Updates on force limiting improvements

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AEROSPACE

Overview

- The following conventional force limiting methods currently practiced in deriving force limiting specifications assume one-dimensional translation source and load apparent masses
  - Simple TDOF model
  - Semi-empirical force limits
  - Apparent mass, etc.
  - Impedance method
- Uncorrelated motion of the mounting points for components mounted on panels and correlated, but out-of-phase, motions of the support structures are important and should be considered in deriving force limiting specifications
- In this presentation "rock-n-roll" motions of the components supported by panels, which leads to a more realistic force limiting specifications are discussed

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New Approaches in Force Limits

- Most commonly used approach for deriving force limiting specification is semi-empirical force limit $S_{ff}(f)$ for random vibration test with input acceleration spectral density of S_{aa}:

$$S_{ff}(f) = C^2 M_o^2 S_{aa}(f), \qquad f < f_b$$

$$S_{ff}(f) = C^2 M_o^2 (f_b/f)^{2n} S_{aa}(f), \qquad f \geq f_b$$

  where C is dimensionless constant that depends on the flight mounting configuration, M_o is the total mass of the test item, f_b is a break frequency (often f_o), and n is a positive constant

- Attempts are made to remove conservatism due to the mismatch in impedances between the test and the flight configurations of the hardware that are being qualified
  - *The hardware interface responses are correlated (in-phase)*
- A new approach that takes into account of the un-correlated hardware interface responses (rock-n-roll) are considered in this presentation using data from a series of detailed acoustic tests

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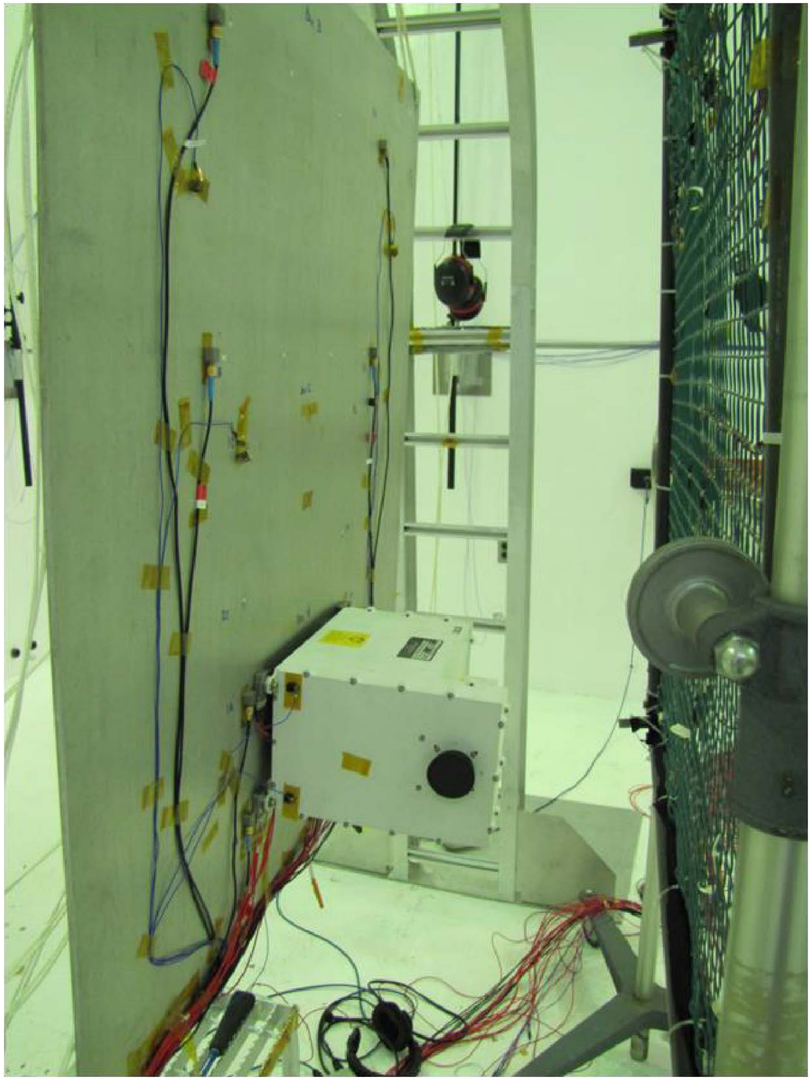
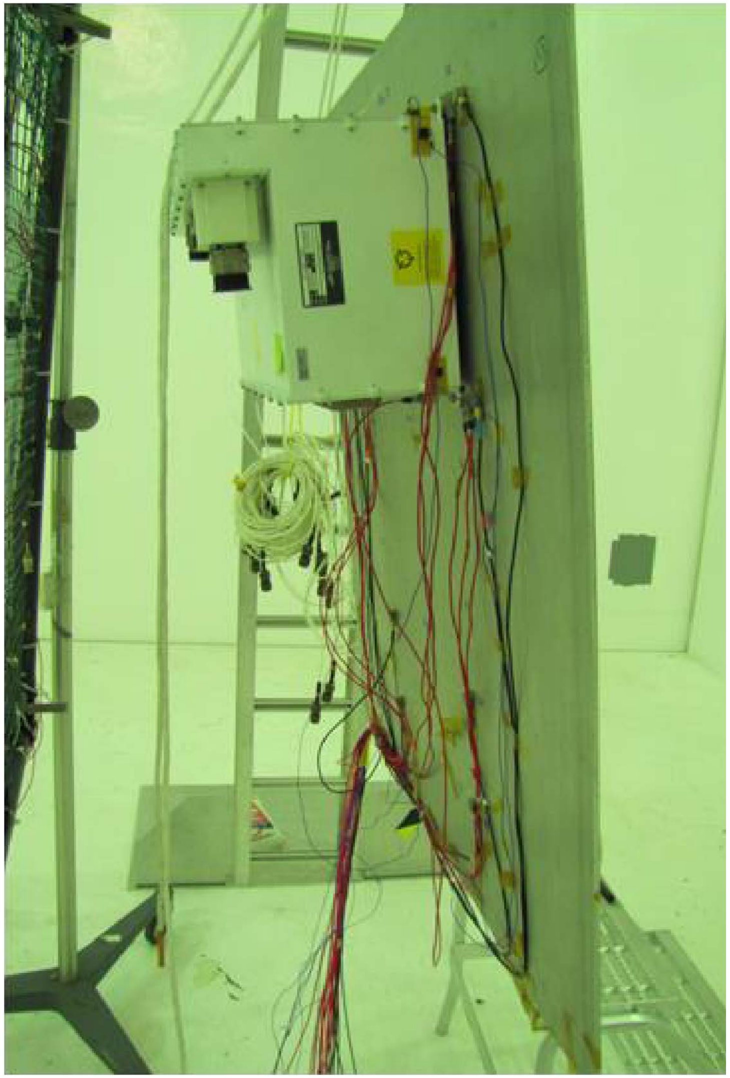
Acoustic Test: Al Panel and Boxes A&B





