Spacecraft/Payload Dynamic Tests: Qualification and Workmanship

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Overview

- Launch Induced Vibrations:
  - Transients, random vibrations, and quasi-sinusoidal.
    - Dominant in low/mid frequencies
  - Acoustics induced vibrations, aerodynamic noise, wind gusts
    - Dominant in the mid-to-high frequencies and only effective for acoustically responsive structures.
- Spacecraft Vibration Test Objectives
  - Uncover workmanship problems in the fully assembled flight spacecraft.
  - Validate the functional and structural integrity of the flight spacecraft for the mission low/mid frequency structurally transmitted vibration environments.
- Spacecraft Acoustic Test Objectives
  - To expose the fully assembled Observatory to mid- and high-frequency launch environments
    - This test covers both dynamic qualification of light weight and large surfaced structures (i.e. solar arrays, reflectors, panels, etc.) and for partial screening/workmanship of the "as-built" hardware.

Spacecraft system vibration test not intended to replace structural strength qualification testing. Vibration testing can detect design issues that cannot be uncovered by static loads or by acoustic testing in the low to mid frequencies.

Spacecraft Vibration Test Benefits (1)

- Vibration is the only test that simulates the low/mid frequency mechanically transmitted launch vibration environment.
  - Acoustics provides significant excitation of low mass/large surface structures only above ~100 Hz for most S/C modes.
  - Acoustic test spectrum typically rolls off quickly below 100 Hz.
  - Heavy components are not excited by acoustics.
  - Vibrations and acoustics excites spacecraft structures differently!
  - If acoustics were really an adequate dynamics qualification test by itself, structure would be designed to the acoustic loads, not to the coupled loads analysis.

Spacecraft Vibration Test Benefits (2)

- Qualification by analysis or by static test is often not practical for frequencies above ~50 Hz and for non-primary structure: L/V - S/C coupled loads analyses typically cuts off at 40 to 60 Hz and S/C model does not include secondary structure, non-structural hardware, or ancillary hardware.
  - *Cable harnesses, bellows, connectors, actuators, plumbing lines, wave guides, brackets, dampers, shades and shields, articulation/deployment mechanisms, shunt heaters, louvers, purge equipment, hinges and restraints, blankets/supports, etc.* are usually responsive to low/mid frequencies.
  - These items are typically tested only at the S/C level.

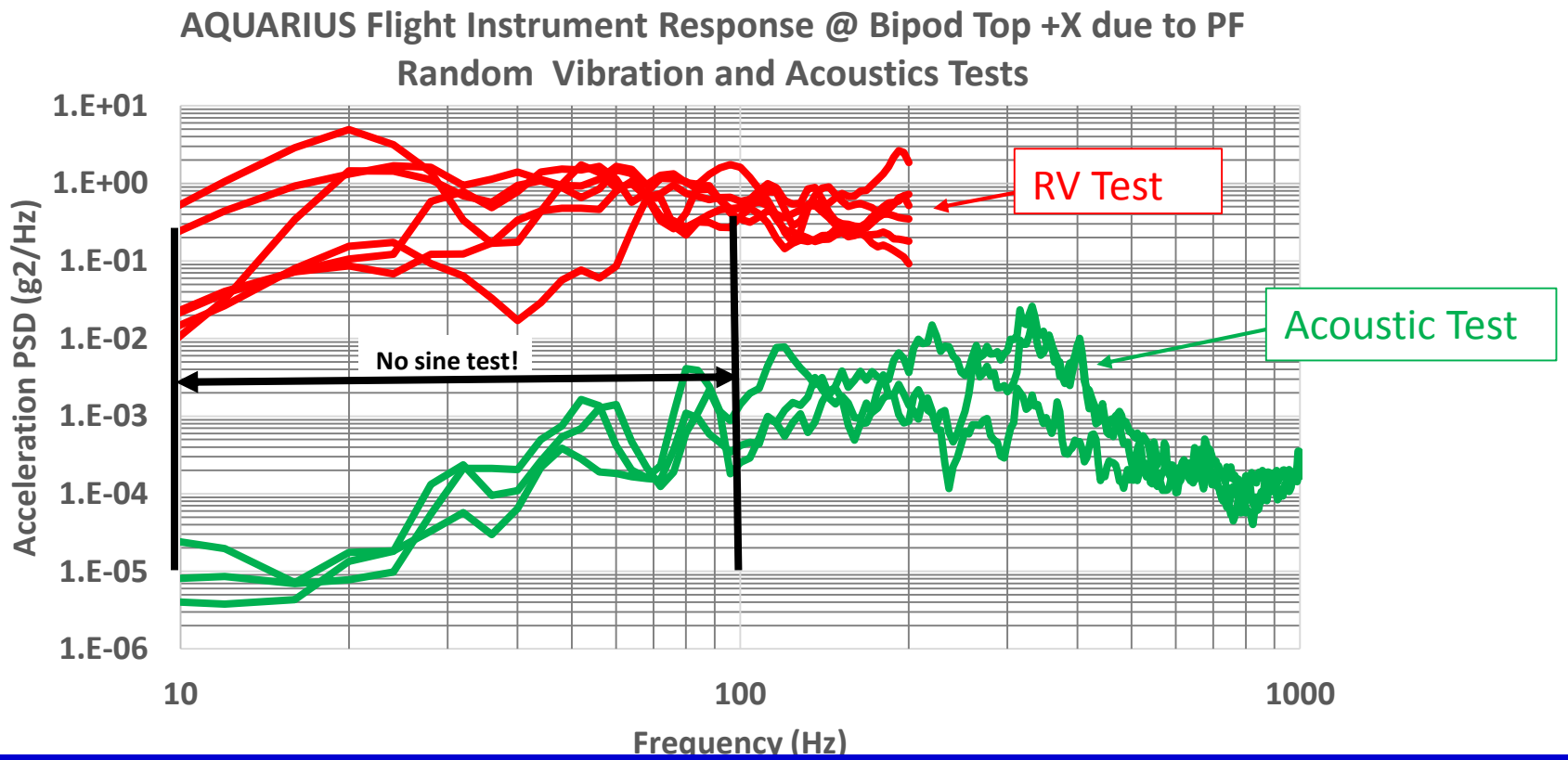
Spacecraft Vibration Test Benefits (3)

