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SEPARATION IN A ROTATING DIFFUSER

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ABSTRACT

Experiments have been conducted in which the boundary layers developing on the walls of a two-dimensional diffuser are subjected to system rotation by rotating the diffuser. Static pressure measurements show the onset of separation on the suction-side wall (the leading wall) as the rotation is increased leading to stall in the diffuser. The separation point is shown to move upstream as the rotation is increased but appears to asymptote to a fixed upstream position beyond a certain rotational speed. Possible mechanisms are discussed.

INTRODUCTION

This work is part of an ongoing project at the University of Melbourne to study the effects of extra strain-rates on turbulent boundary layers. In the present work the aim is to study the development of turbulent boundary layers subject to both system rotation and adverse pressure-gradients. The effects of system rotation on developing zero-pressure-gradient boundary layers in the same apparatus have been described in Watmuff *et al.*. This paper describes an extension of the work of Watmuff *et al.* in which the effects of system rotation are combined with those of adverse pressure-gradient. This may be considered to be a boundary layer with two extra rates-of-strain applied.

APPARATUS

The apparatus used in these experiments is essentially the same as that used by Watmuff *et al.* except that an adverse pressure-gradient is imposed by diverging the walls of the test section. Figure 1 shows a schematic plan view of the configuration. The axis of rotation is vertical. A two-stage axial flow fan driven by a DC motor blows air through a rotating coupling along the axis of rotation of the rotating test-section. This flow is turned (using turning vanes) through three corners, passes through a settling chamber with honeycomb, screens and a contraction and then exits through the working section in a radial direction. The working section has an aspect ratio of 2:1 (height:width) and the boundary layer to be studied develops on one of the vertical perspex walls of the working section (the "measurement-wall") which is parallel to the axis of rotation. The two vertical walls are adjusted (diverged) to give an adverse pressure-gradient. In this study the two walls were set at $\pm 4^o$ to the centre-line which results in attached flow when the tunnel is not rotating. At the outlet of the diffuser a screen and a flow deflector are attached in order to reduce the effect of external conditions such as varying wall-proximity on the measurements. An automated traverse is mounted on the wall opposite the measurement-wall which allows for traversing normal to the wall (y-direction) and transversely across the flow (z-direction). This traverse can be mounted at various streamwise (x) positions to study the development of the boundary layer. The tunnel can be rotated in either direction so that the measurement-wall can be subjected to Coriolis forces of either sign. In this way it is not necessary to measure the boundary layers on both walls. If we consider the internal walls of the duct then, when the tunnel is rotated, the wall which proceeds first in the direction of motion (the "leading wall") experiences a lower pressure relative to the other wall (the "trailing wall") and hence the leading wall is referred to as the suction-side wall and the trailing wall as the pressure-side wall. Static pressure measurements have been made using wall pressure tappings. Velocity measurements were made using a pitot-tube of 1mm diameter.

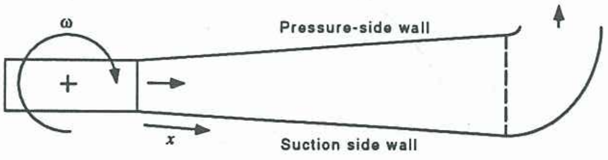

Figure 1: Schematic diagram of experimental set-up.

RESULTS

Measurements were made for eleven different rotation-rates from zero to 2π rad/s. For the sake of clarity only three profiles have been plotted in figures 2 and 3. Each of theses profiles consists of twenty-five static pressure measurements spaced initially at 76 mm with the spacing reduced to 50 mm in the region where separation occurs. When the tunnel is not rotating the flow is attached on both walls but when sufficient rotation is applied separation occurs on the suction-side wall as shown by the sudden drop in pressure-recovery seen on the C_p plots. It may also be noted that the flow appears to remain attached on the pressure-side wall for all rotation cases, but with the pressure-recovery reduced. The reason for this is that the occurrence of a separation-bubble on the suction-side wall leads to an acceleration of the flow on the opposite wall due to the effective reduction in area caused by the presence of the bubble. Spanwise measurements suggest that this separation is essentially two-dimensional in the mean. The conjectured flow pattern is shown in figure 4.

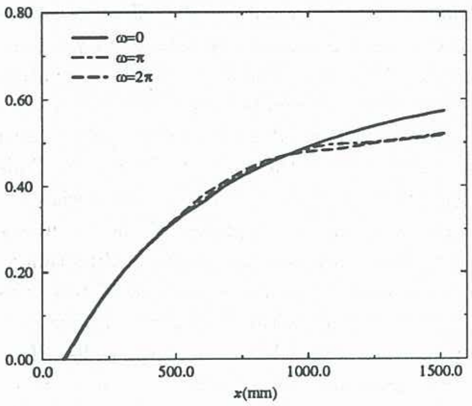

Figure 2: Variation of C_p on suction-side wall for different rotation-rates.

