Pressure Measurements on Wind Tunnel Models of the Aylesbury Experimental House.

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Abstract

Further measurements of wind pressures on models of the experimental Aylesbury house of the Building Research Establishment (U.K.) are presented. Following a previous paper in which mean pressure coefficients only were compared, this study compares fluctuating pressures as well. In these tests, the upwind hedges of the full scale site were modelled, but found to cause little difference to the velocity profiles and to the measured pressures.

1. Introduction

This paper describes some further wind tunnel measurements of wind pressures on models of the Aylesbury experimental house, carried out at James Cook University. The Building Research Establishment (U.K.) obtained a large amount of field data on the prototype house[1,2].

In a previous paper[3], mean or time-averaged pressures on 1/50 scale models of the Aylesbury house were reported and compared with corresponding full scale data. The comparison showed generally favourable agreement, although there was clearly considerable internal scatter in the full scale results. It was suggested that differences in the mean velocity profile may have also affected the comparison, since the reference mean velocity was at about twice the height of the house, and the hedges upwind of the experimental house at the full scale site were not modelled in the wind tunnel.

The main purposes of this paper are, firstly, to present fluctuating pressure data for comparison with full scale, and secondly, to make a quantitative comparison of the James Cook wind tunnel data with similar results from other wind tunnels. In addition, a closer attention to the effect of differences in velocity profiles on the comparisons, including the effect of modelling the hedges present at the full scale site, is given in the present paper.

Section 2, following, is a brief discussion of the experimental methods used for the present results. In Section 3, the results of several velocity profile measurements in both full and model scale are summarised. In the case of the wind tunnel results, the effects of modelling the full scale hedges, by means of wire mesh gauze, are discussed. Section 4 is a statistical comparison of the 1/50 scale model James Cook results with full scale for selected cases. As well as mean pressure coefficients, coefficients of the fluctuating pressures were compared: root-mean-squared fluctuating and peak pressure coefficients. In Section 5, wind tunnel measurements are compared. The 1/50 scale measurements from James Cook are compared with mean pressures from a 1/100 scale model. In addition, the 1/50 scale measurements are compared with wind tunnel results from Oxford University (U.K.), the University of Western Ontario (Canada) and C.S.T.B. (France).

2. Experimental Methods

2.1 The Wind Tunnel

The model tests were carried out in an open-circuit boundary layer wind tunnel with test section dimensions: height, 1.9-2.1 m (adjustable); width, 2.5 m; length, 13.5 m. The axial flow fan of 2.4 m diameter, is driven by a 45 kW AC electric motor through a five-speed gearbox and a pulley-belt transmission system. The fan is mounted downwind of the test section, and exhausts through a 3.7 m long diffuser. For the test described herein, the gearbox was set in fourth gear giving mean flow velocities near the model heights of 10-12 m/s.

A full description of the wind tunnel has been given previously[4].

2.2 The Models

Separate models of the Aylesbury house (full scale dimensions: eaves height 5.3 m; width 13 m; length 7 m) were made for roof slopes of 10° and 22½°. Most of the results described herein were obtained from 1/50 scale models of the building but some measurements from a 1/100 scale model were also obtained and are described in Section 5.1.

The models were made from 5 mm thick "perspex" with pressure taps made from 10 mm lengths of stainless steel hypodermic tubing of 1 mm I.D. The tubing was inserted into holes drilled in the model's walls and roof until flush with the outside surface, and fixed with adhesive.

For the tests on the 1/50 scale models, the pressure taps were connected by 450 mm of 1.5 mm I.D. vinyl tubing to 2 'Scanivalve' pressure scanning devices, each containing a 'Setra' 237 miniature pressure transducer. Halfway along the length of the tubing a brass "restrictor" of 0.3 mm diameter and 3 mm length was inserted in the line to improve the frequency response characteristics of the pressure transmission system.

2.3 Data Acquisition

Fluctuating voltages from the pressure transducers, and from the T.S.I. linearised hot-film anemometer system used for the velocity measurements, were sampled digitally using a 10-bit analogue/digital converter with a PDP8/E mini-computer system (Figure 1). The sampling rates were normally 400 Hz and 8192 points were sampled for each channel, giving a total record length of 20.48 seconds. A running total of sums, sums of squares and maximum and minimum values was kept, thus obviating the need for storing the data. Further processing, including correction for zero drift of the pressure transducer and hot-film anemometer, and calibration drift of the hot-film anemometer, was carried out on a larger DEC-10 machine.

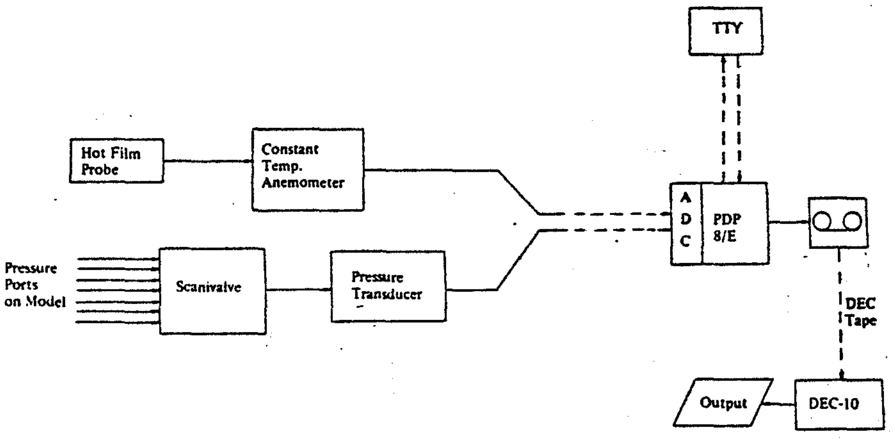

Figure 1 Instrumentation block diagram

2.4 Boundary Layer Simulation

The method of simulating strong wind turbulent boundary layer flow over rural terrain was the same as that used for the previous tests on the Aylesbury house[3] and for other measurements on house models carried out in the wind tunnel[5,6]. Surface roughness, consisting of carpet, covers the floor of the test section up to the turntable, and a solid fence spans the tunnel at the start of the test section. For the 1/50 scale tests the fence height was 300 mm and for the 1/100 scale tests reported in Section 5.1 a 200 mm high fence was used. Basically, the carpet roughness provides the correct mean velocity profile, and the fence superimposes turbulence of a large scale to give adequate flow properties in comparison with full scale measurements. Basic velocity measurements for comparison with standard full scale data given in a previous report[4]. Additional data was obtained to investigate the effect of some upwind hedges at the full scale Aylesbury site, and is reported in Section 3.

Information on the heights and location of the hedges at the full scale site was available, but none on their porosity. Since most of the full scale pressure measurements used for comparison were obtained in winter-time, it was likely that the hedges would be relatively porous. The hedges were modelled in the wind tunnel by lengths of steel wire gauze mesh of scaled height; the porosity was about 50%.

Figure 2 shows one of the 1/50 scale models with the upstream fetch and hedge modelling for one particular wind direction as described above.

2.5 Reference Velocity and Static Pressure

The results of the pressure measurements described later in the report are expressed in the form of non-dimensional pressure coefficients:

$$C_p(t) = \frac{p(t) - p_0}{\frac{1}{2}\rho \overline{u}_r^2} \qquad (1)$$

where p(t) is the fluctuating pressure at a point on the surface.

