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GENERALIZED FLOW NOISE PREDICTION CURVES FOR AIR DUCT ELEMENTS

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1. INTRODUCTION

Over a number of years researchers have sought to establish correlation between the drop in static pressure across a flow spoiler and the noise generated [1–4]. In this paper we report on new findings which suggest that a prediction technique based upon the pressure loss characteristics of real duct components may indeed be practicable. Such a prediction technique would be of enormous practical value since there is a paucity of data available relating to the noise generated by ventilation system elements. This paucity arises from the difficulty in obtaining such data as it requires the use of rare and expensive combined acoustic and aerodynamic measurement facilities.

2. THE PREDICTION MODEL

Any discontinuity in a duct carrying airflow, such as a damper or change of geometry, will "spoil" the airflow and result in the generation of localized turbulence. The work required to generate this turbulence is supplied by the prime mover (the system fan) and is manifest as a drop in static pressure across the discontinuity. Some of the turbulent energy is converted into noise and many investigators have been attracted by the vision of a noise prediction technique based upon pressure loss measurements.

The most significant work on relating the airflow generated noise and pressure loss due to an in-duct flow spoiler is that of Nelson and Morfey [5] who first devised a theoretical model for the sound generated by airflow in a low speed duct from consideration of the fluctuating forces acting on simple strip flow spoilers. As it was impossible to predict the fluctuating forces they developed their model by assuming that the fluctuating forces were proportional to the steady state drag forces expressed in terms of the drag coefficient of the spoilers. This parameter can be determined from measurement of the static pressure loss. Nelson and Morfey collapsed the data obtained from measurements made with a number of different spoiler configurations on the basis of their model. For each configuration the data collapse curves showed very little scatter. In principle these data collapse curves could be used in reverse to predict the noise generated by that flow spoiler for a particular flow velocity.

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The curves obtained by Nelson and Morfey for different configurations were similar in form but when plotted together were clearly different. This suggests that a single universal curve applicable to all spoiler configurations may not exist but that individual spoiler configurations may have their own unique curves.

The Nelson and Morfey equations were developed from consideration of the airflow around simple strip spoilers and include two parameters, the open area ratio at the spoiler and the characteristic dimension of the spoiler. For the spoiler configurations that they studied these parameters could be obtained by simple inspection. In later work on airflow generated noise in ducts arising from the presence of inclined dampers and orifice plates, Oldham and Ukpoho [6] attempted to extend the work of Nelson and Morfey to other spoiler configurations. They first re-wrote the Nelson and Morfey equations in terms of the pressure loss coefficient, which is a parameter more commonly used in ventilation system design than the drag coefficient employed by Nelson and Morfey. They then proposed the use of simple empirical methods based upon measurement of the pressure loss coefficient to determine the open area ratio and the characteristic dimension for more complex spoilers. The resulting equations are as follows.

For $f_c < f_0$,

$$120 + 20\log_{10} K(St) = SWL_D - 10\log_{10}[\rho_0 A\sigma^4 C_L^2 U_C^4/16c_0], \qquad (1)$$

and for $f_c > f_0$,

$$120 + 20\log_{10} K(St) = SWL_D - 10\log_{10}[\rho_0 \pi A^2 (St)^2 \sigma^4 C_L^2 U_C^6/24c_0^3 d^2]$$

$$-10\log_{10}[1 + (3\pi c_0/4\omega_c)(a+b)/A], \qquad (2)$$

where SWL_D is the in-duct sound power level, U is the flow velocity, C_L is the pressure loss coefficient, $\sigma = (C_L^{1/2} - 1)/(C_L - 1)$ is the open area ratio, $U_C = U/\sigma$ is the maximum effective velocity, $St = f_c d/U_C$ is the Strouhal number, ρ_0 is the density of air, c_0 is the speed of sound in air, f_c is the centre frequency of the band of frequencies under consideration, ω_c is the angular centre frequency, $K(St)$ is a Strouhal number dependent constant, f_0 is the cut-on frequency of the duct, A is the cross sectional area of the duct, a is the duct height, b is the duct width and $d = [A(1-\sigma)]/b$ is the characteristic dimension.

Oldham and Ukpoho made measurements of the sound power generated by the interaction of airflow and a number of different damper inclinations and orifice plate diameters, and achieved a collapse of data on the basis of the above equations when plotted against Strouhal number. This led them to suggest that these equations could form the basis of a generalized technique for the prediction of airflow generated noise in ventilation systems. However, they cautioned that it was necessary that further work be carried out on more realistic ventilation system components such as bends.

