DAQ Hardware	- Percent Complete



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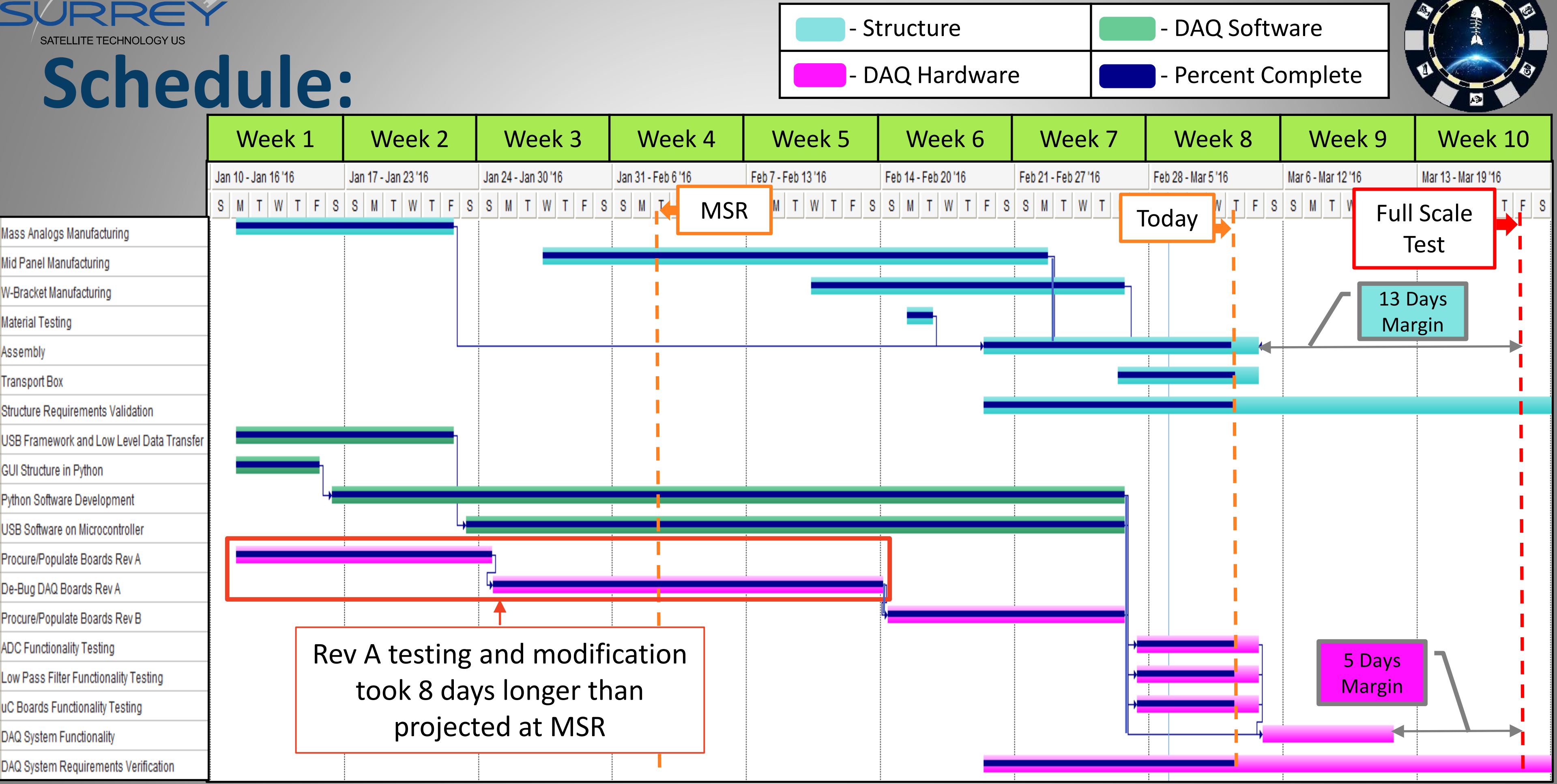
Schedule:



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Schedule:

- Structure
- DAQ Software
- DAQ Hardware
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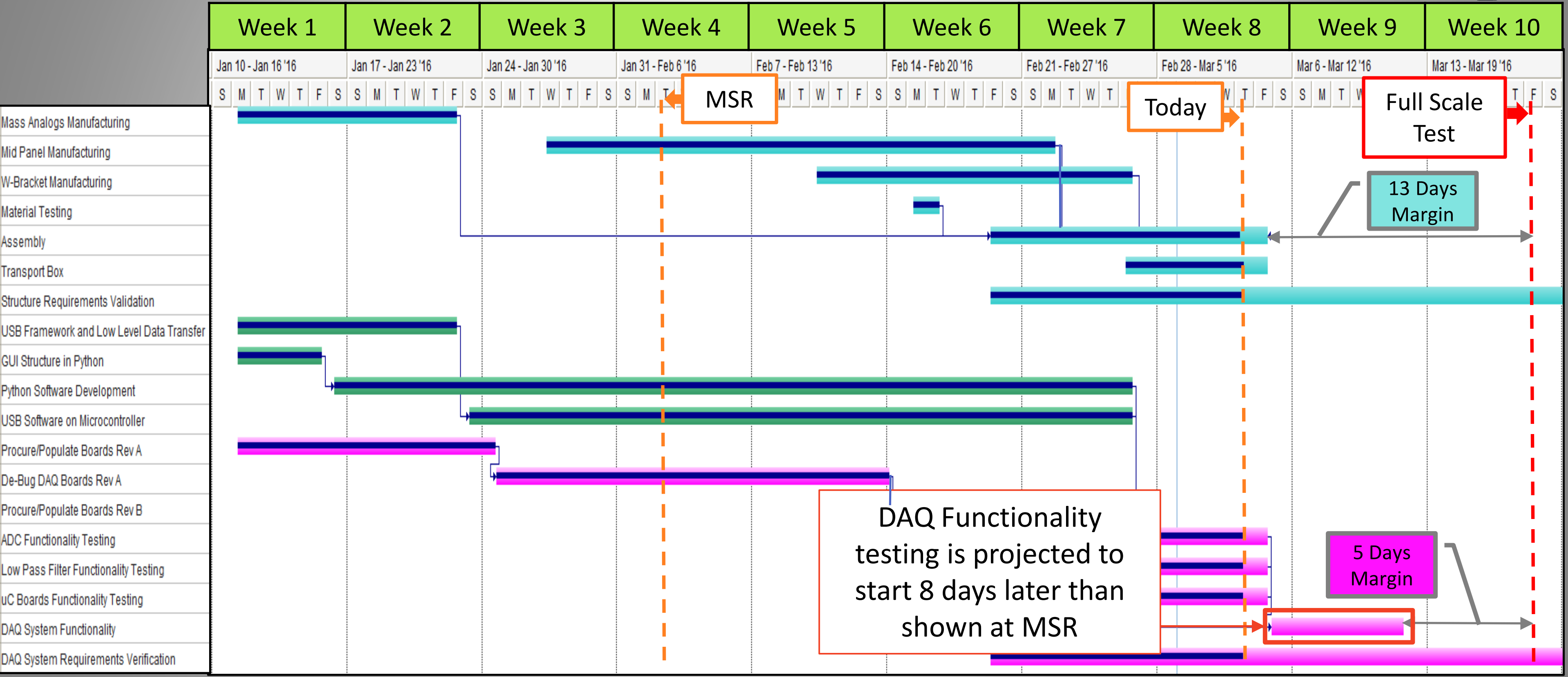
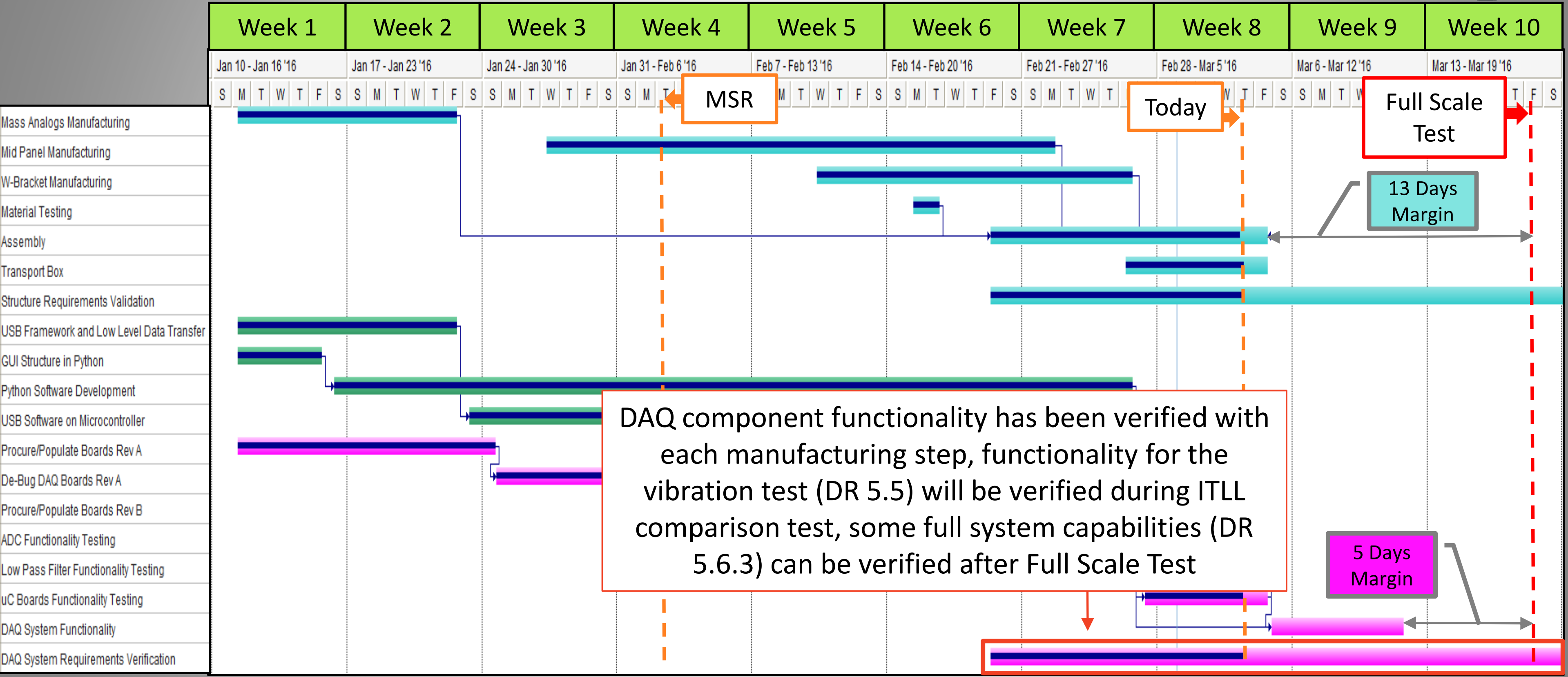


Schedule:

- Structure
- DAQ Software
- DAQ Hardware
- Percent Complete

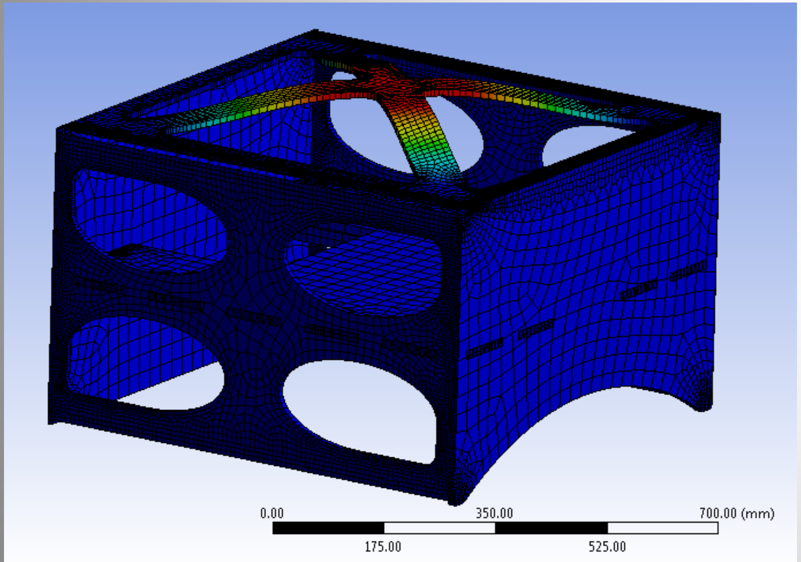


TESTING STATUS

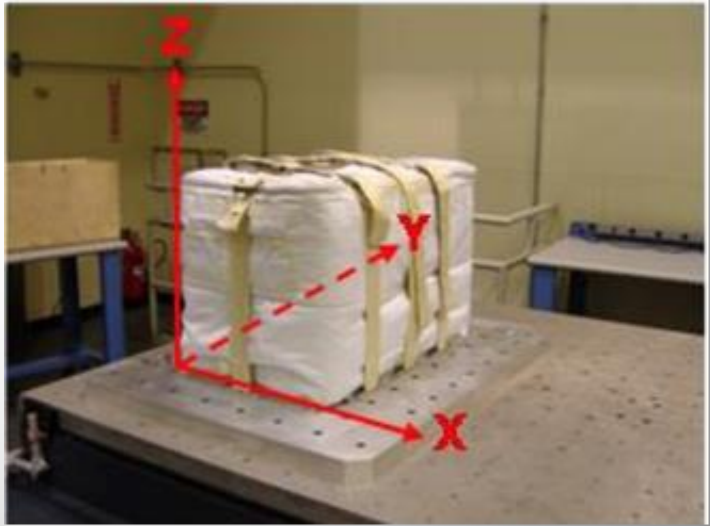
Purpose of Testing:

1. Determine if the natural modes of the structure are the modes predicted by ANSYS

2. Determine if the structure can survive ISS launch conditions is a “soft-stowed” launch configuration



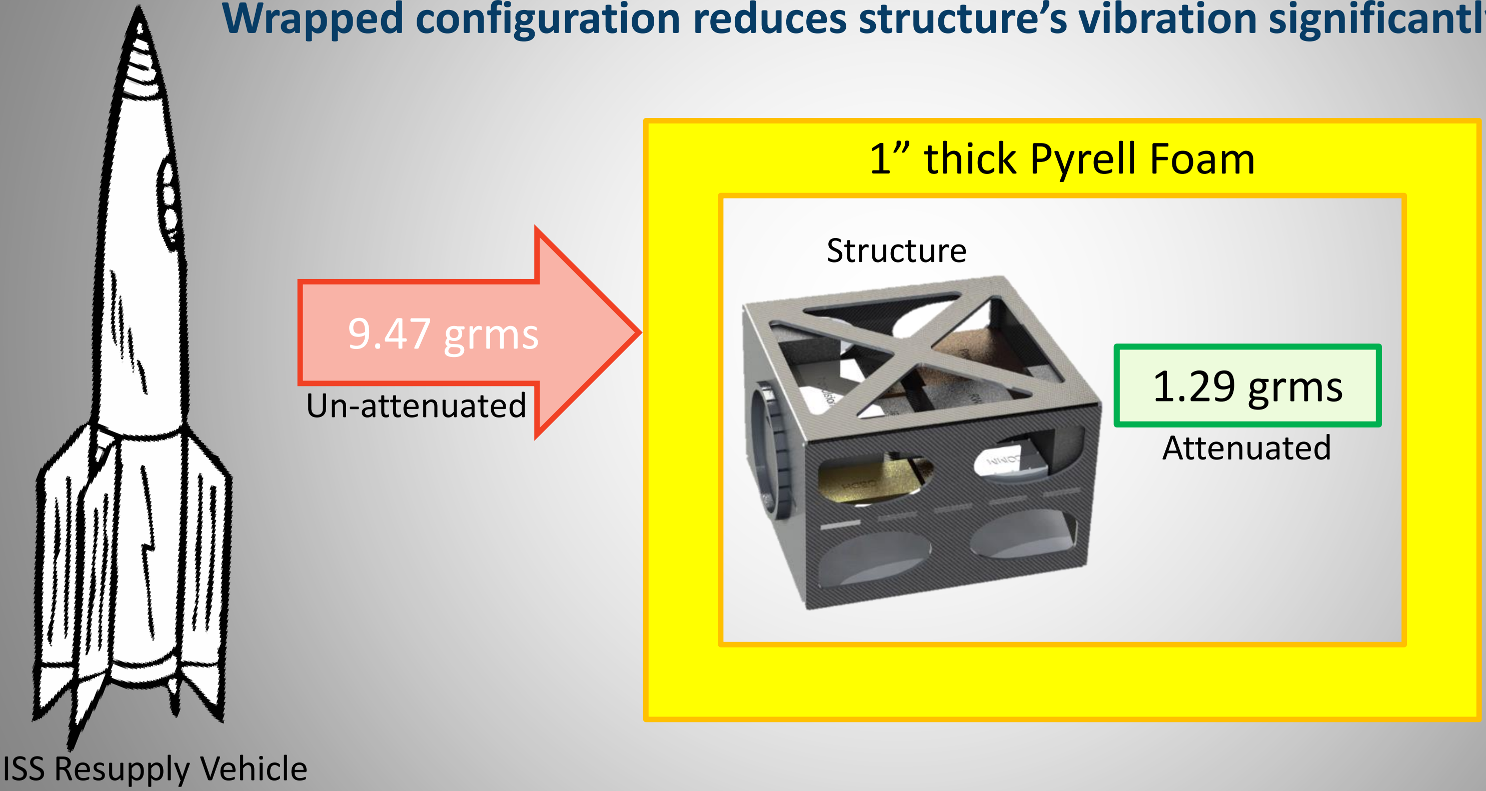
Mode 1 Deflection (mm)



Example of Soft-Stowed Item
(from NASA Gevs)

Launch Configuration:

Wrapped configuration reduces structure's vibration significantly:



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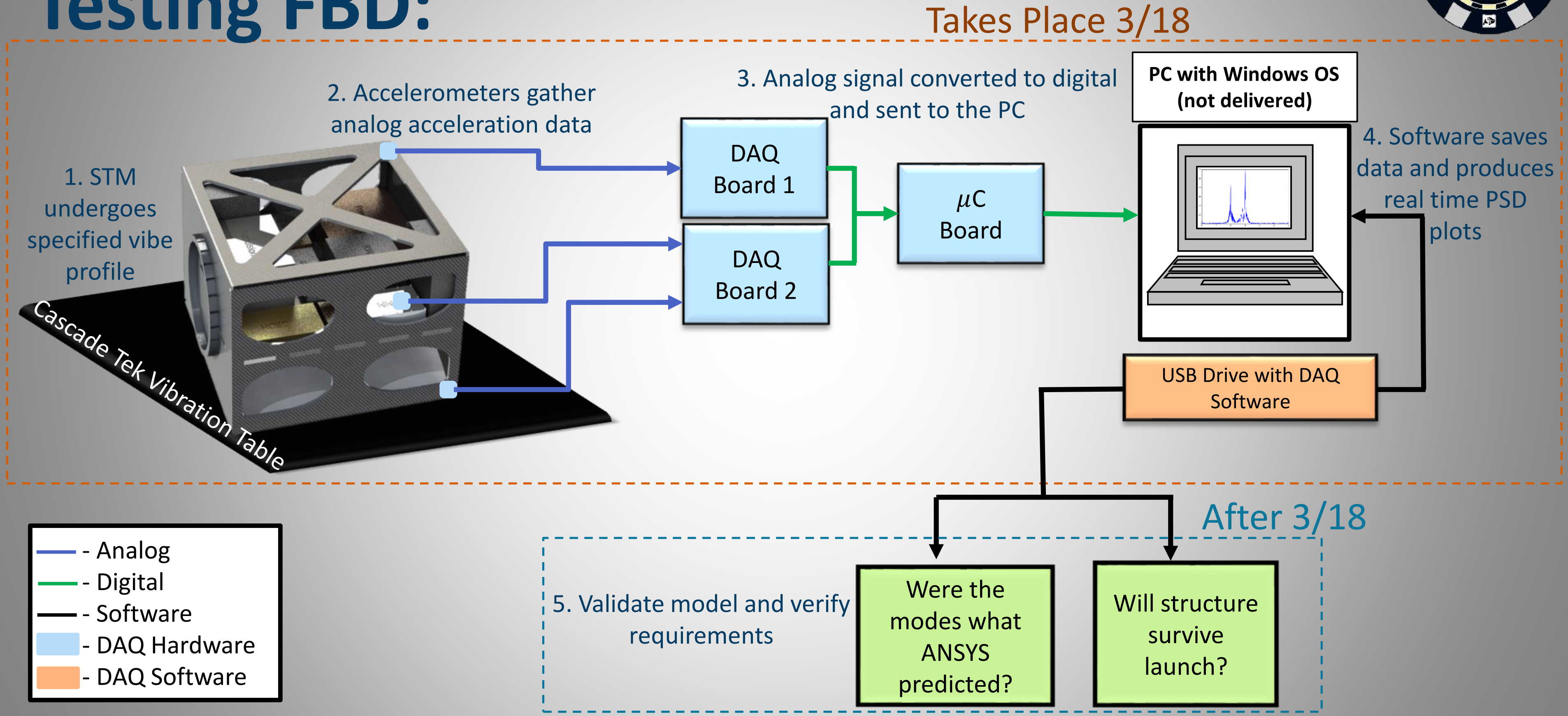
Testing FBD:

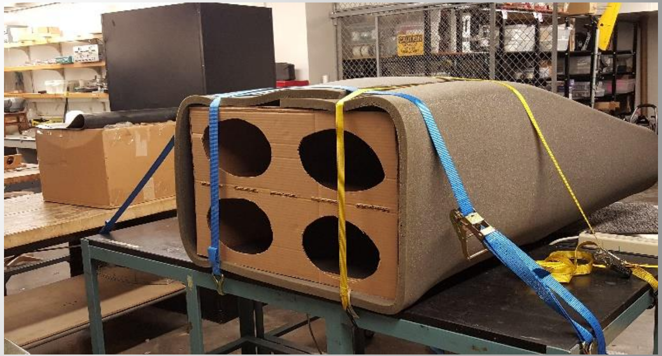


Vibration Test Facility:

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

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

SR16 Shaker (48” x 48”)



Full scale model wrapped in foam

Types of Tests:

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

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

NASA GEVS Vibration Profiles in backup slides

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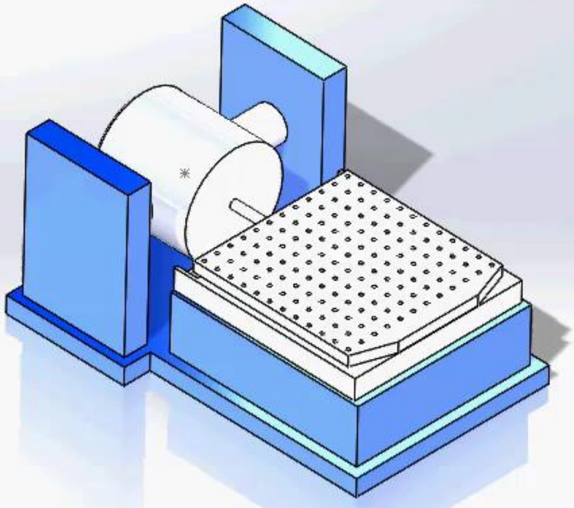
Testing Procedure: Unwrapped Setup

Unwrapped Configuration:

- Used for modal validation modal sweeps
- 2 in each orientation



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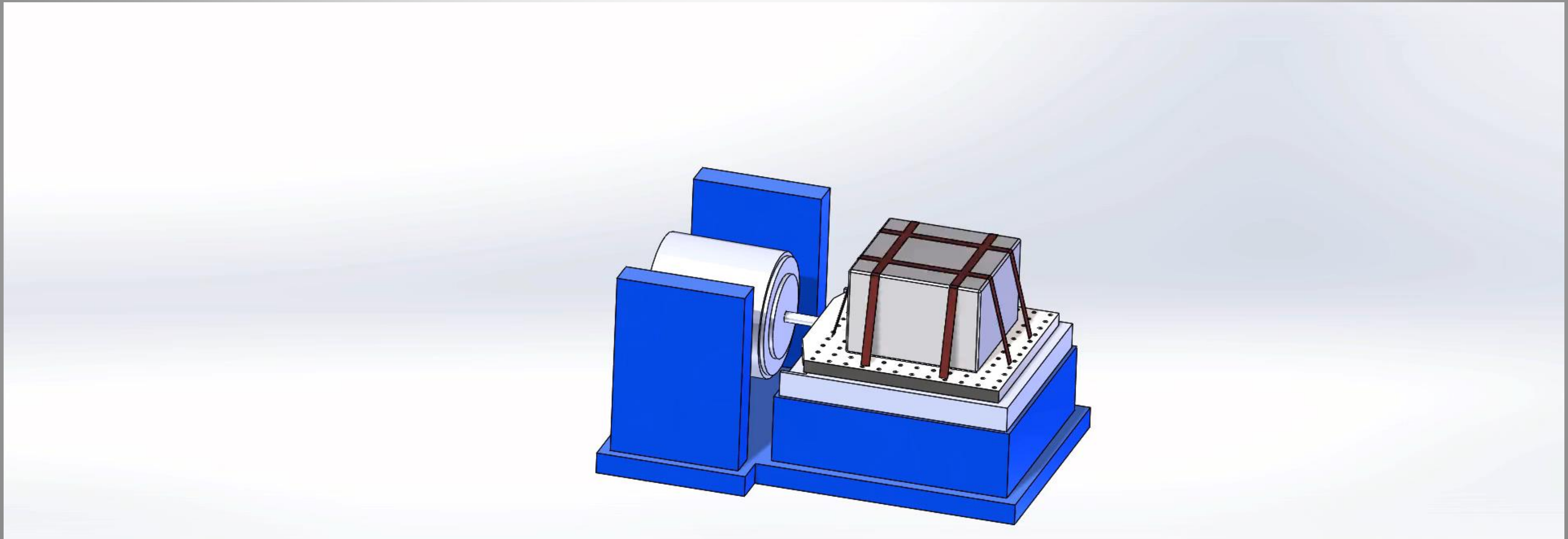
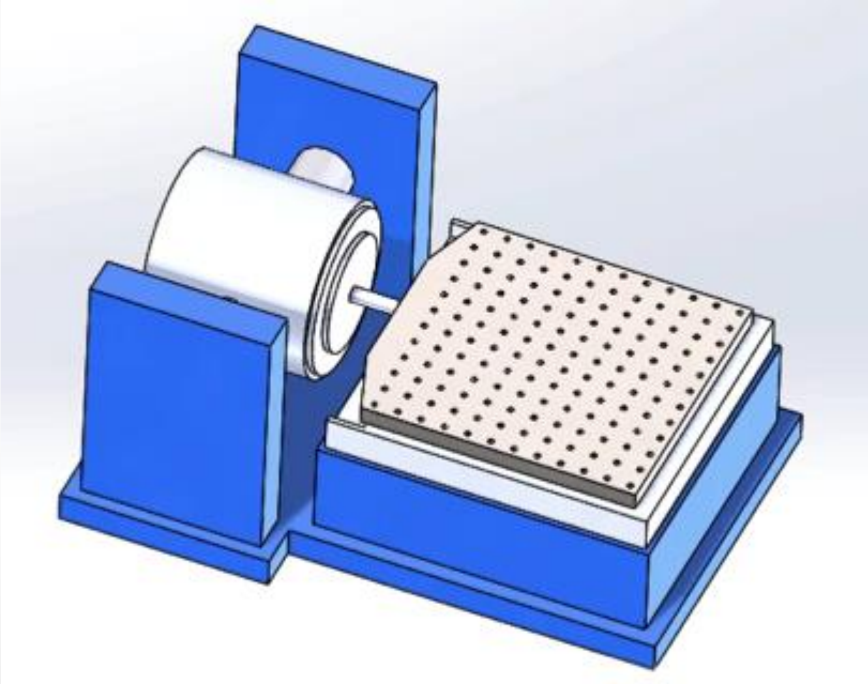
Testing Procedure: Orientations



