Eighth Australasian Fluid Mechanics
Conference, University of Newcastle,
N.S.W., 28 November/2 December 1983.

EFFECTS OF SCALE DISTORTION ON TOTAL LOADS ON SIMPLE GEOMETRICAL SHAPES

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SUMMARY Wind tunnel measurements of total loads in a series of boundary layers on simple three dimensional shapes with pitched roof type sections similar to a low rise building, are presented. Distortion of the integral length scale ${}^{x}L_u$ was difficult to attain without change in turbulence intensity I_u. It was found that plots of the total load coefficients against a non-dimensionalised integral length scale revealed a collapsing of the data for the lower turbulence intensities of 20 to 29 percent. Other plots of the coefficients against turbulence intensity indicated no definite trends towards collapse of the data.

NOTATION

A_x = area of long wall of model (4.2×10^{-3} m^2)
A_y = area of end wall of model (varies)
A_z = area of roof plan of model (14.01×10^{-3} m^2)
C_{F_x} = total horizontal force coefficient ($F_x/\frac{1}{2}\rho \bar{u}_h A_x$)
C_{F_z} = total vertical force coefficient ($F_z/\frac{1}{2}\rho \bar{u}_h A_z$)
C_{M_y} = total overturning moment coefficient ($M_y/\frac{1}{2}\rho \bar{u}_h A_y h$)
d = effective displacement height of zero-plane above ground due to surrounding obstacles
F_x = total horizontal force through centre of model base
F_z = total vertical force through centre of model base
h = wall height of model (constant = 30 mm)
h_1 = ridge height of model (varies)
I_u = turbulence intensity
${}^{x}L_u$ = longitudinal integral length scale
M_y = total overturning moment about axis parallel to longside and through centre of model base
$\bar{u}_h$ = mean velocity at wall height
$\sqrt{\overline{u_h'^2}}$ = r.m.s. fluctuating velocity at wall height
z_0 = roughness length
Λ maximum peak value
V minimum peak value
$-$ mean value
$=$ r.m.s. fluctuating value

1 INTRODUCTION

Wind Tunnel measurements of loads on low rise buildings and structures are normally determined directly or indirectly from wind tunnel measurement. This dependence on wind tunnel measurements requires accurate simulation of the atmospheric boundary layer parameters which is in most cases difficult to achieve thus relaxation of these similarity requirements is accepted. However, the question arises of by how much can the important parameters of turbulence intensity and the longitudinal length scale be relaxed or distorted?

A series of measurements have been carried out on flat plates and prisms by McLaren et. al. (1969), Robertson et. al. (1972), Lee (1976) and Hunt (1982) mainly in low turbulence intensity boundary layers and not directly related to a model building with a pitched roof. Stathopoulos and Surry (1983) examined scale distortion by changing the geometric scaling of low rise building models and concluded that no significant errors in the load measurements occur for a factor of distortion of two. Generally only mean drag and point pressures have been measured, but for the low rise building it is required that maximum and minimum peaks, mean and r.m.s. statistical parameters are to be known.

Still there exists uncertainity in the available full-scale atmospheric boundary layer data of turbulence intensity I_u and longitudinal length scale ${}^{x}L_u$, but Holmes (1978) and Surry et. al. (1978) have found pressure measurements insensitive to scale distortions of about half the accepted full-scale simulation where the maximum model length was less than the peak wavelength of the longitudinal velocity spectrum.

The paper presents results of total horizontal forces, vertical force and overturning moment in the form of peak, mean and r.m.s. coefficients to indicate the effects due to turbulence intensity and distortion of scale in the wind tunnel. Simple three dimensional models with different pitched roof sections were used.

2 EXPERIMENTAL EQUIPMENT

2.1 Wind Tunnel

The wind tunnel is an open circuit type with a 2.5 m wide x 2.0 m high x 17.5 m long test section with a bellmouth entry and straightener tubes. A five-bladed fan driven by a 45 kw A.C. motor together with an exit diffuser are downwind of the test section. This is described in detail by Holmes (1977).

