Int. J. Heat Mass Transfer. Vol. 10, pp. 1623–1624. Pergamon Press Ltd. 1967. Printed in Great Britain

THE DEPENDENCE OF THE IMPERVIOUS WALL EFFECTIVENESS OF A TWO-DIMENSIONAL WALL-JET ON THE THICKNESS OF THE UPPER LIP BOUNDARY LAYER

S. C. KACKER and J. H. WHITELAW

Department of Mechanical Engineering, Imperial College of Science and Technology, London, S.W.7

(*Received* 15 *February* 1967 *and in revised form* 24 *May* 1967)

NOMENCLATURE

- C, mass concentration;
- $\bar{u}_C$, mean velocity of the flow at exit from the slot;
- u_G, free-stream velocity;
- x, distance measured along the wall in the free-stream direction;
- y_C, slot height;
- δ, thickness of the upper lip boundary layer;
- η_I, impervious wall effectiveness defined by $\eta_I = \dfrac{C_S - C_G}{C_C - C_G}$.

Subscripts

- C, pertaining to the flow through the slot;
- G, pertaining to the free-stream;
- S, pertaining to the wall.

INTRODUCTION

In an earlier paper [1], one of the present authors presented measurements of the impervious wall effectiveness of a two-dimensional wall-jet, made with a slot height of 0·25 in. These measurements were reported in less detail in a subsequent paper by Nicoll and Whitelaw [2] which also described an explicit method for predicting the effectiveness of the uniform property, two-dimensional wall-jet. The measurements described in the above two papers indicate that the effectiveness at any downstream station has a maximum at a value of the ratio of the mean velocity in the slot to the free-stream velocity, $\bar{u}_C/u_G$, close to unity. The magnitude of this maximum has been found in [3] to decrease substantially as the slot height is decreased. These observations are in keeping with the trends indicated by the measurements of Seban [4].

The cause of the decrease in the maximum value of the effectiveness can be ascribed to several sources all of which are associated with the geometry of the injection region or of the region upstream of this point; the present authors are presently conducting an experimental programme to investigate these effects. As part of this investigation, the effect of the thickness of the boundary layer on the upper lip of the slot has been investigated and it is the purpose of this note to present the findings. The situation considered is shown schematically on Fig. 1.

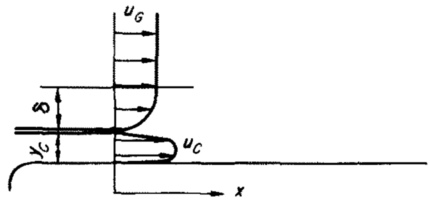

FIG. 1. The injection region of a two-dimensional wall-jet.

PREVIOUS MEASUREMENTS

Two experimental investigations of the present type have previously been carried out: the first by Chin *et al.* [5] and the second by Seban [6]. These investigations were carried out by measuring the adiabatic wall effectiveness: in each case the velocity ratio $\bar{u}_C/u_G$, was restricted to values less than unity. Although both investigations indicated that the effect of the thickness of the upper lip boundary layer was small (i.e. a maximum of 8 per cent of unity) the trends observed by these authors were opposite. Chin *et al.* observed that the difference between measurements made with a thin upper lip boundary layer (equal to eight slot heights) and those made with a thicker one (equal to twenty slot heights) was smaller for low values of the ratio, $\bar{u}_C/u_G$, and tended to a maximum as this ratio tended to unity. This tendency suggested that the thickness of the upper lip boundary layer might be significant in deciding if the effectiveness against velocity ratio curve should have a maximum. Seban, on the other hand, observed that the difference was a maximum for low values of the velocity ratio at a distance of 100 slot heights downstream: the difference appeared more constant at a distance of two hundred slot heights. Seban employed upper lip boundary layers with thicknesses equal to one slot height and equal to ten slot heights.

It should be stressed that within the range of measurement, the differences reported in [5] and [6] were not much greater than the experimental precision. It should also be stated that the absolute values of effectiveness obtained by these two experimenters were significantly different: the measurements of Chin *et al.* being generally higher than those of Seban. This is in keeping with the trends found by Whitelaw [3] since Chin *et al.* used a 0·108-in slot whereas Seban used a 0·063 in slot.

