Comparison Between Thunderstorm Downburst and Developed Boundary Layer Flows

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In recent years there have been several failures of transmission towers and low-rise structures in Australia during thunderstorm events, yet little is known about this phenomenon from a wind engineering viewpoint. It has been reported that one half of extreme events in Australia and one third of extreme wind events in America occur during thunderstorms. One phenomenon known to occur during thunderstorms is the downburst. This is a rapidly descending column of cooler air, which expands radially once it strikes the ground. It is known that the velocity profile during these events is significantly different to those in conventional developed boundary layer flow, but the extent of the differences at low levels, below 100m, is not known. The expected differences in the velocity profile are that during thunderstorm events: there a high velocity nose near ground level, below 100m; much lower velocities at higher levels; a different turbulence structure; and the gust front is expected to be spatially much better correlated.

The Northern Illinois Meteorological Research on Downbursts, NIMROD, and the Joint Airport Weather Studies, JAWS, projects were established for the development of low-level wind shear detection and warning systems for aviation purposes. These projects used Doppler radar to determine the velocity profile. Radar scanning permitted a volume scan every 2 minutes with the lowest observed level centred 20-120m above ground level depending on terrain. The Doppler radar measures a differential velocity from which the mean velocity can be extracted. For aircraft safety it is the differential wind speed that is of interest and therefore the thrust of the published work is in that direction and not towards structural wind loading.

There are however several published normalised wind speed profiles, Fig 1 (Hjelmfelt, 1988). The wind speed is normalised to the maximum velocity and the height is normalised to the height where the maximum wind speed occurred. The maximum velocity generally occurred at a height of between 50 and 100m. This data is based on the Doppler radar measurements. Due to the nature of Doppler radar testing, the accuracy of the field data below approximately 50m is questionable. The band height for the analysis was 50m. In addition, a portion of the lower sections of the Doppler radar beam is absorbed by ground clutter, (Wilson et al., 1984). This suggests that the radar observations may overestimate the low level velocity multipliers in Fig. 1. As well as the Doppler radar there were a series of portable automated mesonets (PAM) located across the test site (Kessinger et al. 1983). These measured the 1s peak and 1minute mean wind velocity and direction at a height of 4m above ground level, as well as other meteorological information. It was found that the PAMs reported a significantly lower wind speed than the Doppler radar recorded at the lowest measured nominal height of 50m, actually somewhere between 20 and 120m. The PAM measurements indicated that the mean wind speed at 4m would be on average 30% lower, and the peak would be 25% larger than the Doppler radar mean velocity, measured at a nominal 50m height. Thus, the normalised velocities at the lower heights in Fig.2, should be reduced to take account of this more reliable low level data, bringing it into agreement with the impinging jet results.

It has been reported on numerous occasions that an impinging jet is adequate at simulating the flow in thunderstorm downburst, and that normalised results agree well with the available field data (Wood & Kwok, 1998). The results reported in this paper are for a stationary impinging jet, of radius 310mm, with a mean exit velocity of approximately $20ms^{-1}$. All measurements have been taken at a radius of 1.5 times the diameter of the jet from the centre of the impact point. This point was chosen as it is the location of the maximum recorded velocities, and the onset of the stabilisation of the expanding boundary layer (Wood & Kwok, 1998).

If it is assumed that the maximum mean velocity peak occurs at a height of 50m, then the available field data, the results from the impinging jet, and conventional boundary layer flow (Standards Australia, 1989) are directly comparable, Fig. 3. The wind speed multipliers for this profile have all been normalised to a value of 0.6, at a height of 10m in accordance with AS1170.2. It is evident that at heights below 50m, all three profiles are similar, although the impinging jet and the thunderstorm downburst would produce larger velocities for the same design wind speed at 10m. Above the arbitrary 50m height, the impinging jet and the field data diverge rapidly from the conventional boundary layer flow.

It has previously been shown that the turbulence in the incident jet has little effect on the velocity profile of the expanding flow. (Letchford & Illidge, 1999). Fig. 4 shows a comparison between conventional boundary layer flow and impinging jet flow. The peak impinging jet results have been normalised to pass through a peak velocity multiplier equal to unity at a height of 10m, in accordance with AS1170.2. The linear scaling is as per the mean results. It is evident that at low heights, the peak velocity multipliers are similar, but at a prototype height of approximately 50-100m the impinging jet profile has noticeably larger peak velocity multipliers. Above 100m the impinging jet, peak velocity multipliers decrease rapidly compared to the conventional boundary layer flow. The impinging jet results agree well with the 4m PAM data described earlier. Despite the low turbulence intensity in the incident flow, below 100m the velocity peak factor was approximately 5, compared with 3.7 for conventional boundary layer flow, AS1170.2.

