Proceedings of the Institute of Acoustics

THE WHY AND HOW OF ACOUSTIC TESTING

D. Sims

Principal Consultant,
D. Sims Associates.

INTRODUCTION

It has been shown, with respect to aircraft carried stores, that the vibration environment is one of the main sources of failure of equipments [1] and this has been confirmed in a wide range of other areas of equipment useage. It is therefore necessary to reproduce this condition in the laboratory in order that the equipments can be tested to ensure that they will operate and survive in the environment and to ensure an adequate level of reliability over long periods of exposure. In doing this it is important to achieve a good representation of the working environment in order to minimise the possibility of unrepresentative failures.

The normal means of applying vibration to a structure is by the use of electrodynamic or hydraulic vibrators coupled by means of a suitable fixture. These mechanical means of vibration have limitations, mainly in their single mode of operation, effect on the dynamic response of the structure and their limited frequency range. The application of high intensity noise often provides a more realistic response if only due to the fact that it provides a better representation of particular service environments. So what service conditions produce high levels of acoustic noise?

THE NOISE ENVIRONMENT

The obvious high noise environments are in areas around jet engines and other high energy power sources. Perhaps not so obvious are those locations which are excited by turbulent fluid flows such as aerodynamic surfaces and pipe walls.

The purist in acoustics would argue that acoustic noise is not the same as aerodynamic excitation, and that is true, mainly with regard to spatial pressure distribution. From an engineering view point however, when we are primarily interested in structural and internal equipment responses to the excitation, they both provide pressure fluctuations at the surface that have a power spectrum with a wide bandwidth and a pressure level that can extend up to 170dB or more. This dynamic pressure can in turn induce high stresses and vibration levels of several tens of g in certain structures [2]. But wide bandwidth and high level are not the only characteristics that concern us. In addition this type of environment gives a distributed input over multiple axes. Let us then consider the various acoustic characteristics that can occur in the working environment.

Spectrum. The spectrum shape of noise from turbulent gas follows a fairly common form. Investigations of aerodynamic pressure fluctuations have extended from that of the earths atmosphere to hypersonic flight with velocities exceeding Mach 10 [3,4]. In all cases it is shown that the spectrum shape is very similar, its position on the frequency scale being determined in the main by the gas velocity. Other investigations in water have shown similarities in this medium as well with particularly high levels being generated by propeller cavitation [5].

In the regime of jet engine exhaust gases and subsonic boundary layers, peak energy is generated in the range 250 to 1250 Hertz and the majority of standard acoustic test specifications have this form of spectrum. As flow velocities increase, so the frequency of peak energy increases such that in supersonic flight this peak frequency can occur at 5 kHz or more.

Pressure Level. Continuous dynamic pressure levels in air from various sources can extend up to values in excess of 180dB re 20 micropascals. Impulse pressures can reach several atmospheres. Noise levels below about 130dB are not generally damaging to equipments. There are however many examples where equipments can be subjected to levels much greater than this.

On high performance military aircraft for example, dynamic surface pressures due to boundary layer excitation can, under certain flight conditions on some aircraft, reach 170dB. Those jet aircraft capable of vertical take off and landing can experience a phenomenon known as fountain flow, where the impingement of the multiple engine exhausts on the ground during vertical landing results in a fountain of hot gases reflecting back onto the underside of the aircraft. This again can cause local excitation at noise levels exceeding 170dB.

Combustion also causes high noise conditions, especially when instability of burning occurs. This is a common cause of high intensity noise adjacent to gas turbines, afterburners and rocket motors.

Satellites, although they are destined to work in the quietest of noise environments, have to be launched by large rockets and are subjected to both combustion noise and boundary layer excitation, in sequence, during this launch phase. Qualification levels of 142dB on flight equipment and 174dB on ground launcher equipment are often specified and these can produce damaging levels of vibration in lightweight structures of large surface area such as antenna reflectors, solar arrays or structural panels [2].

Interface conditions. A significant condition regarding the application of noise is that it is applied over the whole of the exposed surface of the equipment and is then transmitted as vibration through the structure in all axes simultaneously. This distributed input of vibration energy allows for a more efficient distribution of high frequencies, bypassing structural interfaces and normal anti-vibration devices.

THE NEED FOR ACOUSTIC TESTING

Acoustic testing has been used extensively in the aerospace industry, particularly for military and spacecraft equipments, and also for nuclear power applications. The efficiency of this method in producing realistic test conditions and eliminating non representative failures in testing has been demonstrated. In the case of weapons carried on military aircraft it has been shown by the Pacific Missile Test Center in the USA that the use of acoustics for simulation of captive flight vibration has demonstrated itself to be an accurate and cost effective test method [6]. Advantages quoted are, the facilities have high reliability, allow for simple fixturing and handling, can test more than one item at once and provide multi-axis excitation. This has been confirmed by experience in the UK.

In the space field Lockheed have concluded, from a survey of several tests, "System level high intensity acoustic acceptance testing offers more advantages than disadvantages and is recommended as a test that can contribute significantly to the confidence of a spacecraft prior to launch" [7]. Some of the advantages observed by Lockheed are,

Best known test to simulate the flight dynamic vibration environment to detect dynamic related failures.

Problems detected are of such magnitude that if not found and corrected, flights could be jeopardised.

Increases confidence that the spacecraft is properly assembled and is ready for flight.

Disadvantages are, of course, related to cost of the initial test facilities but once these are set up the advantages quoted soon recover this cost through the increased reliability of the equipment produced. Also once the facility is operational for one project it immediately becomes available for those following.

In some cases acoustic testing may be the only method available for stimulating a structure. Printed circuit boards and their associated components are susceptable to high frequency vibration due to their physical size. The frequency limitations of mechanical vibrators may preclude their use in this application if it is required to excite modes above one or two kilohertz. It has been shown that these higher frequency modes are more easily excited by acoustic means [8].

SIMULATION OF THE HIGH INTENSITY NOISE ENVIRONMENT

Two basic methods are available for the production of high intensity noise. These use either a reverberation chamber or a progressive wave tube in which to generate the noise [9] and can provide sufficient flexibility in their application to allow the inclusion of other environments.

<u>Reverberation Chamber.</u> The reverberation chamber is a hard walled room to which is coupled a noise generator via a suitable coupling horn. When acoustically excited this combination provides a diffuse acoustic field into which the test item is inserted. The diffuse field in turn provides the distributed input over the structure to give the required vibration stimulation in a similar manner to that obtained in service. Limitations in the energy spectrum result from the chamber size, cut-off frequency of the coupling horn and acoustic power available from the generator. The acoustic power requirement is related to the chamber size, larger chambers requiring proportionally more power. It has been shown by Bayerdorfer [10] that chamber size is not critical provided that the lowest vibration mode of the test item is excited.

It is usually only necessary to elastically support the test item in the noise field and so mechanical loading or restraint, found when vibration fixtures are used, is avoided. The extended volume over which the diffuse field is obtained will permit the testing of more than one item if these do not themselves significantly alter the sound pressure distribution.

<u>Progressive Wave Tube.</u> It is possible to test either structures, mounted inside the tube, or panels mounted in the wall of the

tube. In the first case the tube can be contoured to suit the shape and size of the test item and in this configuration is often referred to as an acoustic shroud. With a panel mounted in the wall it is possible to provide excitation to one side only as with, say, an aircraft skin panel. With either of these configurations acoustic energy is injected into one end of the tube by means of a coupling horn. A further horn at the other end of the tube couples the acoustic energy into an absorbing termination which thus prevents standing waves, due to reflections, from being set up.

Limitations in this system are attributed to the cut-off frequency of the horns, free cross section of the tube (which may allow cross modes to be set up) and construction methods (which may allow colouration of the spectrum due to discrete frequency losses). For testing smooth contoured structures within a well designed tube, this method is more economical on acoustic power than the reverberation chamber.

Noise Generation. High powered loudspeakers or horn driver units are suitable for generating noise levels up to about 150dB. Above this the displacements required by the moving diaphragms become excessive and result in a marked reduction in operational life.

When significant power is required it is necessary to modulate the energy provided by the flow of a compressed gas. This is achieved by passing the gas through a modulating valve which may be rotating or reciprocating. A rotating valve, or siren, will generate a single tone although radiation distortion will add several harmonics to this. Using multiple rotors allows for the generation of pseudo-random noise at significant power levels.

A more efficient method of air modulation uses a reciprocating sleeve valve driven by an electrodynamic vibrator. A similar generator capable of supplying higher acoustic powers incorporates a poppet valve controlled by a high frequency hydraulic vibrator. The acoustic power available from these air modulating systems ranges from 4kW to 200kW and multiple units may be used in order to increase the overall power or improve the spectrum shaping capability.

Control systems.

Control of the acoustic noise spectrum is commonly achieved by open loop systems using a noise generator and octave or third octave filters. New test requirements, especially in the space field, are calling up closer tolerance control of the spectrum and this requires a finer spectral adjustment. Closed loop control has been available for some time and this has the ability to achieve close control of the test spectrum when multiple noise generators are used. In broad terms this is achieved by dividing the spectrum between noise generators and applying narrow band control to generate the third octave test spectrum. The same principle can be applied to control a structural vibration response.

CONCLUSION

It has often been shown that a realistic vibration response under test conditions can only be obtained by reproducing the operating conditions of the test item. The vibration effects of a high intensity noise working environment are difficult to reproduce by means other than the application of noise. High intensity noise may also be the only way to excite the higher frequency modes in a structure or component.

Component test facilities can be simple in construction although the larger high intensity noise test facilities can be expensive to set up. These facilities however have the advantage that other test environments, such as high and low temperature, can be introduced. In many circumstances vibration testing with high intensity noise may be the only method of identifying some failure modes, the rectification of which can result in the significantly increased reliability of the equipment.

REFERENCES

[1] D.B. Meaker & W.D. Everett.
US Navy experience on the effects of carrier-aircraft environment on guided missiles. AGARD Conference Proceedings CP270, May 1979.

[2] J. Bennett.
Acoustic effects on spacecraft. Noise in the Aerospace Industry Meeting, IOA, May 1988.

[3] J.C. Kaimal, J.C. Wyngaard, Y. Izumi & O.R. Cote.
Spectral characteristics of surface layer turbulence. Quart.J.R.Met.Soc, 98, 1972.

[4] A.L. Laganelli & A. Martellucci.
Wall pressure fluctuations in attached boundary-layer flow. AIAA Journal, Vol.21, No.24, April 1983.

[5] M.C. Junger.
Shipboard noise: Sources, Transmission and control. Noise Control Engineering Journal, Vol.34, No.1, Jan/Feb 1990.

[6] A.M. Spandrio & M.E. Burke.
Acoustics or shakers for simulation of captive flight vibration. Shock & Vibration Bulletin, 48(4), 1978.

[7] D.A. Smith.
The effectiveness of high intensity acoustic noise testing. Sound and Vibration, April 1989.

[8] D.Sims.
Acoustic vibration for stress screening. ESS Seminar on Current Practice & Future Trends, Bracknell, February 1989.

[9] D. Sims.
Acoustic test methods for environmental simulation. Proceedings SEECO´85 & Jnl. Soc. Env. Engrs. June 1985.

[10] G. Bayerdorfer.
Acoustic noise test as part of the dynamic qualification program in aerospace. AGARD-CP-318, 1981.