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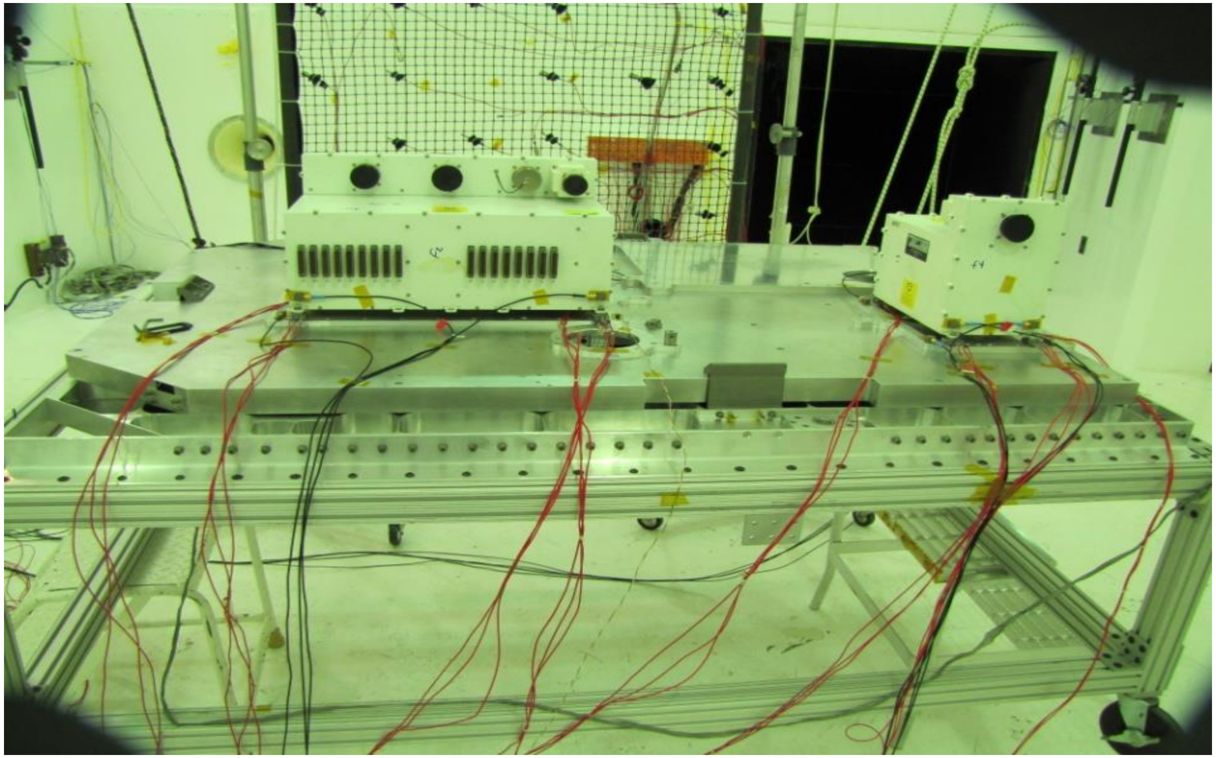
Acoustic Test: Rover Deck and Boxes A&B



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Box A and B Base Shake Test Setup

Box A

Box B

These boxes were base shaked to the input derived using Panel/Box interface responses from acoustic tests

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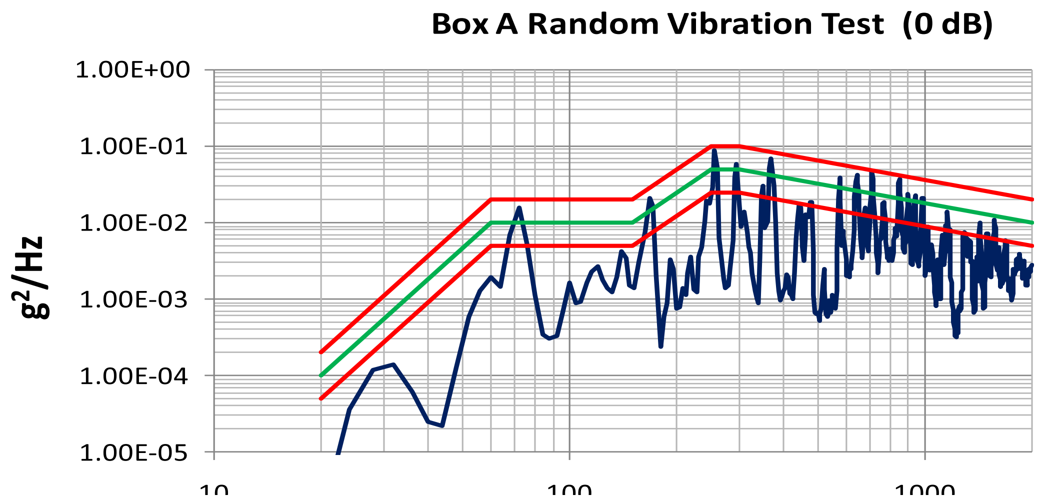
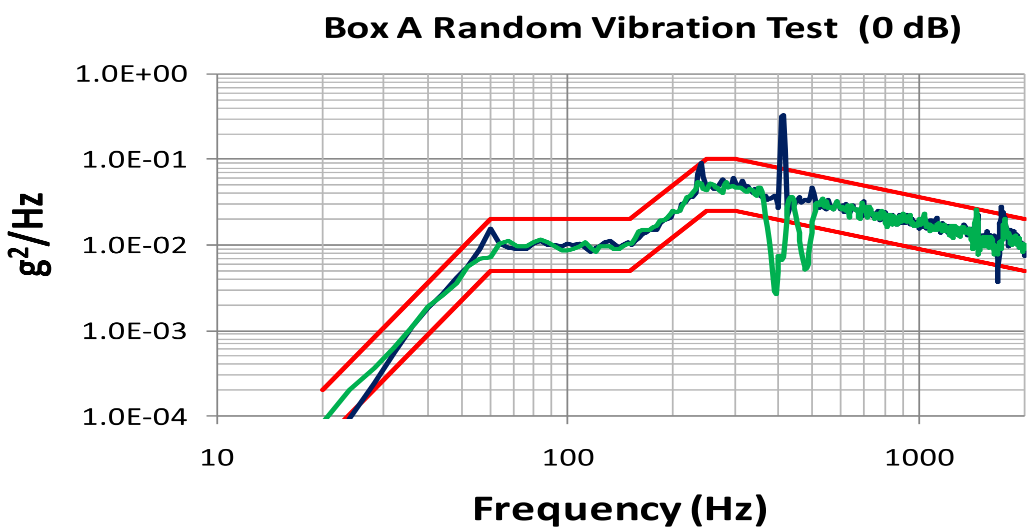
Input Acceleration Specification for Box A



