Undue Conservatism in Random Vibration Design Loads

J. Brent Knight
Dynamic Loads Analyst
Space Systems Thermal and Mechanical Analysis Branch (ES22)
NASA Marshall Space Flight Center

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Agenda

- *Background and Objectives*
- *"Higher Frequencies" - How High is High?*
- *Underlying Premise*
- *Case Study – Simple Cantilevered Beam*
- *Conclusion*
- *Future Work*
- *Acknowledgements*

Random Vibration Design Loads

Background and Objectives

- *Structural design loads due to random vibrations are often suspected of significant undue conservatism*
  - Some reasons for that perception include
    - *Environments are sometimes (maybe all the time) labeled as unrealistic*
      - “Heritage” prediction methods (mass scaling) often are based on data relative to less than ideally similar structures
      - Modern methods (SEA, hybrid methods,...) are new and some are skeptical of their applicability
    - *Dynamic loads specified as static loads are unduly conservative as applied (statically)*
      - A recently retired MSFC vibro-acoustic engineer has been heard to say (numerous times) “it’s a dynamic load, if you want to apply it statically, be my guest”
    - *At “higher frequencies” the effect of vibrations on structures is minimal – this of course begs the question, how high is high?*

Random Vibration Design Loads

Background and Objectives

- *This effort focuses on the notion that above some frequency the strain field associated with a random vibration environment will be insignificant for typical aerospace hardware*

  - This effort is geared towards things such as an avionics box and its interface to primary structure as opposed to circuitry inside the box

- *The objectives of this presentation are: (1) to depict the order of magnitude of potential undue conservatism in specified design loads associated with "higher frequency" modes and (2) to discuss future work in support of this effort*

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Higher Frequencies - How High is High?

- *While a member of the SPACEHAB Science Double Module (SDM) Design Team (1997 time frame), since pertinent hardware was not NASA hardware, significant flexibility in analysis methods existed*
  - If a component or hardware item was inside the SDM it posed no threat to NASA hardware so scrutiny was minimal
  - Methodologies used were reviewed internally on a case by case basis
  - "Engineering judgment" led to the threshold of 300Hz for hardware with typical robustness
    - *For the hardware in question and the applicable environments modes above 300 Hz were not considered in the loads development process*

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Higher Frequencies - How High is High?

- *Recently ISS vibro-acoustic test data was observed that indicated that at around 300 Hz measured strain stopped accumulating*
- *The real answer is that the frequency threshold of concern is dependent on the structure in question and the environment*
  - The specific answer for a given system has to be determined via analysis and/or test of that hardware
- *Nonetheless, for a given structural design and a given environment there is a frequency above which the effects of the random vibration environment is benign*

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Underlying Premise

- Strain is the phenomena of concern

$$\varepsilon = \frac{\Delta l}{l}$$

- For harmonic motion

$$Displacement = X = A\,Sin(\omega t)$$

$$Velocity = \dot{X} = A\omega\,Cos(\omega t)$$

$$Acceleration = \ddot{X} = -A\omega^2\,Sin(\omega t)$$

Disregarding the sense we can say,

$$X = \frac{\ddot{X}}{\omega^2}$$

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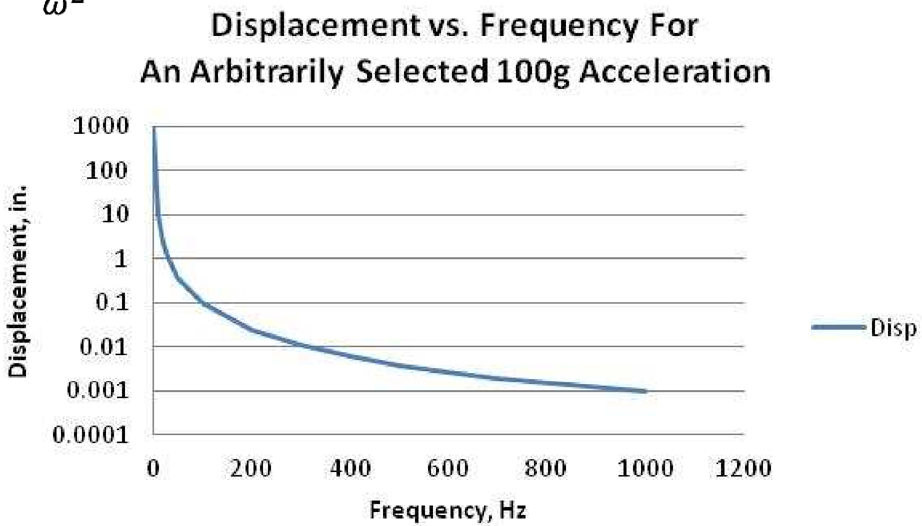
Underlying Premise

