Impinging Jets and their applicability to Modelling Thunderstorm Downbursts

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The significant number of structural wind induced failures are normally attributed to localized storm events e.g. tornadoes, or thunderstorm downbursts. For several cities in Australia (Holmes, 2000) the 1000-year return period regional wind speed is governed by thunderstorm winds. Despite this very little is known of these phenomena, and all the design models and wind tunnel work is based on a synoptic boundary layer.

Currently the only full-scale measurements that there been taken of a thunderstorm downbursts used Doppler radar. This information is only useful for the measurement of the mean wind speed profile and yields little to no information on the turbulence structure of these events, which is crucial for effective wind tunnel modelling. Until reliable full-scale measurements have been taken, designing for these events with any degree of confidence is impossible.

Some full-scale, physical and numerical modelling research are currently being carried out in the United States (predominantly at Texas Tech University) regarding thunderstorm events, but tends to focus on the more visually impressive tornadoes rather than thunderstorm downbursts. A small amount of physical testing using an impinging jet to model the thunderstorm downburst is being carried out at The University of Sydney.

The thunderstorm downburst wind tunnel is supplied by a 15 kW centrifugal blower discharging air into a settling chamber. The settling chamber is 1825 mm long and has cross-sectional dimensions of 1235 mm high by 620 mm wide. The vertical and horizontal contractions have an area ratio of 4:1 and 2:1 respectively. A circular nozzle is connected to the rectangular outlet. The aim of the circular nozzle was to minimise turbulence and create a symmetrically steady outflow while maintaining symmetry. The nozzle had a contraction length of 150 mm and a diameter of 310 mm (D) and circular length of 750 mm. The maximum discharge speed at the jet outlet is approximately 25 ms^{-1}. The vertical test surface is made from 18mm thick plywood, 2.4 m square, mounted on a movable steel frame. This set-up has been used for numerous experiments including velocity and turbulence profiling, speed-up factors for simple topographical features, pressure distributions around simple structures in steady and pulsed flow. This paper aims to discuss the outflow characteristics of the system. A typical mean velocity profile is shown in Fig. 1.

Initial pressure measurements were measured on a model tall building located at a radius of 1.5D from the centre of the jet outlet on the testing surface. The size of the model is also shown on Fig. 1. The pressure tappings are designated by the circles, and the pressure taps of interest are highlighted and labelled A, B, and C. These represent locations on the model where the normalised velocity (normalised against the maximum mean velocity) has a value of approximately 1, 0.75 and 0.5 respectively.

During the initial analysis of the results an unusual reasonably regular low frequency pressure pulse was discovered in the data, Figs 2 and 3. The origin of this approximately 7 Hz pulsing was unknown. There were several possibilities as to the source of the pulsing: physical vibration of the wind tunnel or model, a real fluctuation caused by the wind / model interaction, acoustic resonance in the pipe settling chamber system, impeller speed of the centrifugal fan, pressure fluctuations between the nozzle outlet and the testing surface, instability of the shear layers / air entrainment at the nozzle outlet. Further experiments were carried out to try to determine the cause of the pulsing. From acceleration measurements of the wind tunnel and simple stiffening of the model both these explanations were easily discarded. The wind / model interaction theory was discarded after similar frequency of pulsing was measured at a pressure tapping located at the centre of the testing surface. The first three harmonics of the pipe / settling chamber system were estimated at approximately 7, 20 and 33 Hz and should be independent of wind speed. The first harmonic agreed well with that measured. The next set of experiments consisted of measuring the pressure at the centre of the board for a range of wind speeds. The wind velocity is governed by a frequency controller which was set to 10, 30 and 50 Hz equivalent to velocities of approximately 5, 15, and 25 m/s. The spectra for the pressure at the centre of the testing surface for these wind speeds are shown in Fig. 4. It is evident from Fig. 4 that the pulsing frequency is spread over a range of frequencies, and that the underlying pulsing frequency as increases with wind speed. The underlying frequencies for the three wind speeds agree with the estimated first three harmonics of the pipe system, but there is no apparent reason why the dominant harmonic should change with wind speed. Notwithstanding, the length of the settling chamber was changed and the experiments repeated. These results showed no coincidence between the estimated acoustic resonant frequencies and the pulsing frequencies. It is therefore considered that the acoustic resonance is not the cause of the pulsing.

It is evident that there is an approximately linear relationship between the speed of the fan and the pulsing frequency. However, this frequency does not correspond to the number of blades on the fan, nor was there any pulsing in the distribution network measured at pressure tappings along the pipe wall. There was also no evidence of pulsing when the distribution system was split near the fan and before the settling chamber.

Velocity spectra were measured at the jet outlet at these did not display any pulsing. The distance to the testing surface was also altered to verify if there was pulsing between the end of the nozzle and the testing surface, Fig. 5. It is evident that as the distance from the nozzle outlet to the testing surface increases, the dominant frequency decreases, but the relationship between the distance and frequency is also dependent on wind speed. Fig. 5 also indicates a noticeable drop in the spectra, the reason for this is currently unknown.

