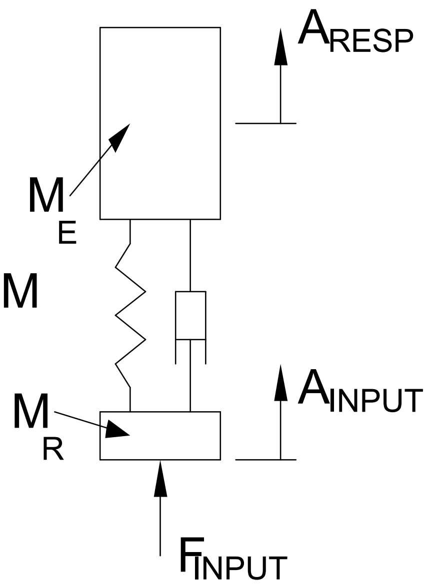
SAND2007-3511C

Derivation of Parametric Limit Levels for Use in Developing a Response Limited Random Vibration Test

$$M_T = M_R + M_E$$



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Introduction

- Random vibration test specifications consisting of straight-line segments are inherently conservative.
- This is due in large part to the fact that these spectra tend to “fill-in” notches that naturally occur in the interface spectra.
- The input spectra can be limited based on estimates of either the maximum realizable interface force or the maximum response of the component.
- There are several approaches for deriving the appropriate limit levels [1].

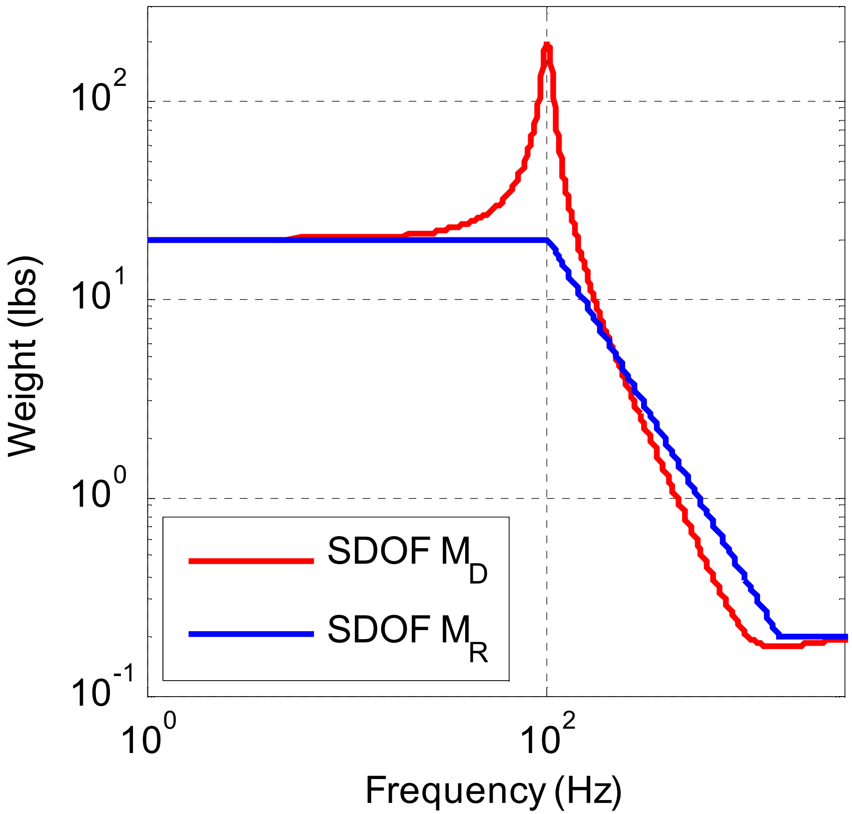
Introduction (cont'd)

- These methods tend to require detailed information about the component (the load) or the carrier (the source) that is not readily available.
- Some methods use engineering judgment based on "like" systems and bounding assumptions to define the missing information.
- The purpose of this presentation is to propose a methodology based on an extrapolation of Sharton's Two-Degree-of-Freedom (TDOF) force limiting model [2].