3. NOISE DUE TO THE INTERACTION OF AIRFLOW AND MITRED BENDS

As stated above, the need for a prediction method is the result of the difficulty in obtaining adequate reliable data because of the nature of the experimental facilities required. The authors have been fortunate in obtaining data obtained by W.S. Atkins Noise and Vibration as the result of a comprehensive series of measurements of airflow generated noise on mitred (simple 90°) bends. The experimental techniques employed to obtain this data have been reported elsewhere [7] and involved the use of an anechoic chamber as a large plenum in order to ensure quiet airflow into the duct section containing the test element. The sound power generated by the bends as a function of air velocity in the duct was determined from measurements of the sound pressure level in a calibrated reverberation chamber into which the test section of duct fed. A standard end correction was applied in order to convert the sound power measured in the chamber into the corresponding in-duct sound power level.

Figure 1 shows the in-duct sound power levels measured due to the interaction of airflow in a 600 mm by 600 mm duct with a simple mitred bend. The results show typical characteristics of airflow generated noise in ducts, such as the highest sound power levels at the lower frequencies and a systematic decrease in sound power level with increasing frequency. There is also evidence that the increase in sound power level with velocity is greater at frequencies above the cut-on frequency than below. This is in line with the predictions of the Nelson and Morfey model [of which equations (1) and (2) are derivatives], which predict a fourth power law dependency of sound power on velocity below cut-on and a sixth power law dependency above cut-on.

Figure 2 shows the data of Figure 1 collapsed on the basis of equations (1) and (2). It can be seen that the data sets fall on almost the same curve. This curve could thus be employed as the basis of a technique for predicting the noise due to mitred bends in 600 mm by 600 mm ductwork for flow velocities encompassed by those over which measured data has been obtained, and could probably be safely extended over the range likely to be encountered in practical ventilation systems.

Figure 3 shows the in-duct sound power levels measured due to the interaction of airflow in a 400 mm by 400 mm duct with a simple mitred bend. The results show similar trends to those of Figure 1 although the values differ. Figure 4 shows the data of Figure 3 collapsed on the basis of equations (1) and (2). It can be seen that three of the data sets fall on almost the same curve. It is interesting to note that the aberrant set of data relates to the spectrum recorded with the lowest air velocity, and hence the sound pressure level values recorded are very low. It is possible that this set of data was affected by system noise. Nevertheless, whether or not this data set were to be incorporated, a curve obtained from Figure 4 could still be employed as the basis of an accurate technique for predicting the noise due to mitred bends in 400 mm by 400 mm ductwork.

Figure 5 shows the data for both configurations collapsed on the basis of equations (1) and (2). The spread of the data is very small, which suggests that a curve obtained from this figure could be the basis of an accurate prediction technique for mitred bends in both sizes of duct. It is probable that this prediction method would prove to give acceptable accuracy if employed with different sized square section ductwork, but the limits of its acceptability remain to be proved.

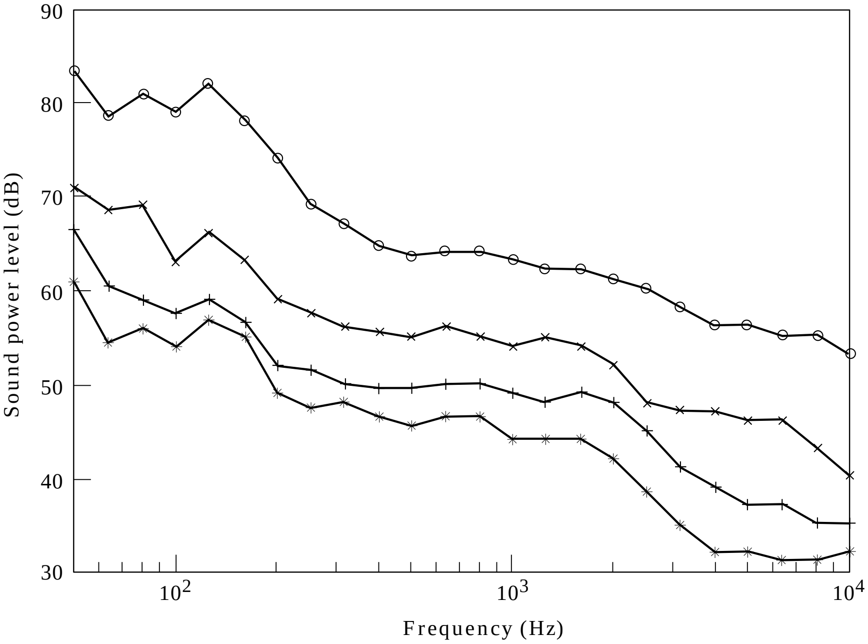

Figure 1. Normalized in-duct sound power levels for 0·6 m × 0·6 m mitred bend without turning vanes. Flow velocities (m s^{-1}): ○, 16·7; ×, 11·8; +, 9·2; $*$, 7·6.

