AN EMPIRICALLY DERIVED ESTIMATE FOR THE MEAN VELOCITY PROFILE OF A THUNDERSTORM DOWNDRAFT

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Introduction

The wind velocity profile generated by a thunderstorm downdraft has been shown (Selvam and Holmes, 1991) to be similar to that of a normal wall jet. The velocity profile differs from a developed boundary layer profile in that a peak occurs near the surface.

In this paper, the development of a normal wall jet velocity profile has been investigated and an empirical technique developed to predict the profile.

Experimental Techniques

The wind tunnel was supplied by a 15kW centrifugal blower discharging air into a settling chamber. The settling chamber is 1825mm long and has cross-sectional dimensions of 1235mm high by 620mm wide. The vertical and horizontal contractions have an area ratio of 4:1 and 2:1 respectively. A circular nozzle was 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 150mm and a diameter of 310mm and circular length of 750mm. The discharge speed at the outflow was approximately $20ms^{-1}$. The vertical test surface was made from 18mm plywood, 2.4m square, mounted on a movable steel frame. Measurements were made with a pair of constant temperature hot-wire anemometers. The reference probe was placed at the centre of the wind tunnel outflow.

A microburst is defined as having a diameter of between 400m and 4km; therefore, a geometric scaling factor of between 1/1300 and 1/13000 is applicable for this series of tests.

Results

For a jet diameter, D, mean velocity profile measurements were taken radially at 0.5D intervals from the centre of the jet impact point up to a distance of 3D, and with the test surface located at distances of 0.5D, 2D, and 5D from the jet. The development of the mean velocity profile is shown in Fig. 1 for the test surface at 2D from the jet outlet. It can be seen that the height to the peak mean velocity increases as the radial distance increases. Assuming a 1km diameter jet, the height to the peak mean velocity at a distance 3D from the jet impact point is approximately 65m.

Fig. 2 shows the same velocity profile having been normalised with respect to the peak mean velocity at that profile, V_{max}, and the height is normalised with respect to the height where the velocity is equal to half the maximum height, δ. The graph also shows a comparison with previous work. Once the velocity profile has stabilised, beyond 1.5D, the profiles agree well with previously published data. Similar results were determined for the test surface at 0.5D and 5D. The further the test surface was from the jet outlet, the greater the radius required to develop the stabilised profile. Equation 1 was found to fit the normalised data well:

$$\frac{V}{V_{max}} = 1.55\left(\frac{y}{\delta}\right)^{1/6}\left[1-\mathrm{erf}\left(0.70\frac{y}{\delta}\right)\right] \qquad (1)$$

where V is the velocity at height y, and erf is the error function.

To estimate actual profiles, an estimate has to be made of the height to half the maximum velocity, and the maximum velocity. Fig. 3 shows the relationship between the ratio of δ to distance to jet and the ratio of radial distance to distance to jet. It can be seen that once the profile has stabilised the relationship becomes linear; therefore, as long as the point of interest is greater than approximately 1.5D from the centre of impact the value of δ can be estimated.

The relationship between the inverse of the peak value of mean velocity/reference velocity and the ratio of radial distance to distance to jet is shown in Fig. 4. For each distance from the jet, this relationship becomes approximately linear once the profile has stabilised. The gradient of the stabilised region is linearly related to the distance of the surface from the jet, given by:

$$\text{Gradient of stabilised region of Fig. 4} = 0.77 \times (\text{distance to jet / jet diameter}) \qquad (2)$$

Estimates can be calculated for the actual mean velocity profile from Equations 1 and 2, and Figs. 3 and 4. Fig. 5 shows the comparison between the calculated and measured results for the test surface at 2D from the jet outlet. It can be seen that the prediction for the profile at a radius of 1D overestimates the actual measured result, due to the unstabilised nature of the velocity profile. Beyond a radius of 1.5D, the predicted and measured results are comparable.

Results were kindly made available by the University of Queensland to be used for comparative purposes. The jet was of rectangular form, being 1225mm wide by 820mm high, and the surface was positioned 880mm from the jet outlet. A profile 2000mm from the centre of impact is compared with that predicted by the above method in Fig. 6. It can be seen that the general shape is similar, but the estimated peak overestimates the measured value. This may be due to a difference in the surface roughness scaling characteristics, as the surface materials were similar.

Conclusions

Experiments using a 310mm diameter jet impinging on a wall normal to the flow compare favourably with published data, and show the development of the velocity profile. An empirical procedure has been developed to accurately predict the measured velocity profile. The method has been shown to approximate the result obtained from a significantly larger jet.