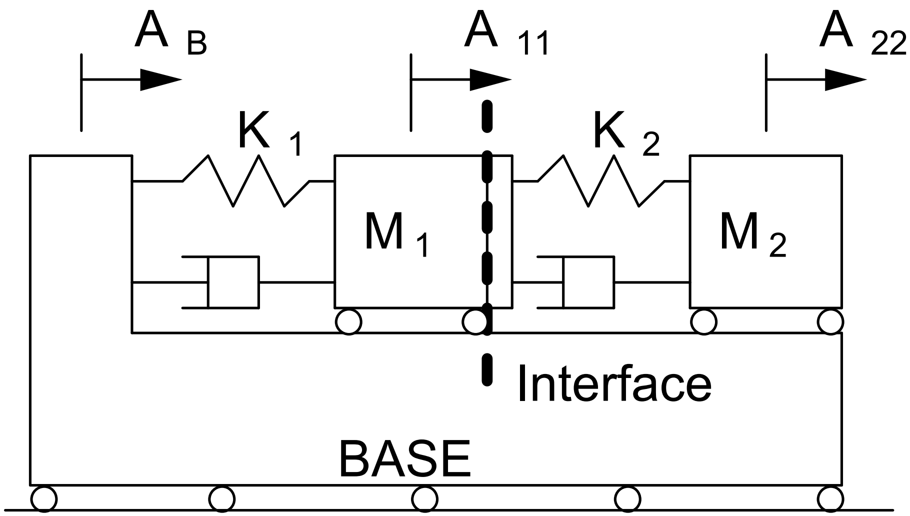
Definitions

- Dynamic or Apparent Mass – the driving point impedance of an item measured at its interface with the next assembly.
  - Becomes quite high at the fixed base resonant frequencies.
  - Tends to roll-off with frequency.
- Residual or Skeleton Mass - the fraction of the mass that still contributes to the driving point impedance after passing through each resonant frequency.
  - The faired version of the dynamic mass.
- ASD, FSD – Acceleration and Force Spectral Density.

Comparison of Dynamic and Residual Mass for SDOF System



TDOF Model



$$\omega_i = \sqrt{K_i / M_i}$$

TDOF Model

$$S_{FF} = \left(S_{AA} M_{2D}^{2}\right)\left[1+\frac{(\omega/\omega_2)^2}{Q^2}\right] \Big/ \left\{\left[1-(\omega/\omega_2)^2\right]^2 + \frac{(\omega/\omega_2)^2}{Q^2}\right\}$$

$$(\omega/\omega_o)^2 = (1+u/2) \pm \left(u+u^2/4\right)$$

S_{AA}, S_{FF} – Interface acceleration and force spectral densities

M_{2D} – dynamic mass of load.

u – ratio of load and source skeleton masses (M_{2R}/M_{1R}).

TDOF Study

Parameter	Source (M_1)	Load (M_2)
Static Weight	1000 lbs	20 lbs
1st Resonant Frequency	4 Hz	100 Hz
Q	---	10

