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Technical note

Generalized flow-generated noise prediction method for multiple elements in air ducts

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ABSTRACT

Unavoidable discontinuities due to in-duct elements in a ventilation ductwork system result in the generation of localized turbulence. Some of the turbulence energy is converted into noise. The flow-generated noise problem caused by in-duct elements is due to the complicated acoustic and turbulent interactions of multiple in-duct flow noise sources. Prediction of the flow-generated noise at the design stage is important in engineering, since it is almost impossible to solve the problem after the installation of a ventilation ductwork system. The measurement and computational fluid dynamics simulation can provide an accurate prediction but are expensive in terms of resources. There is an urgent need for developing a practical prediction method for the flow-generated noise in air ducts. Current design guides only provide a prediction method for aerodynamic sound produced by a single in-duct element in the ventilation system, which is usually not in accord with actual systems. An interaction factor β_m is therefore proposed to take account of the interaction effects of multiple in-duct elements. Experimental measurements were conducted to verify the proposed prediction results. The predicted results show an acceptable agreement with the measurements. The proposed method provides engineers a practical generalized technique for predicting noise produced by multiple in-duct elements.

1. Introduction

Ventilation ductwork system is the essential component in modern buildings to maintain good indoor environment quality. Some unavoidable in-duct elements, such as dampers, sensors, bends, transition pieces, duct corners, branch points or even attenuators will make the air duct become discontinuities. The discontinuities in the air duct will influence the airflow and result in the generation of localized turbulent as the ventilation system begins to operate [1–3]. The interaction between the turbulent airflow and the discontinuities in air duct will lead to the generation of noise, which causes many problems to engineers since it is almost impossible to solve the problem after the installation of the ventilation system [4,5]. It is therefore that the prediction of the flow-generated noise at the design stage is significant in engineering. Accurate determination of the flow-generated noise in the ventilation system can be obtained by measurement. However, some specially combined acoustic and aerodynamic experimental facilities are needed in the measurement [6]. An alternative to the measurement is using computational fluid dynamics (CFD) software packages. CFD is a powerful design tool that could provide an accurate prediction of the fluid flow regimes in the ventilation system [7–9]. However, complex simulation conditions should be taken into consideration in the application of the CFD simulation, which are still a challenge for engineering applications. Besides, time-consuming is an anther obvious drawback of both the measurement and CFD simulation. A simple, rapid and convenient method to obtain an approximate level of the flow-generated noise in ventilation ductwork system is desired in engineers' daily practical cases.

One of the fundamental work with respect to the flow-generated noise prediction was proposed by Nelson and Morfey [10]. Oldham and Ukpoho [11] developed the Nelson and Morfey equations in terms of more commonly used parameters in ventilation system design. Later, Waddington and Oldham [12] suggested a technical prediction method based upon the pressure loss characteristics of real duct components, which was adopted in the CIBSE Guide. Kårekull et al. [6] presented a general prediction method for in-duct orifice geometries of high pressure loss by assuming a momentum flux of the dipole force. However, these works only provide the prediction methods for aerodynamic sound produced by an isolated in-duct element in the ventilation ductwork system. It is only applicable to an isolated component, which is different from practical systems consisted of multiple components. It is therefore that Mak and his co-investigators established a prediction method of the flow-generated noise produced by multiple in-duct elements based on the theory of Nelson and Morfey [13–16]. The

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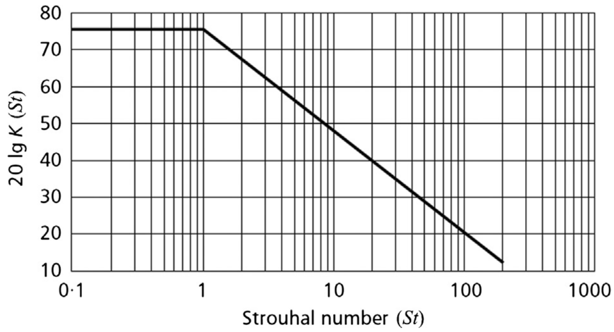

Fig. 1. Determination of term $20\lg(K(St))$ from Strouhal number [17].

interaction effects of the flow-noise sources in the ventilation ductwork were taken into considerations in their method. However, their method seems to be more theoretical rather than practical and has not yet become a practical method in engineering applications.

Current design guides, the CIBSE Guide and the ASHRAE Handbook, only provide a prediction method for the flow-generated noise produced by a single in-duct element in a ventilation system [17,18]. The CIBSE Guide is the current design guide adopted in UK and Hong Kong. It is therefore that this paper proposes a practical generalized prediction method for the flow-generated noise produced by multiple in-duct elements based on the CIBSE Guide as well as the works of Mak and his co-investigators. An interaction factor β_m is introduced to the prediction equations of CIBSE Guide to take account of the interaction effects of multiple in-duct elements. To verify the results predicted by the proposed prediction method, the experimental measurements were conducted. The prediction results show an acceptable agreement with the measurements. The proposed method provides a practical generalized technique for predicting noise produced by multiple in-duct elements and it is a significant improvement to the current design guides for the design of a ventilation system.