References

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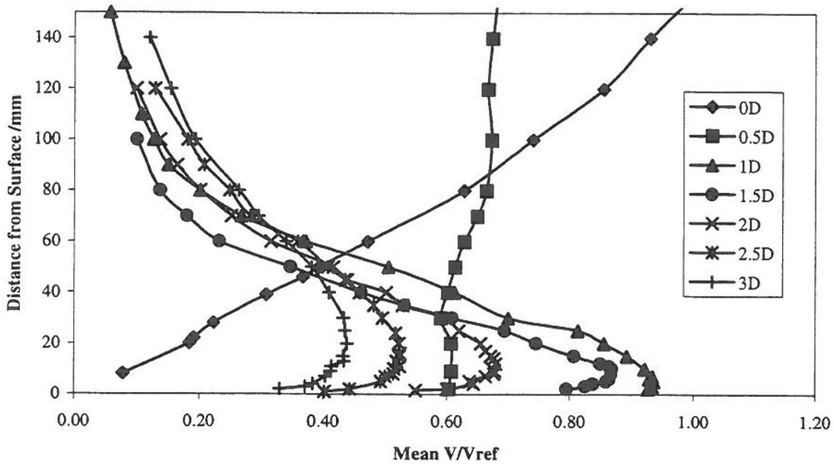

Fig. 1: Radially Developing Mean Velocity Profiles, Surface 2D from Jet

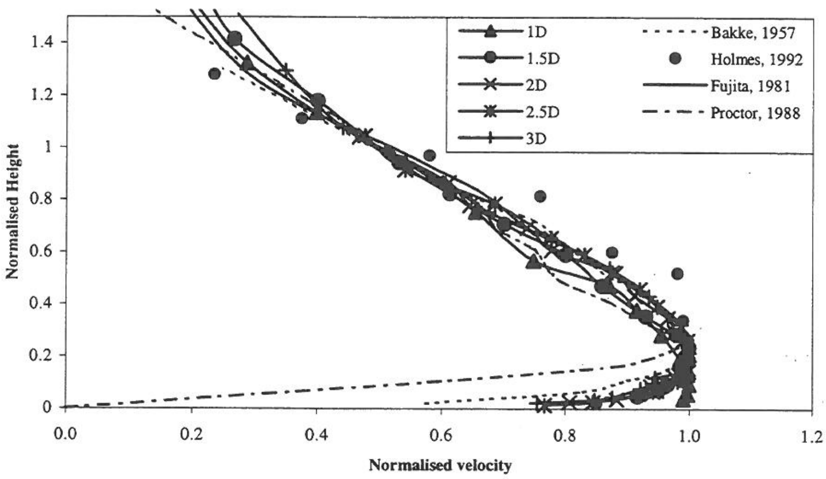

Fig. 2: Normalised Mean Velocity Profiles, Surface 2D from Jet

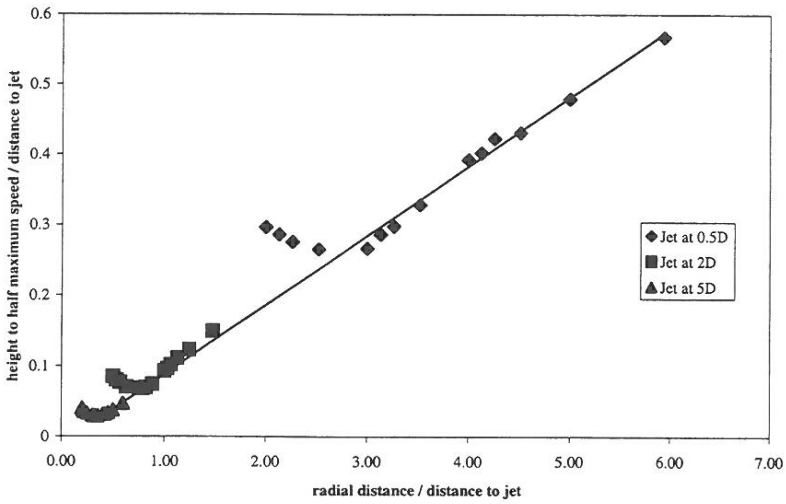

Fig. 3: Normalised Height to Half V_{max} versus Radial Distance for Different Surface Distances

