Reducing Undue Conservatism in “Higher Frequency” Structural Design Loads in Aerospace Components

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This study is intended to investigate the frequency dependency of significant strain due to vibratory loads in aerospace vehicle components. The notion that “higher frequency” dynamic loads applied as static loads is inherently conservative is perceived as widely accepted. This effort is focused on demonstrating that principle and attempting to evolve methods to capitalize on it to mitigate undue conservatism. It has been suggested that observations of higher frequency modes that resulted in very low corresponding strain did so due to those modes not being significant. Two avionics boxes, one with its first significant mode at 341 Hz and the other at 857 Hz, were attached to a flat panel installed on a curved orthogrid panel which was driven acoustically in tests performed at NASA/MSFC. Strain and acceleration were measured at select locations on each of the boxes. When possible, strain gage rosettes and accelerometers were installed on either side of a given structural member so that measured strain and acceleration data would directly correspond to one another. Ultimately, a frequency above which vibratory loads can be disregarded for purposes of static structural analyses and sizing of typical robust aerospace components is sought.

Nomenclature

NASA = National Aeronautics and Space Administration
MSFC = Marshall Space Flight Center
Q = Amplification Factor = $1/2\zeta$

I. Introduction

Any aerospace vehicle will have many small systems or sub-systems attached to the vehicle. These “components” include things such as avionics boxes, cameras, valves, etc. In the development of structural design loads for these hardware items, as well as the vehicle side of pertinent interfaces, it is common practice to assume that the component is a single degree of freedom system and to employ the so called “Mile’s Equation” with a specified random vibration environment and an assumed amplification factor (Q). Undoubtedly, there have been innumerous discussions and debates as to the appropriateness of that application. The vast majority of all parties involved in those dialogues most likely agree that the application is conservative and often extremely conservative. Multiple points can be made as to why the approach is considered unduly conservative but the purpose of this paper is to address only one of them. The focus of this effort is an investigation of the perceived inherent conservatism associated with static application of “higher frequency” dynamic loads.

Numerous writers have highlighted observations that at “higher frequencies” structures sustain loads greater than what they do at “lower frequencies” or that above some frequency strain no longer appreciably accumulates (1,2). Knowing that excessive strain is the phenomena that can result in hardware failure and that strain is a measure of relative displacement, equations of harmonic motion, Equations 1 through 3, shed light on these observations.

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

Equation 1

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

Equation 2

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

Equation 3

From (1) and (3), acceleration is ω^2 greater than displacement which is the quantity that results in potential hardware failure. The point to be made is that within the realm of (1) harmonic motion, (2) typical robust structures, and (3) realistic environments, at higher frequencies high accelerations don't result in comparably high strain fields. It can further be noted that the displacement described by Equation 1 is absolute displacement and the relative displacement of interest is but a fraction of that. This reinforces the subject order of magnitude difference in predicted accelerations and the source of strain. The focus of this effort is to investigate pertinent phenomena and initiate efforts to capitalize on this facet of dynamics to mitigate undue conservatism in structural design loads.

While the above offers an explanation for the phenomena observed, some argue that these observations are due to them, the observations, corresponding to modes with little mass participating or that they are not "fundamental modes." Some engineering judgment and some measured data hint that above a few hundred Hz these observations begin to manifest. However, it is not known that hardware yielding these results had dominant modes above the general threshold described. Hence, to proceed with an investigation of this type it is prudent to utilize hardware with dominant modes above a few hundred Hz.

NASA/MSFC has completed a series of tests in which a flight like curved orthogrid panel that represents a one eighth circumferential section of a segment of a vehicle was fixed between a reverberant chamber and an anechoic chamber. It was loaded in tests via predicted flight acoustic levels. Those tests, designated AD01, are complete. Near the completion of that test, engineers compiled a list of "add-on" tests to be performed utilizing the AD01 Test Article (TA) and the modifications made to the test facility. Six tests were selected and the new series was designated AE01 (3). Data presented herein is from the "Flight Like Avionics box Test" which was the 4th test in the AE01 series. This test utilized 2 existing flight avionics boxes, both of which have their predicted significant modes above 300 Hz. The two boxes were instrumented with tri-axial accelerometers and rosette strain gages at select locations.

II. Test Overview

The test was comprised of a reverberant chamber, an anechoic chamber, a flight like orthogrid panel, a simulated avionics panel, and two avionics boxes. The illustration in Figure 1 shows the acoustic chambers configuration and Figure 2 shows photographs of the orthogrid panel with a simulated avionics panel as well as views from each acoustic chamber.

