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SOUND REFLECTION AT DUCT TERMINATIONS

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INTRODUCTION

It is the practice within the building services industry in the United Kingdom and elsewhere to adopt the approach of the Chartered Institution of Building Services Engineers (CIBSE) when designing environmental systems, and tables of information are published in the Institution's Design Guide (1) to assist the engineer in the achievement of an integrated design. One such table in the Sound Control section gives values of so-called 'end reflection' attenuation of duct borne noise to be used in the design of air distribution systems, the data being presented as functions of frequency and duct outlet area.

Although the provenance of the information contained in this table has not as yet been traced by the present author, it is believed to be based on empirical measurements, possibly those of Levine and Schwinger (2), of the reflection of sound at the open ends of circular cross section ducts, i.e. where the opening is perpendicular to the direction of plane wave propagation. It should be noted that only the reflection of a plane progressive wave is significant in this context, since strong reflection only occurs at low frequency and/or small duct size, i.e. below the cut on frequency of the first cross mode of the duct.

In practice, the assumption that the opening is on the end of the duct is of limited value, since any opening for a grille or diffuser is equally if not more likely to be in the side of the duct as on its end. Also, rectangular section ducts are frequently used in industry, and data obtained from tests on circular ducts may not be directly applicable here. Osborne (3) showed that the behaviour of sound at the end and side opening positions is markedly different but did not attempt to explain the differences, due to the limited amount of data collected. The ASHRAE Guide (4) contains a note concerning the use of its tables for side openings and quotes Sandbakken et al (5) as the source. So far the present author has been unable to obtain a copy of the relevant paper.

EXPERIMENTAL PROCEDURE

The method adopted for the investigation was that of the simple impedance tube, using a B&K Type 4146 12mm microphone fitted with a probe tube inside a 2.4m long section of 200mm x 200mm duct of rigid construction. The free end of the duct had a 200mm x 200mm hole cut in the side, and a hole of similar dimensions at the end, enabling either the side or end opening to be plated over when not under investigation. Both openings were considered to be unflanged.

It should be noted that the configuration used in these tests, with the side opening immediately adjacent to the closed end, is not typical of the majority of outlets in practical systems, which of necessity will be more remote from the duct end; it does however occur frequently enough in practice to justify investigation.

The sound source was the standard B&K Type 4002 standing wave tube loudspeaker, bolted to one end of the duct and excited by a B&K Type 1022 Beat Frequency Oscillator. The microphone was connected to the preamplifier input of a B&K Type 2610 measuring amplifier and was traversed along the duct by means of a simple pulley system.

The cut on frequency of the first cross mode of the duct was about 850 Hz at 20 C. Since end reflection attenuation for this size of duct is only significant up to the 500 Hz octave band, 650 Hz was taken as the upper frequency limit of the tests. Due to the relatively short length of duct, the lower frequency limit was 200 Hz. Pure tone signals were used for all the tests and the open end of the duct radiated into semi reverberant space.

For each of the frequencies used in the tests, a traverse was made along a one metre long section of the duct for both open end and open side configurations. For comparison, a third traverse was made at each frequency with both end and side openings closed.

RESULTS

Figures 1 to 5 show the standing wave patterns of the open ended and open sided duct compared with those for the closed condition for the range of frequencies used. It may be seen that for the lower frequencies the position of the first minimum for the open side occurs at a greater distance from the duct end than that for the open end. As the frequency is increased, the positions of the minima draw closer together until eventually they are reversed, i.e. the first minimum for the open sided duct is now closer to the duct end. At the highest frequency it can be seen that the standing wave pattern for the open sided duct resembles more nearly that for the closed tube than that for the open ended one.

Figure 6 shows the measured reflection coefficients for the two configurations compared with theoretical curves for flanged and unflanged pipes, and interpolated values from the CIBSE Guide. The theoretical curves were evaluated from the simple theory of Kurze (6) which has been shown (3) to agree with that of Levine and Schwinger for frequencies up to about 700 Hz.

