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Analysis on the Specification for Performance Verification in the Gunfire Environment of the Avionic Equipment

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ABSTRACT

This test method is used to demonstrate the ability to withstand the firing environment without compromising the structural stability and functional performance of the mounting equipment. The firing environment includes gun-launched pressure waves crashing into the mounting equipment at gun speed, shock from the structure delivered through the connection structure of guns and mounting equipment, and exposure to transient vibrations produced by a combination of two conditions. This repeated excessive vibration applied to the mounting equipment may cause increased friction or interference between components, resulting in degraded performance or failure. Therefore, it is necessary to analyze the endurance of the mounting equipment at the design stage by generating a specification of the gunfire with the conditions most similar to that of the external environment. In this study, the gunfire specification was analyzed by using numerical analysis methods and the results were compared with the analysis results of the experimental methods through measurement to generate reliable specifications for verifying mounting equipment endurance.

Keywords: Gunfire Environment, Sine on Random Vibration, Sine to PSD, Numerical Analysis, Vibration Stability, Avionics

1. INTRODUCTION

Aircraft mounting equipment need to be designed to withstand static and dynamic loads. The safety verification by dynamic load is divided into the aero-elastic area in which all aircraft structures and tests are performed considering air force, and the vibration environment of mounting equipment is defined and verified according to the mounting position. For aircraft, the area of main target in the flutter analysis is the low frequency band between 0 and 50 Hz and the environmental vibration corresponds to a high frequency area of approximately 50 to 2,000 Hz. Environmental vibration is caused by a source of power, which can accumulate rather than immediately reveal the effects, resulting in a problem that shortens the life of the equipment.

The vibration caused by the firing of a machine gun, an example of environmental vibration generated by an aircraft, causes vibration and mechanical vibration caused by repetitive explosion waves. In particular, repetitive machine gun explosions and vibration

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phenomena are considered one of the extreme dynamic environments of the aircraft. Since these oscillations produce amplitudes and accelerations that are significantly greater than the level of vibration in normal flight, the main systems and structures, including the mounting equipment of the aircraft, should be proven to be safe for these sources of vibration. This means that the structural and functional performance of the aircraft's mounting equipment shall be evaluated against transient, high-speed, repetitive impacts over a relatively rare short period of time that occur in an operating environment during firing.

Previous studies have shown a comparison with the measured strain by interpreting the time response and strain of the structural surface to the machine gun explosion wave of AH-64D Apache attack-type helicopters[1]. Those research were carried out that a study on the dynamic response analysis of gust load of cylindrical panel structure[2] and the characteristic dissipation time due to energy leakage from the detonation of the machine gun using Friedlander Waveform[3]. Based on the scale technique, a code for calculating contour map of a gun fire blast wave was developed[4], and a study was carried out to establish a model of a gun blast wave according to gun characteristics and firing conditions, taking into account the characteristics of a machine gun blast wave[5].

In this study, we propose a method for verifying the vibration stability of mounting equipment according to the location of the aircraft mounting by establishing a procedure for predicting the Sine on Random(SOR) profile in numerical analysis and verifying it in a test method, which is expected to occur during the firing of aircraft-mounted gun.

2. Define of the Derivation Procedure a Gunfire Specification

2.1 SOR Spectrum Prediction Procedure

Gunfire vibration is the criterion for evaluation of the structural and functional performance of munitions against transient, high-speed, repetitive shock of relatively rare short-term duration that occur in an operating environment during firing[6]. Gunfire vibration is also considered a firing shock and is utilized where reliability is required to ensure that the firing environment can be tolerated without structural failure or functional degradation. The firing environment is divided into those exposed to gun-firing pressure waves by air striking military products at gun-firing speed, repeated shock by structures transmitted through gun and linkage structures, and rapid repetitive shocks in the firing environment of excessive vibration produced by a combination of both conditions. Using air-borne gun firing pressure waves, a procedure can generate an expected SOR spectrum by reproducing the information tracked by time of military product input/response measured in accordance with the time waveform replication instructions. Repeated shock transmitted by the structure can produce a stochastic input/response spectrum based on measured time tracking information. Therefore, the two procedures are combined to define the probabilistically predicted gunfire vibration based on the anticipated SOR spectrum and to generate an SOR spectrum assuming a time function as representative of the minimum measured firing response for conservative estimates instead of the time tracking of the gunfire vibration time for mechanical and geometric configuration parameters.

