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ABSORPTION AND DIFFUSION : RESEARCH INTO PRACTICE – YORK UNIVERSITY MUSIC RESEARCH CENTRE

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1 INTRODUCTION TO PROJECT

The project on which this paper is based is the new Music Research Centre for York University, currently under construction and due for completion in February 2004. The design team is led by architects van Heyningen and Haward, with Arup Acoustics appointed as the acoustic consultant.

The key rooms within the building are the teaching and research spaces, a 1250 m^3 auditorium, an editing room, a recording studio, vocal booth and the associated studio control room. The subject of this paper is the control room which measures 6.91 x 4.38 x 3.3 m (L, W, H) giving a floor area of 30 m^2 and a volume of about 100 m^3. The design brief was to provide a building which exhibits an excellent acoustic environment in keeping with a department at the forefront of psycho-acoustic research. As such, the acoustic specification was based on EBU recommendation for monitoring environments[1], though this was refined through considerable dialogue with the University.

Given the well defined acoustic specification, it was clear that the absorption strategy was key, though the restricted budget meant that most proprietary products were too expensive. It was decided therefore, in light of the author's research into mechanisms of passive absorption[2], that a bespoke design of absorber should be adopted. The aim was to develop an absorption strategy which could be built by a non-specialist contractor, using inexpensive materials, whilst exhibiting all the required acoustic characteristics.

2 ACOUSTIC DESIGN

2.1 Requirements

Whilst the EBU recommendations were used as the starting point for the acoustic specification of the studio control room, other factors needed to be considered. The use of surround sound monitoring was part of the design brief, so it was important that the room did not have a 'front' and 'back' like the live-end-dead-end rooms of the 1970's. The author's operational experience of recording studios led to other design intentions such as an even spatial distribution of sound pressure across the audible spectrum, implicit in which is the requirement for heavily damped room modes. The overriding requirement though was for a decay characteristic that was largely independent of frequency and about 0.4 seconds at 500 Hz. In order to achieve this it was decided that a combination of high and low frequency absorbers would be required – the design of which is described in the following sections.

2.2 High Frequency Absorption

Absorption at speech frequencies and above is easily achieved through application of porous material to a room boundary and well established semi-empirical formulas[3] are able to reliably predict the surface normal acoustic impedance of a fibrous or foam material from its flow resistivity, a function of its microscopic structure. Based on this research, a 100 mm thickness of 45 kg/m³ fabric faced mineral wool, mounted flush against the room boundary, was chosen to provide the necessary high frequency absorption.

2.3 Low Frequency Absorption

There are many different ways in which sound energy at frequencies below 500 Hz can be dissipated. The decision of which to employ was based on three factors : an adaptable design utilising inexpensive materials, that exhibits a low Q absorption characteristic and that can be modelled analytically. Based on these criteria, an absorber comprising a perforated timber facing, mineral wool layer and air gap was designed. A sectional view of the high and low frequency wall absorbers is shown in Figure 1. The low frequency absorbers on the ceiling employ a 182 mm air space, giving a total depth of 300 mm.

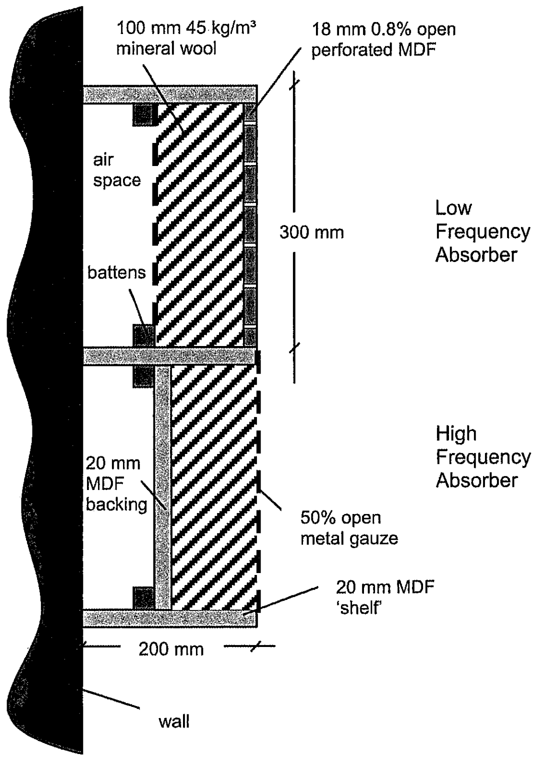

Figure 1 – Section Through Absorbers

Research by Guy[4]T enabled this multi-layer absorber to be modelled analytically; the results were ratified as far a possible by comparison with published experimental data[5] for similar types of absorber. The MatLab program used to model the low frequency absorber calculated values of surface normal acoustic impedance from which the normal and diffuse incidence absorption coefficient was derived. The diffuse field absorption coefficients for the high frequency and low frequency ceiling absorbers is shown in Figure 2.