The final testing carried out was to place a mesh over the end of the jet outlet. This aimed to reduce the amount of air entrained into the jet as it left the nozzle. As can be seen from Fig. 6a the mesh had little effect on the pressure spectra at lower wind speeds, but tended to reduce the amount of pulsing in the data for the higher wind speeds. This is probably caused by the pressure drop across the mesh rather than a significant alteration in the flow.

It is proposed to install a ring around the end of the jet to try and limit air entrainment at the nozzle outlet. However, the endeavour to remove the pulsing may not be required if the peak pressures on structures results from the initial thunderstorm downburst, or if any subsequent full-scale testing indicates the structure to be as currently modelled.

REFERENCES

Holmes, J.D., New Extreme Wind Speed Predictions for Four Cities, 8th AWES Workshop, Perth, 2000.

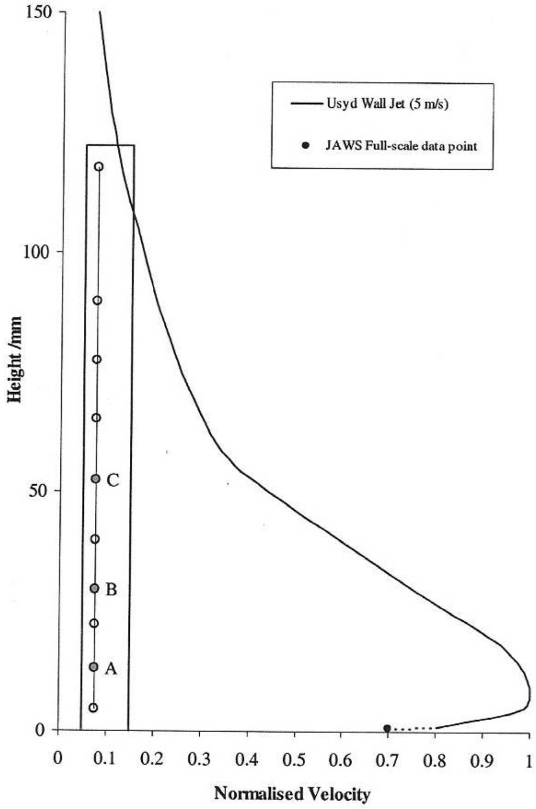
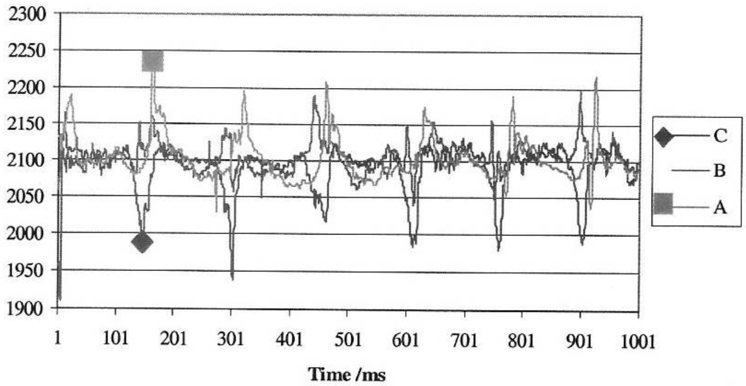
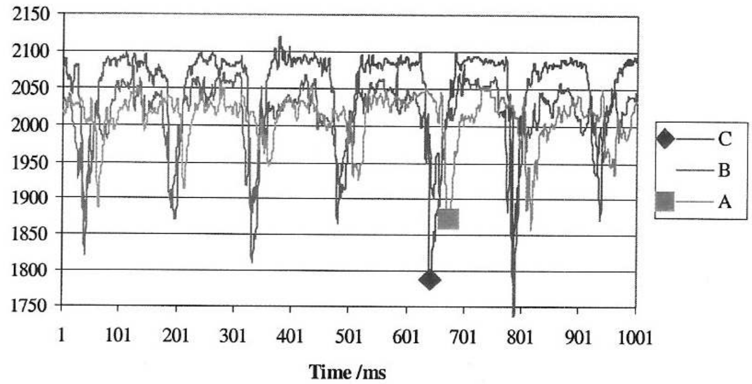


Fig. 1 Velocity profile and tall building model showing pressure tapping locations



a. windward wall



b. side wall

Fig. 2: Pressure distributions with time, testing surface 2D from outlet, 10 Hz

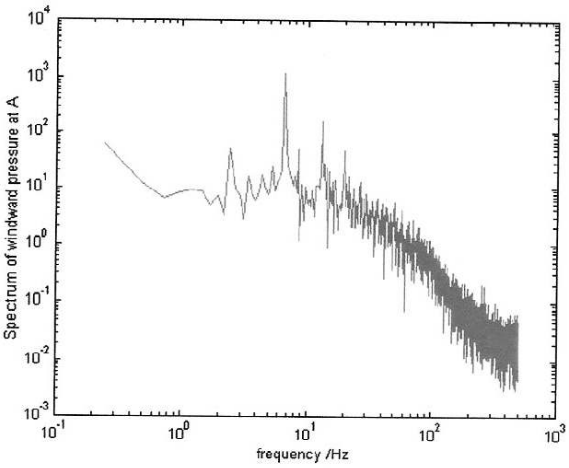


Fig. 3 Typical windward wall pressure spectrum, testing surface 2D from outlet, 10 Hz

