HOT-WIRE STUDIES OF PLANE JET IMPINGEMENT

C.V. Tu
Port Kembla Laboratories
BHP Research, BHP Steel
Port Kembla, New South Wales
Australia

D.H. Wood
Department of Mechanical Engineering
University of Newcastle
Callaghan, New South Wales
Australia

J.D. Hooper
CSIRO, Division of Mineral Physics
New South Wales
Australia

ABSTRACT

This paper describes results from a comprehensive study of velocity fields of normal plane jet impingement using a single hot-wire probe for three non-dimensional distances *H/D*=4, 8 and 12 with the inclusion of measured mean impingement pressure and surface shear stress profiles. The influence of the impingement plate on the jet flow development was found to be confined to a region relatively close to the impingement surface. The decay of the centreline velocity agreed well with the equation derived from Hiemenz solution for stagnation flow.

INTRODUCTION

Impinging jets have many industrial applications such as heating, cooling, drying or coating film thickness control in the gas wiping process and the fundamental study of nozzle impingement is essential to the understanding the related process.

A comprehensive study of velocity fields of normal plane jet impingement using a single hot-wire probe was conducted for three non-dimensional distances to cover the following three impingement conditions: the potential core, transition region and jet flow. Normal impingement was chosen for detailed study since it is considered as a more basic flow and the knowledge of its behaviour may lead to a better understanding of more complicated nozzle configurations. The wall friction was measured by Stanton probe of 0.05 mm height to avoid errors due to probe size as discussed by Tu et. al. (1992) and single hot-wire probe was used to provide the required spatial resolution since the nozzle gap, *D*, and nozzle distance, *H*, were too small for a more sophisticated hot-wire configuration.

RESULTS AND DISCUSSION

The mean and root mean square (RMS) velocity fields in the region between the nozzle and impingement plate for *H/D*=4, 8 and 12 are plotted in Figures 1(a-b), 2(a-b) and 3(a-b) respectively. The corresponding mean wall pressure, *P*, and wall friction, τ, distributions for *H/D*=4 are shown in Figure 1(c). For brevity the corresponding profiles for *H/D*=8 and 12 are not shown. However they are similar to that of *H/D*=4. It should be noted that *b*, half-width of the pressure distribution, was used as the reference length in these figures and *b/D* for *H/D*=4, 8 and 12 was 0.94, 1.17 and 1.56 respectively. From Figures 1 to 3, the extent of the impingement zone, in which the flow is altered by the presence of the plate, can be seen in the variation of the mean velocity from the nozzle exit to the stagnation point.

Although it is difficult to define precisely the extent of the impingement zone, it extends about 0.20*H*-0.25*H*. The extent of influence of the impingement plate agrees well with that measured by Gutmark et al. (1978). A simple way of characterising the impingement region is to plot the centreline velocity. The distributions of the mean and fluctuation component of centreline velocity are given by Figures 4(a-b). Figure 4 (a) shows the variation of the centreline RMS velocity v_c' with y_j / D for various *H/D*, where y_j is the distance from nozzle exit and the initial turbulence levels at the exit of approximately $0.04U_o$ were used as the reference levels for v_c' (denoted as v_o'). After an initial distance of approximately D from the nozzle exit, in which v_c' is nearly constant, the rate of change of v_c' increases with *H/D*.

This implies that there is some unsteadiness associated with impingement that increases with *H/D*. The initial length over which v_c' is constant has the same magnitude,

