SIMULTANEOUS PRESSURE AND VELOCITY MEASUREMENTS IN THE VICINITY OF A CUBOID WIND TUNNEL MODEL

C.W. Letchford[1] , R. Marwood[2] & C.J. Wood[2]
[1] Department of Civil Engineering, University of Queensland, Brisbane 4072, AUSTRALIA.
[2] Department of Engineering Science, Oxford University, Oxford, OX1 3PJ, UK.

1. INTRODUCTION

The quasi-steady theory attributing pressure fluctuations to incident velocity fluctuations is known to fail in regions of flow separation because of distortion of the flow and building generated turbulence, [1], [2]. Not withstanding this the quasi-steady theory is still the most popular framework for codes of practice used in calculating wind loads on most buildings. In the quasi-steady theory, the surface pressures generated on a building respond to atmospheric turbulence directly as if they were changes in mean wind speed and direction. A review of the theory is contained in [1] but the result of interest here is the relationship between the instantanteous wind vector and fluctuating surface pressure. In particular, how does the pressure coefficient at various instantaneous wind directions, at a reference location, compare with the quasi-steady assumption of pressure coefficient defined by the mean wind direction.

2. EXPERIMENT

The pressure and velocity measurements presented here were obtained in the Oxford University Low Speed Wind Tunnel. The tunnel is 4m wide and 2m high and has approximately 14m for boundary layer development. The simulation employed here was nominally a 1:75 scale rural/suburban flow with z_o = 0.1m. Mean wind speed and turbulence intensity at roof top level were 5m/s and approximately 20% respectively. Full simulation details may be found in [3].

The model employed in this study was a 300mm square based prism 140mm high. Pressures were measured at a tap located 8mm (s/h = 0.065) back along a ray originating from the roof corner. The ray subtended 18° to the leading edge. Pressure coefficients were obtained by normalizing by the mean dynamic pressure at roof height. The model was constructed so that the complete model could be tilted about a diagonal to simulate a change in the mean pitch angle of the approach flow. In this way the gradient of pressure coefficient w.r.t. mean pitch angle (θ_w) at an azimuth of 45° were obtained. Gradients of pressure with azimuth angle (θ_v) were also obtained. These are presented and discussed in [4]. Velocity measurements were obtained with a 2 component Dantec laser Doppler anemometer. Cross correlations of velocity and pressure at zero time lag were obtained in a manner detailed in [3]. Briefly, as the laser Doppler measurements are intermittent, a routine was developed [3] to interpolate the velocity data to the same frequency as the pressures. Typically the data sampling rate of the laser was less than 100Hz and this was used as the interpolation frequency for subsequent data analysis. Data was sampled for 120seconds.

3. RESULTS & DISCUSSION

Figure 1 shows the cross correlations of pressure and velocity components, u, v, and w made at three locations upstream of the model. The model was set at an azimuth of 45° and velocity measurements were taken at roof top height upstream along the model centre line. At 2h upstream there is little correlation between pressure and any velocity component. This contrasts with relative high correlations reported in full scale observations [1] at distances of 12h upstream. As the model is approached there is an increase in correlation in v and w, with v being much more significant. The importance of v component turbulence to pressures beneath conical vortices has been previously demonstrated [5]. It should be noted that a less than perfect correlation is expected due to natural decay in turbulence components over the separation distance. The appropriate turbulence length scales, as obtained from Taylor's hypothesis and integral time scales at roof top height in the freestream flow, were ${}^{x}L_u = 5.7h$, ${}^{x}L_v = 3.2h$ and ${}^{x}L_w = 1.3h$ indicating that decay of <u>large</u> scale turbulence components occurs over distances at least greater than 1h. No information concerning the behaviour of small scale turbulence is available from these integral values.