- The flight system vibration test traditionally provides the only test verification of the mechanical integrity of flight subsystem interfaces. (Structural loads tests are often performed only on non-flight primary structure.)
- The spacecraft vibration test signature survey may eliminate the requirement for a separate fixed base modal test for some spacecraft, especially those with structural design heritage.
- **Bottom line:** Spacecraft vibration tests provide a workmanship screen and qualifies the flight system for a significant mission environment. Analysis and other tests, such as static loads or acoustics are not a substitute. The vibration test may also be used to satisfy FE model verification requirements.

JPL Rational for Random Vibration Testing

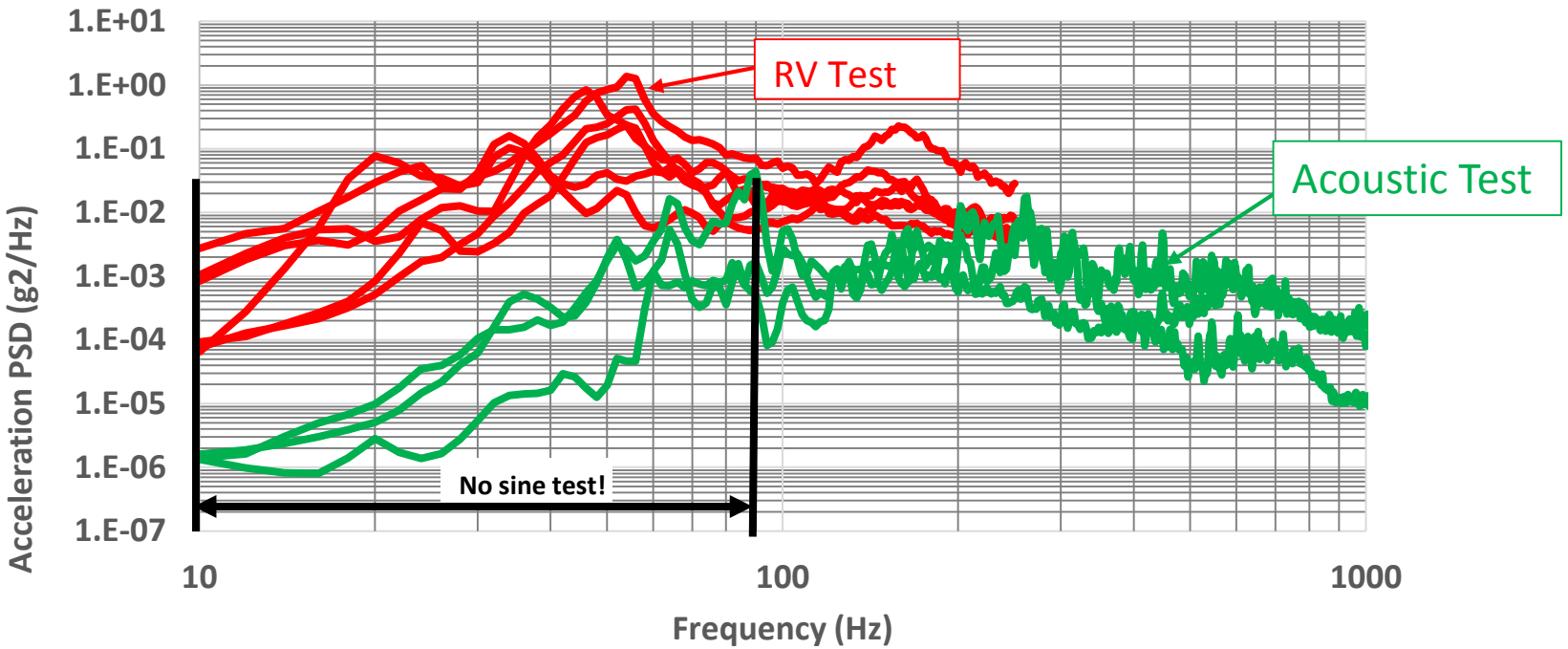
- Workmanship related issues often uncovered by random/sine vibration tests
- Random vibration is effective workmanship screen for non structural hardware that is typically tested only at the system level, such as
  - Cable harnesses, bellows, connectors, actuators, plumbing lines, wave guides, brackets, dampers, shades and shields, articulation/deployment mechanisms, shunt heaters, louvers, purge equipment, hinges and restraints, blankets/supports, etc.
- Random vibration is good simulation of the flight vibration environment characteristics, alleviates the over-test inherent in sine vibration test.
- Reduces resonance buildup. Sine vibration is swept relatively slowly across resonance frequencies, allowing full build up of each resonance. Random vibration induces excitation of all frequencies at once, with randomly varying amplitudes.
- Random vibration reduces the number of peak response cycles when compared with an equivalent sine sweep test.
- Excites modes simultaneously thus simulate flight environment well since dominant flight events are often broadband.