Average Acceleration Responses (Acoustic test) is enveloped (green curve) to be used in shaker test as input acceleration



Shaker Input Acceleration
Blue: low level run extrapolated to 0 dB
Green: Force limited input acceleration at 0 dB

The average Box A acceleration responses from acoustic test (AI +Box A) is used to derive the base shake input

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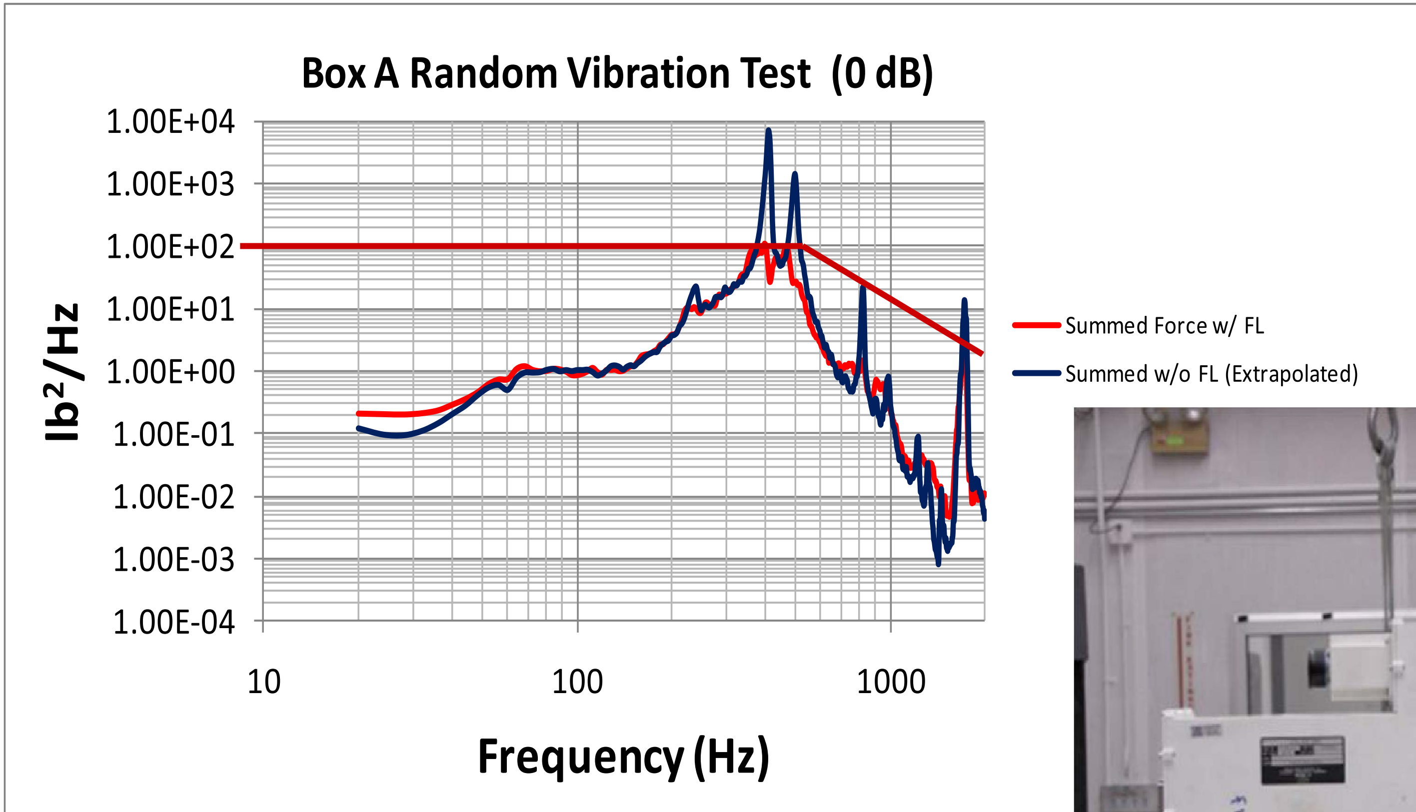
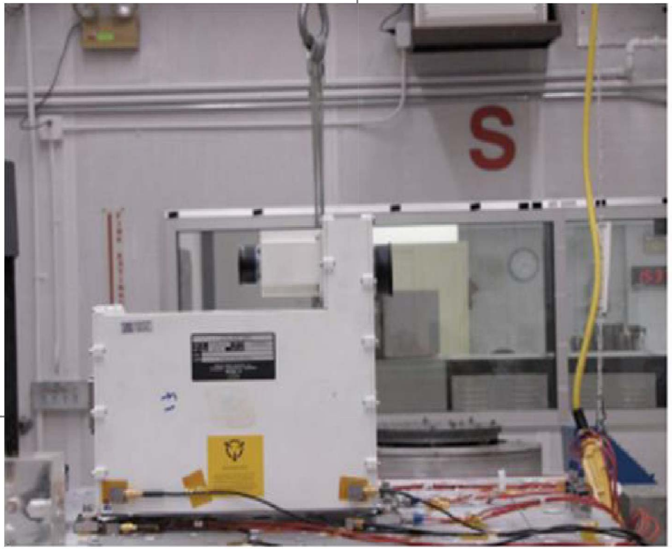
Box A Shaker Test Force Limit: Semi-Empirical Method





