# AIRCRAFT EQUIPMENT RANDOM VIBRATION TEST CRITERIA BASED ON VIBRATIONS INDUCED BY TURBULENT AIRFLOW ACROSS AIRCRAFT EXTERNAL SURFACES

JOHN F. DREHER
*Air Force Flight Dynamics Laboratory*
Wright-Patterson AFB Ohio

The paper describes the development of random vibration test criteria for aircraft equipment whose prime source of vibration is turbulent airflow at the surface of the aircraft. Associated criteria for equipment vibration caused by jet engine noise or operation of aircraft guns can be found in references 15 and 16, respectively. The paper shows that the random vibration levels, as derived from the study of 4 jet aircraft, are generally less severe than existing applicable sinusoidal tests. The test levels are adaptable to a particular aircraft/equipment location and are based on the aircraft's aerodynamic pressure (q) and its surface geometry. The criteria contain both functional and fatigue test procedures. The paper stresses the importance of functional testing to alleviate operational malfunction. The fatigue test levels are adaptable from the standpoint that the level is based on the number of flights the equipment will be operational as well as the total qualification test time.

## INTRODUCTION

Vibrations within jet aircraft are caused by a number of phenomena. The principal sources, generally, are: jet engine noise and turbulent airflow (pseudo-noise) which impinge on aircraft external surfaces; gust, landing, and takeoff loads; and on-board mechanical equipment such as engines and pumps. This paper describes the structural vibrations induced by turbulent airflow and generalizes the findings to develop pertinent, adaptable random vibration test criteria for aircraft equipment. These criteria are those recently proposed for inclusion in Method 514 of MIL-STD-810C, "Environmental Test Methods."

The results of the study are based on statistically significant quantities of measured flight vibration data from four distinct jet aircraft. Two of the aircraft used are fighter-bomber types and two are cargo types. Both fighter-bomber vehicles have engines which exhaust at or near the extreme aft fuselage such that most of the flight data measured could be considered as produced by turbulent surface airflow rather than from the jet engine noise. On the other hand, the cargo aircraft have wing mounted engines such that only the forward quarter fuselage data was considered applicable.

## RELATIONSHIP BETWEEN VIBRATION & TURBULENT SURFACE AIRFLOW

The turbulent airflow impinging on an aircraft surface during high speed flight has sufficient oscillatory energy to cause significant vibrations in the surface structure [1]. This phenomena has caused extensive fatigue cracks in many military flight vehicles [2]. These surface vibrations are directly transferred, then, through the vehicle's internal structure and into the vehicle's equipment. Thus, the equipment vibration environment is a direct function of the surface airflow and the structure's dynamic transmissibility.

The characteristics of this turbulent airflow have been well established [3, 4, 5, 6]. Generally, it has a randomly oscillating amplitude and exhibits a frequency spectrum that varies continuously over a broad range. Its rms amplitude has been shown to be a function of the aircraft's aerodynamic pressure (q), Mach number (Mn), and local surface geometry. Generally, its magnitude increases with increasing q in a more or less linear fashion. Perturbations to this linear relationship occur at certain Mach numbers and are generally caused by local "shocks". These often occur in the transonic range (0.8 to 1.0 Mn) as well as at certain supersonic speeds. The flow over vehicle surfaces with irregular geometry is generally 15 to 25 decibels (5 to 20 times) more turbulent than flow over smooth surfaces. Such irregularities commonly found on aircraft are speed brakes, blade antennas, reentrant surface angles, engine boundary layer control



82 12 27 051

devices, open weapons bays, gun muzzles, and air conditioning exhaust ports.

Thus, we can expect equipment located in compartments adjacent to and immediately aft of surface irregularities to experience vibrations significantly higher than equipment in compartments adjacent to smooth external surfaces. Furthermore, since the aerodynamic source is random, the vibratory response is random [7]. The frequency characteristics of the input to the equipment is affected by the filtering (transmissibility) characteristics of the intermediate structure.

Over a broad range of flight vehicles, these structural filtering characteristics are reasonably similar. For example, most aircraft surfaces are principally monocoque consisting of light gage sheets riveted to stringers, frames, and longerons. Characteristically, these sheet metal surfaces, upon which the oscillating air directly impinges, have a sequence of natural vibration frequencies whose fundamental frequency is between 200 and 400 cps. While they vibrate at all of the forcing frequencies, they greatly amplify the vibrations at their natural frequencies. These frequencies, then, coupled with any significant resonances of the internal structure, are the dominant points on the frequency spectrum perceived by the aircraft's equipment. Figure 1 shows a typical spectrum of the structural vibration measured near an equipment mount.

## DEVELOPMENT OF FUNCTIONAL TEST LEVELS

In the past two decades, and perhaps since the genesis of test specs, there has been considerable criticism that vibration test specifications are not realistic. The bulk of the criticism from industry, and recently from DOD equipment project officers, has been that test levels are too high. This criticism is especially intense when it has been discovered that an equipment item cannot pass its vibration test.

Environmental engineers have great difficulty in justifying the existing specifications, especially when they know that the environment is random while the test is sinusoidal, and when they know that the environmental levels vary appreciably from aircraft to aircraft and from point to point in the same aircraft while the existing specifications are relatively rigid. It is little wonder that reduction or complete waiving of test requirements has become more the rule rather than the exception in the last several years.

It follows that adaptable, random vibration tests are needed. Yet, since it is the usual custom that the equipment project engineer, rather than an environmental engineer, establishes the environmental test requirements for his equipment, any new adaptable test should be as easy to understand and apply as practicable. Thus, it is necessary to investigate the many parameters upon which test levels are dependent with a view toward simplifying the final criteria.

As discussed in the previous section, the aircraft equipment's environment is heavily dependent upon the characteristics of the turbulent flow at the vehicle's adjacent surfaces and the local structural dynamic transmissibility. As for this dynamic transmissibility, it is usually very difficult or impossible to determine. Perhaps the only practical approach is to statistically analyze measured flight vibration data from several flight vehicles and relate these, respectively, to the characteristics of the turbulent airflow at the vehicle surface adjacent to the vibration pickups, thus determining an average structural transfer function. Again, this is based on the assumption that most vehicles have similar construction.

As for the external flow, it can generally be parameterized in terms of the vehicle's surface geometry, aerodynamic pressure (q), and Mach number (Mn). As pointed out earlier, the vehicle's surface geometry causes a significant difference in the magnitude of the external flow turbulence for a given q. Thus, a practical approach in analysis is to break out the measured vibration data into various aircraft zones. These are characterized as zones adjacent to irregular surface geometry and zones adjacent to smooth surface geometry [6].

To include Mach number as a prediction parameter would also add a large degree of complication. Mach number effects are highly dependent upon local surface geometry and thus require too detailed a knowledge of the particular aircraft structure to be practical for use

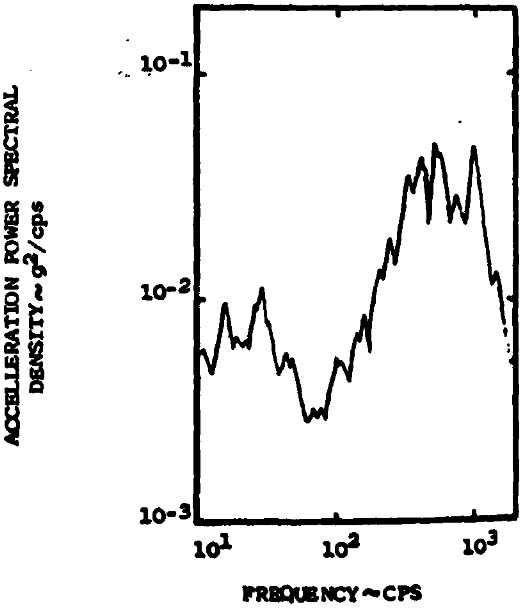



Fig. 1 Typical aircraft structural vibration spectrum measured near an equipment mount.

in such a document as MIL-STD-810.

Although Mach effects can occur at supersonic speeds, many occur at transonic speeds (0.8 to 0.95 Mn) at surface irregularities. The usual effect is a relatively abrupt increase in the magnitude of the local turbulence as the critical speed is approached, followed by a relative reduction in magnitude as this speed is exceeded. This phenomena is shown in Figure 2.

range. Furthermore, this linearity assumption is consistent with the relationship between vibration level and q in zones of smooth geometry.

Thus, the approach taken in this study was to assume that aircraft vibration levels are proportional to aerodynamic pressure (q), both in zones of smooth and irregular surface geometry, with the constant of proportionality, k, derived on the basis of a line that forms the

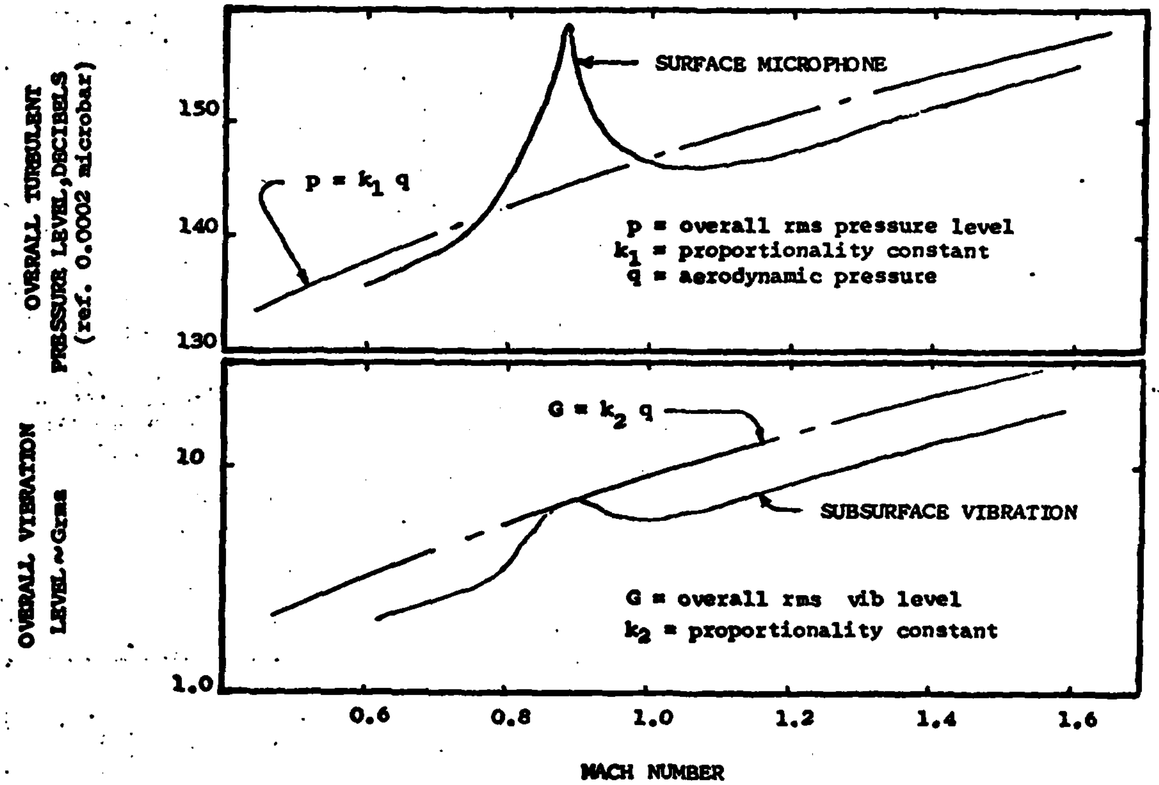



**Fig. 2** Comparison of turbulent pressure and corresponding aircraft structural vibration as a function of Mach number (constant altitude).

Note in this figure that the turbulence level as well as the proximate vibration level tend generally to increase with increasing Mach number (and q), notwithstanding the perturbation at the critical Mach number. This suggests an approach which relates the vibration level directly as a linear function of q ($G = kq$) with the use of the vibration level at the critical Mach number to evaluate the coefficient k. Such a curve is also shown in Figure 2. This approach is described in more detail in references 8 and 9.

Admittedly, this relationship provides a conservative estimate of the vibration level at other Mach numbers. However, a significant percentage of the flight time of most vehicles is spent in this transonic range, and test levels are often based on measurements in this

upper tangent to the G vs q curve. As far as practicable, each vehicle used in the study was divided into zones of smooth and irregular surface geometry. When possible, the measurements in each zone were statistically analyzed (mean value, standard deviation $\sigma$) and the vibration level was established on the basis that 95% of the data in each zone was covered (mean value $+1.6\sigma$). The details of this process are shown in the next section.

## ANALYSIS OF AIRCRAFT A

Aircraft A is a fighter-bomber type with extensive surface irregularities. The vibration data was separated into zones adjacent to smooth surfaces and zones adjacent to irregular surfaces. Although only small amounts of data were available from wing, stabilizer, and aft fuselage (aft of wing trailing edge) zones, these zones were put in the irregular surface category. This step is considered reasonable because of high turbulences caused by external pylons and stores. Furthermore, equipment within wings and stabilizers are much closer to the source of vibration (i.e., less structural attenuation).

Figure 3 shows how the overall vibration levels vary with aerodynamic pressure. The curve representing each accelerometer is normalized based on its vibration level at 0.9 Mn. The curves shown were taken from flights at altitudes of 2000 feet and 30,000 feet. Note that a linear relationship between vibration level and q is not totally unrealistic.

the appropriate one-third octave bandwidth. Following this operation, all levels were increased by 4.5 decibels to insure enveloping the narrow band peaks [10]. This 4.5 decibel factor was determined by comparison of one-third octave band and narrow band plots of the same data. Figure 4 shows the results for both zones.

ANALYSIS OF AIRCRAFT B

Aircraft B is also a fighter-bomber. The analysis used was the same as used with Aircraft A. Unfortunately, no data was available to show the relationship between vibration level and q. However, vibration levels measured during takeoff and landing were available

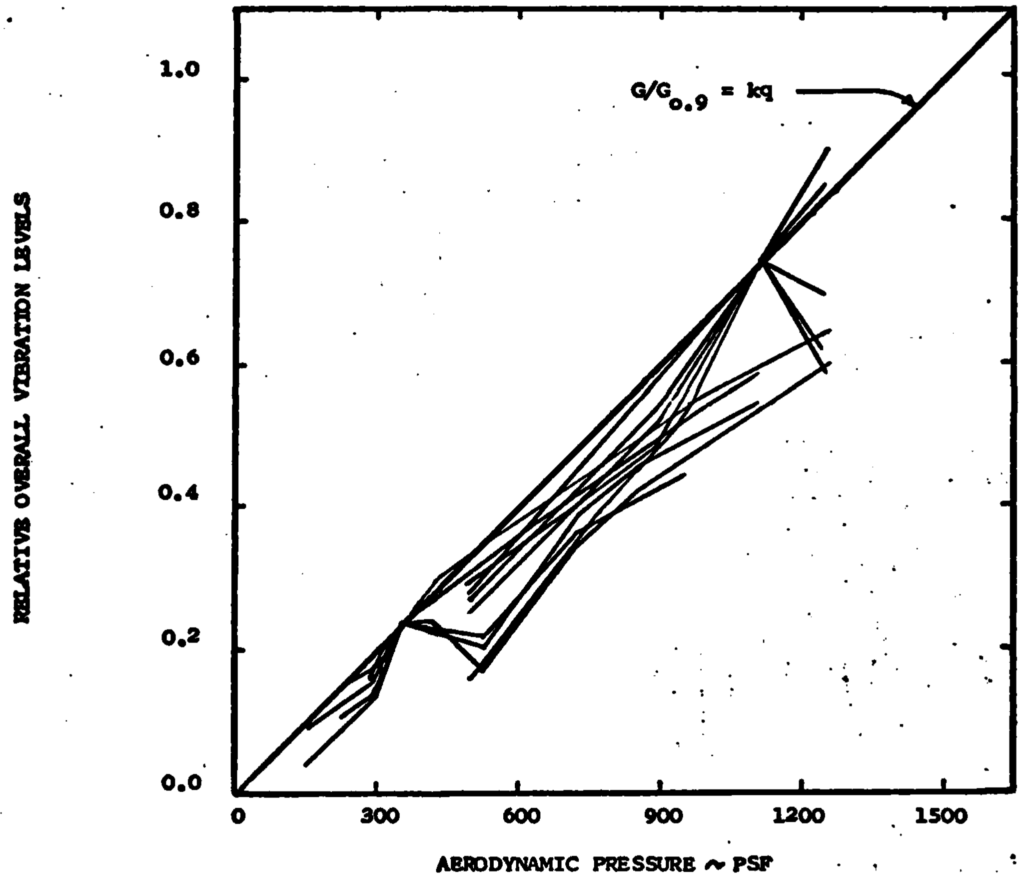



Fig. 3 Comparison of aircraft overall vibration level vs aerodynamic pressure. Data is taken from five accelerometers during flight at altitudes of 2000 feet and 30,000 feet. Vibration levels from each altitude have been normalized based on their levels at 0.9 Mach number.

To develop a test level, vibration data were used for flight conditions in the transonic range. One-third octave band frequency spectra were used to compute the mean level and standard deviation for each zone. These one-third octave band levels were then converted to power spectral density levels by squaring the one-third octave $G_{rms}$ levels and dividing by

and are shown in Figure 5 along with the mean vibration levels and other parameters for transonic flight. Note how the takeoff and landing vibrations greatly exceed the flight vibration levels below 200 cps. This suggests that takeoff and landing should be considered in the development of the vibration test criteria. This subject is addressed further in the

Comparison of All Data section.

## ANALYSIS OF AIRCRAFT C

Aircraft C is a four engine (wing mounted) jet cargo aircraft. Only data in the fuselage forward of the engines was used in the analysis

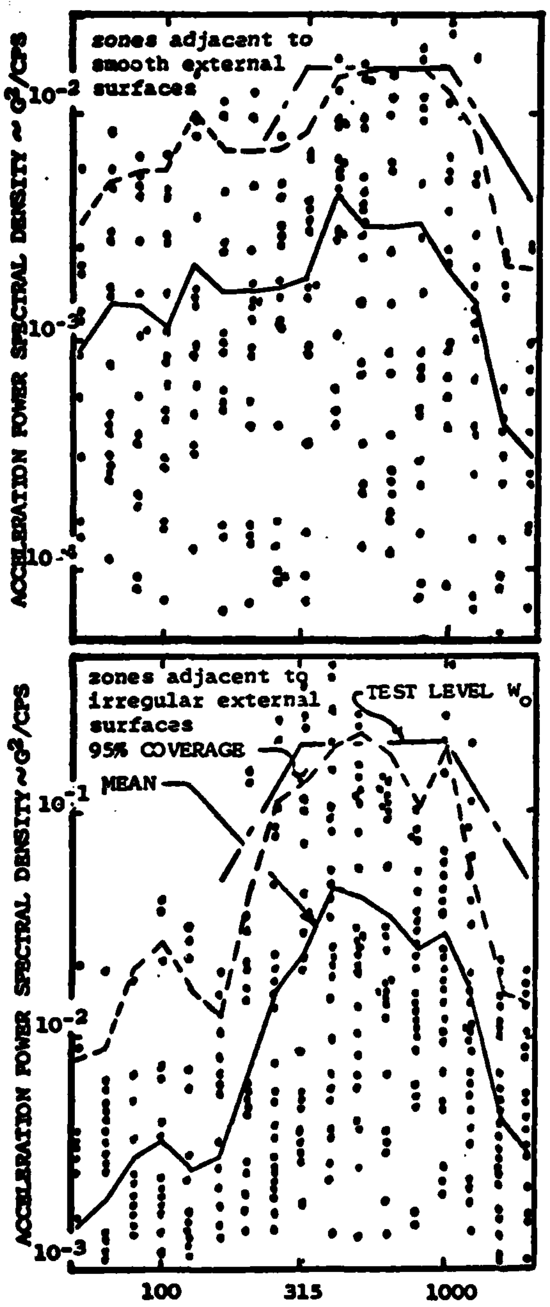



Fig. 4 Comparison of measured aircraft vibrations with qualification test levels for Aircraft A flying at 2000 feet and 0.9 Mach number (q = 1120 psf).

so as to eliminate the effects induced by jet engine noise. The data available for analysis was presented in terms of $g^2$/cps based on a 5 cps filter bandwidth analysis. Insufficient data was available to show the relationship between vibration level and q. Figure 6 shows the measured vibration levels and other parameters for q = 280 psf as well as during ground operations. In this case, the 95% qualification test level was obtained by constructing a line approximately 2 to 3 decibels below the maximum measured levels shown. This 2 to 3 decibel factor was derived from comparison of maximum levels and the 95% level from Aircraft A and B.

## ANALYSIS OF AIRCRAFT D

Aircraft D is also a large four engine (wing mounted) jet aircraft. Again, only fuselage vibration data measured forward of the engines was used in the analysis.

Although a large number of accelerometers was used in this section of the fuselage, the available data was not sufficiently described so that mean zone levels and standard deviations could be computed. Rather, the available data was based on octave band filter analysis and only the upper 60% (two tail) confidence limits were shown. In an attempt to get at least ballpark results, these confidence limits were raised by a factor of 10 decibels and were used in that form as an estimate of the 95% data coverage curve. These are shown in Figure 7. The 10 decibel factor is the sum of a 7 decibel increase to insure enveloping the narrow band peaks [10, 5 (Page 25)] and a 3 decibel increase which the authors of reference 5 suggests will cover "most of the data" in the mid-frequency range (300 to 600 cps).

## COMPARISON OF ALL DATA

Let us consider that a representative test curve can take the form shown in Figure 8. Then, Figure 9 shows the $W_o$ test levels of Figures 4, 5, 6, and 7 plotted vs aerodynamic pressure. It can be seen that the relationship

$$W_o = 2.7 \times 10^{-8} \times q^2 \quad g^2/\text{cps} \qquad (1)$$

approximates the data for zones adjacent to smooth surfaces, and that the relationship

$$W_o = 14 \times 10^{-8} \times q^2 \quad g^2/\text{cps} \qquad (2)$$

approximates the data for zones adjacent to irregular surfaces.

With regard to the test level $W_1$ shown in Figure 8, it is sometimes more difficult to relate it to q. Vibrations in the low frequency range depend on the excitation of the bending and torsion modes of the vehicle's fuselage, wings, and empennage. While the higher frequency vibrations are almost totally dependent upon local surface flow and are thus highly repeatable from flight to flight [6, Page 97].

the lower frequency amplitudes are more dependent on transient exciting forces such as wind gusts, touchdown, and runway roughness, and are thus much less repeatable from flight to flight. Furthermore, the highest levels measured do not occur every mission, and perhaps occur only a few times over the life of the aircraft.

Since insufficient data is available to statistically characterize the vibration levels in this low frequency range, it was decided to use a test level that is based on sinusoidal test levels of approximately $\pm$ 1G to $\pm$ 2G which are commonly used in this frequency range (reference MIL-STD-810). Using a process similar to that described in a later section (comparison of Random and Sinusoidal Vibration Testing) for random/sine equivalence, the following test level was derived.

$$W_1 = 0.04 \quad g^2/cps \qquad (3)$$

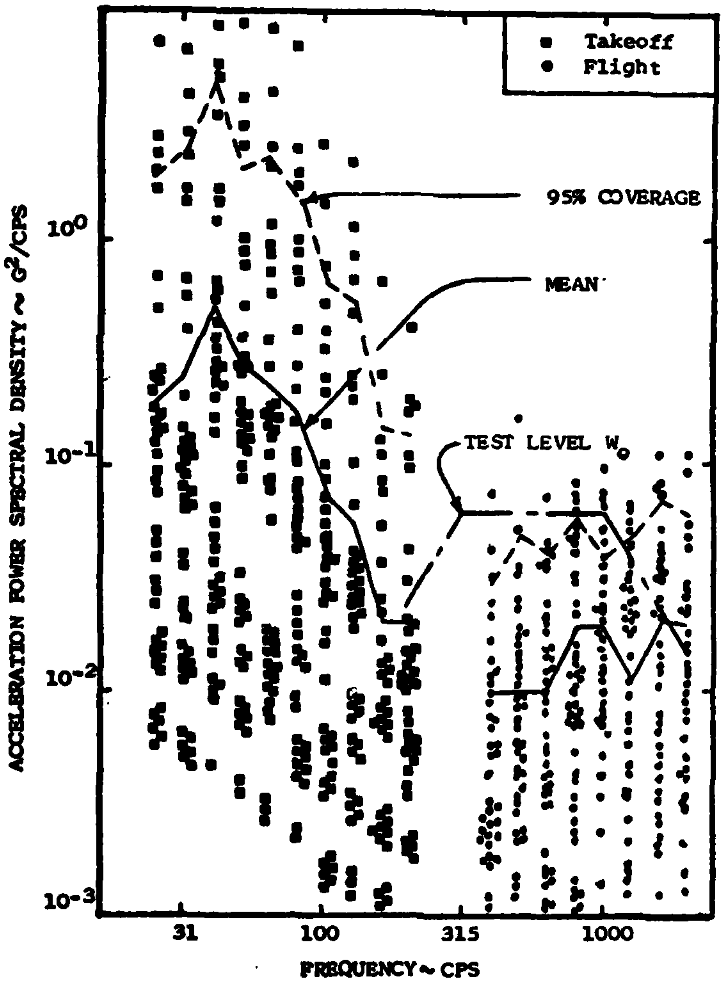



Fig. 5. Comparison of measured aircraft vibrations with qualification test levels for Aircraft B during ground operations and while in flight at 0.9 Mach number and 5,000 feet altitude (q = 1000)

As can be observed from Figures 4, 5, 6, and 7, this level is generally higher than flight measured data, but lower than some data measured during ground operations.

## DEFINITION OF FUNCTIONAL TEST LEVELS

On this basis, the equipment functional qualification test levels shown in the Appendix were formulated. It is recommended that these functional test levels be computed using the maximum aircraft q. Such a practice will ensure that the equipment will function properly throughout the operating range of the flight vehicle.

Note that, unlike most conventional test specifications, the criteria in the Appendix contain both functional and fatigue tests. A separate functional test is deemed necessary so that the performance of an equipment item in the operational environment can be evaluated. Many instances of operational malfunction have been reported as caused by improper (or lacking) functional checks during laboratory vibration qualification [8, 11].

## FATIGUE TEST LEVELS

Many operational equipment failures have also occurred because of material fatigue [11]. In developing qualification tests, it is a common practice to raise the test levels above the operational levels so that the test can simulate, in a relatively short time, the entire service life of the equipment.

In order to define an equivalent elevated fatigue test level, an equation of the form [12, 13]

$$G_f = G_0(T_0/T_f)^{\alpha} \qquad (4)$$

is often used, where $G_f$ is the rms fatigue test level, $G_0$ is the rms operational level, $T_0$ is the operational time spent at vibration level $G_0$, $T_f$ is the test time spent at level $G_f$, and $\alpha$ is a constant representing the slope of the curvalinear relationship between applied oscillatory stress and respective time (stress reversals) to fatigue failure of a given material. Although the reported values of $\alpha$ range considerably, values of 0.10 to 0.15 are often used for random vibration. In this case, the value of 0.125 is used because it appears to be a reasonable average. Thus, in terms of acceleration power spectral density ($g^2$/cps), we have, using equations of the forms (1) and (2) as an operational level and equation (4),

$$W_f = (W_o)(T_o/T_f)^{1/4} \; g^2/cps \qquad (5)$$

where $W_f$ is the fatigue test level. Note that, when equation (4) is converted from terms of rms to terms of psd, the exponent becomes 2 α (i.e., 2x0.125 = 1/4).

Analysis of the mission profiles of several aircraft, including those in this study, shows that the flight time spent at maximum or near maximum q is approximately 20 minutes per flight. The exceptions to this are supersonic vehicles that obtain maximum q in the supersonic regime. They spend only a very small fraction of their time at maximum q, however, because of such factors as fuel economy and weapon delivery speed limitations. Their normal maximum q is usually about 1200 psf at which they usually spend a fatigue equivalent of 20 minutes per flight.

Thus, if we let N equal the total number

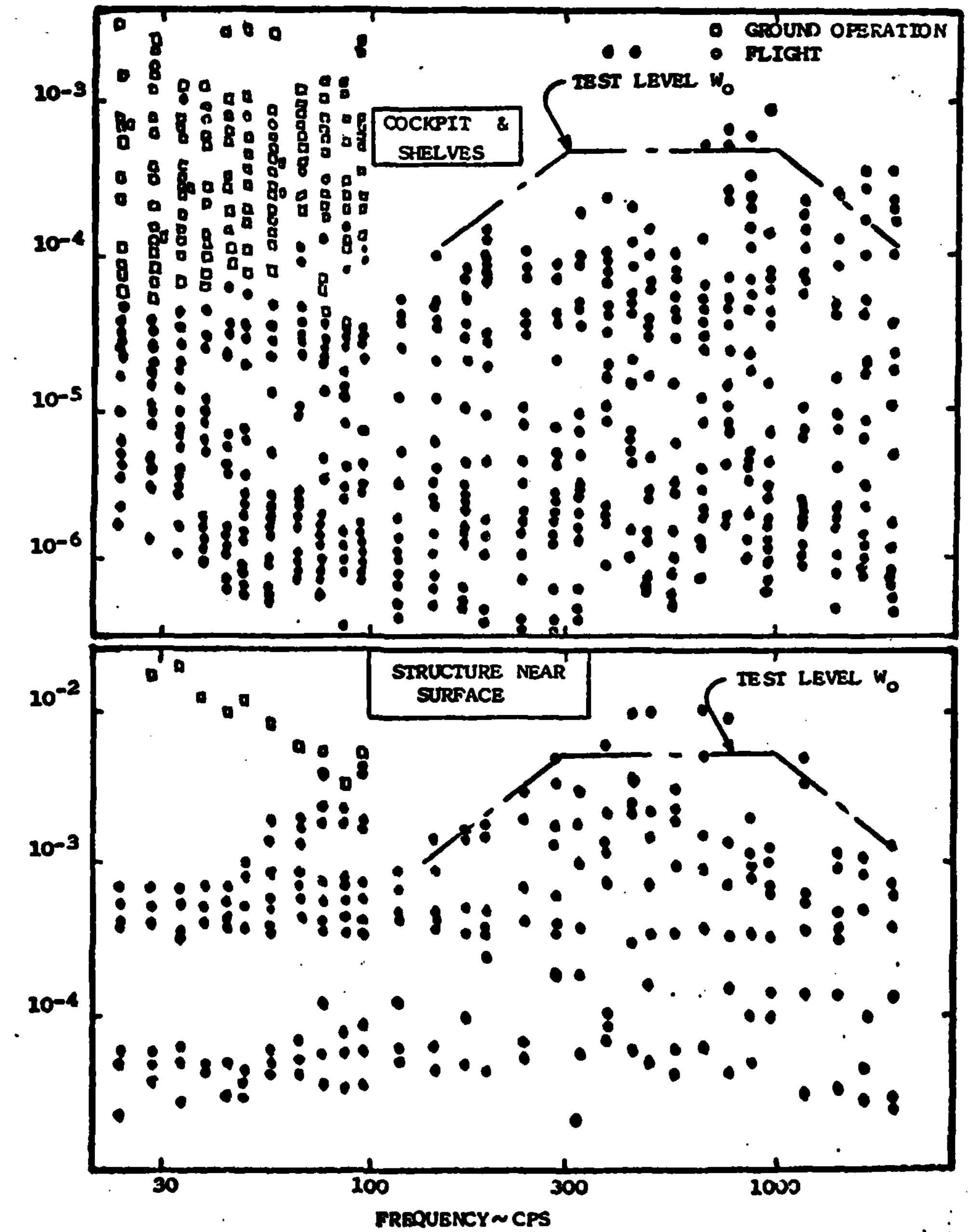



**Fig. 6.** Comparison of measured aircraft vibrations with qualification test levels for Aircraft C during ground operations and while in flight at 0.68 Mach number and 22,000 feet altitude (q = 280).

of missions a vehicle (or equipment) will fly over its lifetime, then

$$T_o = N/3 \text{ hours} \qquad (6)$$

and equation (5) becomes

$$W_f = (W_o)(N/3T)^{1/4} \qquad (7)$$

where T is the fatigue test time in hours and $W_o$ is restricted by not allowing q to be larger than 1200 psf.

Equation (7) forms the basis for the fatigue (endurance) qualification tests shown in the Appendix. These fatigue tests are unique compared to most specifications since the test time is allowed to be variable and is left to the testing laboratory to decide. Permission to extend test time and thereby lower the fatigue test level is very practical in situations involving very heavy loads (relative to the shaker capacity) and in situations where high test levels may cause interference of equipment components (abrasion) which would normally not occur at operational (functional) vibration levels.

GENERAL PURPOSE EQUIPMENT

In many instances, an equipment item, such

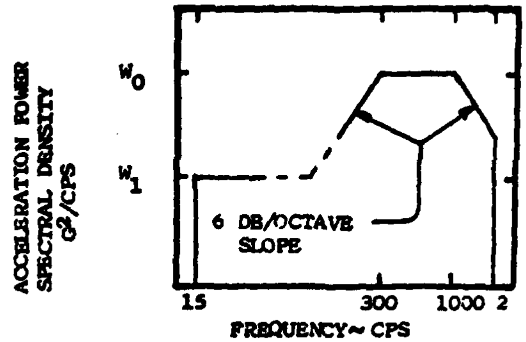



Fig. 8 Random vibration qualification test curve with undefined amplitude.

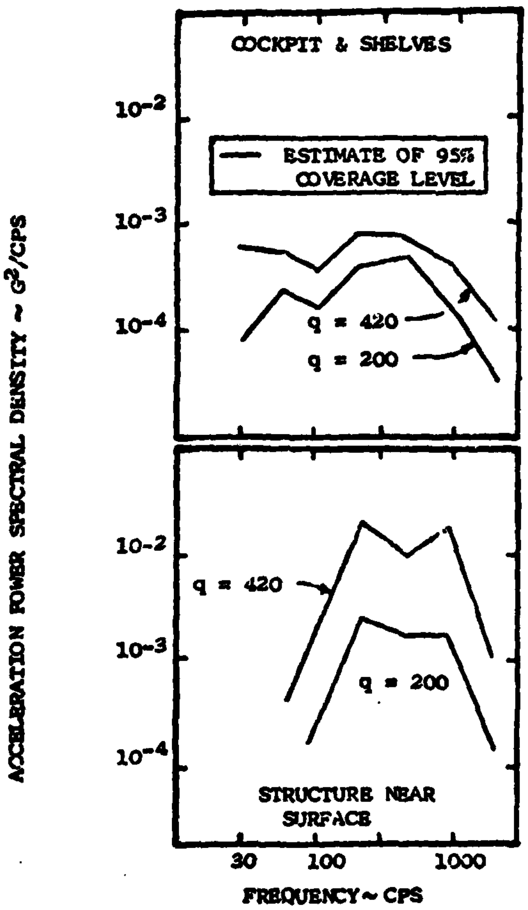



Fig. 7 Comparison of measured vibration levels and aerodynamic pressure, q, for Aircraft D.

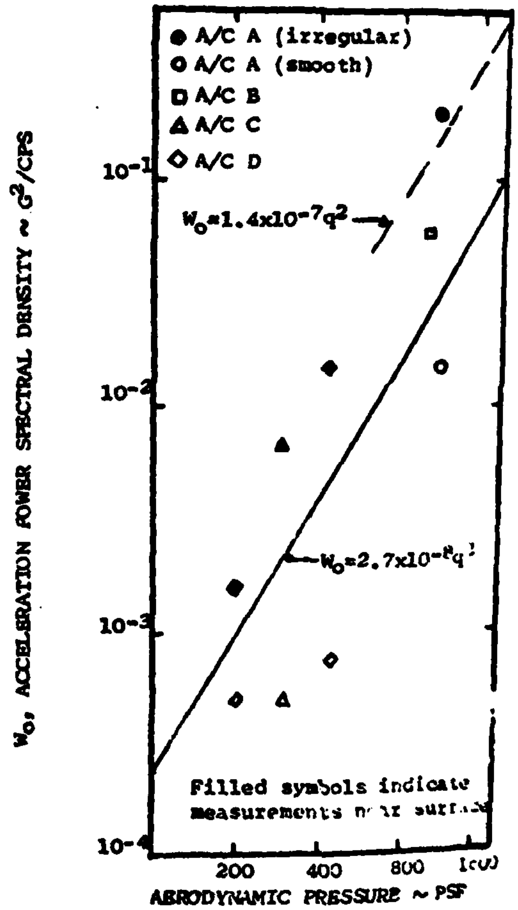



Fig. 9 Comparison of aerodynamic pressure q and $W_o$ levels (ref Figure 8) for aircraft A, B, C, and D.

as a communication or navigation unit, is developed for use in a number of different aircraft types such that the project officer may not know all of its potential vehicle applications. In this case, the test criteria in the Appendix suggest a test suitable for a high performance fighter-bomber capable of flight at q = 1200 psf. Based on the assumption that these units may be placed in a compartment adjacent to an irregular surface, the test levels are

$$W_o = 0.20 \quad g^2/cps \quad (8)$$

$$W_f = (0.20)(1300/T)^{1/4} \quad g^2/cps$$

JUNK TESTS

In addition to the vibration and shock environments produced by aircraft, an equipment is also exposed to many dynamic environments produced by handling. As examples, consider removal and installation environments, accidental drops during transfer, and riding without its packing crate in the back of a jeep or field truck.

Equipment that could not survive this kind of environment has been labeled as junk. Of course, it is very difficult to determine exact amplitude and frequency statistics of this environment. However, our forebearers faced this problem by instituting a relatively simple sinusoidal test which is contained in a number of procedures in Method 514 of MIL-STD-810. In essence, the vibration level in this procedure is contained by the 0.10 inch double amplitude and ±2G curves and provides four ten-minute resonances and a sweep on each of three mutually perpendicular axes. The test is in a "hard mounted" configuration and is applied to equipment that is isolated when installed in the aircraft. It was assumed that unisolated equipment would experience the standard ±10G test and, therefore, did not require this "extra" ±2G test.

In the test criteria in the Appendix, the ±2G test is also recommended for aircraft isolated equipment. To account for junk testing of equipment that are not aircraft isolated, however, a random junk test was developed. This is manifested by requiring a minimum fatigue (endurance) test level of 0.04 $g^2$/cps. Although the criteria in the Appendix states that this minimum level be applied to all equipment, it is relatively benign for isolated equipment.

This level was derived by equating the fatigue life expected when an equipment is exposed to a ten-minute, ±2G (or 0.10" DA) resonant environment and the fatigue life expected when exposed to a random level for one hour [13, 14]. This approach is explained in more detail in the next section.

COMPARISON OF RANDOM AND SINUSOIDAL VIBRATION TESTING

There are many who criticize random vibration tests as being much more severe than standard sine tests. Many people add up the total energy under the random curve (from 20 cps to 2000 cps) and exclaim that it is much greater than ±10G peak commonly found in sine tests. Yet the scientists tell us that it is not the total energy but only the energy near the resonance bandwidths that do the damage [13, 14].

On this scientific basis, let us compare the fatigue damage potential of the random tests herein and the standard ±10G peak test. References 12, 13, and 14 show us that the "fatigue equivalent" sinusoid $G_f$ to the random power spectral density $W_f$ is

$$G_f = \pm A\sqrt{\frac{\pi f_o W_f}{2Q}} \quad (9)$$

where A is an amplification factor relating the sinusoidal and random fatigue (S-N) failure curves for a given material, $f_o$ is the resonance frequency, and Q is the amplification factor of the resonance.

If we can consider that the ratio $f_o/Q$ = 10 in the 300 to 1000 cps frequency range and that A = 2 for a test time of 1/2 to one hour [14], then equation (9) becomes

$$G_f \cong 8\sqrt{W_f} \quad (10)$$

Applying equation (10) to a fatigue test level of $W_f$ = 0.10 $g^2$/cps, which is a typical level found in quiet aircraft zones, we find that the equivalent sinusoidal test level is only $G_f \cong$ ±2.5G. In fact, it takes a level of $W_f \cong$ 1.6 $g^2$/cps to be equivalent to a ±10G sinusoid. It is thus obvious that the test levels proposed in the Appendix are much less severe than most widely used sine tests.

Unfortunately, it is very difficult or impossible to draw "functional equivalences" between sine and random vibration. It is the author's judgment, however, that the random test is much more thorough. It has been observed that operational malfunctions were reproduced with random vibration which could not be reproduced by sine testing [8]. Sine testing is limited by the fact that only 4 (or a comparably small number) resonance dwells are run per axis while even the less complex equipments have many more resonances. While it is true that the associated sine sweeps do excite most of these other resonances, one must consider the short time period spent in any one resonance bandwidth and the fact that many of these resonances aren't excited long enough to peak out [12]. In contrast, the random test excites every resonance for the duration of the test.

It appears, then, that the random test proposed is a less severe but more thorough test.

## SUMMARY

The paper describes the development of random vibration test criteria for aircraft equipment whose prime source of vibration is turbulent airflow at the surface of the aircraft. Associated criteria for equipment vibration caused by jet engine noise or operation of aircraft guns can be found in references 15 and 16, respectively.

The paper shows that the random vibration levels, as derived from the study of 4 jet aircraft, are generally less severe than existing applicable sinusoidal tests. The test levels are adaptable to a particular aircraft/equipment location and are based on the aircraft's aerodynamic pressure (q) and its surface geometry.

The criteria contain both functional and fatigue test procedures. The paper stresses the importance of functional testing to alleviate operational malfunction. The fatigue test levels are adaptable from the standpoint that the level is based on the number of flights the equipment will be operational as well as the total qualification test time.

## REFERENCES

1. H. H. Hubbard, J. C. Houbolt, "Vibration Induced by Acoustic Waves," Ch. 48, Shock & Vibration Hdbk, McGraw-Hill, 1961.

2. Proceedings of the Symposium on Fatigue of Aircraft Structures, *WADC Technical Report* 59-507, Aug 1959.

3. K. M. Eldred, W. Roberts, R. White, "Structural Vibrations in Space Vehicles," WADD-TR-61-62, Mar 1961.

4. R. H. Lyon, "Random Noise and Vibration in Space Vehicles," Shock & Vibration Monograph SVM-1, U.S. Govt Printing Office, Wash DC 20402, 1967.

5. R. L. Barnoski, et al, "Summary of Random Vibration Prediction Procedures," NASA CR-1302, Apr 1969.

6. J. F. Dreher, W. D. Hinegardner, "RF-4C Vibration and Acoustic Environment Study," Shock & Vibration Bulletin 37, Supplement, Jan 1968.

7. S. H. Crandall, W. D. Mark, "Random Vibration in Mechanical Systems," Academic Press, 1963.

8. J. F. Dreher, E. D. Lakin, E. A. Tolle, "Vibracoustic Environment & Test Criteria for Aircraft Stores During Captive Flight," Shock & Vibration Bulletin 39, Supplement, Apr 1969.

9. J. F. Dreher, "The Effect of Tailfins on the Vibracoustic Environment of Externally Carried Aircraft stores," Shock & Vibration Bulletin 41, Supplement, Dec 1970.

10. D. L. Earls, J. F. Dreher, "Statistical Approach to Optimize Random Vibration Test Spectra," Shock & Vibration Bulletin 41, Supplement, page 30, Dec 1970.

11. A. Dantowitz, G. Hirschberger, D. Pravidlo, "Analysis of Aeronautical Equipment Environmental Failures," AFFDL-TR-71-32, May 1971.

12. M. Gertel, "Specification of Laboratory Tests," Chapter 24, Shock & Vibration Hdbk, McGraw-Hill, 1961.

13. J. W. Miles, "On Structural Fatigue Under Random Loading," Journal of Acoustic Society, Nov 1954.

14. G. Fitch, et al, "Establishment of the Approach to, and Development of, Interim Design Criteria for Sonic Fatigue," ASD-TDR-62-26, Jun 1962.

15. J. H. Wafford, J. F. Dreher, "Aircraft Equipment Random Vibration Test Criteria Based on Vibration Induced by Jet and Fan Engine Exhaust Noise," Shock & Vibration Bulletin No. 43, 1973.

16. R. Sevy, J. Clark, "Aircraft Gunfire Vibration," AFFDL-TR-70-131, Nov 1970 and Method 519, MIL-STD-810.

## APPENDIX

### PROPOSED TEST CRITERIA FOR METHOD 514 OF MIL-STD-810*

4.6.3 Procedure IA - Random vibration test for equipment installed in jet airplanes. (Not for turbo prop aircraft or jet powered helicopters.) The random vibration environment which occurs at equipment locations in jet aircraft stems from four principal sources:

a. Turbulent aerodynamic air flow along external surfaces of the aircraft structure.

b. Jet engine noise impinging on aircraft structure.

c. Gun blast pressure impinging on aircraft structure from high speed repetitive firing of installed guns.

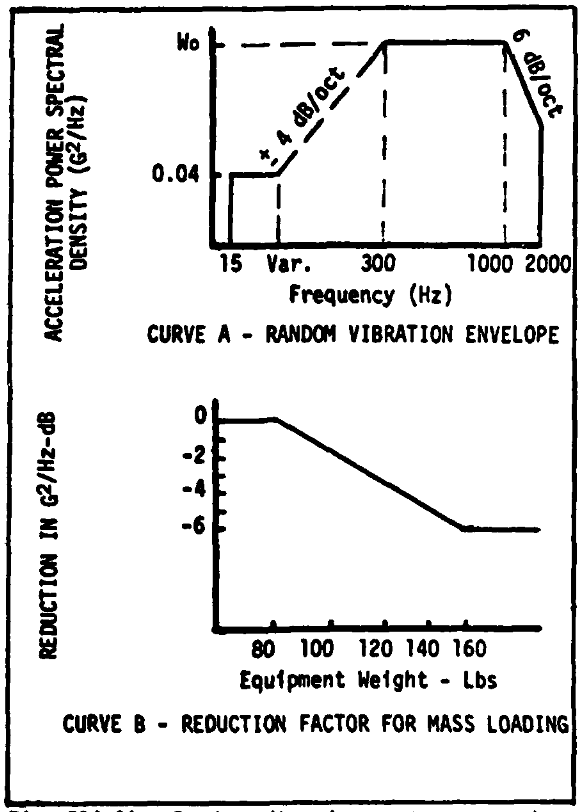
d. General aircraft motions caused by such factors as runway roughness, landing, and gusts.

The tests outlined in the procedure consider all of these environments and require design to the most severe of these. These tests are preferred for use with equipment in jet aircraft in lieu of the sinusoidal tests of Procedure I, Table 514-II, Figure 514-2, except for jet engine mounted equipment. For equipment mounted directly to aircraft jet engines, use Procedure I. To determine an equipment specific random vibration test, compute functional and endurance test levels for aerodynamic induced and for jet engine induced vibration from Table 514-IIA and Figure 514-2A. Use the more severe of the two functional levels as the equipment's functional test, and the more severe of the two endurance levels (on an equal time, T, basis) for the equipment's endurance test. Gun blast tests shall be conducted in addition to this procedure, as applicable, in Method 519, if they are a higher level of severity.

4.6.3.1 Performance of Test. The individual equipment test item shall be subjected to broadband random vibration excitation. The power spectral density tolerances of applied vibration shall be according to para. 4.5.2. The test item shall be attached to the vibration exciter according to para. 4.2. Equipment hard mounted in service shall be hard mounted to the test fixture. Equipment isolated in service shall use service isolators when mounted on the test fixture. If service isolators cannot be made available during the qualification test, isolators shall be provided with characteristics such that the isolator/equipment resonant frequencies shall be between 20 hz and 45 hz with resonant amplification ratio between 3 and 5. Vibration shall be applied sequentially along each of the three orthogonal axes of the test item. Two test levels are required, a functional level and an endurance level. For each axis, one half of the functional test shall be conducted first, then the endurance test, followed by the second half of the functional test. The equipment shall perform according to the equipment specification operating requirements (ref. General Requirements, para. 3.2) during the functional testing. The acceleration power spectral density ($G^2$/Hz) of applied vibration, as measured on the test fixture at mounting points of the test item, shall be according to Table 514-IIA and Figure 514-2A. The functional and endurance test time durations and other test conditions shall be determined from the test level equations and other parameter values from Table 514-IIA.

4.6.3.2 Equipment with Isolators. Equipment designed for operational installat[illegible] on vibration isolators shall also be subj[illegible] to a minimum rigidity endurance test w[illegible] the isolators removed. This test shall [illegible]onducted according to para. 4.6.2, Table 5[illegible], and Curve AR of Figure 514-2. At the [illegible]lusion of this test the equipment shall [illegible]de specified performance. (Ref. General [illegible]ents, para. 3.2.)

*Proposal also contains criteria for vibrations caused by jet engine noise.



CURVE A - RANDOM VIBRATION ENVELOPE

CURVE B - REDUCTION FACTOR FOR MASS LOADING

Fig. 514-2A. Random vibration test curve and mass loading reduction factor for jet aircraft equipment

TABLE 514-IIA

Random Vibration Test Criteria for Jet Aircraft Equipment

| Criteria |
| --- |
| Aerodynamic induced vibration (Curve A, Figure 514-2A) |
| Functional test level [1,5,6] $W_o = K(q_1)^2$ |
| Endurance test level [2,3,5,6] $W_o = K(q_2)^2\ (N/3T)^{1/4}$ |
| Jet Engine noise induced vibration (Curve A, Figure 514-2A) |
| Functional test level [1,4,5,6,7,8] $W_o = (0.48 \cos^2\theta/R)[D_c(V_c/1850)^3 + D_f(V_f/1850)^3]$ |
| Endurance test level [2,3,4,5,6,7,8] $W_o = (0.48 \cos^2\theta/R)[D_c(V_c/1850)^3 + D_f(V_f/1850)^3](N/10T)^{1/4}$ |
| Gunblast induced vibration (See Method 519) |
| **Definitions** |
| K = $2.7 \times 10^{-8}$ for cockpit panel equipment and equipment attached to structure in compartments adjacent to external surfaces that are smooth, free from discontinuities. |
| K = $14 \times 10^{-8}$ for equipment attached to structure in compartments adjacent to or immediately aft of external surfaces having discontinuities (cavities, chins, blade antennas, speed brakes, etc.) and equipments in wings, pylons, stabilizers, and fuselage aft of trailing edge wing root. |
| $q_1$ = maximum aerodynamic pressure for carrying aircraft, psf. |
| $q_2$ = 1200 psf or maximum aircraft q, whichever is less. |
| N = maximum number of anticipated service missions for equipment or carrying aircraft. $(N \geq 3)$ |
| T = test time per axis, hours $(T \geq 1)$ |
| $D_c$ = engine core exhaust diameter, feet (for engines without fans, use maximum exhaust diameter). |
| $D_f$ = engine fan exhaust diameter, feet |
| R = minimum distance between center of engine aft exhaust plane and the center of gravity of installed equipment, feet. |
| $V_c$ = engine core exhaust velocity, feet per sec. (for engines without fans, use maximum exhaust velocity without afterburner). |
| $V_f$ = engine fan exhaust velocity, feet per sec. |
| $\theta$ = angle between R line and engine exhaust axis (aft vectored), degrees. |
| **Notes** |
| 1. Functional test time shall be 1 hour per axis.<br>2. Use $W_o = 0.04\ g^2/hz$ if calculated endurance test level values are less than $0.04\ g^2/hz$, T = 1.<br>3. If one hour (T = 1) endurance test level is $\leq$ functional test level, no endurance test is required except according to Note 2.<br>4. If aircraft has more than one engine, Wo shall be the sum of the individually computed values for each engine.<br>5. If aircraft equipment location and/or using aircraft is unknown, use functional level, $W_o = 0.20\ g^2/hz$ and endurance level $W_o = (0.20) \times (1300/T)^{1/4}$.<br>6. For equipment weighing more than 80 pounds, the vibration test level may be reduced according to Curve B, Figure 514-2A.<br>7. For $70° \leq \theta \leq 180°$, use $\theta = 70°$ to compute Wo.<br>8. For engines with afterburner, use Wo which is 4 times larger than Wo computed using maximum $V_c$ and $V_f$ without afterburner. |

## DISCUSSION

Mr. Volin (Shock and Vibration Information Center): What do you consider to be a realistic percentage of aircraft life to use in design of equipment?

Mr. Dreher: What do you mean by realistic?

Mr. Volin: The percentage of the number of hours in the life of an aircraft.

Mr. Dreher: Well we kind of hedge that question and leave it up to the project engineer. I am the sort of a person who likes to see the equipment last for the life of the vehicle, like the radio in your automobile.

Mr. Volin: In short, you would like to see the radio outlast the airplane.

Mr. Dreher: Why don't we make it three or four lifetimes. We could use it in three or four airplanes.

Mr. Gertel (Kinetic Systems): Is there any variation of the test specification requirements made for different levels of equipment installation? In other words, are there any differences for components and sub-equipments within larger systems?

Mr. Dreher: No. These particular levels are for the black box type of assembled unit. It's not for an electronic unit that is part of a black box.

Mr. Gertel: Is any consideration being given to developing criteria for sub-structures or sub-components?

Mr. Dreher: Not right now, at least not by our organization. Rome Air Development Center does this kind of work. Perhaps they have some data.