2.2 Define of numerical expressions and parameters

For the prediction of the SOR spectrum, the proposed general parameter expression is used as follows. The general parameter expressions and parameter definitions proposed for the 3 levels of broadband irregular vibration(T_j) defining the spectrum in Figure 1 are the same as Equation 1 and Table 1, expressed in dB(1 g^2/Hz) of g^2/Hz.

$$\mathbf{10log_{10}(T_j) = 10log_{10}(NF_1E) + H + M + W + J + B_j - 53dB \quad j = 1,2,3 \quad \cdots \quad (1)}$$

The general parameter expression proposed for four levels of single frequency vibration is the same as in Equation 2, as expressed in dB(1 g^2/Hz) of g^2/Hz.

$$\mathbf{10log_{10}(P_i) = 10log_{10}(T_3) + K_i + 17dB \quad j = 1,2,3,4 \quad \cdots \quad (2)}$$

$\mathbf{10log_{10}(T_j) = 10log_{10}(NF_1E) + H + M + W + J + B_j - 53dB}$ $\mathbf{10log_{10}(P_i) = 10log_{10}(T_3) + K_i + 17dB}$	
for	
N	Maximum number of closely spaced guns firing together. For guns that are dispersed on the host aircraft, such as in wing roots and in gun pods, separate vibration gunfire test spectra are determined for each gun location. The vibration levels, for test purposes, are selected for the gun that produces the maximum vibration levels.
E	Blast energy of gun
H	Effect of gun standoff distance, h
M	Effect of gun location M = 0 unless a plane normal to the axis of the gun barrel and located at the muzzle of the gun does not intersect the aircraft structure, then M = -6 dB.
W	Effect of weight of the equipment to be tested. If the weight of the materiel is unknown, use W = 4.5 kilograms (10 lbs).
J	Effect of the materiel’s location relative to air vehicle’s skin.
B_j	Effect of vector distance from the gun muzzle to the materiel location.
F_1	Gunfiring rate where F_1 = fundamental frequency ($F_2 = 2F_1$, $F_3 = 3F_1$, $F_4 = 4F_1$)
T_j	Test level in g^2/Hz
P_i	Test level for frequency F_i in g^2/Hz (where i = 1 to 4)
K_i	Effect of vector distance on each vibration peak, P_i.

Tabel 1. Suggested generalized Parametric Equations for Gunfire-induced Vibration

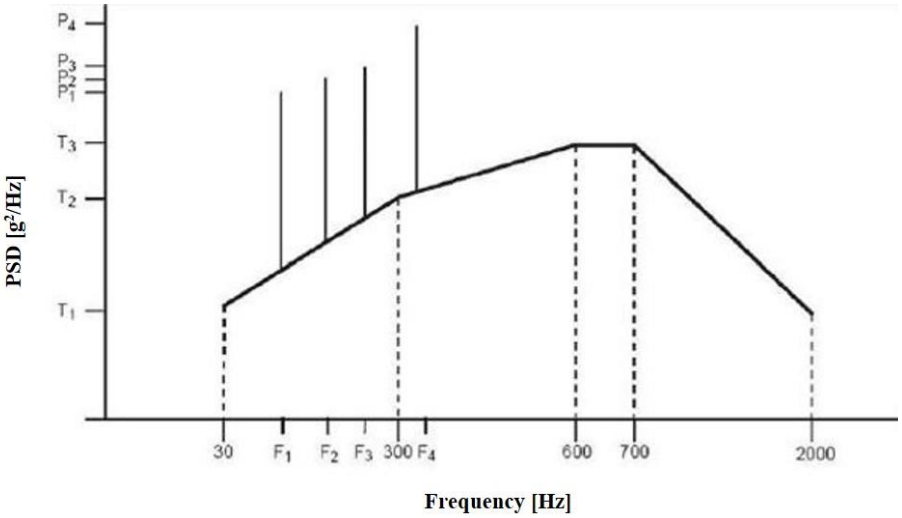

Fig 1. General Shape of Gunfire Vibration Spectrum

The main geometric factors used in the determination of the SOR spectrum are distance vector, distance of guns, depth parameter, and gun diameter. Distance vector is the average vector distance from the muzzle of a gun to the point of support for the mounting device. For multiple gun configurations, the origin of vector D is measured relative to the center point of the gun. Gun distance means the vertical distance between the gun-barrel and the plane's surface. The depth parameter refers to the distance perpendicular to the surface of the aircraft from the location of the mounting equipment inside the aircraft, the gun diameter is defined in milli-meters or inches, and is based on the vibration peak bandwidth converted from measured response data during operation to Fast Fourier Transform(FFT). If there is no data during operation, the vibration peak bandwidth can be calculated as shown in Equation 3.

$$\boldsymbol{BW_{3dB} = \left(\pi F^{1/2}\right) \div 4 \quad \cdots \quad (3)}$$

Where, BW3 dB is the bandwidth at the level of 3 dB(2 times) below the peak ASD level and F is either the fundamental frequency or the high frequency F_1, F_2, F_3, F_4.