Force Limit using semi-empirical method with C^2 of 6: Accounts for mismatch in impedances flight configuration of the Box (correlated interface responses)

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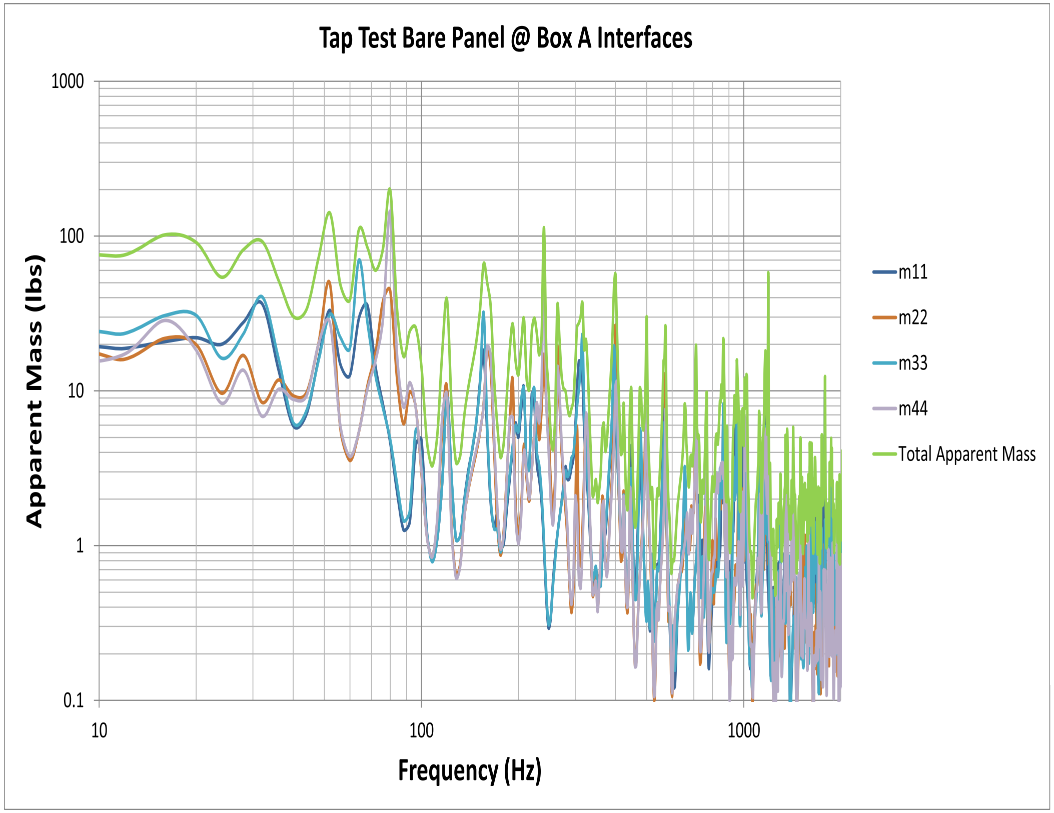
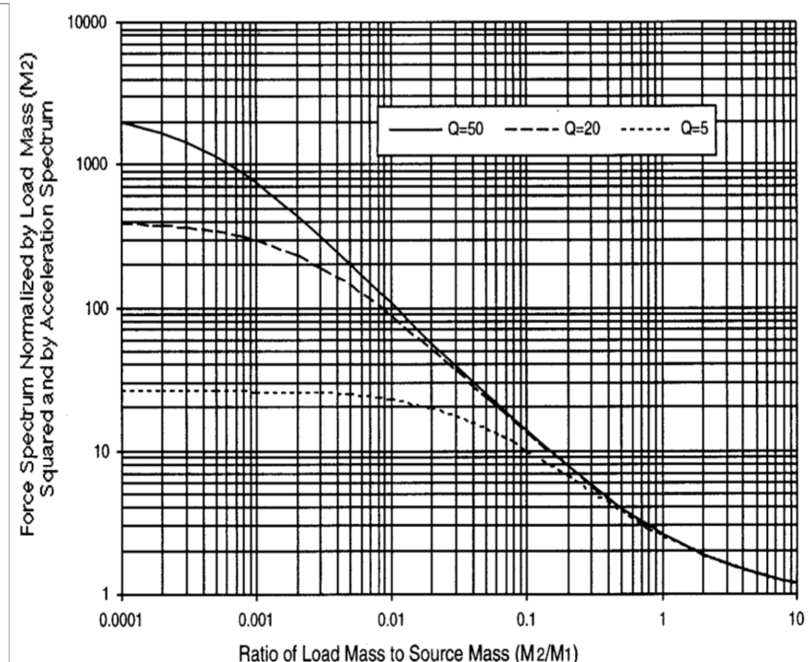
C^2 Estimate Using Apparent Mass (Box A) Source Structure: Al Panel





M_2/M_1 ~ 17.5/10 ~1.75 w/ C^2 of ~2

The apparent mass estimated by tapping Al panel w/o boxes @ four Box A interfaces
Box A Mass (M_2) ~17.5 lbs
The Source Mass (M_1) estimated to be ~ 10 lbs

Asymptotic (frequency average) values of the source impedance is used in force limiting analyses

