Combined Environment Testing to Reduce Payload Mass, Cost and Mission Risk

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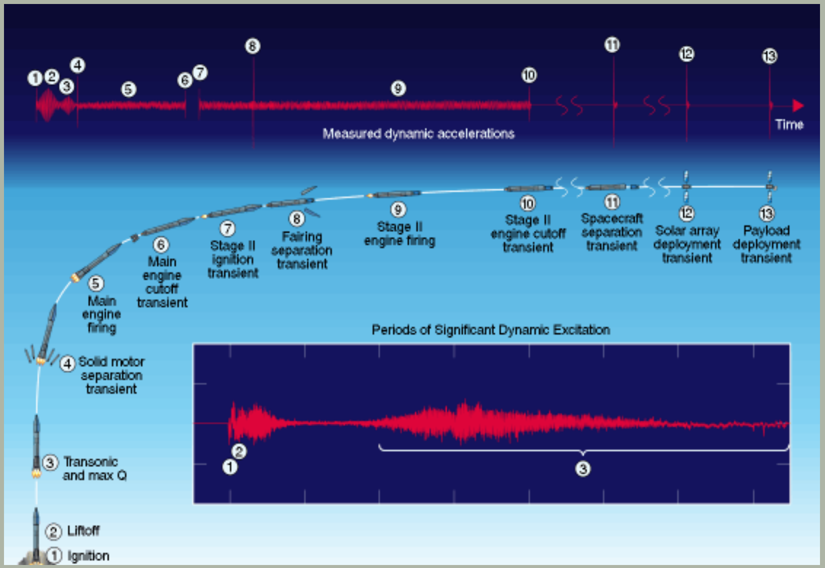
Main Objective

Combine Vibration, Shock and Acceleration Environments for Equipment Testing to Launch and Re-entry Profiles



Project Contributors

- Joint project between three entities
  - Drexel University
    - Provide test article
    - Perform dynamic system modeling and simulations
  - American Aerospace Advisors Inc and ETC's NASTAR Center
    - Developing an integrated centrifuge-shaker system to replicate launch and re-entry profiles

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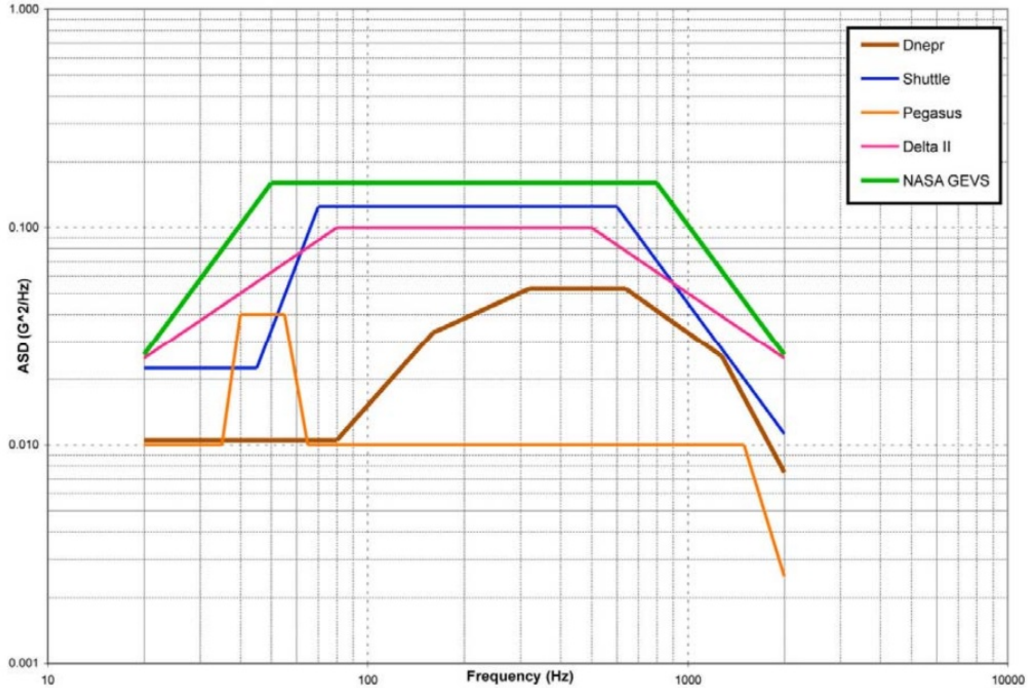
Background

WHY IS THIS TYPE OF TESTING USEFUL?