2.2 Models and Force Balance

Models of a simple house on the ground type building at 1/100 scale were used. These were 70 mm wide x 140 mm long with a wall height of 30 mm. Four different gable ended models with pitch roofs of 10, 15, 20, 30 degrees with 12 mm verges along the longside and 4.5 mm along the short sides were used. The roof ridge was central and parallel to the longside of the model.

A force balance for measureing total loads was set up with all the models. This balance is described in detail by Roy (1982). Static calibrations of the models and balance gave a weighting coefficient matrix for use in digitising the on-line analogue signals from the balance transducers/amplifiers after passing through 50Hz. low-pass filters. The weighting of digitised data from the transducers gave the three force and moment parameters about the centre of the model base. Digitisation was carried out at 300 Hz for an 18 second duration.

3 EXPERIMENTAL RESULTS

3.1 The Boundary Layers

Table 1 shows the characteristics of the five simulated atmospheric boundary layers. A fetch of carpet together with a 250 mm high plain fence was used to generate the boundary layers. These correspond to B1, B2, B3, B4 and B5 for the fence locations of 4.0, 5.5, 7.0, 8.5 and 10.0 m respectively from the model.

The average turbulence intensities of B1 and B2 are high and would be boundary layers with regions of unsteady motion and flow reversal which cannot be determined by a hot film probe (Melbourne 1978). Consequently a false turbulence intensity value is measured which is conservatively high. However, the measured turbulence intensities in B1 and B2 although suspect have been used in the data to give an approximate indication of these intensities.

The longitudinal length scales ${}^xL_u$ shown in Table 1 have been determined by the empirical relationship from E.S.D.U. (1974)

$$ {}^xL_u = \frac{25(h-d)^{0.35}}{z_0^{0.06}} \qquad (1)$$

where d = 0 and z_0 was determined from logarithmic plots of the mean velocity profiles.

TABLE 1

BOUNDARY LAYER CHARACTERISTICS

Boundary Layer	$I_u = \sqrt{\overline{u'^2}}/\bar{u}_h$ (%)	z_0 (mm)	${}^xL_u$ (mm)
B1	54	0.060	507
B2	29	0.100	491
B3	22	0.104	489
B4	19	0.136	481
B5	20	0.380	451

3.2 Results

A set of twenty total load measurements for the direction normal to the longside and ridge of the model were made for each boundary layer and averaged to give with confidence, values of the peak, mean and r.m.s. statistics. This was carried out for the four pitched roof models. In all cases the Reynolds number, based on the model wall height of 30 mm and the wall height velocity, increased from about 10^4 to 2×10^4 for the boundary layers B1 to B4 respectively and then decreased to a value close to that in B3 for B5.

Plots of a set of the horizontal and vertical forces and overturning moment coefficients are shown in Figures 1(a), 1(b) and 1(c). Similar plots are shown in Figure 2(a), 2(b) and 2(c) for the force and moment coefficients against the non-dimensional ratio of the length scale ${}^xL_u$ and the model ridge height h_1.

4 DISCUSSION

Figures 1(a), 1(b) and 1(c) of horizontal force, vertical force and overturning moment coefficients respectively plotted against turbulence intensity show no definite trends in collapse of the data, although there is a grouping of the data and an indication of a decrease or an increase with increasing turbulence intensity. Lee (1976) plotted base pressure against turbulence intensity (of the range 3 to 13 percent) for square prisms and found a similar relationship that there was no collapse of the data with the parameter of turbulence intensity.

Figures 2(a), 2(b) and 2(c) show contour plots of the scales against the forces and moment coefficients corresponding to the different turbulence intensities. Clearly those which are adversely affected correspond to the high turbulence intensity and do not collapse with the data from the boundary layers of low turbulence intensity (i.e. 20 to 29 percent). This occurs for all cases of peaks, mean and r.m.s. coefficients and for all the four models. It would be of interest to have measurements between the two high turbulence intensities although the trends do indicate that a family of curves is likely.