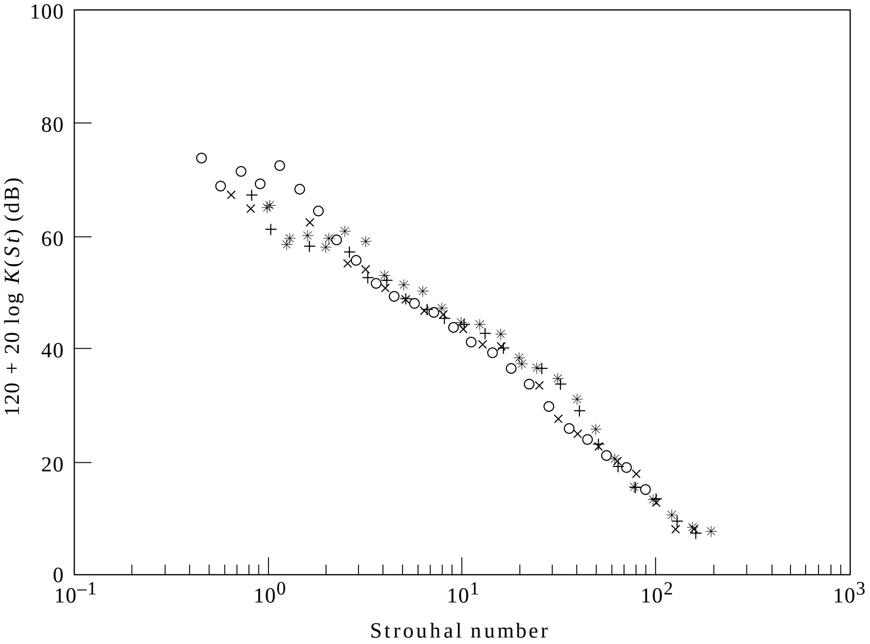

Figure 2. Data of Figure 1 collapsed on the basis of equations (1) and (2).

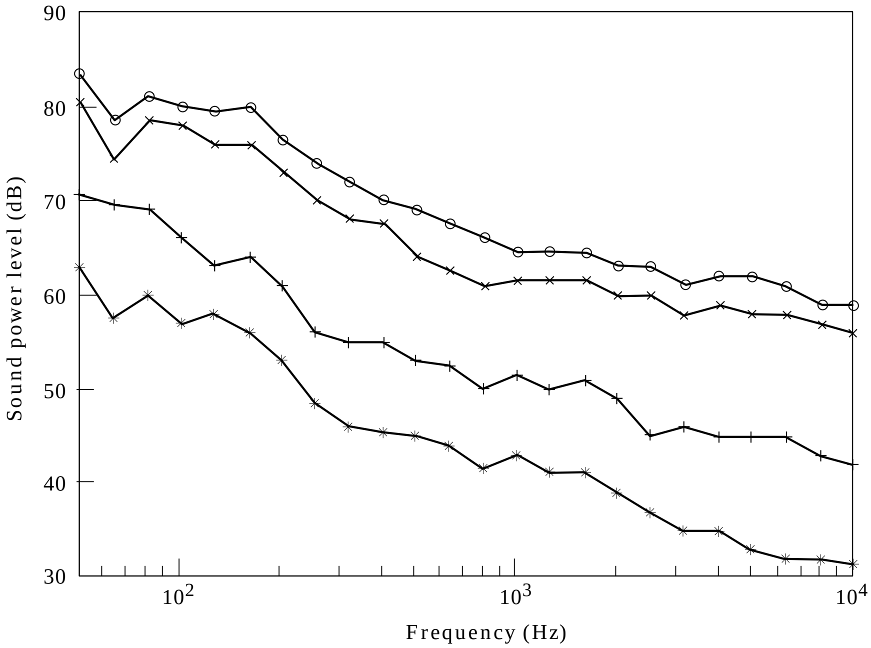

Figure 3. Measured in-duct sound power levels for 0·4 m × 0·4 m simple mitred bend. Flow velocities (m s^{-1}): ○, 22·4; ×, 18·9; +, 12·0; ∗, 7·2.

