Proceedings of The Institute of Acoustics

# ACOUSTIC TESTING, ANALYSIS METHODS AND FACILITIES AT BRITISH AEROSPACE, WEYBRIDGE

G. A. FAILEY

BRITISH AEROSPACE, AIRCRAFT GROUP, WEYBRIDGE.

CONTENTS

# ACOUSTICS TESTING AT BAE WEYBRIDGE

## 1. INTRODUCTION

The Acoustics Laboratory at Weybridge was built in 1966 for work on aircraft associated problems. Figure 1 shows the general layout, with a central control room and a number of test cells. One advantage of this layout is that test equipment and instrumentation can be used for more than one type of test without being moved. This reduces test set up time and the need for frequent rechecking of tape recorders and amplifiers which are rack mounted. The siren room contains the high intensity channel, which can generate noise levels up to 165 dB OASPL, and a small reverberant chamber (6.5 cu.m.) connected to the channel for testing electronic equipment. A second siren test channel is in operation in the large Noise Room. These channels are used mainly for testing structures, systems and electronic equipment at high noise levels. The reverberant suite consists of two rooms with a 10 sq.m. interconnecting hatch. The rooms are 105 cu.m. and 128 cu.m. volume, with lower cut off frequencies of 160 Hz and 140 Hz respectively, and are independently supported on anti-vibration mounts. The anechoic room is lined with 1.1m long foam wedges giving a lower cut off frequency of 100 Hz and has a usable volume of 48 cu.m.

In addition to the main laboratory there is a mobile laboratory for aircraft and general outside noise and vibration measurement, a portable siren rig and a high temperature model jet noise rig. The Acoustics Department has a separate analysis and computing centre which deals with detailed analysis.

## 2. ACOUSTICS DEPARTMENT CAPABILITIES

The acoustic capabilities of the department are summarised in Table 1.

TABLE 1

| | | |
|---|---|---|
| Fixed Laboratory | - high intensity testing | - structures<br>- equipment<br>- combined loading |
| | - transmission loss tests<br>absorption measurement<br>sound power measurement<br>insertion loss measurement<br>model tests | |
| Mobile Laboratory | - aircraft flyover noise measurement<br>aircraft cabin noise measurement<br>building noise and vibration measurement | |
| Jet Noise Rig | - model nozzles | - noise distribution<br>- noisè sources<br>silencing |
| General | - factory noise and vibration measurement<br>factory equipment noise reduction<br>environmental noise prediction<br>and measurement surveys. | |

ACOUSTICS TESTING AT BAE WEYBRIDGE

3. ANALYSIS METHODS

A comprehensive collection of analysis tools is available and this is basically divided into two groups (Fig. 2).

(a) Hardware. Simple analysis is done in the laboratory during or immediately after the test. Data can be analysed in octave or $\frac{1}{3}$ octave bands, using stepped or real time analysers, or in narrow bandwidths (usually 6% frequency) using frequency sweeping analysers. Sometimes this is done as a "first look" approach in order to set up a particular test spectrum or to check the output of strain gauges or accelerometers before doing a more detailed analysis. Outputs can be plotted directly using level recorders or an X-Y plotter, U-V trace recorder or Polaroid pictures.

(b) Computer. For more detailed analysis, particularly on structural tests, the data is recorded on magnetic tape then analysed on a computer system (Fig. 3). This detailed analysis programme yields Power Spectral Densities of strain, acceleration or acoustic excitation, structural mode shapes, auto and cross correlation, statistical properties and damping factors. This method can be used with discrete frequency or random excitation tests and the flow chart for the latter is shown in Fig. 4. The output can be plotted in a number of ways. PSD's are plotted directly and mode shapes are derived from gain spectra and phase relationships using a common datum strain gauge or accelerometer. Damping ratios can be obtained from random data information by using a basic Kennedy-Pancu system and the display of phase and amplitude spectra of a gauge and a reference gauge. A VDU inter-active system for circle fitting with a printed output gives damping factors at resonant frequencies.

4. TEST REQUIREMENTS

The design and building of aircraft often produces some unusual problems due to noise and vibration. Figure 5 shows the possible noise sources on a supersonic aircraft. Military and civil aircraft have different kinds of problems due to the different design and operating philosophies. One example is the varied design life of the structure, where the operational life of a civil aircraft may need to be ten times that of a military airframe. There is a requirement to demonstrate that a civil aircraft structure shall not fail catastrophically due to acoustic loading (FAR Part 25). Fatigue failures can result from the fact that, although the absolute pressure loading from noise may be low and create low stress levels, the structural response frequencies are high (up to 1000 Hz) so that a large number of load reversals is built up in a relatively short time. The demonstration of structural integrity is usually done in a high intensity siren test rig, described in detail in Section 5.

Electronic equipment is particularly susceptible to acoustically induced vibration, especially items packed in thin-walled metal boxes. There are various specifications to be met with modern equipment, e.g. MIL-STD-810, BS 3G 100 and acoustic testing at high noise levels is used to demonstrate system integrity.

Cabin noise levels must not be discomforting and guarantees are required of the aircraft manufacturer that this noise will not exceed certain levels. All likely sources and transmission paths must be investigated.

ACOUSTIC TESTING AT BAE WEYBRIDGE

## 5. TEST METHODS

### 5.1. Structure and Equipment

Structural acoustic testing is done in the siren channel (Fig. 6). High intensity acoustic loading is used to determine structural response frequencies, mode shapes, damping and fatigue life. Either discrete frequency or broad band excitation can be used. Grazing incidence excitation along the channel is generally used as it is more representative of true aircraft conditions than normal incidence (Fig. 7).

Installation of equipment in an aircraft can be a problem, one example being the location of some equipment in an engine nacelle area where the noise levels were high. In-flight failures occurred and a test with a simulated installation in the siren channel (Fig. 8) produced similar failures. The aircraft structure was represented by a plywood plank to give the same stiffness and during the test some relays failed and some operated erratically. The equipment was modified and re-tested until adequate life was achieved.

Electronic equipment is usually tested in the small reverberant chamber at the end of the siren channel. Figure 9 shows the result of one item subjected to 165 dB OASPL for 8 minutes. The metal container broke and a number of components became detached.

One problem which occurred early in the life of the siren channel came from the use of fibreglass wedges at the channel exit to reduce reflected waves. At a level of 165 dB OASPL with a fairly flat spectrum the wedges went up in smoke (Fig. 10) and measured temperatures reached 1000°C in about eight minutes. This was due to the high absorption qualities of the fibreglass and the mechanism of absorption is to convert the energy to heat. Fibreglass is also a good heat insulator so the wedges retained the heat, and the internal temperature built up until the resin burnt and the whole wedge became charred cinders. A variety of materials were tried as replacements and eventually very fine steel wool was used. This absorbs the noise and allows the heat generated in the wedge, to escape. Similar potential problems on another high intensity noise test installation were checked and the wedge material tested in the siren channel. Some of the thick specimens of mineral wool were also charred.

### 5.2. Combined Loadings

In structural integrity demonstration tests it is sometimes necessary to perform the tests using combined loads of noise and pressure or in-plane stresses, e.g. to check crack propagation rates. Care must be taken with all pressurisation tests for obvious safety reasons. One such test, with a fuselage subjected to noise and pressure, was conducted in a special sandbagged enclosure built to contain the results of a possible catastrophic failure. A mobile siren test rig was used to generate noise on the fuselage and compressed air supply provided the pressurisation. Figure 11 shows the configuration of horns and fuselage during the rig build outside the enclosure. The test consisted of varying the noise and internal pressure levels which were programmed to represent a typical flight.

Cuts were made in various structural components such as stringers (Fig. 12) and the changes in static and oscillating stress levels and the crack growth measured. After 1000 simulated flights there were no major failures or uncontrolled crack propagation.

Another type of combined loading test was done in the siren channel on an aircraft fin box containing various systems (Fig. 13). During exposure to high intensity noise the hydraulic electrical and mechanical systems were operated and their performance monitored. In general the various systems operated satisfactorily but the test did reveal several problems with the structural supports, attachments and bearings.

5.3. Noise Transmission

Cabin interiors must be kept reasonably quiet and comfortable for the passengers sake and to meet production guarantees. Cabin noise may come from the boundary layer, the engines, the air conditioning or the hydraulic systems, and the transmission paths must be controlled. A common weak spot is around the doors, which may not seal properly and are usually full of mechanisms with inadequate room for sound proofing. One investigation on door transmission was conducted in the reverberant rooms. Initially a simple door was installed in the hatch between the two rooms and a standard test performed (BS 2750). This was repeated with furnishings and trim. Then the door was fitted to a test capsule representing a section of fuselage and installed in the corner of Reverberant Room No. 1 (Fig. 14). The walls of the capsule were packed with sandbags in order to increase the wall transmission loss and ensure that the test results were for the door and its adjacent wall. The bags were also a protection against pressure failure. The capsule was lined with foam blocks to give the same level of absorption as the predicted cabin furnishings. Noise was generated by loudspeakers in the room and internal and external noise levels measured to determine door transmission loss. The interior was then pressurised in stages up to 11 psig and the test repeated. The interior measured data was adjusted for pressure and absorption effects to find the difference due to pressurisation on the door transmission loss. Pressurisation usually stiffens a structure, changing the natural frequencies and transmission loss levels. In this case the door was so stiff that the change in pressure had little effect. The effect of the seal was to improve the transmission loss by about 5 dB above 1 kHz and the furnishing gave a further improvement of about 10 dB in the same range.

5.4. Noise Power Measurement

Turning now to the anechoic room, the low ambient noise levels (17 dBA, 35 dB OASPL) make it suitable for measurement of the acoustic power output of fans and similar equipment and the calibration of microphone systems. One particular piece of equipment to be measured was an instrument used in Air Traffic Control centres. It contained a moving ball bearing system and was required to produce less than 35 dBA at 1 metre. This level is difficult to measure in a normal workshop or office and a very quiet environment is necessary.

Another use for the anechoic room is the cablibration of microphone systems using long cables which must be done in a quiet environment so that the effect of the cables can be measured. The anechoic room is sufficiently large to get all the parts of the system connected and a total system calibration performed.

5.5. Jet Noise Rig

To go to the other extreme of noise level we have a high temperature model jet rig used in the investigation of nozzles. (Fig. 15). The test rig uses compressed air from the factory system through valves and a long length of straight pipe containing a burner section to the nozzle exit. Hydrogen is used in the burner and nozzle temperatures up to 800°C can be obtained. High velocity jets generate considerable noise from mixing with the ambient air. Full scale effects can be simulated by using model nozzles and adjustment of the nozzle area and flow temperature. Modifications to the nozzles can reduce jet noise and model studies are used to measure the effects of the modifications. Unfortunately shape changes usually produce losses in thrust.

One recent investigation was aimed at reducing the jet noise of an existing engine on an aircraft in production. Different types of model nozzle using multiple flutes or lobes were tested in conjunction with an ejector. The models were also tested in a wind tunnel to check the potential thrust losses. The best compromise gave a noise reduction of up to 9 dB with a performance benefit. Similar designs evaluated at full scale have confirmed the figures predicted from the model tests.

Another, slightly different, model test was the measurement of noise distribution around a rear fuselage and tail construction (Fig. 16). Due to the high temperatures involved, a system of water cooled microphones was developed. The diaphragms of the microphones were protected by porous metal and the body of the microphone and cathode follower assemblies were surrounded by a spiral channel carrying the cooling water. The outer casings were also wrapped in an insulating case. The measured model data were later confirmed by measurements made on the aircraft.

6. INSTRUMENTATION

During structural development testing it is necessary to measure strains and accelerations as well as noise. The strain gauges used are small so that there is minimum effect of mass on light weight structures and to measure strains close to areas of stress concentration. Figure 17 shows the siren data collection system and the circuits used for static and dynamic strain measurement. The gauges are restricted to 120 $\Omega$ or 600 $\Omega$ to fit the half bridge system installed. Ambient temperatures in the channel are usually stable and a stabilised power supply or batteries are used for power. The weak link is the attachment of the wires to the gauge tags and these have to be bonded to the structure with RTV silicone adhesive to prolong their fatigue life.

Acceleration measurements are made using very small accelerometers (B&K 4344 2 gms). These are bonded to the structure and a conditioning (charge) amplifier system with measuring amplifiers allows the signals to be either read directly or recorded. They are kept in place for a minimum time to avoid fatigue failures of the cables.

ACOUSTIC TESTING AT BAE WEYBRIDGE

7. MOBILE LABORATORY

The mobile laboratory is used in the measurement of aircraft and environmental noise. It can be fitted with various analysis equipment to form a self-contained base with man-mobile systems and radio communications are used when covering a large area.

Smaller mobile measurement and recording systems are used when dealing with individual tasks such as factory noise or building noise and vibration.

8. CONCLUSIONS

To summarise the activities in the BAe Acoustics Laboratory we can say that, although designed and built primarily for aircraft and equipment tests, it is suitable for a wide range of testing. Many varieties of acoustic testing and measurement, including mixed loading, can be catered for as well as standard transmission loss, absorption and sound power level measurement. The noise, acceleration and strain measuring instrumentation used are generally of standard types with particular care taken in the installations.