inter-noise 83

NOISE GENERATED BY AIR JETS FROM RECTANGULAR SLITS

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INTRODUCTION

Due to the extensive use of compressed air in industry free turbulent jets occur in many factories and workshops, and those jets are everywhere recognized as extremely powerful noise sources. A few attempts have been made to develop quiet air outlet systems and more silent nozzle designs, but so far no systematic investigation of the influence of the geometry and the dimensions of the outlet opening on the emitted noise has been carried out.
This work presents a theoretical and an experimental study of flow and noise data arising from jets issued from 4 different rectangular slits. The noise data, i.e. sound power levels, frequency spectra, directivity patterns, are experimentally determined as a function of volumetric mean velocity of the flow in the slit and geometrical shape of the slit. And the experimental noise data are compared with a theoretical model for flow noise generated by a two-dimensional jet issued from a narrow slit.

THEORETICAL BACKGROUND

Using Lighthill's inhomogeneous wave equation [1] and Batchelor's theory of axisymmetric turbulence [2] it is shown by Larsen [3] that the noise intensity received at a distance X from a two-dimensional jet issued from a narrow slit of cross-section a × L, where a is the smallest dimension, may be expressed by:

$$I(\vec{X}) = \frac{U_0^8 a \cdot L \rho_0}{C_0^5 |\vec{X}|^2} \frac{K_1(\theta)}{(1-M_c \cos\theta)^5} \quad (1)$$

where U_o is the volumetric mean velocity of the jet, ρ_0 and C_0 are the density and sound velocity of the ambient air, respectively, $K_1(\theta)$ is a dimensionless function only depending on the angle of emission θ and M_c is the eddy convection mach number.

At fixed Strouhall's number St. = $f \cdot a/U_0$, where f is the frequency, the frequency spectrum of the noise intensity emitted at right angle to the jet axis ($\theta = 90^o$) is found to be [3]:

$$I_{90}(X,f) = K_2(St.) \frac{\rho_0 U_0^7 a^2 L}{c_0^5 |\vec{X}|^2} \quad \text{for} \quad f = St. \frac{U_0}{a} \qquad (2)$$

where $K_2(St.)$ is a dimensionless function only depending on the Strouhall's number.

EXPERIMENTAL SET-UP

Four different types of slits were tested, each with a throat area ($a \times L$) of 1.5 mm × 100 mm. See figure 1.

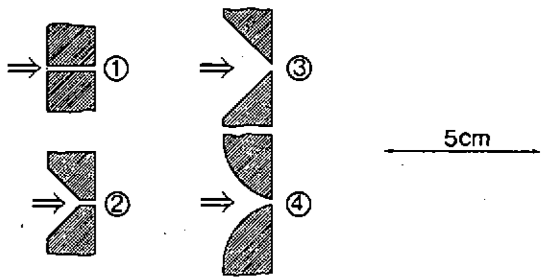

Figure 1 *Cross sections of the four slits tested shown with indication of flow-direction.*

The noise measurements were performed under anechoic conditions according to ISO 3745 by averaging the sound pressure level with a microphone over the surface of a hypothetical hemisphere with radius 1 m. No weighting network was used. The signal to noise ratio was in all measurements better than 20 dB. Four fixed pressure drops across the slits were studied, namely: 2160 Pa, 2690 Pa, 4310 Pa and 5810 Pa.

EXPERIMENTAL RESULTS AND COMPARISON WITH THEORY

For each of the slits, the emitted sound power level, L_W, and the volumetric mean velocity of the flow in the slit were found as functions of the pressure drop, ΔP, across the slit. The velocities are listed in table 1,and in figure 2 the measured sound power level is plotted versus volumetric mean velocity.

As may be seen from the figure a U_0^8-variation of sound power level with velocity is found for all 4 slits. Considering eq.(1) and disregarding the variation of the factor $(1-M_c\cos\theta)^{-5}$ with velocity, which is small compared with the variation of U_0^8, the experimental results are seen to correspond well with theory.