Current Test Methods

- Vibration Testing
  - Shock
  - Sinusoidal
  - Random
- Current testing standards simulate loads much greater than actual launch conditions
  - With current test methods, large test loads are necessary because actual launch environments cannot be simulated

NASA-GEVS random vibration profile, the CubeSat standard, in some cases, greatly exaggerates the launch vehicle's random vibration environment

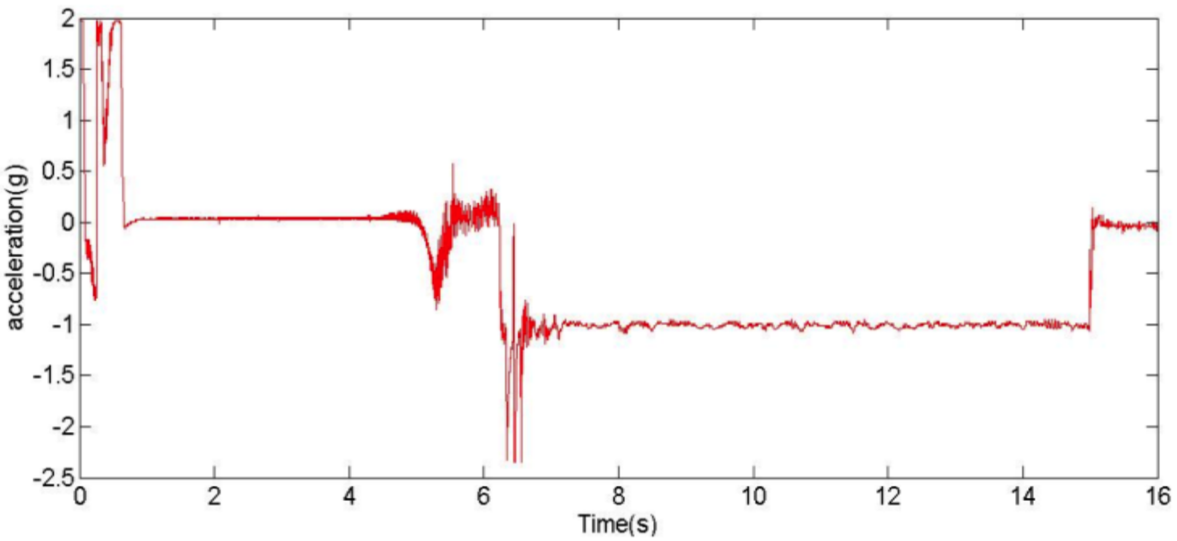


http://www.cubesat.org/images/LaunchProviders/mkIII/p-pod%20mk%20iii%20icd.pdf

Random vibration profile of various launch vehicles

Ground shake tables do not simulate sustained acceleration.