Results for the open ended duct agree closely with theory over the selected frequency range, and fall between the theoretical curves for flanged and unflanged pipes, approaching more closely the flanged condition particularly at the higher frequencies. Although the duct had been considered to be unflanged, the presence of a small (40mm) flange for fixing the end plate may have affected the results. Further differences between the theoretical and measured values may be due to the difficulty of evaluating the significant dimension of the rectangular duct in order to compare results with theory derived from tests on circular section ducts.

Results for the open sided duct show no correlation with currently accepted theory. Below about 350 Hz the reflection coefficients are smaller than theory predicts but above this frequency are much larger. It is impossible to determine a predictable pattern from the small amount of data so far available.

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CONCLUSIONS

The measured results of sound pressure reflection coefficient for the open ended duct show good agreement with theory and also with the CIBSE design data. The latter gives slightly lower values, but it is possible that the effect of a terminating grille has been included in this data, which has been shown (3) to give smaller reflection coefficients at low frequency.

When the opening is on the side of the duct currently accepted theory is not applicable. Using data for open ended ducts in this situation could result in sound levels emitted at grilles being underestimated by around 3 dB at the lower frequencies for this size of duct. It is therefore suggested that at present no allowance should be made for end reflection attenuation where grilles are positioned on the side of the duct.

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(5) Sandbakken, M., Pandy, L., Crocker, M.J.
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(6) Kurze, U.
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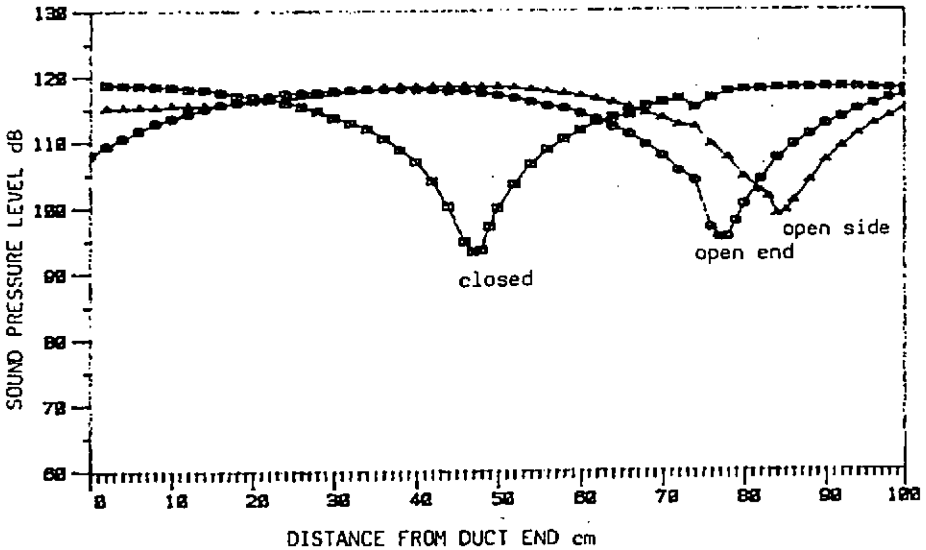

