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THE ENVIRONMENTAL ENGINEERING HIGH INTENSITY ACOUSTIC FACILITY.

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1. INTRODUCTION

The high intensity acoustic facility was conceived as a means to simulate the environment of air carried weapons on a range of modern high performance military aircraft. Previous work in the United States and at Hatfield had shown that this method was superior to pure vibration testing in its ability to provide a more uniform input of energy (a closer approximation to boundary layer noise) and it led to less non representative failures which occurred with single point vibration excitation. Further, high intensity noise covered a wider frequency spectrum than vibration systems whose output fell off rapidly from 2000 Hz.

The Acoustic Test Centre at Hatfield (Figure 1) was built in 1984-1985 in the shell of an existing wind tunnel constructed in 1945 to test propellors. In 1985 the Minister of State for Information and Technology, Mr Geoffrey Pattie opened the facility which became the first in Europe able to perform a high intensity combined environment test on missiles.

2. THE REVERBERATION CHAMBER

Entry to the high intensity facility is through a set of double doors retained from the old wind tunnel. A wide passage leads into the Preparation area where missiles, spacecraft antenna and smaller test items are brought and prepared for testing. The preparation area leads into the 100 cubic metre Reverberation Chamber through a vertically opening Markus sound attenuating door and through the main chamber reinforced concrete door.

The reverberation chamber has been constructed of steel reinforced concrete with walls, roof and door each half a metre thick and with a floor 1.5 metres thick. A high mass structure was necessary to contain the high noise levels and to resist the acoustic fatigue that these levels can induce in the structure. The floor provides a reaction mass for the vibrators and a support for the chamber door so that the whole reverberation chamber sits on a common base constructed directly on the existing subsoil. A vibration break surrounds the chamber base and makes this transmission path insignificant compared to the direct sound through the walls/roof/door etc. The Preparation area levels are less than 80 dB(A) for Chamber levels of 160 dB(A) and although this must be considered a noisy environment, it is possible to conduct work in this area during chamber testing. 5 tubes in the side walls allow instrumentation cables into the chamber. These tubes have a break part way down their length to prevent structure borne vibration.

The perimeter steel channel of the chamber door acts as both the sealing surface for the door seals and the running surface for the rollers under the door. The door weighs approximately 30 tonnes and is driven by an electric motor and triplex chain. Roller alignment is critical. With the high noise and vibration levels inside of the chamber it was necessary to install guide rollers to prevent movement of the door away from the two parallel B shaped seals, which are retained to prevent sideways movement and are inflated to a pressure of 15 psi. Under pressure the centre expands outwards onto the door.

The inner surfaces of the chamber have been coated with an epoxy resin since the finish obtained from the shuttered concrete had too many surface irregularities which would increase the absorption coefficient of the bare concrete. This epoxy resin finish effectively seals the pores leaving a smooth hard reflective surface. Reverberation times were estimated from an average absorption coefficient of 0.03 for the concrete over the frequency range 63 to 4000 Hz. The measured reverberation times, which account for the absorption of the horns, roof vents, duct entries, cable ports, any high frequency air absorption, and the concrete, gave an average absorption coefficient of 0.035 for the epoxy coated concrete.

3. REVERBERATION CHAMBER TESTING

The primary function of the high intensity test centre lies in air weapon environmental testing and the simulation of the air carried and free flight environments of missiles. This covers both temperature and vibration (vibration from the aircraft and the launcher, and as high intensity acoustic excitation from the turbulent air flow around the missile). Most of the work at the acoustic test centre is on Reliability Growth. Early missiles are subjected to noise, vibration and temperature conditioning for long periods of time at test levels determined from flight sortie data. It should be stressed that this form of high intensity acoustic testing is a means of producing vibration in the test unit. Testing is controlled not on the acoustic levels and

THE ENVIRONMENTAL ENGINEERING HIGH INTENSITY ACOUSTIC FACILITY.

spectrum shape but on the vibration response of the missile, consequently only one microphone is used to measure the chamber spectrum. Additionally, the facility conducts flight clearance shakedowns on the missiles and launchers.

A typical missile set up (Figure 2) comprises two missiles attached to one of the hydraulic vibrators. These vibrators are each rated at 90 kN thrust and have a two inch displacement. The missiles are also supported by sprung loaded stands. Each missile is enclosed in an acoustically transparent temperature envelope (on the left) which is flexible and strong enough to withstand high intensity noise while attenuating the noise by only 2dB over the frequency range. At each end of these bags there are the transformation boxes which are connected to the roof ports and allow the inlet and exhaust conditioned air to be divided between the two missile. These boxes are constructed from fibreglass laminate and are held in position by acro props. Various types of commercial ducting have been tried for the vertical link to the roof ports with varying success. Also in the roof are a series of Halfen channels which provide anchor points for test objects like the satellite antennas. They are particularly good for this purpose because of the 'T' headed bolts which lock into the roof inserts.

In contrast to missile testing, the set up for space work is quite different. With these tests we attempt to simulate the high acoustic levels associated with the launch and early stage of the flight through the lower atmosphere. For this test we must meet an acoustic spectrum which defines this early flight condition. The empty chamber contains the antenna supported on a fixture representative of the way it would be held in the bay of the launch vehicle, the fixture being supported from the roof by a series of elastic "bungy" cords. Upto eight microphones are arranged around the antenna, panel or solar array and these are recorded on magnetic tape in the control room (most space tests last for one or two minutes). Control of the acoustic spectrum is usually on the multiplexed average of the measuring microphones. The plot (Figure 3) shows the results of an antenna test in third octave bands with the achieved spectrum within the tolerance bands of the required spectrum through the whole frequency range. This plot shows one of the difficult aspects of using a high intensity noise system to produce a defined spectrum, and that is in the control of the high frequencies. At low frequencies the spectrum controlled by the input shaping is within the required tolerance bands, however above approximately 1000 Hz the spectrum is only just in tolerance. In this region the frequencies are the harmonics of the input signal and therefore there is little scope for changes without taking the lower frequencies out of tolerance.

THE ENVIRONMENTAL ENGINEERING HIGH INTENSITY ACOUSTIC FACILITY.

Above 2500 Hz the spectrum in this case is generated by air noise. In general spectra of this type can be achieved with individual microphones within +/_ 2.5 dB over most of the frequency range.

Other instrumentation recorded during these high intensity tests include strain gauges and accelerometers which show the effects of the random noise on the lightweight composite panels used in space craft.

4. NOISE GENERATORS

The system employed at the acoustic test centre has the ability to cover a wide range of overall sound pressure levels from around 130 dB with a Ling air modulator to approximately 164 dB with the Team modulators. The Ling electropneumatic modulator produces levels upto 145 dB with a frequency range of 20 Hz to 1000 Hz, however the chamber spectrum covers 50 Hz to 20,000 Hz, the lower frequency limit being set by the chamber modes and the horn coupling the modulator to the chamber. Similarly the Team system operates upto 800 Hz with a 50 Hz lower frequency cut off.

4.1 LING 10kW EPT1094

The Ling EPT 1094 driver is an electronically controlled air modulator giving a high intensity acoustic power output from random, sine or complex input signals. There are two slotted valve assemblies, one stationary, one reciprocating, with the driver coil wound on the reciprocating valve. Air flows through the permanent magnet and is modulated by the moving valve. Upstream of the modulator are the on/off and pressure control valves and the 5 micron filter to remove contaminants before they reach the modulator inlet filter. The Ling modulator operates from a rack in the control room (Figure 4) which contains a 450 watt power amplifier (interlocked with the chamber door) and the shut down indicators. A displacement clipper with a master gain provides constant air modulator valve displacement and prevents overmodulation of the EPT1094 by clipping the input random noise signal. The transducer meter panel monitors the rms current.

4.2 TEAM MODULATORS

Northrop Aviation developed the air modulators 20 years ago to perform work on the structural acoustic interaction of aircraft components. The BAe system comprises two Mark VI modulators on a common horn, with each modulators capable of producing 85kW of acoustic power. Acoustic pressures of approximately 60% of the supply pressure (200 psi) are achieved downstream of the valve. This extreme pressure pulse amplitude produces a travelling wave which is a shock front saw tooth, giving the fundamental and both odd and even harmonics. Team modulators work as large reciprocating poppet valve, similar to the inlet and exhaust valves of an internal combustion engine. Unlike the car valve, the modulator valve can be biased off its seat. Mechanical movement of the air valve is achieved by a high performance servohydraulic system with the valve hydraulic actuator forming the rear part of the air valve. Hydraulic pressure from the power pack acts on the actuator piston forcing it to move against the air pressure to close the valve and with the air pressure to open the valve. Full displacement (0.3 inch) of the actuator occurs upto 80 Hz, above this frequency the actuator is acceleration limited. The control of the oil pressure to the actuator is achieved by the high frequency V50 servo valve bolted to the actuator and controlled by an electromagnetic voice/field coil assembly driven from the system power amplifier. A constant voltage is fed to energise the field coil and the input signal drives the voice coil which is attached to a four way spool valve, and it is the movement of the spool valve that diverts the hydraulic oil into the oilways leading to the actuator piston.

Air exits from the plenum to the horn throat through radial airways in the valve head and through the perimeter gap produced when the valve head leaves the seat. To prevent the valve main shaft and piston spinning, there is an antirotation arm on the main shaft at the rear of the actuator block.

The system uses feedback control for biasing the valve and setting its mean position. On the outer end of the air valve mainshaft there is an LVDT, which converts the valve linear motion to a proportional voltage which is fed back to the 1522 Servo Controller. The electronics of the system consist of a 500 watt low distortion current amplifier, a Servo Controller and a Digital Servo Display.

5. SPECTRUM SHAPING

The sound spectrum produced in the Chamber by a modulator is controlled by the impedence characteristics of the horn and the reverberation chamber into which it is driving. The spectrum will in general be smooth and continuous with the exception of the low frequencies where room modal density may be insufficient for adequate modal overlap to occur. At low frequencies the roll off also depends on the flair constant of the horn - an exponential horn giving the smoothest spectrum. Changes to the chamber spectrum shape and level can be achieved by adjustment to the input spectrum shape, the air supply pressure, and the Valve mean position.

The input drive spectrum is generated from a Bruel & Kjaer 1405 noise generator passing through a B&K 5612 third octave band spectrum shaper (Figure 4) into a pre amplifier. There is very little scope for adjusting the high frequencies (above 1000 Hz) since these result mostly from the harmonics of the lower frequency input. Generally spectrum control lies with the input signal shape.

6. COUPLING HORNS

Since most modulators have relatively small mouths, the sound energy must be transferred to the chamber by a horn having a suitable mouth size for the lowest required frequency. Horn flare rate and length both influence the efficiency of the horn to couple the modulator to the chamber. Here the coupling horns are exponential since these are relatively short with a fairly well defined lower cut off frequency. Even so, horns of this length can degrade the high frequency response of the system by attenuation in the horn. A 50 Hz cut off was chosen since this limits horn length and keeps the acoustic power in the third octave bands where more than one chamber mode exists. The horns enter the chamber near to but not in the corners. It is generally considered important that the horn is built into the corner in order that all possible room modes are supported.

7. REVERBERATION CHAMBER DESIGN

In general the larger the chamber the more uniform the reverberant sound field to lower frequencies. It is usually recommended that there should be at least 10 modes in the lowest third octave band of interest and this determines that in the 100 cubic metre chamber the lowest third octave band would be 100 Hz (92 Hz lowest frequency for a uniform diffuse field). With this density it should be possible to excite any resonance frequency of the test object, in that band. Having decided on a volume (usually based on a 10% rule for the size of the test item), the optimum room dimensions can be found. Deciding on the exact shape is another problem, should you opt for the greatest usable floor area and a rectangular room or for an irregular shape to provide a more diffuse sound field? The BAe facility utilises a rectangular box based on 100 cubic metres with room dimensions of 5.85x4.64x3.68 metres. Generally the power rating for the modulator to cope with all losses and the low frequency modal density can be obtained by adding 6 dB to the maximum required overall sound pressure level. In our facility, operating at 165 dB(L) maximum, normal calculation for a reverberant room suggests a power requirement of 38,000 acoustic watts however the addition of the 6 dB brings this upto 150,000 acoustic watts. This 6 dB also allows some scope for spectrum shaping. The importance of having small absorption coefficients can be seen when the effect of the specimen absorption is considered in respect of power requirements. If the test object were 6 square metres with an absorption coefficient of 0.5, then the new power requirement would be 251,000 acoustic watts.

8. ACOUSTIC SILENCERS

The air ducting system at the Acoustic Test Centre was specially designed to attenuate the chamber noise levels reaching the Conditioned Air Rigs, to reduce the noise to the outside of the building (the chamber air vent), to limit noise radiated from the ducts to the surrounding areas and to maintaining rapid heating and cooling at the test item. Temperature changes of upto 20 degrees per minute have been achieved by limiting the metal content of the duct inner skin. The outer skin of the ducting is fabricated from 3 mm carbon steel lined internally to a depth of 200 mm with long strand glass fibre packed to a density of 120 kg/cubic metre. The fibres are retained by a glass fibre cloth, a stainless steel cloth and a stainless steel weld mesh. Care has been taken to reduce the transmission of sound and vibration along the duct structure by the use of flexible connectors and in the prevention of thermal losses to the concrete at the points where the ducts pass through the Chamber roof. The 1000 mm diameter attenuators have the same outer construction as the ducts but have in addition a central 350 mm pod held by spiders radiating to the outer casing. All ducting is supported from the hexagon roof by isolated hangers. The design of the chamber vent reduces the chamber noise to below 90 dB(A) at 1 metre from the vent outlet on the roof of the hexagon.

9. MONTFORD CONDITIONED AIR RIGS (CAR's)

Along with the effects of vibration, temperature changes play an important part in the reliability of air carried weapons. Thermal cycling has been achieved with the Conditioned Air Rigs and associated Profile temperature controllers. On the outlet side of the CAR ducting there are a series of solenoid valves arranged in two banks. These allow the liquid nitrogen to be injected into the duct. Also in the outlet ducting are the heater banks. Again there are two banks, one for normal heating and the second for boost heating. The power consumption of these heaters is 180 kwatts. Finally, the duct contains the control sensors (platinum resistance thermometers PRT's) which monitor the duct temperatures to ensure that the system cannot be thermally overloaded.

Nitrogen for the CAR units is stored in a large vacuum insulated tank outside of the building. This tank holds some 50,000 cubic litres of liquid nitrogen (approximately 30 tonnes) when full at a pressure of 45 psi. The tank is pressurised to force the nitrogen liquid upto the Phase Separator on the roof of the hexagon. Pipework from the tank to the Phase Separator and to the CAR units is all vacuum insulated however some gas will separate from the liquid. This gas is vented off at the Phase Separator thus supplying liquid to the CAR units. Incorporated into the controls of the Phase Separator are monitors to sense and control the liquid level, while manual valves in the CAR units and at the nitrogen tank are used to shut off the supply at other times.

10. PLANT ROOM

Design calculations prior to construction indicated that acoustic louvres would not be required to contain the plant room noise levels and subsequent measurements have confirmed this. Noise levels in the plant room of 102 to 103 dB(A) are attenuated to 82 dB(A) at one metre from the plant room doors. Horn room levels upto 116 dB(A) do not contribute to plant room levels mainly because of the double acoustic door system between these areas. Similarly noise levels of 90 dB(A) in the CAR room are due to the conditioned air rigs because of a 25 dB partition separating the upper plant room from the CAR room. The noise levels in the plant room are generated by the compressor, the two hydraulic power packs and the cooling water system. The Centac compressor is rated at 3000 scfm at 200 psi and requires nearly 750 kwatts of electrical power. Air is drawn into the compressor, passes through the 3 stages and after cooler before entering the air receivers outside of the building. Noise levels of 80 dB(A) in the courtyard are due to the cooling tower on the roof, the passage of air through the receivers and the compressor bypass silencer. There is no contribution from the reverberation chamber. From the receivers air is piped back to the horn room to feed the Ling and Team modulators.

The hydraulic power packs are situated on the upper platform over the compressor and provide the hydraulic supplies to the vibrators and to the Team modulators. Both power packs provide oil at 3000 psi.

THE ENVIRONMENTAL ENGINEERING HIGH INTENSITY ACOUSTIC FACILITY.

11. CONTROL ROOM

Signals from the instrumentation are relayed to the control room (Figure 4) where they end at measuring instrumentation or recording devices. Signals to control the noise modulators, the air valves, the vibrators, the temperature conditioning units and the plant are all sent from this room. The facility safety interlock system can only be operated from the control room.

Apart from the control racks, instrumentation consists of chart recorders for temperatures, and an SE7000 14 track FM tape recorder. Microphone signals from quarter inch Bruel & Kjaer condenser microphones pass through power supplies and onto a multiplexer to provide the average chamber level upon which most spacecraft tests are controlled. The output from the multiplexer can be analysed using a Scientific Atlanta SD375 dual channel real time analyser and plotted on a Hewlett Packard plotter or stored on 1 inch magnetic tape for subsequent analysis. Similarly, the strain gauge signals are taken to Fylde strain gauge amplifiers and the accelerometers to Environmental Equipment charge amplifiers before being routed to the tape recorder or analyser. Thermocouple signals are displayed directly on chart recorders.

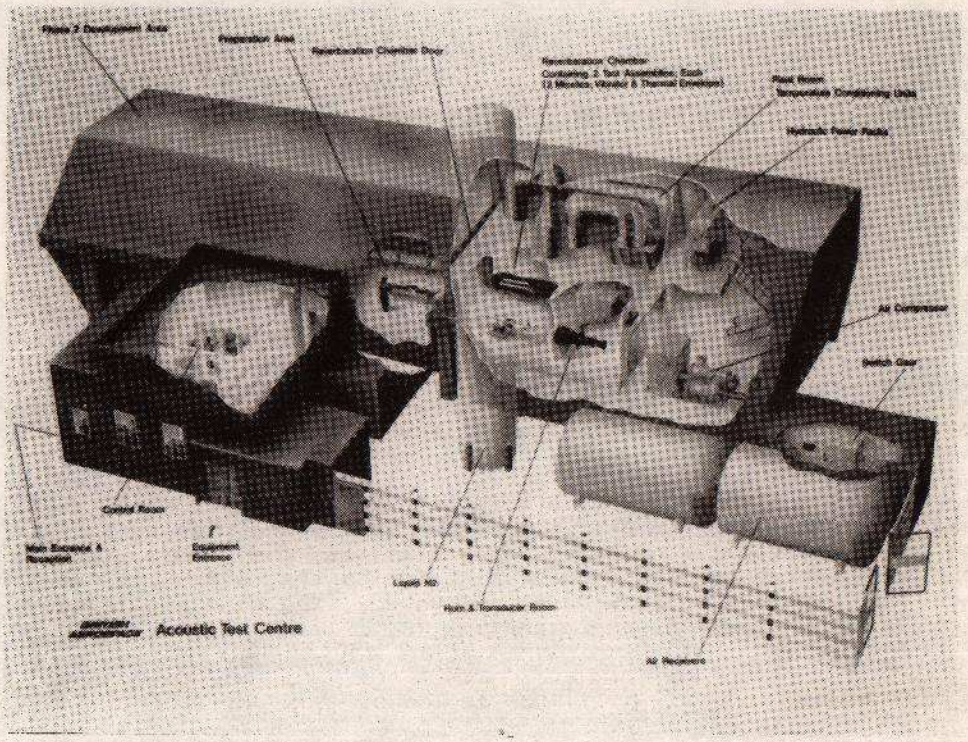
Operation of the noise and temperature systems can only take place when the interlock key transfer system has been completed. This prevents the accidental exposure of personnel to high noise levels which could be fatal. The system operates by removing a key (which is locked into the panel until the door closes on a microswitch and the door seals have been inflated), from the panel near the Markus door in the preparation area, and placing it into the main control room panel which releases the start inhibit controls on the conditioned air rigs and on the hydraulic power pack for the Team noise generating system. The Ling amplifier is also linked to this interlock panel.

12. CONCLUSION

The British Aerospace Acoustic Test Centre has been in operation for nearly six years during which time it has provided a test facility for high intensity noise testing of missiles, space and aerospace components. It has demonstrated that an acoustic test can reduce the failures in components used in the extremely harsh environments of spacecraft launch and on high performance aircraft and provides a useful research and development method for future developments in the aerospace industry.

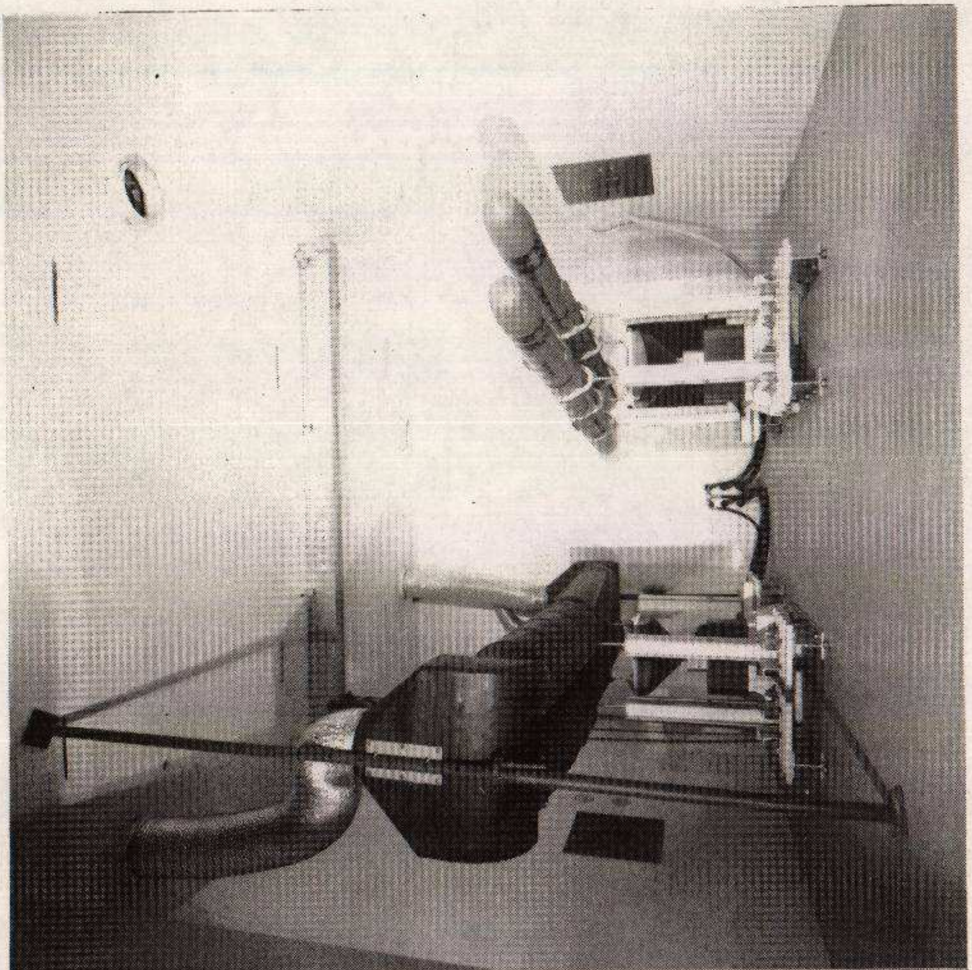
THE ENVIRONMENTAL ENGINEERING HIGH INTENSITY ACOUSTIC FACILITY

FIGURE 1. BAe ACOUSTIC TEST CENTRE



THE ENVIRONMENTAL ENGINEERING HIGH INTENSITY ACOUSTIC FACILITY

FIGURE 2. 100 m^3 REVERBERATION CHAMBER



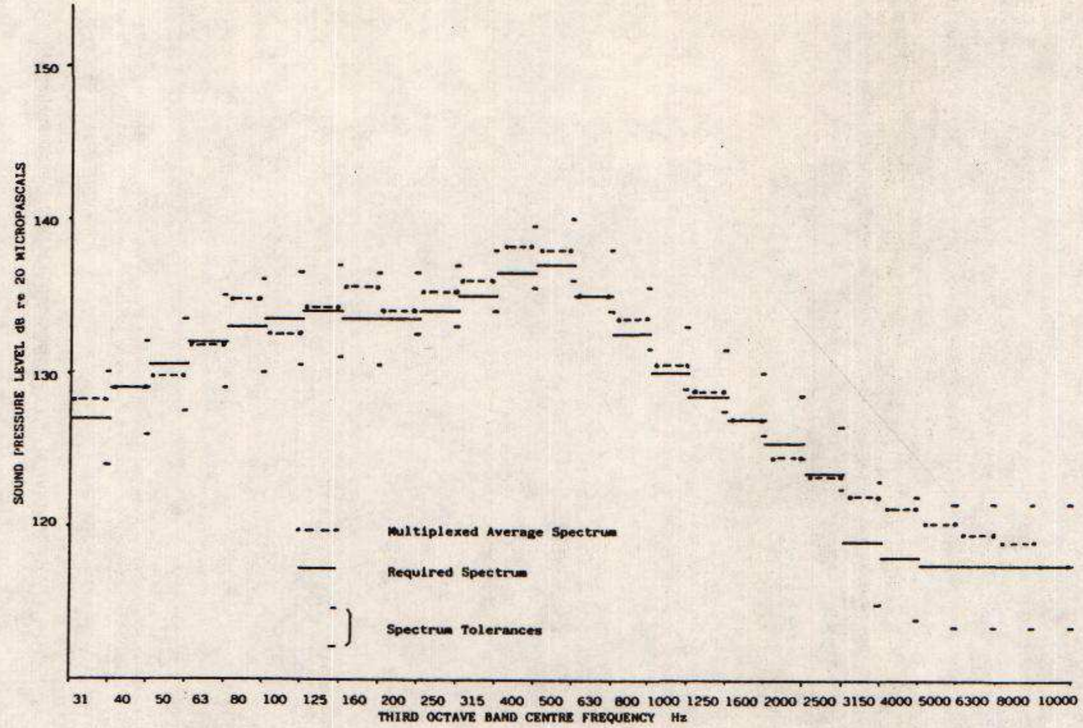