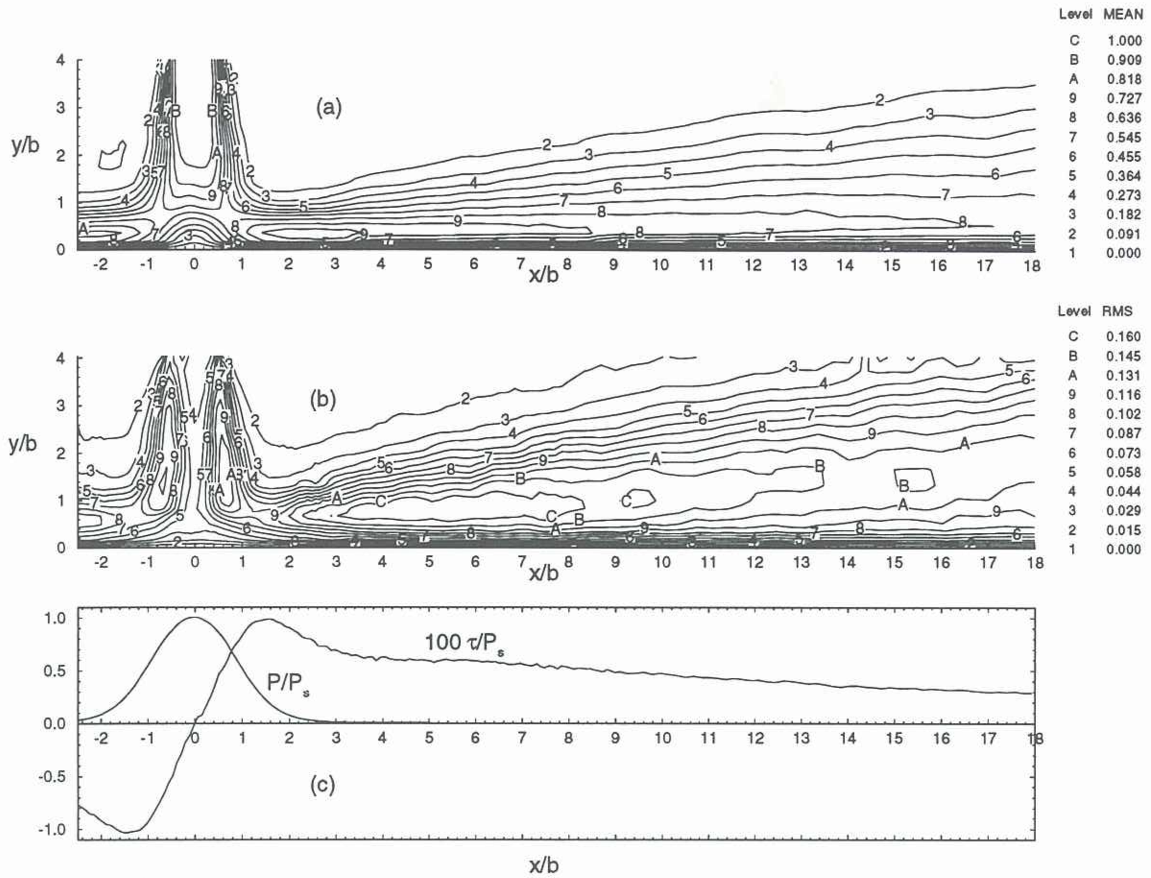

FIGURE 1

VELOCITY CONTOURS FOR *H/D*=4
(a) MEAN VELOCITY (b) RMS VELOCITY
(c) IMPINGEMENT PRESSURE AND SURFACE SHEAR STRESS

approximately 1*D*, in the study of round nozzles reported in Gauntner et al. (1970).

Let V_c and U_o denote the mean centreline velocity and the nozzle centreline exit velocity respectively. From Figure 4(b), for *H/D*=4, which corresponds to the case of potential core impingement, V_c / U_o, is essentially constant from the exit to the mid position between the jet and impingement plate after which V_c / U_o starts to decay toward zero at the plate. For *H/D*=8 and *H/D*=12, V_c / U_o remains constant over the region of 4*D* to 5*D* and 2*D* to 3*D* respectively from the nozzle exit before reducing to zero at the stagnation point. Since the boundary layer thickness, as estimated from the Hiemenz solution, are only in the order of 0.008*D*, the attenuation of centreline velocity fluctuations near the stagnation region must be a direct effect of the surface on the velocity fluctuations normal to the surface. The attenuation of v'_c is partly a consequence of the large integral scale of the turbulence from the results of Bearman (1972) and others. There is no substantial evidence of any y_j^2 increase in v'_c, Figure 4(a), indicating that the fluctuation level in the potential core is dominated by the background turbulence. Finally it was found that the attenuation of v'_c begins closer to the plate than the attenuation of V_c.

For small *H/D*, the impingement pressure profiles, such as shown in Figure 1(c), can be closely described by a Gaussian distribution of form:

$$P / P_S = e^{-\alpha\zeta^2}, \qquad (1)$$

where $\alpha = -\ln(1/2)$, $\zeta = x/b$ and P_s is the peak pressure at x=0. In the vicinity of the stagnation position, applying Hiemenz flow condition, $U=cx$, $V=-cy$ and assuming that U is related to the wall pressure through the Bernoulli's equation then from Eq.(1) it can be shown that $c = U_o \sqrt{\alpha} / b$ and the centreline velocity is therefore:

$$V_c / U_o = y \sqrt{\alpha} / b \qquad (2)$$

As shown in Figure 4(b), the linear decay of the measured centreline velocity agreed well with Eq.(2) (plotted as Lines (i) and (ii)) for all tested *H/D*. However it should be recalled that the measured wall shear stress variation in the impingement region was significantly below that predicted from Hiemenz solution for two-dimensional stagnation flow in infinite fluid as discussed elsewhere (Tu et al., 1992).