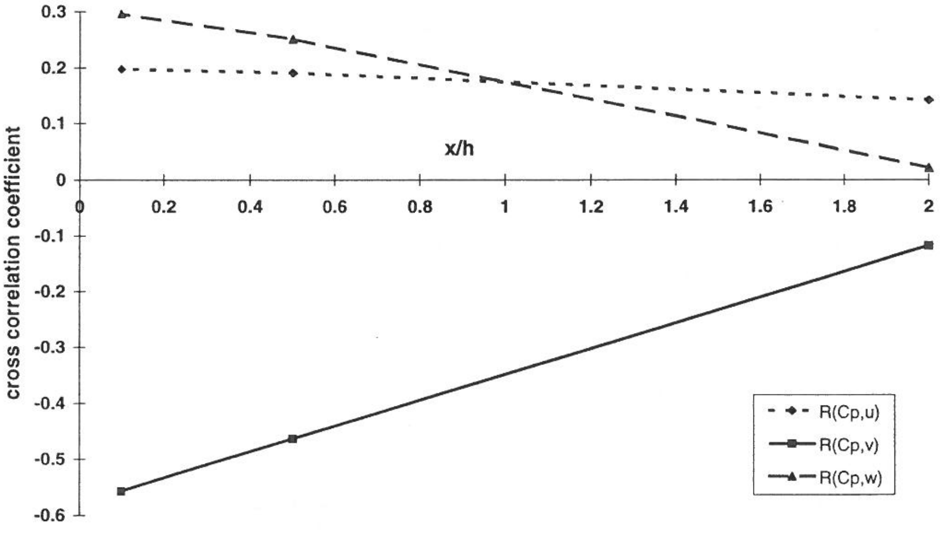

Figure 1. Pressure velocity cross correlations upstream of model.

Figures 2 & 3 show the variation of mean and conditional mean pressure coefficients with azimuth and pitch angle respectively for velocities taken at the three locations upstream. The conditional mean pressure coefficients are formed from the sets of simultaneous pressure and velocity component data by a procedure [3] which calculates instantaneous wind vectors (azimuth or pitch) and then orders the data on this basis. This rearranged data set has then been averaged over consecutive 500 points to form a conditional mean pressure and associated average 'instantaneous' wind direction.

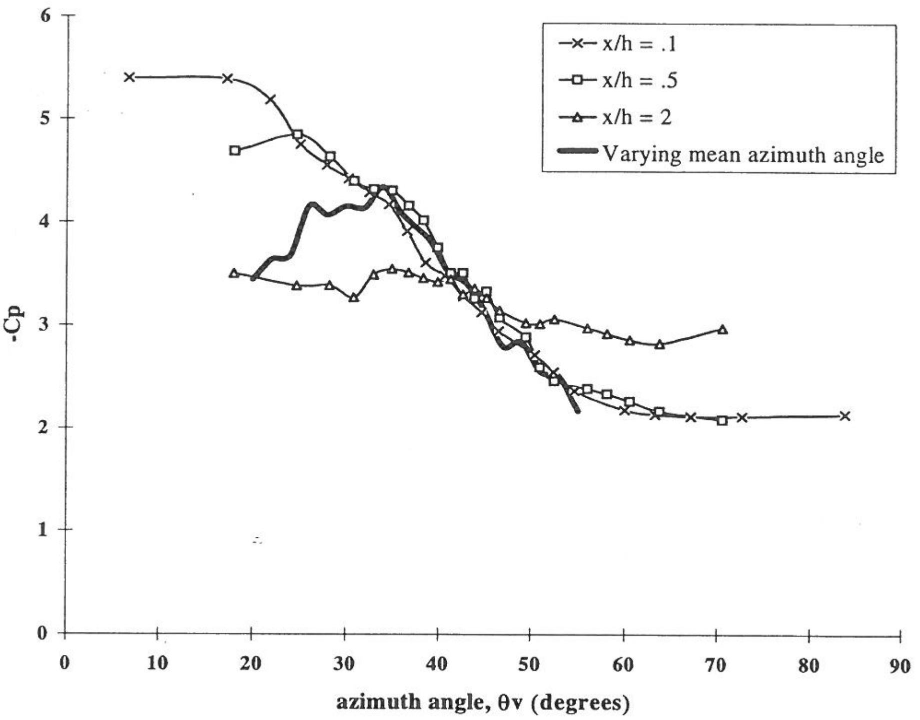

Figure 2. Mean and conditional mean Cp variation with azimuth (θ_v) along 18° ray at s/h = 0.065 for θ_w = 0°.