The reference velocity, $\overline{u}_r$, for all the measurements described in this paper is the mean velocity in freestream at a height of 10 m in full scale, or at an equivalent height in the wind tunnel (200 mm for a geometric scale of 1/50). In the full scale case, the reference mast was about 30 m to the south-east of the experimental house. The wind tunnel reference position was an equivalent position to this for a wind direction, θ, relative to the N-S axis of the building, of 235°; for other wind directions it was slightly displaced.

The reference static pressure, p_0, was, in the full scale case, from a manhole some distance downwind of the experimental house. In the case of the wind tunnel tests, the reference static pressure was chosen to be that at the reference height as described above. In practice however, the pressure transducers were vented to the static pressure holes in a pitot-static tube mounted in a relatively low turbulence region near the top of the tunnel. In a separate test, a profile of static pressure through the boundary layer was obtained by traversing a second pitot-static tube vertically. From this test, a small correction was obtained to correct the building pressure coefficients to the static pressure at the reference height.

3. Velocity Characteristics and Effect of Hedges

3.1 Profiles Without Hedges

Figure 3 shows the profiles of mean velocity and longitudinal turbulence intensity from the wind tunnel reference position. In addition, full scale data is shown for wind directions, parallel or nearly parallel to the line of the main 5 m hedges; in these cases, the effect of the hedges on the profiles can be taken as negligible. Profiles based on the logarithmic law, with a roughness length of about 35 mm in full scale (0.7 mm in the wind tunnel) are reasonable fits to the measured data. The E.S.D.U. curve in Figure 3(b) is derived from data recommended by the Engineering Sciences Data Unit[7], and based on existing full scale data from a number of sources. The modifying factor, F_u, is a function both of roughness length, z_0, and height, z:

$$F_u = [0.867 + 0.556 \log_{10} z - 0.246 (\log_{10} z)^2] [0.76/z_0^{0.07}] . \qquad (2)$$

