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The Prediction of Airflow-Generated Noise in Mechanical Ventilation Systems

D.C. Waddington D.J. Oldham

Acoustics Research Unit, School of Architecture and Building Engineering, University of Liverpool, UK

Key Words
Noise · Ventilation systems · Prediction

Abstract
Buildings located in noisy areas require a high degree of sound insulation. This will usually involve making the building envelope virtually airtight, and as a result losing the possibility of utilising natural ventilation. The solution is to employ a mechanical ventilation system, but such systems can themselves constitute a source of intrusive noise. Discontinuities in ducts result in the generation of flow noise and a loss of static pressure. The greater the discontinuity, the greater is the loss in static pressure and the greater is the sound power generated. This paper describes work carried out at the University of Liverpool which is aimed at providing system designers with more accurate methods of predicting noise from airflow generated in mechanical ventilation systems. We show that for a typical duct discontinuity, it is possible to predict the sound power generated from knowledge of its pressure loss characteristics.

Introduction

Buildings located in noisy areas require a high degree of sound insulation. This will usually involve making the building envelope virtually airtight and as a result losing the possibility of utilising natural ventilation. The solution is to employ a mechanical ventilation system, but such systems can themselves constitute a source of intrusive noise. Three sources of noise associated with mechanical ventilation systems can be identified: fan noise, break out noise and flow generated noise. The first noise source is well recognised and the system designer will normally seek to reduce this problem by the use of suitable attenuators at the fan outlet. The other sources are less well understood and the system designer will normally employ simple engineering formulae in an attempt to predict potential problems so that remedial action can be taken. Unfortunately, the engineering formulae employed frequently produce inaccurate results with the consequence that noise problems arise on commissioning the system which can be difficult to overcome. Both noise breakout and flow noise generation are currently the subjects of research carried out in an attempt to overcome the limitations of current design methods. In this paper we describe work carried out at the University of Liverpool which is aimed at providing system designers with more

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Prof. D.J. Oldham
Acoustics Research Unit, School of Architecture and Building Engineering
University of Liverpool
Liverpool L69 3BX (UK)
E-Mail djoldham@liverpool.ac.uk

accurate methods of predicting airflow-generated noise in mechanical ventilation systems.

Airflow-generated noise arises when air travelling along a duct encounters a discontinuity, such as a damper or change of geometry, which disturbs the flow and results in the generation of localised turbulence. The work required to generate this turbulence is manifest as a drop in static pressure across the discontinuity. Some of the turbulence energy is converted into noise, and many investigators have been attracted by the vision of a noise prediction technique based upon pressure loss measurements. 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. Over a number of years, therefore, researchers have sought to establish a 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.

Prediction Model

Nelson and Morfey [5] derived a theoretical model for the sound generated by airflow in a low-speed duct by considering 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 which could be determined from measurement of the static pressure loss. They collapsed the data obtained from a series of measurements made with a number of simple strip 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.

The Nelson and Morfey [5] equations included 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 [5] 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. 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 shown below.

For $f_c < f_o$,

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

and for $f_c > f_o$,

$$120 + 20 \log_{10} K(St) = SWL_D - 10 \log_{10}[\rho_o \pi A^2 (St)^2 \sigma^4 C_L^2 U_C^6 / 24 c_o^3 d^2]$$
$$- 10 \log_{10}[1 + (3\pi c_o / 4\omega_c)(a + b)/A] \qquad (2)$$

where $K(St)$ is a Strouhal-number-dependent constant, Strouhal number

$$St = \frac{f_c d}{U_C},$$

maximum effective velocity

$$U_C = \frac{U}{\sigma},$$

flow velocity U, open area ratio

$$\sigma = \frac{C_L^{1/2} - 1}{C_L - 1},$$

pressure loss coefficient C_L, in-duct sound power level SWL_D, density of air ρ_o, speed of sound in air c_o, centre frequency of the band of frequencies under consideration f_c, angular center frequency ω_c, cut-on frequency of the duct f_o, cross sectional area of the duct A, duct height a, duct width b, and characteristic dimension

$$d = \frac{A(1 - \sigma)}{b}.$$

Oldham and Ukpoho [6] made measurements of the sound power generated by the interaction of the 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 the Strouhal number. This led them to suggest that these equations could form the basis of a generalised 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.