Testing Procedure: X/Y Axes

1. Bare Table Characterization

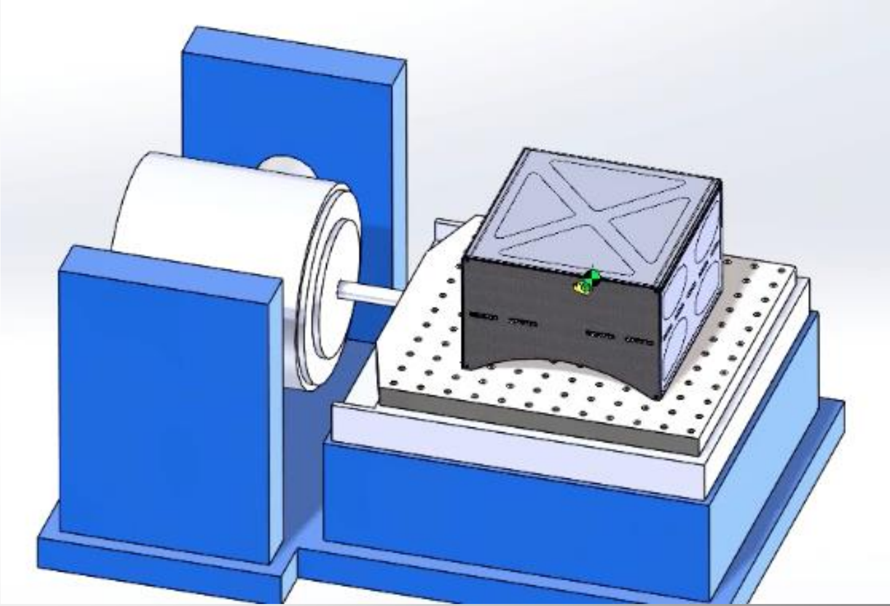
2. Place Accelerometers on predetermined X-axis locations on STM



Testing Procedure: X/Y Axes

3. Mount unwrapped STM in Ram/Wake (X) orientation

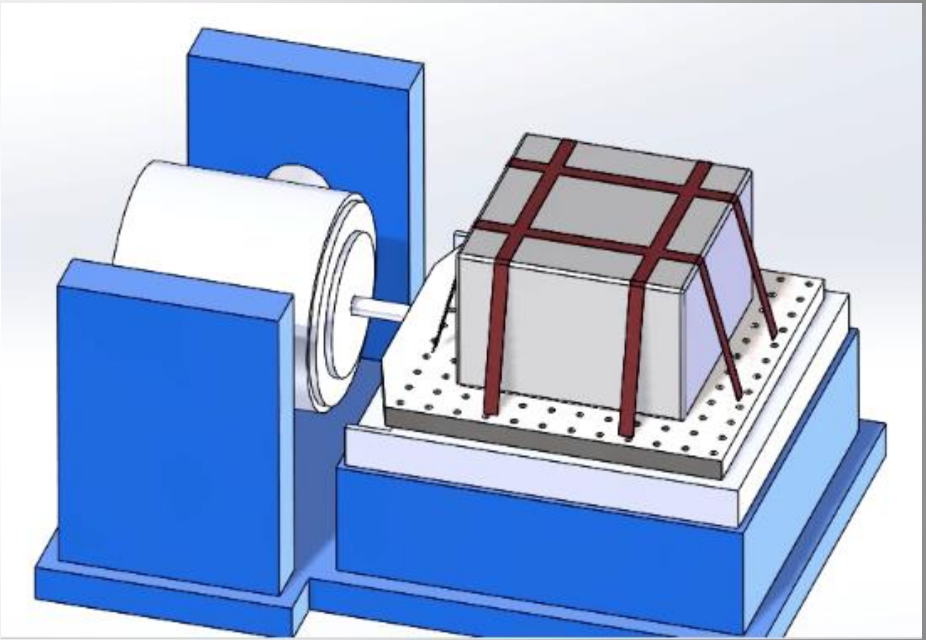
4. Perform unwrapped modal sweep: 20 Hz. to 2 kHz. at 2 oct/min sweep rate



Testing Procedure: X/Y Axes

5. Foam wrap and secure structure with ratchet straps

6. Perform wrapped modal sweep



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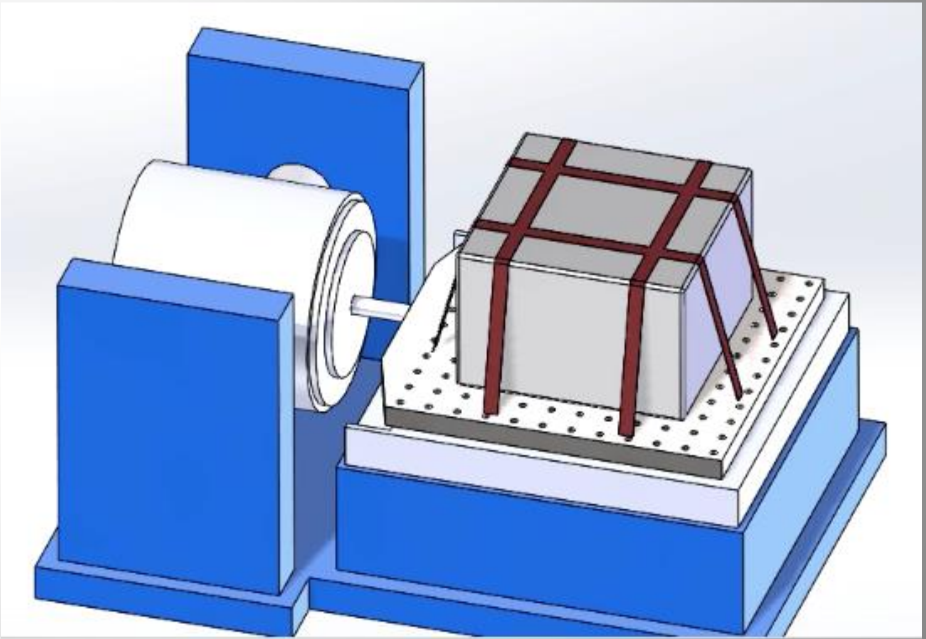
Testing Procedure: X/Y Axes

7. Begin random vibration at unwrapped profile -12 dB

8. Increment by dB until input accelerometer (inside foam) measures 1.29 grms

9. Conduct 60s test at 1.29 grms

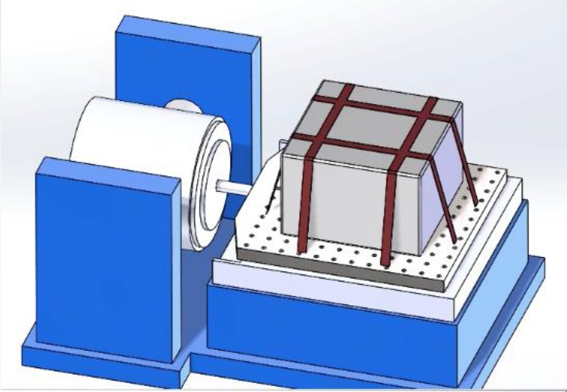


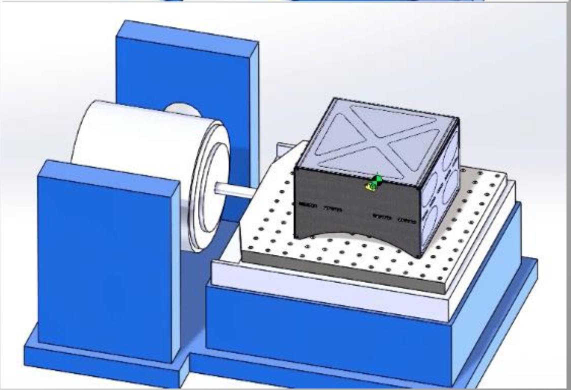
Testing Procedure: X/Y Axes

10. Perform wrapped modal sweep

11. Unwrap and mount STM

12. Perform unwrapped modal sweep

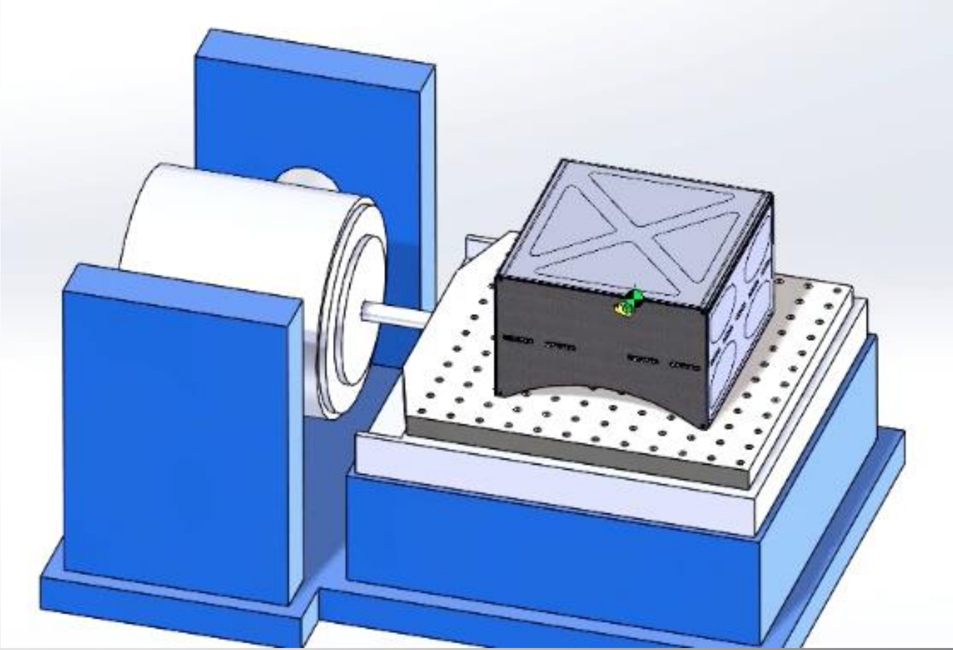




Testing Procedure: X/Y Axes

13. Visually inspect the structure for large scale failure

14. Repeat steps for Y Axis



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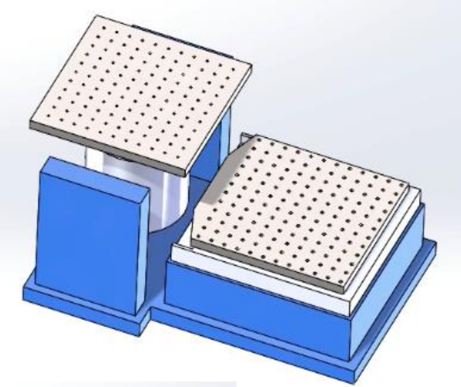
Testing Procedure: Z Axis

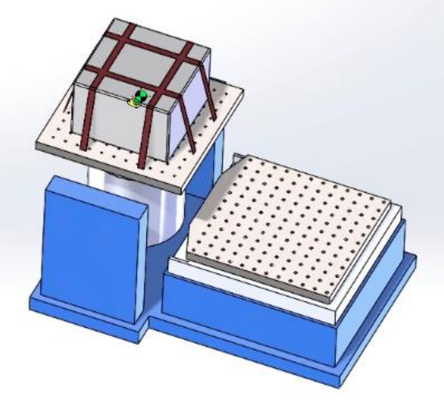
1. Re-orient SR16 to zenith orientation

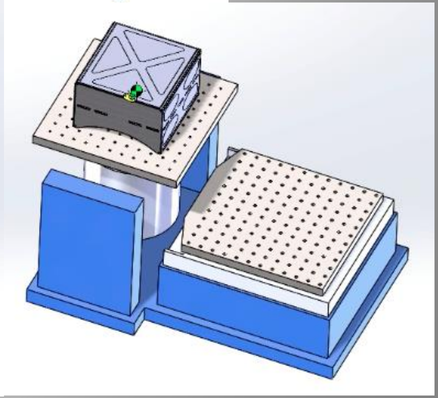
2. Perform bare table characterization

3. Place accelerometers on Z-axis locations on STM

4. Repeat x/y steps 3-13



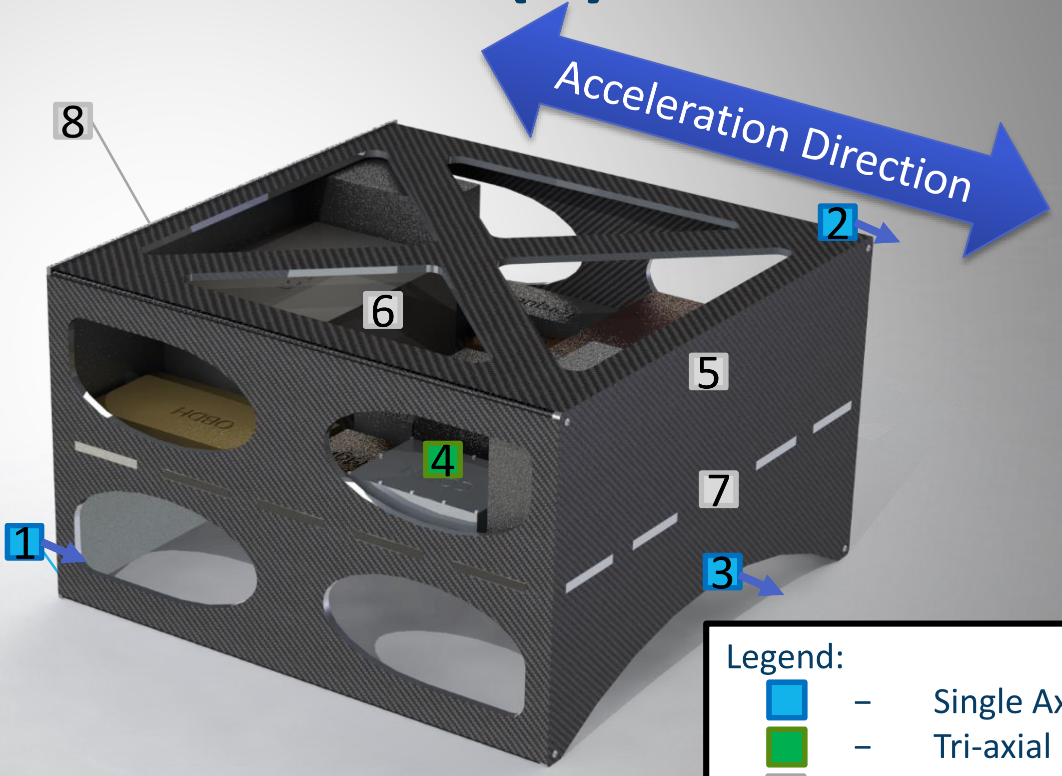




Accelerometer Locations: Ram (X)

Key

1. "Input" Accelerometer
   - On lower right of prop plate, outer face
2. Solar Panel Accelerometer
   - On top of solar panel (not pictured) above Velcro interface
3. Panel Accelerometer
   - Outside face of radiator panel, lower center
4. Avionics Accelerometer
   - On ram side of Torquer in middle of avionics bay