By using combined environments we can study effects of combining multiple types of loads and the possibility of reducing the magnitude of these loads

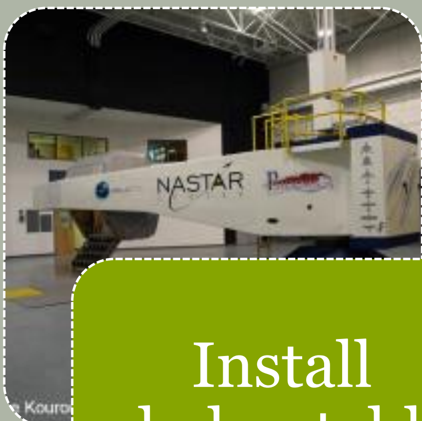


Actual Launch Data from a NASA Terrior-Orion Sounding Rocket

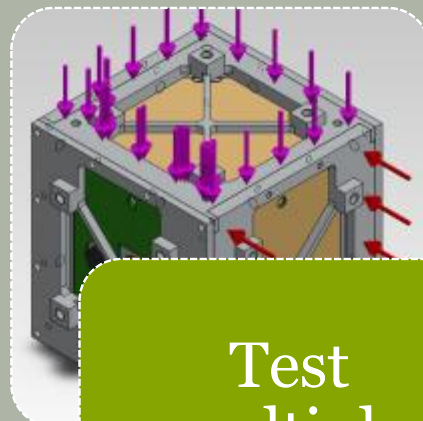
Capabilities

- ATFS-400 Space Training System
  - Human Space Training
    - Currently training Virgin Galactic pilots and customers
  - 25' planetary arm
  - Max G level 12G's (25G optional)
  - Max G onset/offset rate 10G/s
  - Gondola has ±360° pitch and roll
  - Force feed back control loading

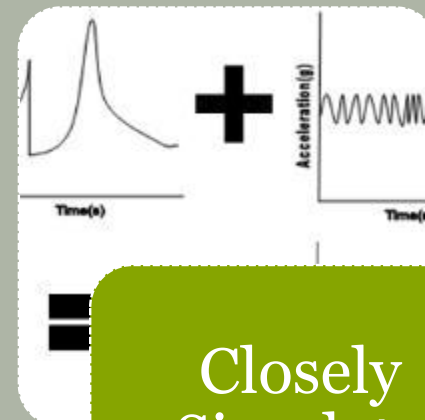
Combined-Load Testing



Install shaker table inside of centrifuge



Test multiple axes at one time



Closely Simulate Launch Conditions

Benefits of Combined Testing

- Fly the 3D mission profile before launch
  - Realistic, dynamic 3-DOF acceleration, vibration and shock profiling
  - Reduces risk of unknown effects of combined environments
- Guidance, Navigation and Control (GNC) system development & testing
  - With physical inputs to Inertial Measurement Units (IMU's)
- Fluid Systems – tanks, valves, piping, assemblies…
- Flight Termination Systems
- Integrated Testing
  - Eliminates sequential testing
    - Saves time, labor and cost
    - Reduces schedule risk
  - May allow qualification to lower overall levels
    - Resulting in lower mass and improved system performance

