SAND2013-9441C

The Derivation of Maximum Predicted Environments for Externally Carried Stores from a Small Number of Flight Tests*

84th Shock and Vibration Symposium.
November 4-8, 2013
Atlanta, Georgia

Jerome S. Cap, Sandia National Laboratories

Melissa K. C' de Baca, Sandia National Laboratories

Troy J. Skousen, Sandia National Laboratories

* Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

- Purpose of Work
- Definition of Approach
- Raw Data Ensemble
- Scaling Model
- Homogeneous Ensemble
- Maximum Predicted Environment

Purpose of Work

- Stores that are carried externally on high performance aircraft are exposed to intense vibroacoustic excitation
- The best approach to quantify this environment is to perform flight tests using instrumented stores
  - However, flight tests are costly and therefore one almost never has data from repeated flights

Purpose of Work

- **We needed to generate a Maximum Predicted Environment (MPE) having a 99% probability of occurrence and a 90% confidence (denoted as P99/90) using the data from 8 flights with 3-4 widely assorted test conditions per flight**
  - **A heterogeneous database does not lend itself to developing extreme statistical estimates of the MPE**

Definition of Approach

- **This study will focus on the straight and level flight events associated with a single station on one type of aircraft**
  - **The primary remaining source of variation is the wide range of flight conditions**
- **The solution was to create a model that could extrapolate the data for any given flight condition to any other flight condition**
  - **The selected model was based on the fact that References [1,2] indicated that the rms vibration was linearly proportional to the dynamic pressure (Q)**

Sandia National Laboratories

Definition of Approach

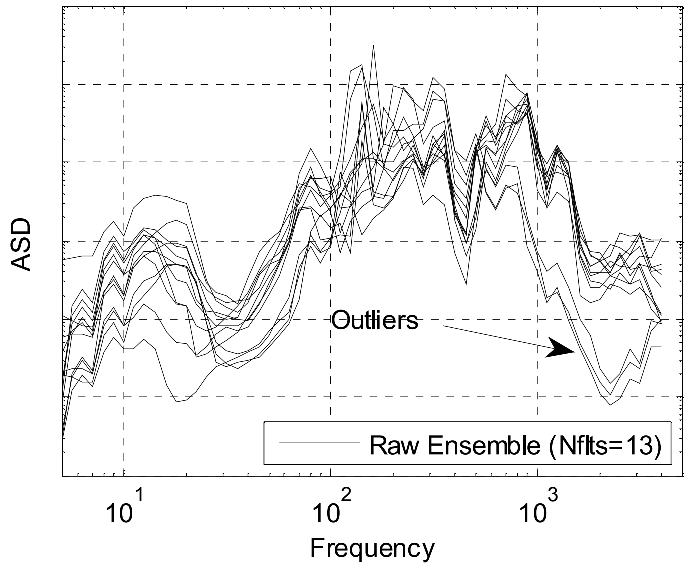
- If all of the data lay exactly on a linear curve relating Q and Grms then one could infer that there was no flight-to-flight variability
- Conversely, the differences between the raw data points and the linear Q curve are assumed to represent the flight-to-flight variability
  - Measurement errors and small differences in aircraft configuration will introduce "phantom" variability

Raw Data Ensemble

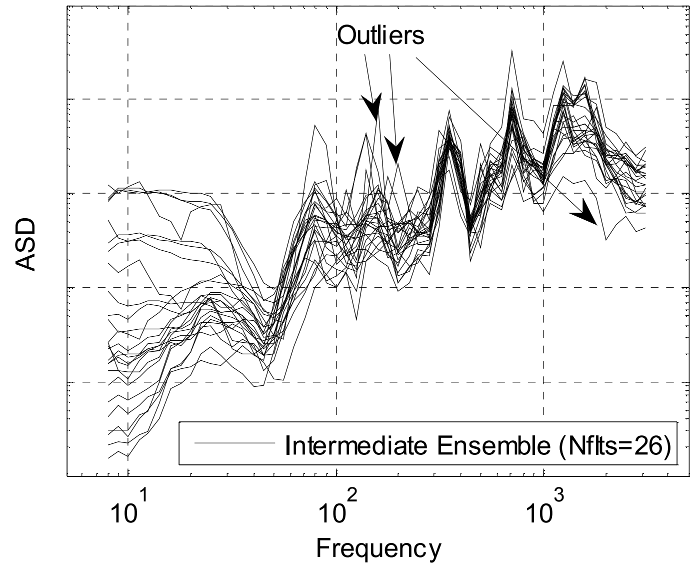
- **Upwards of 25-30 straight and level flight events were available**
  - The available data were ranked according to the dynamic pressure, Q
  - Mach number was also tracked as a possible model parameter but no discernible pattern was observed
- **The ensembles had some uncertainty**
  - The measurement locations were not always obvious
  - The upper cut-off frequency may have changed over time
- **The ensembles were scrubbed and obvious outliers were removed**

