Determination of Appropriate Multiple *K* of Damping Standard Deviation for Use in Calculation of Turbine Blade Forced Response

Andy Brown

NASA/MSFC

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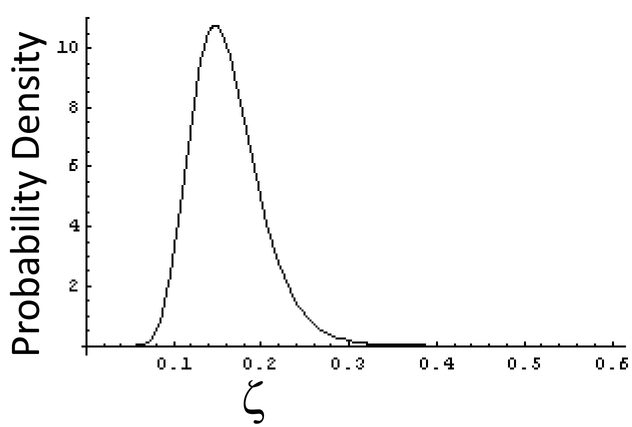
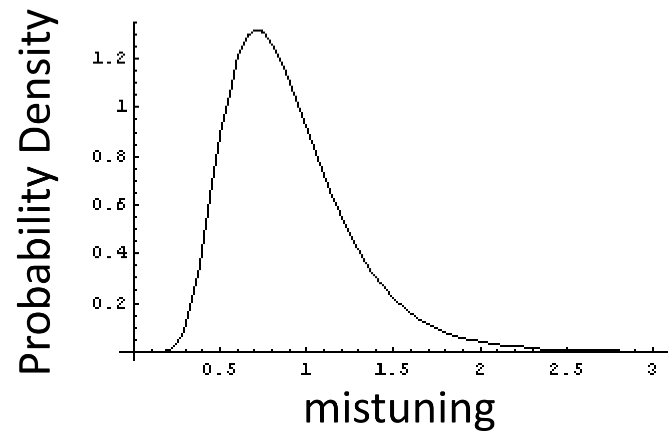
How to Use Damping Statistics?

- Considerable debate on most appropriate use of statistics from whirligig. Options discussed:
  1) Following typical procedure for random variables in engineering design, use -3σ value from all data.
  2) Under assumption that only highest responding blades are of interest, only look at the top-responding half.
     2a) use mean of this half.
     2b) use -3σ of this half.
- MSFC Proposal: Use New "Combined 3σ Environment" Procedure
  - Concept is that mistuning variability and damping variability contribute similarly to the random variability of the blade response
    - We've already determined (by analysis and agreement), that we will use a mistuning value of 2.0 which is the 3σ statistic.
    - We should therefore choose a statistic of damping that when combined with M=2.0, represents a total probability of 3σ (99.86%).
  - Consultations with Dr. Jim Rogers/QD34, reliability expert, verify that using this type of "combined 3σ environment" is typical procedure for assessing responses that are functions of several random variables.
  - Consultation with Dr. Steve Manwaring, GE Aircraft, on Industrial Practice:
    - Measure damping in spin pits, use mean as way to compare different damper concepts, evaluate trends.
    - After design complete, measure actual response of blades during test and use 3σ value to evaluate margin against Goodman.
  - If we cannot measure the actual blade response during test, we view the "combined 3σ environment" procedure as the closest approximation to this approach.

Combined 3σ Environment” Procedure

- Calculate statistics of damage fraction Φ as function of random variables M and ζ (using damping from Whirligig measurements).





- From finite life calculations (B. Wright, PWR, S. Delessio/ER41), we have

$$A_{eq} = \frac{S_a \times FAF \times M_t \times \left(\frac{0.0025}{\xi}\right)}{1 - \frac{S_m}{Ftu}}$$

$$N_{accum} = Speed(s)_n \times T_{service} \times end.factor$$

$$N_{fail\_Unconservative} = 10^{\left(-25.727 \times Log_{10}(A_{eq}) + 53.197\right)}$$

$$\Phi_{HCF} = \frac{N_{accum}}{N_{fail}}$$

- Perform Monte Carlo Analysis - generate 1,000,000 sample set of ζ, M, plug into above equation, obtain 1,000,000 samples of Φ, find Quantile at 99.865%, which is Φ=93156.6 .
- Since we are using a value of M =2.0 by agreement, plug Φ=93156.6 and M =2 into above damage fraction equation and solve for **ζ=.0934**.
- Looking at PDF for zeta, we see that this value occurs at μ-1.649σ. I.E. , *K*=1.649.