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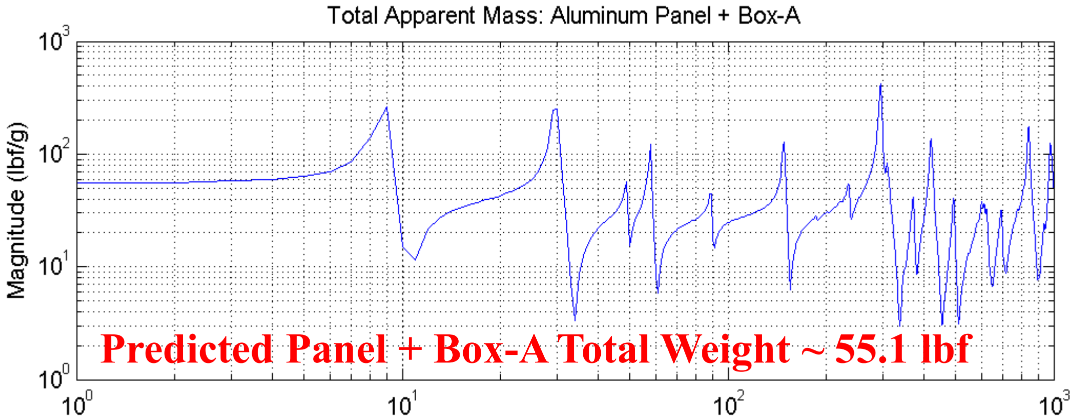
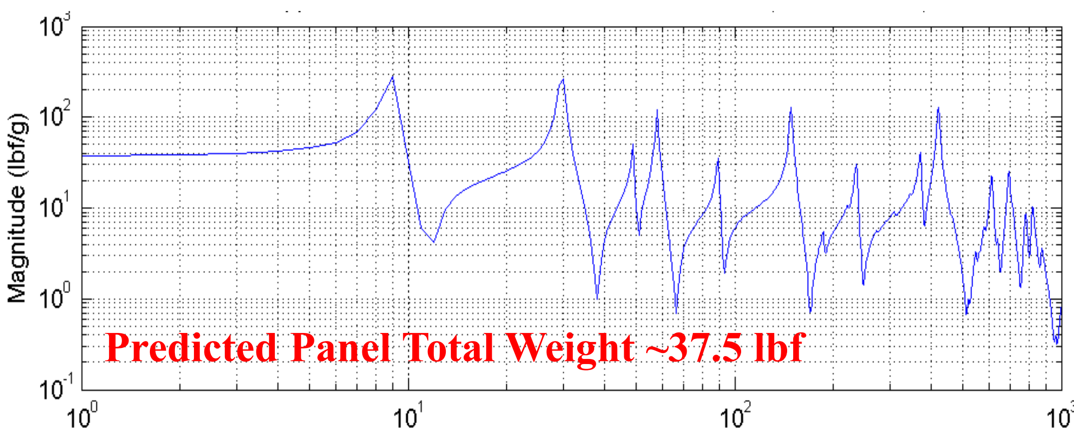
FE Apparent Mass Prediction: Panel + Box A



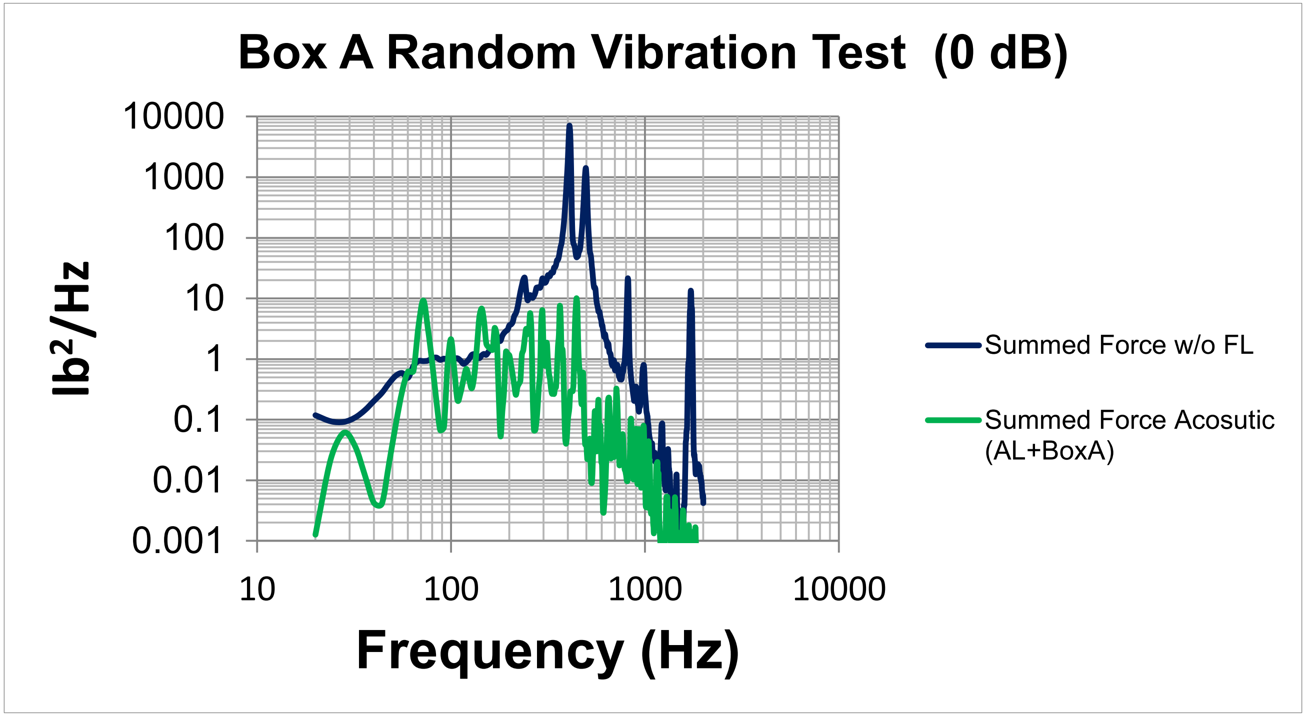
$$\left|\frac{F(f)}{A_s(f)}\right| = \left|\frac{M_s(f) x M_l(f}{[M_s(f) + M_l(f)]}\right|$$



Asymptotic (frequency average) values of FEM of the source and load impedances should be used in force limiting analyses

Predicted apparent masses of the source and source + component can be used to obtain the force limiting spectral for a given input (free) acceleration.