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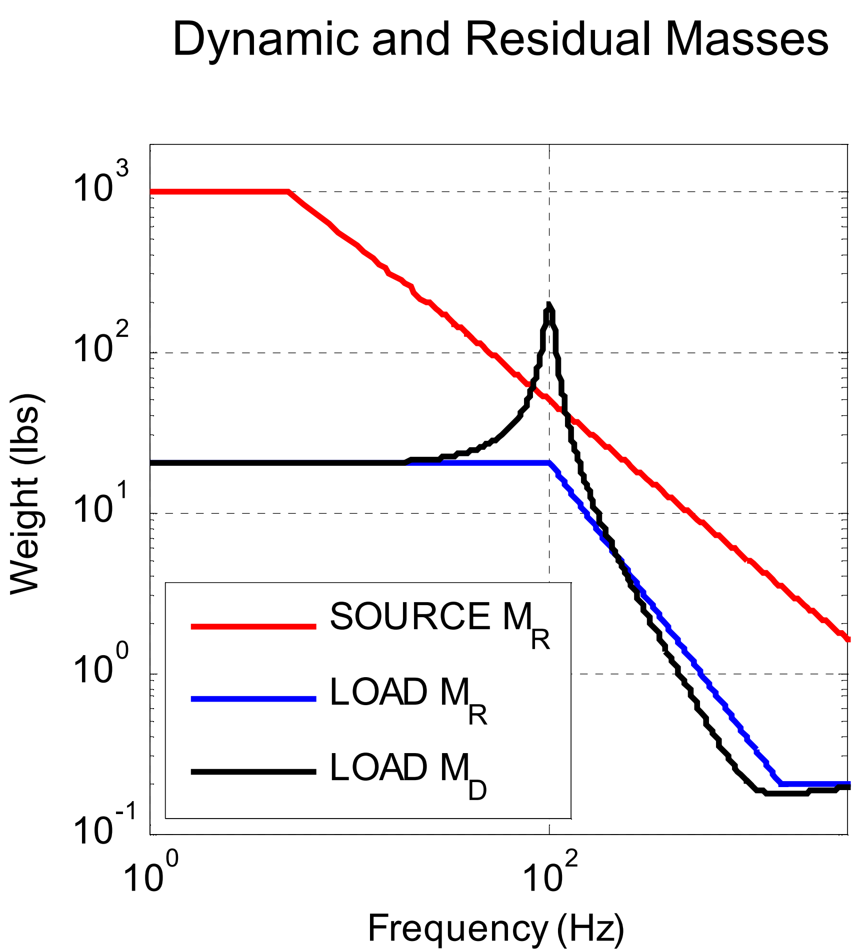
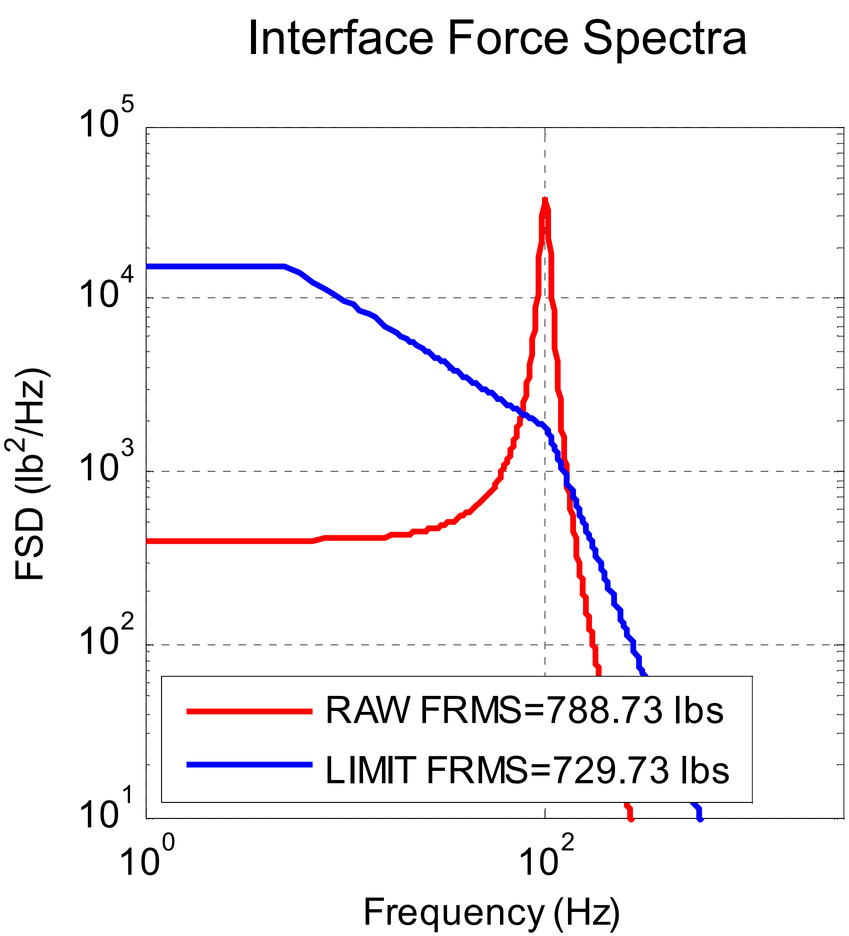
TDOF Study

