AN EMPIRICAL MOVING JET MODEL OF A DOWNBURST

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INTRODUCTION

A 'downburst' was defined by Fujita [1] as "a strong downdraft which induces an outburst of damaging winds on or near the ground". He further subdivided downbursts into 'microbursts', with "damaging winds extending only 4km or less", and 'macrobursts' with "outburst winds extending in excess of 4 km in horizontal dimension". Radar observations, particularly those made during the NIMROD and JAWS programmes in the U.S.A. [1,2], have provided most of what is known about the wind structure near the ground in these events.

Spillane [3] discussed two alternative models of downburst winds : the vortex ring model of Caracena [4], and the impinging wall jet model of Hjelmfelt [2]. Although there is qualitative evidence for the vortex ring type, the mean velocity profiles produced on the wall by the impinging wall jet in a laboratory experiment and by computation, have been shown to be quite similar to that observed in a downburst [2,5,6]. The impinging jet is used as a basis for the model described in this paper.

The present paper describes a model of the horizontal wind speed and direction in a travelling downburst, generated by the vector summation of the 'environmental' wind speed, or translation speed, and the radial wind generated by an impinging jet. The motivation for the development of this model was twofold :

a) to reconstruct anemometer records (anemographs) produced by downbursts and recorded by the Bureau of Meteorology, and hence to determine the physical dimensions of these events.

b) to develop a wind loading model of downbursts for transmission line systems. It has been well documented that downbursts cause frequent failures of high voltage towers in the eastern states of Australia [7].

The model could also be used as a basis for the inflow conditions for computational fluid dynamics studies of downburst wind flow around buildings.

RADIAL JET VELOCITY

The velocity distributions in an axisymmetric impinging jet have been documented and measured by Poreh and Cermak [8]. In the stagnation region, the horizontal radial velocity increases approximately linearly with increasing radial distance from the stagnation point out to a maximum velocity, $V_{r,max}$; this is the potential flow solution given by Schlichting [9].

Outside the stagnation region, the radial velocity at a fixed height (say 10 metres) may be reasonably be approximated by either of the following two functions :

$$V_r = V_{r,\,max} \,.\, \exp\{-[(x-r_{max})/R]^2\} \qquad (1)$$

or, $V_r = V_{r,max} / \{1 + [(x-r_{max})/R]^2\}$ (2)

In both cases, R is a radial length scale. x is the radial distance from the storm centre and r_{max} is the radius at which the maximum horizontal wind speed occurs.

These functions allow for both the radial diffusion of the maximum velocity, and for the growth of the boundary layer at ground level. These functions and their derivatives exhibit similar behaviour at low and high values of x, and there is no compelling argument for adopting one or the other. With appropriate values of R and r_{max}, both can be used to represent experimental data for laboratory jets. However for the current model, Equation (1) has been used to represent the radial wind speed, relative to the moving storm, outside the radius of maximum winds. Figure 1 shows the horizontal velocity profiles inside and outside the stagnation region, with representative values of r_{max} and R. There is also good agreement between these profiles and the radar observations described by Hjelmfelt [2], when R is taken as about 50% of r_{max}.

The model allows for a decay of the downburst with a defined time constant and and exponential decay function. Then Equation (1) becomes :

$$V_r = V_{r,\,max} \cdot \exp[-t/T] \,.\, \exp\{-[(x-r_{max})/R]^2\} \tag{3}$$

where t is the time measured from when the downburst is at peak intensity, and T is the time constant.

STORM TRANSLATION SPEED

A significant component of the observed horizontal wind velocity at a fixed point near the ground results from the translation speed of the downburst (termed "environmental" wind speed by Oliver [10]). Reliable information on these speeds is difficult to obtain. However, the location of two observing stations in the Sydney region only 18 kilometers apart (Bankstown and Mascot) enables estimates to be made of the translation speed for a few events. Some of these events and the computed translation speeds, assuming that the same downburst produced the maximum gust at each station, are listed in the following Table. Other estimates of the storm translation speeds, can be made from the upper level 'steering' wind speed.

Date	Time (and value) of max. gust at Bankstown	Time (and value) of max. gust at Mascot	translation speed (m/s) from gust times	upper level wind speed (m/s)
29/3/1975	15.35 (24.7 m/s)	15.53 (28.8 m/s)	17	11
23/11/1975	17.45 (26.7 m/s)	18.00 (42.2 m/s)	20	12
21/1/1977	16.07 (34.5 m/s)	16.25 (25.7 m/s)	16	15

Clearly, although there are differences in estimations, the translation speeds are a significant fraction of the recorded maximum gust speeds in these events.

COMBINED WIND VELOCITY

The combined wind velocity experienced at a point as a downburst passes is assumed to be the vector summation of the radial impinging jet velocity and the translation velocity. When a downburst passes directly over a point there will normally be a change in wind direction of 180 degrees. However, usually a downburst passes over a point with an "offset", i.e. the point is displaced from the storm track. In this case the wind direction given by the model, changes by less than 180 degrees.

SIMULATION OF ANDREWS A.F.B. DOWNBURST

Fujita [1] describes the case history of a downburst that occurred at Andrews Air Force Base on August 1 1983. The event produced a recorded peak gust of 67 m/s at a height of 5 metres, as shown in Figure 2. Fujita also gives the barometric pressure field from which the radius to "a low pressure ring" can be obtained. This can be taken to be r_{max} (about 1000 metres). The further distance to the "high pressure ring" (700 metres) can be taken as the radial scale, R. The offset distance of the downburst track was about 150 metres.

