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Technical Note

Summary At small pressure differences, the airflow through small perforations is reduced due to frictional effects. A relation between velocity and pressure drop is presented which has been verified by experiment for a limited range of geometries.

Airflow through perforated screens at small pressure differences

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List of symbols

d	Perforation diameter	m
L	Screen thickness	m
ΔP	Pressure difference	Pa
R	Dimensional parameter	m^{-1}
R_p	Reynolds no. Vd/ν	
V	Mean flow velocity	m/s
ν	Kinematic viscosity	m^2/s
ϱ	Density	kg/m^3

1 Introduction

Experimental and theoretical studies of airflows through perforated screens at small pressure differences have been carried out at Sheffield University. This work was initiated by an interest in the ventilation of marine freight containers by means of perforated grilles at floor and ceiling level. Small pressure gradients are developed across these grilles by small temperature differences between cargo and ambient air, the cargo often being coffee or cocoa[1]. These studies are equally relevant to the natural ventilation of buildings and to the design of many types of deliberate ventilation openings such as trickle ventilators and eaves ventilators.

2 Theoretical relationship

Consider a single circular perforation of diameter d in a plate of thickness L. The mean flow velocity due to a pressure difference of ΔP may be calculated by considering the sum of the pressure drops due to skin friction ΔP_f and end effects ΔP_{end}, after the method of Etheridge[2,3]. It can be shown[4] that for steady laminar flow through a circular cross-section

$$\Delta P_f = \frac{64}{R_p}\,\frac{L}{d}\,\varrho\,\frac{V^2}{2} \tag{1}$$

where R_p is the Reynolds number Vd/ν and

$$\Delta P_{end} = (K_{inlet} + K_{exit})\,\varrho\,V^2/2 \tag{2}$$

For a perforation with an abrupt inlet and exit, the loss coefficients K_{inlet} and K_{exit} are 0.5 and 1.0 respectively, by experiment[4]. Thus combining equations (1) and (2), the total pressure drop is the sum of the skin friction and end effect pressure drops:

$$\Delta P = \frac{64}{R_p}\,\frac{L}{d}\,\varrho\,\frac{V^2}{2} + 1.5\,\varrho\,\frac{V^2}{2}$$

or

$$\Delta P = \frac{32\,\varrho\,\nu L}{d^2}\,V + 0.75\,\varrho\,V^2 \tag{3}$$

For air at 20°C and 1 bar, this becomes

$$\Delta P = 0.9\,V^2 + 0.582\,RV\ \text{(Pa)} \tag{4}$$

where $R = 10^{-3}\,L/d^2$ (m^{-1}).

The scale factor 10^{-3} in the definition of R leads to convenient values when L and d are measured in mm.

The validity of equation (3) and its application to grilles containing a large number of perforations have been examined experimentally, as described in section 3.

3 Experimental arrangement

Perforated screens were pressurised in a chamber capable of holding test panels up to approximately 1 m square. Pressurisation or depressurisation was carried out by a combination of two 150 mm diameter axial fans in series with a bleed valve (Fig. 1), enabling pressure differences as low as 0.01 Pa and flow rates down to 0.002 m/s to be measured using low range pressure transducers (0–0.5 mm WG and 0–1 mm WG) and an orifice plate constructed to

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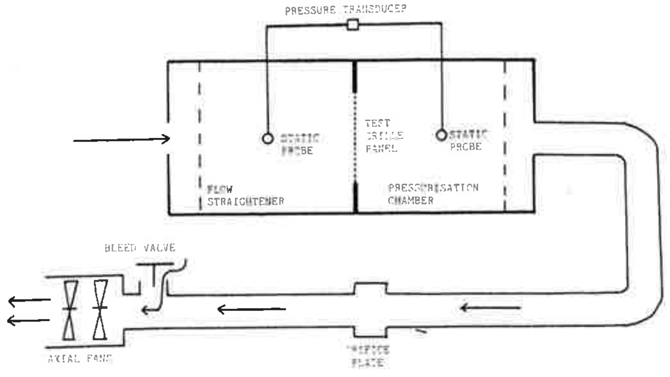

Fig. 1. Experimental arrangement.

BS 1042 respectively. With this equipment, it is estimated that both pressure drop and flow rate can be measured to better than 5% accuracy.