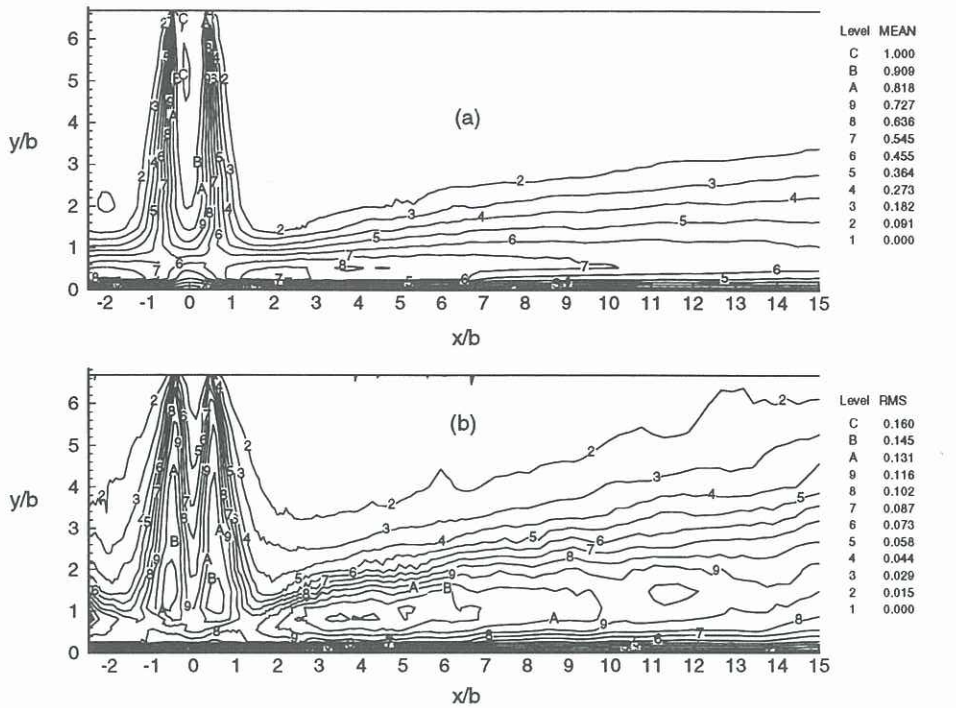

FIGURE 2

VELOCITY CONTOURS FOR *H/D*=8
(a) MEAN VELOCITY (b) RMS VELOCITY

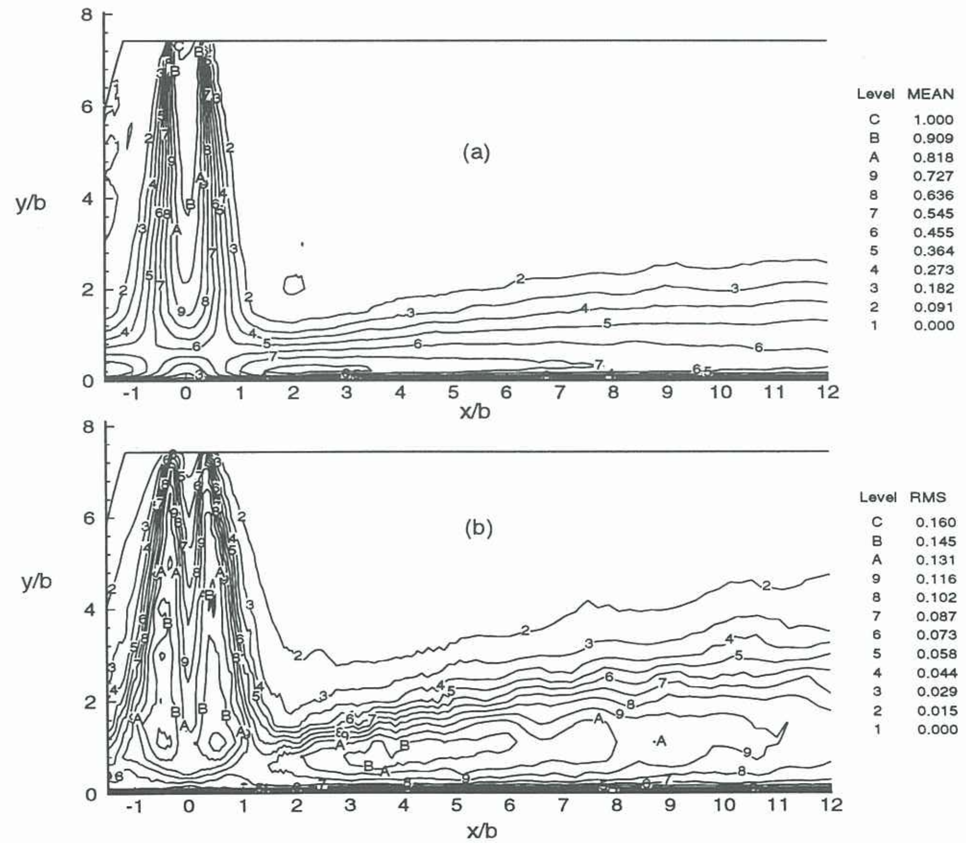

FIGURE 3

VELOCITY CONTOURS FOR *H/D*=12
(a) MEAN VELOCITY (b) RMS VELOCITY

