PRESSURES ON SURFACE-MOUNTED RECTANGULAR PLATES

J.D. Holmes*

Introduction

Measurements of normal pressures and form drag on flat plates, normal to an airstream at high Reynolds Number, date back to the classical early study of drag and wake structure of two-dimensional (infinite aspect ratio) plates by Fage and Johansen [1]. Fail, Lawford and Eyre [2] later investigated the drag and wake characteristics of rectangular plates with aspect ratios between 1 and 10. Maskell [3], in the process of deriving blockage corrections for bluff bodies and stalled wings in closed wind tunnels, examined the results from References [1] and [2], and contributed his own measurements on square plates. The corrected values of drag coefficient on rectangular plates in smooth flow, derived by Maskell, were about 1.15 for square plates, and 1.86 for two-dimensional plates.

Arie and Rouse [4] examined the pressures and forces on a two-dimensional plate, with a downwind splitter or tail-plate, to prevent oscillation of the wake; this was a first approximation to the effect of a surface or ground plane. They found a significant reduction in drag coefficient - to a value of about 1.4.

Drag on Plates in Turbulent Boundary Layers

Good and Joubert [5], and Sakamoto and Arie [6], describe measurements on two-dimensional and finite width plates mounted in smooth wall turbulent boundary layers of various depths. Sakamoto and Arie found a minimum drag coefficient at an aspect ratio of 5.

Ranga Ragu *et al.* [7] describe measurements on two-dimensional plates in turbulent boundary layers, and present a graph of drag coefficient, based on friction velocity, as a function of h/z_o, where h is the height of the plate, and z_o is the roughness length. This graph is reproduced in Fig. 1 of this paper. The data points are obtained from many tests in smooth and rough wall boundary layers, with values of h/δ, where h is the height of the fence or plate, and δ is the boundary layer thickness, varying from less than 0.05 to greater than unity.

The drag coefficient C_D^*, based on the friction velocity, u*, can be related to the drag coefficient C_{Dh}, based on the mean velocity at the height of the plate, for plates fully immersed in the region of the boundary layer in which the logarithmic mean velocity profile applies, by the following:

$$C_D^* = C_{Dh} \left[\frac{1}{k} \ln \left(\frac{h}{z_o}\right)\right]^2 \qquad (1)$$

where k is von Karman's constant.

Equation (1) with C_{Dh} equal to 1.1 is a good fit to the data of Ranga Raju *et al.* in the range of h/z_o from 40 to 1000. For h/z_o greater than 1000, the drag coefficients are up to 10% less. This may be due to the effect of low free stream turbulence, although Bearman [8] reports little effect of free stream turbulence on two-dimensional normal plates in unsheared flow.

CSIRO Measurements

Recently, measurements have been made by the Division of Building Research to determine wind pressures and forces on walls or solid fences for structural

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* CSIRO Division of Building Research

design (Holmes [9]). An instrumented plate, of aspect ratio 1.5, was constructed with transmission channels machined within the thickness of the plate on both sides. A total of 48 pressure taps - 24 on each side were provided. The pressure taps were internally manifolded in groups of six, forming a total of eight separate panels - four on each side. Each panel was connected via p.v.c. tubing with small diameter 'restrictors' inserted in the line to a Honeywell 163 pressure transducer so that simultaneous fluctuating pressure measurements were possible. Each pressure measurement system was separately dynamically calibrated using a sinusoidal pressure generator and the restrictors were adjusted to give a flat amplitude frequency response to about 200 Hz. The phase responses were close to linear to 200 Hz and matched for the eight panels.

The panel pressures across the wall were subtracted and the four net panel pressures were added, to give sample records of the fluctuating normal force on the plate. In this way, peak and r.m.s. total forces, as well as mean values, could be determined.

The plate was mounted in a simulated atmospheric boundary layer created by the barrier-roughness technique described by Holmes and Osonphasop [10]. The barrier generates coherent eddy structures of a large scale, which are retained downwind well after the re-attachment of the shear layer shed from the barrier (e.g. Troutt, Scheelke and Norman [11]). At the position of the plate, the longitudinal turbulence scale at the height of the plate (64 mm) is about 400 mm, or more than six times the height of the plate. The value of h/z_o for the simulated boundary layer flow was about 160.

To represent walls of various aspect ratios, the plate was mounted on its own (aspect ratio, 1.5) and with non-instrumented side pieces to form walls of aspect ratios of 5, 10 and approaching infinity. In the latter case, the wall completely spanned the 2 m wide wind tunnel test section.

Table I shows the mean and peak normal pressure coefficients for the wind direction normal to the plate. Corrections for blockage were made using the method of McKeon and Melbourne [12].

