Proceedings of the Institute of Acoustics

REGENERATED NOISE LEVELS DUE TO CLOSELY SPACED DUCT ELEMENTS

A.U. Ukpoho(1) and D.J. Oldham(2)
(1) Department of Mechanical Engineering, Calabar College of Technology, Nigeria.
(2) School of Architecture and Building Engineering, University of Liverpool, UK.

1. INTRODUCTION

In recent years the trend in ventilation system design has been towards high velocity systems. High velocity systems have certain advantages over low velocity systems including economy of space utilisation, the ability to follow complex shapes (and therefore to be integrated into a building design) and small energy losses when carrying warm air. Their principle disadvantage is that they can cause noise problems in ventilated spaces. This noise is caused by the interaction of the air flow with duct discontinuities and the noise generated is generally reckoned to increase by 15-18 dB per doubling of air velocity.

This phenomenon is termed regenerated noise as the noise is generated on the quiet side of the primary attenuators of the ventilation system. The standard technique for predicting regenerated noise due to air duct elements that is to be found in the Handbook of the American Society of Heating, Refrigeration and Air Conditioning Engineers [1]) and Part B12 of the British CIBSE Guide [2] seriously underestimates the levels of regenerated noise likely to be encountered in practical systems. Both design guides, however, recognise this fact and warn the designer against placing too much reliance on the design methods contained within them. The ASHRAE publication states that the most probable cause of differences between predicted and actual noise levels is the interaction of closely spaced duct elements.

The designer is thus faced with a prediction technique which appears to be applicable only to the most unnatural of situations, i.e. long straight duct runs between each element. It can be argued that a predictive technique which consistently underestimtes the level of air flow generated noise is worse than useless. The aim of the work described in this paper was to investigate the interaction between simple duct elements in high velocity systems with a view to obtaining some quantitative data.

2. THE SOUND POWER LEVEL GENERATED BY IN DUCT FLOW SPOILERS

Flow induced noise in ducts is the result of fluctuating forces due to turbulence acting upon surfaces inside that duct. A flow spoiler in a duct causes a drop in static pressure between a point upstream of the spoiler and a point downstream. The system fan has to provide power to overcome this loss in static pressure. The fan power consumed in the vicinity of the spoiler is converted into the kinetic energy of the turbulence field. The majority of the kinetic energy of the turbulence field is dissipated by viscous effects over a fairly short distance but a small fraction is converted into acoustic energy that can propagate efficiently down the duct.

The power balance equation relating the static pressure loss, ΔP, to the mean square turbulence velocity, V_{ms}, (assuming the fraction of energy converted to sound is relativity small) is:

$$\Delta PUA = 0.5 \rho_0 V_{ms} UA \tag{1}$$

where U is the mean duct flow velocity
and A is the duct cross sectional area

A parameter termed the pressure loss coefficient, C_L, is usually employed to quantify the aerodynamic performance of an in duct element where

$$C_L = \Delta P / 0.5 \rho_0 U^2 \tag{2}$$

Thus

$$C_L = V_{ms}/U^2 \tag{3}$$

The turbulence intensity, T, is the ratio of the rms velocity of an air stream to the d.c. velocity. Therefore:

$$T = C_L^{0.5} \tag{4}$$

Because of viscous effects the turbulence intensity decreases over a short distance from its initial high value to a value similar to that associated with a free stream .

A number of attempts have been made to devise methods of predicting the noise generated by the interaction of air flow with in duct spoiler with a view to devising predictive methods for use by ventilation system designers. Noise production by in-duct flow spoilers has been studied in a series of experiments by Gordon [3,4]. The basis of Gordon's model was that the sound power radiated can be related to the total fluctuating drag force acting on the spoiler.

REGENERATED NOISE

Recently Nelson and Morfey [5] have extended the work of Gordon and have obtained two expressions for the sound power generated by an in-duct spoiler, one corresponding to frequencies below the duct cut on frequency, fo, and one corresponding to frequencies above the duct cut on frequency.

