Rapid Calculation of Safe Acceleration Values for External Aircraft Structures under Flight Test

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When flight testing an aircraft there may be a number of external structures susceptible to vibration and buffet, such as antennae, radomes, and panels downstream of protuberances. It can be quite difficult to accurately predict what the level of excitation may be on these structures, and thus it is not uncommon that they will be instrumented such that the flight test results can be used to verify that vibration levels are acceptable. Furthermore, material allowables for random vibration fatigue loading can be scarce as sinusoidal based fatigue data is not suitable to be used in a random excitation environment. During testing this means that any unusual results will need to be assessed and sentenced very quickly if the flight test is not going to be delayed; therefore, a means of quickly developing acceleration allowables to compare with flight test instrumentation results can cut costs and risk.

The method described here is a means to quickly generate allowable acceleration levels for accelerometers used when certifying external modifications to aircraft. The method maximises use of existing detail stress analysis and published sinusoidal (rather than random) fatigue data and does not rely on a good understanding of the damping of the system. To further aid rapid turnaround when dealing with compressed flight schedules a nomograph has been supplied which can allow quick calculation without relying upon theoretical knowledge of the methods. The method applies to lightly damped structures primarily excited at their fundamental mode such as antennae, radomes, and panels, but may be able to be conservatively extended if multiple modes exist.

The method relies upon some basic simplifications that greatly streamline the process with minimal effect on accuracy in many cases:

1. The structure will primarily be responding at its fundamental mode, and therefore that frequency can be used for the upwards crossing rate and also used to govern the relationship between acceleration and displacement
2. At the fundamental mode the relationship between displacement and detail stress can often be estimated based upon quasi-static considerations – e.g. a panel under constant pressure instead of the panel first eigenvector
3. When high cycle random stress-life fatigue date is not available then sinusoidal SN data can be converted by taking advantage of the Gaussian distribution of load magnitude at a given RMS stress level (aka Steinberg factor)

It will be demonstrated where these simplifications provide accurate answers. This process can transform an ordinarily complex, error prone, assessment method into a relatively quick and accurate means to assess flight test results.

The relevant parameters are

- f_n, fundamental mode frequency in Hertz,
- σ/δ, the relationship between displacement at the accelerometer position and detail peak stress in the part (may or may not be collocated)
- L, the safe life in hours
- C_{safe} and b, the safe-life Basquin equation, [1], for the detail in question ($\sigma = C_{SAFE}N^b$)
- G_{RMS}, the RMS acceleration at sensor position

With this information available, and knowledge of Miles' Equation (ref [2]) the following relationships are appropriate

- Relationship between RMS acceleration and RMS displacement:
  - $G_{RMS}/\delta_{RMS} = (2\pi f_n)^2/(386.089\ [(in/s^2)/g])\ [g/in]$
- Relationship between RMS stress and safe life in hours:
  - $\sigma_{RMS} = (C_{safe}(3600 f_n L)^b)\ [psi]$
- Relationship between RMS stress and RMS displacement:
  - $\sigma/\delta\ [psi/in]$
- Together these give:
  - $G_{RMSallow} = ((2\pi f_n)^2/(386.088))(C_{safe}(3600 f_n L)^b)/(\sigma/\delta)$

In addition, the following extension to the ‘Steinberg’ 3-band technique (ref [3]) can be used to convert sinusoidal SN data in terms of stress amplitude to random SN data in terms of RMS stress:

$$(C_{RMS}/C_{Sinusoidal})^{1/b} = \Sigma((1)^{1/b}/(0.683)+(2)^{1/b}/(0.271)+(3)^{1/b}/(0.043)+\ldots)$$

Considering that when results come in off flight test aircraft there can be a need for immediate answers: “*are we still safe to fly?*”, “*is the structure going to survive?*”, etc, then a means to quickly generate checks on results that is resistant to error and easy to check is desired. Here a nomogram can be used, as shown in Figure 1. This nomogram relates the parameters above using a pencil and ruler, and an indication of severity of recorded accelerations can be quickly generated with limited information.