With an increase in scale in Figure 2(a) there is a general decrease in C_{F_x}. $\overline{C}_{F_x}$ decreases about 60 percent with increase in scale and decrease in roof pitch from 30 to 10 degrees. This is of note particularly with reference to loads derived from wind tunnel tests, however the horizontal force must be considered also together with the vertical force and overturning moment to obtain an optimum load combination. Lee (1976) showed a set of curves for base pressure against scale (in a similar range), for a square prism. Each of Lee's curves had a peak compared with the nearly linear curves in Figure 2(a). The total horizontal force in Figure 2(a) indicates possibly the effect of low correlation between the windward wall and leeward or base wall pressures, however, a direct comparison is difficult to make because of the difference in the range of turbulence intensities between the two tests. Further data at different length scales is required to confirm the generally accepted increase in mean drag or horizontal force with a reduction in the local turbulence intensity, and conversely a reduction in the mean drag at lower length scales, (Lee 1976).

In Figure 2(b) the vertical force increases with scale of turbulence and again the very high turbulence in B1 removes these data from the collapsed curves. The mean is affected most and is shown increasing about 40 percent with increase in scale and decrease in roof pitch. Clearly the change in roof pitch from 10 to 30 degrees is most sensitive to the mean vertical force which in turn contributes to the mean overturning moment, however, the sensitivity is generally not high for each model although for the low mean vertical force $\overline{C}_{F_z}$ (Figure 2(b)) at low scales there is about a 40 percent change in the coefficient on the 30 degree model.

Overturning moment shown in Figure 2(c) plotted against length scale is a representation of the influences of both horizontal and vertical forces in overturning the model. Similarly for the horizontal and vertical forces in Figure 2(a) and 2(b) the influence of the high turbulence intensity of B1 does not allow collapse of these data onto those of B2, B3, B4 and B5. Also for the low mean overturning moment $\overline{C}_{M_y}$ (Figure 2(c)), as was the case with the low vertical force, the 30 degree model has a 35 percent change in the coefficient at low scales.

Results in all cases shown in Figures 2(a), 2(b) and 2(c) for the lower turbulence intensity (20 percent) and scale (451 mm) in boundary layer B5 show a slight difference compared to those results in B2, B3 and B4. However, generally the data collapses for the results in B2, B3, B4 and B5 boundary layers.

5 CONCLUSION

Total loads determined from wind tunnel tests in a set of five different boundary layers have been presented for a set of low rise building type models with various pitched roof sections. Some effects have been noted, particularly those of the highly turbulent boundary layer where turbulence intensity is difficult to measure with reasonable accuracy. The results corresponding to this high turbulence did not collapse with those of the boundary layers of lower turbulence intensities when plotted against the integral length scale.

Distortion of the integral length scale ${}^xL_u$ does not have a significant effect on the total loads including the statistical parameters of maximum and minimum peak, mean and r.m.s. for the range of integral length scales investigated. However, some sensitivity to scale and turbulence intensity was found in the low mean vertical force, $\overline{C}_{F_z}$ (Figure 2(b)), and the low mean overturning moment, $\overline{C}_{M_y}$ (Figure 2(c)), which was of the order of 40 percent and 35 percent respectively for conditions of low integral length scales in the range considered.

Further investigation with attempts at keeping turbulence intensity reasonably constant while the integral length scale is varied and similarly keeping the integral scale constant while the turbulence intensity is varied for reasonably large ranges in both cases is desired, but this may be impossible to achieve.

