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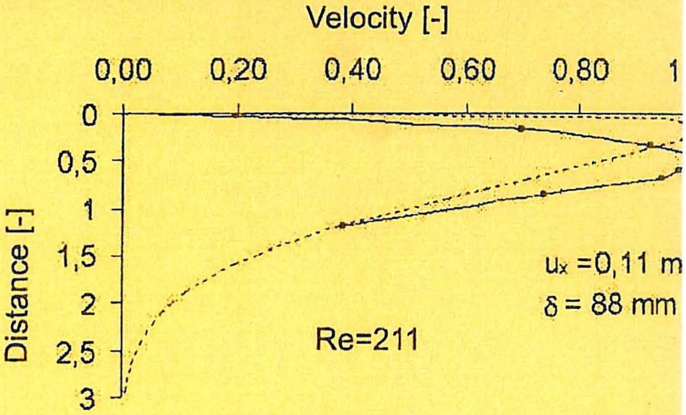

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MODEL EXPERIMENTS WITH LOW REYNOLDS NUMBER EFFECTS IN A VENTILATED ROOM

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ABSTRACT

The flow in a ventilated room will not always be a fully developed turbulent flow. Reduced air change rates owing to energy considerations and the application of natural ventilation with openings in the outer wall will give room air movements with low turbulence effects.

This paper discusses the isothermal low Reynolds number flow from a slot inlet in the end wall of the room. The experiments are made on the scale of 1 to 5. Measurements indicate a low Reynolds number effect in the wall jet flow. The virtual origin of the wall jet moves forward in front of the opening at a small Reynolds number, an effect that is also known from measurements on free jets. The growth rate of the jet, or the length scale, increases and the velocity decay factor decreases at small Reynolds numbers.

KEYWORDS

Room air flow, low Reynolds number effects, scale-model experiments, plane isothermal wall jet.

INTRODUCTION

Most of the theory behind the description of room air movement as e.g. flow elements, zonal models, throw and CFD predictions is based on an assumption of fully developed turbulent flow. This assumption represents a simplification of the theory. The flow elements can be given by equations without any adjustment for the velocity level and the turbulence model in the CFD predictions has a universal character independent of the velocity level.

The flow in a ventilated room will not always be a fully developed turbulent flow. Reduced air change rate owing to energy considerations as well as the application of natural ventilation may cause a flow with low turbulence effect in the air movement. This paper shows how it is possible to adjust the flow element of a wall jet to be valid for low turbulent flow. The measurements are also made for the validation of Large Eddy Simulation (LES) which is a promising method for the prediction of flow with low turbulence effect as shown by Davidson et al. (2000).

SCALE-MODEL EXPERIMENTS

The scale-model experiments are related to a full-scale room with the dimensions, height H, width W and length L equal to 2.5 m, 3.6 m and 4.2 m, see Topp et al. (2000). Figure 1 shows the layout of a room. The full-scale room is ventilated by a supply slot of full width with the height h_o of 2 cm located in one end wall and a return opening located in the opposite end wall.

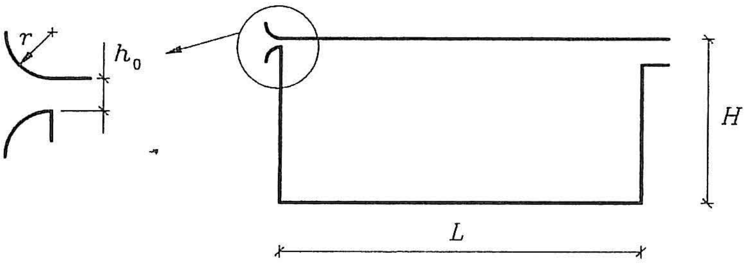

Figure1: Room geometry and supply slot.

TABLE 1

FULL SCALE AND MODEL GEOMETRY

Scale	h_o/H	W/H	L/H
1:1	0.008	1.44	1.68
1:5	0.008	1.44	1.68 - 2.88

The length of the model is different from the length of the full-scale room in some of the measurements, see Table 1. The increased length in the model makes it possible to study the penetration depth of the supply jet. It is assumed that the flow in the wall jet is a parabolic flow and therefore independent of the room length within the limits given in Table 1.

A model experiment with isothermal flow is identical with the full-scale flow if the Reynolds number Re is the same in both cases. The Reynolds number is defined as

$$Re = \frac{h_o u_o}{\nu} \qquad (1)$$

where h_o is the slot height and u_o the supply velocity. ν is the kinematic viscosity of air.

Model experiments are often used to study room air movement when it is convenient to work in a small scale. Here the method is used because the reduced scale will increase the velocity level accordingly and improve the measurements at small Reynolds numbers. It is important to have the same boundary conditions in both full scale and in model scale. Figure 1 shows the contraction used in the model to obtain low turbulence in the inlet opening, $r/h_0 = 11.75$. The inlet opening in the full-scale room has a one-sided contraction and upstream installations that will generate some turbulence in the inlet flow.