Why Random Vibration is Required?
(Example from Aquarius RV and Acoustic Tests)



RV from 10 Hz to 200 Hz provided qualification and workmanship screening test, whereas acoustic did not (no sine test was performed); design flaws were discovered!

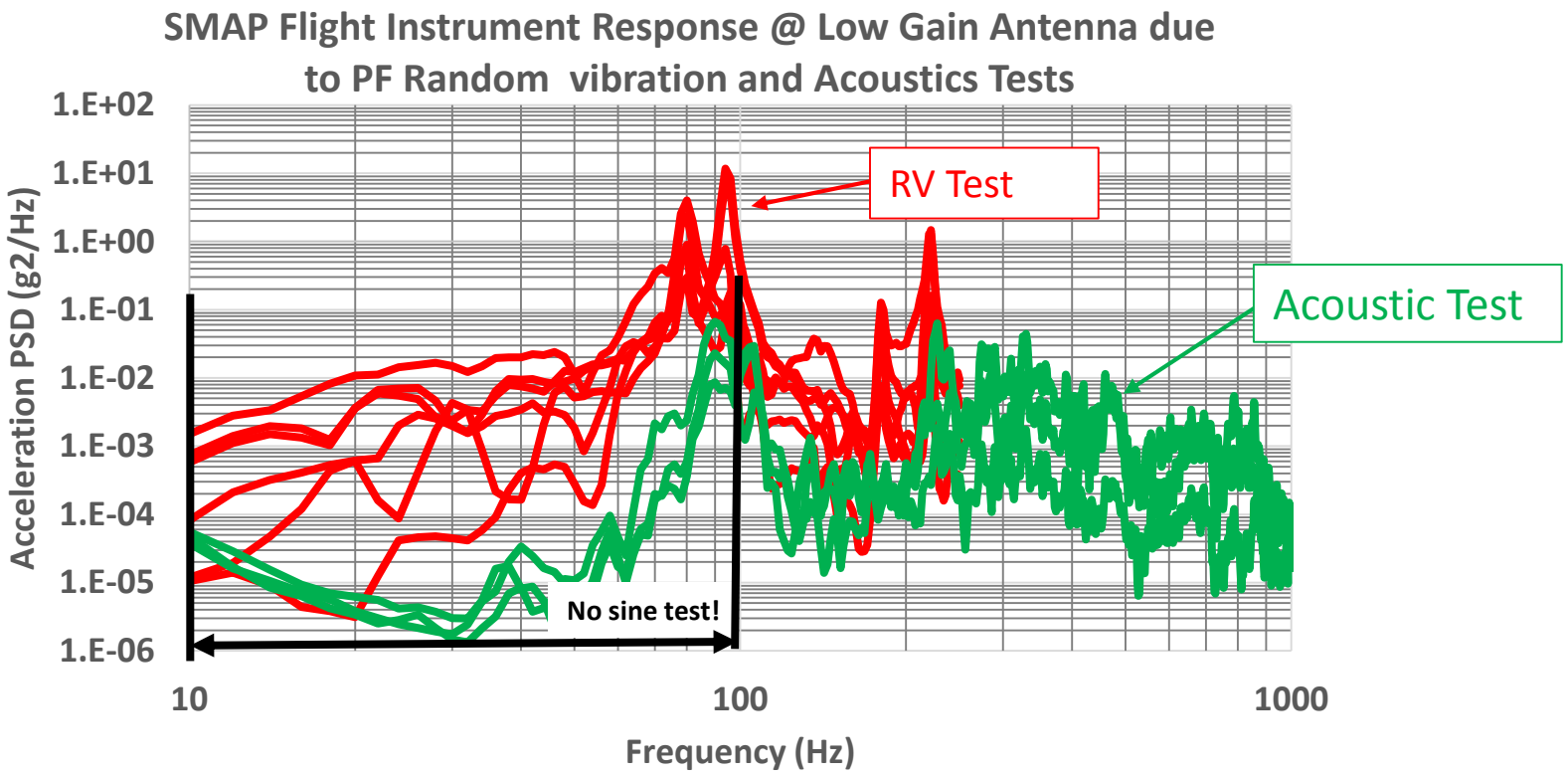
Why Random Vibration is Required?
(Example from SMAP RV and Acoustic Tests, 1/2)