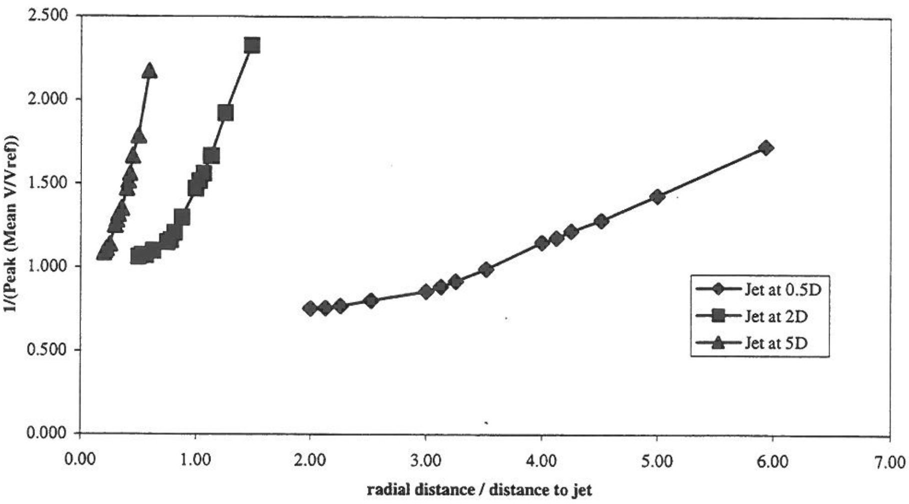

Fig. 4: Normalised Peak Mean Velocity versus Radial Distance

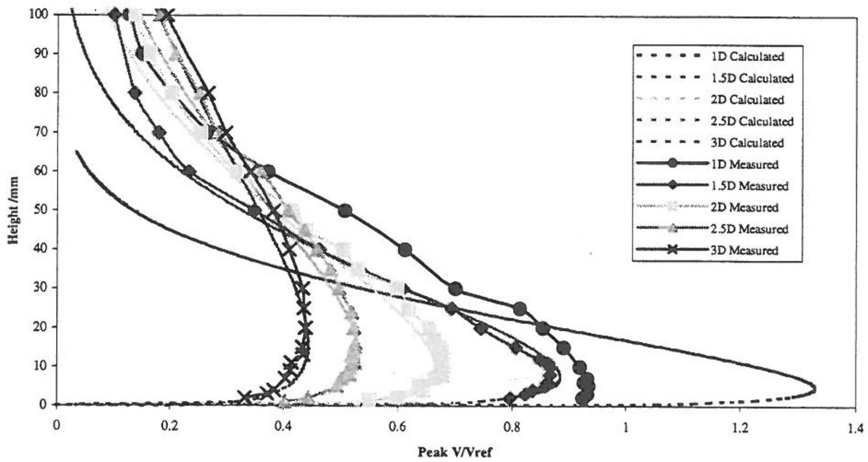

Fig. 5: Comparison of Predicted and Measured Mean Velocity Profiles, Surface at 2D from Jet

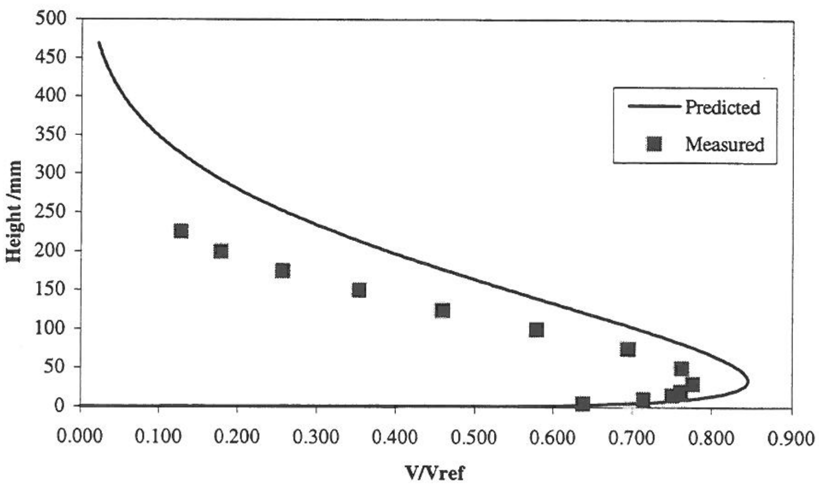

Fig. 6: Comparison of Predicted and Measured Mean Velocity Profile for Large Jet