As will be evident from the Figure 2, the low absorber was designed so that it 'crossed over' with the high frequency absorber, much in the same way a two-way loudspeaker does. It was hoped that the combination of the two would yield a room response that was reasonably frequency independent.

2.4 Distribution of Absorption

The way in which the high and low frequency absorbers were distributed was based on two factors : a Sabine Reverberation Time calculation and the requirement for non-plane room boundaries. The former, though invalid below the Schroeder Frequency (~ 200 Hz in the control room), was used to provide an idea as to the relative surface areas of high and low frequency absorption required. The latter was important for weakening the axial modes within the room, maximising absorption through the so called 'edge effect' and having a proportionally even coverage of both types of absorption throughout the room. The resultant 'chequerboard' distribution will be evident from the BE model that is shown in Figure 3. The initial design used equal surface areas of high and low frequency absorbers.

2.5 Limitations in Analytical Methods

Given the high acoustic specification of the studio control room, there was concern that a simple Sabine calculation, based on a non-existent diffuse field, might give misleading results, particularly at low frequencies. It was decided therefore that, in light of the predicted acoustic impedance data and the resources within the Arup Advanced Technology Group (ATG), a Boundary Element Model of the studio control room should be built. It was hoped that the results from the model would confirm whether or not the bespoke absorption strategy was successful.

3 DETAILED ANALYSIS

3.1 Boundary Element Model

The modelling was carried out by James Hargreaves of ATG, a senior member of the group with considerable experience in numerical modelling. A Boundary Element Model was constructed from the architectural plans and sections and the aforementioned surface normal acoustic impedances of the absorbers and carpet were assigned to the relevant element faces. The BE Model is illustrated in Figure 3. Two spherical sources described the positions of the loudspeaker monitors. A grid of field points formed a horizontal plane at seated head height (1.2 m) and the results at each of these nodes were exported to a text file. The initial frequency range of the analysis was 28 – 350 Hz, though it is intended to extend this to 700 Hz. A MatLab program was used to read the BEM text file and interrogate the results.

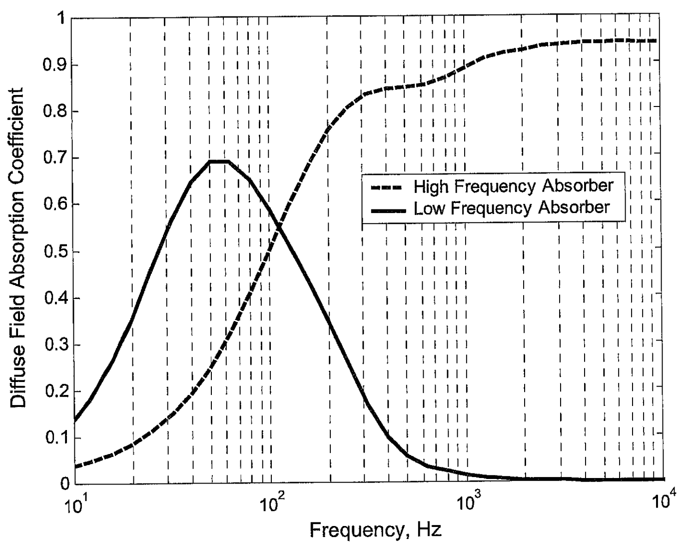

Figure 2 – Predicted Absorption Coefficients for the Absorbers

It was felt that the result would be best presented as a time-energy-frequency waterfall plot at a fixed spatial position and a spatial distribution of pressure in ⅓ octave bands. At the time of writing, the former is not available, so only the latter is presented in this paper.

There was concern, however that unless there was a way of ratifying the BE model, one could not be completely confident of the results. In response to this, a exact 3-D analytical model of a simple rectilinear room was formed.

3.2 Verification of BE Model Through 2-D Analytical Model

The model has the same dimensions as the studio control room, though the walls and ceiling are plane surfaces characterised by the predicted surface normal acoustic impedance of 50 mm thick rigidly backed 45 kg/m³ mineral wool; a predicted impedance is used to describe the carpeted floor. The sound field in the room is described by forward and backward going waves in the three axes