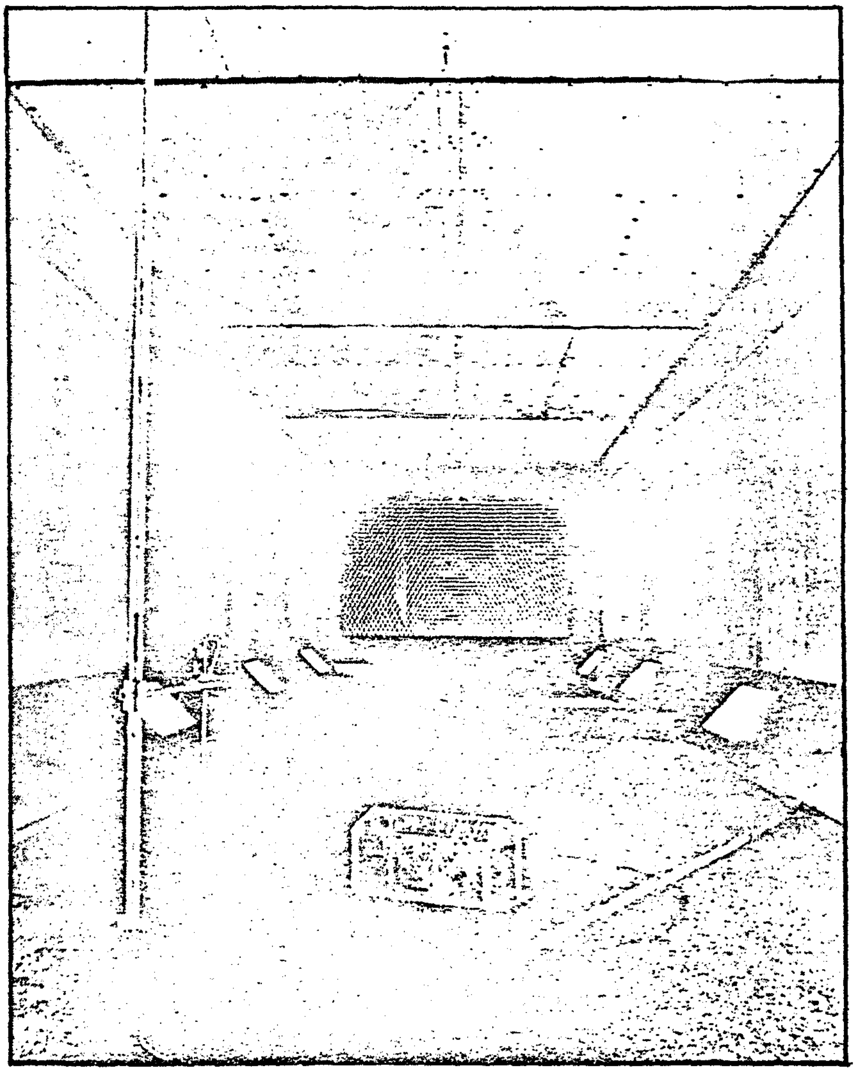

Figure 2 Model with upstream fetch for $\theta = 235^\circ$

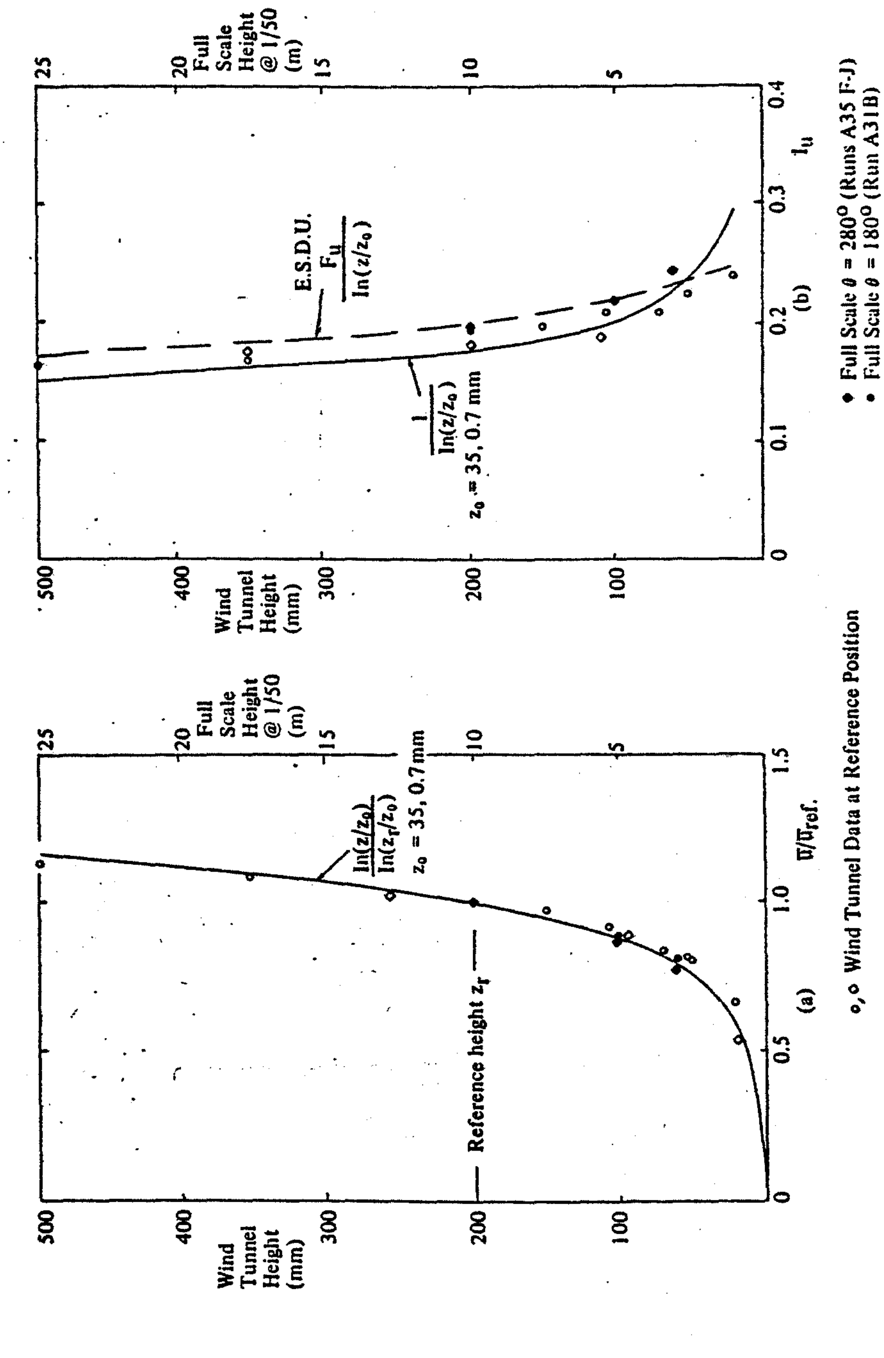

Figure 3 Mean velocity and turbulence intensity profiles

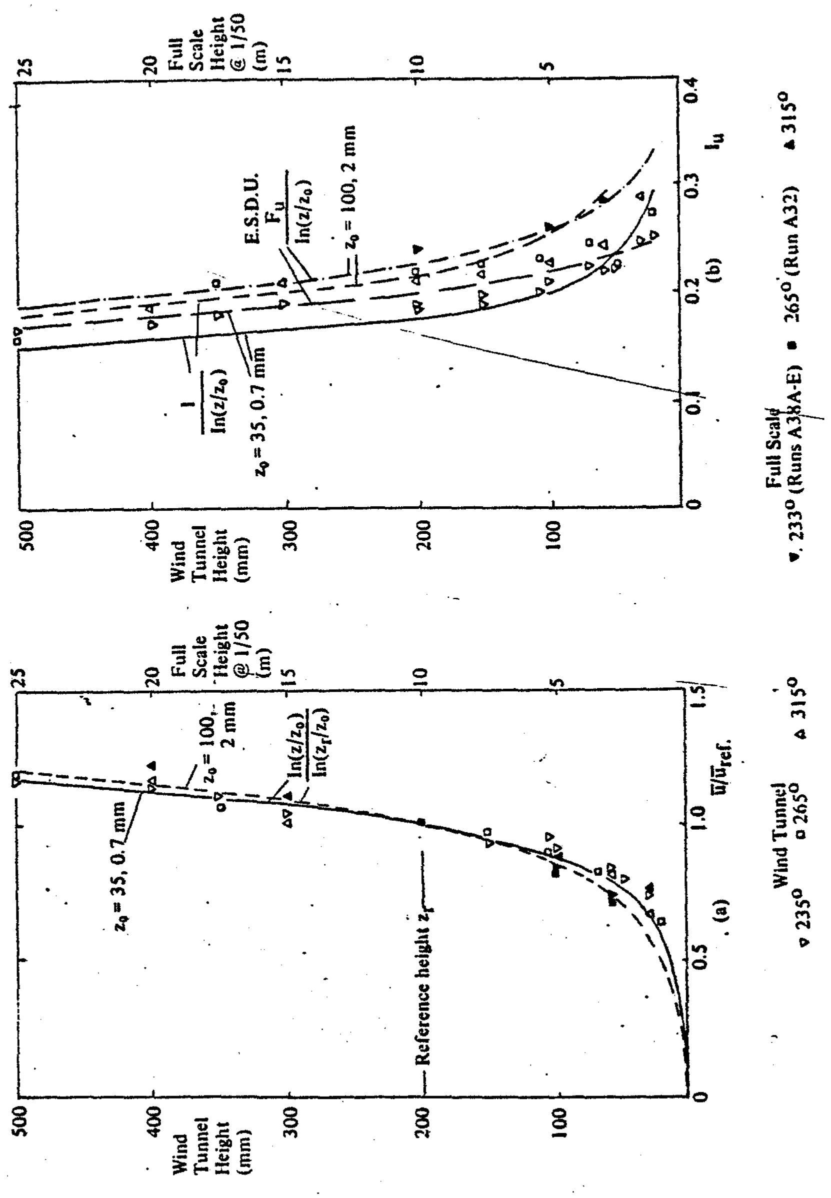

Figure 4 Mean velocity and turbulence intensity profiles – effect of hedges

3.2 Effect of Hedges

The effects of hedges on the profiles, both full scale and model, are shown in Figure 4. The full scale data appears to show a significant effect due to the hedges. For wind angles of 233° and 265°, the profiles show an increase of effective roughness length by a factor of about 3 to 100 mm.

The wind tunnel results, however, show much less effect from the modelled hedges. The absolute mean velocities show a significant shelter effect but this effect extends up to the reference height of 200 mm and the relative velocity ratios below that height are changed little. There is some increase in turbulence intensity but this is significantly less than those recorded in full scale, although there are limited data available in the latter case.

Although possibly better agreement with the full scale profiles could have been achieved by varying the porosity of the modelled hedges, it was decided to proceed with the pressure measurements using the model hedges as described and to assess the results keeping the small differences in profiles in mind.

3.3 Velocity Spectrum

A comparison of longitudinal velocity spectra from full scale and the wind tunnel was made previously[3] for a full scale height of 10 m. Figure 5 shows the spectrum from the wind tunnel at close to the eaves height of the model compared with a standard Von Karman-Harris curve using a peak wave length λ_u derived from E.S.D.U. data[7].

4. Model/Full Scale Comparison

4.1 1/50 Scale Model Results

Results were obtained from the 22½° roof slope model for wind directions of 180°, 235° and 265° and from the 10° roof slope for a wind direction of 235°.

Results are given in the form of pressure coefficients with respect to the mean velocity at a scaled height of 10 m, i.e. 200 mm in the wind tunnel, as discussed in Section 2.5. As for the full scale data, results are given in the form of mean pressure coefficient $\overline{C}_p$, root-mean-square fluctuating pressure coefficient C_p' and peak pressure coefficient $\hat{C}_p$. The latter is defined as the larger in absolute magnitude of the maximum or minimum pressure coefficient at any point.