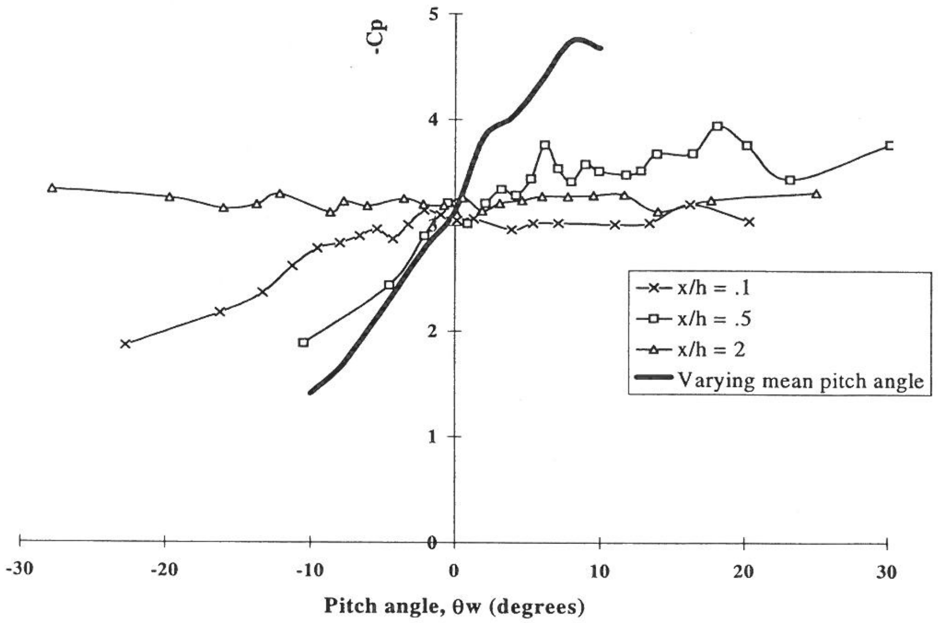

Figure 3. Mean and conditional mean Cp variation with pitch angle (θ_w) along 18° ray at s/h = 0.065 for θ_v = 45°.

It is seen from Figure 2 that over the azimuthal range 30° to 60° the quasi-steady assumption holds well, namely: the pressure coefficient defined by the 'instantaneous' wind direction (conditional mean) is very similar to the pressure coefficient obtained from the mean wind direction. The agreement improves as the building is approached being best at distances closer than 0.5h and this is in line with the cross correlation measurements presented in Figure 1. For angles outside this band (+/- 15°) around the mean azimuth $\theta_v = 45^\circ$, discrepancies with the quasi steady theory amount and in particular for instantaneous angles less than 30° and approaching 0°, which is normal to the model side adjacent to the pressure tap, the pressure magnitudes are much larger than would be predicted by quasi steady theory. It is when the instantaneous wind direction diverges from the mean azimuth by large angles that the peak pressures occur. These large excursions of wind direction may well be associated with very concentrated local vortices being convected with the mean flow which impact on the conical vortex flow structure on the model and lead to the production of the extreme surface pressures. A complete flow field map would be required to ascertain the validity of this hypothesis and a way forward would be through particle image velocimetry (PIV) of the flow field in the vicinity of the model.

In contrast to changes in azimuth, Figure 3 shows poor performance of the quasi steady theory in relation to changes in pitch angle. Irrespective of upstream distance there is almost no agreement between the pressure coefficient defined by the 'instantaneous' wind direction (conditional mean) and the pressure coefficient obtained from the mean wind direction. This lack of correspondence could be anticipated from the poor cross correlations between pressure and w component turbulence shown in Figure 1.

It is interesting to note that in the six runs which form the basis of Figures 2 & 3, the rms and extreme pressure coefficients were very similar (approximately 2 & -16 respectively) however whereas large excursions in azimuth were associated with extremes in pressure there was no such relationship for extremes in pitch angle and pressure. It appears that the conical vortex is rather robust to changes in pitch angle but rather sensitive to changes in azimuth. The simultaneous velocity and pressure techniques employed here give further insight into the flow structures that cause peak pressures within conical vortices. A way forward to a greater understanding of this relationship is via whole flow field measurements as offered by PIV techniques.

4. REFERENCES

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