If the sound power levels from jets issued through slit no.1 are compa-

Table 1. *Volumetric mean velocity of the flow in the slit as a function of pressure drop across the slit.*

Slit no.	U_0 (ΔP=5810 Pa)	U_0 (ΔP=4310 Pa)	U_0 (ΔP=2690 Pa)	U_0 (ΔP=2160 Pa)
1	272 m/s	242 m/s	196 m/s	177 m/s
2	298 m/s	271 m/s	222 m/s	200 m/s
3	223 m/s	205 m/s	162 m/s	147 m/s
4	307 m/s	272 m/s	219 m/s	199 m/s

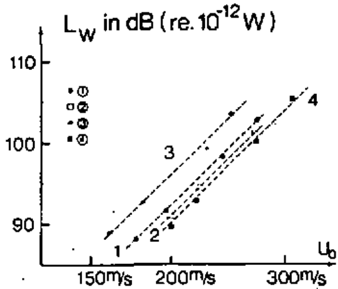

Figure 2 *Sound power level, L_W, emitted from the jet as a function of volumetric mean velocity (on a logaritmic scale). The dashed lines are $L_w \sim U_0^8$ according to eq.(1).*

red with the levels associated with slit no.2,a reduction of about 1.5 dB is observed. This is due to the convergent inlet section of slit no.2. In addition if a smooth inlet section to the slit is used (slit no.4), an additional reduction in sound power level of about 1 dB can be obtained. Slit no.3 presents the worst case since it has a sharp edge at the outlet of the slit. Its sound power level is 6 dB above the level of slit no. 4.

The sound pressure level (SPL) was measured in 5 different angles of observation to the jet axis, namely: 84.3^0, 72.5^0, 60^0, 45.6^0 and 25.8^0. In figure 3 the SPL in these 5 directions are shown relative to the SPL in the direction θ=84.3^0. For all slits the SPL is seen to have minimum at θ=84.3^0 and to increase with decreasing angle of observation to the jet axis. This result is in good agreement with eq.(1).

The frequency spectra of the jet noise was measured at an angle θ=84.3^0 to the jet axis. And in order to compare spectra from jets with different velocities, the frequency spectra were all normalized using eq.(2). In figure 4 the spectra are represented by the K_2(St.)-function. Apart from level, the spectra are seen only to differ slightly, and they all have maximum at a Strouhall's number of approximately 0.04.

CONCLUSIONS

It is found that the sound power level from a jet issued from a slit

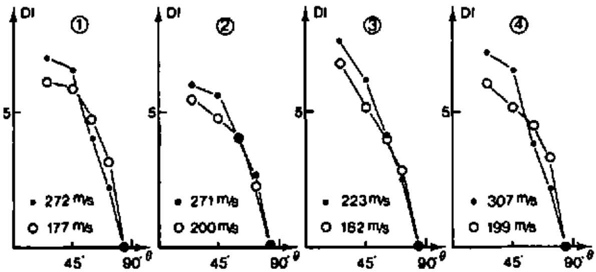

Figure 3 *The directivity in sound pressure level relative to the sound pressure level in the direction corresponding to* θ*=84.3*^{0}.

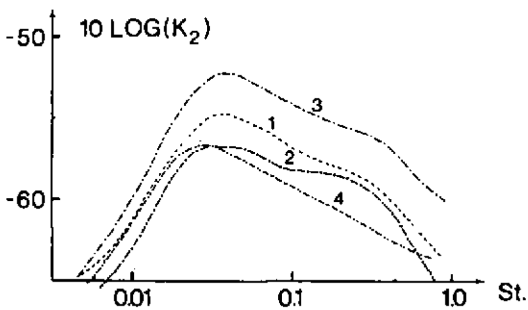

Figure 4 *The frequency spectra obtained at* θ*=84.3*^{0} *and normalized using eq.(2).*

with a smooth inlet section is about 2.5dB below the level of a jet issued from a slit with no inlet section. Further it is concluded that the shape of the inlet section will not markedly influence the general form of the frequency spectrum and the directivity of the emitted noise. The experimental data are found to be well represented by the theoretical model.

REFERENCES

[1] Lighthill, M.J.: On sound generated aerodynamically. I (General theory). Proc. Roy. Soc. London, A211, 1952, 564-587.
[2] Batchelor, G.K.: The theory of axisymmetric turbulence. Proc. Roy. Soc. London, A186, 1946, 480-502.
[3] Larsen, P.N.: Noise generated by air jets from a rectangular slit. Ph.D. thesis. Technical University of Denmark. To be published spring 1983.