Legend:
- Single Axis
- Tri-axial
- Potential

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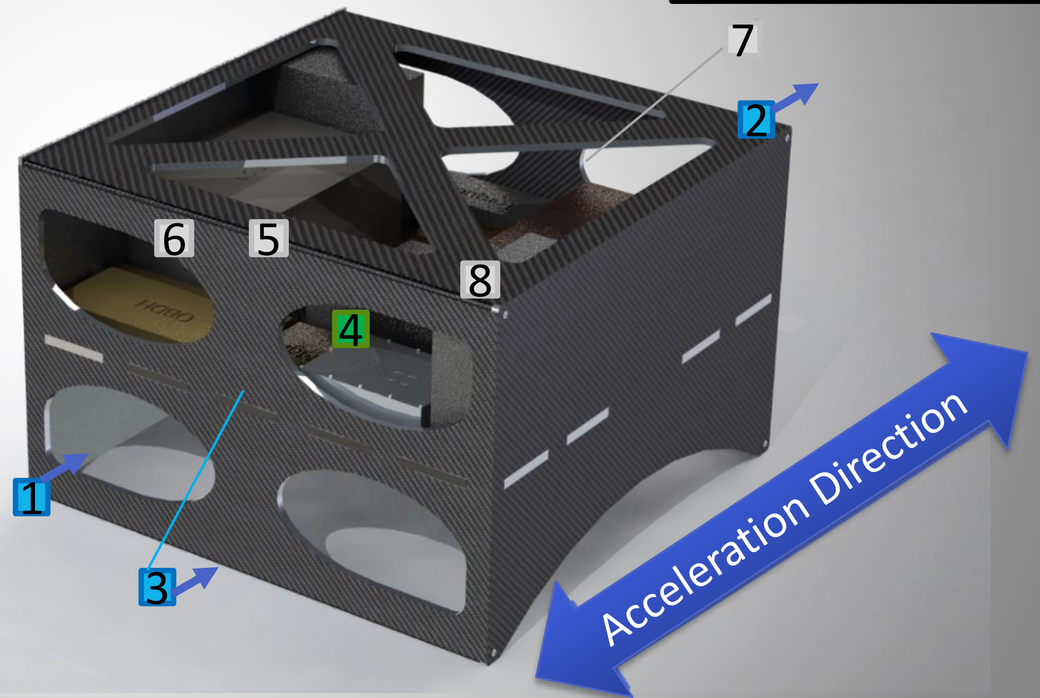
Accelerometer Locations: Side (Y)

Legend:
- Single Axis (blue)
- Tri-axial (green)
- Potential (grey)

Key

1. "Input" Accelerometer
   - On lower left corner of starboard side panel, outside face
2. Solar Panel Accelerometer
   - On top of solar panel (not pictured) above Velcro interface
3. Panel Accelerometer
   - Outside face of starboard side panel, off center
4. Avionics Accelerometer
   - On starboard side of Torquer in middle of avionics bay



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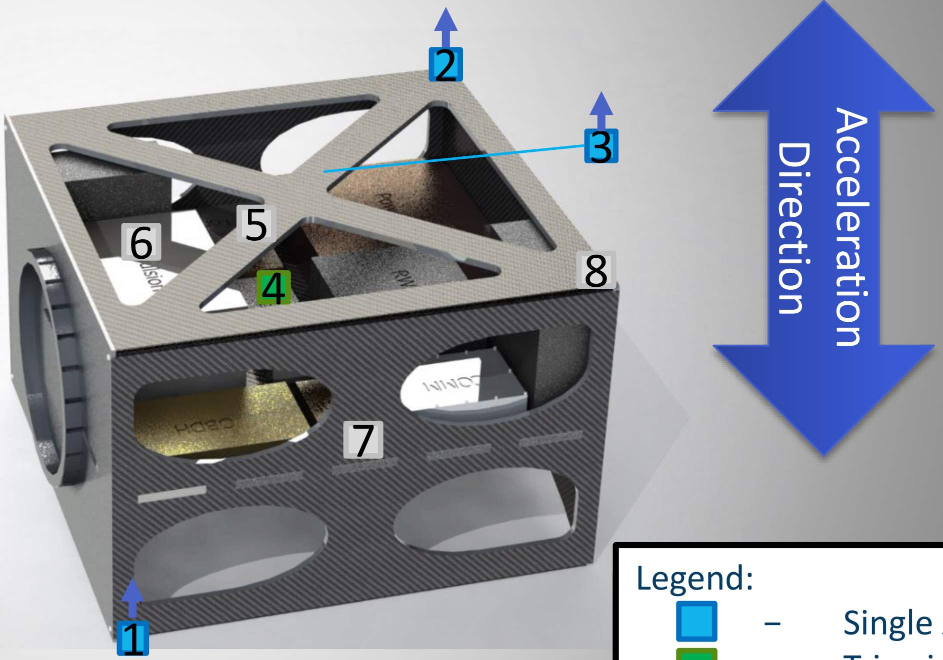
Accelerometer Locations: Zenith

Key

1. "Input" Accelerometer
   - On top of beam, inside of lower right corner of prop plate
2. Solar Panel Accelerometer
   - On top of solar panel (not pictured) above Velcro interface
3. Panel Accelerometer
   - Off center on top of top panel
4. Avionics Accelerometer
   - On top of Torquer in middle of avionics bay



Legend:
- Single Axis
- Tri-axial
- Potential

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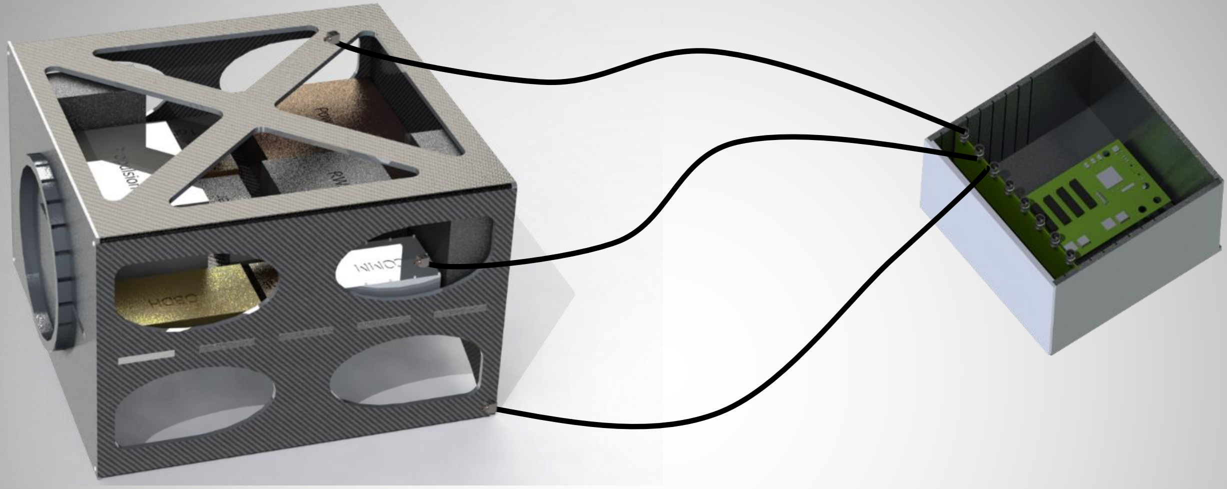
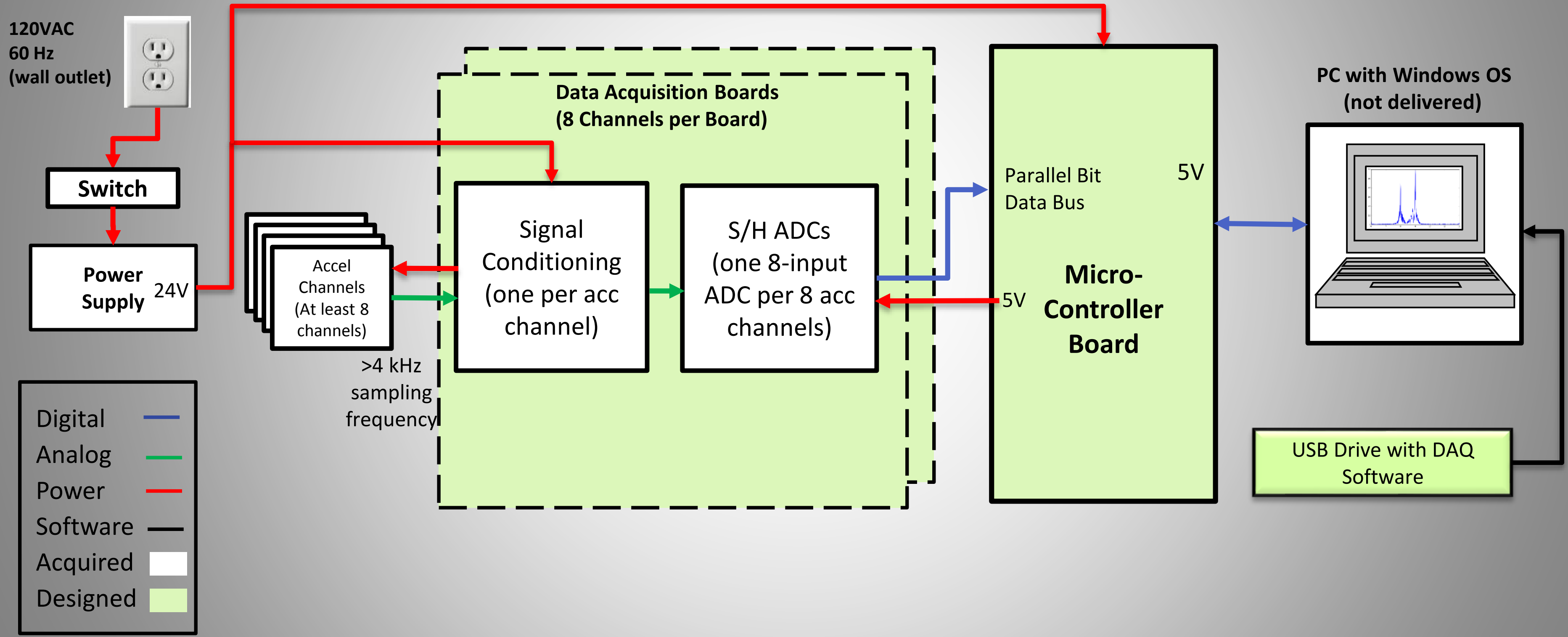
Vibration Testing: Safety Concerns

- Carrying the Structure
  - STM will be moved by 4 team members at all times
- Noise levels
  - Earplugs will be worn inside vibration room while tests are in progress
- Potential for components to detach
  - Team members will be a minimum of 10 ft. from the table during random vibration
- All tests will be conducted under the supervision of professional test engineers



DAQ STATUS

DAQ Hardware FBD:



Component Testing:

Component:	Test Purpose:	Status:
Signal Conditioning Circuit	Convert acceleration reading to ADC-readable voltage	COMPLETE
Power Regulation	Provide all components proper power levels for operation	COMPLETE
USB Protocol	Demonstrate USB protocol functionality	COMPLETE
Data Analysis Software	Compute PSD and create quasi-real-time plots	COMPLETE

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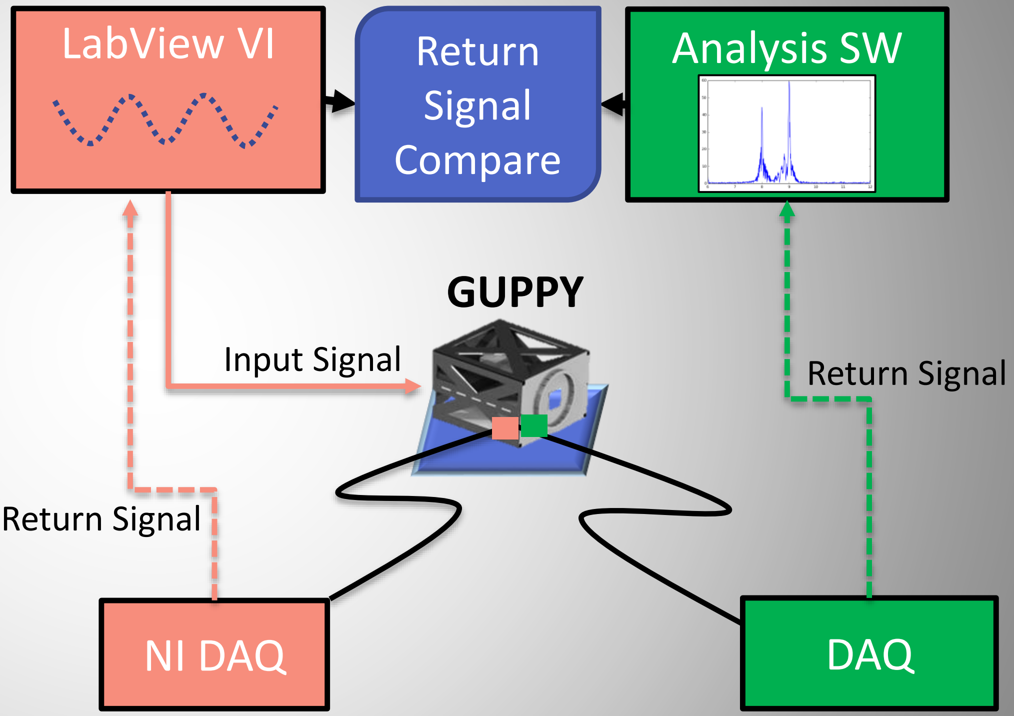
DAQ Test Plan:

- High-level verification test using NI DAQ and small vibe table in ITLL
- GUPPY will be tested under predetermined vibration profile
- Results from NI will be used as “truth” comparison for DAQ verification
- Correlation coefficient and cross correlation will be used as metrics