The instrumented avionics boxes, shown in figure 3, were fixed to the simulated avionics panel and the exterior side of the simulated vehicle orthogrid panel was subjected to flight level acoustic fields. Accelerations and corresponding strains on the avionics boxes were measured and recorded. Accelerations on the simulated avionics panel, the input to the avionics boxes, were also measured and recorded.

III. Conclusions

Data acquired from tests described in this paper will contributed to illuminating the phenomena of higher frequency structural capabilities. It will be utilized in efforts exerted to evolve methodologies or engineering rules of thumb intended to mitigate undue conservatism in structural design loads.

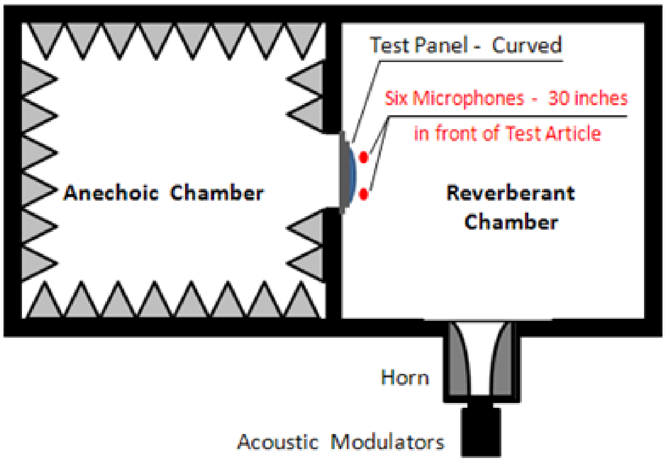
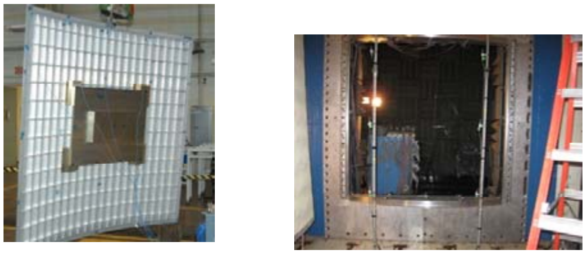


Figure 1. Acoustic Chambers Layout



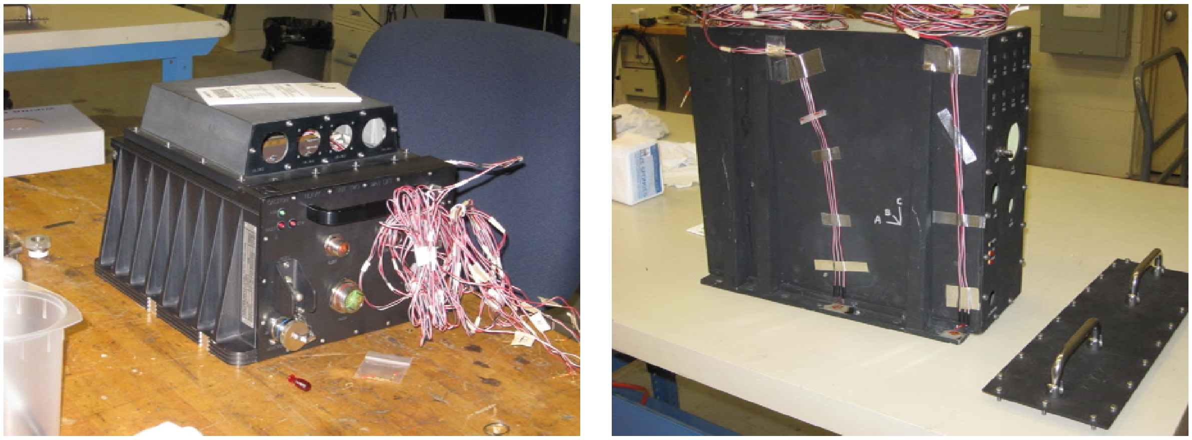
Orthogrid Panel With An Avionics Panel Simulator

View Looking From The Reverberant Chamber To the Anechoic Chamber

Orthogrid Panel Installed - View From Anechoic Chamber

Orthogrid Panel with TPS Installed - View From Reverberant Chamber

Figure 2. Photographs of the Orthogrid Panel and Simulated Avionics Panel



Heavy Box
Approximately 50 Lb
First Predicted Significant Mode is at 847 Hz

Light Box
Approximately 25 Lb
First Predicted Significant Mode is at 341 Hz

Figure 3. Avionics Boxes

Acknowledgments

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