– *Plotting* $X = -\frac{\ddot{X}}{\omega^2}$ *for an arbitrarily selected 100 g*



– *As one goes up in frequency the corresponding displacement goes down dramatically*

- The displacement associated with strain, Δl, is but a fraction of that

– *Obviously, the above trend would be notably different for a higher or a lower acceleration*

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Underlying Premise

- Clearly, for a given situation (component and environment), as one goes up in frequency the significance of acceleration goes down with respect to the corresponding strain field
  - *At times, load factors or static equivalent loads are specified for structural design that correspond to high frequency modes and this principle is not employed*
  - *In one case, 700 - 800 g's was specified as a structural design load for a fairing and those loads corresponded to a mode at about 1100 Hz*
  - *Another example is that of a camera mounted on Ares IX that had in one direction 577 g specified and that was associated with a 934 Hz mode*
    - This is perceived as extremly^2 (*"extremely squared"*) conservative

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Case Study – Simple Cantilevered Beam

- *The goal of this study was to as closely as possible compare “apples to apples” and investigate the strain due to an excited dominant/significant mode with its frequency at about 40 Hz to that of a one with its frequency at about 300 Hz*
  - In both cases the same cross section was reacting the load
  - In both cases the mode in question was a significant mode
  - An approximately equivalent oscillating force was used
- *A simple cantilevered beam was designed as the Test Article (TA)*
  - It accommodated addition of mass to produce the desired low frequency mode

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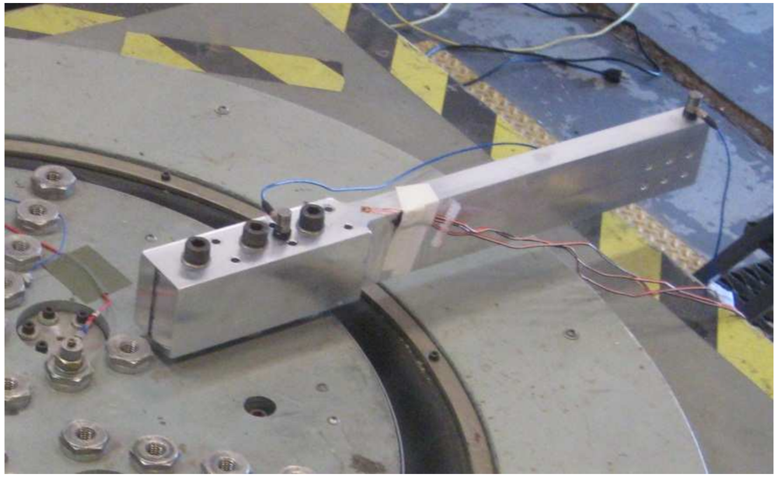
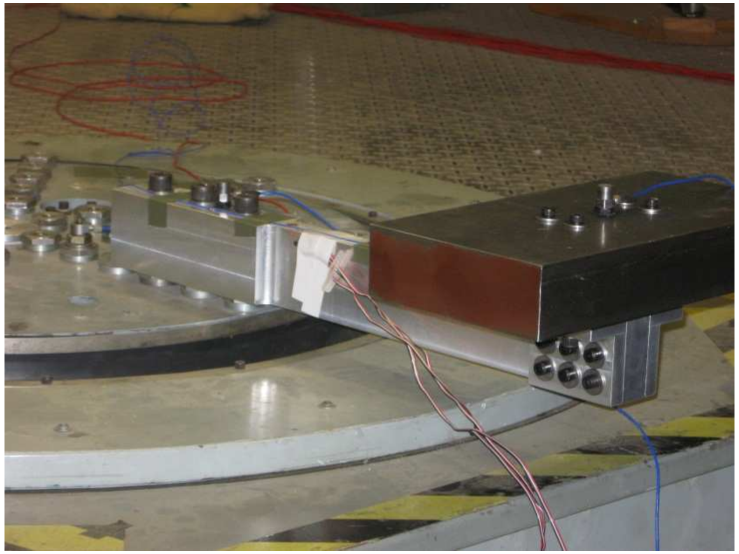
Case Study – Simple Cantilevered Beam

– *Test Configurations*



Configuration 1 – Beam without the mass
f≈300 Hz, M= 6.5 Lb., M_{CL}≈ 4 Lb.