Nelson and Morfey state that the scaling laws can be expressed in terms of easily determined engineering parameters together with the single Strouhal number dependent constant K(ST) which contains the information regarding the spectral content of the noise. In devising their equations, Nelson and Morfey assumed that the fluctuating drag force acting on their test spoilers was in direct proportion to the steady state drag force. This is the same assumption as used by Gordon. The collapse of the experimental data into a generalised spectrum was achieved by the evaluation of a constant of proportionality (KSt) between the fluctuating and steady state drag forces.

The authors have extended the work of Nelson and Morfey so that it can be applied to spoiler configurations other than the simple idealised ones with which they worked to yield the following equations[6]:

for $f_c < f_0$,

$$120 + 20 \log K(St) = SWL_D - 10\log_{10}[\rho_0 A \sigma^4 C_L^2 U_c^4 / 16 c_0]; \qquad (5)$$

for $f_c > f_0$,

$$120 + 20 \log K(St) = SWL_D - 10 \log_{10}[\rho_0 \pi A^2 (ST)^2 \sigma^4 C_L^2 U_c^6 / 24 c_0^3 d^2] - 10 \log [1 + 3c_0 / 8 r f_c]. \qquad (6)$$

Here $d = \pi r(1-\sigma)/2$ and $St = f_c \pi r(1-\sigma)/2U_r$.

In devising their theory, Nelson and Morfey assumed that the spectral content of the flow induced noise is related to the spectral content of the turbulence field resulting from the action of the flow spoiler. If the air flow immediately upstream of the spoiler already has a significant degree of turbulence then it is to be expected that the spectral content of the turbulence at the downstream element will differ from that in smoother upstream flow conditions.

In the simple interaction model assumed in this work the turbulence intensity at the downstream spoiler is determined by the turbulence generated at that spoiler plus turbulence generated at the upstream spoiler. The latter will have been attenuated over the distance between the two spoilers. In terms of equations (5) and (6), the effect of the enhanced stream pre-turbulence will be to modify the value of K(St) such that this parameter will no longer be only a function of Strouhal number but also of factors which determine the decay of turbulence such as duct dimensions and the separation distance between the two elements.

3. EXPERIMENTAL INVESTIGATION OF NOISE GENERATED BY A SINGLE SPOILER

A schematic diagram of the apparatus employed is shown in Fig. 1. An unusual feature of the experimental arrangement was the use of a large anechoic chamber as a plenum to reduce the fan noise. The ductwork employed had an internal diameter of 300 mm and was made from thick walled high density polypropylene in order to minimise the problems of duct noise break out.

The in-duct element selected for this investigation was a simple damper. This element has the advantage of enabling an almost infinite variety of configurations to be studied very simply.

In order to ensure that the sound generated in the ductwork was efficiently radiated into the reverberant chamber used for the measurements the ductwork was terminated by a large exponential horn. The sound power level generated by the various damper configurations was calculated using standard methods from the measured reverberant field sound pressure level in the reverberation chamber and the relevant parameters of the chamber. The mean velocity of the air within the duct was measured using a pressure transducer which reads the drop in static pressure over a length of ductwork. The pressure transducer was calibrated against the readings obtained from a pitot static tube which was used to measure the velocity profile of air in the duct. A pitot static tube was also used to calibrate a pressure transducer which was used to measure the drop in static pressure across the damper.

The output of the pressure transducer was measured using a digital voltmeter equipped with an IEEE 488 Bus. The reverberant sound pressure level was measured using a B&K Type 2131 Digital Frequency Analyser. This unit is also equipped with an IEEE 488 bus. Both instruments were connected to a microcomputer. This enabled the very rapid acquisition of data.

The experimental data obtained from a variety of damper settings was collapsed using equations 5-6 and plotted on the curves of Nelson and Morfey. The experimental results were found to lie along the curves[6], but although Nelson and Morfey have claimed that these curves could form the basis of a generalised prediction technique there is a considerable degree of scatter between them (in excess of 10 dB). There is, however, sufficient consistency between the results obtained in this work for a single damper setting for curves obtained from these data to be used as the basis of a single damper regenerated noise prediction method for use in the next part of the work. (See Figure 3).