Holmes (2000) has shown that the design wind speed during thunderstorm events is greater in certain Australian cities than that for conventional developed boundary layer flow. The increase in both mean and peak velocity multipliers at low levels has significant implications for the wind loading on structures. If this increase in velocity is combined with a more highly correlated gust front, this could explain the recent structural failures during thunderstorms. The difference in the design wind speeds and the velocity profiles may necessitate two different design procedures for the two different flow types, otherwise some hybrid design wind profile may be required.

All the work reported in this paper has considered a stationary jet. However, it has been previously shown that an impinging jet in an external stream can be approximated by the superposition of the external flow with the wall jet flow (Sadeh & Mukherji, 1974). This implies that a profile for a travelling microburst could be obtained by advecting the boundary layer winds with the downburst wind profile. Therefore, by defining a stationary microburst profile it would be possible to obtain the profile for a travelling microburst of any magnitude using the method outlined by Sadeh & Mukherji.

In conclusion, the work outlined in this paper highlights the importance of localised storm events for the design of structures. These storms have not been well characterised in the field especially from the structural wind engineering standpoint. Until a body of work is organised to study these events from an appropriate standpoint there will be no basis for structural design.

References

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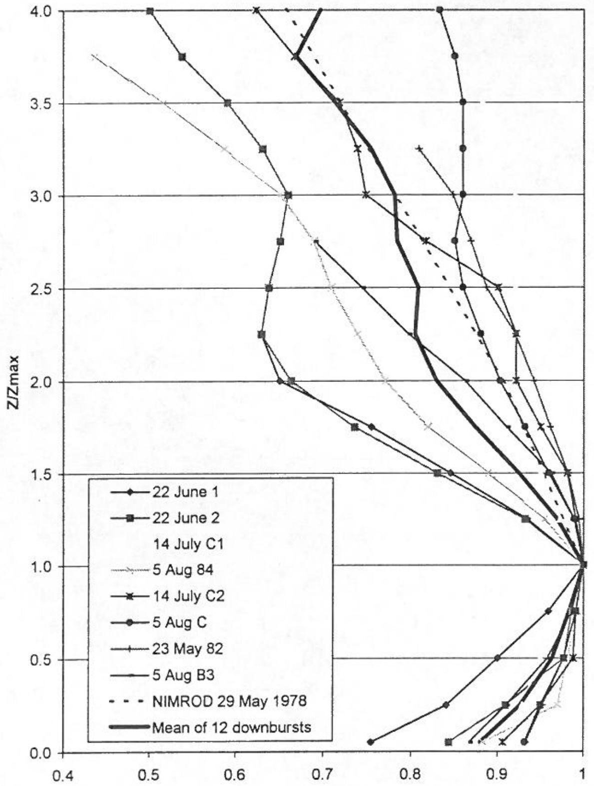

Fig. 1: Normalised Mean Thunderstorm Downburst Field Data

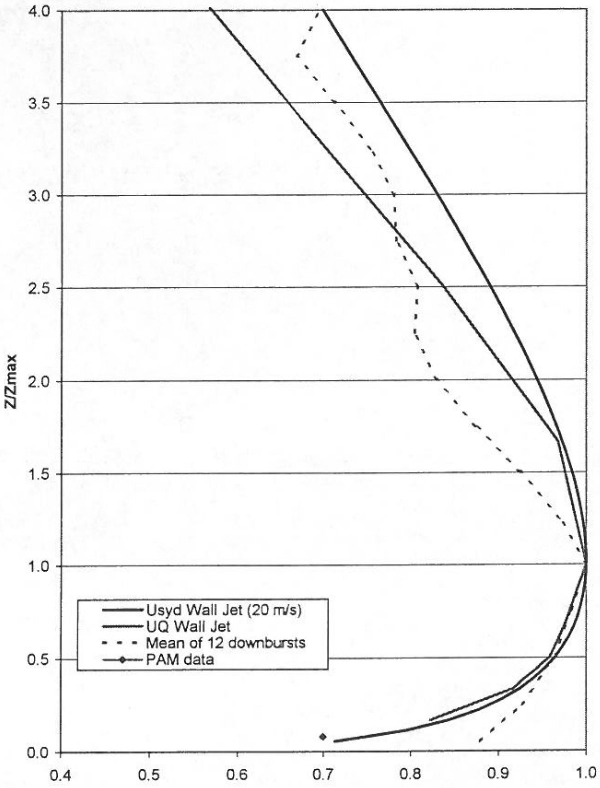

Fig. 2: Normalised Mean Thunderstorm Downburst Field Data Compared Against Impinging Jet Flow