Configuration 2 - Beam with added mass
f≈40 Hz, M= 48.5 Lb., M_{CL}≈ 46 Lb.

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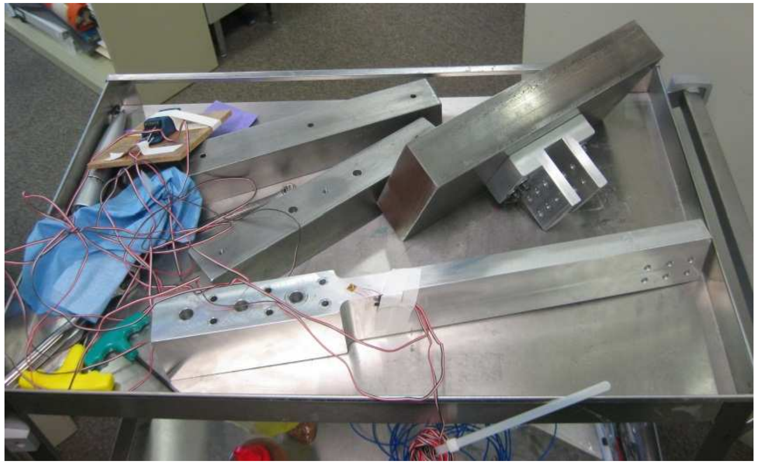
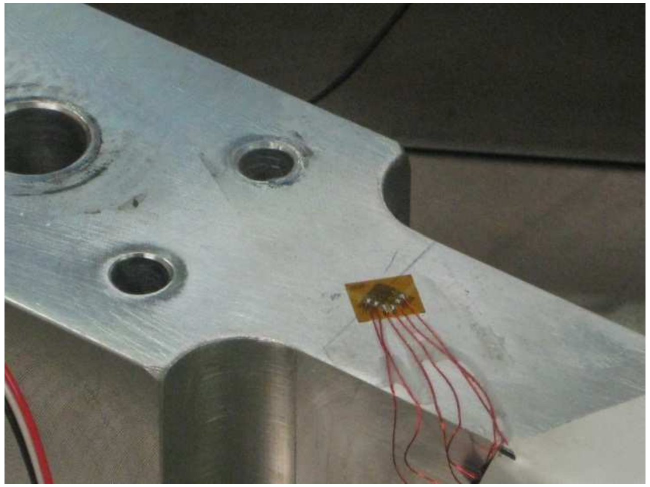
Case Study – Simple Cantilevered Beam

– *The beam had a strain gage rosette installed*





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Case Study – Simple Cantilevered Beam

- *The fundamental mode of each configuration was measured*
  - Case 1, the beam without the added mass, had a 304 Hz mode
  - Case 2, the beam with the added mass, had a 40 Hz mode
- *The high frequency case was then excited via sine dwell at 304 Hz with response amplitude of about 24.5 g*
  - It had 4.0 Lbs. oscillating (the weight of the cantilevered part of the beam)
  - That yields an oscillating force of approximately 98 pounds

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Case Study – Simple Cantilevered Beam

- *The low frequency case was then excited via sine dwell at 40 Hz with response amplitude of 2 g*

  - It had 46 Lbs. oscillating which yields an oscillating force of about 92 Lb.

