TOPOGRAPHIC EFFECTS IN SIMULATED THUNDERSTORM DOWNDRAFTS BY WIND TUNNEL JET

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Abstract

In this study, a continuous jet impinging on a wall has been used to simulate the downdraft in a thunderstorm. Velocity and turbulence characteristics have been studied at various distances from the stagnation position and over topographic features, such as embankments and hills. Comparisons with earlier jet flow studies confirm that speedup over topography is weaker for jet flows than for boundary layer flows, but perhaps not as weak as previously observed.

1. Introduction

Thunderstorms are responsible for approximately 50% of extreme gust wind speeds in Australia outside of the tropical cyclone region [1] while in the United States it has been reported that about 1/3 of extreme gusts speeds were associated with thunderstorms [2]. Yet, they remain a meteorological phenomenon that has received little attention from Wind Engineers. Holmes & Selvam [1] undertook numerical modelling of the thunderstorm downburst phenomenon and were able to demonstrate reasonable agreement between a numerical model and limited full-scale data. Later, Holmes [3] undertook physical model studies of a jet impinging on a wall and again found reasonable agreement between numerical model, physical model and full-scale observation of a jet outflow velocity profile. These experiments established the usefulness of the continuous jet impinging on a wall as a tool in developing our understanding of thunderstorm outflows. A single topographic feature (embankment) was examined by Holmes & Selvam [1,3] and an indication of the speedup of flow over such a feature obtained. Generally it was observed that the speedup in this flow phenomenon was much less than in boundary layer flow.

Two recent failures of transmission lines in Australia [4,5] occurred on exposed ridgelines during severe thunderstorms. Although Holmes & Selvam's [1] results would indicate a lesser flow acceleration than in boundary layer flow, they examined only the one embankment (height = 40mm, slope = 0.25). The present study grew out of a need for further data on topographic effects in downdraft flows.

2. Experimental procedure

The tests were conducted using the Department of Civil Engineering's Environmental Wind Tunnel. A jet was formed in the aeronautical section by removing the downstream diffuser and replacing it with a plane wall. The tunnel exit is 1225mm wide and 820mm high and has corner chamfers of 270mm wide by 170mm high, giving a hydraulic diameter of 1.01m. This cross section is 3.6m in length and is proceeded by a 6:1 area contraction and a series of screens. The jet centreline is 1.07m above the laboratory floor and 1.3m below the ceiling above. The wall was constructed of 18mm plywood sheeting carefully butt joined and placed 880mm away from the tunnel exit. The wall extended floor to ceiling (2.4 high) and 4.7m in width, with jet centreline located 1.8m from one side. The jet outflow was not constrained in the horizontal direction.

Two basic model types were included in this study, flat topped ridges (embankments) and bell shaped hills. Three different slopes were studied; $\phi = 0.2$, 0.4 and 0.6 which, for the bell shaped hill, represented the average slope over the upper half of the hill. All hills were 100mm high and were constructed of smooth plywood. The length of the flat top portion on the embankments varied with slope, being 125mm, 185mm and 375mm for slopes of 0.6, 0.4 and 0.2 respectively.

Velocity measurements were obtained using DANTEC's streamline system and single hot wire probes mounted parallel to the ground. The hot wire was regularly calibrated against a pitot-static tube located in low turbulence flow. Vertical velocity profiles were obtained above the crest for bell shaped hills and above the leading edge of flat top portion for embankments. Two jet flow types were studied, a smooth jet, exit level turbulence intensity of 0.6% and a turbulent jet, with ~7%. The additional turbulence was produced by introducing a screen at the upstream end of the working section of the tunnel. The mean reference velocity in each case was approximately 9m/s. The jet flow results were sampled at 400Hz for 30seconds.

3. Results and Discussion

The mean velocity profiles at various distances from the stagnation point (X = 1000, 1400 and 1800mm) are shown in Figure 1 for the smooth jet. As the impacting jet spreads out over the ground plane, a characteristic profile develops with a maximum speed at a radial position of approximately 1.4 times the jet diameter. At this radial position the velocity profile is approximately constant up to a height of 50mm and then drops off reaching half the maximum velocity around 150mm. It is only beyond this radial position that the effect of the boundary layer growing on the wall is observed, leading to a peak in the vertical velocity profile between 30 and 50mm. Holmes [1,3] observed these general flow features and when compared with radar measurements of actual thunderstorms indicate a length scale of 1:1000.