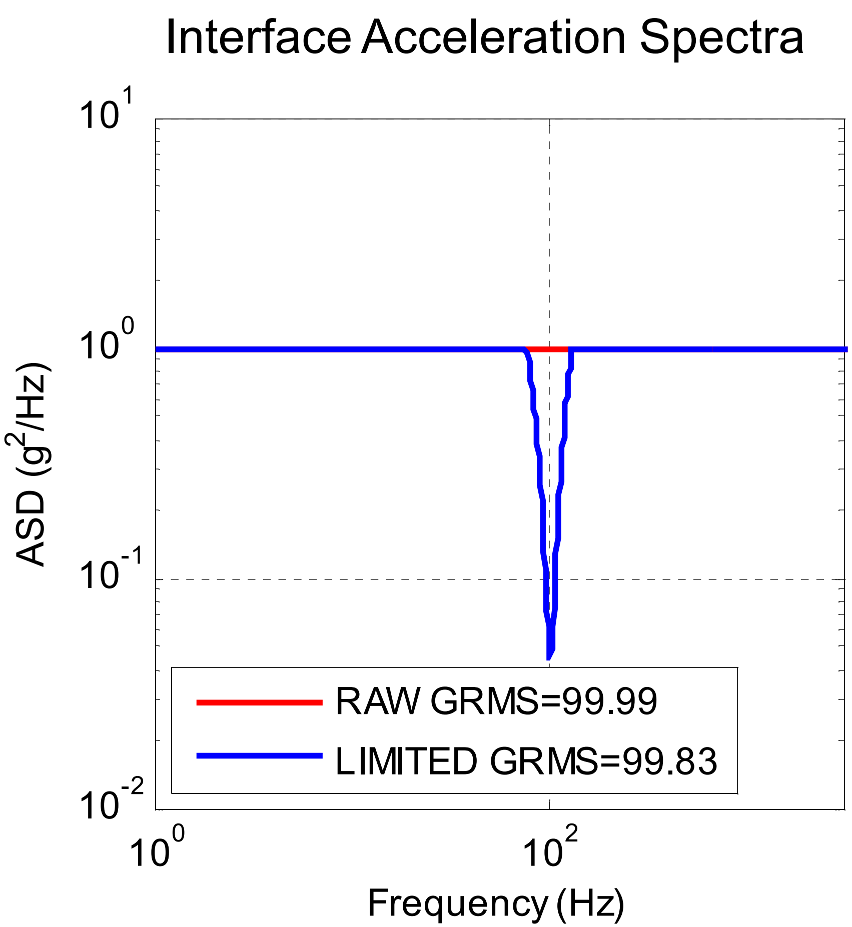


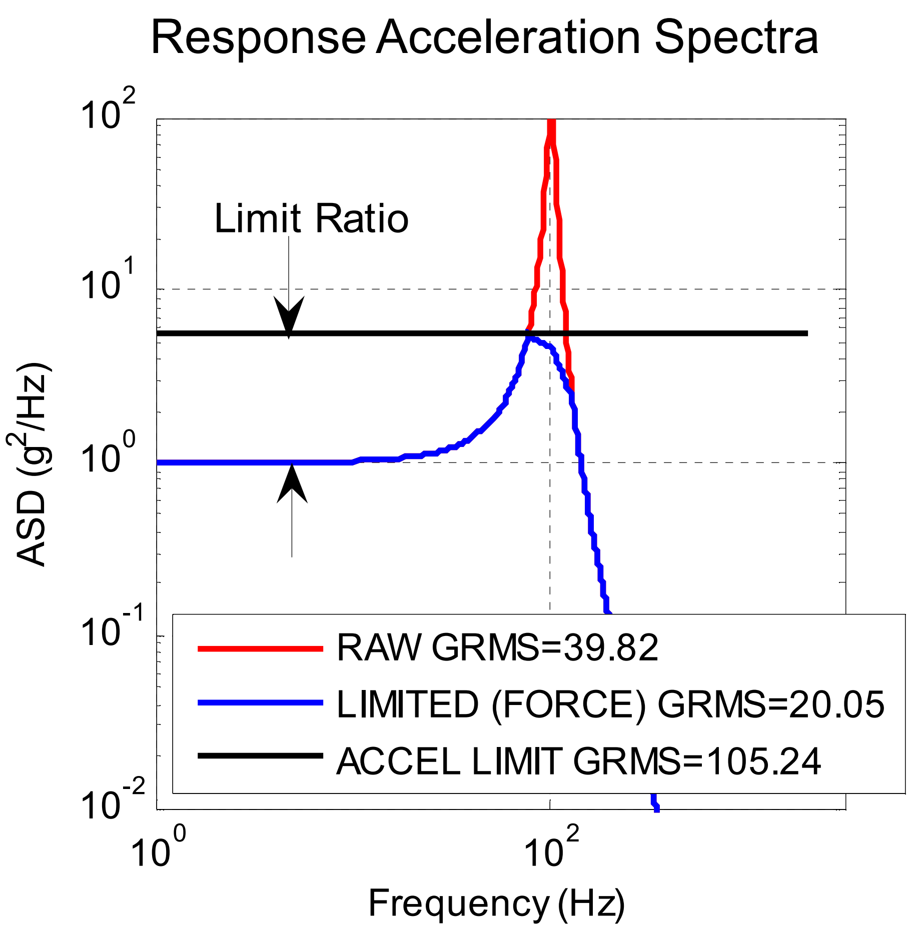
Dynamic and Residual Masses
Weight (lbs)
10^3
10^2
10^1
10^0
10^-1
10^0
10^2
Frequency (Hz)
SOURCE M_R
LOAD M_R
LOAD M_D



Interface Force Spectra
FSD (lb^2/Hz)
10^5
10^4
10^3
10^2
10^1
10^0
10^2
Frequency (Hz)
RAW FRMS=788.73 lbs
LIMIT FRMS=729.73 lbs

TDOF Study





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Need for Parametric Model

- Performing a tailored study every time a component designer shows up on the doorstep of the vibration lab is impractical.
- The goal of this study was to develop a parametric model that allowed the component designer to define his/her own limit levels using information readily available to the designer.