- *Therefore the oscillating effective forces were close to equal in both cases (which was the goal)*

- *The measured strain traces both correspond to (1) the same cross section reacting the load, (2) a very similar oscillating force, and (3) a dominant mode*

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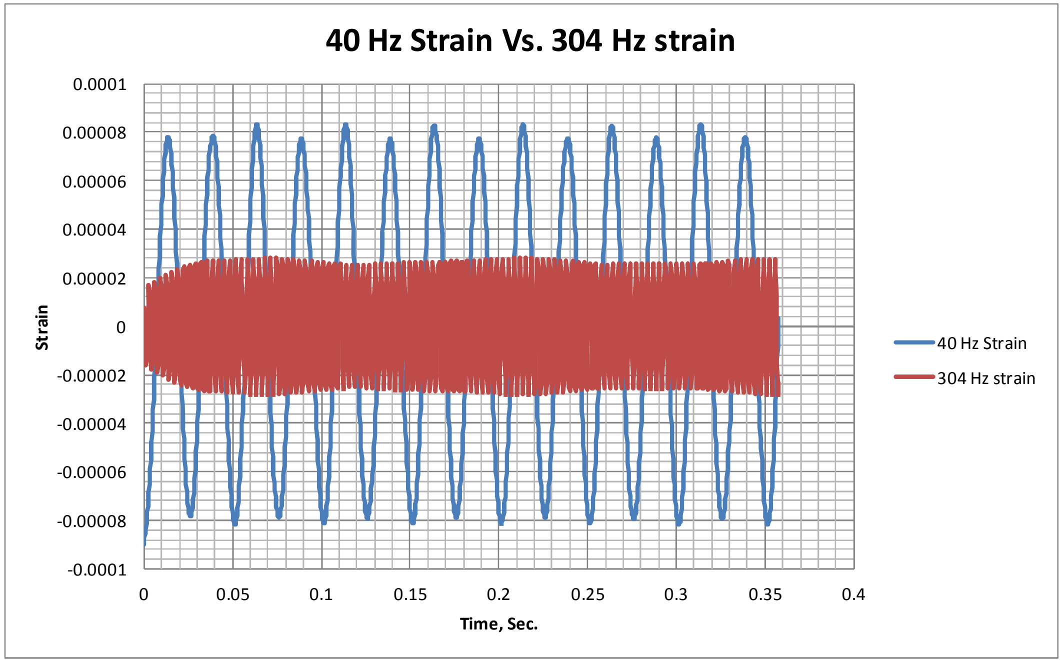
Case Study – Simple Cantilevered Beam

- Results – measured 40 Hz and 304 Hz strain



- A factor of approximately 3 was observed between the two cases

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Conclusion

- Efforts in this arena are planned to continue until a method to leverage this principle is evolved and accepted by the dynamics community
  - *This notion will only aid a subset of components, those with dominant modes above their frequency threshold*
    - This would have most likely helped the fairing with 800 g's specified as structural design criteria
  - *A method of identifying the frequency threshold for a given structure and environment is needed. So, again, "how high is high?"*
  - *While, all the nuts and bolts of the pursued methodology are not established, the underlying premise is valid and the can contribute to mitigating undue conservatism*
  - *There are other areas of future focus relative to mitigation of undue conservatism, this one was seen as the lowest hanging fruit*

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Future Work

- *Acquiring additional data from different structures is planned*
  - Additional data points will be acquired with the TA described in this presentation
    - *Data has been acquired but not yet post-processed*
  - The recent MSFC/AD01/AE01 test series included two flight like avionics boxes
    - *Strain and acceleration were measured in those tests*
    - *The predicted modal frequencies of those boxes are high enough to include them in these studies*
  - Other hardware with significant modes above 300 will be acquired and small scale testing is planned

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Future Work

- *Ultimately, all pertinent results will be utilized in efforts to develop a methodology that will facilitate using this principle to mitigate undue conservatism*

- *The longer term pursuit is that of dynamics analysts writing out stress/strain from dynamic analyses and those being combined with stress/strain from static loadings*

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Acknowledgements

- *The MSFC Technical Excellence program provided resources with which raw materials as well as tools and measurement equipment were acquired in support of these efforts. It is planned for these efforts to continue utilizing those resources*
- *Multiple individuals have supported the efforts "under the radar"*
  - MSFC/ES21 supported these efforts thru their Mechanical Development Facility and their personnel. ES21's Bob Beard fabricated the TA
  - MSFC/ET40 Steve Rodgers provided the shaker table/excitation to the TA
  - MSFC/ET40 Dan Lazor post processed measured strain data

– The efforts and resources above are much appreciated!

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Thank you