4. THE INTERACTION OF DUCT ELEMENTS

The experimental arrangement employed was similar to that described above, but two dampers were employed. An upstream damper in the air stream generated turbulence plus noise and the turbulent air flow impinged on a downstream damper. Two spoiler separation distances were investigated, 1.5 and 3 m. It was believed that positioning the two dampers closer together would have resulted in them effectively acting as only one element.

Figure 4 shows some examples of the difference between the measured and predicted values for 1.5m and 3m separation. The net sound power level generated compared to those predicted for the individual elementstypically increased with the pressure loss coefficient of the upstream spoiler (i.e. the level of upstream turbulence) although the increase is smaller (or the sound power level actually decreased) at around 500-1000 Hz.

The reason for this is not yet understood but it is possible that sound from the upstream spoiler is being absorbed in the region of very high turbulence in the neighbourhood of the downstream spoiler. Another possible explanation is that part of the turbulence spectrum due to the first spoiler having a frequency comparable to that of the duct cut on frequency is more efficiently converted into acoustic radiation than other components of the turbulence field thus resulting in a more rapid decrease in turbulence with distance for this frequency. As a result there is no additional turbulence in this frequency range to add to that generated by the second spoiler.

Finally, it is known that the injection of an acoustic signal into a unstable region of flow can sometimes reduce the instability [7]. It is possible that a similar effect is being observed in the region of the downstream spoiler.

The increase in regenerated sound power level is particularly marked at approximately 250 Hz for a spoiler separation of 1.5 m and at 125 Hz for a separation of 3 m. It is believed that this is due to a resonance effect as the separation distance in each case is approximately equal to the wavelength of sound in air at these frequencies.

5. CONCLUSIONS

At the present time only qualitative (or semi-quantitative) results have been obtained from this part of the project. However, the following general conclusions can be drawn:

1. The overall level of regenerated noise does increase when two duct elements are closely spaced above that due to the two elements in relative isolation.

2. The increase in regenerated sound power level is frequency dependent. The effect is enhanced at frequencies for which the acoustic wavelength is similar to the element separation distance. The effect is suppressed for frequencies for which the acoustic wavelength is equal to or twice the duct diameter.

3. The magnitude of the increase in the regenerated sound power level is a function of the pressure loss coefficient of the upstream element.

6. REFERENCES

[1] ASHRAE Directory (Systems Volume).
[2] CIBSE Guide, B12.
[3] C.G. GORDON, Spoiler generated flow noise - I: the experiment, J.A.S.A., 43, 1041-1048 (1968).
[4] C.G. GORDON, Spoiler generated flow noise - II: the results, J.A.S.A., 45, 214-223 (1969).
[5] P.A. NELSON & C.L. MORFEY, Aerodynamic sound production in low speed flow ducts, J. Sound Vib., 79, 263-289 (1981).
[6] D.J. OLDHAM & A.U. UKPOHO, 'A pressure based technique for predicting regenerated noise levels in ventilation systems', J Sound Vib, 140 p259 (1990)
[7] J.E. FOWCS-WILLIAMS, Active control of unsteady flow, Proc. Internoise 87, Beijing, 7-12, (1987).