SMAP Flight Instrument Response @ RBA Reflector Deployment Motor Interface due to PF Random Vibration and Acoustics Tests

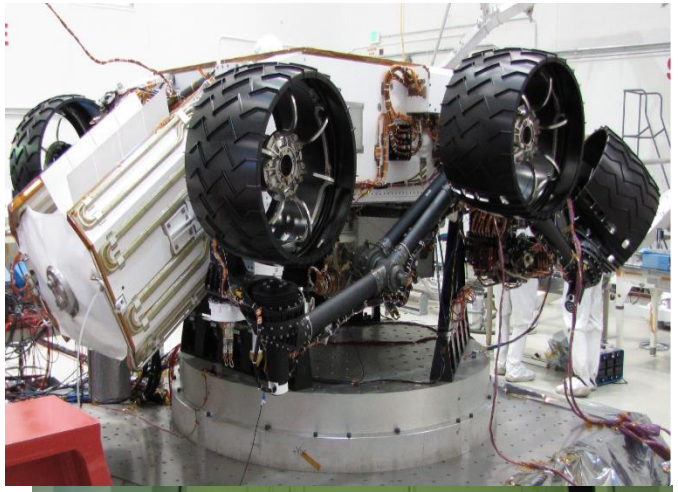
RV from 10 Hz to 200 Hz provided qualification and workmanship screening test, whereas acoustic did not (no sine test was performed)

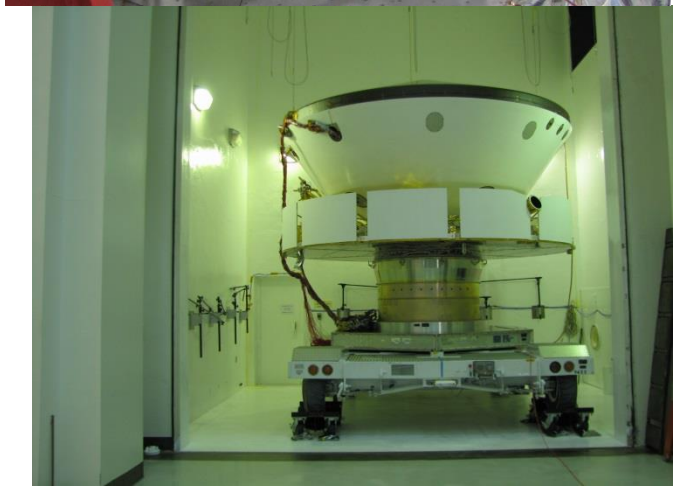
Why Random Vibration is Required?
(Example from SMAP RV and Acoustic Tests, 2/2)

