A Study of Turbulence Effect on Surface Pressures in Separated/Reattaching Flows

Q. S. Li and W. H. Melbourne
Department of Mechanical Engineering, Monash University

1.SUMMARY

An experimental study was conducted to investigate the free-stream turbulence effect on surface pressures on a flat plate with rectangular leading-edge geometry using turbulence - producing grids. The measured mean, standard deviation and peak pressure coefficients are presented and discussed.

2.INTRODUCTION

Numerous wind tunnel studies have been carried out to study the effect of turbulence intensity and scale on the surface pressures on flat plates and rectangular cylinders for the last three decades. In particular these include Vickery(1966), Bearman(1971), Gartshore(1973), Melbourne(1975, 1979), Lee(1975), Hillier and Cherry(1981,1987), Kiya and Sasaki(1983,1985), Nakamura and Ohya(1984, 1987). However, much of these studies have involved extensive measurements in the reattchment zone where the maxmum rms pressure occurs. Saathoff and Melbourne(1987,1989) focused their investigation on the peak pressures which occur in the forward part of the bubble and are primary concern in wind engineering. But the largest ratio of turbulence scale to plate thickness in their studies was less than 2.1. More work is required over a much larger range of turbulence scale to be relevant to the wind engineering field. Although Nagamura and Ozono(1987) investigated the effect of turbulence on streamwise pressure over a large range of turbulence scale, only mean pressures were measured in theirk study.

This paper describes a study of the effect of free-stream turbulence on mean, fluctuating and peak pressure on a flat plate over a larger range of turbulence intensity and scale.

3.EXPERIMENTAL ARRANGEMENTS

The experiments were carried out in a 450kw closed-circuit wind tunnel with a working section 2.0m wide and high in the Department of Mechanical Engineering, Monash University. Free-stream turbulence was generated by using grids, and three grids were used, which had bar widths of 300mm, 100mm,and 35mm, respectively. The ratio of mesh size to bar width was 4.0 for each grid. A blunt flat plate with rectangular cross-section was used for experimental model which had a thickness, D, of 50mm and a chord/thickness ratio, L/D, of 20. The spanwise dimension was 1.6m, giving an aspect ratio of 32. The model was mounted between endplates located 200mm from the each side wall of the tunnel. Wind tunnel solid blockage was 2.5% and the data have not been corrected. The Reynolds number based on plate thickness was approximately 4.5×10^4. Pressure data on the model were collected using Honeywell 163pc transducers connected to pressure tappings with 60mm lengths of PVC tubing with an internal diameter of 1.5mm. Restrictors placed in the tubing provided a flat frequency response within 10% up tp 250Hz. Streamwise pressure distributions were measured using a row of tappings on the centreline of the bottom surface.

4.EXPERIMENTAL RESULTS

Distribution of mean pressure coefficient, C_p, in turbulence and smooth flow are presented in Figure 1. The turbulence flows have two values of turbulence intensity, I_u, of about 8 and 15%, and the ratio of turbulence scale to plate thickness, L_x/D, are over the range from 1.4 to 8.4. It can be seen from the figure that an increase in free-stream turbulence intensity reduces the size of the separation bubble and reduces the minimum value of Cp, as noted by previous researchers. The data presented in figure 1 also show little effect of turbulence scale on mean pressure distribution. However, investigation by Nagamura and Ozono(1987) indicated that mean pressure distributions are scale-dependent for $L_x/D > 2.0$. Fig.2 shows the distribution of reduced pressure coefficients which was proposed by Roshko and Lau(1965) are defined as follows.

$$\tilde{C}_p = \frac{Cp - Cps}{1 - Cps}$$

where Cps is the mean pressure coefficient at the separation point. It is more clearly seen in figure 2 that little scale effect is evident in the mean pressure distributions over the wide range of scale.