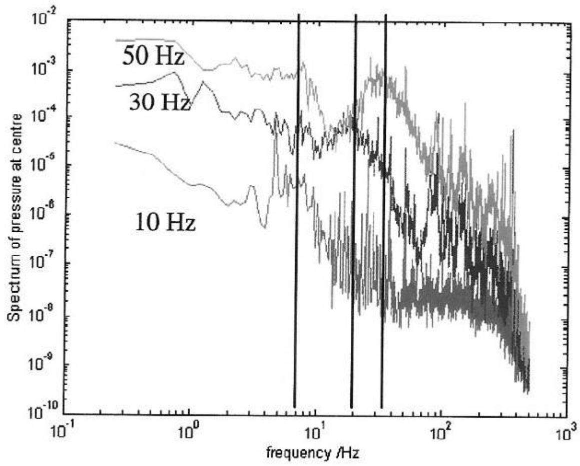
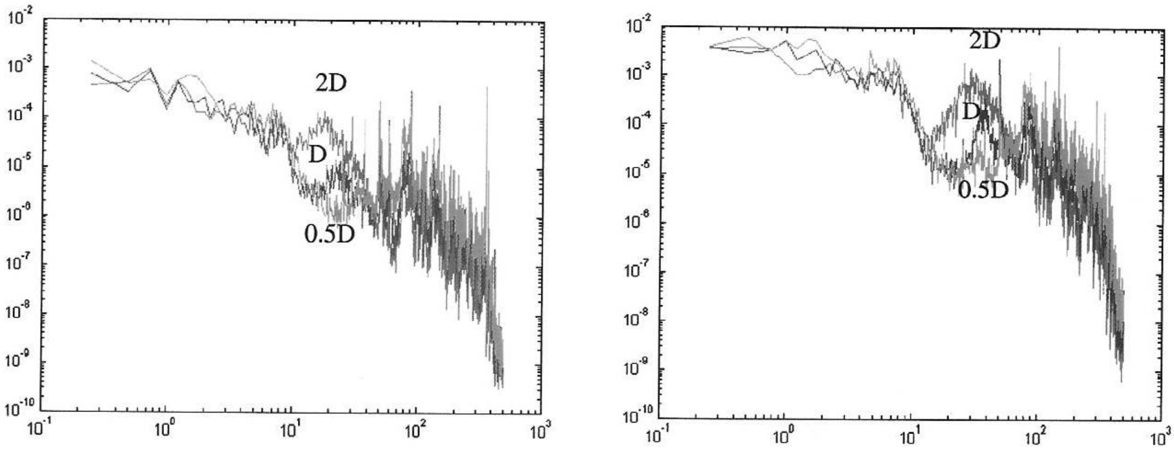


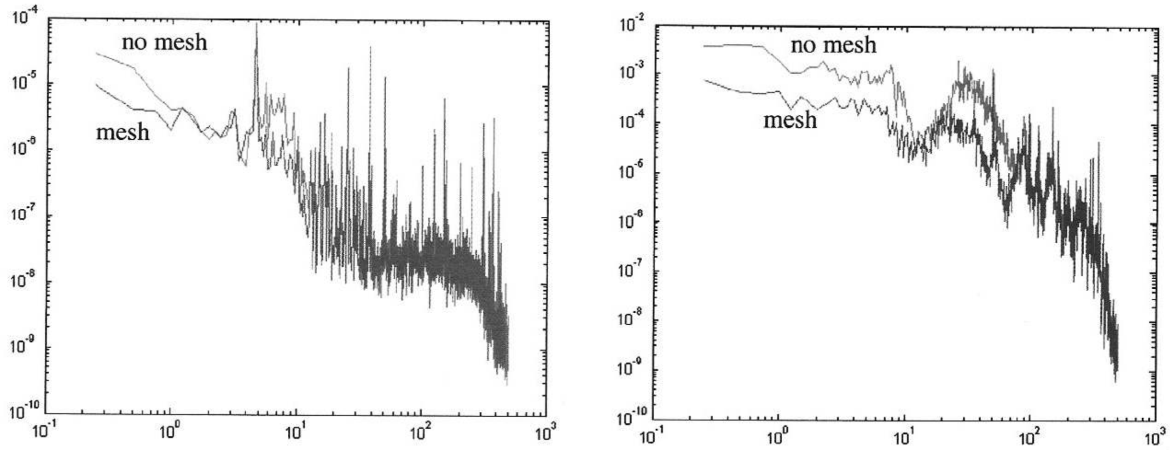
Fig. 4: Spectra of pressure at centre of testing surface 2D from outlet



a. outlet velocity approximately 15 m/s

b. outlet velocity approximately 25 m/s

Fig. 5 Pressure spectra at the centre of the testing surface



a. outlet velocity approximately 5 m/s

b. outlet velocity approximately 25 m/s

Fig. 6: Pressure spectra at the centre of the testing surface with and without mesh over the nozzle outlet, distance to testing surface 2D.