QUALIFICATION OF FREE-FIELD ROOMS – THE NEED FOR A STANDARD

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1. ABSTRACT

The free-field room or anechoic chamber is one of the basic test environments used for acoustical investigations of sound sources and receivers. In a primary laboratory the anechoic chamber provides a facility for free-field calibration of microphones. Understanding the interaction of an acoustic wave with the geometrical configuration of material surfaces and the absorption of sound in those materials has led to a range of designs for linings (predominantly wedges) of these rooms. However, despite there being many free-field facilities worldwide, there exists no definitive method for determining and therefore defining their performance. International standards dealing with sound power measurements, ISO 3745 Annex A and similar ANSI S12.35 Part 9, give procedures for qualifying anechoic test rooms. These rely on a draw-away test to assess the free-field conditions, determining the extent to which a spherically radiating wave deviates from the ideal inverse law for pressure. This is a time consuming test which has been found to be difficult to perform and so several researchers have demonstrated other methods of evaluating the free field by using intensity, constant separation or tone-burst techniques. There is a need for standardisation and NPL have been involved in a project to assess these methods, which should ultimately result in a recommendation to ISO.

2. INTRODUCTION

2.1 THE FREE FIELD

A free field is an isotropic, homogeneous environment, free from bounding surfaces. In an acoustic free field, the sound energy radiating from an idealised point source would be distributed evenly over the surface of a sphere. This spherical spreading (Figure 1) means that the acoustic power W from the source is distributed over an area $4\pi r^2$ and the intensity is given by:

$$I = \frac{W}{4\pi r^2} \qquad (1)$$

The intensity is inversely proportional to the square of the distance from the source, commonly referred to as the inverse square law. From Equation 1 it can be shown that the sound pressure level (SPL) decreases by 6 dB for every doubling of distance from the source.

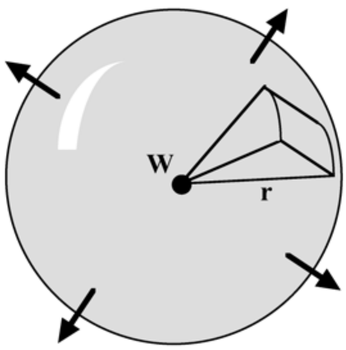

Figure 1: Spherically spreading sound waves in a free field

2.2 ANECHOIC CHAMBERS

An acoustic environment will be effectively free field if it has bounding surfaces that absorb all of the sound energy incident upon them. The anechoic chamber attempts to achieve this by treating all surfaces with an acoustically absorbent lining, so that no sound reflections are produced, in the frequency range of interest. The requirements on this absorptive treatment are high; the absorption coefficient should be at least 0.99 for all angles of incidence.[1] As an example, if the surfaces of a room had an average absorption coefficient of only 0.9, then the sound pressure level of the reflected wave would be 10 dB less than the incident, and the space would not approximate a free field. Typically anechoic rooms are treated with a wedge lining (Figure 2), the wedge shape attempts to facilitate impedance matching at the air/absorbent interface.

Figure 2: NPL's anechoic chamber

However, no absorbent lining is perfect and some reflections will occur distorting the free field and the range of the free field within the anechoic chamber will become restricted. The reflections from the walls of a wedge lined anechoic chamber increase at low frequencies when the length of the wedge becomes comparable with the wavelength of the sound, setting a lower frequency limit for the room. The absorption coefficient of the wedge may also be frequency dependent and so the evaluation of the performance of the absorptive treatment is of importance – especially if the chamber is used for primary calibrations.

At low frequencies, the absorption coefficient of the wedge may be found from measurements in an impedance duct, at high frequencies it has been shown[2] that the most practical method is to evaluate the completed room. Since the performance of the room depends on the properties of the lining and the configuration, the complete facility must be evaluated.

3. MODELLING THE FREE FIELD

In order to assist in visualising the sound pressure distribution and deviations from free field in different room configurations, it is useful to be able to model the reflections from the room boundaries.

Wang and Cai[3] have demonstrated a simple image model for calculating deviations in an anechoic chamber using the interference from the first reflection. This model has been implemented at NPL, including allowances for air absorption.