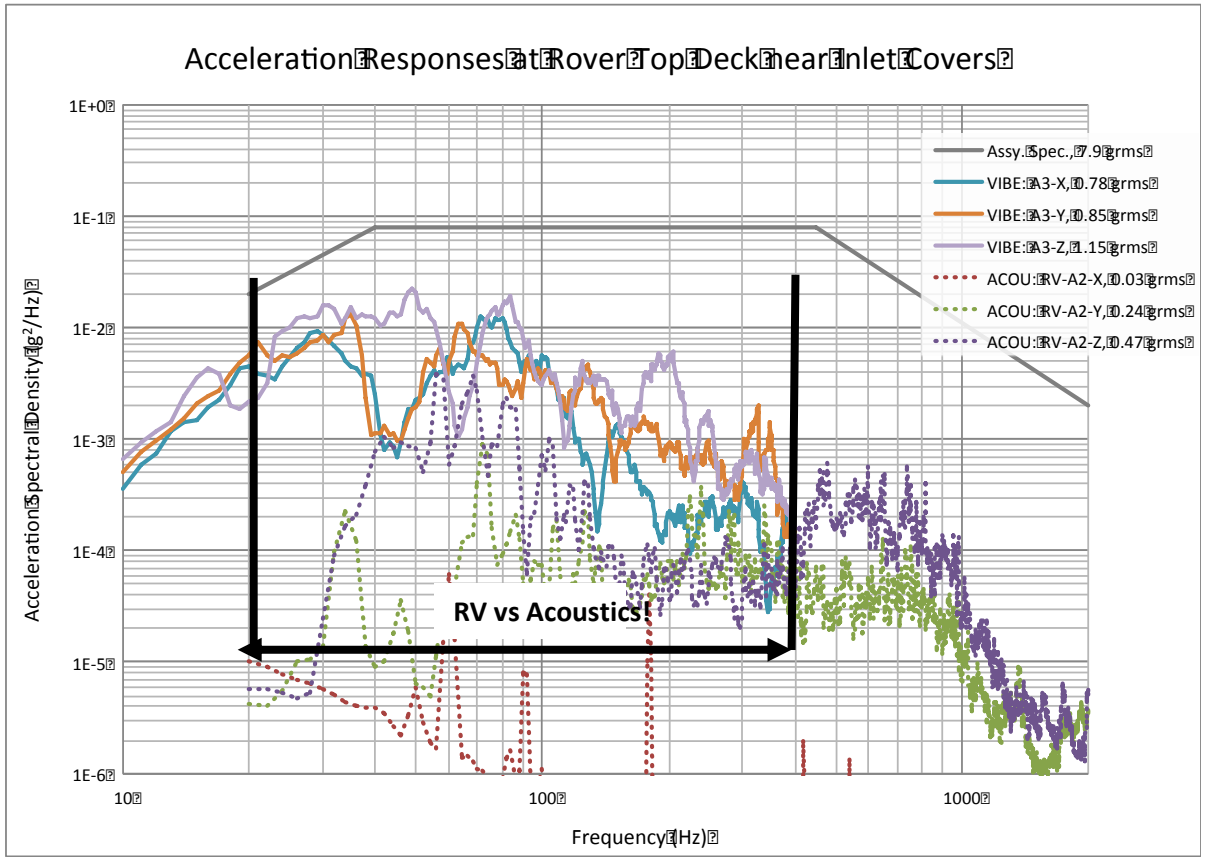


RV from 10 Hz to 200 Hz provided qualification and workmanship screening test, whereas acoustic did not (no sine test was performed)

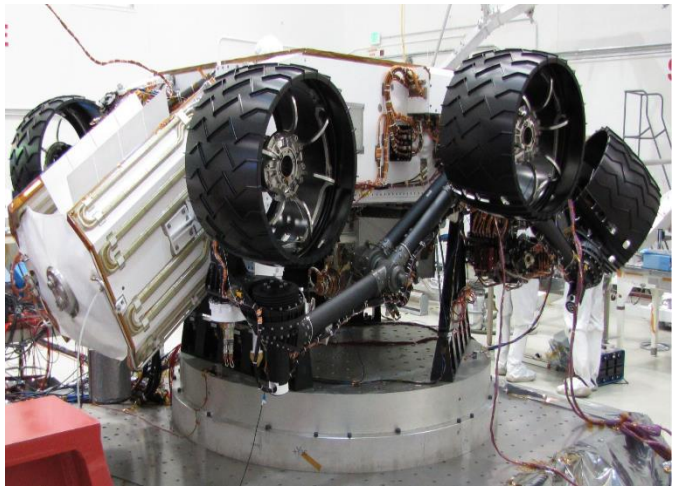
Why Random Vibration is Required?
(Example from MSL RV and MSL S/C Acoustic Tests, 1/3)