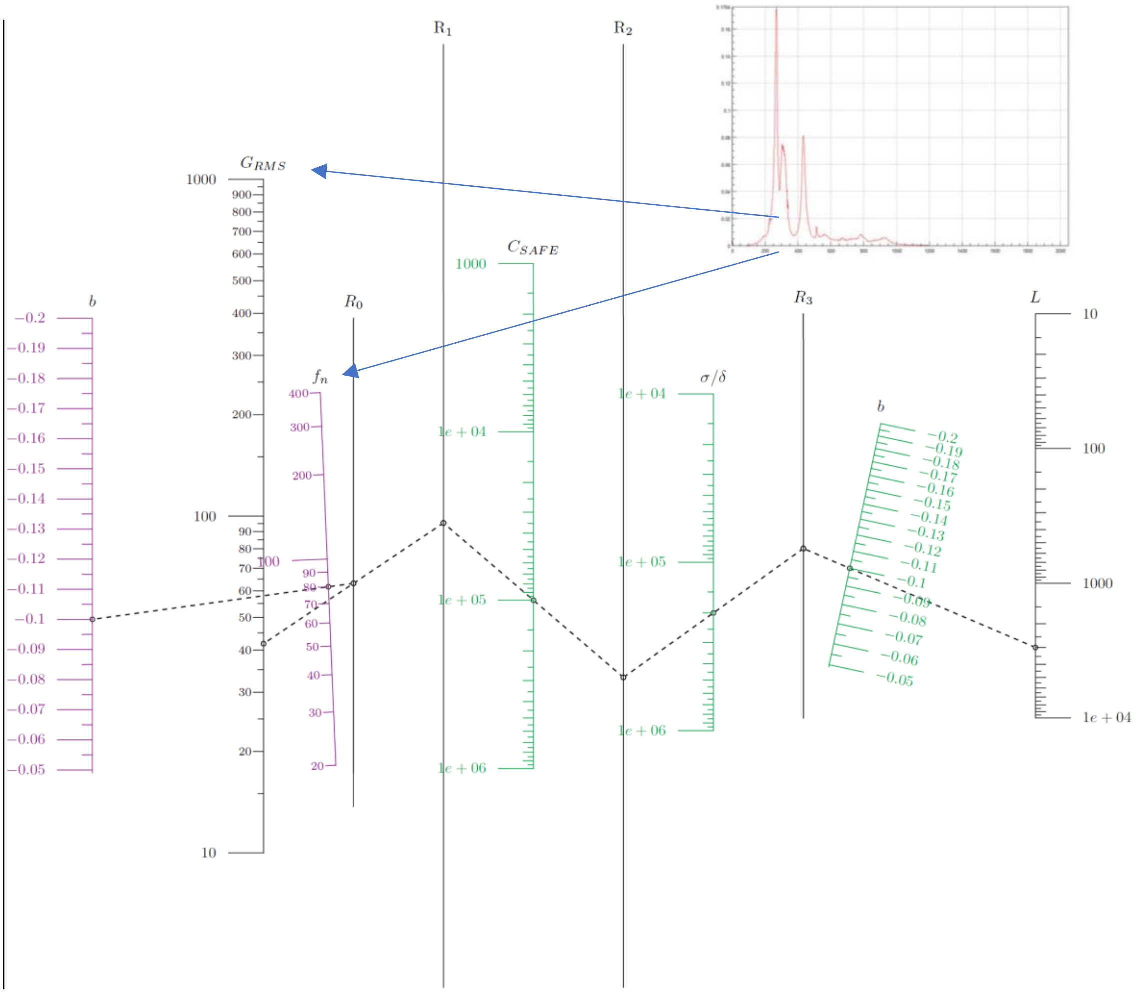

Figure 1. Example Nomograph (b = -0.10, f_n = 80 Hz, C_{SAFE} = 1E5 psi, σ/δ = 2E5 psi/in, and L =3000 hrs)

References:

[1] Basquin, O. H., "*The exponential law of endurance test*". Proceedings of the American Society for Testing and Materials. 10: 625–630, 1910.

[2] Simmons, R., “*Miles’ Equation*”, FEMCI The Book, NASA Goddard Space Flight Center https://femci.gsfc.nasa.gov/random/MilesEqn.html, May 2001.

[3] Steinberg, D., “*Vibration Analysis for Electronic Equipment*”, 3rd Edition, Section 9.16, John Wiley & Sons, 2000.

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