Modelling of Thunderstorm Downburst Gust Fronts using a Pulsed Jet

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One of the missing links in wind engineering regards the structure and effect on structures of thunderstorm downburst winds. Notwithstanding the fact that few full-scale measurements have been recorded, modelling is only being conducted in few laboratories around the world. The structure of these severe short term events and their interaction with structures is unknown. What is known is that numerous cases of structural storm damage occur during thunderstorms each year, some of these failures are attributed to thunderstorm downbursts. Fujita (1981) first classified thunderstorm downbursts. The more severe downbursts, microbursts, last 2 to 5 minutes and are defined as having a descending column of air of between 400 m and 4 km diameter. The descending column of air expands horizontally as it hits the ground. The high level vertical wind shear caused during downburst events has been a focus of the aviation industry, but little research has been conducted on the expanding lower level winds important for structural design.

The impinging jet technique has often been used to model thunderstorm downburst winds Holmes (1992), Letchford & Illidge (1999) Chay and Letchford (2002). The apparatus used for this series of experiments is described in Wood et al. (1999). Most physical experiments have used a steady jet to investigate the velocity profile and topographical effects. However, Letchford and Chay (2002) used a moving jet to try and simulate the initial gust front. These tests were successful in that they managed to reproduce the expected pressure distribution created during a thunderstorm downburst, Fig. 1, although a high transient travel speed was required. The transient pressure distribution around a cube was also measured.

In is proposed that the difficulties associated with creating a moving jet wind tunnel can be overcome by developing the gust front by suddenly creating the jet. This has been achieved by building a simple lever operated aperture mounted at the jet outlet. The aperture can be opened in approximately 0.1 s and produces good repeatability.

Initially tests were conducted on a flat test surface to determine the radial pressure distribution. Pressure tappings were placed at 0.2D spacing, where D is the diameter of the jet, and the testing surface was at 1.5D from the jet outlet. Each pressure tapping was connected to via a short length of PVC tubing containing two restrictors to reduce resonant effects to a Honeywell Type 163 pressure transducer. The response of the tubing system was accurate to within 15% to 300 Hz, with a linear phase angle. The pressure transducer signals were filtered at 300Hz and the recorded at 1 kHz per channel. Pressure coefficients were calculated using the mean steady state jet outlet velocity, approximately 13.8 m/s for the results reported herein.

Fig. 2 shows a typical radial pressure coefficient distribution with time. Initially the aperture is closed, then opened at approximately 3 s. It is evident that at the time of impact the central tapping experiences a high pressure gust before reducing to a steady state. The radial expansion of the gust front and the similarity with the expected shape of the radial pressure distribution, Fig 1, can also be observed.

To investigate the pressure distribution on a structure, a model tall building was placed in the flow. The model was 17 mm square in plan and 122 mm high. The size of the building was designed to be significantly taller than the height of the peak velocity 'nose' of the expanding jet, which occurs at approximately 15 mm above the testing surface. Three tests were conducted to measure the vertical pressure distribution on the windward, side, and leeward walls, Figs 3 to 5 respectively. The model was placed at a radius of 1.5D from the centre of the jet, and the testing surface was at a distance of 2D from the jet outlet.

A typical windward wall pressure coefficient distribution is shown in Fig. 3. It is evident that as the gust front reaches the lower portion of the building the positive pressure coefficient increases rapidly until it reaches a steady condition. The upper portion of the model experiences a relatively high negative pressure coefficient as the gust front hits the building, but drops off rapidly to an ambient condition.

The side wall pressure coefficient distribution is shown in Fig. 4, note that negative pressure coefficients have been plotted. Just prior to the arrival of the gust front, the entire side wall experiences a small positive pressure, which is quickly followed by a well correlated suction up the entire height of the model. After the gust front passes the values drop quickly to a lower fluctuating level.

The leeward wall pressure coefficient distribution is shown in Fig. 5. As with the side wall, just prior to the arrival of the gust front the entire face experiences a small positive pressure, which is followed by a well correlated negative pressure coefficient up the entire height of the model. After the passing of the gust front the magnitude of the pressure coefficients decreases and the peaks become more intermittent.

In conclusion, this paper presents the results of modelling a thunderstorm downburst using an impinging jet and an aperture. The results indicate that a short well correlated gust front strikes the building before the pressures decrease.

References

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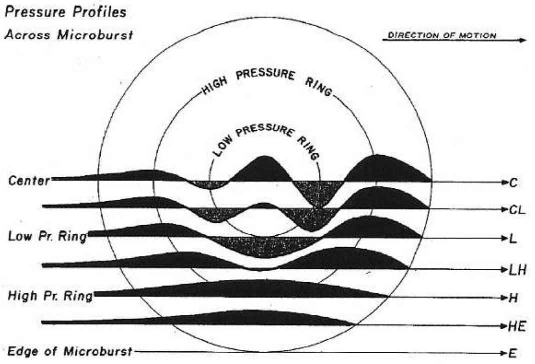

Fig. 1: Expected pressure field of a microburst (Fujita, 1985).