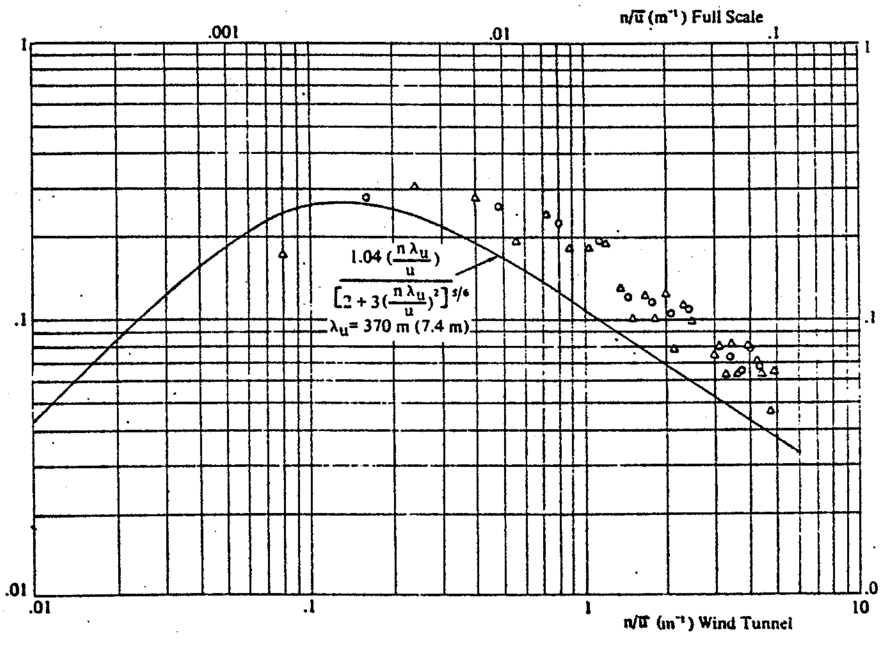

Figure 5 Longitudinal velocity spectrum at 100 mm height in wind tunnel

4.2 Mean Pressures

A graphical comparison between the mean pressure coefficients from full scale and the 1/50 scale model (with hedges) is shown in Figure 6. As expected from the small effect of the modelled hedges on the profiles, the model mean pressure coefficients were very similar to those measured previously[3]. A linear regression of $\bar{C}_p$ full scale on $\bar{C}_p$ model was carried out and the resulting line is shown in Figure 6. Although positive conclusions cannot be drawn, because of the relatively low correlation coefficient of 0.79, it appears from the intercept, that there is little difference in the static pressure reference used for the two sets of results.

The slope of the line however indicates that the full scale pressure coefficients are, on average, about 30% less than the model values. Since the pressure coefficients are defined with respect to the mean velocity at 10 m, or equivalent model height, differences in the mean velocity profiles would cause differences in the magnitudes of all the coefficients. However, the profile differences indicated by Figures 3(a) and 4(a) would explain only about 10% of the difference in slope from unity in Figure 6.

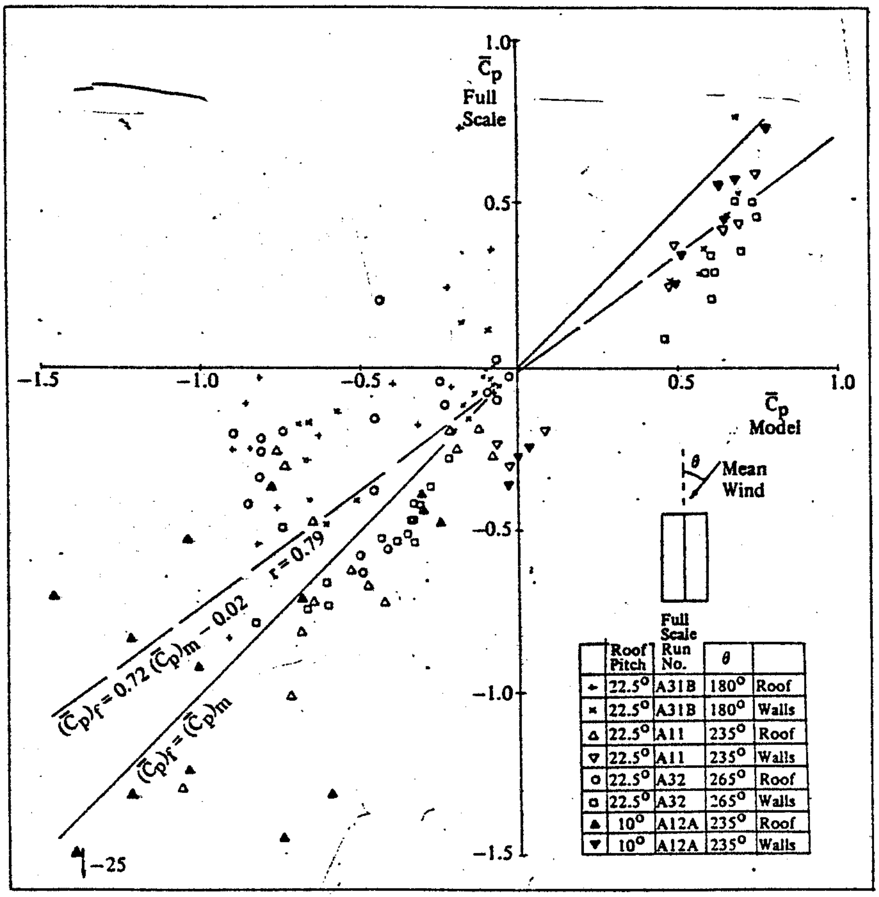

Figure 6 Model/full scale comparison – mean pressure coefficients

If the difference in Reynolds Number had any effect on the comparison, it might be expected to show up on the suctions in the separated flow regions. However no consistent difference appears in Figure 6. The only observation that can be made is that for wind directions near normal to a face the highest roof suctions are higher on the model. On the other hand, for the oblique wind direction of 235°, the full scale suctions are higher.

The full scale data shows considerable scatter when comparing two full scale runs (A7 and A32) of the same roof slope and wind direction as observed previously[3]. This probably explains satisfactorily the remaining differences in the