Raw Data Ensemble

Major Outliers



Minor Outliers

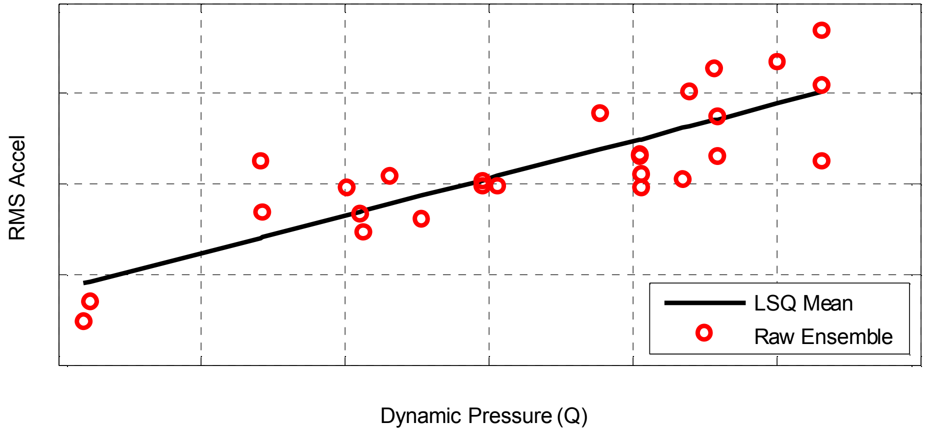


ASDs with major outliers were completely removed from ensemble
ASDs with minor outliers only have the narrow band anomaly removed

Scaling Model

- **The decision was made to start with a simple first order model relating the rms G to the dynamic pressure, Q**
  - **Used rms G instead of the ASDs because the scrubbed ensemble of ASDs have a similar spectral content**
  - **The y-intercept was set to zero (in reality it should have a small positive value due to engine noise)**

$$G_{MN}=m_{MN}Q$$



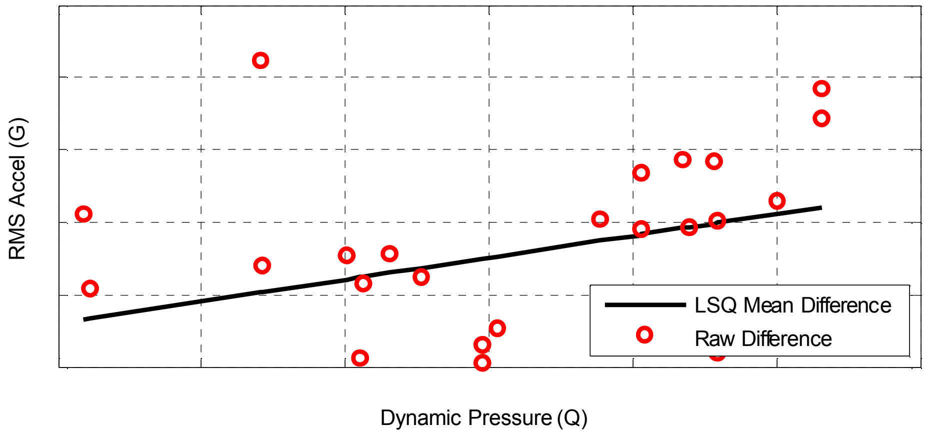
Scaling Model

- **There appeared to be some dispersion that increased proportional to Q so the difference between the measured values of the rms G and the mean rms G was also fit with a first order linear model**