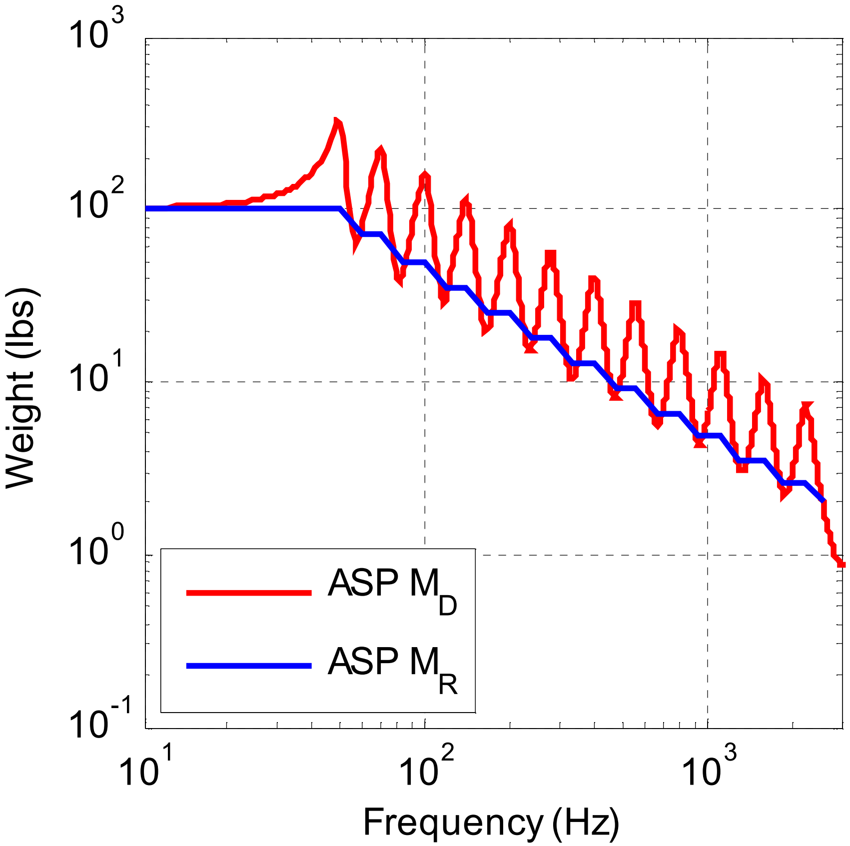
Test Item (Load) Parameters

- There are two parameters that must be defined for the test item.
  - The apparent mass.
  - The skeleton mass.
- In the TDOF model these can be approximated by the equivalent static weight, the first resonant frequency, and the Q.
- The designer can identify the weight for each and every part of concern (circuit boards, panels, or the entire assembly).
  - The weight should be based on the fraction of the total weight that is expected to participate in the first resonant mode.
- The test engineer can obtain the resonant frequencies and Q factors for any part that can be monitored during a low level random vibration survey.

Carrier (Source) Parameters

- There is one parameter that must be defined for the carrier.
  - The skeleton mass.
- All we need to approximate the skeleton mass line is the static weight and the first resonant frequency.
  - Assume 1/frequency roll-off.
  - This behavior can be produced by an asparagus patch model with a logarithmic modal density and a modal mass that is inversely proportional to frequency.
- The parametric model assumes a 1 Hz resonant frequency for the source. Corrections can be made for other values.

Asparagus Patch Skeleton Mass Line



1/3rd Octave modal density

Modal mass proportional to 1/frequency

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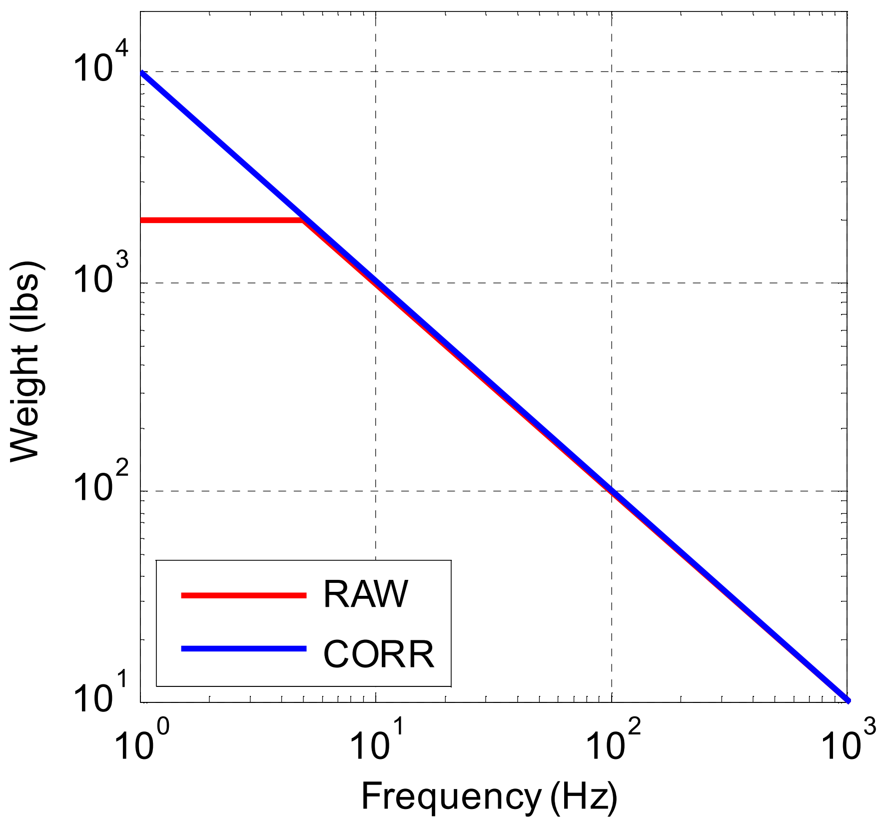
Source Skeleton Mass Line