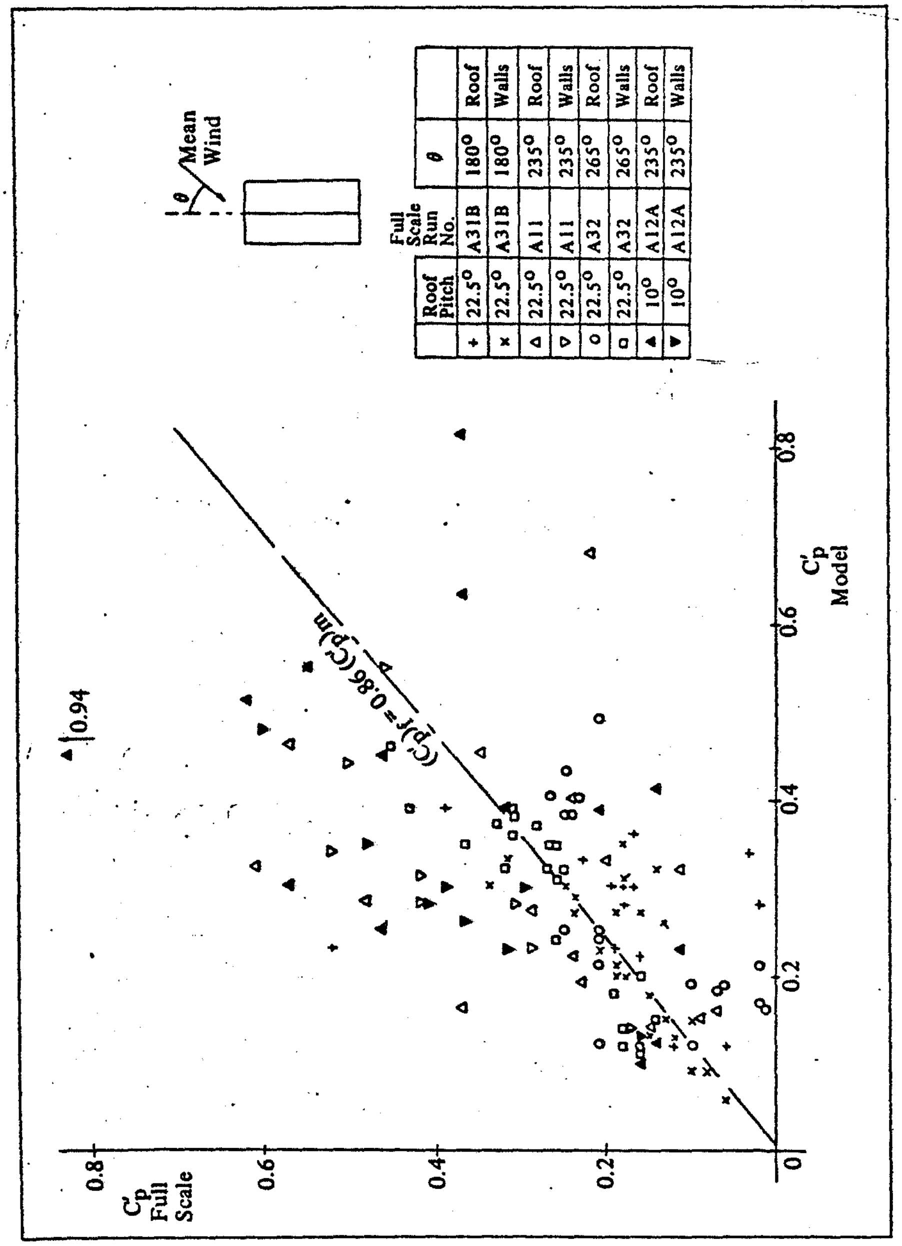

Figure 7 Model/full scale comparison – R.M.S. fluctuating pressure coefficients

slope of the regression line and the scatter in Figure 6. The internal scatter of the full scale data is probably inevitable with field measurements of this type. Possible sources are –

(i) Fluctuations in the reference pressure to which the backs of the transducers are vented;

(ii) Uncorrected zero drifts in the pressure transducers;

(iii) The presence of 'trends' (i.e. low frequency components of period longer than the length of the records);

(iv) Changes in wind direction or other atmospheric conditions.

4.3 Fluctuating Pressures

A comparison of r.m.s. fluctuating pressure coefficients is shown in Figure 7; peak pressure coefficients are compared in Figure 8.

Linear regression lines have also been drawn in both figures. However for the r.m.s. fluctuating coefficients, the line has been forced to go through the origin since it is not possible for C_p' to be negative.

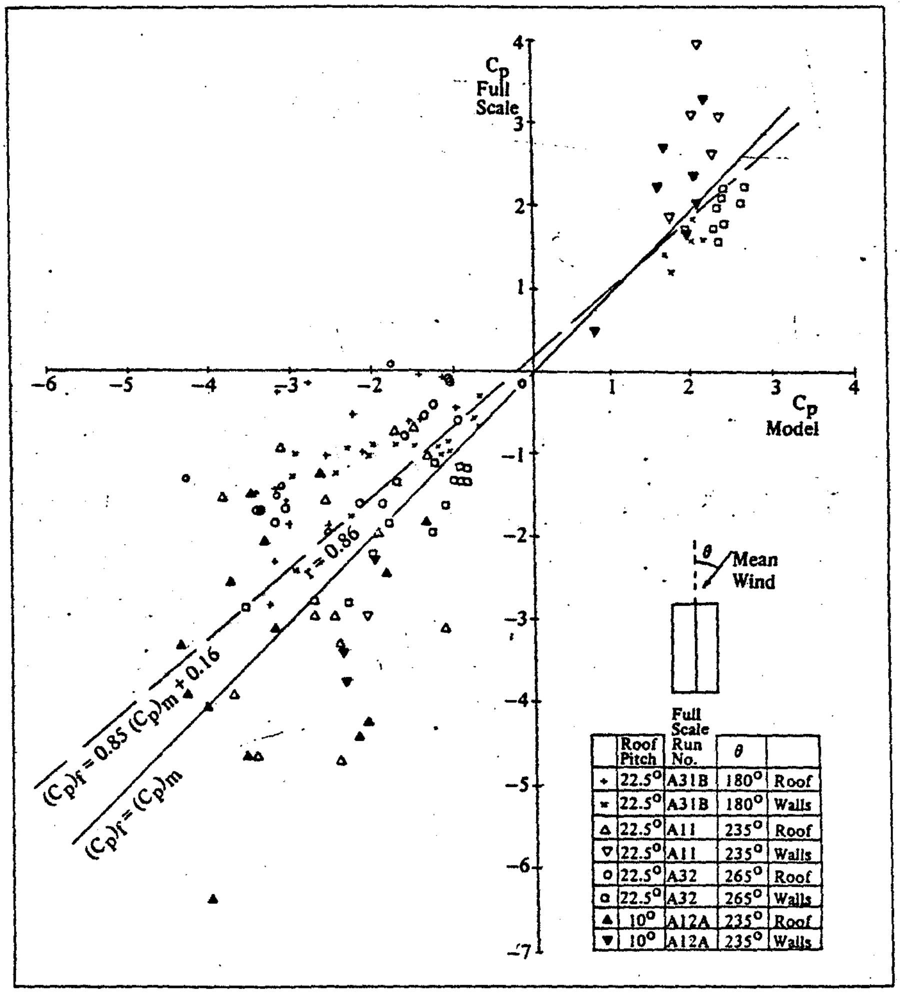

Figure 8 Model/full scale comparison – peak pressure coefficients

Similar scatter occurs, as for Figure 6, in the comparison of the fluctuating pressures. The only observable trend is that there is again a tendency for the full scale coefficients to be greater than model values for the wind direction, θ, of 235°, with the reverse the case for directions normal to the faces. It would be difficult and unwise to attribute a physical reason for this, however, and the internal scatter in the full scale data is again emphasised.

5. Model/Model Comparison

5.1 Comparison with 1/100 Scale Model

Mean pressures were obtained from a 1/100 scale model of the 22½° slope model. However, no attempt was made to reproduce the effect of the hedges in this case. A comparison for three wind directions is shown in Figure 9. The linear regression line showed a slope of 0.89; this can be related to the slight difference in relative profiles for the two tests. A high correlation is shown consistent with the expected small random errors in the measurements.

5.2 Comparison with Wind Tunnel Tests from Elsewhere

Some data was available for the 22½° case from Oxford University[8], from the University of Western Ontario[9] and from the C.S.T.B. (France)[10], enabling comparisons to be made with the James Cook 1/50 scale measurements; these are made graphically in Figures 10-13. A complete tabulation of the mean pressure coefficients for the case of $\theta = 265°$ is also given in Tables I and II.