FIGURE 1 : TRAVERSE 200 Hz

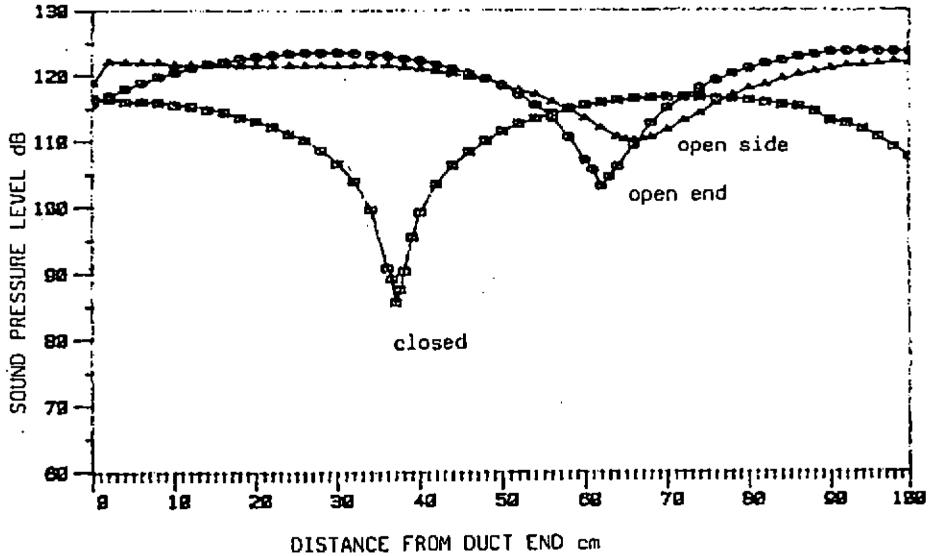

FIGURE 2 : TRAVERSE 250 Hz

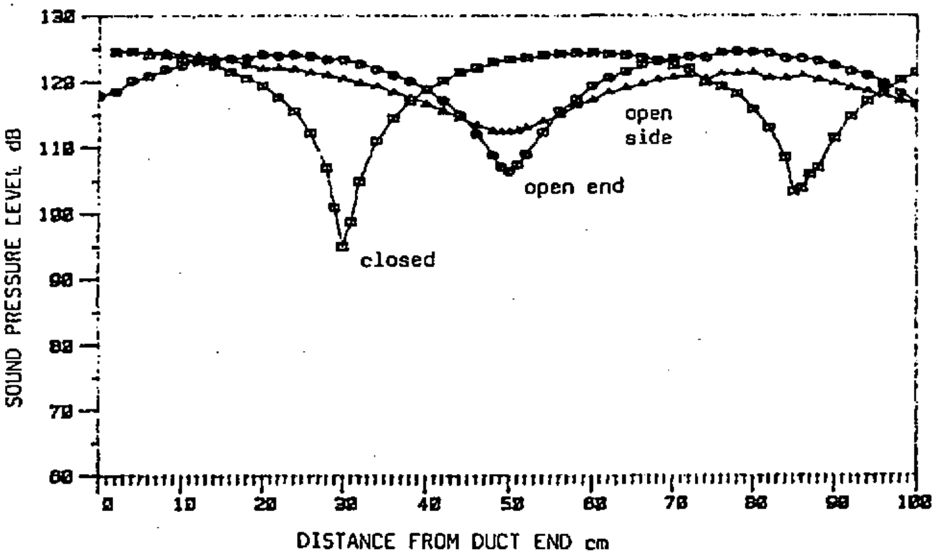

FIGURE 3 : TRAVERSE 300 Hz

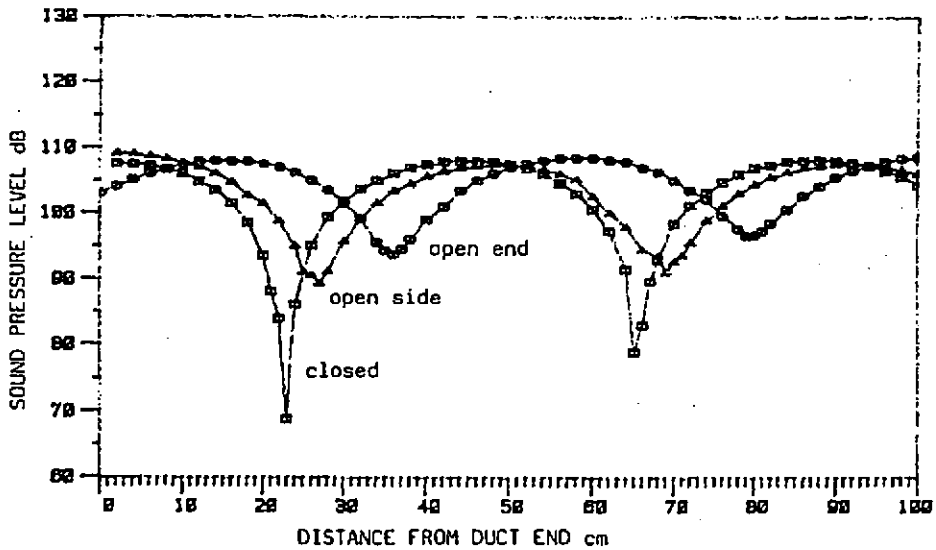