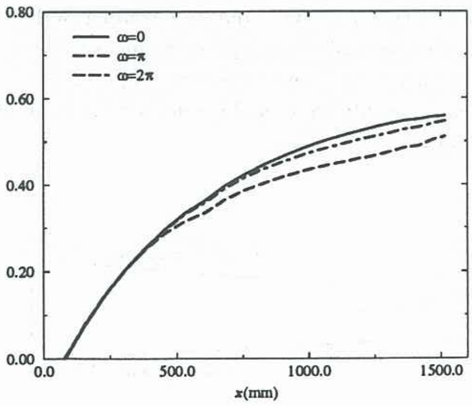

Figure 3: Variation of C_p on pressure-side wall for different rotation-rates.

Another effect of interest is the increase in pressure-gradient which occurs upstream of the bubble on the suction-side wall. This is due to the deflection of the streamlines away from the wall due to the bubble which acts like an obstacle in the flow as shown in figure 4.

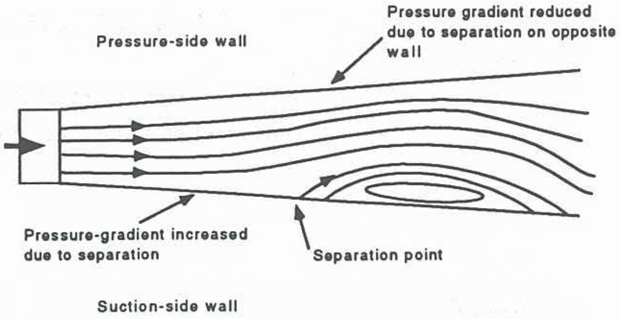

Figure 4: Conjectured flow pattern.

The results also show the movement of the separation point upstream as the rotation is increased. By examining the derivative of the C_p distribution it is possible to locate the separation point as a distinct minimum in dC_p/dx. Although this measure does not identify the separation point explicitly it gives a good estimate of where the flow departs from consistent pressure-recovery and begins to level out. Figure 5 shows the variation of this position as the rotation is increased. The separation point moves upstream with increasing rotation but appears to be asymptoting to a fixed position at large rotation rates. A simple dimensional analysis suggests that an appropriate parameter to describe the effect of rotation near separation is

$$\frac{\omega(x_{sep} - x_o)}{U_1} \tag{1}$$

where U_1 is the local mean velocity, ω is the rotation-rate and x_o is some virtual origin. If we make the assumption that this parameter reaches some critical value, C, at, or near, separation then

$$(x_{sep} - x_o) = \frac{CU_1}{\omega} \tag{2}$$

As ω increases for a given U_1 then we would expect the separation point to move upstream. Measurements show that the variation of U_1 in the region near the separation is not large. If we neglect the variation of U_1 over the range in which the separation point moves (as a first approximation) then we find that the form of the variation should be

$$x_{sep} = \frac{A}{\omega} + x_o \tag{3}$$

where A is some constant. A curve-fit of this function to the data is shown in figure 5. The values of the constants are $A = 0.857$ and $x_o = 0.952$. The value of A corresponds to a value of C of approximately 0.12. Although this behaviour has been derived on dimensional grounds it may be understood physically as due to the effect of finite duct size. A separation bubble which forms is limited in size by the physical constraint of duct size and hence we would expect that when the bubble has grown to some proportion of this width the growth cannot proceed further. This then would suggest an upstream limit to the position of the separation point which is reflected in the analysis since as $\omega \rightarrow \infty$ $x \rightarrow x_o$.

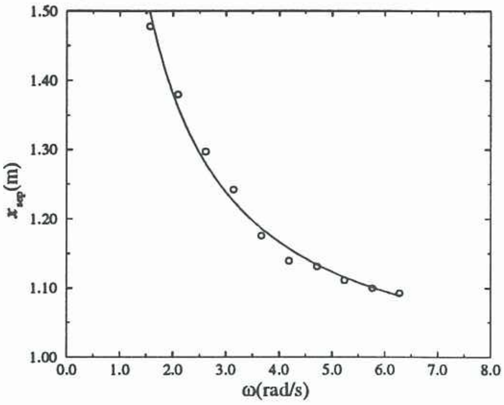

Figure 5: Position of separation point versus rotation rate. Solid line is curve-fit to the data using (3)

CONCLUSION

The occurrence of separation in a rotating diffuser has been discussed based on preliminary measurements of the static pressure distribution. The results show separation occurs when the diffuser is rotated and the separation point moves upstream with increasing rotation-rate. Simple dimensional reasoning gives the correct trend for the behaviour of separation point with rotation-rate. Simple physical arguments give some explanation of the behaviour as being due to finite duct size effects. Further measurements are being undertaken with the aim of gaining a better understanding of the mechanisms involved.

REFERENCES

WATMUFF, J.H., WITT, H.T. and JOUBERT, P.N. "Developing turbulent boundary layers with system rotation", *J. Fluid Mech.*, **157**, 405, 1985. 29-51, 1998.