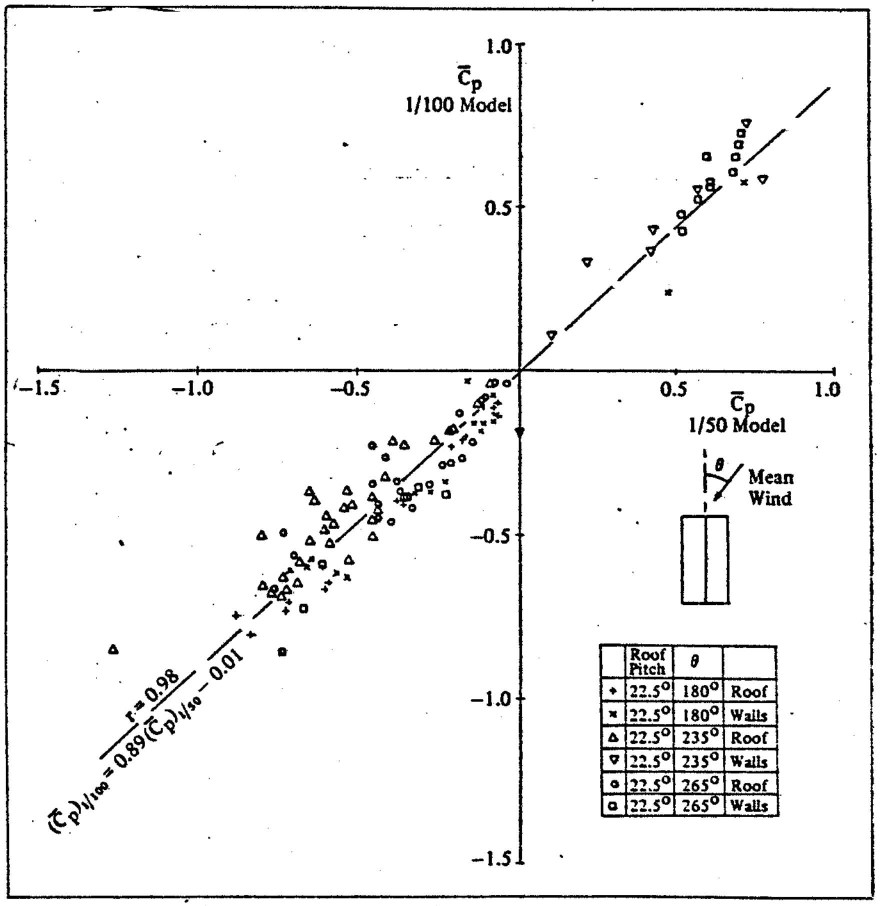

Figure 9 Model/model comparison. 1/100 scale with 1/50 scale mean pressure coefficients

Table 1 Comparison of Aylesbury Experimental House Mean Pressure Coefficients 22½° Roof Slope

$\theta = 265°$. ($\bar{C}_p$ based on 10 m mean velocity)

Full Scale Tape No.	Full Scale		Wind Tunnel					
			1/50 J.C.U.N.Q. $h/z_0 = 150$		1/100 J.C.U.N.Q. $h/z_0 = 100$	1/75 Oxford $h/z_0 = 75$	1/500 U.W.O.	
	A7 $h/z_0 \simeq 50$	A32 $h/z_0 \simeq 50$	without hedges	with hedges	without hedges	with hedges	$h/z_0 = 150$ with hedges	$h/z_0 = 3200$ with hedges
3 WW 1	–	+ .09	+ .40	+ .46		+ .22	+.27•	+.20•
3 WW 2	–	+ .21	+ .52	+ .60		+ .40	+.37•	+.40•
3 WW 3	+ .24	+ .29	+ .57	+ .58	+ .53	+ .44	+.37•	+.42•
3 WW 4	+ .26	+ .29	+ .61↓	+ .60↓	+ .58↓	+ .45	+.40•	+.47•
3 WW 5	+ .21	+ .29	+ .60	+ .61	+ .66	+ .47	+.37•	+.47•
3 WW 6	+ .06	–	+ .52	+ .50	+ .48	+ .40	+.37	+.38
3 WW 7	– .09	–	–	–	+ .36	+ .25	+.29	+.21•
5 WW 1	–	+ .34	+ .58	+ .60		+ .37	+.36•	+.32•
5 WW 2	–	+ .51	+ .64	–		+ .50	+.40•	+.45•
5 WW 3	– .27	+ .50	+ .68	+ .73	+ .61	+ .53	+.40•	+.47•
5 WW 4	–	+ .54	+ .69	+ .69↓	+ .66↓	+ .54	+.40•	+.47•
5 WW 5	–	+ .51	+ .71	+ .68	+ .73	+ .55	+.40•	+.47•
5 WW 6	–	+ .46	+ .70	+ .74	+ .70	+ .55	+.37	+.47
5 WW 7	+ .12	+ .35	+ .61	+ .70	+ .57	+ .31	+.32	+.34
3 EW 1	– .48	– .43	– .31	– .31	–	– .33	–	–
3 EW 2	–	– .48	– .32↓	– .37↓	–	– .36	– .07•	– .42•
3 EW 3	– .46	– .47	– .32	– .33	–	– .32	– .05•	– .38•
3 EW 4	–	– .54	– .31	– .33	–	– .33	– .05•	– .42•
3 EW 5	–	– .53	– .38	– .39	–	– .37	–	–
5 EW 1	– .51	– .37	– .31	– .28	– .36	– .34	– .08	– .42
5 EW 2	–	– .39	– .33↓	– .36↓	– .39	– .35	– .07•	– .42•
5 EW 3	–	– .42	– .30	– .33	–	– .33	– .05•	– .42•
5 EW 4	–	– .47	– .34	– .34	– .39	– .35	– .08•	– .45•
5 EW 5	–	– .52	– .32	– .43		– .39	– .08•	– .47•
3 SW 1	– .58	– .49	– .67	– .74	– .73	– .76	–	–
3 SW 2	– .70	– .73	– .67	– .60	–	– .63	– .08	– .85
3 SW 3	– .60	– .51	– .35	– .36	– .41	– .39	– .00	– .34
3 SW 4	– .49	– .28	– .22	– .22	– .38	– .27	– .00	– .38
5 SW 1	–	– .78	– .76	– .83	–	– .65	–	–
5 SW 2	–	– .74	– .74	– .67	– .86	– .66	– .13	– .68
5 SW 3	–	–	– .28	– .32	–	– .34	– .03	– .47
5 SW 4	–	–	– .19	– .24	–	– .27	– .03	– .51
3 NW 1	+ .06	– .66	– .61	– .61	– .59	– .57	– .11	– .64
3 NW 2	– .56	– .76	–	–	–	– .61	– .19	–1.02
5 NW 1	–		– .62	– .64	–	– .58	– .11	– .76
5 NW 2	–		– .80	– .75	–	– .66	– .16	– .72
(5 NW 3)				– .52				– .59

• Averaged from adjacent points ↓ model measuring points displaced from equivalent full scale positions

Table II Comparison of Aylesbury Experimental House Mean Pressure Coefficients 22½° Roof Slope