WALL JET FLOW

Fully developed isothermal two-dimensional wall jet flow is given by the following equations, see e.g. Rajaratnam (1976),

$$\frac{u_x}{u_o} = K_p \sqrt{\frac{h_o}{x + x_o}} \tag{2}$$

$$\frac{\delta}{h_o} = D_p \frac{x + x_o}{h_o} \tag{3}$$

where u_x is the maximum velocity in the wall jet profile and δ is the thickness or length scale of the wall jet measured from the surface to the velocity $u_x/2$ in the profile. x_o is the distance from the supply slot to the location of the virtual origin of the jet flow. This location will in a fully developed flow often be located behind the diffuser corresponding to a positive x_o. K_p and D_p are characteristic constants for the diffuser. They are constant for the fully developed turbulent flow. The dimensionless wall jet profile (u/u_x versus y/δ) will be a universal profile for high Reynolds number flow.

Eqns. (2) and (3) are, as mentioned above, based on the assumption of fully developed flow. It is also possible to develop a corresponding set of equations for laminar flow. The behaviour of the flow in the transition regime (low turbulent regime) could be handled by expressions that connect the two sets of equations but here it is decided to express the transitional regime by the following modifications of Eqns. (2) and (3)

$$\frac{u_x}{u_o} = K_p(Re) \sqrt{\frac{h_o}{x + x_o(Re)}} \tag{4}$$

$$\frac{\delta}{h_o} = D_p(\mathrm{Re}) \frac{x + x_o(\mathrm{Re})}{h_o} \tag{5}$$

K_p *(Re)*, D_p *(Re)* and x_o *(Re)* are considered to be functions of the Reynolds number *Re* and they will develop asymptotically to constant values for increasing Reynolds numbers.

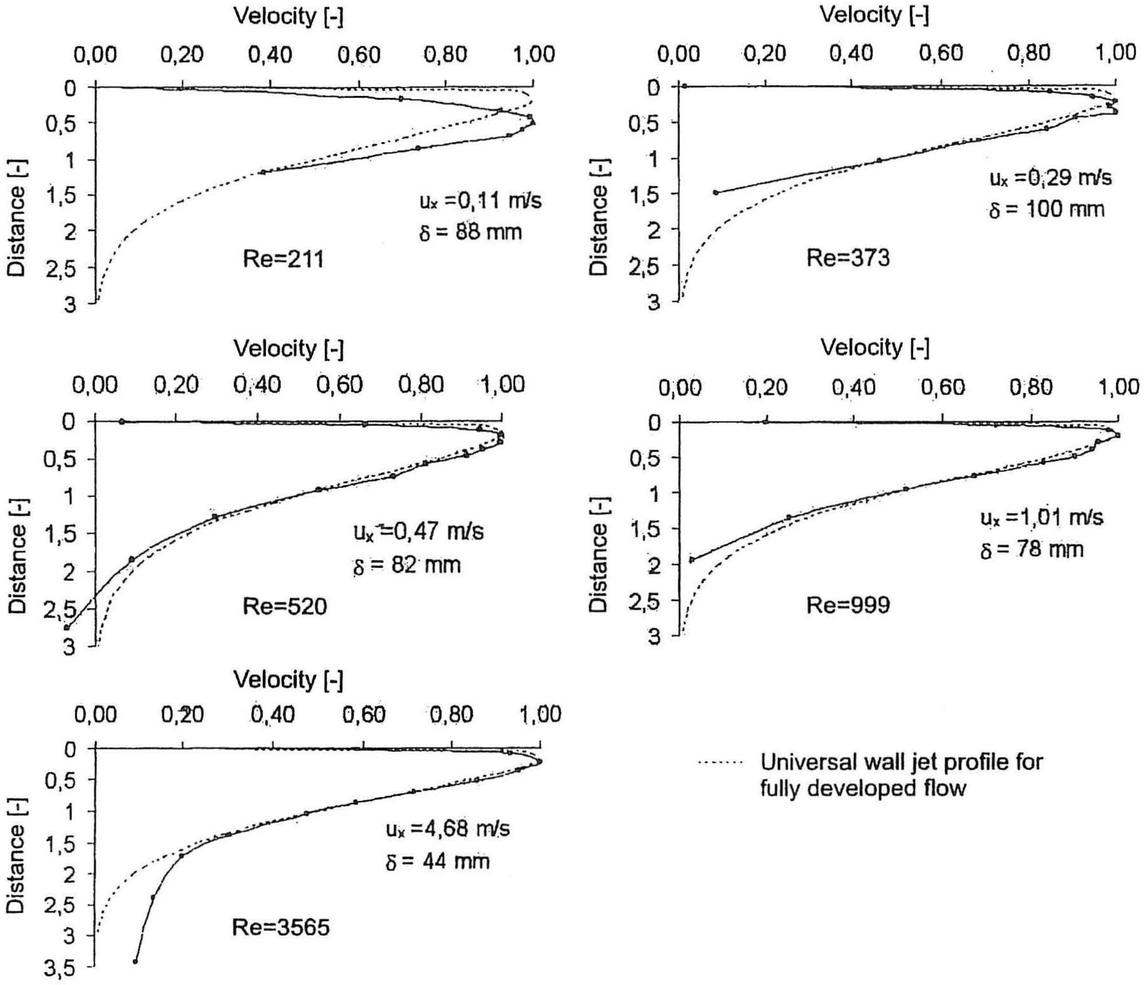

Figure 2: Dimensionless wall jet profile measured at different Reynolds numbers. The profile is located at $x/H = 0.8$. The universal wall jet profile for fully developed turbulent flow is given by e.g. Verhoff (1963).