3. Engineering verification of PSD conversion procedures

3.1 Establishment of the PSD conversion procedures

Severe dynamic phenomena that can occur during aircraft operations are generated in the gunfire of a Sine on Random by combining the vibration of aircraft from flutters, turbulence, buffet, random vibrations by engines, etc. and repetitive gunfire from firing on aircraft wings. In order to analyze the vibration stability of the mounting equipment by using finite element method for the spectrum of the Sine on random waveform, it is necessary to convert the Sine waveform into a PSD and convert it into a random vibration type profile. Therefore, using the empirical formula for converting the Sine waveform to PSD as shown in Figure 4, a numerical analysis method is used to produce a profile in the gunfire of random vibration.

$$\boldsymbol{a_{psd} = a_{pk}^{2} \div \Delta f \div 3 \quad \cdots \quad (4)}$$

where a_{pk} is the size of the sine waveform, the a_{psd} is the sine waveform converted to PSD, and Δf is the FFT frequency resolution per unit frequency.

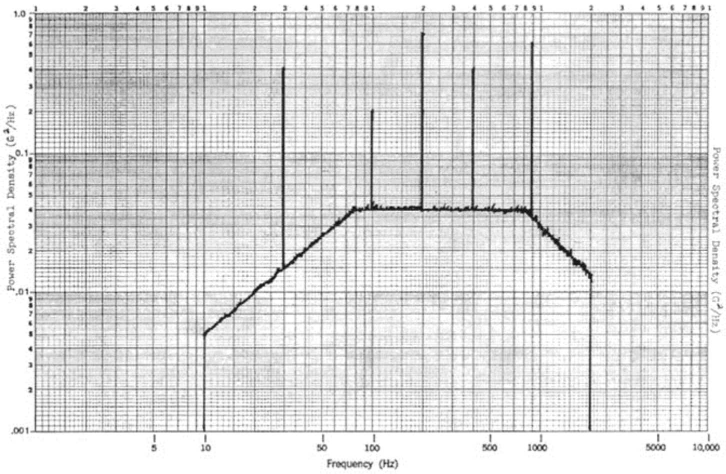

Fig 2. Combined Random and Sinusoidal Vibration Profile

An example of the SOR spectrum was illustrated in Figure 2, and the numerical analysis was performed assuming that sine peak A is 2.6 g_{peak} and PSD level B of random vibration is 0.015 g^2/Hz. The sine peak was converted to PSD using Equation 4 and the expected Grms figure was calculated using Equation 5,6 by synthesizing it with a random vibration profile expressed in PSD. A series of processes resulted in the calculation of the overall level L as 4.63 Grms, with the result and PSD profile illustrated in Figure 3. Where, m is the quantity of the segment.

$$\boldsymbol{a_i} = \begin{cases} \left[\dfrac{\boldsymbol{y_i}}{\boldsymbol{f_i}^{\boldsymbol{n}}}\right]\left[\dfrac{\mathbf{1}}{\boldsymbol{n}+\mathbf{1}}\right]\left[\boldsymbol{f_{i+1}}^{\boldsymbol{n}+\mathbf{1}} - \boldsymbol{f_i}^{\boldsymbol{n}+\mathbf{1}}\right], \ \boldsymbol{for\, n \neq -1} \\ [\boldsymbol{y_i f_i}]\left[\mathbf{ln}\left(\dfrac{\boldsymbol{f_{i+1}}}{\boldsymbol{f_i}}\right)\right], \ \boldsymbol{for\, n = -1} \end{cases} \quad \cdots \quad (\mathbf{5})$$

$$\boldsymbol{L} = \sqrt{\sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{m}} \boldsymbol{a_i}} \quad \cdots \quad (\mathbf{6})$$

A series of processes resulted in the calculation of the overall level L as 4.63 Grms, with the result and PSD profile illustrated in Figure 3.