Table I
Mean and Peak Pressure Coefficients
for wall section at CSIRO (θ = 0°)

Aspect Ratio b/h	$\bar{C}p$	$\hat{C}_p$
1.5	1.17	3.10
5	1.07	2.81
10	1.04	2.50
∞	1.21	2.53

As may be seen, minimum values of both $\bar{C}_p$ and $\hat{C}_p$ occur at the aspect ratio of 10. This can be compared with Sakamoto and Arie's minimum for the mean total wall drag at an aspect ratio of 5. The value of their minimum drag coefficient, C_{Dh}, was 0.98, when adjusted to a reference mean wind speed at wall height.

The value of $\bar{C}_p$ for the two-dimensional wall at CSIRO, is also shown on Fig. 1, where it lies slightly above the measurements of Ranga Raju *et al.*, which presumably were made in turbulence of considerably lower intensity and scale. However the present result lies within the scatter of measurements of Ranga Raju *et al*.

Conclusions

i) Minimum values of mean and peak normal pressure and drag for surface-mounted plates in turbulent boundary layers occur at aspect ratios of 5 to 10.

ii) Although an apparent collapse of data on drag coefficients or two-dimensional plates, immersed in turbulent boundary layers may be achieved by plotting C_D^* against h/z_0 (Jensen Number), this correlation may disguise variations due to turbulence intensity and scale in the boundary layer. However these variations seem to be small, and over a large range of h/z_0, a constant value of C_{Dh}, based on the mean velocity at the plate height, can be assumed, for practical purposes.

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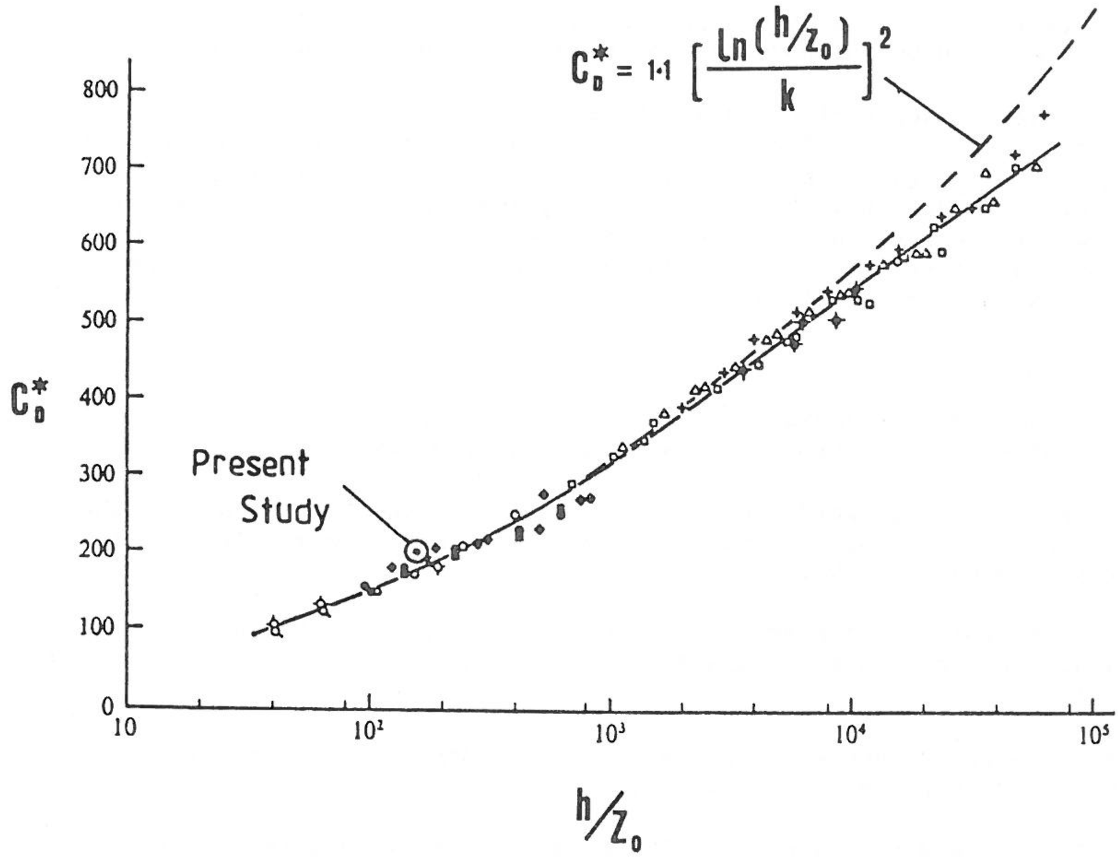

Figure 1. Drag coefficients for two-dimensional walls in turbulent boundary layers (from Reference [7])