FIGURE 4 : TRAVERSE 400 Hz

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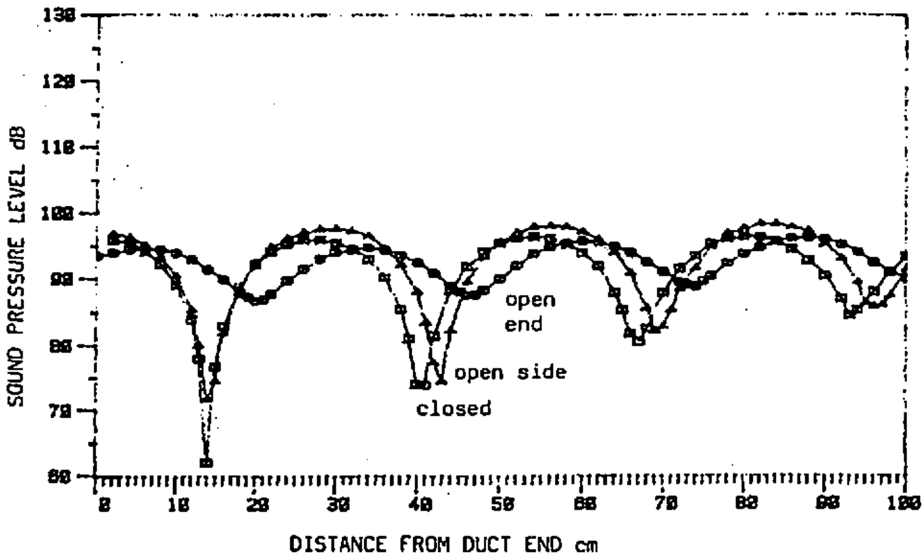

FIGURE 5 : TRAVERSE 650 Hz

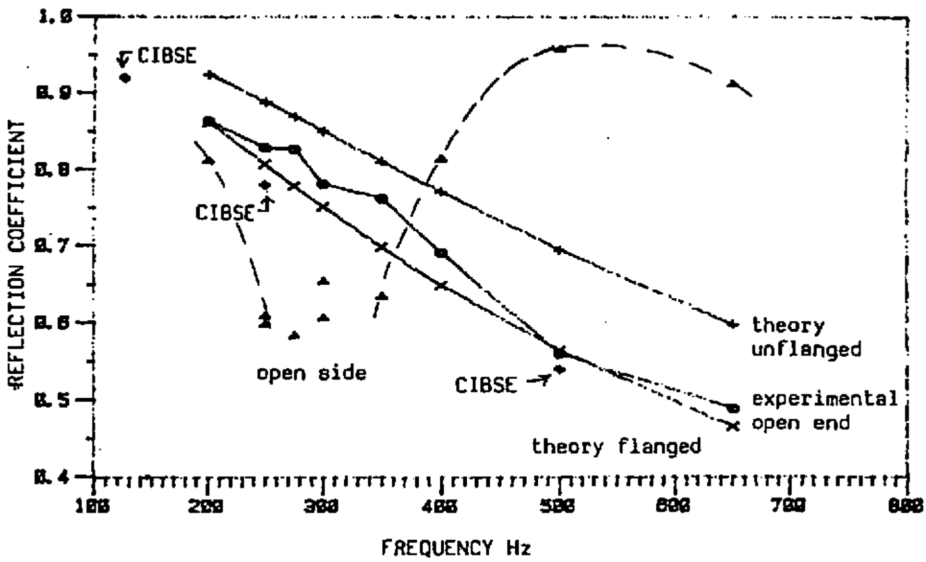

FIGURE 6 : REFLECTION COEFFICIENTS