$G_{DF}=m_{DF}Q$

Where

$m_{DF}=(G_{MEAS}-G_{MN})/Q$

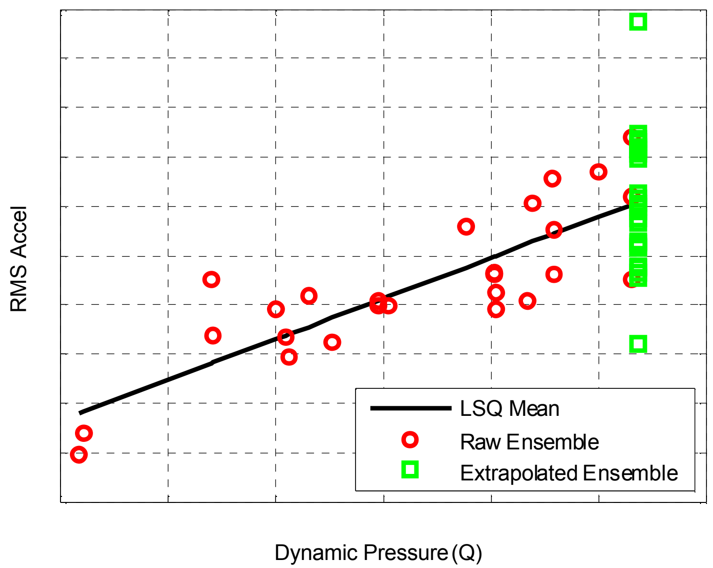


Sandia National Laboratories

Extrapolated Ensemble

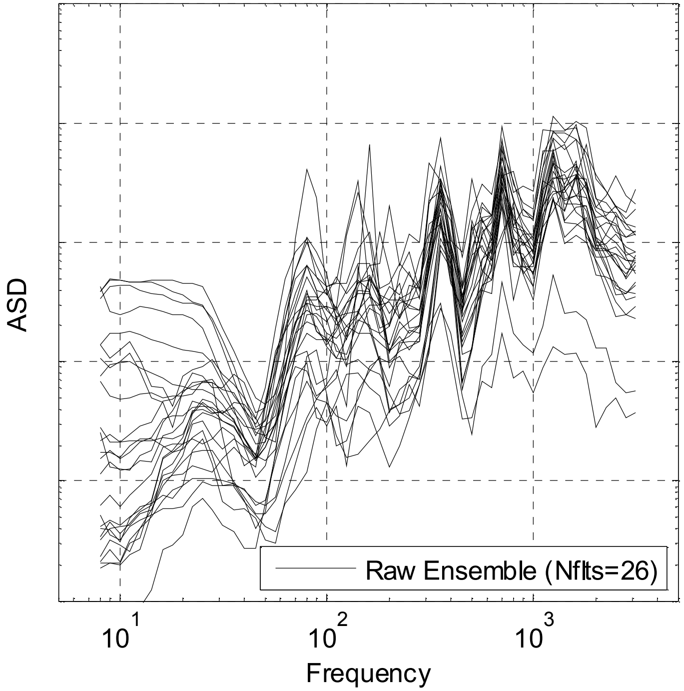
- The extrapolated Grms values, G_E, for the desired dynamic pressure, Q_E, were computed from the corresponding raw values, Q_R and G_R

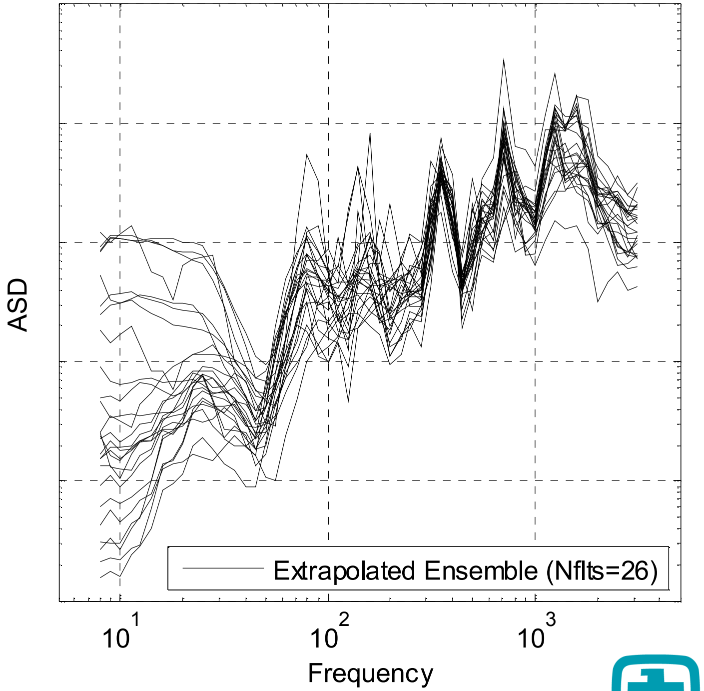
$$G_E = G_R + m_{MN}(Q_E - Q_R) + m_{DF}(Q_E - Q_R)$$