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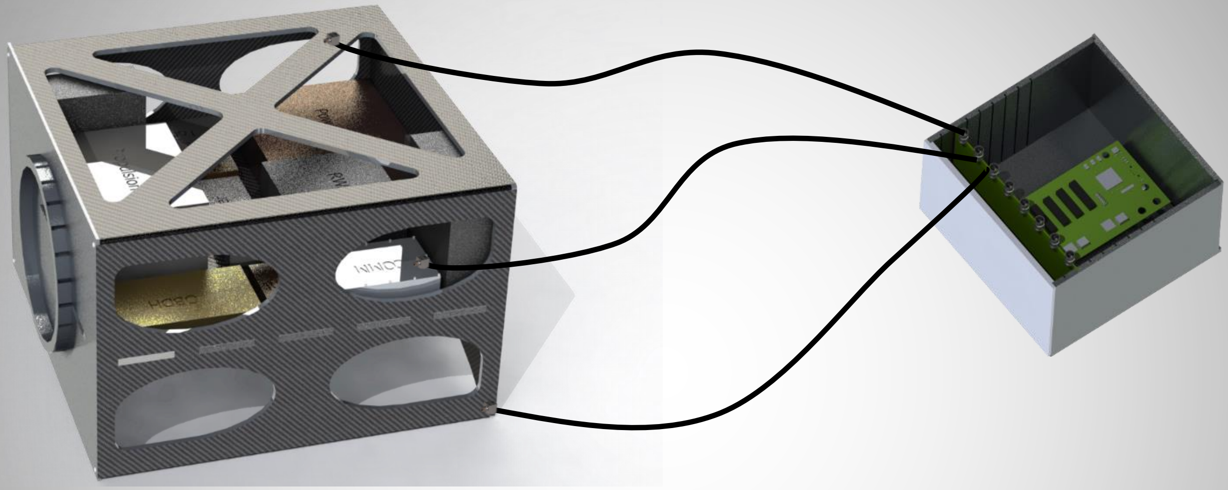
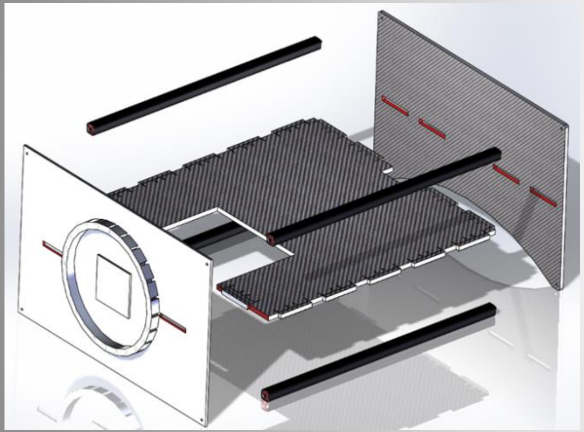
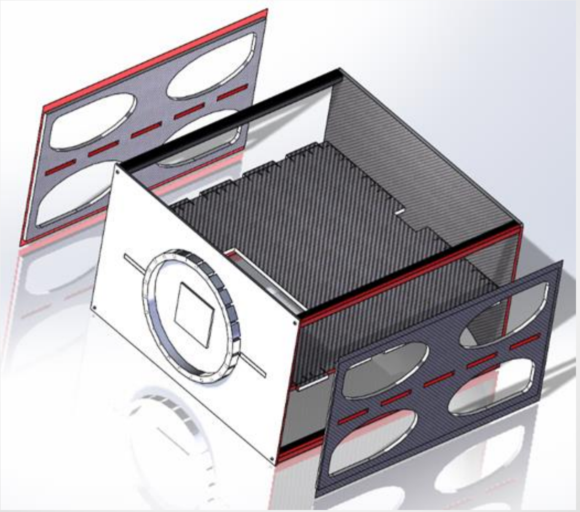


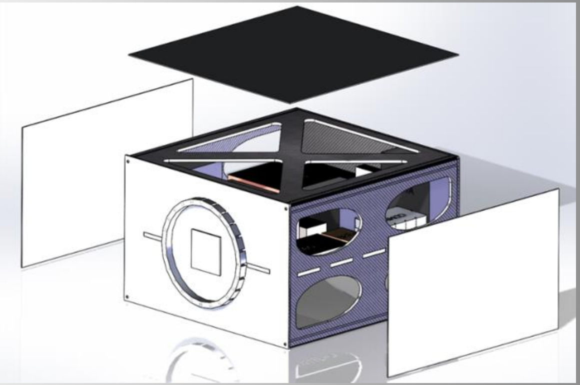
STRUCTURE STATUS

Baseline Design – Structure:

30”x 30”x 19” structure, designed to weigh 4.48 kg







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

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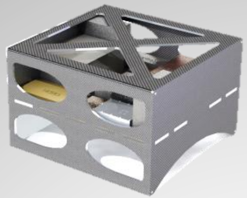
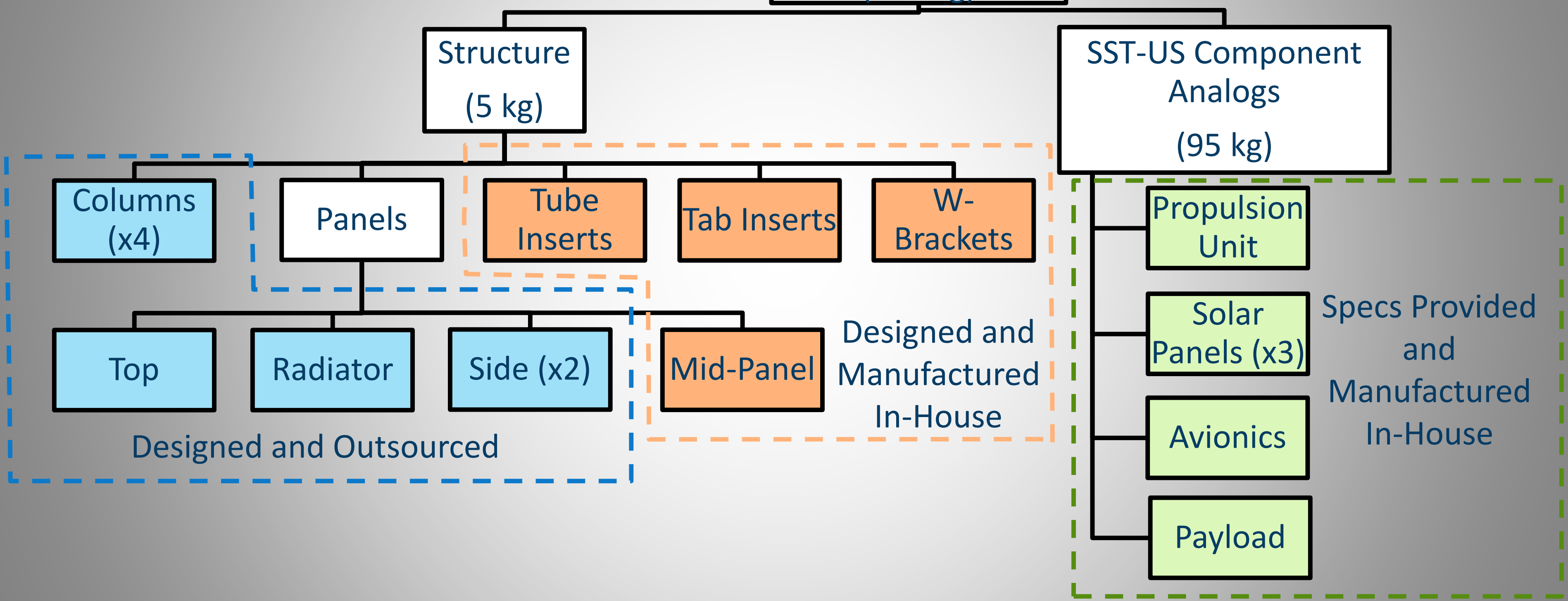
Structure FBD:





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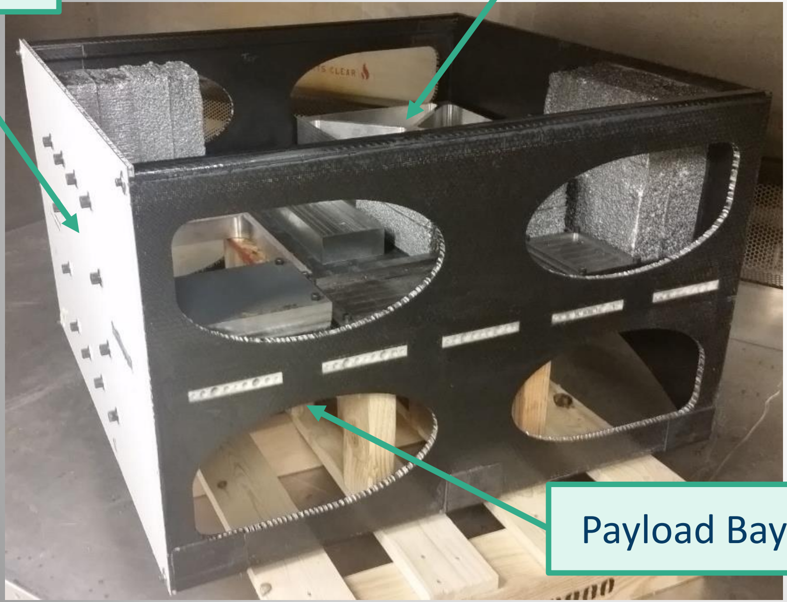
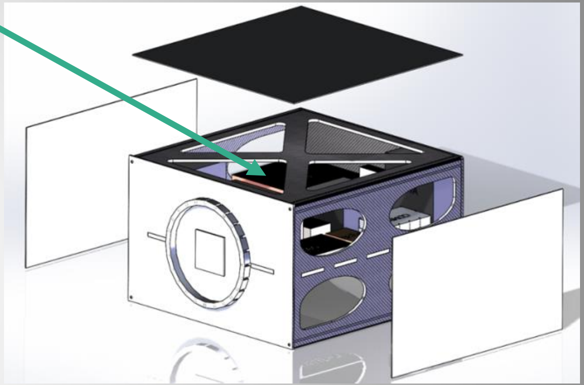
Assembly:



Assembly Progress as of 2/29


SolidWorks Model of Assembly

Required Mass:	< 5 kg
Predicted Mass:	4.48 kg
Achieved Mass so far:	3.99 kg

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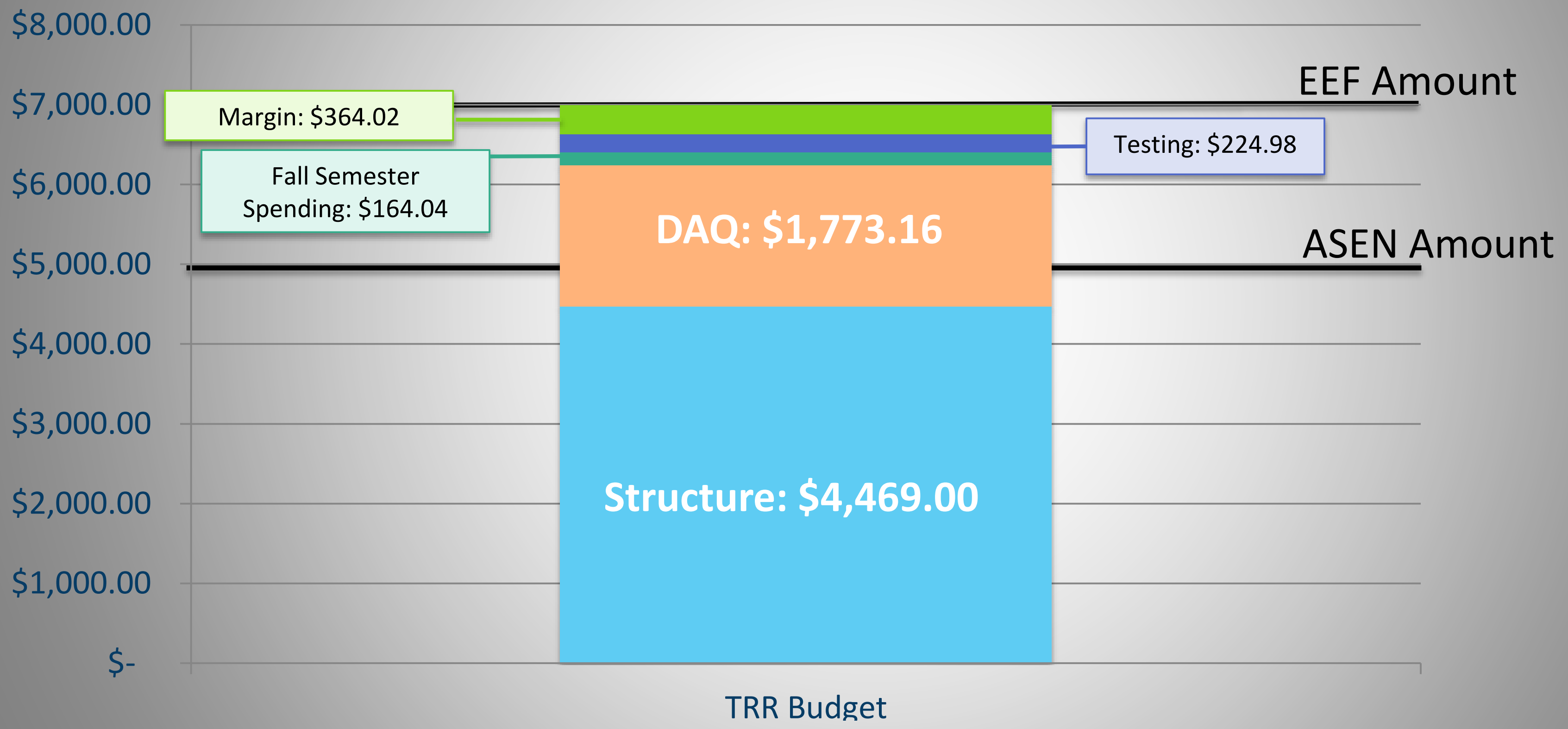
Component Testing Since MSR:

Test:	Purpose:	Results:
Tab Inserts New Material	Determine if a cheaper material would change the strength of tabs	Cheaper material performed as well as more expensive one, **tab strength higher than expected**
Mid-panel Bending	Determine mid-panel bending modulus and integrate into model	In-house mid-panels strength was repeatable and modulus determined to be 524 N/mm
Adhesive Tension	Compare adhesive strength with in-house carbon fiber with last semester's adhesive tests	Composite failed just below previous adhesive strength, **still achieving a 78% margin**
Delamination	Determine the failure mode of the mid-panel to component interface	Composite bond between carbon fiber and aluminum honeycomb failed **above required strength**
Compression Sleeve	Determine if a compression sleeve is needed in tube interface	Compression Sleeve added, 1 hour of assembly time added

BUDGET

Budget:



$8,000.00
$7,000.00
$6,000.00
$5,000.00
$4,000.00
$3,000.00
$2,000.00
$1,000.00
$-
EEF Amount
ASEN Amount
Margin: $364.02
Fall Semester Spending: $164.04
Testing: $224.98
DAQ: $1,773.16
Structure: $4,469.00
TRR Budget

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Acknowledgements:

References:

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

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

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SURREY SATELLITE TECHNOLOGY US

QUESTIONS?