Draw actual (RAW) skeleton mass line

Extend slope back to 1 Hz

Magnitude at 1 Hz is effective weight

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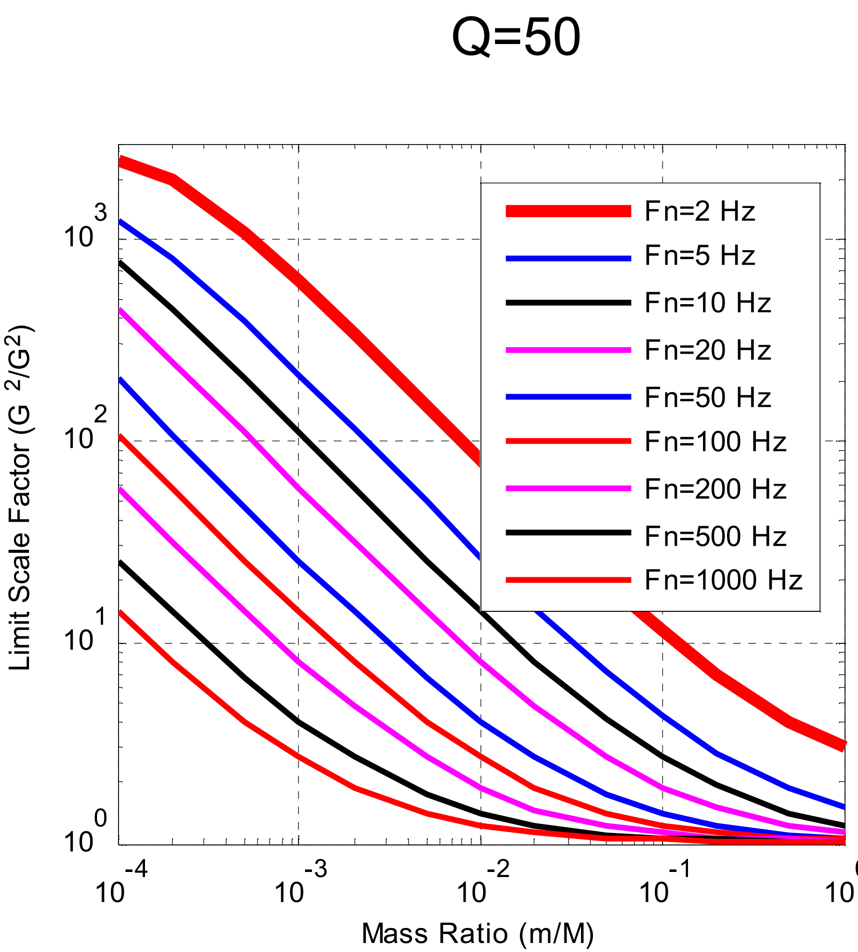
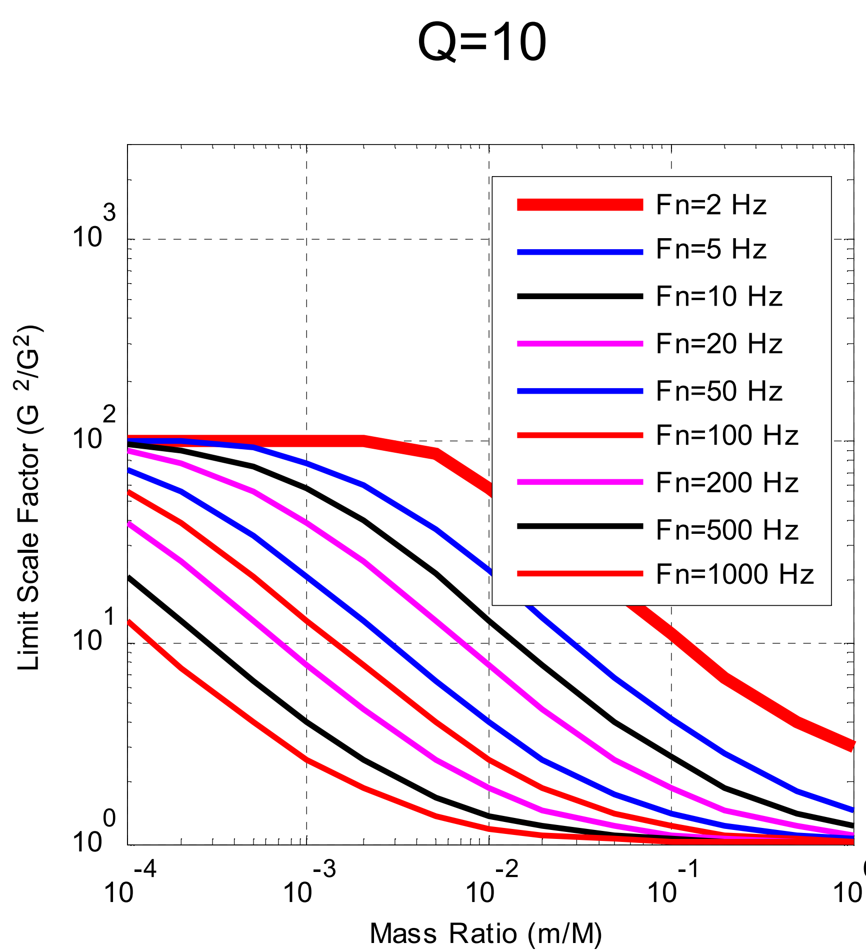
Parametric Model