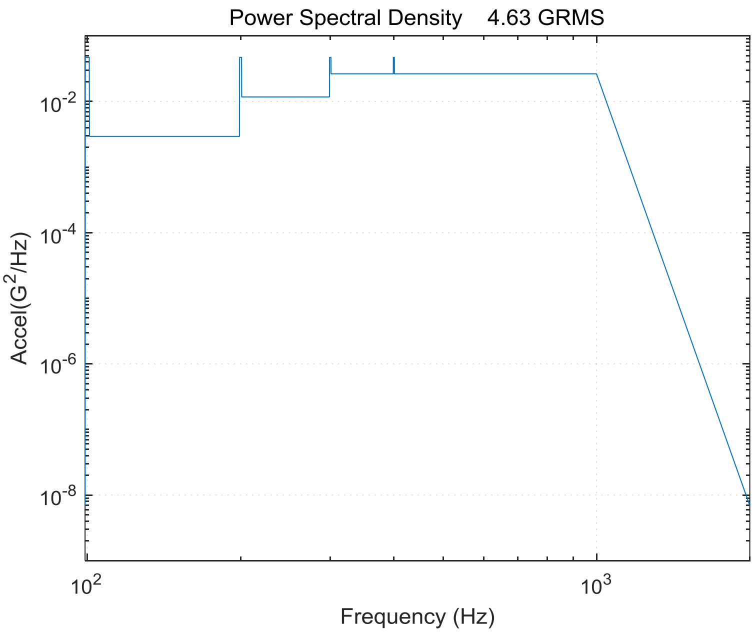

Fig 3. Result of the Numerical Analysis

3.2 Reliability Verification by testing

To verify the validity of the results of the numerical analysis, tests were carried out using the shaker. The input profile is shown in Figure 1, and the average of the data measured five times over 160 seconds to ensure the reliability of the data. Acceleration data collected in the Time domain was transformed by FFT method and unnecessary signals were removed through Band Pass Filter in the 90 to 2,000 Hz. The results are shown in Figure 4 and the Grms are derived as 4.65 to confirm that they are similar to the results of the numerical analysis method.

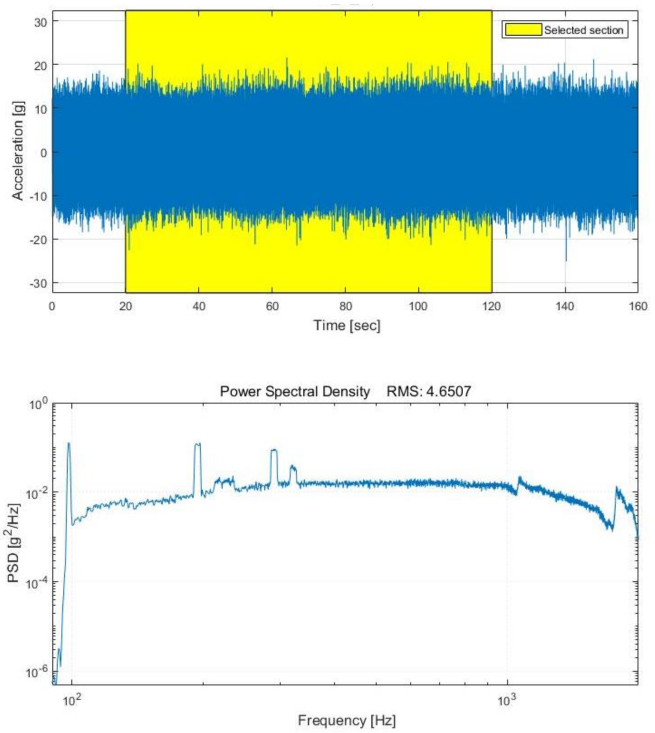

Fig 4. Result of the SOR Vibration Test

4. CONCLUSIONS

A procedure has been established to analyze whether the aircraft mounting equipment has secured vibration stability for vibration environmental conditions caused by repeated explosion of the gun fire. The spectral prediction procedure of the gunfire specification was analyzed to define the formula and parameters required for establishing the specification, and the process of converting Sine vibration to PSD was proved by numerical analysis. To ensure reliability of the analysis results, a reliable specification calculation procedure was established to verify the durability of the mounting device by comparing the response to the SOR vibration input conditions with the numerical analysis results. The specification calculation procedures established in this study is able to be used as a useful method for predicting the vibration effects and assessing of the vibration stability transmitted to the aircraft mounting equipment by the shock of gunfire.

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