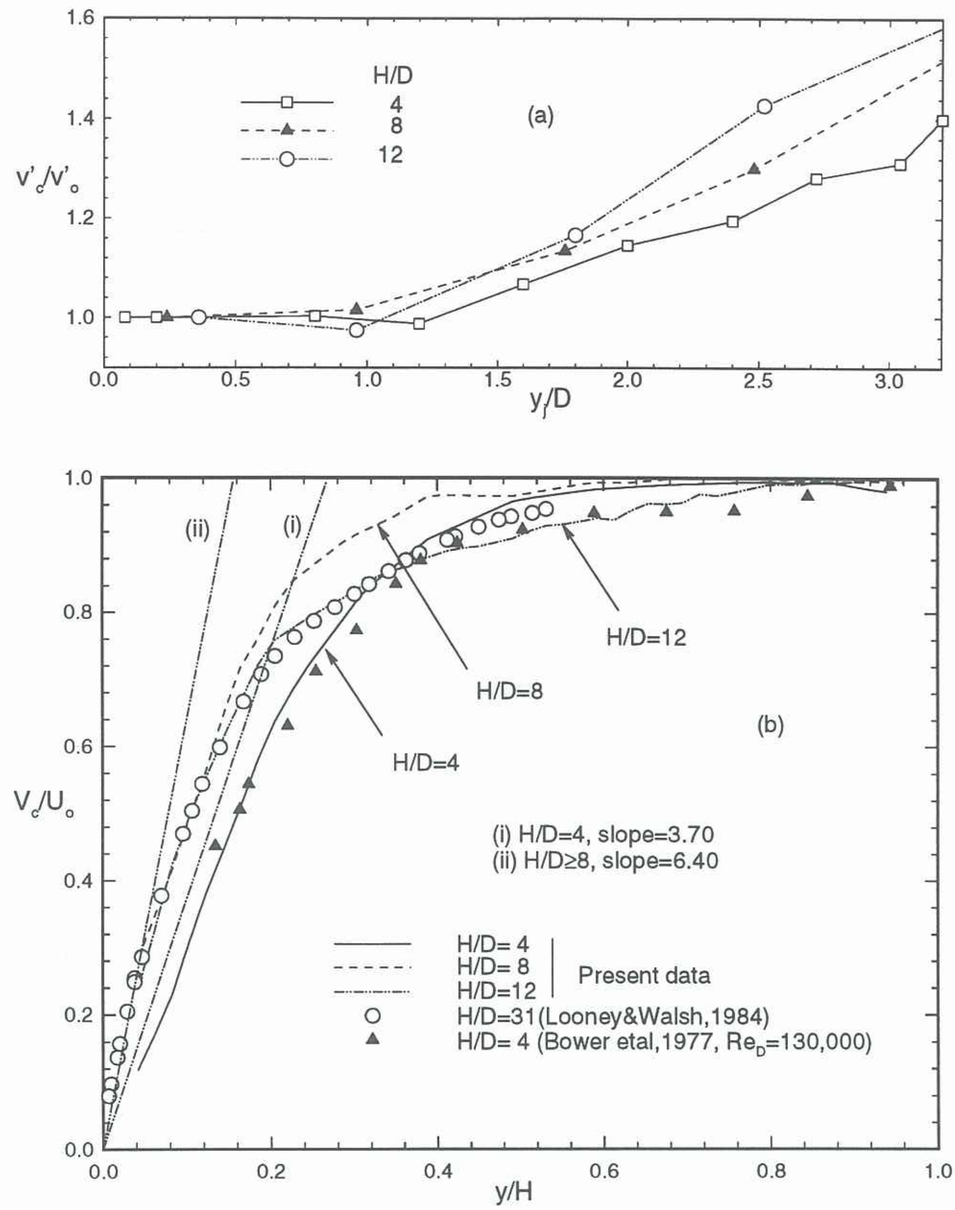

FIGURE 4

(a) VARIATION OF VELOCITY FLUCTUATION ALONG NOZZLE CENTRELINE FOR *H/D*=4, 8 AND 12
(b) MEAN CENTRELINE VELOCITY VARIATION FROM THE STAGNATION POINT

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