$\theta = 265^\circ$ ($\overline{C}_p$ based on a 10 m mean velocity)

Full Scale Tape No.	Full Scale		Wind Tunnel					
			1/50 J.C.U.N.Q. $h/z_0 = 150$		1/100 J.C.U.N.Q. $h/z_0 = 100$	1/75 Oxford $h/z_0 = 75$	1/500 U.W.O.	
	A7 $h/z_0 \cong 50$	A32 $h/z_0 \cong 50$	without hedges	with hedges	without hedges	with hedges	$h/z_0 = 150$ with hedges	$h/z_0 = 3200$ with hedges
WR 1A	–.13	–.20	–.87	–.90	–	–.60	.00	–.55
WR 1B	–	–.34	–.77	–.82	–.67	–.66	–	–
WR 1C	–	–.20	–.71	–.75	–.57	–.66	.03	–.55
WR 1D	–	–.22	–.74	–.82	–.50	–.65	.03	–.59
WR 1E	–.19	–.26	–.73	–.82	–	–.67	.03	–.59
WR 1F	–	–.42	–.76	–.86	–	–.67	–.01*	–.55*
WR 3A	+.21	–.10	–.11	–.07		–.10	.05	–.21
WR 3B	+.28	–.03	–.04	–.03	–.04	–.11	–	–
WR 3C	+.24	+.02	–.08	–.07	–.04	–.13	.08	–.30
WR 3D	–	–.08	–.11	–.10	–.08	–.17	.08	–.34
WR 3E	+.46	–	–.12	–.13	–.09	–.16	.08	–.34
WR 3F	–	–	–.19	–.19	–.13	–.19	–	–
WR 3G	–	–	–.15	–.15	–.22	–.22	.03*	–.30*
WR 4A	+.01	–.05	–.23	–.25		–.27	.03	–.25
WR 4B	–	–	–.18	–.22	–.27	–.27	–	–
WR 4C	–	–	–.21	–.23	–.28	–.30	+.03	–.30
WR 4D	–	–	–.24	–.26	–.29	–.30	+.03	–.30
WR 4E	.00	–.12	–.23	–.24		–.32	+.03	–.30
WR 4F	–	–	–.28	–.29	–.25	–.32	+.02*	–.32*
ER 1A	+.19	–.56	–.38	–.42		–.41	–.08	–.55
ER 1B	–.50	–.63	–.46	–.50	.35	–.45	–.11*	–.57*
ER 1C		–.58	–.47	–.51	–	–.47	–.10*	–.59*
ER 2A	–.26	+.20	–.38	–.45	.34	–.43	–.08*	–.55*
ER 2B	–	–	–		–29	–.41	–.08*	–.53*
ER 2C	–	–.38	–.35	–.47	.40	–.40	–	–
ER 2D			–		–.43	–.41	–	–
ER 2E			–		–.52	–.44	–	–
ER 3A	–.06	–.16	–.41	–.46		–.41	–.08	–.55
ER 3B	–	–	–.37	–.41	–.37	–.38	–.08*	–.51*
ER 3C	–	–	–.40	–.43	–.46	–.44	–.10*	–.53*

* Averaged from adjacent points

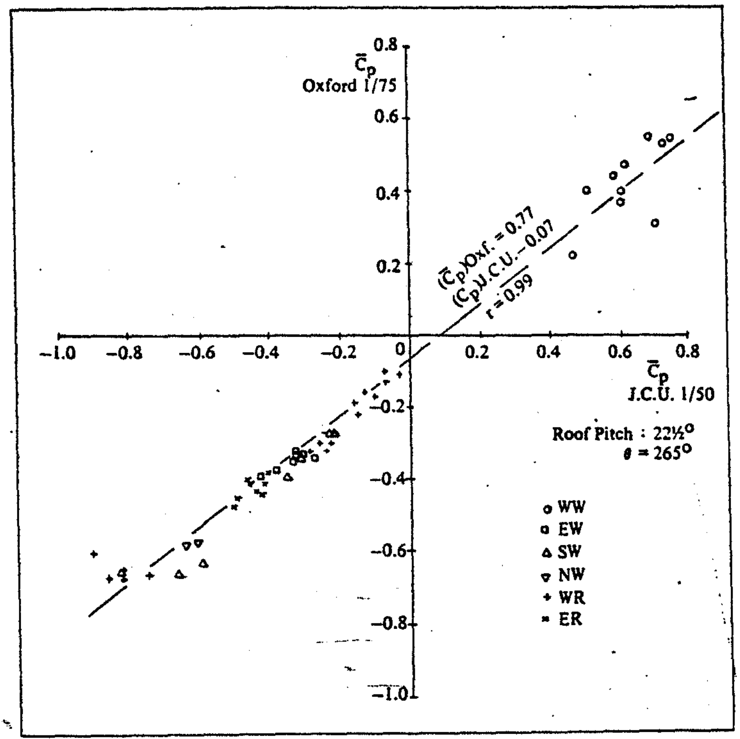

Figure 10 Model/model comparison. Oxford 1/75 scale with 1/50 scale mean pressure coefficients

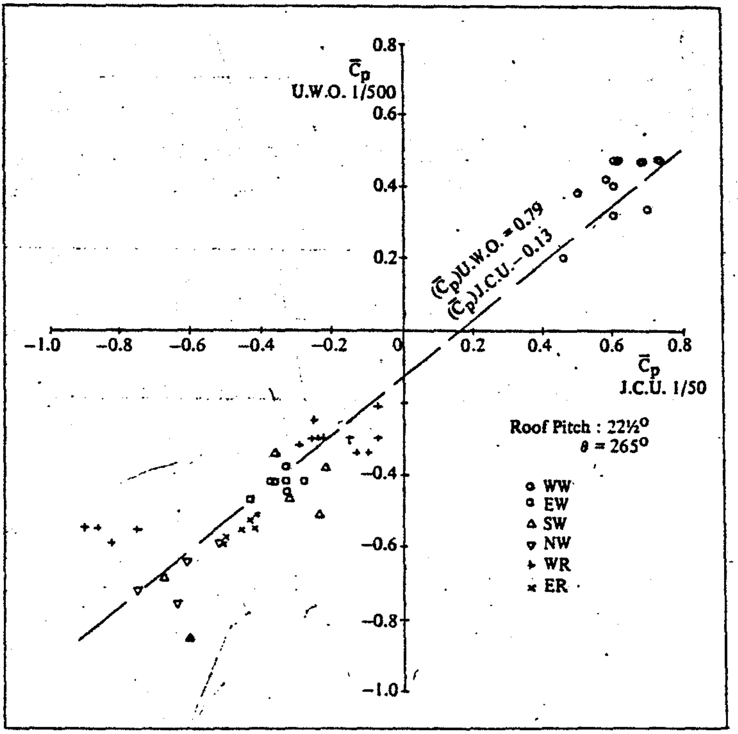

Figure 11 Model/model comparison. 1/500 scale U.W.O. with 1/50 scale mean pressure coefficients