Figure 3 and Figure 4 show the deviations modelled in a cubic room (5x5x5 m) lined with a planar absorber, with a nominal absorption coefficient of 0.99, and a point source in the centre of the room. Accounting for just one reflection the deviations from free-field conditions are substantial along a room diagonal (source to room corner). Air attenuation is incorporated in the model according to ISO 9613-1.[4]

Note however, that this model assumes a nominal wall absorption coefficient for all angles of incidence, which may have implications when modelling at high frequency.

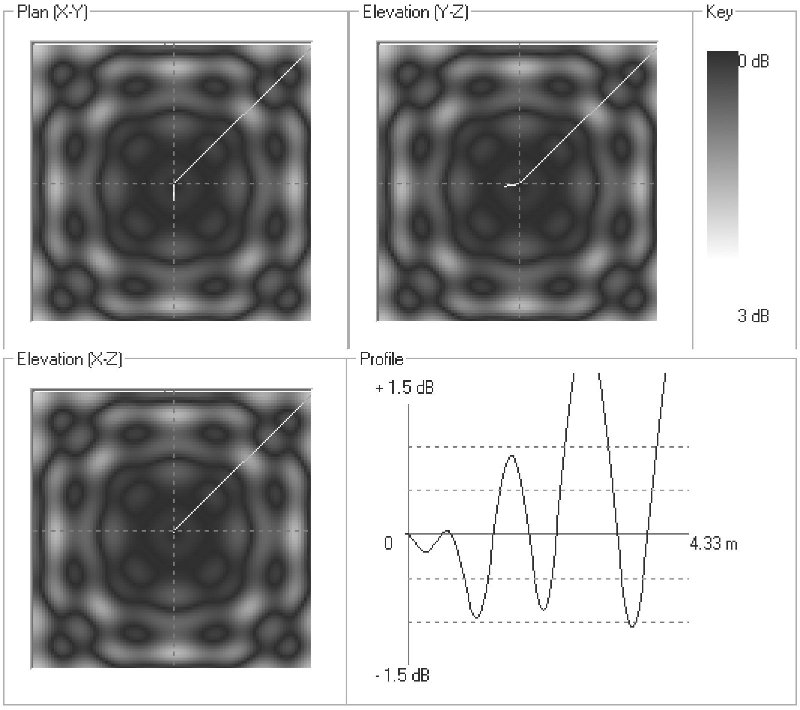

Figure 3: Deviations 250 Hz (5x5x5 m, a=0.99)

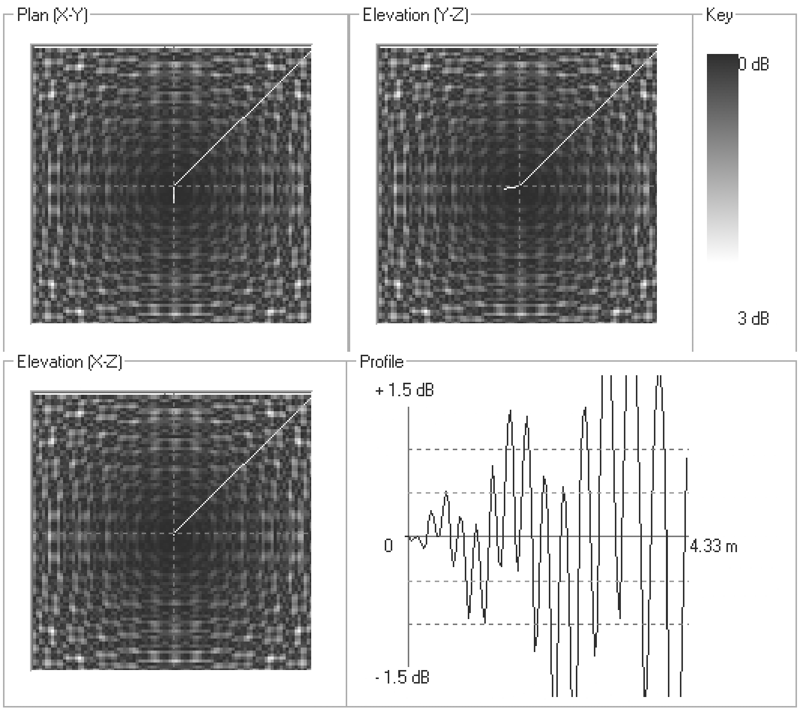

Figure 4: Deviations 1000 Hz (5x5x5 m, a=0.99)