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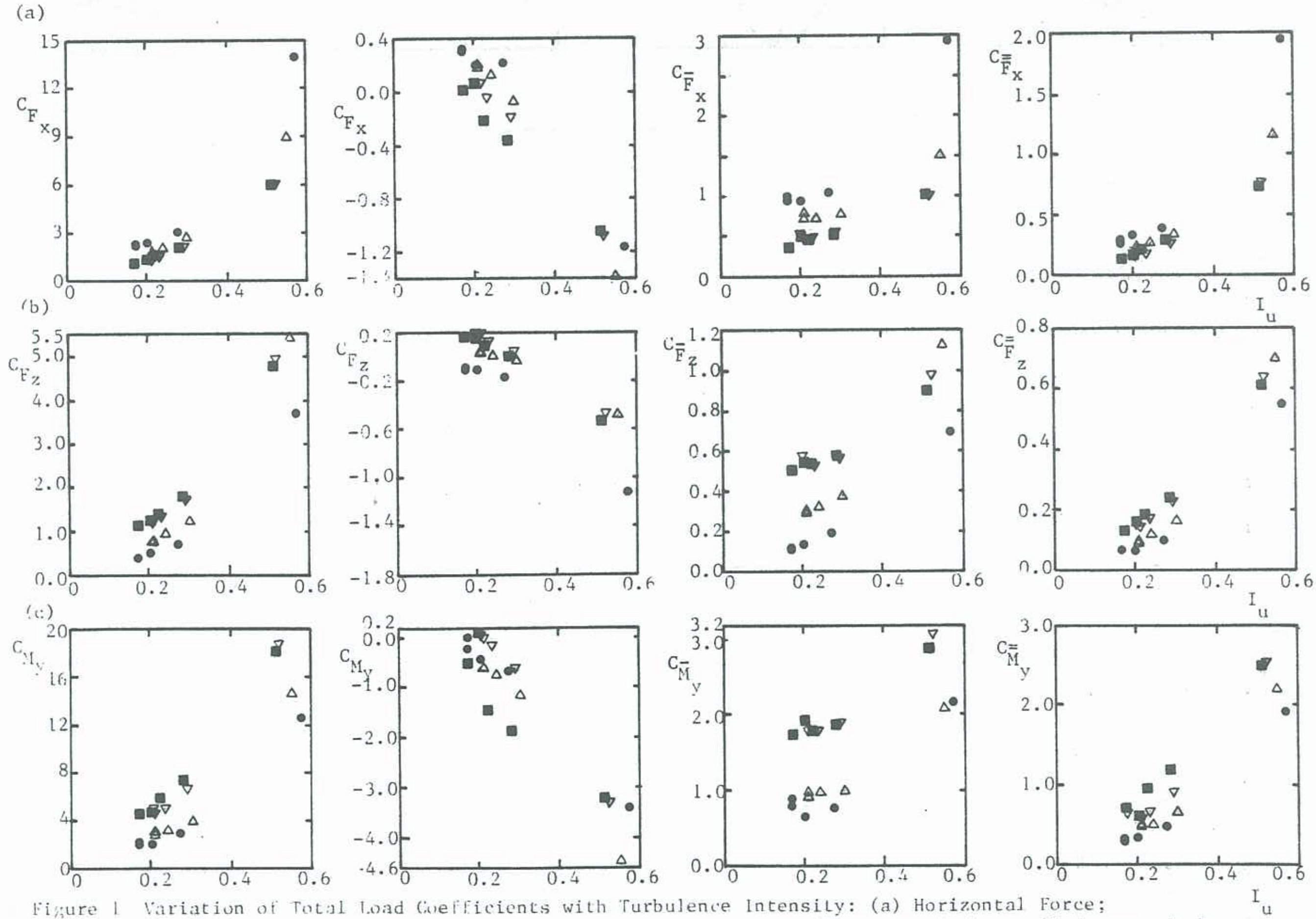

Figure 1 Variation of Total Load Coefficients with Turbulence Intensity: (a) Horizontal Force; (b) Vertical Force; (c) Overturning Moment; Model type: ■, 10 degree pitch; ▽, 15 degree pitch; △, 20 degree pitch; ●, 30 degree pitch.