Box A: Force Response Comparisons



Summed forces measured at Box A interfaces:

- **Random vibe test on shaker head (Vertical axis)**
- **Acoustic test of Box A mounted on AL Panel (free-free B.C.)**

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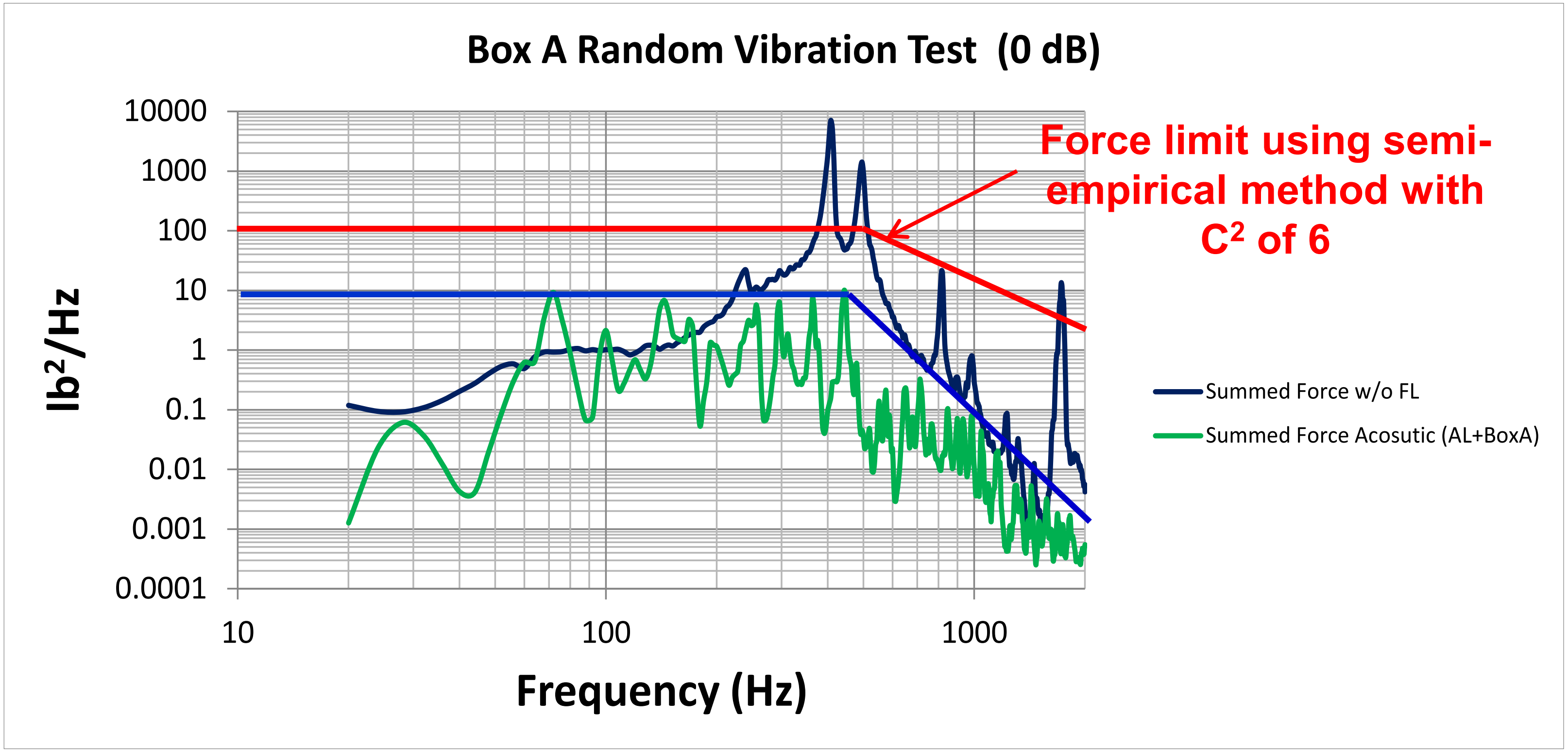
Semi-Empirical Force Limit vs. Acoustic Test (flight-like)



Force limiting specifications: Red line obtained using semi-empirical equation (shaker test, correlated responses) and blue is the envelop of the acoustic test data forces (un-correlated responses)

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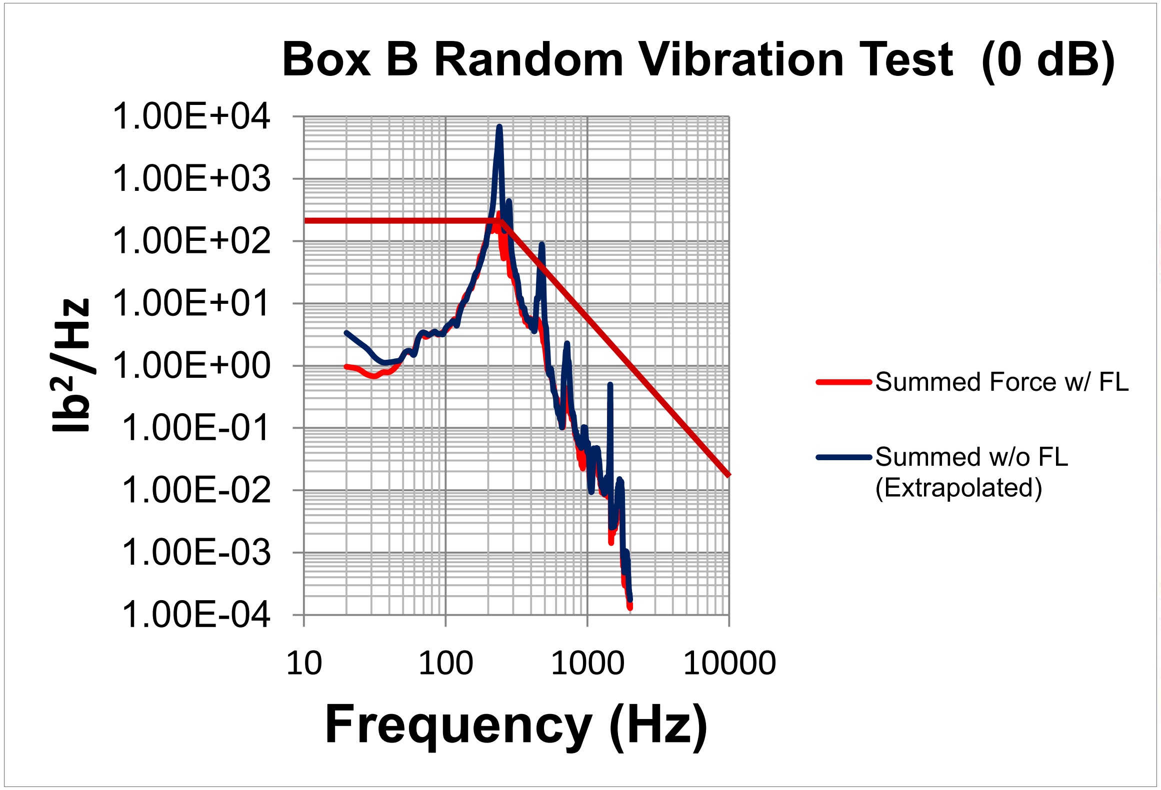
Box B Shaker Test Force Limit: Semi-Empirical Method