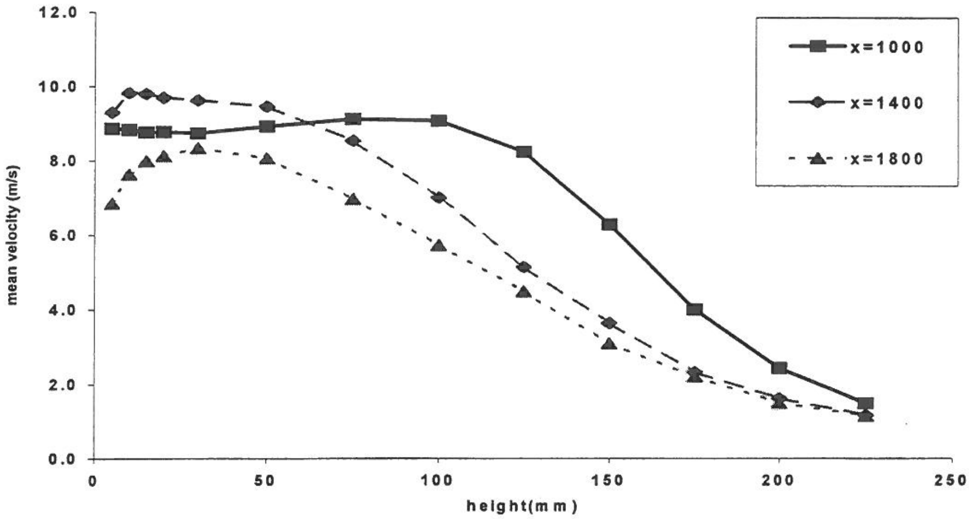

Figure 1. Mean velocity profiles at distances X, away from the stagnation point.

Figure 2 compares the present results with those of Holmes [3]. The velocity profile has been normalized by the maximum velocity and by the height (delta) at which half this speed is reached. Holmes' profile was measured at X = 1000mm from an almost identical jet size (1150 by 850mm) impacting on a plane 1.4m from the exit. (c.f. 880mm here) The agreement for the two radial position's of 1000mm is very good with Holmes having a delta = 157mm and the present study producing 168mm at the same radial position. The mean velocity profiles for the turbulent jet (Intensity = 7%) indicate little difference to the smooth jet results when presented in non-dimensional format.

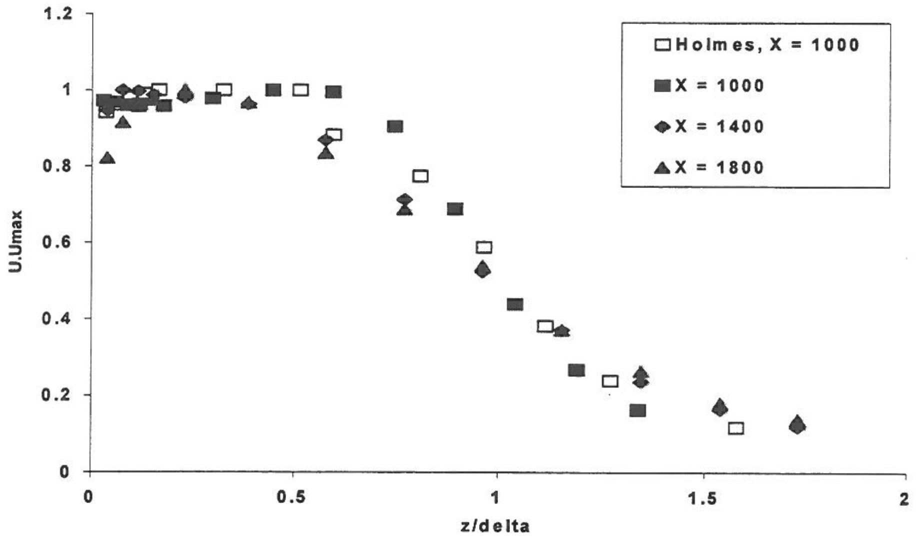

Figure 2. Comparison of non-dimensional velocity profiles with Holmes.

Figure 3 shows the topographic multipliers, Mt (mean velocity at height z above hill / mean velocity at same height above flat ground at the same radial position X = 1000mm), for Holmes' embankment, slope = 0.25, and the present study, with slope = 0.2. It is seen that there is very good agreement at the leading edge of the flat-topped embankment.