Figure 2 shows the dimensionless velocity profile u/u_x versus y/δ. The profile is measured at $x/H = 0.8$ for the following Reynolds numbers 211, 373, 520, 999 and 3565. It is seen that the profile develops into the universal wall jet profile for fully developed turbulent flow. The measured profile at $Re = 211$ is similar to the laminar (Glauert) profile measured e.g. by Quintana et al. (1997). The profile has a characteristic location of the maximum velocity u/u_x at $y/\delta \sim 0.5$.

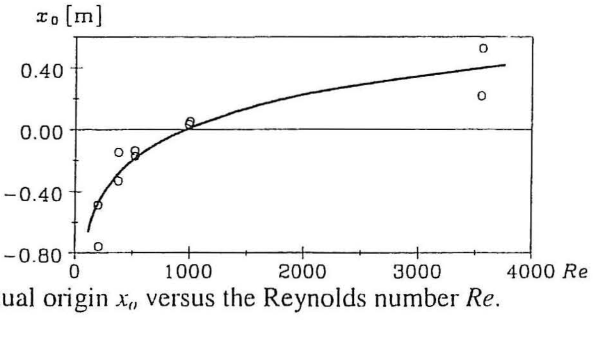

Figure 3: Distance to virtual origin x_o versus the Reynolds number Re.

A depiction of δ as a function of x for the different Reynolds numbers gives x_o and D_p. Figure 3 shows that the distance to the virtual origin x_o is negative at low Reynolds numbers corresponding to a location in front of the supply slot. This is very typical of a semilaminar flow. The jet leaves the opening as a laminar flow with a small growth in thickness. Disturbance changes the flow into a turbulent flow at some distance from the opening with a large increase in the growth rate as a consequence. The new growth rate will have a virtual origin close to the transition point from laminar to turbulent flow.

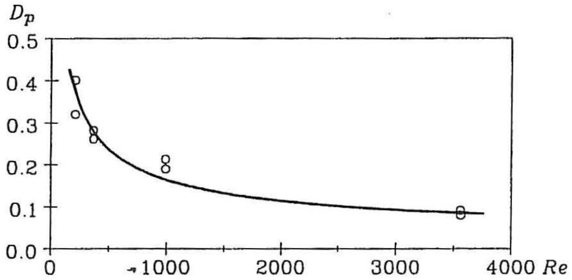

Figure 4: Growth rate D_p versus *Re*.

Figure 4 shows the growth rate D_p as a function of the Reynolds number. A growth rate of 0.1 is very typical of a fully developed isothermal wall jet. An increase in the growth rate at small Reynolds numbers is also typical as measured earlier by Nielsen and Möller (1988) for a ceiling-mounted slot diffuser. The K_p value for the slot is given in Figure 5. This value has also the expected asymptotic development for increasing Reynolds numbers. All the measurements in Figure 3, 4 and 5 are in good agreement with the measurements in the full-scale room, see Topp et al. (2000).

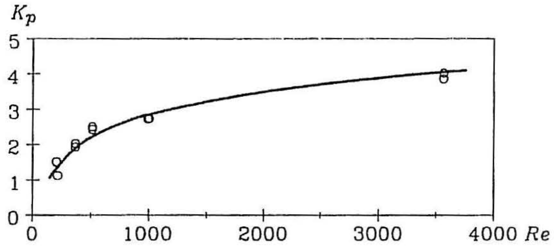

Figure 5: K_p value for the slot and the two-dimensional wall jet versus *Re*.

PENETRATION DEPTH OF THE WALL JET

Earlier measurements and CFD predictions show that is should be possible to measure a restricted penetration depth for the isothermal wall jet and a corresponding reattachment line in the occupied zone. The penetration depth and the location of the reattachment line l_{re} are functions of the Reynolds number at low turbulent flow and l_{re} will go to zero for $Re \rightarrow 0$, see Davidson and Nielsen (1998) and Armaly et al. (1983).

It was not possible to measure these quantities in full-scale flow, but there are some indications of a restricted penetration depth at low Reynolds numbers in the 1:5 model.

CONCLUSIONS

The flow in a ventilated room will not always be a fully developed turbulent flow but it is possible to use the equations for a fully developed flow in the transitional regime if involved "constants" are given as functions of the Reynolds number.

A detailed description of an isothermal wall jet has been developed from scale-model experiments and the results are in good agreement with full-scale experiments and earlier measurements.

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