Force Limit using semi-empirical method with C^2 of 2: Accounts for mismatch in flight vs test impedances of the Box (correlated interface responses)

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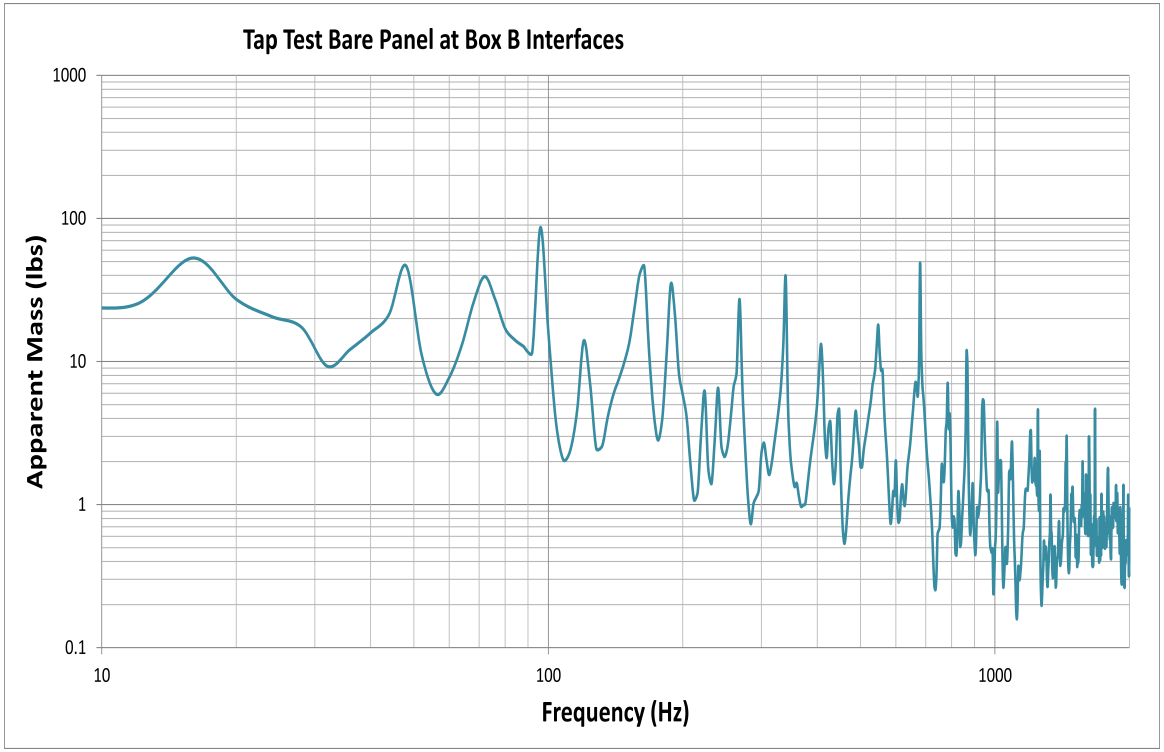
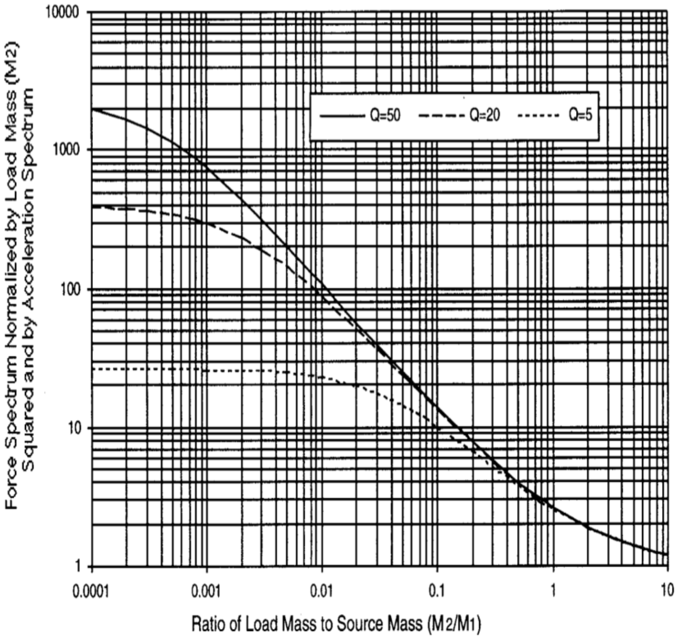
C^2 Estimate Using Measured Apparent Mass (Box B) Source Structure: AL Panel





M_2/M_1 ~ 45/10 ~4.5 w/ C^2 of ~1.5

The apparent mass estimated by tapping Al panel w/o boxes @ four Box B interfaces
Box B Mass (M_2) ~45 lbs
The Source Mass (M_1) estimated to be ~ 10 lbs

Asymptotic (frequency average) values of measured values of the source impedance is used in force limiting analyses