Extrapolated Ensemble

- The raw ASDs were scaled to match the extrapolated Grms values
  - If the process is working the variance in the ensemble should be reduced





Maximum Predicted Environments

- The final step was to generate the MPE responses
- Based on guidelines in NASA 7005 [3] the extrapolated ASDs, S_{XX}, were assumed to be lognormal distributed
  - The mean is computed as

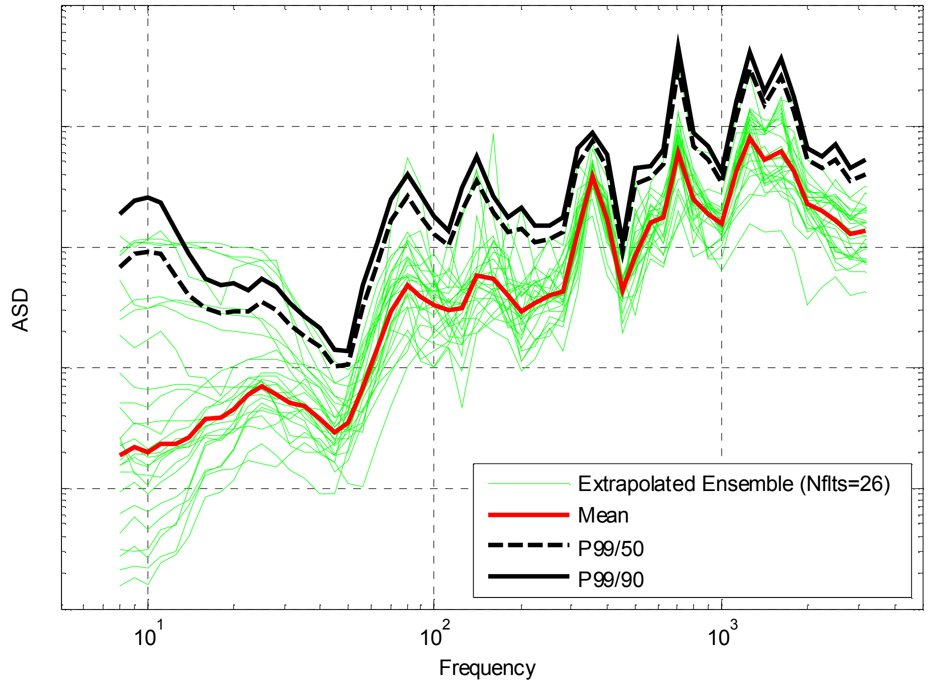
$$S_{XXM}=10^{(mean(log(S_{XX})))}$$

  - The response for a given probability and confidence is computed as

$$S_{XXU}=10^{(mean(log(S_{XX}))+k*std(log(S_{XX})))}$$

  - Where *k* is defined in NASA 7005

Maximum Expected Environments



Summary

- The extrapolation model presented in this study is considered to be a useful tool for developing statistically significant MPEs for a sparse data set
- In the future we intend to gather more test conditions spanning the possible range of flight conditions
  - Special attention will be given to gathering data that can be used to determine if the Mach number should be included in the scaling model
- It might be appropriate to use a non parametric statistical model such as Karhunen-Loeve
- Consider performing the analysis using the ASDs rather than the rms G

References

- [1] MIL-STD-810E; "Environmental Test Methods and Engineering Guidelines.“
- [2] Technical report AFFDL-TR-71-158; “Vibration and Acoustic Test Criteria for Captive Flight of Externally Carried Stores”
- [3] NASA Handbook 7005; “Dynamic Environment Criteria”