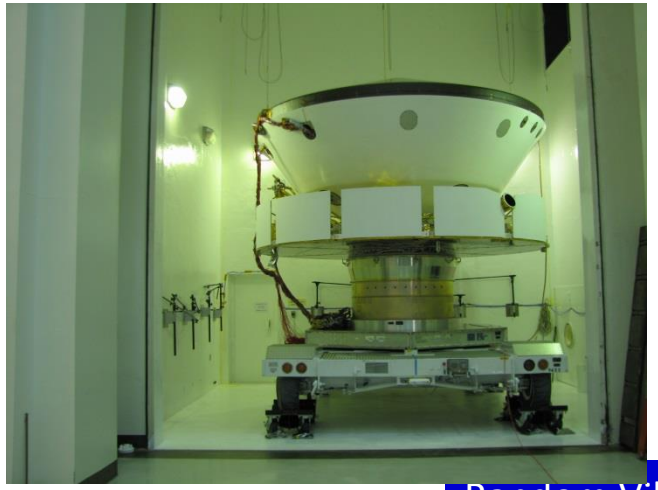


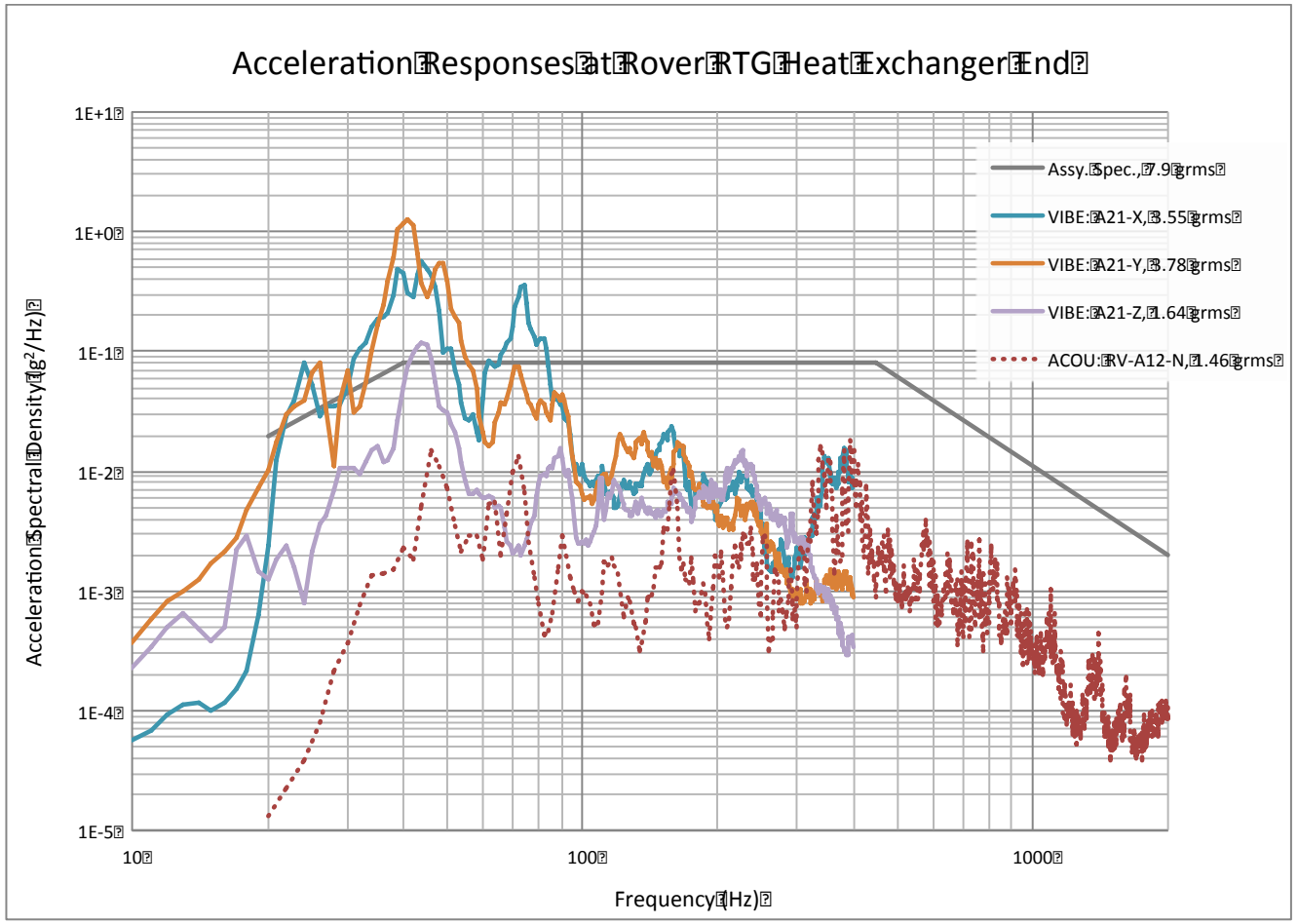




MSL SC Acoustic vs Rover Vibe, 2/3

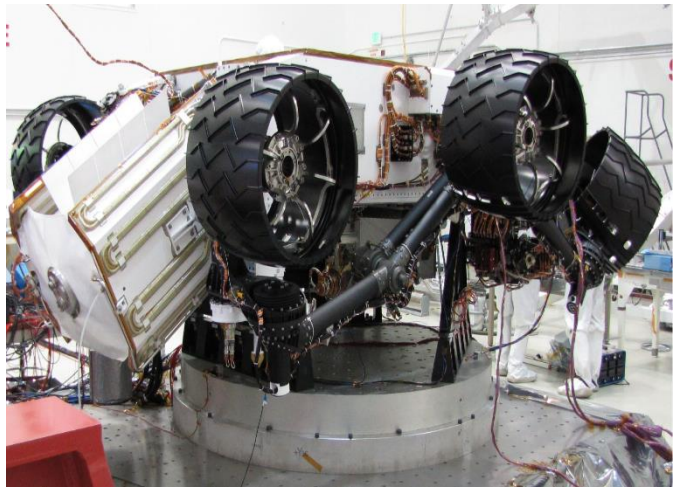


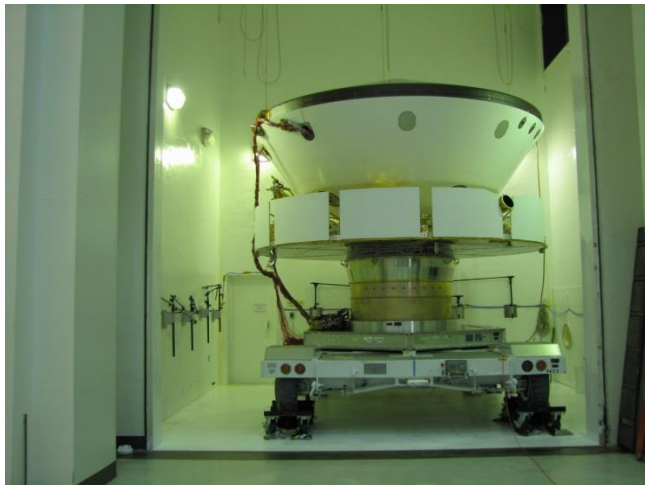


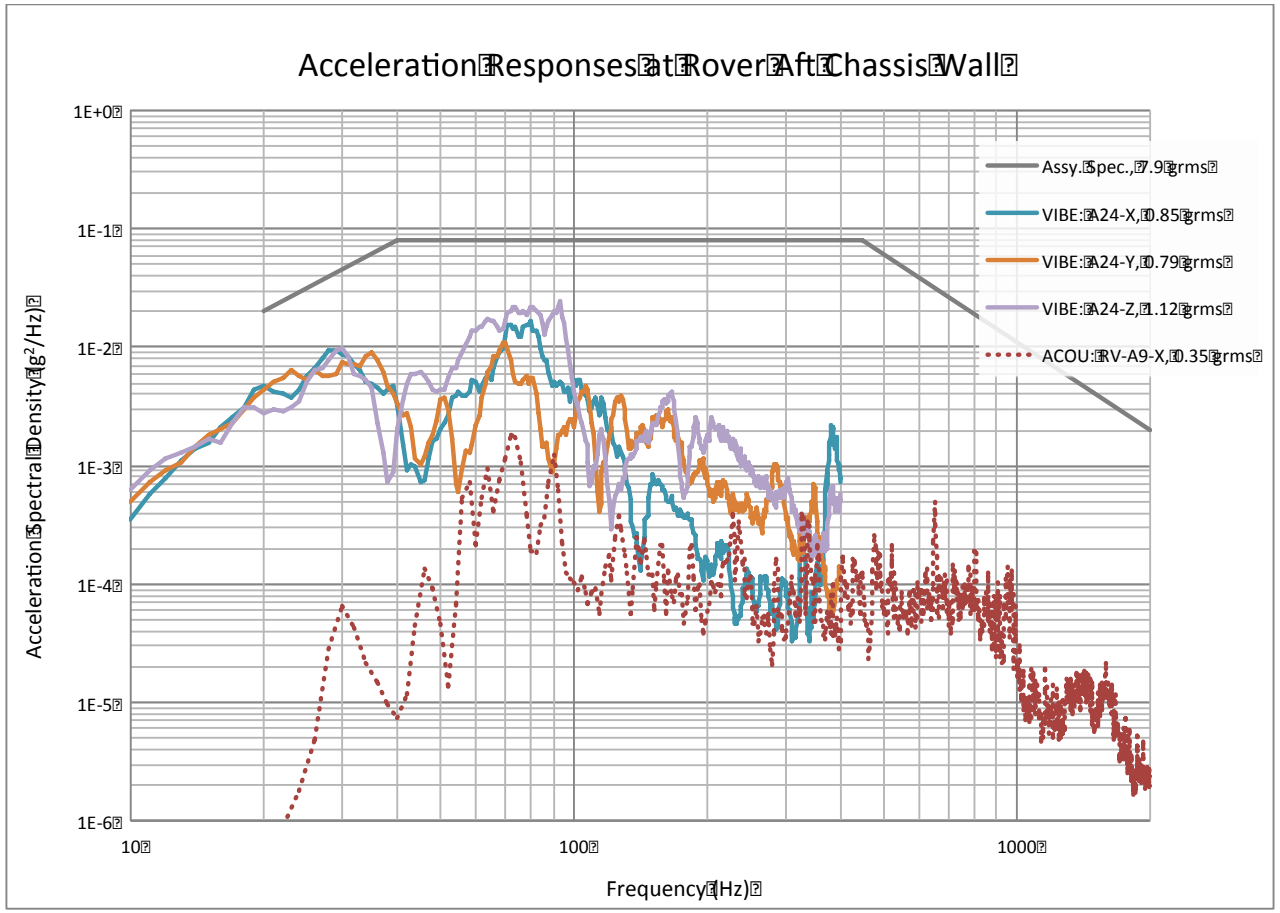


Random Vibration Test from 10 Hz to 200 Hz provides qualification and workmanship screening, whereas acoustic test did not (sine was not performed)

MSL SC Acoustic vs Rover Vibe. 3/3







Random Vibration Test from 10 Hz to 200 Hz provides qualification and workmanship screening, whereas acoustic test did not (sine was not performed!)

Summary

- Spacecraft vibration tests provide qualification for a significant mission environment and are effective at detecting workmanship defects.
  - An essential element in the qualification and workmanship verification program.
- Analysis, static loads testing, and acoustics testing are not a substitute for the spacecraft vibration test in the low- to mid-frequencies.
  - Acoustic tests do not provide adequate responses of low surface area and heavy structure to reveal workmanship defects,
- The vibration test data often can satisfy FE model test verification requirements for the CLA.
- Spacecraft force limited random vibration testing is significantly more realistic and effective, safer, and quicker than conventional spacecraft vibration test methods.

Backup Charts

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JPL SC Force Limited RV Tests (1)

- Cassini spacecraft vertical force limited random vibration test at JPL, November 1996:
  - Only one channel - the total vertical force - was used for notching. (Previous spacecraft sine vibration tests - Galileo, TOPEX - typically required hundred-plus response limiting channels for notching).
  - The test was successfully completed in two and a half days.
- Deep Space 1 spacecraft two axis force limited random vibration test at JPL, November 1997.
- QuikSCAT spacecraft two axis force limited random vibration test at Ball, October 1998.
- ACRIMSAT spacecraft three axis force limited random vibration test at Orbital Sciences, August 1999.
- GALEX spacecraft three axis force limited random vibration test at Orbital Sciences, January 2002.
- Mars Exploration Rover spacecraft three axis force limited random vibration test at JPL, October 2002.
- Deep Impact spacecraft three axis force limited random vibration test at Ball Aerospace, September 2004.

JPL SC Force Limited RV Tests (2)

- CloudSat spacecraft three axis force limited random vibration test at Ball Aerospace, November 2004.
- Dawn spacecraft three axis force limited random vibration test at Orbital Sciences, Nov./Dec. 2006.
- Orbiting Carbon Observatory three axis force limited random vibration test at Orbital Sciences, May 2008.
- Wide-field Infrared Survey Explorer three axis force limited random vibration test at Ball Aerospace, February 2009.
- Mars Science Laboratory Descent Stage system three axis force limited random vibration test at JPL, June 2010.
- Aquarius/SAC-D Observatory three axis force limited random vibration test at INPE/LIT, Brazil, September 2010.
- Mars Science Laboratory Rover system three axis force limited random vibration test at JPL, February, 2011.