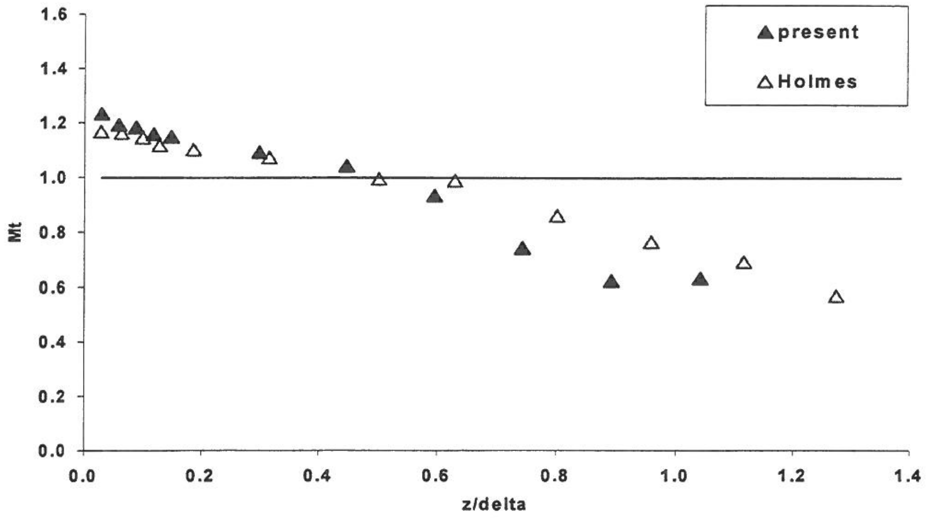

Figure 3. Comparison of topographic multipliers for mean speeds for embankments with slopes around 0.2.

Figure 4 shows the topographic multipliers for mean velocities for the three different embankment slopes (0.2, 0.4 & 0.6) at the same radial position of 1000mm as Figure 3. The height has again been non-dimensionalised by delta (=168mm at this location). It is seen that Mt values in excess of 1.2 can occur for heights up to 0.2 z/delta = 35mm or 35m at 1:1000 scale.

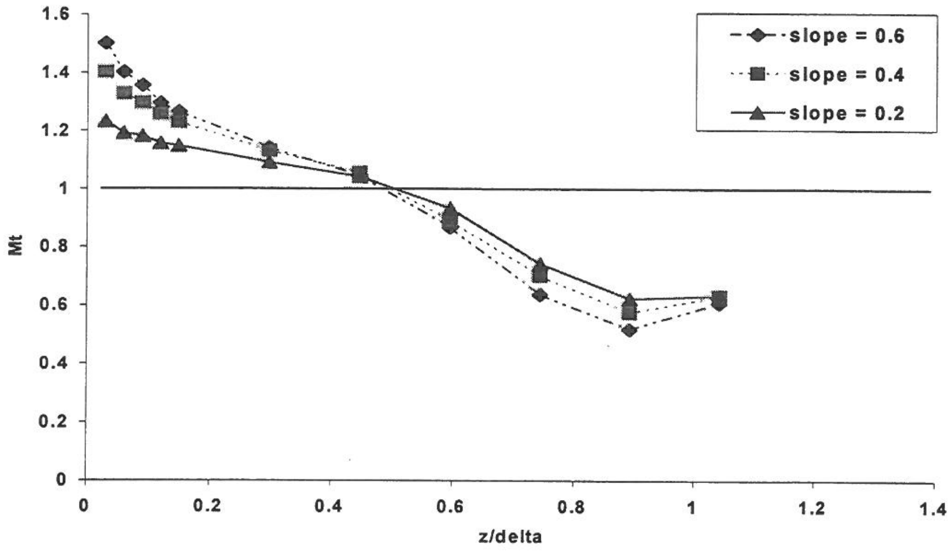

Figure 4. Topographic multipliers for various sloped embankments at X = 1000mm.

4. Conclusions

Following on from the successful preliminary experiments of Holmes in simulating thunderstorm downbursts by a wind tunnel jet impinging on a wall, a comprehensive study has been undertaken to examine the flow acceleration over generic topographic features. Good agreement with the earlier work has been found and the results extended for a range of parameters including; initial turbulence of impinging jet, radial position from jet stagnation, hill type and slope. The distortion of mean and gust wind speeds over the hills has also been obtained, along with correlation measurements. These results support the preliminary finding by Holmes that jet flow acceleration over topographic features is less than in boundary layer flows. However, higher values of Mt have been found for steeper hills.

5. References

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