With a maximum radial speed, $V_{r,max}$ of 47 m/s, a translational speed of 12 m/s, and a time constant of 4000 seconds, the model produces the time history of wind speed shown in Figure 3. Apart from the undershoot immediately following the second peak, the model reproduces quite well the recorded wind speed trace shown in Figure 2, when the turbulent gustiness is smoothed out. The model predicts a 170 degree shift in wind direction in the vicinity of the second peak followed by a return to the original direction; this also is in good agreement with the recorded directions shown in Figure 2.

CONCLUSIONS

An empirical model of the horizontal wind speed and direction generated by a travelling downburst has been described. Good agreement is achieved between the model and recorded data from a high intensity downburst that occurred at Andrews Air Force Base in 1983.

ACKNOWLEDGEMENT

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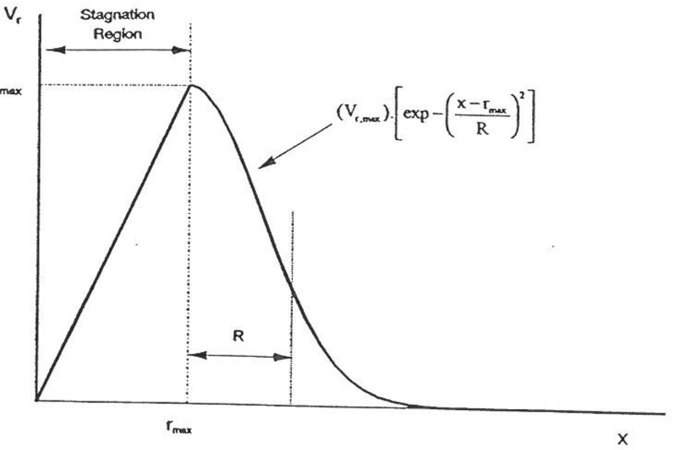

Figure 1. Profile of horizontal radial velocity

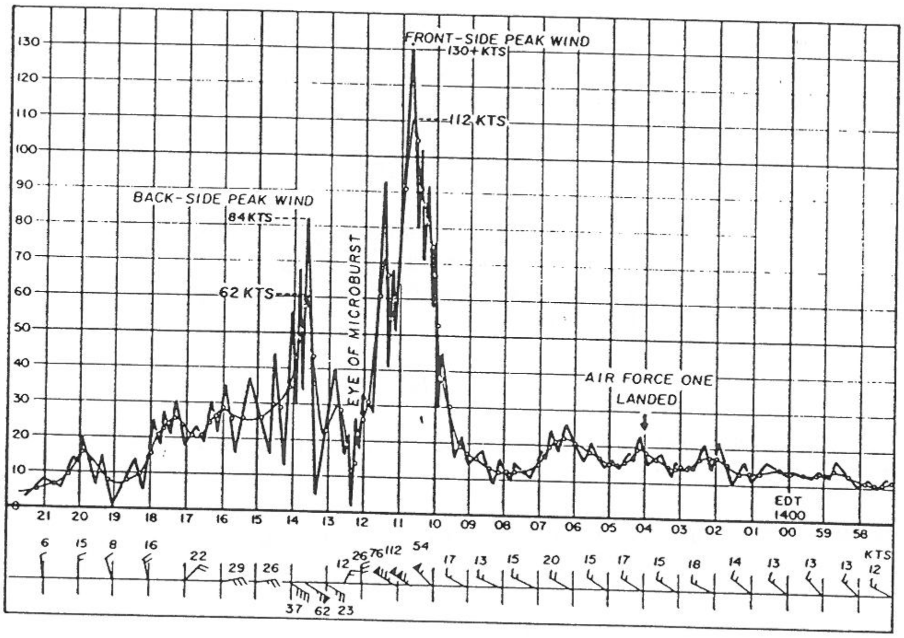

Figure 2. Recorded wind speed and direction for Andrews A.F.B. downburst (1/8/1983)

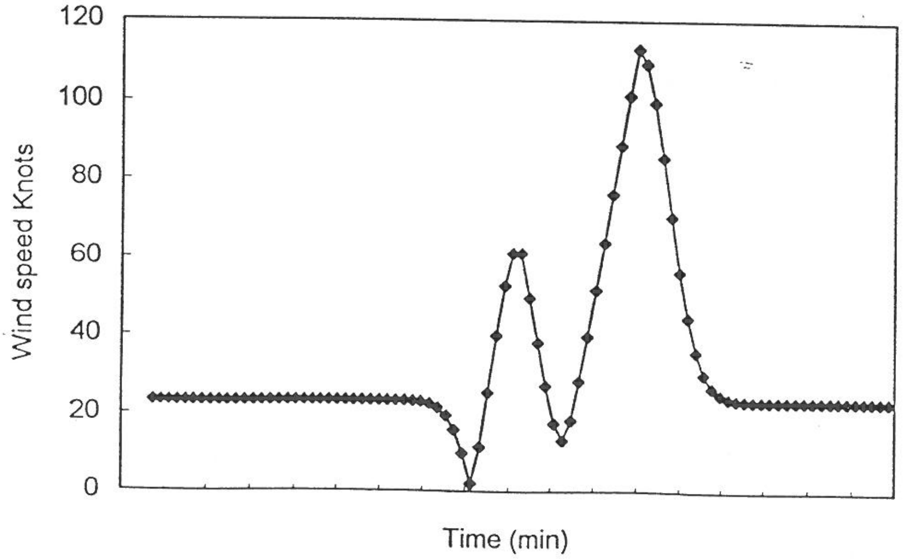

Figure 3. Simulated wind speed record for Andrews A.F.B. downburst