Streamwise distributions of standard deviation of pressures, C_{σ_p}, are shown in fig.3 and fig.4. An increase in Iu causes fluctuating pressures to increase and the location of maximum C_{σ_p} to move closer to the leading edge. An increase in Iu from 8% to 15% moves the position of maximums C_{σ_p} upstream from 1.7D to 0.9D. Also C_{σ_p} increases with increasing scale. Saathoff and Melbourne(1987) have shown that C_{σ_p} correlates well with the parameter $\eta = (\sigma_u/u)(Lx/D)^{0.15}$, except at large scales. Figure 5 shows data from Cherry, Saathoff and the present study. Although the amount of data obtained in this study is not sufficient to draw firm conclusion, reasonable correlation was provided by the parameter η over the range of larger turbulence scale.

Streamwise distributions of negative peak pressure coefficient,$C_p{\vee}$ are shown in Fig.6 for smooth and turbulent flow. Since the value of $C_p{\vee}$ depends on the length of sampling record, figure 6 is presented mainly to show the effect of turbulence intensity and scale on the negative peak pressures. The peak pressure coefficients also show a dependence on both turbulence intensity and scale. In particular, the effect of turbulence scale on peak pressures becomes greater as turbulence increases. The mininum value of $C_p{\vee}$ measured in the large-scale turbulence is about four smaller times than that obtained in smooth flow. The peak pressures occur in the forward part of the bubble, and as turbulence intensity increase is to produce a contraction of the bubble length, the position of minimum peak pressure also moves closer to the leading edge.

5.CONCLUSION

Preliminary experiments were condacted to study the free-stream turbulence effect on streamwise surface pressures on a flat plate. Experimental data have indicated that mean pressure distribution are strongly dependent on turbulence intensity but are not significantly affected by turbulence scale over a wide range of large scale. On the other hand, fluctuating pressures are dependent on both turbulence intensity and scale and pressure fluctuatinns near separation correlate well with the parameter, $(\sigma_u/u)(Lx/D)^{0.15}$, even when$L_x/D >> 1.0$. The magnitude of large negative peak pressures also increases with Iu and L_x/D. The effect of turbulence scale on peak pressures becomes greater as turbulence intensity increases.

It is clear that correct modelling of both turbulence intensity and scale is necessary when endeavouring to estimate the highest magnitude of design pressure on structures.

REFERENCE

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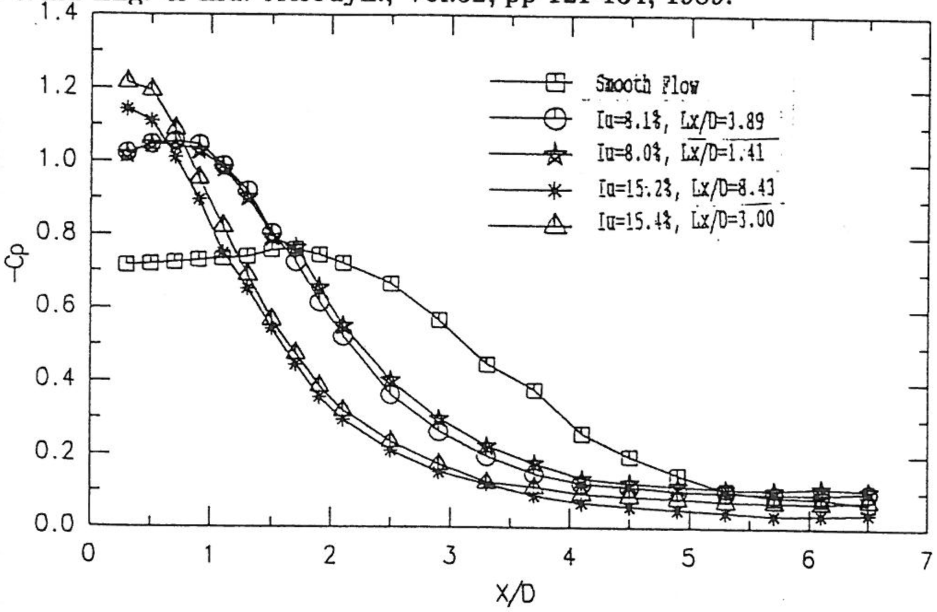