SATELLITE TECHNOLOGY US

Slide Index:

SATELLITE TECHNOLOGY US

Back-Up Slide Index:

Mechanical Tests:	DAQ Tests:	Requirements:	Testing:
3 pt. Bending	Signal Conditioning	Functional	CDR predictions
Tab Insert	PSD	Structure	R/W placement/validate
Compression		DAQ	R/W expected modes
Tube Inserts			P/SB placement/validate
Adhesive			P/SB expected modes
Tension Results			Z placement/validate
Delamination – description			Acc. Mounting
Delamination – results			Random Vibe Profile
			Facility/Equipment
			Test Concept
			Profile 1 –Primary
			Profile 1 – Plot
			Profile 2 – Flight
			Profile 2 – Plot
			Contingencies
			GRMS definition
			GRMS method
			Wrapping/Mounting
			DR 5.4 – Foam Wrapping

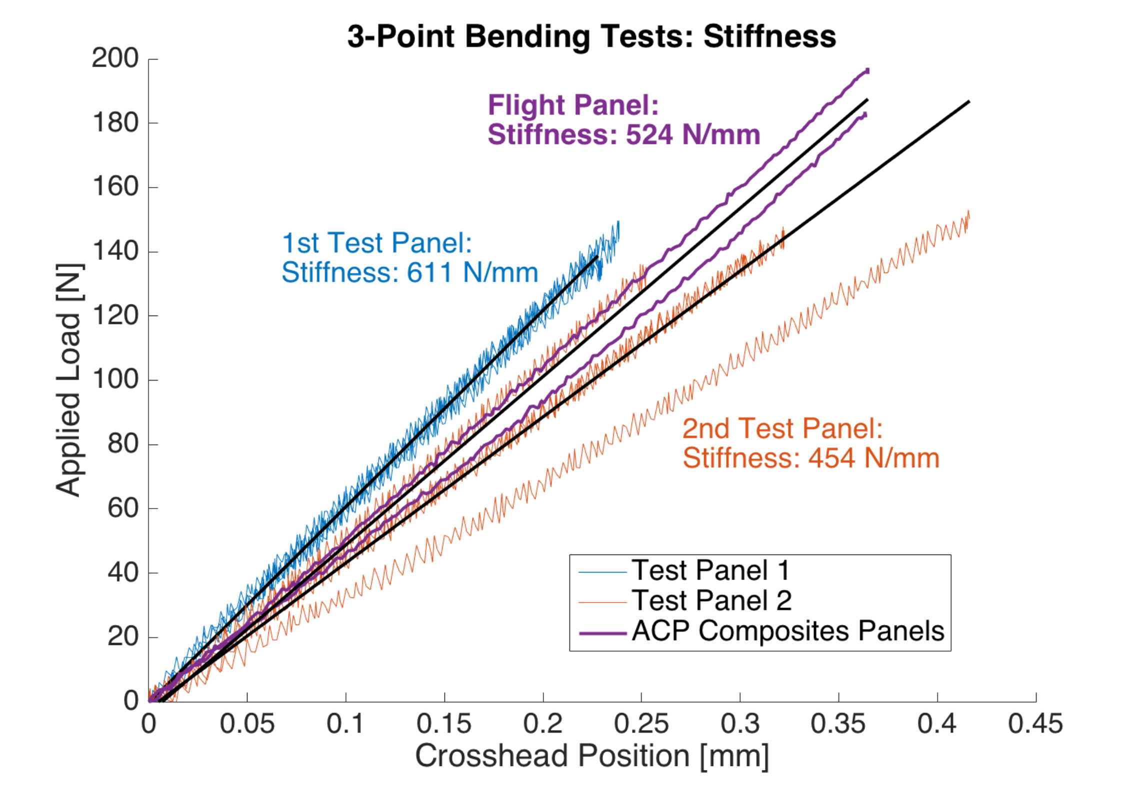
BACK-UP SLIDES

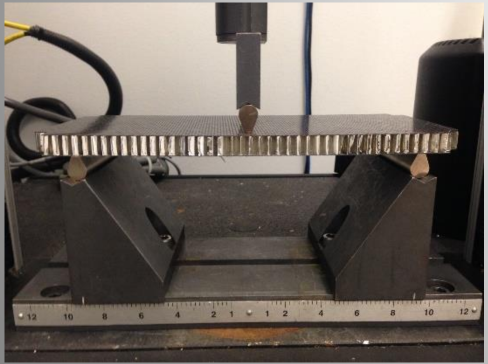
3-Point Bending Test:

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

Results: ~ 524 N/mm

Input for modeling of natural frequencies of the Structural Test Model

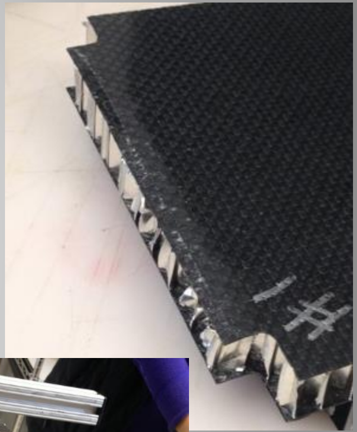


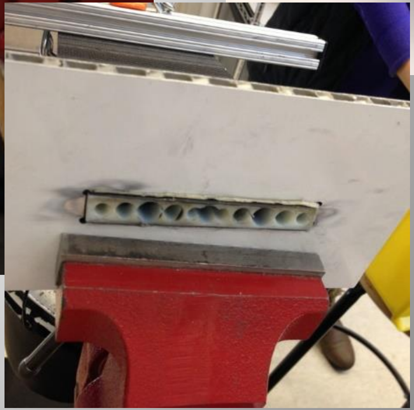


Tab Insert Interface Bending Test:

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

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

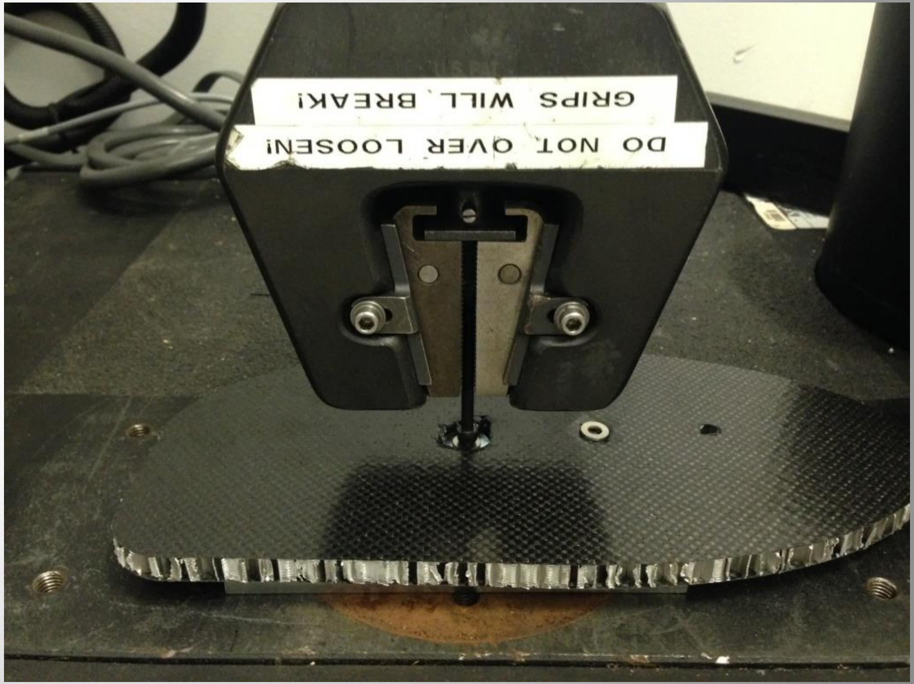




Compression of Radiator Panel at the Tube to Panel Interface:

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

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



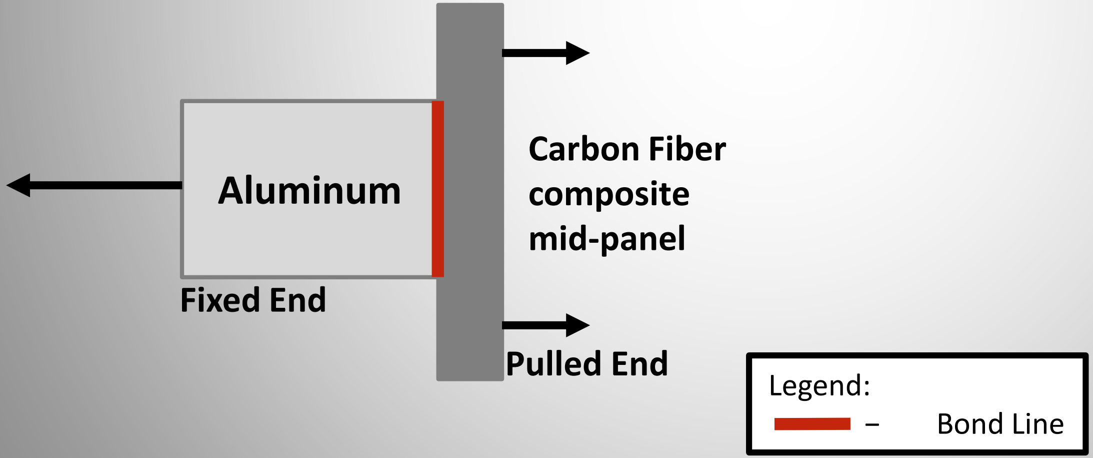
Tube Inserts Bonding Line Test:

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

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

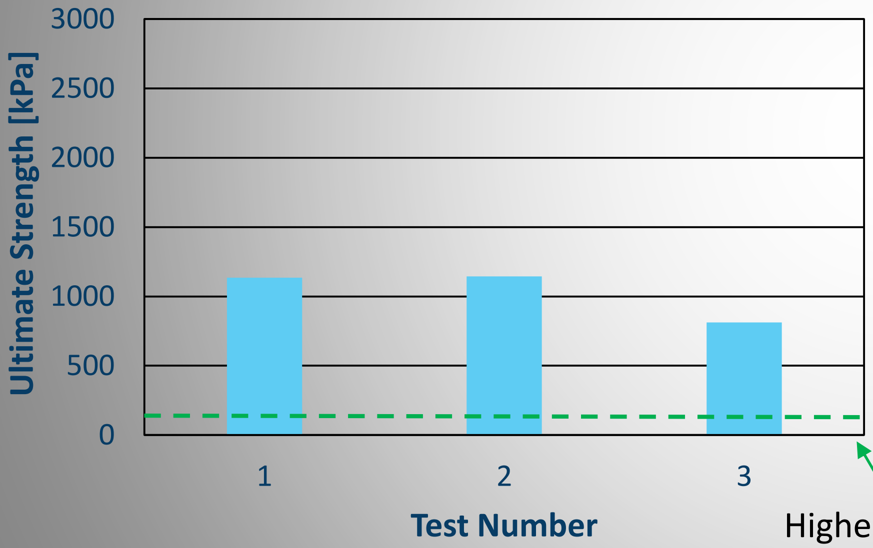
Adhesive Test Results:

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

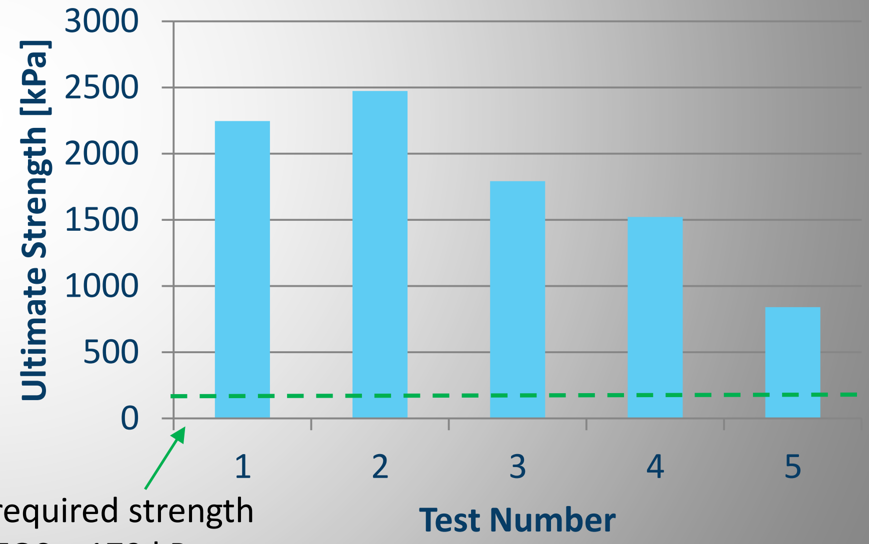


Adhesive Tension Test Results:

Spring Semester
In-house CF to Aluminum
(CF Composite Failed)



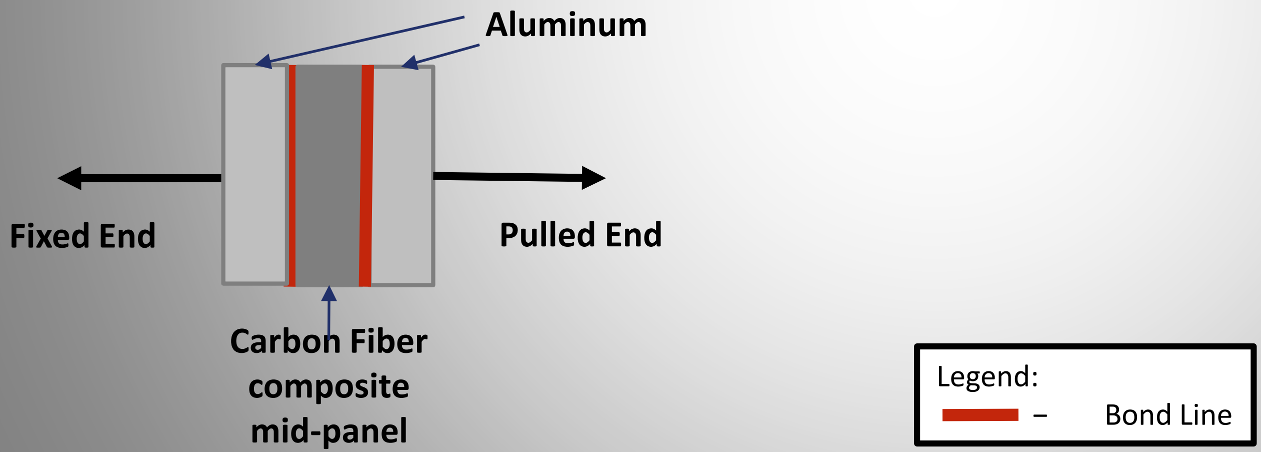
Fall Semester
Out-Of-House CF to Aluminum
(Adhesive Failed)