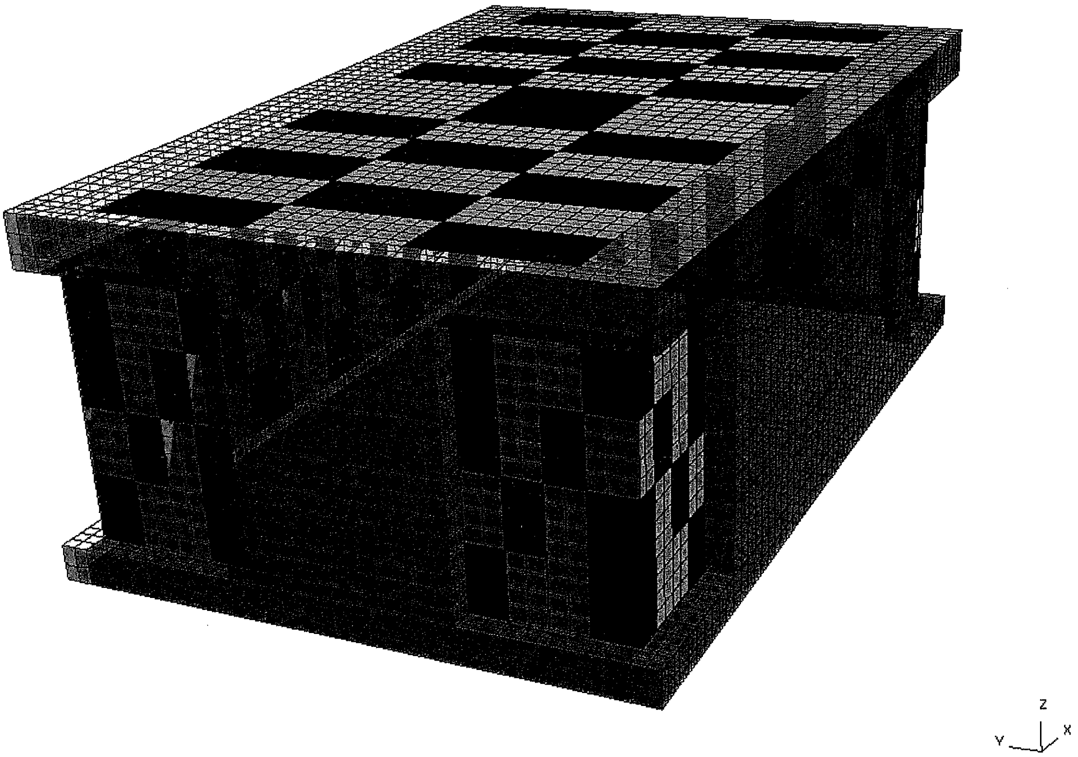

Figure 3 – Boundary Element Model of Studio Control Room

and as a sum of the first eight modes. A Newton-Raphson iteration was used to solve the transcendental equation describing the complex wavenumbers, from which it is possible to calculate the complex pressure at any point in the room, for a given frequency, as a sum of modes. The comparison between the numerical and analytical result is ongoing and as such will not be presented here. Preliminary results suggest, however that this technique is useful in checking the reliability of the results obtained through Boundary Element Analysis.

4 RESULTS

Given the use of the studio control room it is important that the results have a subjective relevance, hence the spatial pressure expressed in ⅓ octave bands. The MatLab program reads the results a node at a time and sums the narrow band results over the ⅓ octave. Once calculated, the results are read into a new matrix and the process repeated for the other field points. The results are expressed using a colour map proportional in size to the control room. Figures 4 – 6 show the results for the 32 Hz, 100 Hz and 250 Hz ⅓ octave bands respectively.

The spatial pressure distribution at 32 Hz shown in Figure 4 clearly illustrates the relationship between the dimensions of the room and the wavelength of sound, as the first natural frequency front to back is evident and there is slight curvature left to right due to the non-rigid room boundary. Even so, the 15 dB difference between node and anti-node suggests this axial mode is well damped.

The ⅓ octave pressure distribution in Figure 5 relates to the forth mode in the left-right axis of the room, though as before the sound field varies very little in amplitude over the majority of the room, with only the extreme corners deviating significantly.