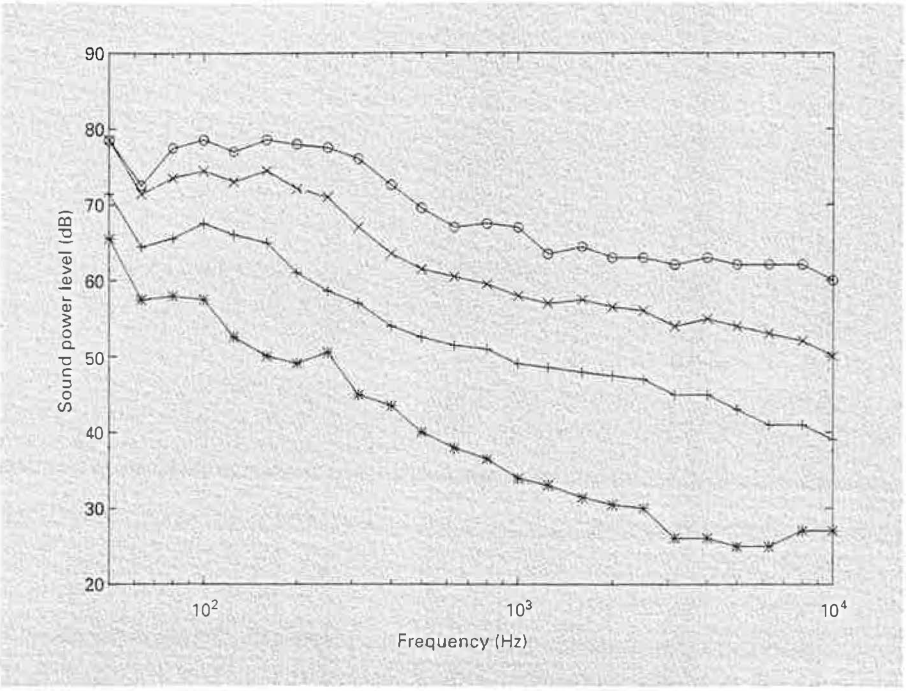

Fig. 1. Measured in-duct sound power levels for 200-mm-diameter circular 90° bend. Flow velocities ($m \cdot s^{-1}$): ○ = 41.9; × = 30.1; + = 20.8; * = 10.7.

Noise due to the Interaction of Airflow and Right-Angled Bends in Circular Ductwork

The need for a prediction method results from the difficulty in obtaining adequate reliable data because of the nature of the experimental facilities required. The authors have been fortunate to obtain data generated by 'W S Atkins Noise and Vibration' (Epsom, UK) as the result of a comprehensive series of measurements of airflow-generated noise on mitred (simple 90°) bends in circular ductwork. 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 the duct fed.

Figure 1 shows the in-duct sound power levels measured due to the interaction of airflow in a 200-mm-diameter duct with a simple right-angled 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.

Figure 3 shows the in-duct sound power levels measured due to the interaction of airflow in a 350-mm-diameter duct with a simple 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 again be seen that the data sets fall on almost the same curve.

Figure 5 shows the in-duct sound power levels measured due to the interaction of airflow in a 600-mm-diameter duct with a simple bend. The results show similar trends to those of figure 1 although the values differ.

Figure 6 shows the data of figure 5 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