- NuSTAR Observatory three axis force limited random vibration test at Orbital Sciences Corporation, September 2011.
- **No handling accidents or inadvertent over tests occurred in any of the above tests.**

JPL Spacecraft Anomalies Revealed from Random Vibration Testing

- **Cassini:** experienced an RTG electrical short to spacecraft mount in system RV test. Significant degradation in spacecraft electrical power could have resulted. Spacecraft mount was redesigned and retested.
- **Deep Space 1:** experienced several workmanship problems during system random vibration test - a hydrazine liquid service valve opened prematurely, the Spherical Langmuir Probe fell off the bottom of the Remote Sensing Unit, one screw in the Star Reference Unit backed out part way and two fell out, and fasteners loosened in the Star Tracker bracket leaving chatter marks on the shear panel. Any one of these problems may have seriously degraded the mission.
- **MER 1:** vibration test revealed improper torque of bolts on tank attachment brackets, which would have reduced tank frequencies and may have invalidated coupled loads analysis results.
- **CloudSat:** Cloud Profiling Radar waveguide failure due to apparent poor workmanship of adhesive bonding. Possible loss of science data adverted.
- **MSL Rover:** experienced several motor encoder screws back out of at least one of the Rover actuators. The actuators are used throughout Rover and the issue was unlikely to have otherwise been found before launch, which could have been a serious threat to the mission.
- **Aquarius:** Instrument level RV revealed serious design issues with mono-ball bipods/Instrument interfaces