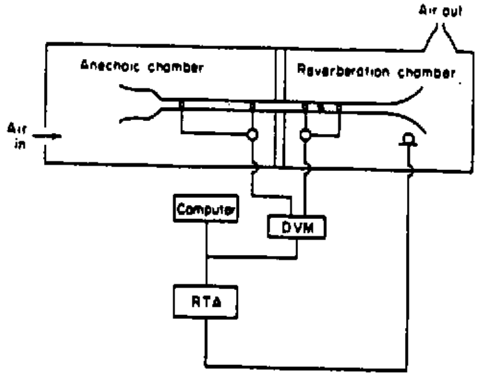


Figure 1 Apparatus

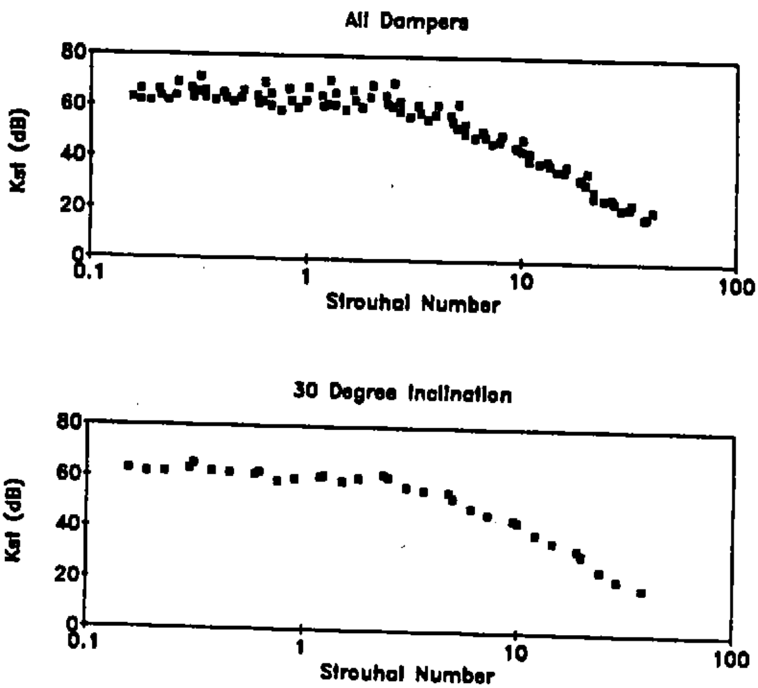
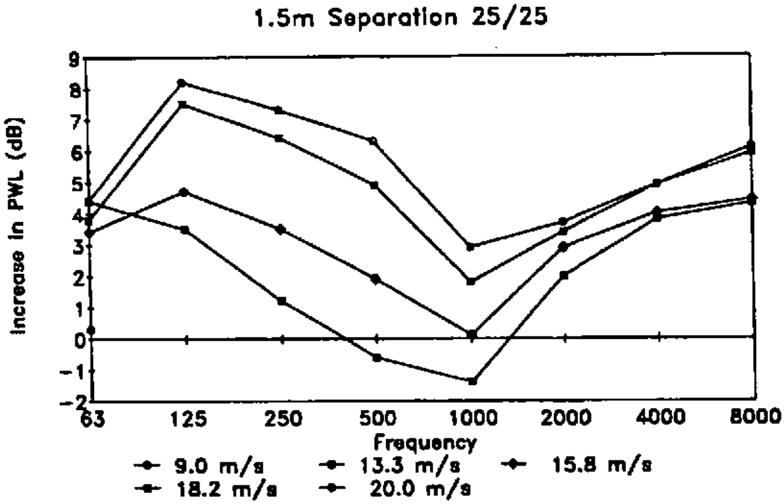


Figure 2 Collapse of Data - Comparison of All Dampers and Single Setting

REGENERATED NOISE



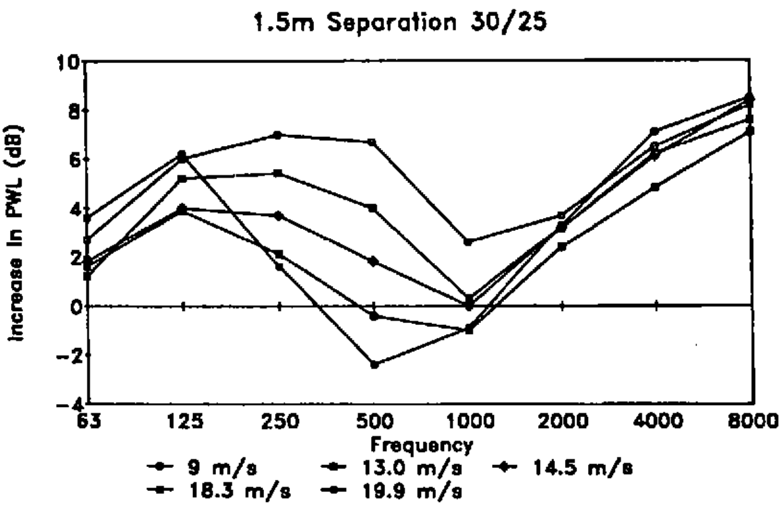


Figure 3 Increase in Sound Power Level
Due To Spoiler Interaction