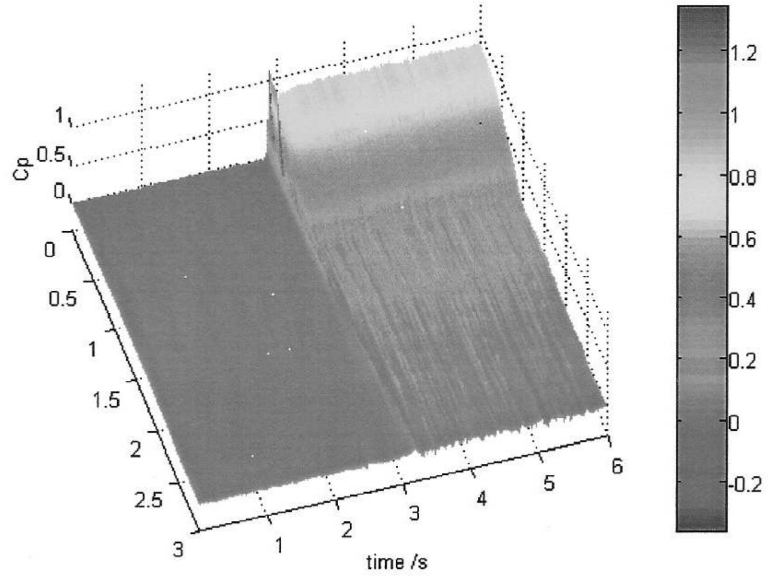

Fig. 2: Radial pressure coefficient distribution with time

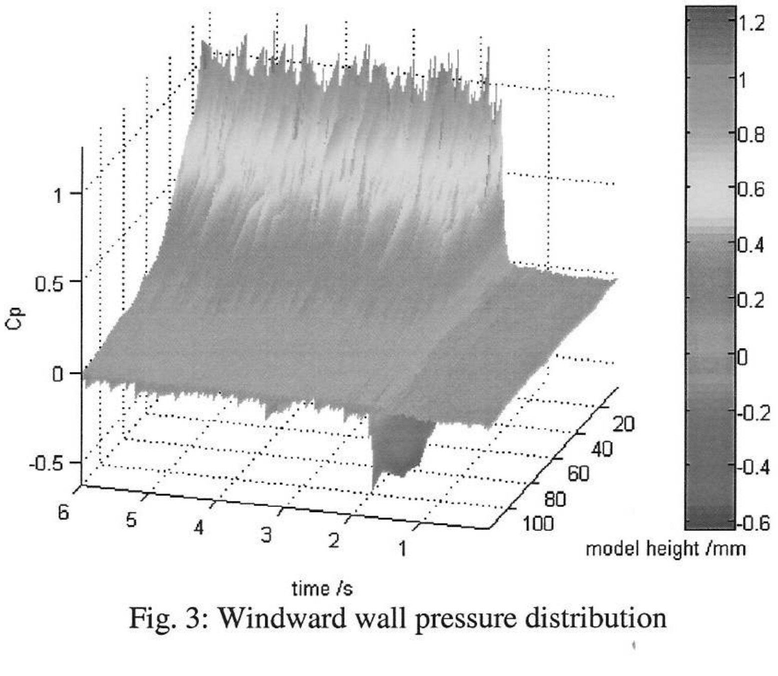

Fig. 3: Windward wall pressure distribution

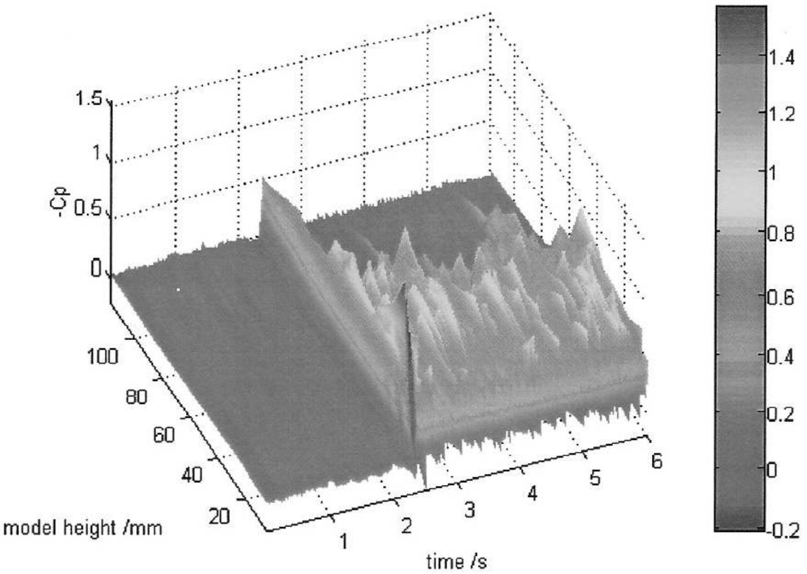

Fig. 4: Side wall pressure distribution

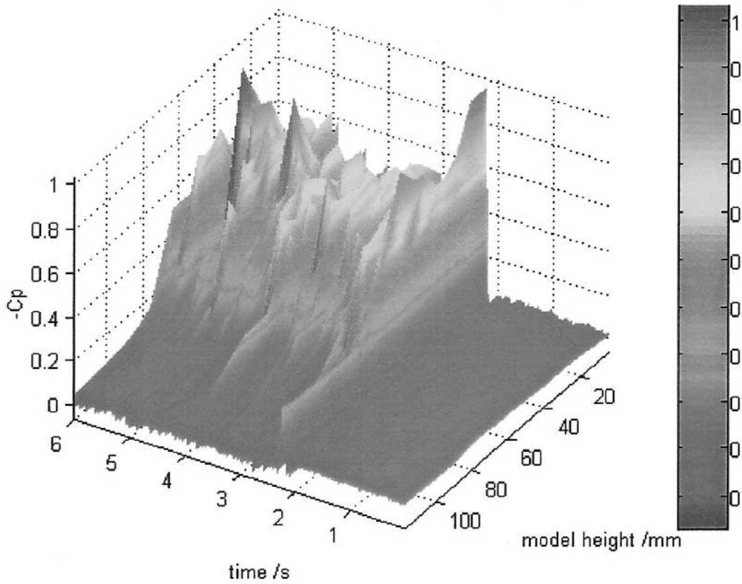

Fig. 5: Leeward wall pressure distribution