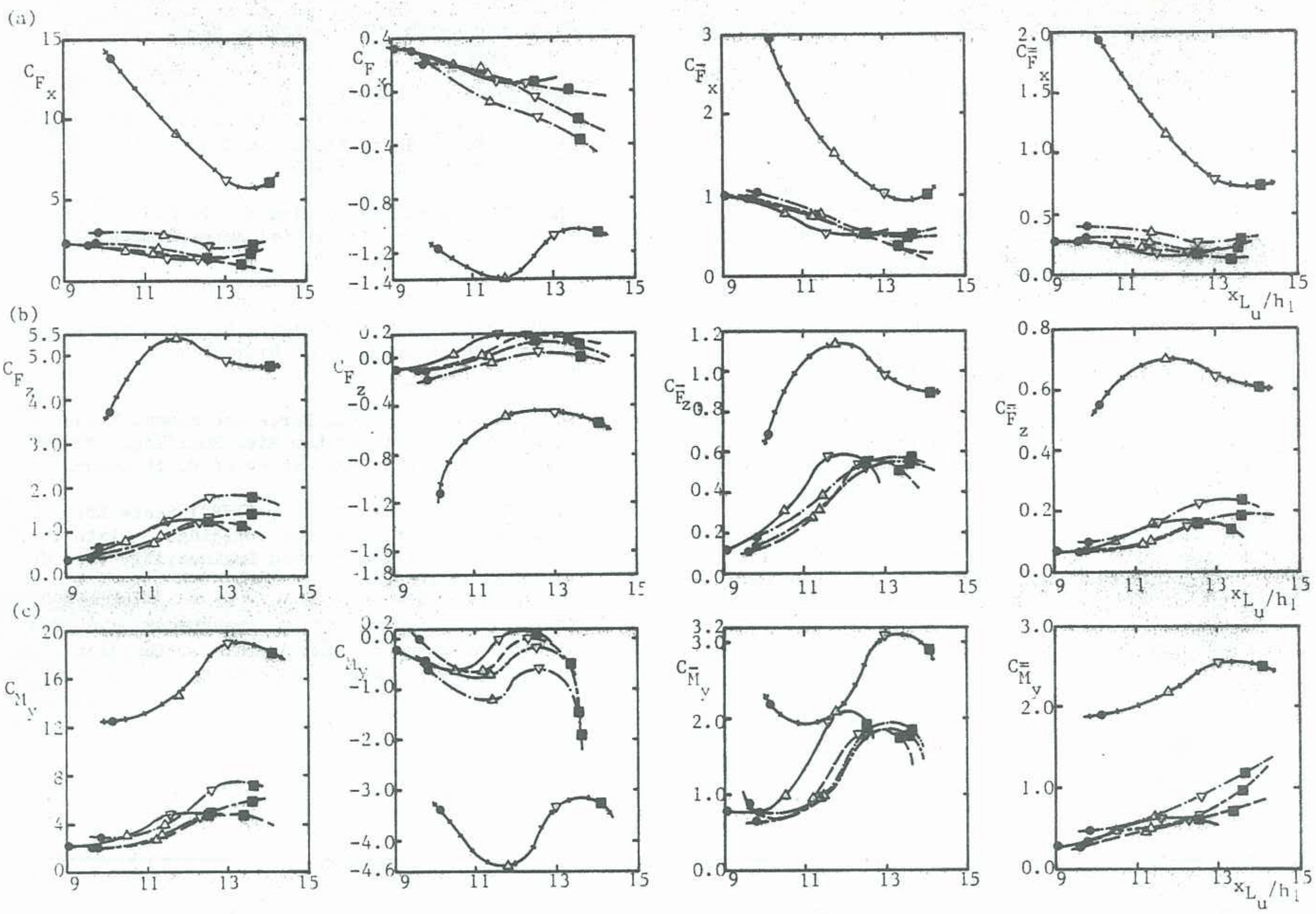

Figure 2 Variation of Total Load Coefficients with Length Scale ^xL_u: (a) Horizontal Force; (b) Vertical Force; (c) Overturning Moment. Boundary Layers: —+—+— B1; —··— B2; —·—·— B3; — — — B4; ——— B5. (Refer caption in Figure 1 for symbol representation.)