2. Generalized prediction method for flow-generated noise

2.1. CIBSE Guide for a single in-duct element

For the sake of completeness, a brief description of the prediction method in the CIBSE Guide B4 is presented here. Two prediction equations for the flow-generated noise produced by a single in-duct spoiler are given in the CIBSE Guide B4 to determine the sound power level L_W in respect of different frequency ranges (below and above the "cut-on" frequency f_c of the duct). The cut-on frequency f_c, which is only decided by the geometries of the duct as $f_c = c/2l$ for rectangular ductwork or $f_c = 1.841c/2\pi r$ for circular ductwork (where c is the velocity of sound, l is the longest sectional dimension of the rectangular ductwork and r is the radius of the circular one), determines the wave

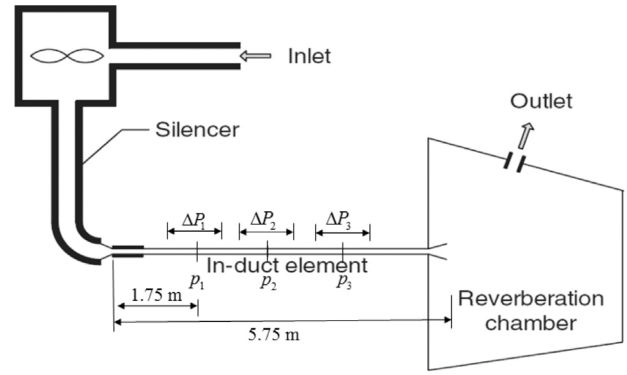

Fig. 3. Schematic diagram of the experimental test rig (ΔP with subscript represents the static pressure drop across the in-duct element).

propagation modes through the duct. According to the CIBSE Guide B4, the equations for the sound power level L_W are given as [17]:

For $f_0 < f_c$ (below the cut-on frequency).

$$L_W = -37 + 20\lg(K(St)) + 20\lg\zeta + 10\lg A + 40\lg u \tag{1}$$

And for $f_0 > f_c$ (above the cut-on frequency).

$$L_W = -84 + 20\lg(K(St)) + 20\lg(St) + 10\lg\zeta - 40\lg\sigma + 10\lg A + 60\lg u \tag{2}$$

where f_0 represents the octave band center frequency, A is the cross-sectional area of the duct, u is the air velocity in the duct, ζ is the pressure loss factor, $\sigma = (\zeta^{1/2}-1)/(\zeta-1)$ is the clear area ratio, and $K(St)$ is an experimentally determined factor related to the Strouhal number $St = af_c\sigma(1-\sigma)/u$ (a represents duct height or duct diameter). Fig. 1 illustrates the determination of term $20\lg(K(St))$ from Strouhal number. The $20\lg(K(St))$ can be obtained once the Strouhal number is derived. It should be noted that pressure loss factor ζ could be gained according to the CIBSE Guide C for a particular element [19] or the expression of $\zeta = \Delta P/0.5\rho u^2$ (ΔP is the static pressure drop due to the component, ρ is the density of air) [20].

2.2. Generic formulae for multiple in-duct elements

The flow-generated noise problem caused by in-duct elements is due to the complicated acoustic and turbulent interactions of multiple in-duct flow noise sources. The interaction effects of flow-noise sources in the ventilation ductwork are taken into consideration by introducing an interaction factor β_m to the prediction equations given in the CIBSE Guide B4. The sound power generated by a single in-duct element could be obtained according to Eq. (1) (for $f_0 < f_c$) and Eq. (2) (for $f_0 > f_c$) in respect of different frequency ranges. For the sound power generated by multiple in-duct element, a simple relationship between the sound power level due to multiple elements and that due to a single element is

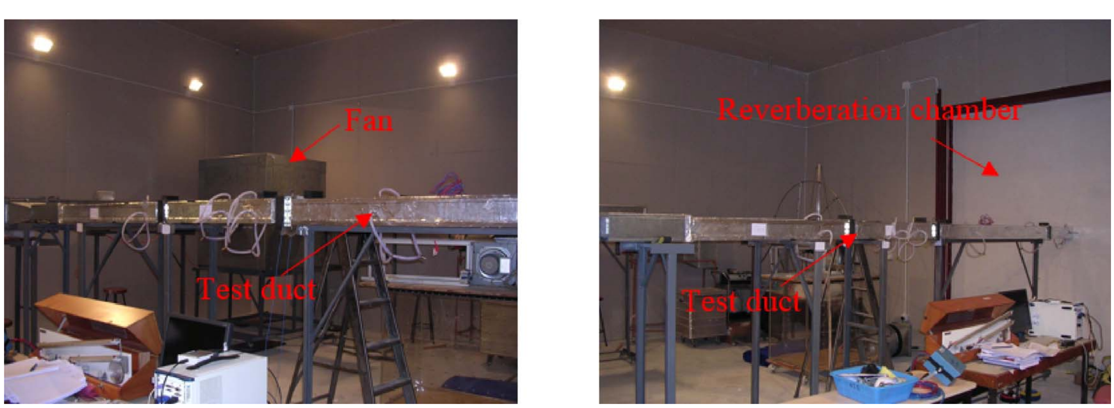

Fig. 2. Experimental test rig photography.