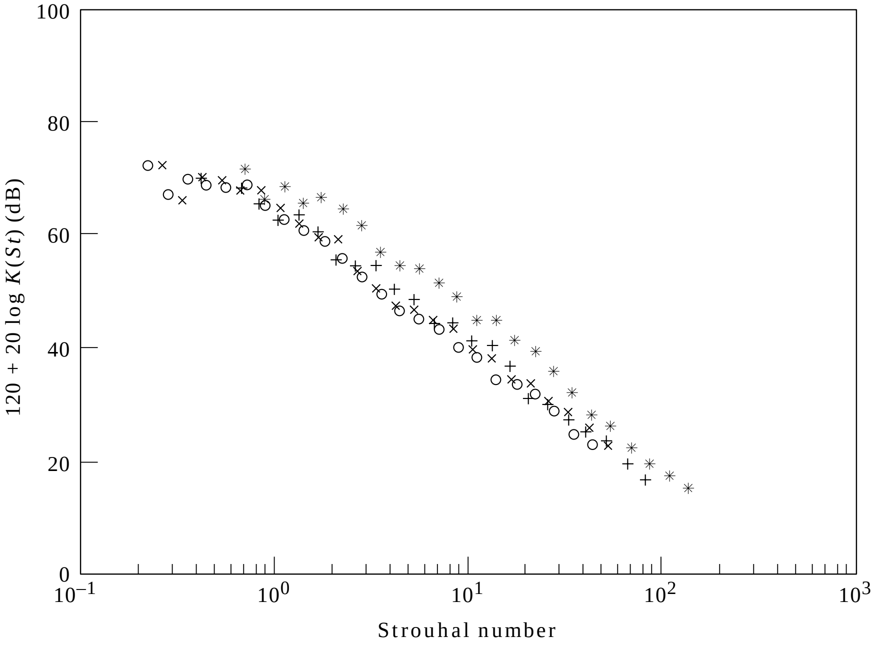

Figure 4. Data of Figure 3 collapsed on the basis of equations (1) and (2).

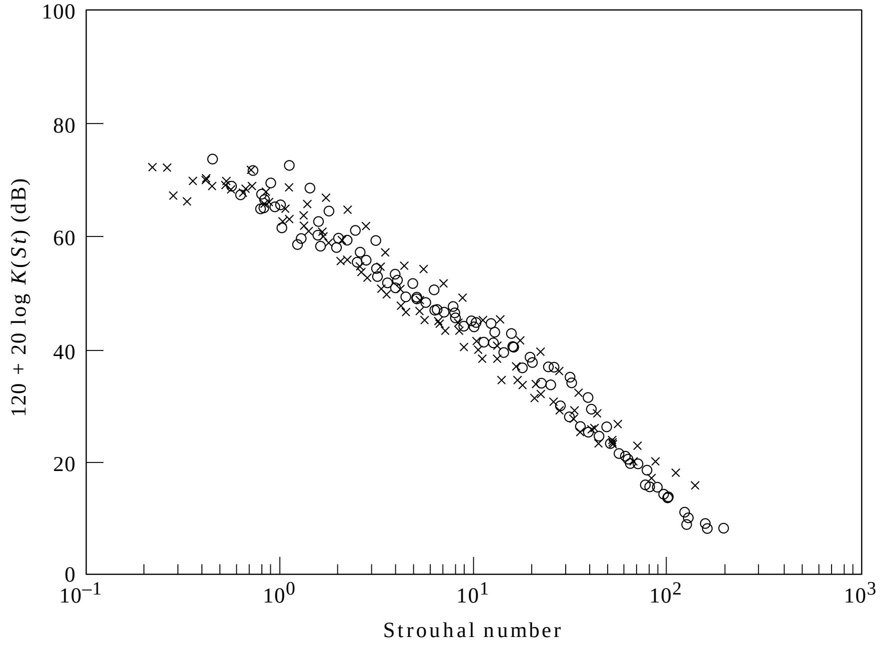

Figure 5. Data for both configurations collapsed on the basis of equations (1) and (2). ○, 0·6 m × 0·6 m bend; ×, 0·4 m × 0·4 m bend.

4. CONCLUSION

Earlier work on devising generalized noise prediction techniques for ventilation system elements based upon simple flow spoiler configurations has been extended to the study of the noise generated by mitred bends. The simple semi-empirical technique proposed by Oldham and Ukpoho has been employed to collapse the experimental data onto a universal curve based upon a modified version of the Nelson and Morfey equations. The resulting curve could form the basis of a technique for predicting the airflow generated noise due to mitred bends in square section ductwork. It is not proven that a single universal curve for the prediction of the airflow generated noise due to any duct component exists, but this work lends support to the theory that a range of component specific curves might exist and provide a means of accurately predicting airflow generated noise in ventilation systems.

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