PRESENT MEASUREMENTS

The present measurements were made using the apparatus described in [1] and [2]. The free stream velocity in all cases was nominally 68 ft/s and, as in the previous measurements, the impervious wall effectiveness was determined by injecting a tracer of helium into the secondary stream, sampling the fluid at the wall at downstream locations and measuring the mass fraction of helium in each sample with the aid of a gas chromatograph. Considerable experience with this technique suggests that the impervious wall effectiveness can be determined to a precision of ±1·5 per cent. The value of the velocity ratio is obtained by measuring the velocity profile across the slot and integrating the result: the precision of this procedure diminishes as the value of the velocity ratio diminishes but should not be worse than ±5 per cent. The measurement of downstream distance is accurate to at worst 0·005 in, i.e. less than 0·1 per cent.

The slot height used for the present investigation was 0·074 in and the upper lip boundary-layer thicknesses used were 0·18 in, 0·36 in and 0·75 in. The 0·18-in thick boundary layer was obtained as a result of the design of the slot and its upstream geometry. The other boundary-layer thicknesses were obtained by extending the upper lip of the slot into the contraction of the wind-tunnel. In all cases, the mean velocity profile of the upper lip boundary-layer proved to have the normal turbulent boundary-layer shape.

Figure 2 shows the measurements of effectiveness obtained from the present investigation and indicates that the effect of the upper lip boundary layer on the impervious wall effectiveness is of a second order for the range of values tested.

CONCLUSIONS

The results of the present investigation show that the effect of the thickness of the upper lip boundary layer on the impervious wall effectiveness is not greater than 5 per cent of unity in the range of velocity ratios $0.3 \leqslant \bar{u}_C/u_G \leqslant 2.05$. The tendency is for the effectiveness to decrease as the upper lip boundary-layer thickness is increased. This confirms the general conclusions of Chin *et al.* and of Seban for values of the velocity ratio less than unity and extends this conclusion to higher values of the velocity ratio. The absolute values of the effectiveness agree closely with those of Seban which was to be expected since the present investigation used a similar slot height to that of Seban.

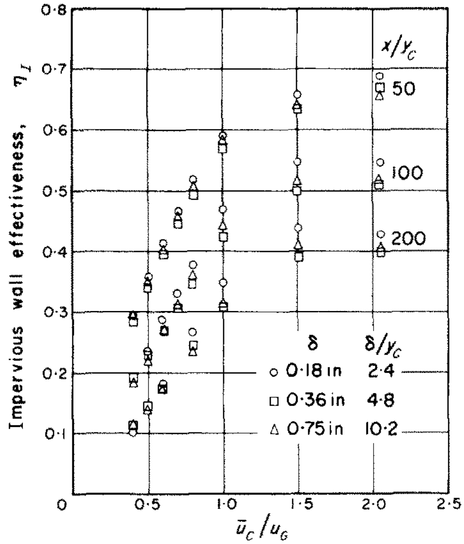

FIG. 2. Measured values of the impervious wall effectiveness.

ACKNOWLEDGEMENT

This work was supported by the Ministry of Technology (Agreement PD/37/043) to whom grateful acknowledgement is made.

REFERENCES

1. J. H. WHITELAW, An experimental investigation of the two-dimensional wall jet, Aero. Res. Council Report No. 28179 (1966).
2. W. B. NICOLL and J. H. WHITELAW, The effectiveness of the uniform density, two-dimensional wall jet, *Int. J. Heat Mass Transfer* **10**, 623 (1967).
3. J. H. WHITELAW, The effect of slot height on the effectiveness of the uniform density, two-dimensional wall-jet, Imperial College, Department of Mechanical Engineering, Report No. EHT/TN/4 (1967).
4. R. A. SEBAN, Heat transfer and effectiveness for a turbulent boundary layer with tangential injection, *J. Heat Transfer* **82**, 303 (1960).
5. J. H. CHIN, S. C. SKIRVIN, L. E. HAYES and A. H. SILVER, Adiabatic wall temperature downstream of a single, tangential slot, A.S.M.E. Paper No. 58–A–107 (1958).
6. R. A. SEBAN, Effects of initial boundary-layer thickness on a tangential injection system, *J. Heat Transfer* **82**, 392 (1960).