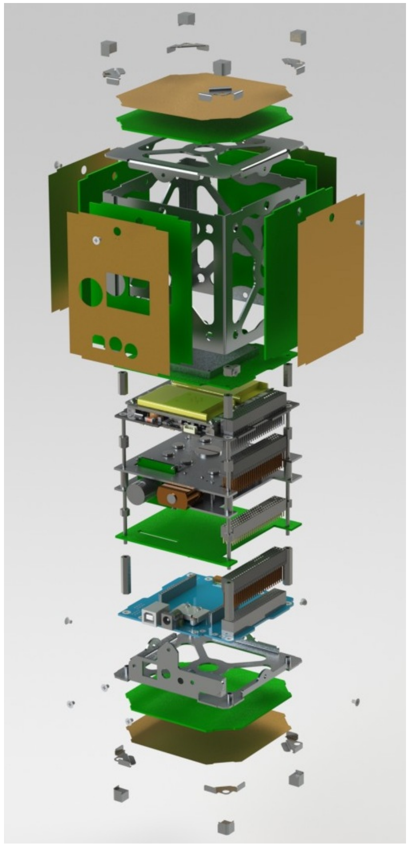
Modeling, Simulation and Analysis

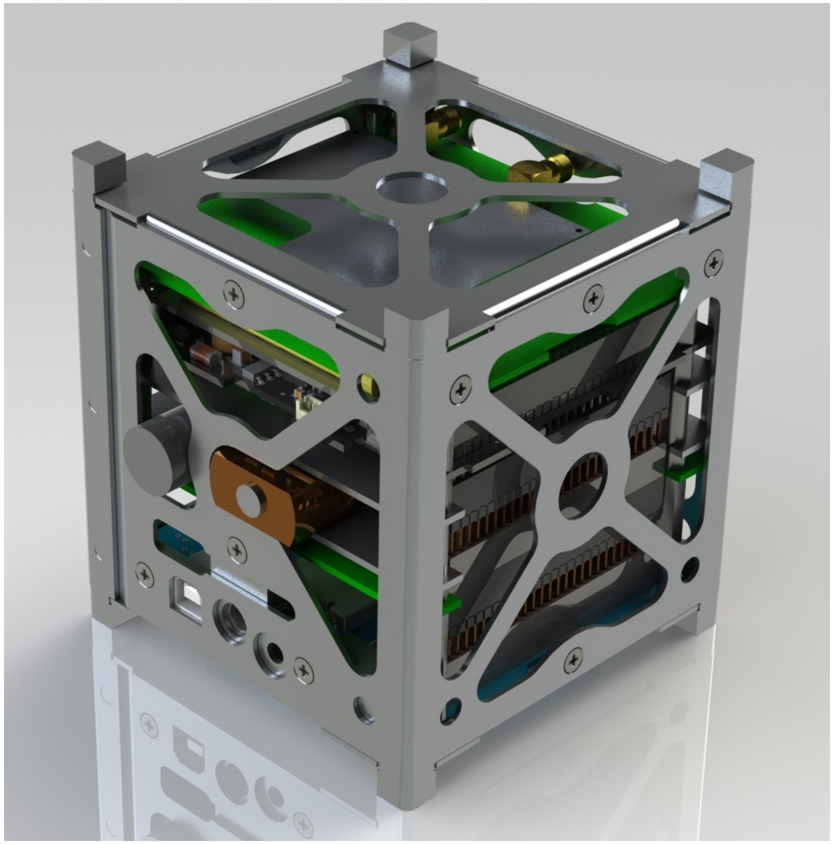
COMBINED-LOAD TESTING ON DRAGONSAT-1

Method of Analysis

1. 3D Modeling
2. Frequency Analysis & Result Verification
3. Random Vibration Simulations
4. "Combined Environment" Frequency Analysis

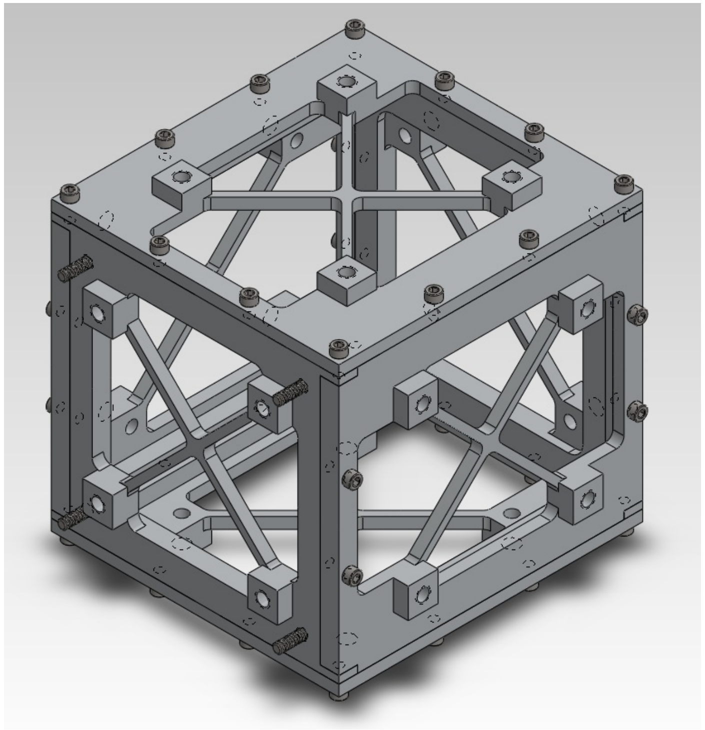
Drexel's fully modeled and assembled 1-U CubeSat DragonSat-1 will be tested using proposed method.