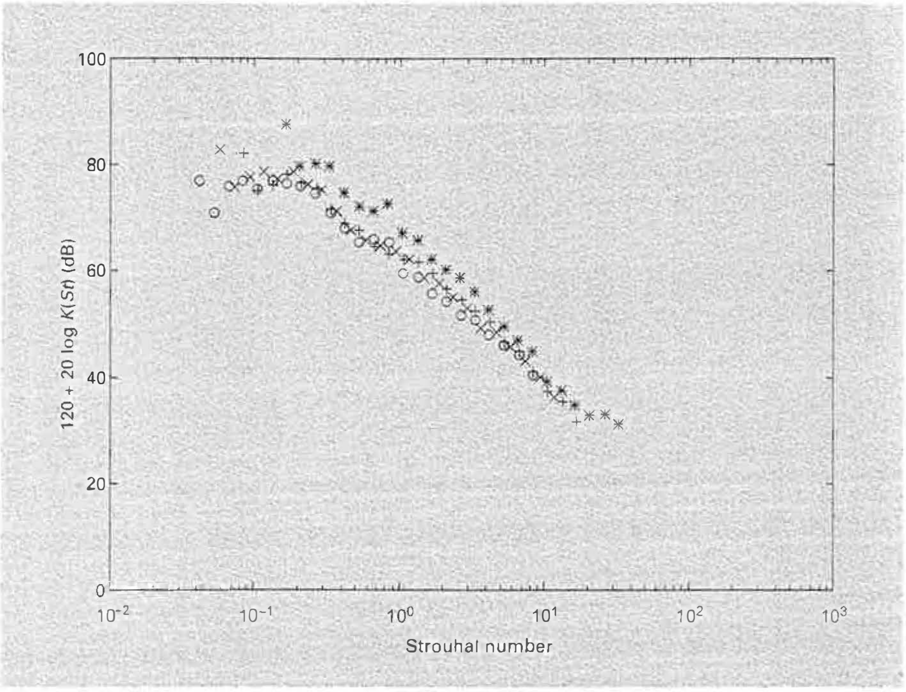

Fig. 2. Normalised in-duct sound power levels for 200-mm-diameter circular bend. Flow velocities (m·s^{-1}): ○ = 41.9; × = 30.1; + = 20.8; * = 10.7.

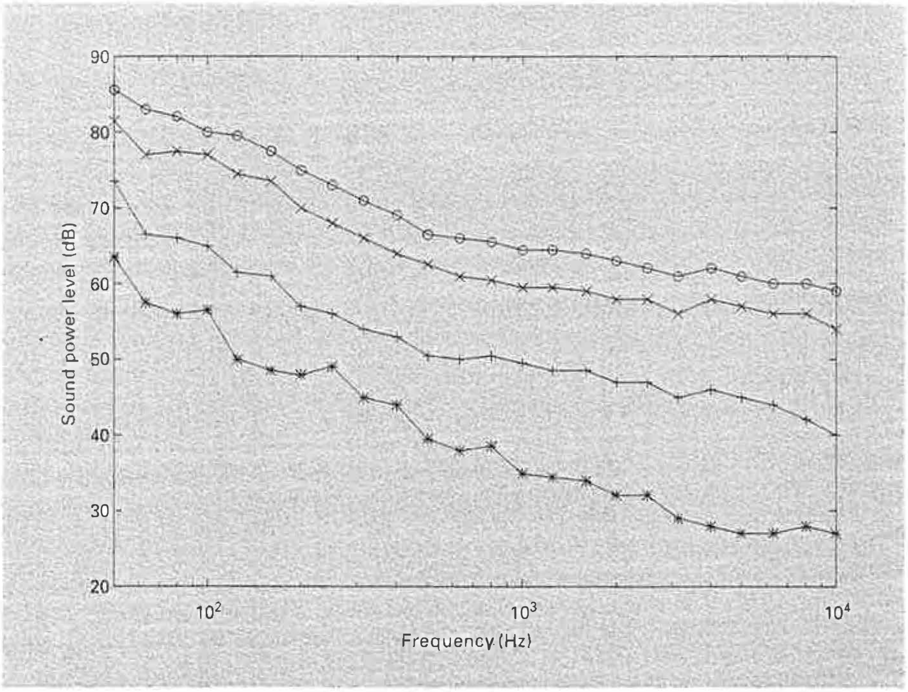

Fig. 3. Measured in-duct sound power levels for 350-mm-diameter circular 90° bend. Flow velocities (m·s^{-1}): ○ = 35.3; × = 30.0; + = 20.3; * = 10.5.

that this set of data was affected by system noise. Nevertheless, whether or not this data set is included, a curve obtained from figure 6 could still be employed as the basis of an accurate technique for predicting the noise due to right-angled bends in 600-mm-diameter ductwork.

Figure 7 shows the data for all three 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 right-angled bends in all three sizes of