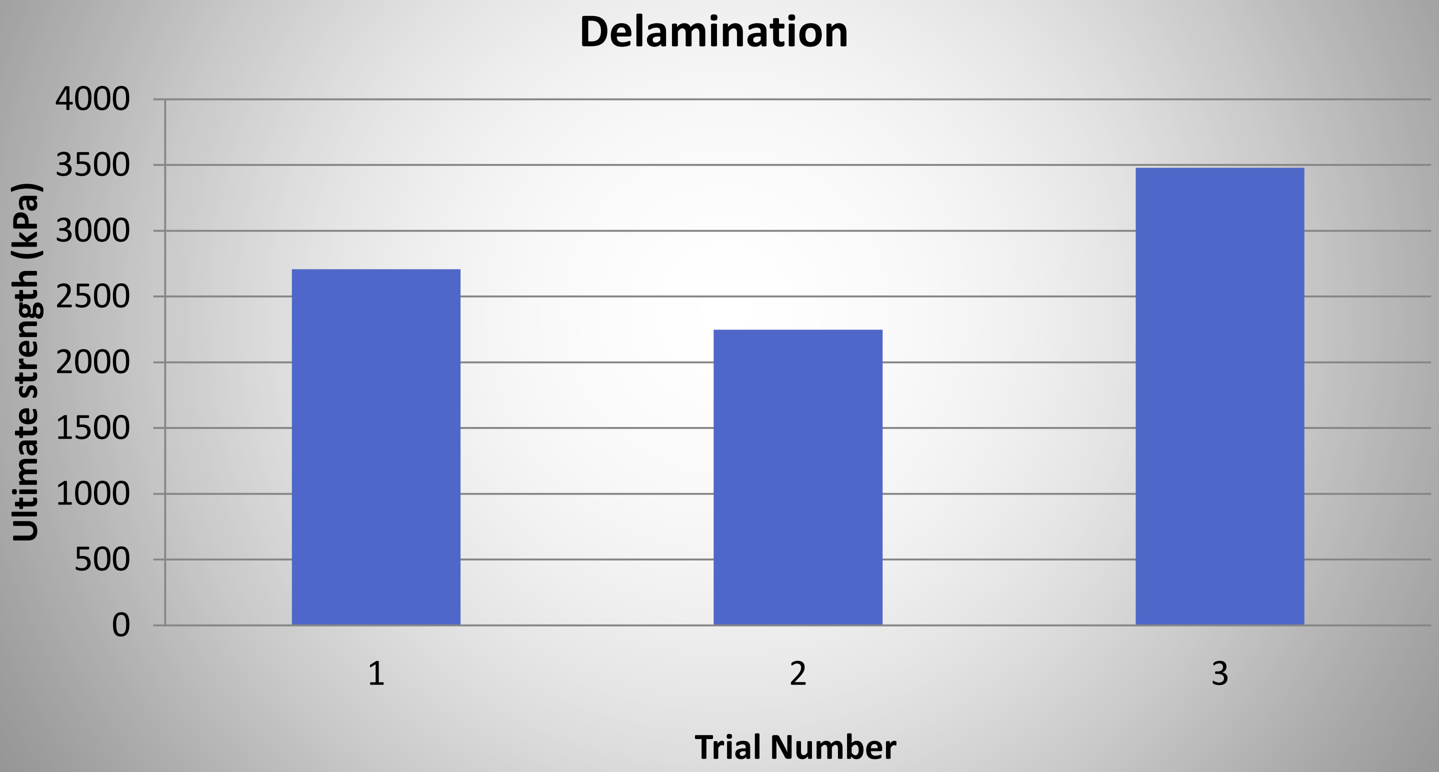
Highest required strength
with FOS = 179 kPa

Delamination Test Results:

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



Delamination Test Results:



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Functional Requirements:

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

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Structure Requirements

Completed

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

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DAQ Requirements

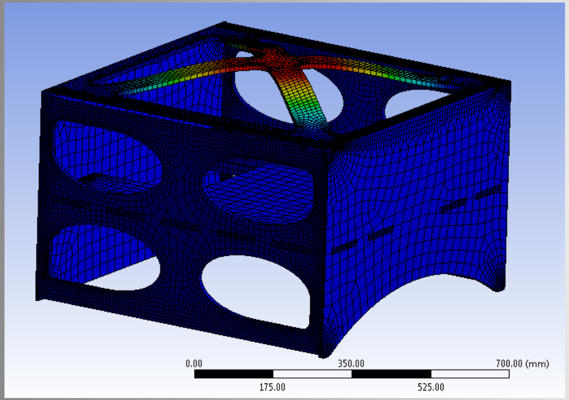
Completed

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

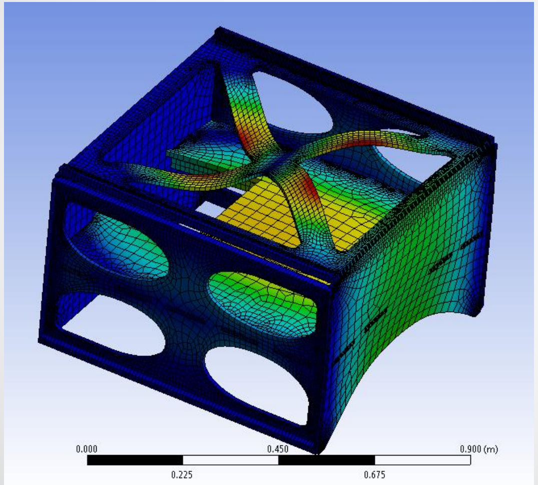
CDR Modal Sweep Predictions:

- Mass Dummies add significant stiffening

Mode 1: 39Hz



Mode 2: 104Hz



Note: Deformations are **not to scale**

Validates DR 5.2

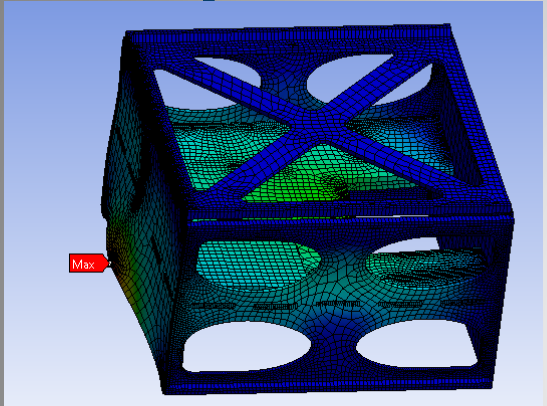
Expected Modes		
Mode	Freq (Hz)	Location (Orientation)
1	35	Top (Zenith)
2,3	95	Top, Mid (Zenith)
4	120	Top (Zenith)
5	170	Radiator (Port)
6	170	Mid, Side (Side)
7	185	Radiator (RAM)

SURREY SATELLITE TECHNOLOGY US

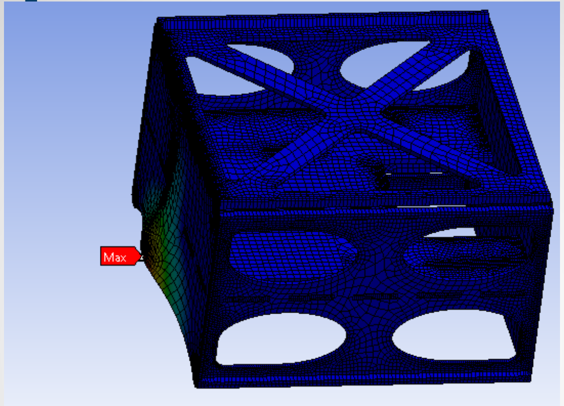
Accelerometer Placement and Validation

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

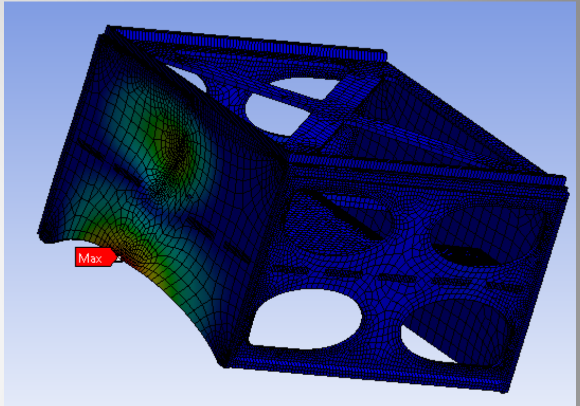
Ram/Wake: Expected Modes



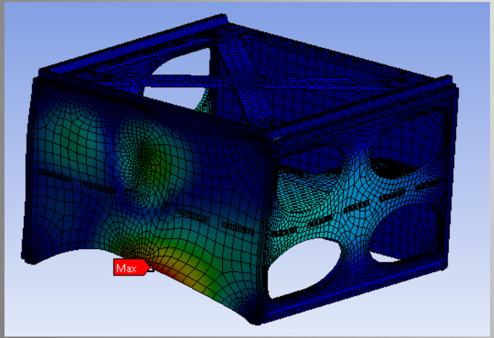
Mode 5: 170 Hz



Mode 7: 185 Hz



Mode 12: 330 Hz



Mode 16: 400 Hz

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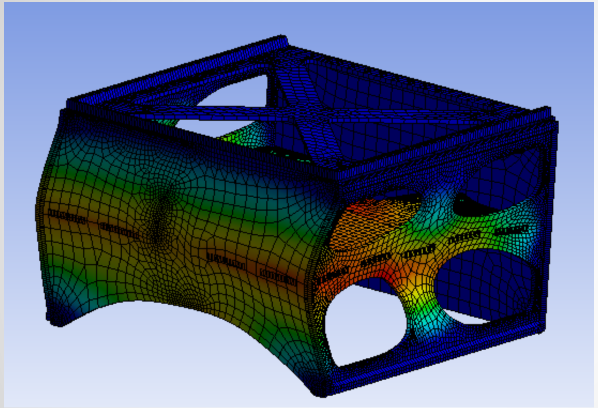
Accelerometer Placement and Validation

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

Port/Starboard: Expected Modes



Mode 6: 170 Hz

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Accelerometer Placement and Validation

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

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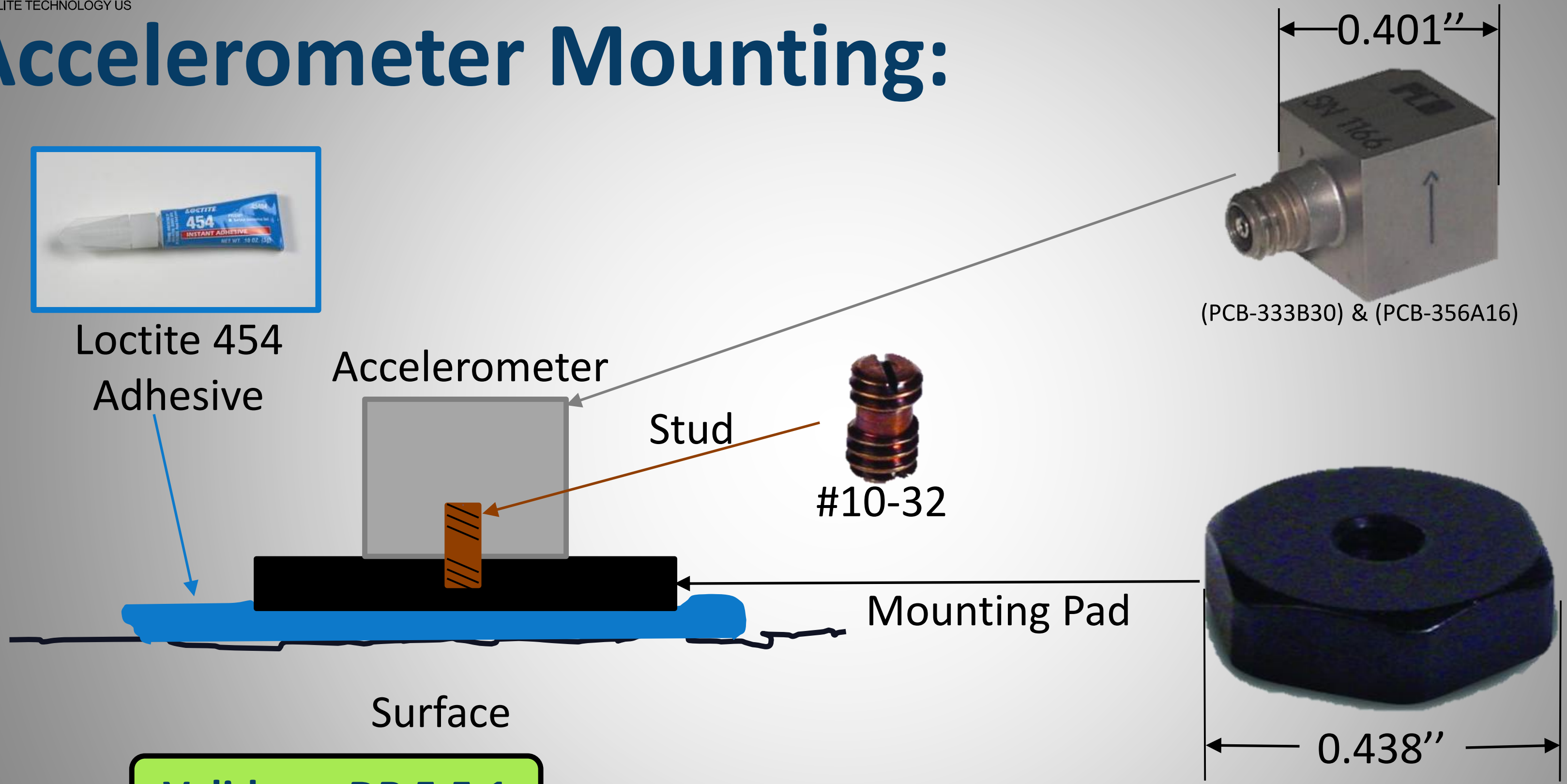
Accelerometer Mounting:



Validates DR 5.5.1

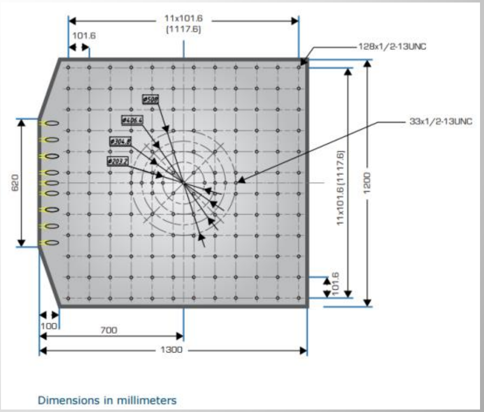
Images from PCB.com

Random Vibration Profile

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

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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Test Concept

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

Random Vibration Profile 1 – Primary Profile

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

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

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

Random Vibration Profile 1 – Primary Profile

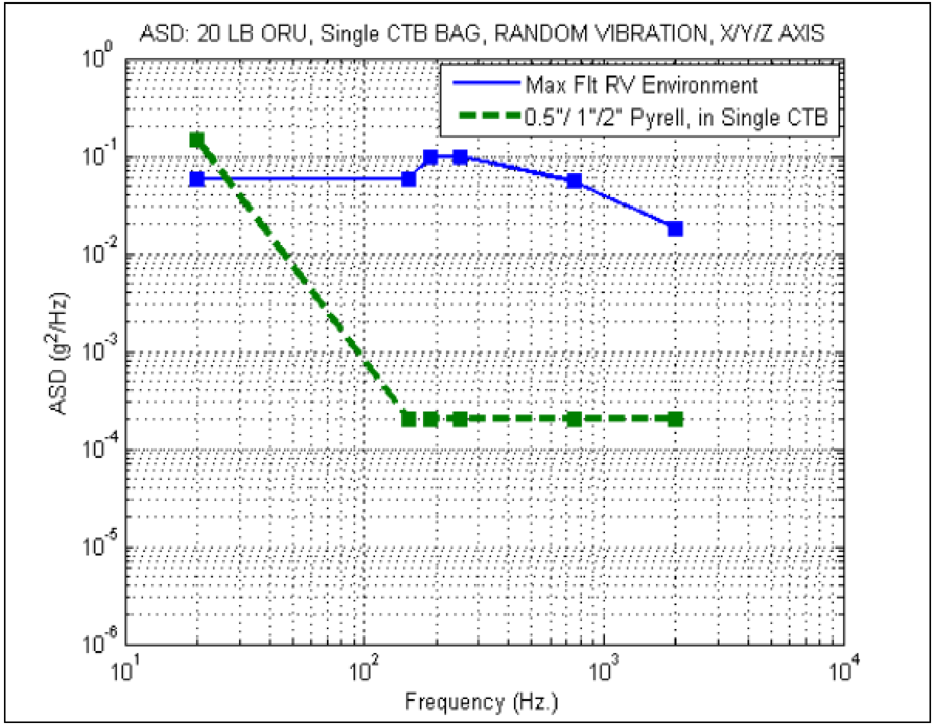

FIGURE 3.1.1.2.1.2.3.2-1 ATTENUATED RANDOM VIBRATION ENVIRONMENT FOR END ITEMS PACKED IN PYRELL AND SOFT-STOWED IN A SINGLE CTB, X/Y/Z AXIS

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Random Vibration Profile 2 – Flight Profile

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

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

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

Random Vibration Profile 2 – Flight Profile

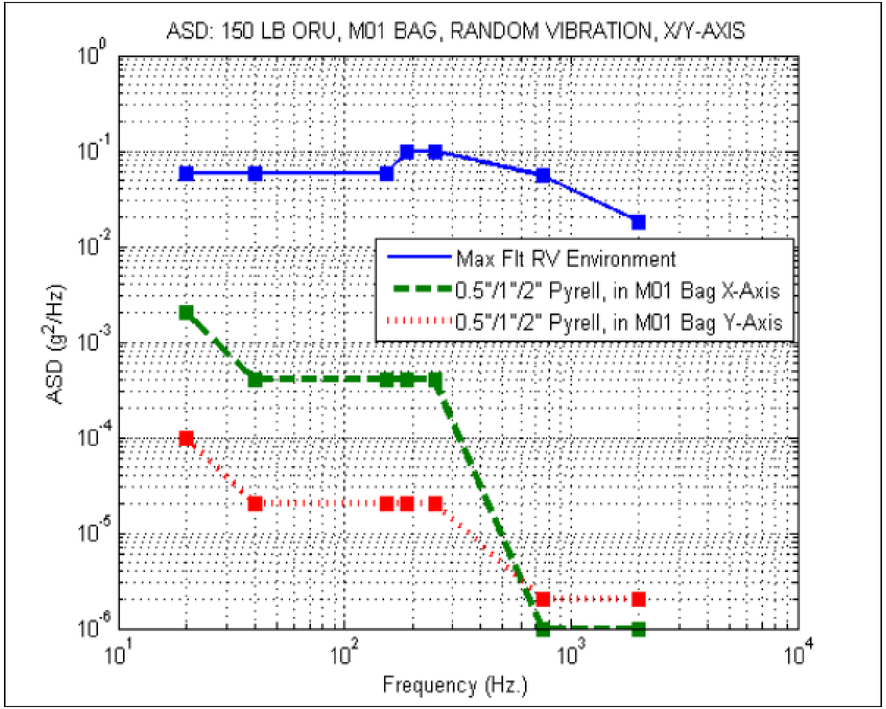

FIGURE 3.1.1.2.1.2.3.2-2 ATTENUATED RANDOM VIBRATION ENVIRONMENTS FOR END ITEMS SOFT-STOWED IN AN M01 BAG, X/Y AXIS

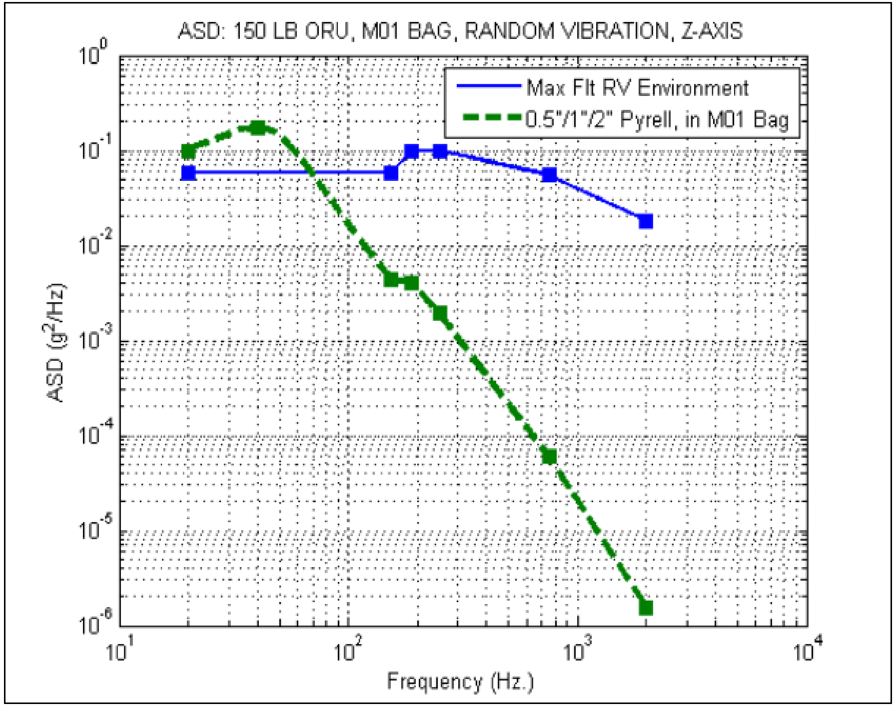

FIGURE 3.1.1.2.1.2.3.2-3 ATTENUATED COMPOSITE RANDOM VIBRATION ENVIRONMENTS FOR END ITEMS SOFT-STOWED IN AN M01 BAG, Z-AXIS

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Vibration Testing – Contingencies

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

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

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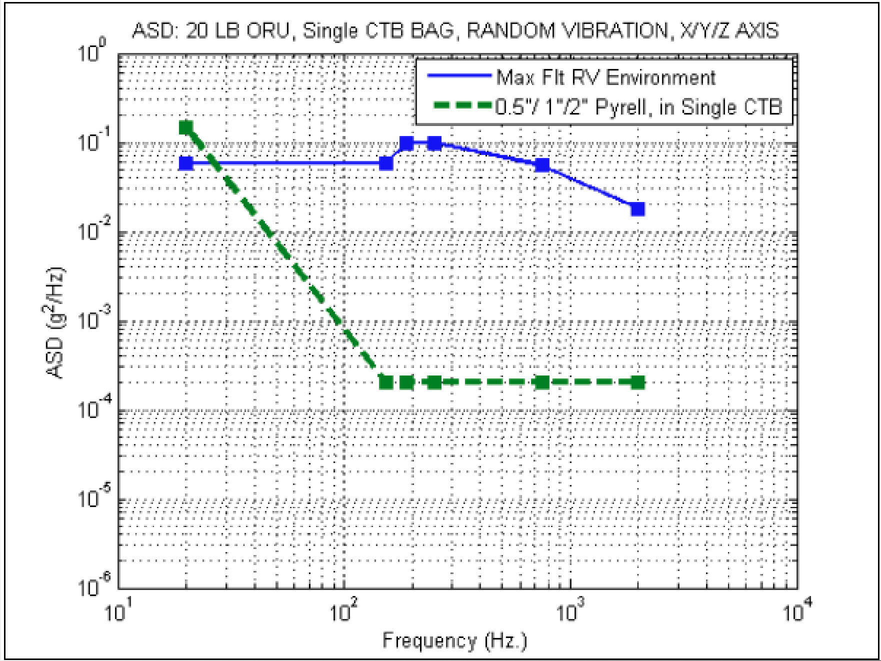
GRMS

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

GRMS Methodology

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

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



Sample ASD Plot for unattenuated and attenuated random vibration

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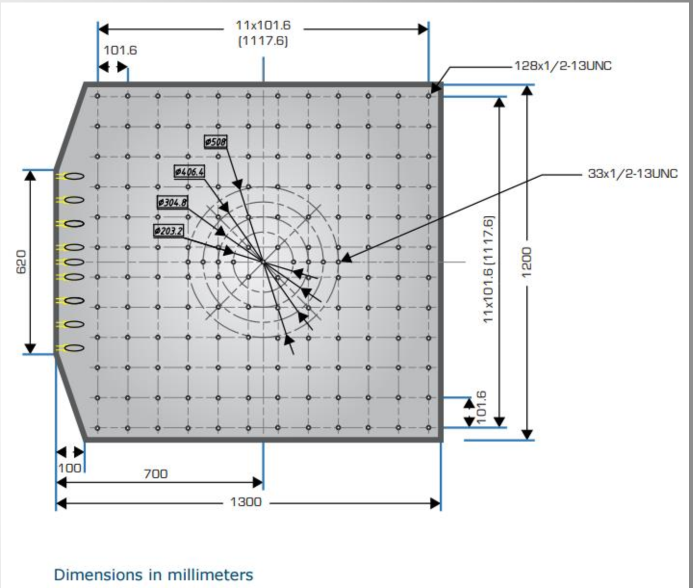
Wrapping & Mounting

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



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

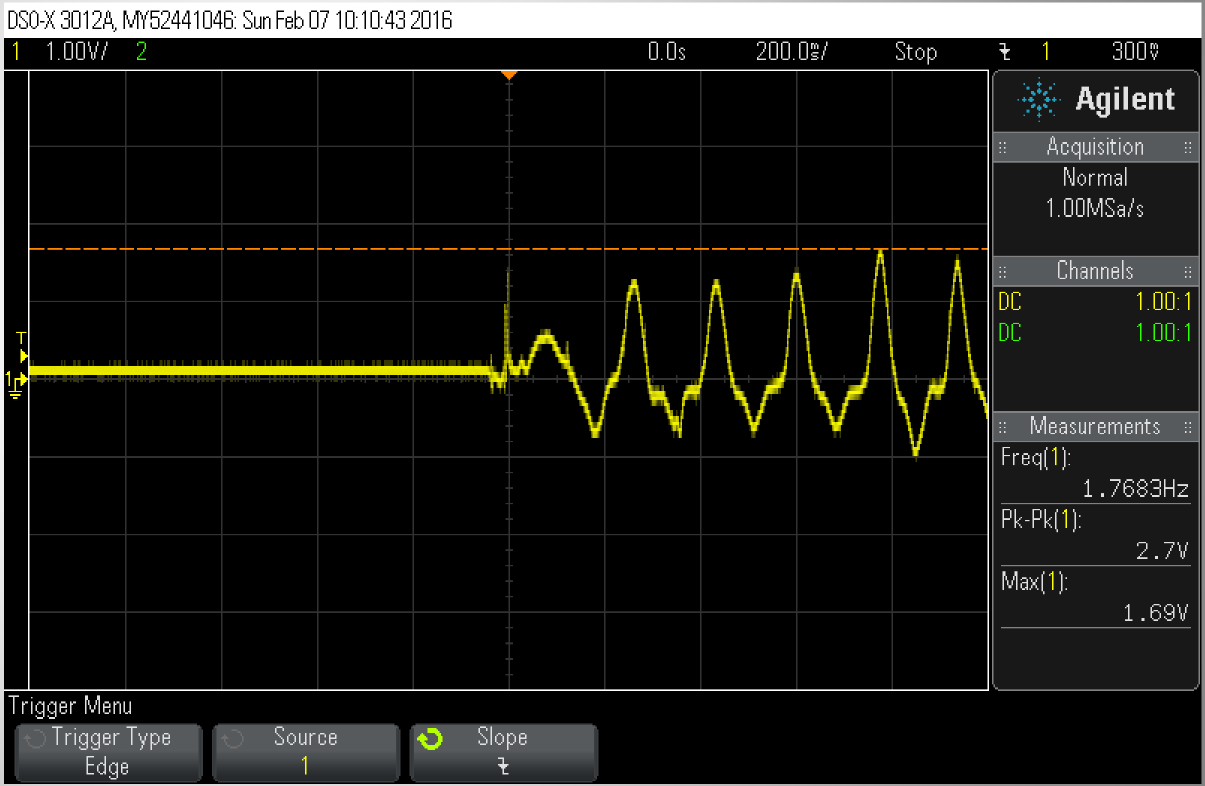
DR 5.4 – Foam Wrapping

- 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	

Signal Conditioning Test Results:

- Functionality test from the accelerometer to the ADC.
- Shook accel and recorded output from signal conditioning circuit



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PSD Test Results: