# Structures

Mark Campbell

AA420 Space Design

# Outline

- Driving Issues and Requirements
- Types of Structures
- Types of Materials
- Fasteners
- Interfaces/Attachments
- Tools
- Design Approach
- Testing

- References:
  - Sections 10.4, 11.6, 12.4, 18.3 of Larson and Wertz
  - Sarafin, Spacecraft Structures and Mechanisms: From Concept to Launch
  - Blevins, Formulas for Natural Frequencies and Mode Shapes

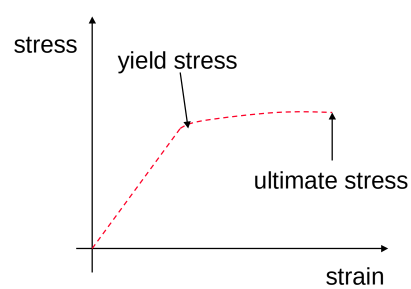
## Driving Issues and Requirements

- Mass
- Static loads from launch
- Vibration and acoustic loads from launch
- Flexible frequency
- Shock loads from deployment, launch
- Thermal stresses, material differences (next lecture)
- Interface attachments
  - ejection system
  - component attachments (bolts, adhesives)
- Safety
- Cost

- Many of these flow down from higher level requirements to constrain the designer to a smaller area.

## Driving Issues and Requirements: Static Loads

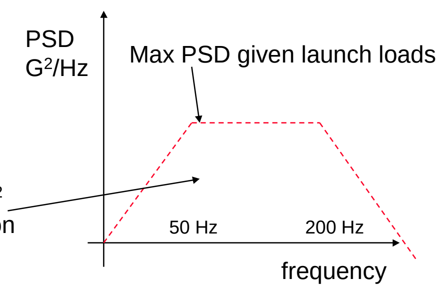
- Maximum during launch
- Really dependent on launch vehicle
- Usually in terms of
  - yield stress
  - ultimate stress
  - factors of safety
- Factors of safety usually depend on safety plan
  - analysis alone (1.6)
  - analysis and test (1.2)




- Margin of Safety = $\dfrac{\text{AllowableStress}}{\text{SafetyFactor*ActualStress}} - 1$ must be $> 0$
- Usually not a big driver in the structural design
- Best tool: Finite element analysis

## Driving Issues and Requirements: Dynamic Loads

- Acoustic loads are very important at lift-off (ground reflection), with large affects on thin materials
- Aerodynamic and internal pressure loads are also important
- Most important is the vibration loads due to primary rocket engine, ground handling, etc.
- Power spectral density is usually the unit of measure




- This is usually the biggest driver in the structural design
- Best tool: Testing and a MATLAB analysis

## Driving Issues and Requirements: Flexible Frequency

- Usually coupled with dynamic response
- Objectives:
  - make sure launch loads do not overly excite first flex mode
  - make sure there is little coupling with launch vehicle
- The first objective is usually met with a minimum frequency requirement, and the dynamic analysis/test
- The second objective is usually met using a minimum minimum frequency requirement
- Best tool: Finite element analysis and testing

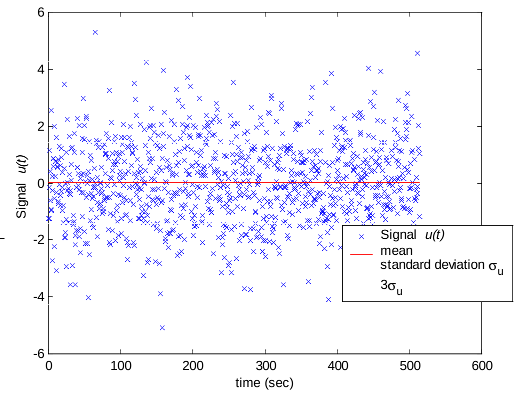
# Random Variables

- Given a random signal *u(t),* the mean, variance, standard deviation, and other statistics can be calculated.

$$\text{mean } \bar{u} = \frac{1}{N}\sum_{i=1}^{N} u_i(t)$$

$$\text{variance } v_x = \frac{1}{N}\sum_{i=1}^{N} \left(u_i(t) - \bar{u}\right)^2$$

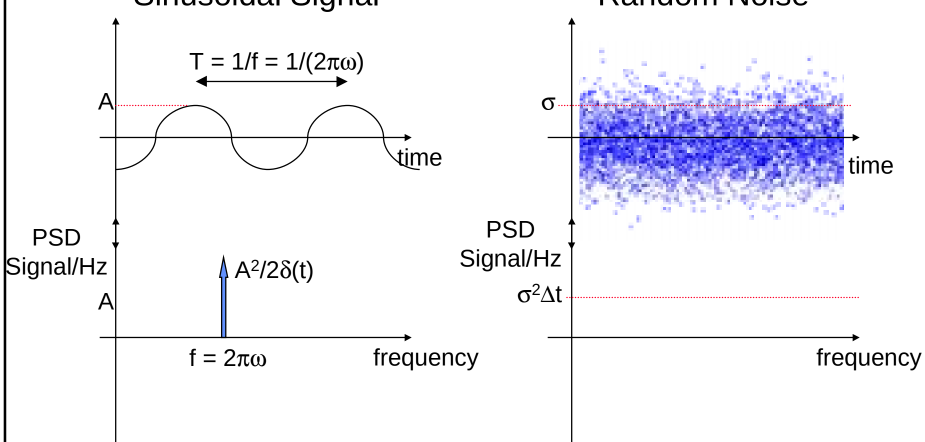
$$\text{stand deviation } \sigma_x = \sqrt{\frac{1}{N}\sum_{i=1}^{N} \left(u_i(t) - \bar{u}\right)^2}$$




- The 3σ value is usually a bound where 99% of the random variable values lie within the boundary.
- For the above example: dt=0.5; N=1028; u=randn(N,1)/sqrt(dt);
- MATLAB functions: mean(u)=0.03; var(u)=2.03; std(u)=1.43;

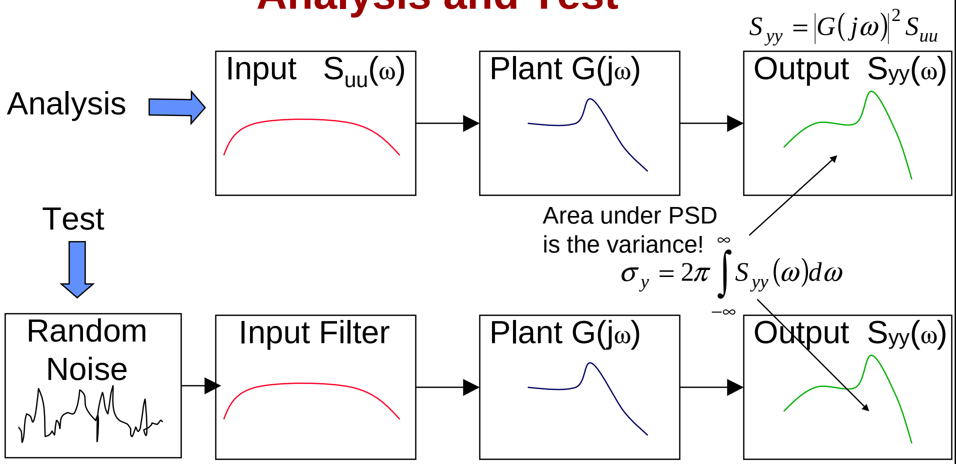
# Stochastic Analysis for Sine and Random Noise

Sinusoidal Signal | Random Noise



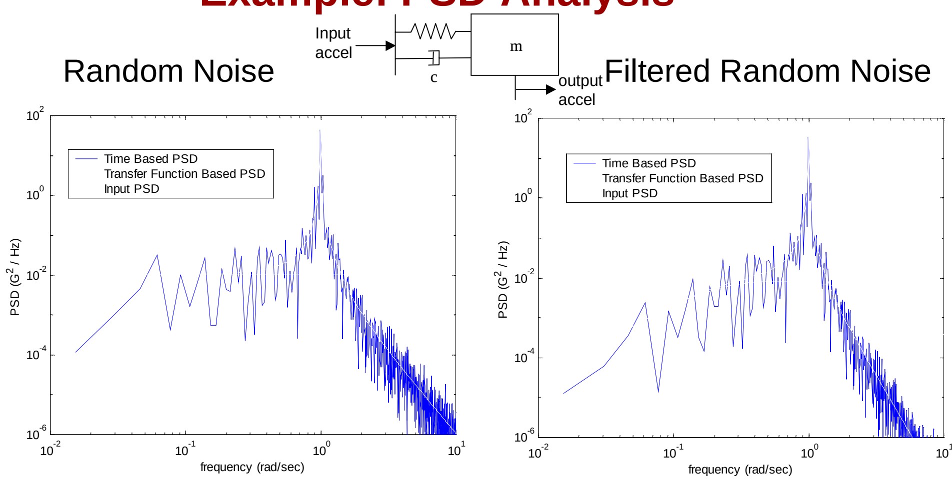

- Sinusoids have all power at one frequency
- Random (white) noise has power at all frequencies - a fictitious mathematical tool

## Random Vibe Analysis and Test




- Analysis can be done given the input spectrum & plant model. MATLAB: Given Suu(ω) and G(jω), then Syy=abs(G).^2.*Suu;
- Testing passes random (white) noise through a filter to create the given input spectrum Suu(ω).

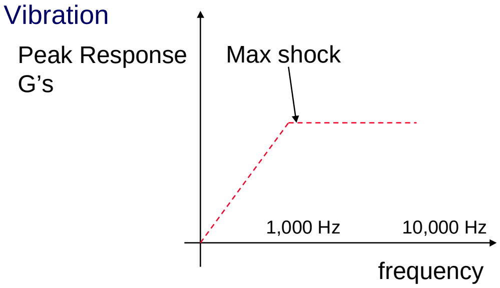
## Example: PSD Analysis




- Time Based Approach: y=lsim(…,u,t), xf=fft(x), Sxx=xf.*conj(xf)/T;
- TF Approach: Sxx=abs(G).^2.*Suu
- The filtered random noise changes the energy in the output

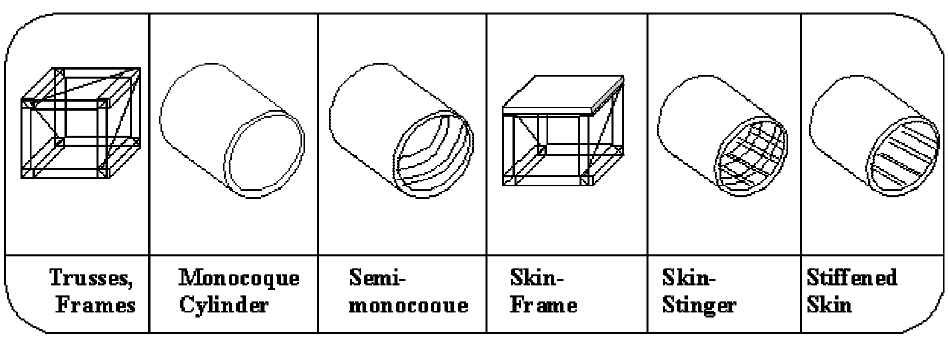
# Driving Issues and Requirements: Shock Loads

- Usually caused by
  - pyrotechnic events (ejection)
  - launch (second stage, etc.)
  - ground handling
- Approach is similar to Vibration




- Best tool: Testing and a MATLAB analysis

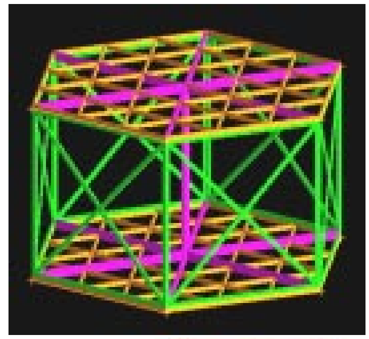
# Types of Structures

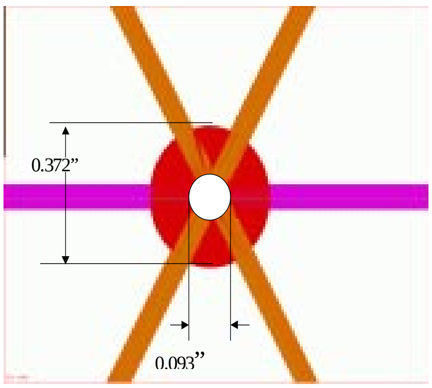


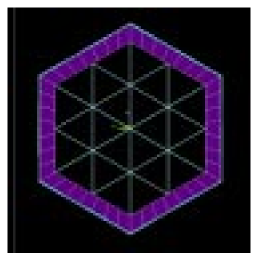

- Also:
  - Honeycomb panels
  - inflatables
  - deployables

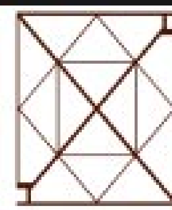
## Example: Isogrid of the UW Dawgstar

- Right Hexagonal Prism
- 18” dia, & 12.625” high
- Aluminum 6061-T651 isogrid
- Total structure mass 2.2 kg





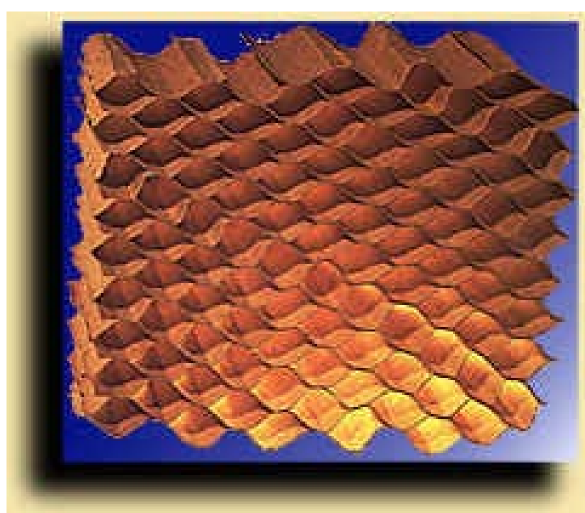


SIDE

TOP

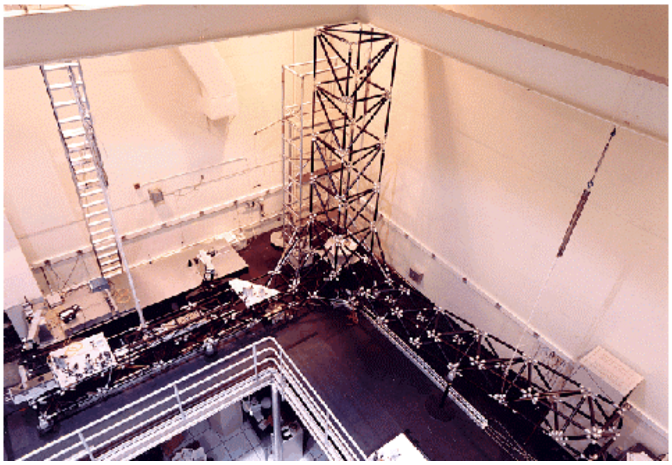
## Example: Honeycomb Panel

- Aluminum panels
- Honeycomb structure in between
- Benefits:
  - lightweight
  - strong
- Drawbacks
  - machining/pricing



## Truss Structure

- Benefits: Strong
- Drawbacks: Not many attachment points for small satellites



JPL Interferometry testbed

## Types of Materials

- Aluminum
- Magnesium
- Titanium
- Beryllium
- Composites
- Section 11.6 has a good discussion of the trades

- Aluminum has been the norm, but this is changing (composites)

- Problems with composites:
  - dependent on human manufacturing, so it must be tested more so than metallic structures - i.e. higher risk
  - attachments (epoxy is difficult, holes introduce stresses)
  - thermal differences

## Types of Fasteners

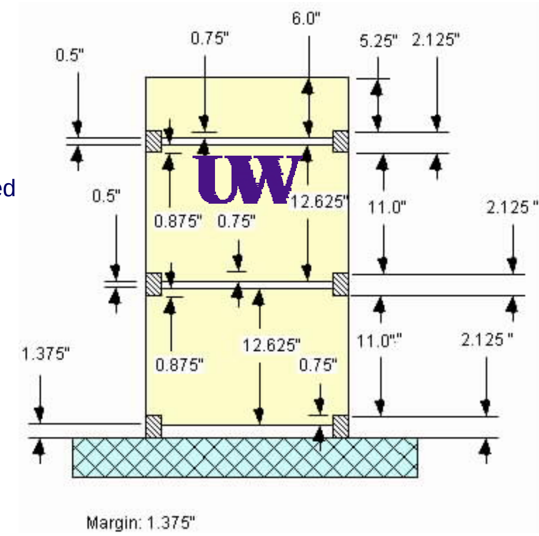
- Aerospace fasteners
  - structural fasteners must be sonsistent with NAS and MIL standards
  - UW Nanosat will just purchase them from NASA GSFC
  - These are #10's at a minimum
- Flat washers are usually used to prevent scratching of finishes
- Torques are usually specified in requirements, and enforced with a torque wrench
- Threaded fasteners require a locking mechanism
  - staking - an epoxy patch on fastener head
  - vispel pellets - polyester patches on screws

## Attachments and Mechanisms

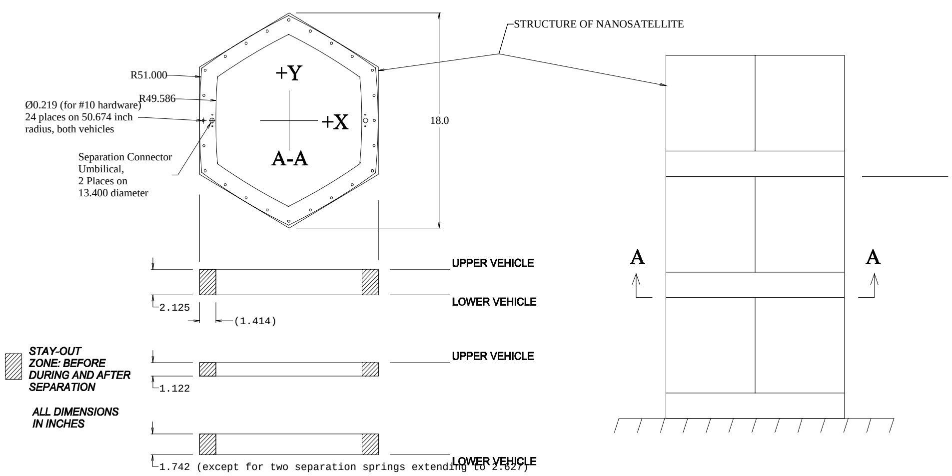
- Attachments and mechanisms drive structural/system design more than one would think
  - ejection system and attachment
  - inner wiring
  - inner electronics box
  - inner battery box
  - deployable antennas
  - deployable booms
- Smart loads analysis can help with this design

# Good Example of Loads Analysis and Requirements Definition: ION-F Deployment

- Stacked with
  - USU: 6”
  - UW: 12.625”
  - VT: 12.625”
- Lightband system selected
  - simple
  - little surface area
  - will be qualified

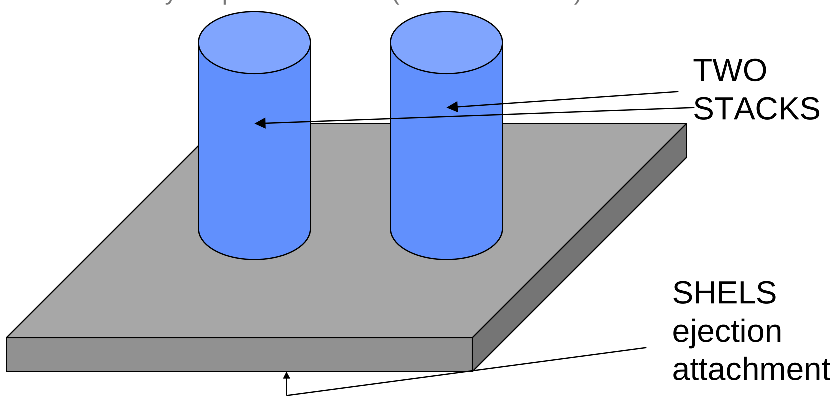



# Lightband deployment system



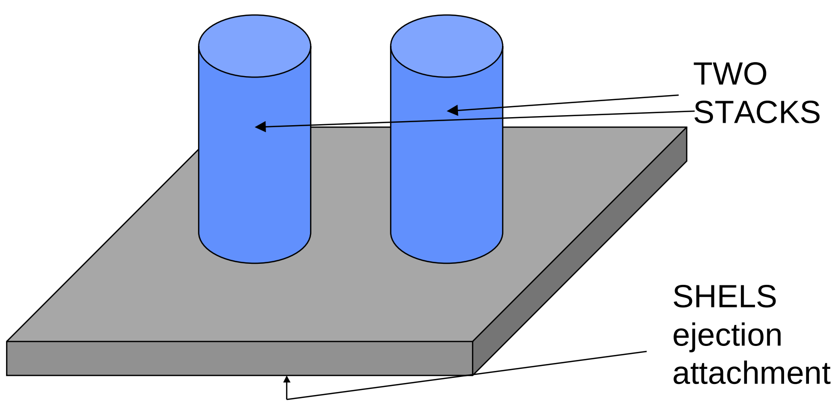
## Flexible Frequency Requirement

- From the Shuttle SHELS platform
  - 100 Hz if only using analysis
  - 50 Hz if using analysis and test for first mode
  - 35 Hz minimum requirement - requires full modal analysis to show how it may couple with Shuttle (15 Hz first mode)



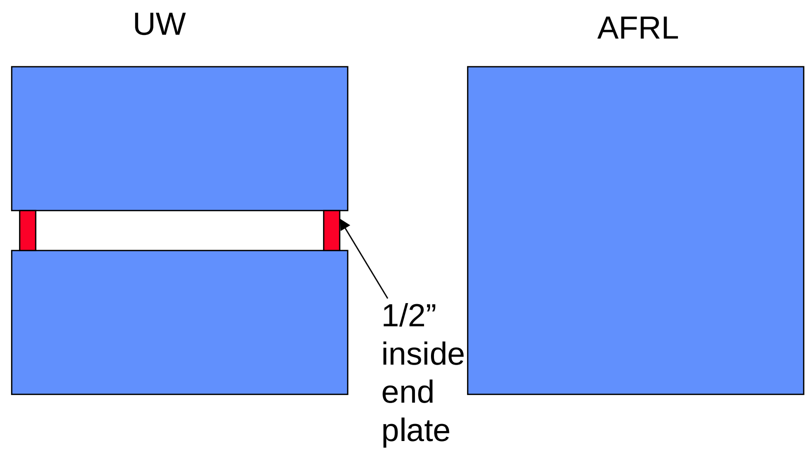

## Flexible Frequency Requirement

- First Requirement from AFRL: 50 Hz for each nanosat
- A few months later: 50 Hz for each stack (~90 Hz for each nanosat)
- A few months later: 50 Hz for whole platform, 150 Hz for each stack



## Flexible Frequency Requirement

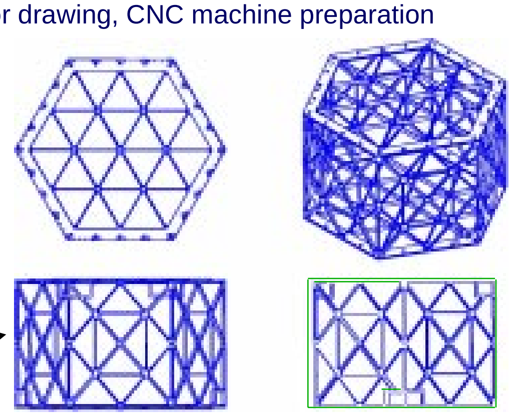
- Dawgstar analysis of stack: currently at ~55 Hz
- AFRL analysis of each stack: ~140 Hz
- Why?: ejection system modeling (watch how your loads move!)




## Tools

- Finite Element Analysis (static and dynamic loads)
  - ANSYS (on AA system)
  - Nastran
- MATLAB for dynamic loads analysis (on AA system)
- CAD or like packages for drawing, CNC machine preparation
  - Unigraphics (on AA system)
  - IDEAS (on Nanosat Lab system, can also do thermal analysis with the same model!)
  - Autocad
  - etc.

Dawgstar IDEAS model



## Design Approach

- List design drivers, associated calculations, narrow requirements
- Fill out more detailed specification based on template and mass, test, and and other requirements
- Examine types of materials to see the benefits and drawbacks to each (Al, composite)
- Examine types of structures to see the benefits and drawbacks to each (isogrid, Honeycomb sandwich, truss)
  - This includes price, lead time, whether we can develop it here, mass, etc. i.e. all of the design drivers!
- List and examine each of the interfaces (see previous slides)
- After narrowing the options to 1-2, do a first cut model in ANSYS to analyze static, dynamic requirements
- Move to IDEAS/Unigraphics for the prototype

- All during this process, update specs and keep systems engineers informed of changing designs, options, conclusions, etc.

## Testing

- Random Vibe: a vibration table, similar to the one at Primex for vibrations in three DOF.
- Sine Sweep: similar, but stepping through a series of sinusoidal excitation frequencies - good for nonlinear systems.
- Shock: Impact testing, similar to a hammer
- Static: simply add an even distribution of weight to the structure.