- The TDOF model was used to generate hundreds of parametric simulations.
  - The ratio of the load and source residual masses, $u=M_{2R}/M_{1R}$, were varied from 1e-4 to 1.
  - The value of Q was varied from 5 to 50.
  - The value of the load resonant frequency, f_N, was varied from 2 Hz to 1000 Hz.
- The "limit ratio" (the equivalent response limit divided by the nominal input ASDs - S_{LIM}/S_{INP}) was plotted as a function of u, Q, and f_N.

Parametric Limit Levels





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Interpreting Parametric Results

- A lower limit level means more notching.
  - A limit level equal to Q^2 signifies that no notching will occur.
- Higher values of Q appear to warrant deeper notching.
  - Higher apparent mass (?).
- Heavier, stiffer test items warrant deeper notching.
  - Big tail, little dog.

Applying Parametric Results

- The designer and test engineer identify the resonant modes for the points of interest on the test item.
- The necessary parameters are established using a combination of design knowledge, intended carrier(s), and low level testing of the item.
- Interpolate between the different charts to obtain the appropriate limit level.
- Response limits are then applied at the points of interest using scaled versions of the input spectra.
  - Sometimes no limiting is warranted.

Summary

- The TDOF model allows the user to account for some characteristics of the load and the source.
- Process would be improved with more knowledge about test item.
  - Better estimate of dynamic mass associated with each resonant mode of interest.
  - This might even allow for the consideration of modes beyond the first mode (shaped limit spectrum).
- The assumption that the skeleton mass line for the source rolls-off as 1/frequency cannot be proven but a limited number of experimental and FEA models support this assumption [3].

References

- NASA Reference Publication RP-1403; written by T. D. Scharton; May 1997; “Force Limited Vibration Testing Monograph.”
- Scharton, T. D., ”Force Limits for Vibration Tests”, CNES Conference on Spacecraft Structures and Mechanical Testing, Paris, FR, June 1994, p 1024.
- Neubert, V. H., *Mechanical Impedance: Modeling/Analysis of Structures*, Josten Printing and Publishing, State College, Pa., 1987.

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