Figure 1. Mean Pressure Distributions On Model Surface In Turbulent and Smooth Flows

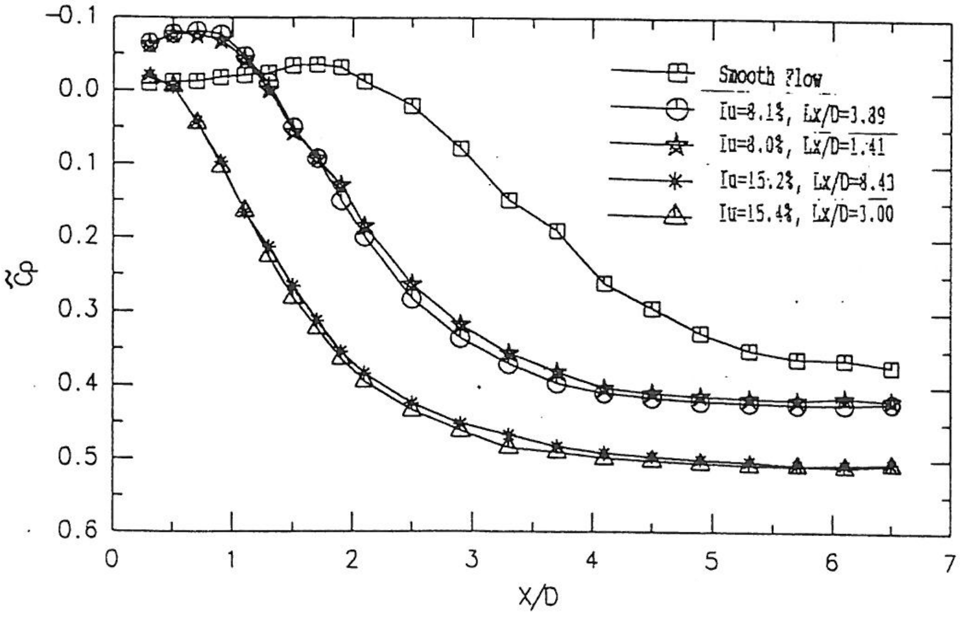

Figure 2. Reduced Mean Pressure Distributions On Model Surface In Turbulent and Smooth Flows

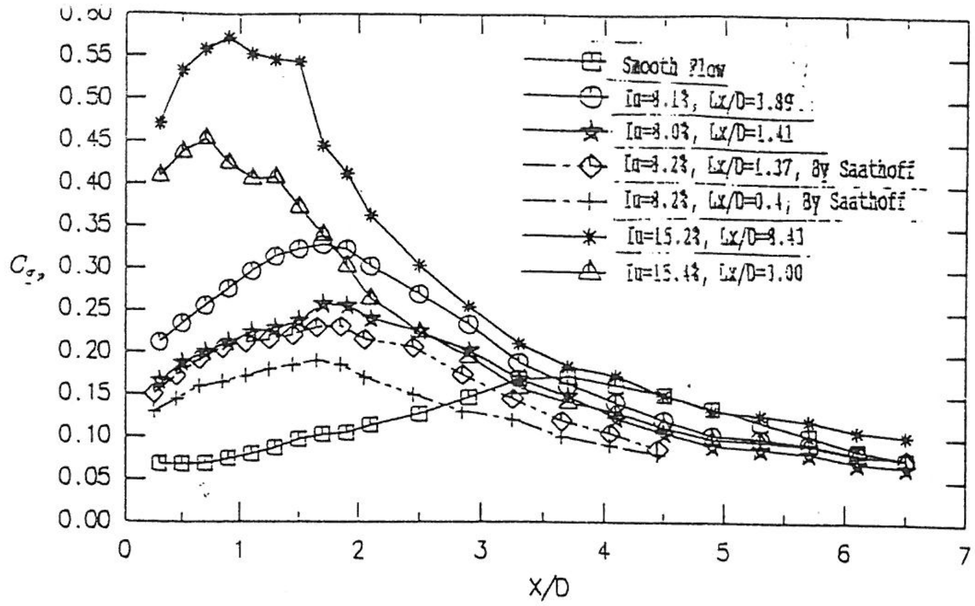

Figure 3. Distributions of Fluctuating Pressure Coefficient In Turbulent and Smooth Flows