4. MEASURING THE FREE FIELD

Many different measurement techniques have been used to determine the nature of the free field within anechoic chambers. Early tests measured reverberation using an interrupted source[5], but this sort of measurement is difficult in modern chambers with very short decay times. The use of short pulses, tone burst echo testing[5,6,7], time windowing[8], or maximum length sequences[9], are now viable techniques and work is scheduled at NPL to investigate the feasibility of these types of test.

It may also be possible to use highly directional detectors to determine the level of reflection from the chamber walls – but this is not a direct test of the chamber's performance.

In order to evaluate the chamber's performance the sound pressure is usually measured and compared with an expected theoretical value.

A frequency response test, comparing the response of the receiver to a particular sound source for different separations of the source and receiver,[10] and for fixed separations but different positions within the chamber gives some indication of the performance of the entire facility.

Diestel[11] proposed a carousel measurement, where the source and receiver are mounted on a rotating turntable at constant separation. Variations in the measured SPL are considered to be due to boundary reflections. This method has been employed successfully in anechoic[12] and hemi-anechoic chambers[13,14], where the source proximity to the reflecting ground plane means that a divergence loss test is difficult to perform due to the ground reflections.

The most commonly used test method is the inverse distance draw-away test, or divergence loss test, where the measured pressure should be inversely proportional to the source-receiver separation.[1,2,12,15-25] Whereas the carousel method gives an indication of the deviations in a plane, the divergence loss test assesses the deviations along a room dimension, or radial path from a source. A comparison of the two methods found differences between the results, but the draw-away test was in accord with low-frequency impedance tube testing of the absorbent material.[12]

The divergence loss test is usually implemented using pure tones, moving the receiver away from the source, continuously[1,2,15,19,21-25] or in discrete steps[17,20,22,23,25]. Research has shown that continuous traverse measurement is the most comprehensive test.[22,23,25] This can easily be demonstrated by considering the deviation patterns modelled in Figure 3 and Figure 4. Discrete sampling of the sound field may easily miss the close spacing of the true deviation. Figure 5 shows the result of measuring using a continuous traverse in an anechoic chamber at 2 kHz. The data are presented as inverse microphone voltages (proportional to inverse pressure) against distance from the sound source. The inverse voltage should show a linear relationship to the source-receiver separation if the space is a free field. Deviations from the straight line can be seen as the separation increases. Also marked on Figure 5 (black squares) are the points that would be measured if discrete 30 cm intervals were chosen. The discrete sampling clearly does not show the true nature of the deviations in the chamber.

If the entire chamber is to be evaluated, several paths must be measured. Delaney[2] recommended using a small omnidirectional source and measuring the pressure on radial paths from the source. This form of testing is recommended in ISO 3745 Annex A (1977)[26] a standard dealing with sound power measurements. The type of testing required involves mounting a microphone for measuring the sound pressure to a moving traverse which passes along a number of chords from the source in the room centre to the room corners.