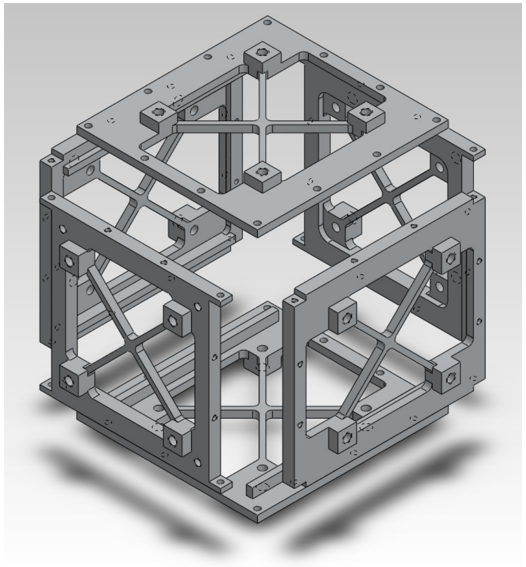




Test Article

A test pod has been designed as part of the test fixture to contain the CubeSat while replicating the P-POD environment





Test Pod

Frequency Analysis

- Calculated natural frequencies and mode shapes
- Required for accurate random vibe results
- 100 modes calculated to achieve >80% MPF in all three axes

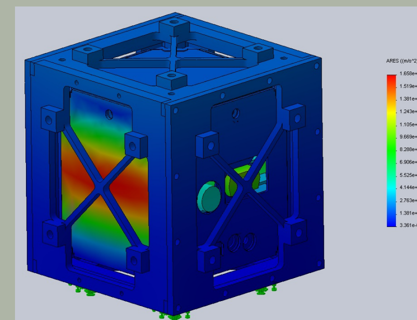
Mode No.	Freq (Hertz)	X direction	Y direction	Z direction
1	259.74	1.153E-05	1.179E-06	3.263E-02
2	274.73	1.807E-02	7.042E-06	2.175E-02
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
98	2256.3	2.016E-03	8.545E-07	1.457E-04
99	2271.8	9.642E-07	2.491E-04	2.833E-10
100	2325.3	2.980E-04	2.286E-06	2.463E-04
		Sum X = 0.84251	Sum Y = 0.90207	Sum Z = 0.83589

Random Vibration Simulations

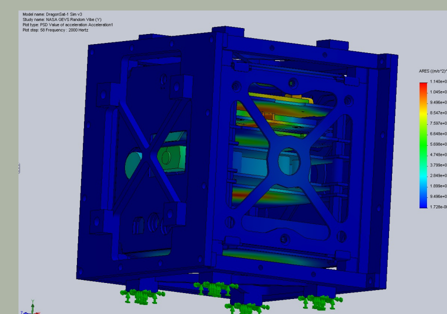
- Random Vibration simulations have been performed in all three axes
- NASA GEVS Qualification ASD profile was used

Generalized Random Vibration Test Levels
Components (STS or ELV)
22.7-kg (50-lb) or less

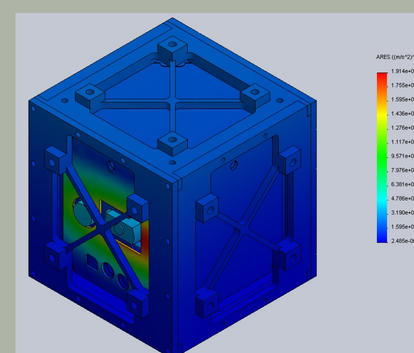
Frequency (Hz)	ASD Level (g^2/Hz)	
	Qualification	Acceptance
20 20-50 50-800 800-2000 2000	0.026 +6 dB/oct 0.16 -6 dB/oct 0.026	0.013 +6 dB/oct 0.08 -6 dB/oct 0.013
Overall	14.1 G_{rms}	10.0 G_{rms}



X-Axis Excitation

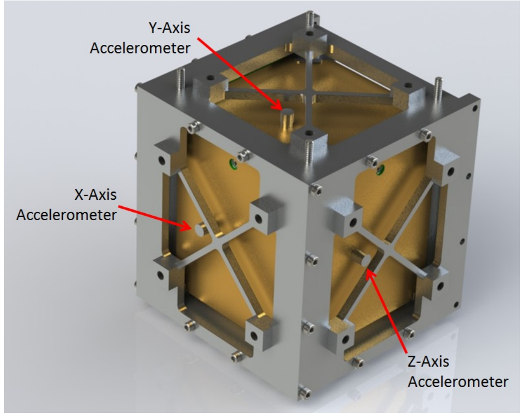


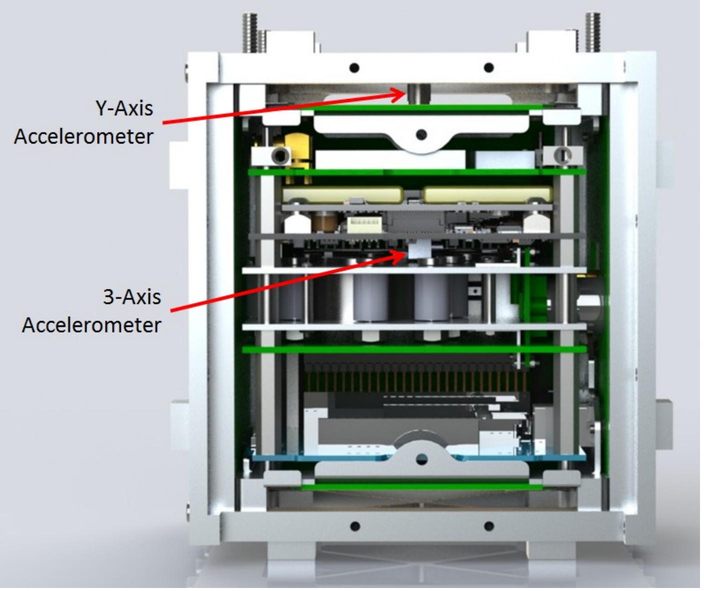
Y-Axis Excitation



Z-Axis Excitation

Random Vibration Simulation determined ideal accelerometer placement for real world test





Accelerometer Locations

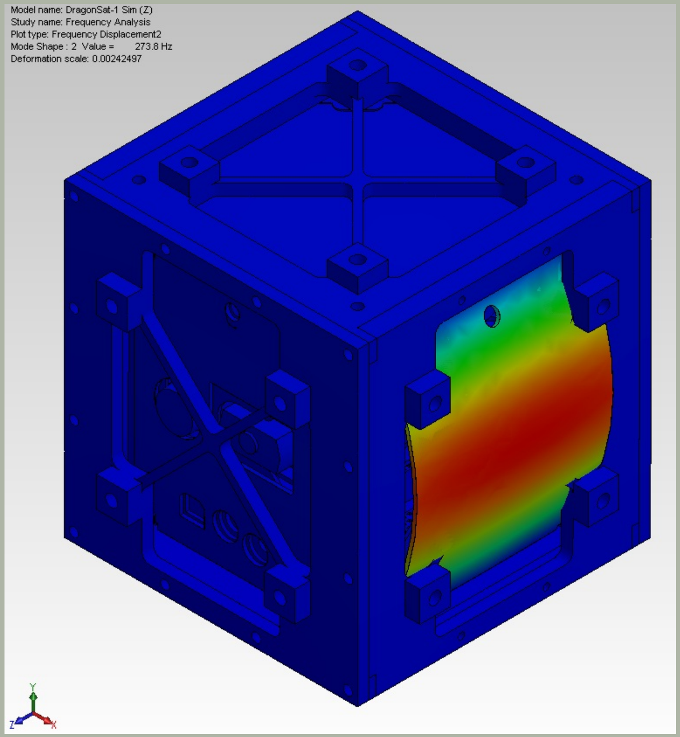
“Combined Environment” Frequency Analysis

- Frequency Analysis has also been performed using “Combined Environments”
  - Centrifugal Force has been added around an external axis
    - Simulates hub of centrifuge

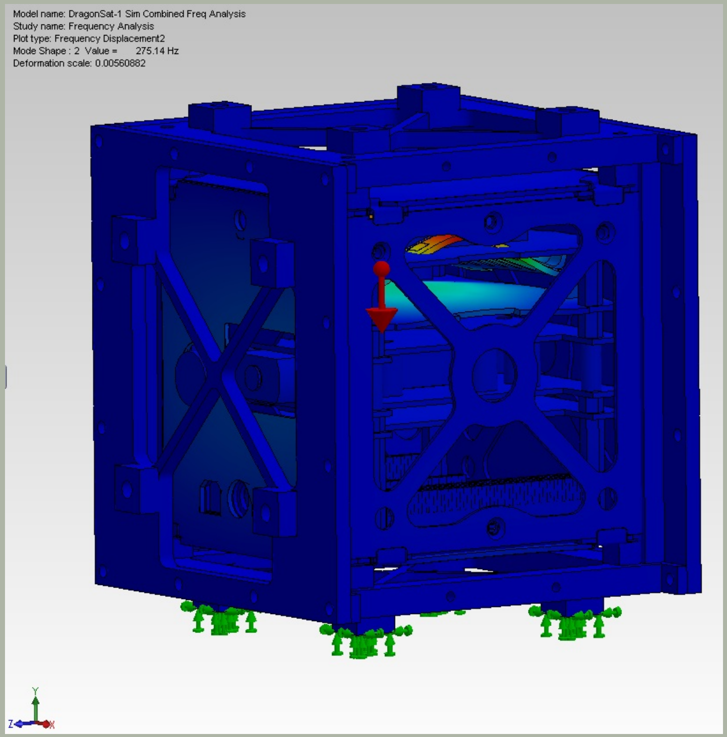
Mode #	Traditional Environment		Combined Environments	
	Natural Frequency (Hz)	Direction of Mode Shape	Natural Frequency (Hz)	Direction of Mode Shape
1	259.74	Z	272.33	Z
2	274.73	Z	275.14	Y
3	274.81	X	283.25	X
4	278.40	Y	287.69	X
5	285.90	X	287.79	Z

Natural frequency shifts and mode shape changes as expected with “combined environments”

Example of “Combined Environment Effects



Mode 2 using traditional analysis



Mode 2 using “combined environments” analysis

“Combined Environment” Frequency Analysis Results

- External forces created “preloaded” conditions on panels
  - Essentially increased the spring constant “k” of the component
  - Higher frequency required to excite the component
- In some cases, the “preload” condition made a substantial difference
  - Spring constant of a component became much higher
  - Other components became excited first
    - Complete change in mode shape and direction

Moving Forward

- Frequency analysis will be performed on AAAI's shaker table designs
- Test procedure will be finalized within the month
- DragonSat-1 assembly will be completed
- Baseline ground testing will occur prior to full scale combined environments test in late September

Conclusions

- Testing can replicate actual launch environment
- Models thus far indicate shifts in results as compared with traditional testing
- Risk of unknown reactions in combined environments is reduced
- Time spent on testing is greatly reduced
- Lower test levels may be acceptable saving mass and improving performance

Thank you. Questions?

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