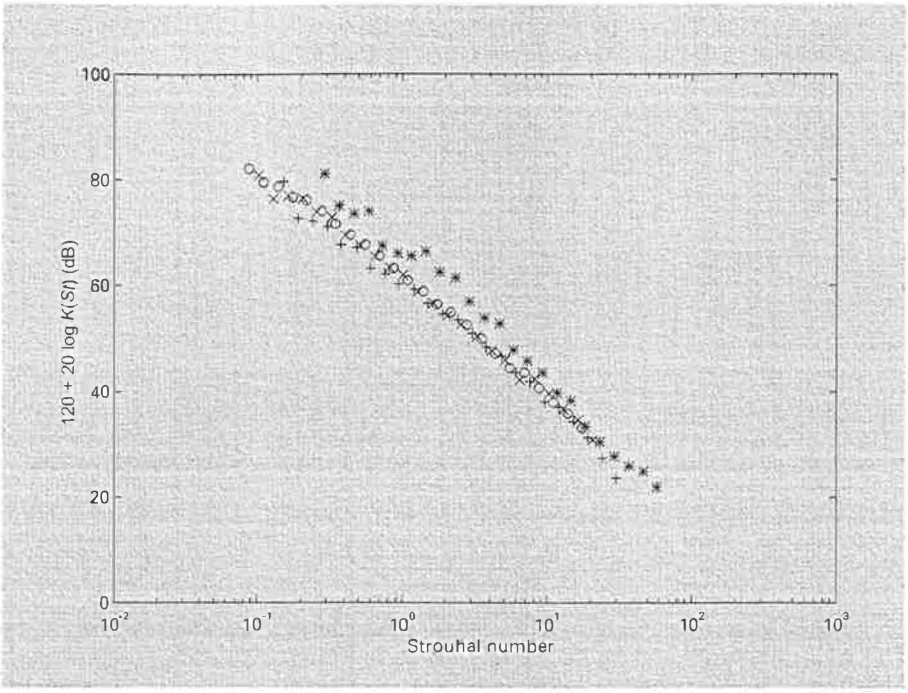

Fig. 4. Normalised in-duct sound power levels for 350-mm-diameter circular bend. Flow velocities ($m \cdot s^{-1}$): ○ = 35.3; × = 30.0; + = 20.3; * = 10.5.

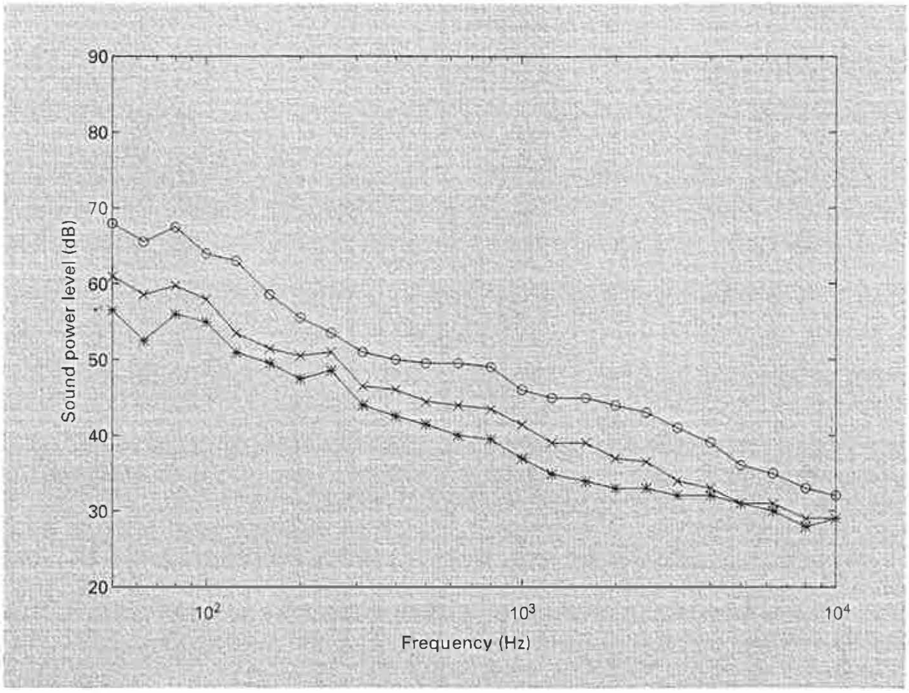

Fig. 5. Measured in-duct sound power levels for 600-mm-diameter circular 90° bend. Flow velocities ($m \cdot s^{-1}$): ○ = 14.5; × = 11.2; * = 7.3.

duct. It is probable that this prediction method would prove to give acceptable accuracy if employed with different-sized circular section ductwork, but the limits of its acceptability remain to be proved.