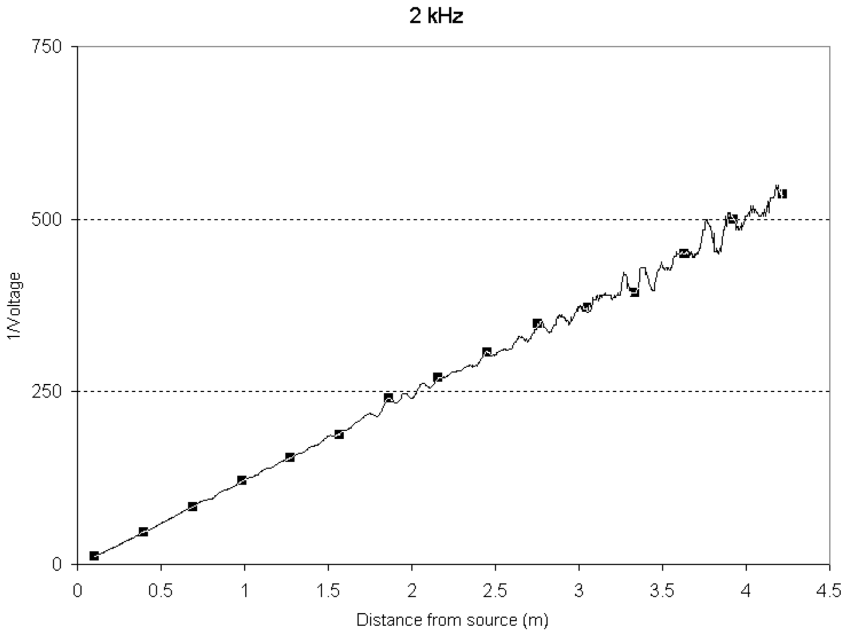

Figure 5: Inverse voltages measured using a continuous traverse in an anechoic chamber

5. INTERPRETING THE RESULTS

The measured data can be displayed on a plot of the reciprocal of sound pressure against distance. This gives a qualitative display of the room performance, since the graph should show a linear relationship. A quantative single figure for each frequency of interest is often quoted, this typically being the maximum deviation of the measured pressure from a theoretically expected value.

Table 1 shows the criteria set out in ISO 3745 for the allowable deviations from the inverse square law. However this is tailored for sound power measurements and the acceptable deviations are quite large, especially if these criteria were used to qualify a facility for primary calibrations.

Table 1: Allowable deviations from the inverse square law ISO 3745

Frequency (Hz)	Anechoic room maximum deviation	Semi-anechoic room maximum deviation
f <= 630	± 1.5 dB	± 2.5 dB
800 < f < 5000	± 1.0 dB	± 2.0 dB
f >= 6300	± 1.5 dB	± 3.0 dB

Delaney and Bazley[2] argue that the root-mean-square deviation from ideal inverse law is a reliable index of a chambers' performance. Sound pressure level as a function of source-receiver separation might not be useful since there is a large range and deviations may not be obvious, and the maximum value of deviation over a specific interval may be an unstable quantity due to small changes in the speed of sound producing large changes in observed maximum deviations.

A parameter to assess industrial room performance has been proposed by Ondet[27], where the parameter relates to the reduction in SPL per doubling of distance. A value of 0 dB means that the room is diffuse, a value of 6 dB means that it is perfectly anechoic. A similar figure could be investigated for anechoic chambers.

No standardised method of calculating the deviations from the theoretical pressure decrease has been adopted. Some have reported[13] the standard deviation of the pressure about the mean value of the pressure. The deviations should be those from a best-fit based on inverse proportionality.[2] Ballagh[20] argues that the best fit should be based on a logarithmic least squares fit, but most work has used a linear fitting approach. The approach for finding this best fit may be based on a fixed reference where the pressures are compared with the pressure at a reference distance, or on an optimal reference where the theoretical decay is based on a source strength and acoustic centre. These analysis approaches have been investigated[25] and the optimal reference method has been included in the latest draft of ISO 3745.

6. THE NEED FOR A STANDARD

Currently, qualification of free-field facilities is only discussed in the testing of sound power of machines (ISO 3745, ANSI 12.35), and testing facilities for sound system equipment (IEC-60268-5). The ISO standard and local equivalents dedicate a large section to the qualification of the free-field facility, but these criteria only need to be adopted for the sound power tests, and are not necessarily applicable or appropriate for a general facility qualification. IEC-60268-5 calls for the free-field test room to exhibit sound pressure decrease with distance from a point source to an accuracy of 10%. No guidelines are given as to how this may be measured, interpreted or achieved.

With many different methods and analyses available it is clear that there is a need for a standard test method that is practical and would facilitate intercomparison so that measurements made within these chambers can be compared.

7. ACKNOWLEDGEMENTS

This work is supported by the National Measurement System of the Department of Trade and Industry.

8. REFERENCES

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