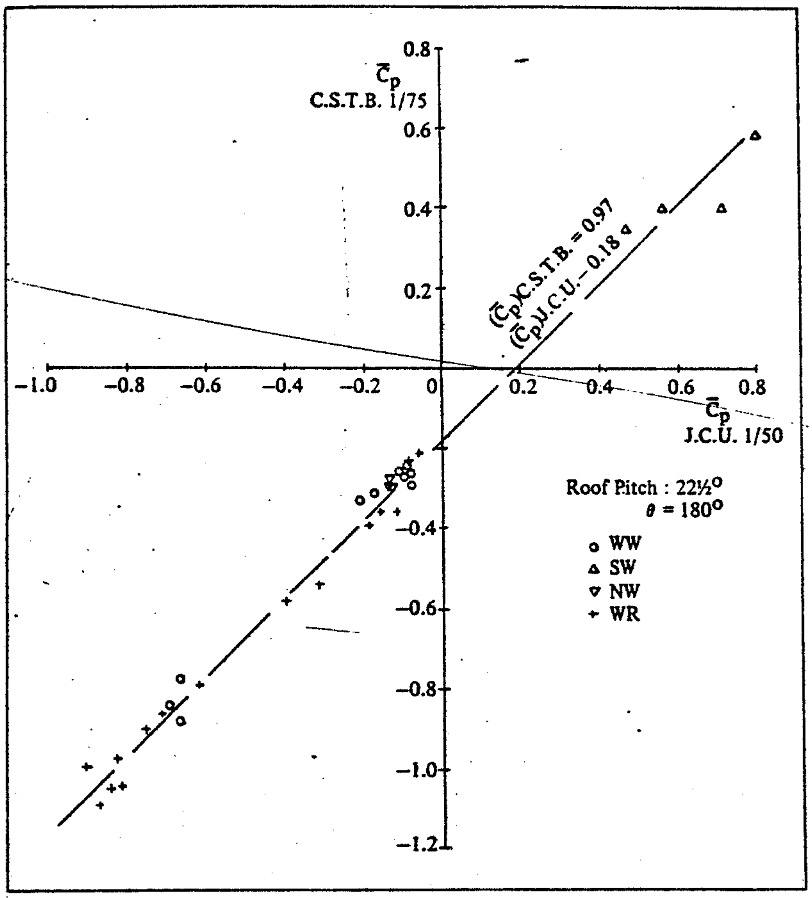

Figure 12 Model/model comparison. 1/75 scale C.S.T.B. with 1/50 scale mean pressure coefficients

As well as differences in scale there were slight differences in mean velocity profile, as indicated by the ratio h/z_0 where z_0 is the roughness length. The linear regression lines show up these differences and, more significantly, differences in the static reference pressures. The hedges were modelled in all tests except those at C.S.T.B.; however a comparison with the latter tests is made only for a wind direction of 180°, for which the large hedges are parallel to the flow direction and hence of no significance.

All the mean pressure coefficient comparisons (Figures 10-12) show high correlations particularly between models of similar scale. The regression line in Figure 10, however, has a slope whose difference from unity is greater than can be explained by the difference in mean velocity profiles. The results from U.W.O. in Figure 11 are those for which h/z_0 was quoted to be 3,200; very poor agreement was found with the results for which the profile parameter was quoted to be 150, although the latter is the figure appropriate to the James Cook tests. Possibly the values of roughness length used in the University of Western Ontario tests need re-assessment; alternatively there may be some scale effect due to the very small scale of the model (1/500).

The mean velocity profile used by C.S.T.B. (Figure 12) was fitted by a power law with an exponent of 0.13. This is closely similar to the James Cook tests and the slope in Figure 12 reflects this. However, the intercept is quite large in this case, indicating a static pressure reference at C.S.T.B. higher by a coefficient of about 0.18. Significant, although lesser, differences in static pressure reference are also indicated in Figures 10 and 11. These differences show the importance of stating the position at which reference pressures are obtained in wind tunnel tests, as well as full scale, as small deviations may well occur with height. For the James Cook tests it seemed logical to state the measured pressures with reference to the static pressure at the position where the reference velocity was measured, i.e. the equivalent to 10 m in full scale.

A comparison of r.m.s. fluctuating pressure coefficients is given in Figure 13. There is a tendency for the C.S.T.B. values to be greater than those from James Cook. No explanation can be given for this, although two factors affecting fluctuating pressure measurements in wind tunnels are the frequency response of instrumentation and the possible presence of spurious pressure fluctuations originating from the fan blades or from tunnel wall vibrations.

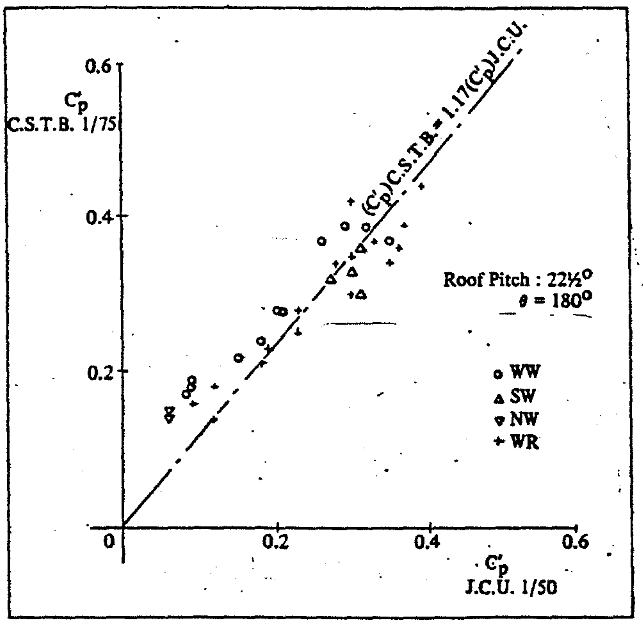

Figure 13 Model/model comparison. 1/75 scale C.S.T.B. with 1/50 scale R.M.S. fluctuating pressure coefficients

6. Conclusions

(i) The modelling of hedges present at the Aylesbury site had little effect on the profiles of mean velocity and turbulence intensity, or on the measured pressure coefficients.

(ii) A comparison of 1/50 scale model mean and fluctuating pressure coefficients with full scale measurements on the Aylesbury house showed some scatter which could be largely attributed to the internal scatter in the full scale data.

(iii) Much better correlation was obtained when comparing wind tunnel model data, although significant differences in mean velocity profile and static pressure reference was revealed in some cases.

(iv) The agreement between the 1/50 scale and the 1/100 scale James Cook model results suggests that house tests may be conducted at either of these scales, with the respective boundary layer simulation techniques, to give satisfactory and consistent results.

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List of Symbols

C_p – pressure coefficient
F_u – factor in empirical expression for turbulence intensity (equation (2))
h – eaves height of building
I_u – longitudinal turbulence intensity $= \sqrt{\overline{u'^2}}/\overline{u}$
n – frequency
p – pressure
p_0 – reference static pressure
r – (i) subscript – reference height
(ii) correlation coefficient
$S(n)$ – spectral density function
t – time
u – longitudinal velocity
$\overline{u}_r$ – mean velocity at reference height
z – height above ground
z_0 – roughness length
z_r – reference height
λ_u – peak wave length of longitudinal turbulence spectrum
ρ – air density
θ – wind direction with respect to house axis (see Figure 6-10)
$\overline{\ }$ – mean (time averaged) value
$'$ – r.m.s. fluctuating value
$\hat{\ }$ – peak value

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