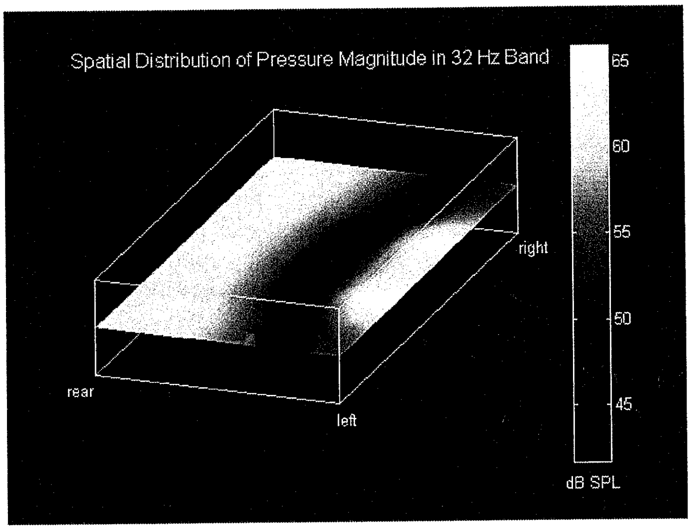

Figure 4 – Spatial Pressure in the 32 Hz ⅓ Octave Band

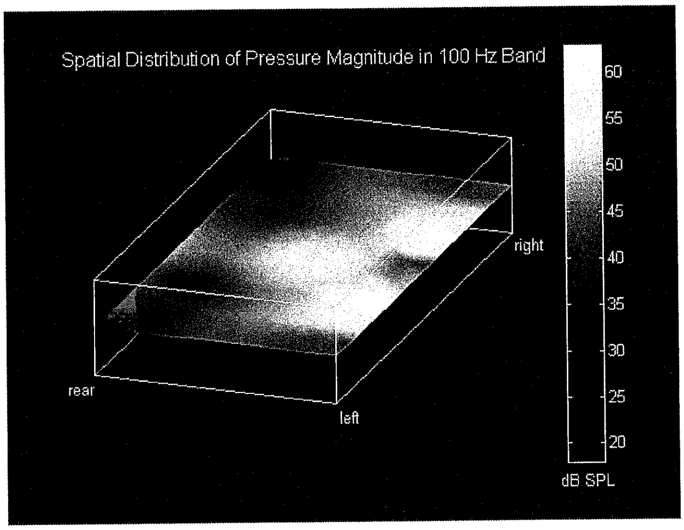

Figure 5 – Spatial Pressure in the 100 Hz ⅓ Octave Band

At the higher frequencies, the sound field appears increasingly diffuse as seen in the 250 Hz ⅓ octave band plot (Figure 6). Maximum variations in pressure in the majority of the space is about 15 dB as with the lower frequencies.

Whilst these representations of the sound field are interesting, there is still a need for results in the time domain. In order to calculate these results, the BE results at two nodes are read from the field point text file and the transfer function between the two calculated. An inverse Fourier Transform is then calculated to give the corresponding impulse response. Through backwards integration of the squared impulse response a broad band decay can be calculated. From this, a narrow band waterfall plot of the decay can be calculated which would complement the spatial representations and give a more complete picture of how successful the studio control room is.

5 SUMMARY

A bespoke design of acoustic absorption has been described, which was designed to provide a high specification monitoring environment. Whilst the absorbers could be optimised with reasonable confidence, using analytical techniques, the resultant room characteristic remained largely unknown, especially at low frequencies. The use of Boundary Element Analysis was employed to provide this information.

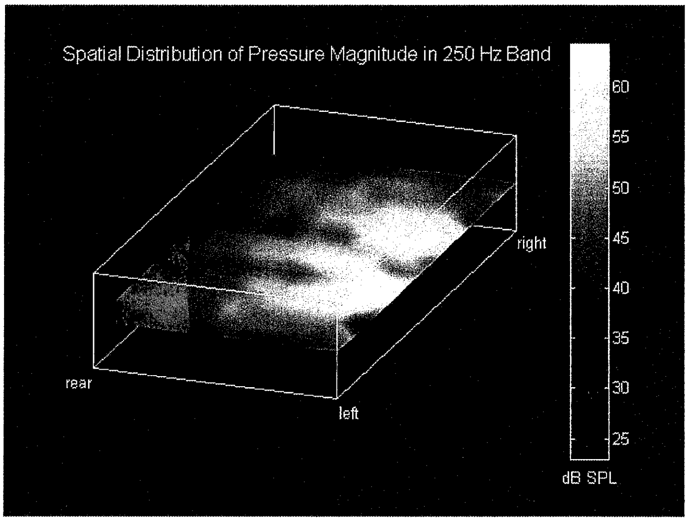

Figure 6 – Spatial Pressure in the 250 Hz ⅓ Octave Band

The results from the BE Model correspond well with predictable low frequency room responses, which suggests that it is a reasonably accurate description of the sound field within the room. The plots of spatial pressure magnitude indicate that the absorbers are performing as expected.

It is difficult however, to draw definite conclusions in the absence of time domain representations of the sound field. Without a knowledge of the decay characteristic, the single most important performance criterion, one is unable to determine the success of the design. In addition, ratification of simple Boundary Element Models is essential if confidence is to be placed in results obtained from more complicated geometries.

This preliminary study, although still a work in progress, describes how an acoustically critical room may be designed and modelled and that model ratified. The use of other programs allows for the results obtained through Boundary Element Analysis to be presented in a variety of different ways, giving an indication of the acoustic performance and informing the design, thus allowing optimisation.

6 REFERENCES

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