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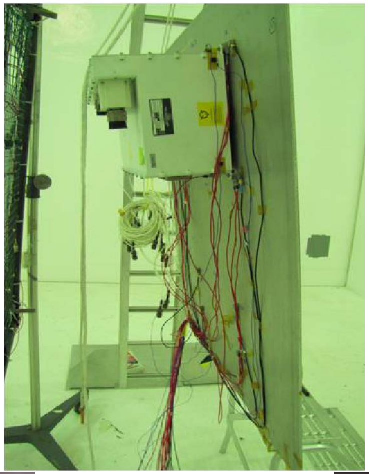
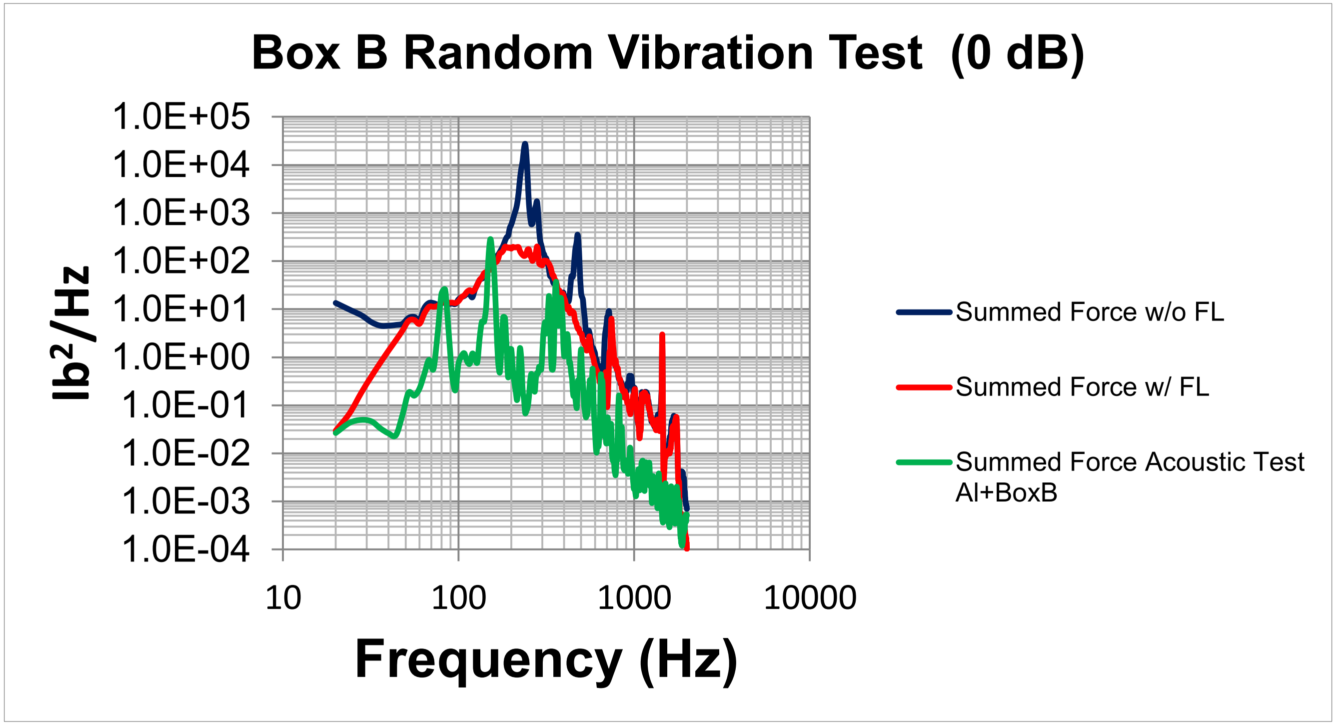
JPL Acoustic Chamber Modes

Acoustic Test



Shaker Test



Force Limits: Acoustic Test vs. semi-empirical method with C^2 of 2.

- **@ f_0 in the random vibration test w/o FL the force is approximately 50 dB above that with the box mounted on the acoustically excited panel!**
- **In the FL random vibration test, the force @ f_0 is still about 30 dB above that with the box mounted on the panel.**
- **However, the force in the random vibration test is a pretty good envelope (red curve) of the maximum forces with the box mounted on the panel (green curve).**

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LIMITATIONS OF EXISTING FORCE LIMITING METHODS

- Existing force limiting methods, which are based on one-dimensional translation source and load apparent mass considerations, do not, taken alone, guarantee realistic vibration tests.
- One must remember that the payload natural frequencies and response mode shapes will seldom be the same on the shaker as in the field.
- About all one can do with traditional force limiting methods is to try and achieve the same maximum vibratory force on the shaker as that predicted in flight, but the frequencies and mode shapes will not be correct.
- In the foregoing, in the case of Box B, whose apparent mass is larger than that of the mounting plate, force limiting based on translational apparent masses worked about as well as can be expected. Even though the limited force at the resonance frequency on the shaker is ~ 18 dB higher than at the same frequency with the box mounted on the panel, the force on the shaker is a good envelope of the interface forces measured on the panel. (Chart 15)
- But in the case of the lighter Box A, whose apparent mass was less than that of the mounting plate, the force in the force limited test was still 10 dB above the maximum force with the box mounted on the panel. (Chart 12)

CONSIDERING “ROCK AND ROLL” MOTION (1)

- In 1964, Salter observed that uncorrelated motion of the mounting points is the second thing (the first being apparent mass considerations) that results in overtesting. (J. P. Salter, “Taming the General-Purpose Vibration Test”, Shock and Vibration and Associated Environments, Bulletin No. 33, Part III, March 1964, pp. 211-217)
- For lightweight payloads mounted on panels, such as those in this investigation, uncorrelated motion of the mounting points is indeed an important consideration, particularly at the higher frequencies, but the test results also suggest that one should consider the effect of correlated, but out-of-phase motion of the supports, i.e., rotations.
- This is an example of the situation where the mode shape in the field mounting configuration may be significantly different than on the shaker.

CONSIDERING "ROCK AND ROLL" MOTION (2)

- **There are at least two reasons why a light payload, such as the panel mounted boxes studied here, may favor rotations:**
  - ***1) The energy of a rotation when the center-of gravity (CG) of the payload does not move, is typically less than that of an equivalent translation, which involves the same amplitude of the motion of the supports and of the CG. (For example, for a rigid bar, the kinetic energy of the rotation is only one-third that of the equivalent translation.)***
  - ***2) Bending modes of a panel involve both rotation and translation, and a light-weight payload is likely to pretty much follow the unloaded input (free panel) motion.***
- **For a payload in pure rotation, i.e., with it's CG standing still, the total translational reaction force is zero. So, measurement and analysis of the moment and angular acceleration may be required when rotation is involved, e.g., for light-weight boxes mounted on an acoustically excited panel, such as those in this investigation.**

Thank you