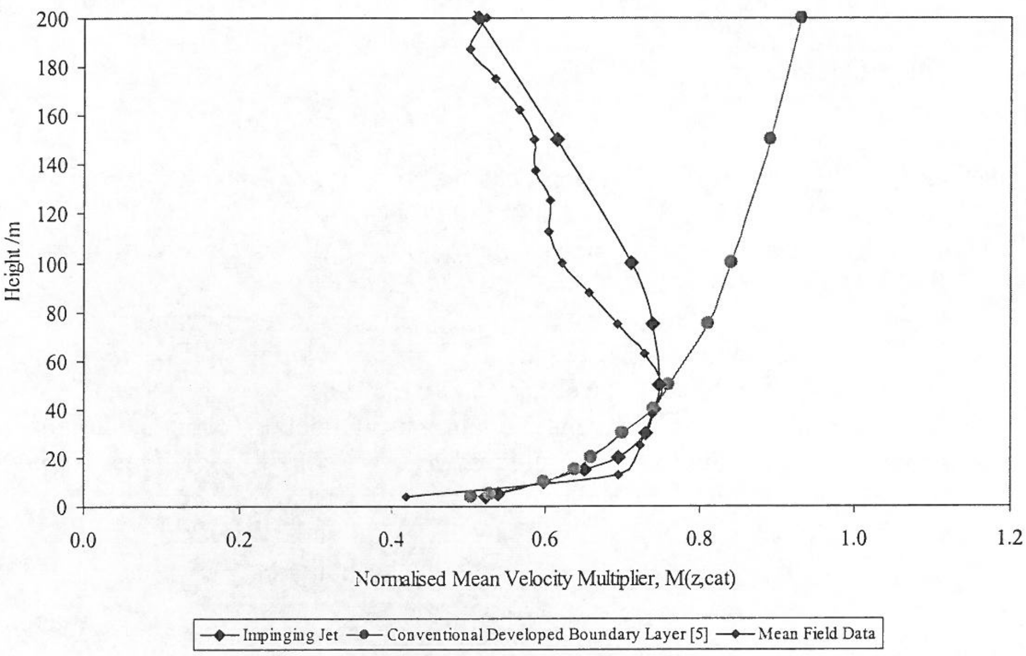

Fig. 3: Comparison Between Normalised Mean Velocity Multiplier

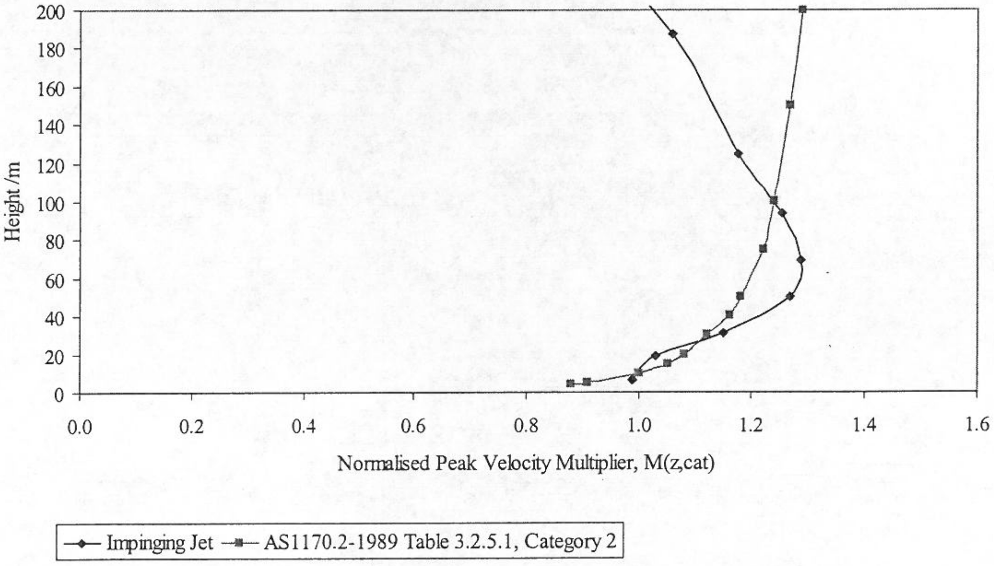

Fig. 4: Comparison Between Normalised Peak Velocity Multiplier