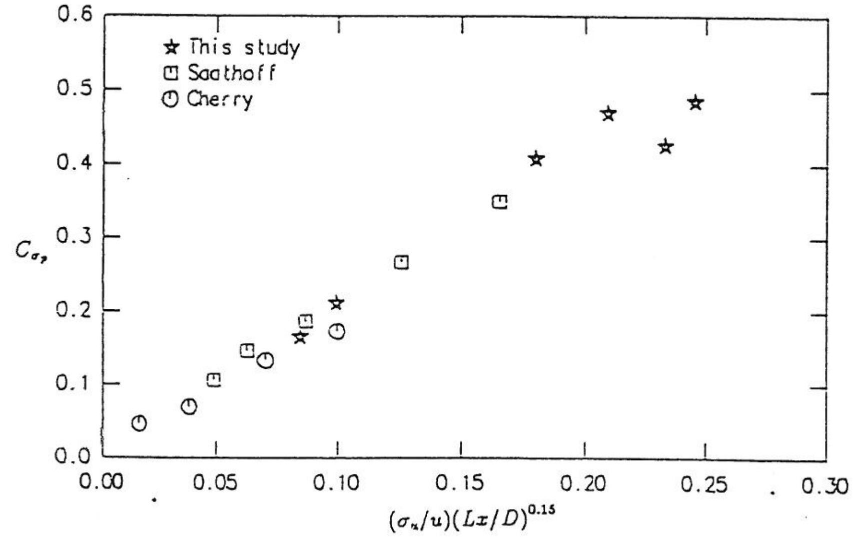

Figure 4. Fluctuating Pressure Coefficient Near Separation As a Function of the Turbulence Parameter, η

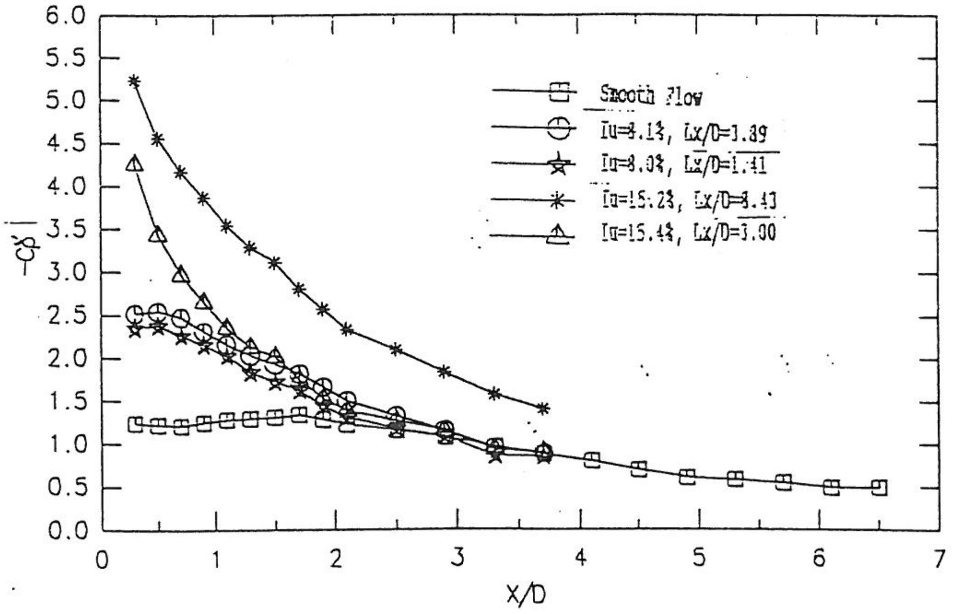

Figure 5. Distributions of Nagative Peak Pressure Coefficient In Turbulent and Smooth Flows