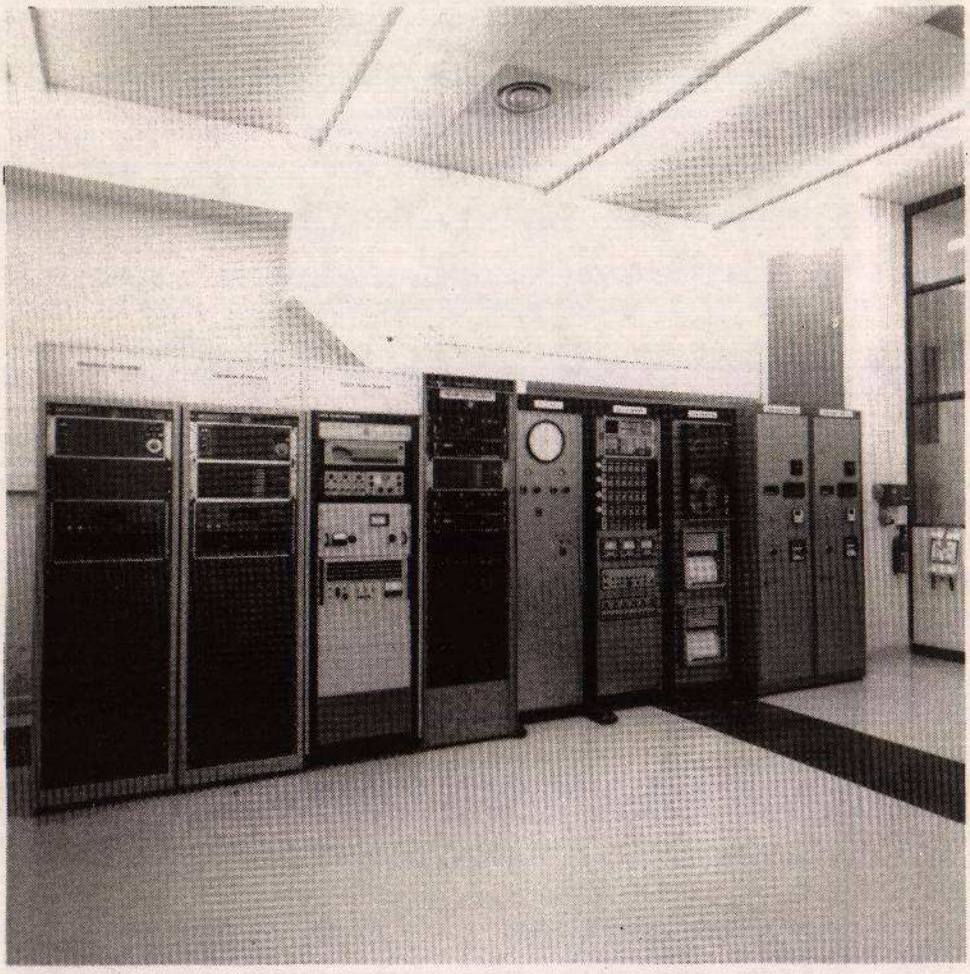


FIGURE 3. TYPICAL SATELLITE ANTENNA TEST RESULTS
(MULTIPLEXED AVERAGE OF 6 MICROPHONES)

THE ENVIRONMENTAL ENGINEERING HIGH INTENSITY ACOUSTIC FACILITY

FIGURE 4. CONTROL ROOM



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