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IN-FLIGHT MEASUREMENT OF BOUNDARY LAYER NOISE AND ITS VIBRATION EFFECTS.

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INTRODUCTION

Externally carried stores on military aircraft often contain sensitive electronic equipment and mechanisms which have to be designed to meet the environmental conditions induced by carriage on the parent aircraft. It is normally required that they be submitted to simulated environments to prove the design and demonstrate their long term reliability.

To meet these requirements, design and test specifications need to be prepared and the current trend is to base the test specifications on real life conditions [1,2,3]. Depending upon the test requirement, conditions equal to, lower or higher than the real life situation may be applied. For example, equipment with safety implications will, at some time in its test sequence, be subjected to levels higher than the maximum expected in service conditions.

In order to derive these various specifications it is necessary to measure the real life conditions over the whole of the life cycle of the equipment. With an aircraft carried store this, of course, includes the period of time when the store is being carried on the aircraft which can be the major part of the total life cycle in terms of level and endurance.

One of the most severe environments experienced during aircraft carriage is that of vibration. The main source of vibration in these conditions is the surface pressure fluctuation provided by the turbulent boundary layer and these pressures and the resulting vibration levels are essential parameters to measure during flight trials. For this reason it is also essential to measure vibration responses on a dynamically representative store, that is, one that is as nearly representative of the real thing as possible.

TRANSDUCER SELECTION

Noise is usually measured at both the surface of the store and at one or more internal locations. This latter measurement is required to confirm the noise levels adjacent to internal units which will all require their individual specifications.

Boundary layer conditions are measured with microphones or pressure transducers mounted flush with the skin of the store. These may be of peizoelectric or semiconductor strain gauge construction, the parameters influencing selection including physical dimensions, mounting details, sensitivity, bandwidth and conditioning amplifier and power requirements.

Physical size and mounting details affect the locations at which the microphone can be mounted. With flush mounted transducers an internal volume is required to accommodate the instrument and this is not always readily available on an operational store. The location is therefore often a compromise from the ideal to that made available by the internal design of the equipment. Additionally the size and position of the necessary hole in the skin must be such that the integrity of the structure is not compromised.

Sensitivity and bandwidth are obvious requirements. Sensitivity should be such as to provide, in conjunction with the conditioning amplifier, adequate signal and dynamic range to optimise the input signal to the tape recorder. Bandwidth needs to cover the frequency range of interest which may, for operational reasons, be limited but can extend to 10 kHz or higher.

The microphone signal will need to be conditioned before being recorded. This process covers impedance matching, signal gain control and, if necessary, filtering. A peizoelectric microphone is a capacitive device with an inherently high output impedance. This requires the use of a high quality, low noise, coaxial cable in the high impedance circuit between the microphone and its conditioning amplifier. In order to minimise the effects of cable length between the microphone and amplifier a charge converting amplifier is normally used. This converts the dynamic charge developed by the microphone into a proportional voltage and subsequent stages provide for gain control and present a low output impedance. When a strain gauge type of microphone is used a stable power supply is required to energise the internal bridge and an amplifier to provide gain control for the output signal. It is found that considerable space saving can be achieved by the use of multiple amplifiers on single printed circuit boards instead of using single amplifier modules. The use of a single amplifier circuit design then simplifies the overall instrumentation system concept.

For vibration measurements a wide range of accelerometers may be used depending upon the expected vibration levels, mass loading effects, available space, etc. Peizoelectric accelerometers are commonly used, usually of low mass and hence sensitivity, due to space limitations where their small size is advantageous. These are fed through charge amplifiers in a similar manner to the peizoelectric microphones. Small accelerometers are now available with built in electronics which require only external power and some gain adjusting amplification. The use of these again simplifies the system design, permitting the use of twisted pair cables for interconnection between the transducers and their amplifiers [4].

Except where special requirements exist for the monitoring of particular components, vibration measurements are usually made at structural strong points and at the attachment points of internal assemblies. Generally three axis information is required but, as responses in the longitudinal axis of a long thin store are not normally as severe or variable as the transverse axes, longitudinal measurements are often limited in number in order to optimise the data points in the other axes.

Other parameters such as temperature, strain and surface pressures are also recorded in these measurement trials.

MEASUREMENT RECORDING SYSTEMS

A typical trial might involve the selective recording from about 100 accelerometers, 4 microphones, 20 strain gauges and 30 temperature sensors. Selections are made from these prior to flight, the selection used depending upon the sortie conditions to be undertaken by the trials aircraft. The number of data channels that can be recorded at any one time is limited in part by the capacity of the tape recorder. Typically, the type employed will conform to IRIG standards [5] and will normally have 14 or 28 tracks recorded on 1" magnetic tape. In order to accommodate a larger number of data channels a technique of frequency multiplexing is used, as shown in figure 1, where a number of modulated carriers at fixed frequency intervals are modulated by the data signals and recorded on a single track that will accommodate the total frequency bandwidth. The recording is then made in direct mode where the IRIG system allows a total bandwidth of 125 kHz at a tape speed of 7½ inches per second using a Wide Band II standard.

It is common to multiplex six channels on a single track which allows a total of 72 data channels spread over twelve tracks of the tape recorder. The remaining tracks are used for IRIG time code information, crew speech and some aircraft parameters which are recorded in order that the measured data can be related to the flight conditions. A standard 10½ inch reel of tape provides up to 120 minutes of recording time and this period is broken down into fixed sample lengths initiated by the aircrew at each stage of the trial flight sortie in accordance with a predefined brief. In total the flight trial, which may consist of several individual flights, will explore the full flight envelope of the aircraft including the extremes of speed, altitude and manoeuvring conditions.

The ideal situation is to contain the full data system, including the tape recorder, within the store. This allows the store to be independent of the aircraft, except for the supply of power and a control signal from the crew, and permits the installation on a number of aircraft without significant aircraft modification.

This is not always possible as the tape recorder can often be too large to be contained within the envelope of the store. Although miniature recorders are available their size limits the amount of tape that can be carried and therefore restricts the recording time to an amount that seriously increases the cost of data gathering. In the case of the smaller store it is usual to install the recorder in the aircraft. This in turn requires that all of the data be fed to the recorder and hence necessitates modifications to the aircraft wiring.

A further option is to use telemetry and transmit the data to a ground station. This is obviously the only way to obtain data from a store that is separated from the aircraft and subjected to powered or free flight. It is also used for carried flight trials where it is not possible to modify the aircraft and in this instance the trial must be carried out within direct line of sight of the ground receiving station. Data is then digitised and transmitted using a PCM system, the encryption method providing the necessary security of data. The PCM data is then recorded at the ground station for subsequent decoding and analysis. This procedure poses limitations on the number of data channels and/or data bandwidth that can be accommodated.

For maximum capacity the use of the frequency multiplexed analogue system is still preferred. An equivalent digital system for, say, only 30 channels of 2 kHz bandwidth with an 8 bit word would require a minimum data rate in excess of 2 Megabits per second. Recording this on magnetic tape would probably require the use of a fan-out technique to put the data on eight tracks of the recorder in order to achieve an acceptable bit density and recording time. With the resultant fan-in at the analysis phase this results in a more complex and costly system.

DATA REDUCTION AND ANALYSIS

Once all of the data is stored on the master flight tape it is copied to form a working tape. This is then demultiplexed to provide the individual data channels from which time histories for each flight and frequency spectra for each sortie condition within the flight are prepared. A typical spectral density analysis from an accelerometer might take the form shown in figure 2. From a series of these, graded in terms of flight dynamic pressure and manoeuvre condition, composite spectra are constructed to cover the vibration conditions for groups of conditions, the number of groups depending upon their relative severities. For example, it is common that separate spectra are derived for cruise conditions and for high speed flight at low altitudes, as shown in figure 3, although intermediate levels may also be defined if there is a large variation between these. The cruise condition is one that may persist for a large proportion of the life of the store whereas the high speed at low altitude scenario only occurs for relatively short periods under combat and training conditions. The resulting vibration severities are therefore separated so that they may be applied in the test laboratory in their appropriate time relationships.

Analysis of these data shows the critical vibration conditions that occur in service and the relative length of time that they may persist during the carried life of the store. It may be that, for a carried life of several hundred hours, only about 30 or 40 hours are spent under the more arduous high speed and manoeuvring conditions and this must be reflected in the application of laboratory tests. These tests are defined in terms based upon the specified levels derived in the above procedures and these may have factors applied in terms of time or level depending on the purpose of the test.

LABORATORY TESTING

All aircraft carried stores must be subjected to vibration conditions in the laboratory for a number of reasons. The most important of these are;

a. Flight clearance of development stores
b. Type approval testing
c. Reliability growth
d. Reliability demonstration
e. Production acceptance

Vibration may be applied using either mechanical vibrators or by the use of high intensity noise. Mechanical vibration methods are quite satisfactory for the majority of test requirements but have some disadvantages when it is required to demonstrate fault conditions under simulated service environments. As previously stated, the main source of vibration in carried flight is the turbulent boundary layer. This has a bandwidth extending to beyond 10 kHz and significant energy is present in the range above 1 kHz. Mechanical systems cannot reproduce this as their power output is effectively cut off above about 2 kHz due to velocity and acceleration limitations on the moving parts. The only way that sufficient energy can be induced at these higher frequencies is by the use of high intensity noise which, as in the case of the boundary layer, is applied as a distributed input over the whole of the surface of the structure [6]. This in turn is further transmitted into the internal structures as both vibration and attenuated noise. The transmitted noise avoids the interface losses that occur when only mechanically coupled vibration exists and also bypasses any vibration isolation systems that may exist.

By these means the laboratory test method can be made to approximate the real flight condition so closely that it can be reasonably assured that any failures produced under the simulation would also result in flight. Conversely, any failure that might occur in flight can be reproduced on the ground and corrective action applied before the store goes into service. This enables the development of such equipment with a high operational reliability.

REFERENCES

[1] Anon. Environmental Handbook for Defence Materiel, DEF STAN 00-35. M.O.D.(PE),

[2] Anon. Environmental Test Methods and Engineering Guidelines, MIL-STD 810D. U.S. Department of Defense, July 1983.

[3] Anon. Basic Environmental Testing Procedures, GAM-EG13. Delegation Generale pour l'Armement. France, June 1986.

[4] A.S. Freeman. Private communication. February 1989.

[5] Anon Telemetry Standards, IRIG 106-80. Inter-Range Instrumentation Group, Range Commanders Council, White Sands Missile Range, New Mexico, U.S.A., Sept 1980.

[6] D. Sims. Acoustic Test Methods for Environmental Simulation. SEECO 85, Society of Environmental Engineers, June 1985.

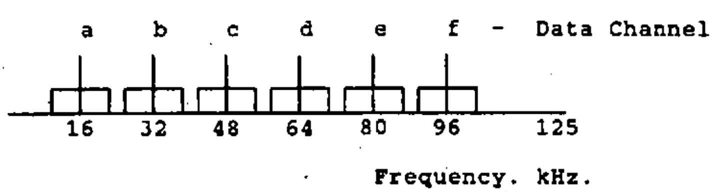

Figure 1. FDM Data Distribution

IN-FLIGHT BOUNDARY LAYER NOISE AND VIBRATION EFFECTS

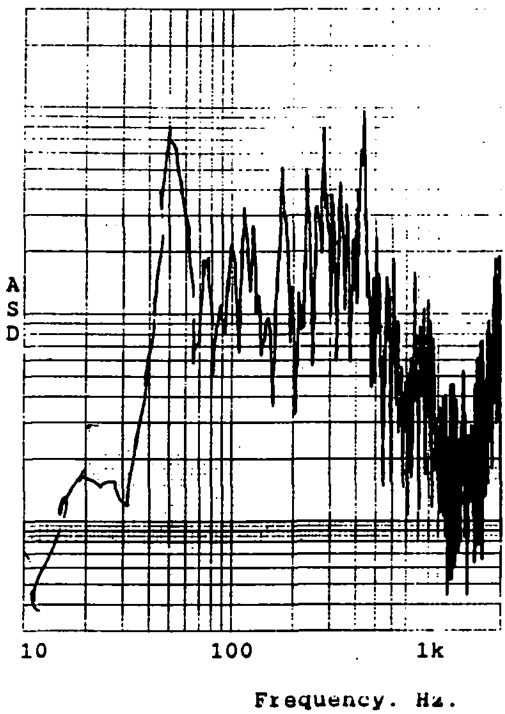

Figure 2. Typical Vibration Response

Single Point,
Single Flight Condition.

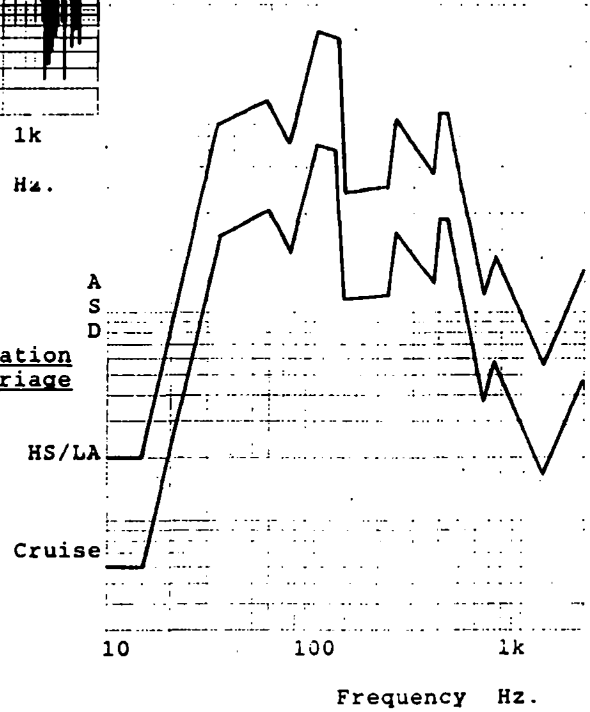

Figure 3. Typical Specification for Aircraft Carriage Vibration