Conclusion

Earlier work on devising generalised noise prediction techniques for ventilation system elements based upon simple flow spoiler configurations has been extended to

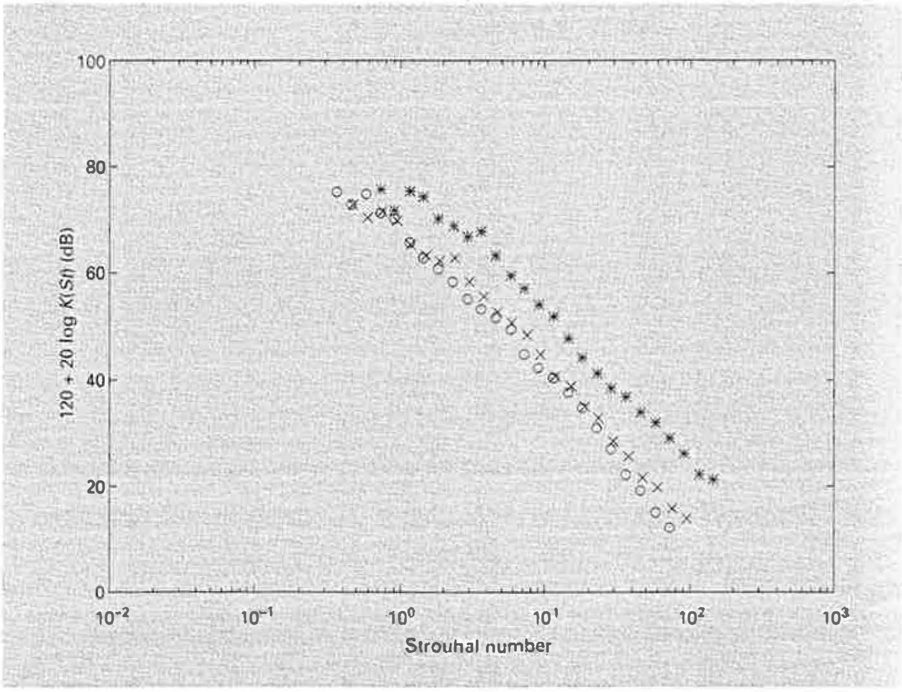

Fig. 6. Normalised in-duct sound power levels for 600-mm-diameter circular bend. Flow velocities ($m \cdot s^{-1}$): ○ = 14.5; × = 11.2; * = 7.3.

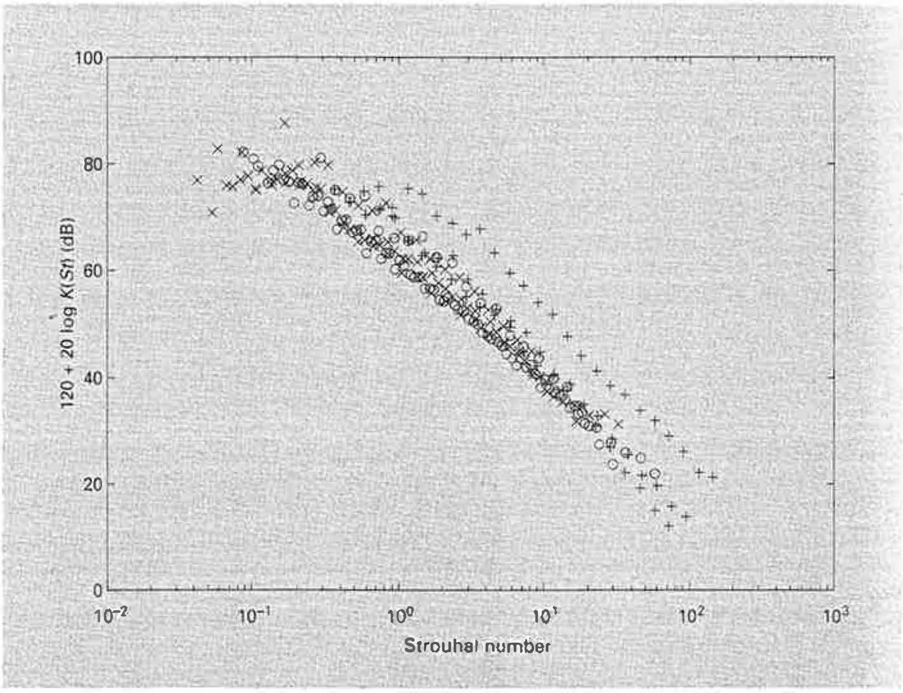

Fig. 7. Collapse of all normalised data: 200-mm-diameter bend (○), 350-mm-diameter bend (×), 600-mm-diameter bend (+).

the study of the noise generated by right-angled bends in circular ductwork. The simple semi-empirical technique proposed by Oldham and Ukpoho [6] 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 right-angled bends in circular ductwork. It is suggested that a single universal curve for the prediction of the airflow-generated noise due to any duct component does not exist, but that a range of component-specific curves may exist and provide a means of accurately predicting airflow-generated noise in ventilation systems.

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