The mean flow velocity V due to a pressure drop ΔP was simply obtained by dividing the experimentally measured volume flow rate by the screen open area, which was taken as $n\pi d^2/4$, where n is the number of perforations and d is the perforation diameter. These experimentally derived values of V could then be compared with those predicted by equation (3).

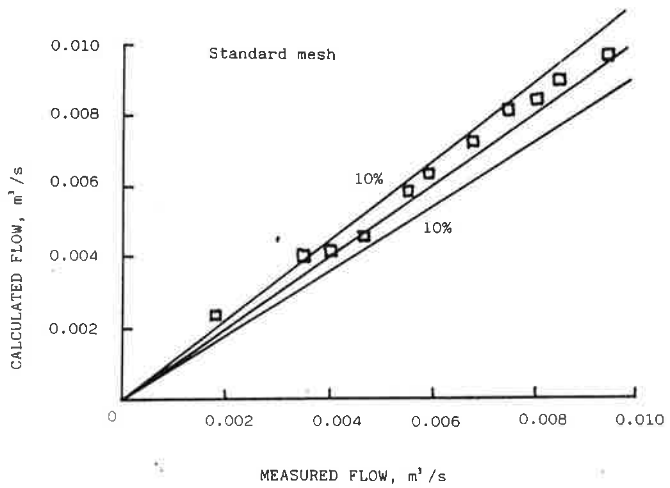

Fig. 2. Comparison of measured and calculated flow rates.

4 Results

Fig. 2 shows that for a commercially used screen with a free area of approximately 60% consisting of over 7000 perforations of diameter 2.7 mm in a screen thickness of 1.5 mm ($R = 0.21$), experimentally measured flows agree well with calculated flows. Equally good results were obtained for a 3 mm thick screen with 175 perforations each 9 mm in diameter ($R = 0.04$).

Fig. 3 shows the relation described by equation (4) for pressure differences of 0.01 to 1 Pa and R values from 0 to 1.0. The line for $R = 0$ corresponds to a screen of zero thickness, corresponding to the frequently assumed case of a simple orifice. $R = 1.0$ corresponds to a 1 mm diameter hole in a 1 mm thick screen. As R increases and ΔP decreases, flow is reduced appreciably due to frictional resistance.

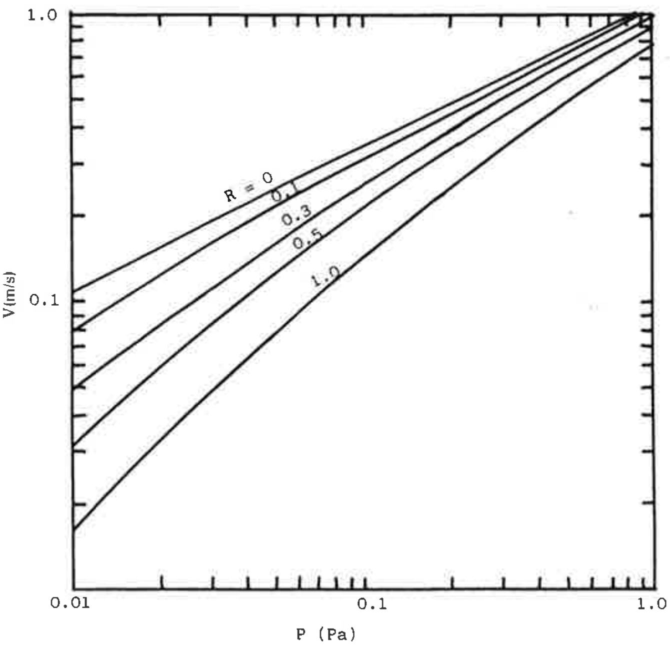

Fig. 3. Relation between velocity V and pressure drop ΔP as a function of the dimensional parameter $R = 10^{-3}L/d^2$ (m^{-1}).

This relation has beed used to compute the ventilation through a container with top and bottom vents 2 m apart with a driving force due to a 10 K temperature difference. In this case, the pressure difference across a vent screen is 0.1 Pa, and flow differs by a factor of 2.4 between $R = 0$ and $R = 1.0$ for the same open area.

For a particular measured example with $R = 0.2$, the computed value of V of 0.27 m/s agrees well with measured values.

Equation (4) has been verified for two very different perforation geometries and could be valid widely. Fig. 3 may be used to assess the range of pressure differences over which holes of a particular geometry have an appreciable added frictional resistance, and for which the assumption of a constant discharge coefficient is therefore invalid.

5 Acknowledgement

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