Wind loads on a cube in a simulated downburst

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Abstract

The aim of this study was to investigate the pressures created on a cube immersed in a simulated thunderstorm downburst-type flow. A traveling wall jet was created for this experiment and pressures were sampled on a small cube in a variety of flow conditions to examine the effects of transient downburst-type flow.

Downbursts

Boundary layer wind profiles currently form the basis for calculating wind loads on structures. However, downbursts are responsible for design wind speeds in many parts of the world. A non-linear increase in wind speed with elevation characterizes the boundary layer flow modeled in ASCE7-98 (1998) and AS1170.2 (1989) however; this is contrary to velocity profile in a downburst. Downbursts occur in thunderstorms when a strong downdraft collides with the surface of the earth and diverges. Peak wind speeds during a downburst tend to occur approximately 80m above ground level (Hjelmfelt, 1988) with wind speeds decreasing above and below this height. These peak speeds occur approximately one diameter of the parent downdraft from the center of the downburst, where the depth of the diverging flow is narrowest.

The Moving Jet Wind Tunnel

To simulate the diverging flow of a downburst embedded in a moving thunderstorm, an inverted wall jet cable of translational movement, entitled the Moving Jet Wind Tunnel was built at Texas Tech University. Set on rails, the jet facilitated lateral movement at approximately constant speeds (1m/s and 2m/s in this case). The jet diameter was 0.51m and discharged against a flat testing surface positioned 1.7 diameters above its outlet. The approximate scale of the simulation was 1:3000.

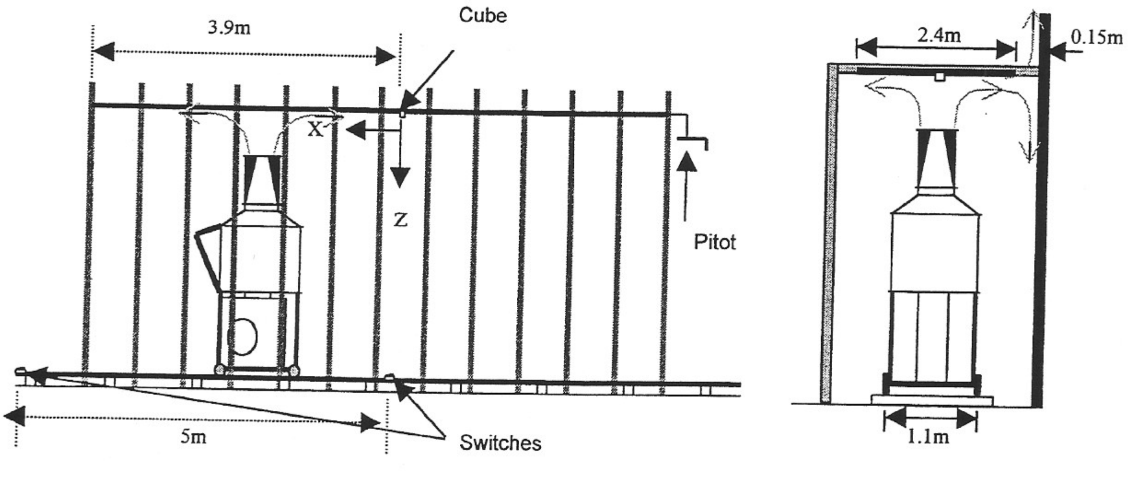

Figure 1. Moving Jet Wind Tunnel

Results & Discussion

The velocity profile across the outlet was approximately uniform, showing a slight increase towards the edges of the outlet. Exit velocity of the jet at the reference location of half an outlet diameter above the center of the nozzle, was approximately 10m/s. The jet had a turbulence intensity of approximately 4% across most of its width.

Figure 2 shows the mean velocity profiles as a function of distance from the jet stagnation point. With the jet positioned in the range $1.0 \leq X/D \leq 1.5$, the wind speed profile of the diverging flow shows little variation over the height of the model ($H/D=0.059$), and decays rapidly above model height. The stationary jet generated the fastest mean wind speeds at $X/D=1$. The radially diverging flow in this location reached speeds slightly lower than the mean reference speed of the jet ($V_{max}/V_{Ref}=0.99$).

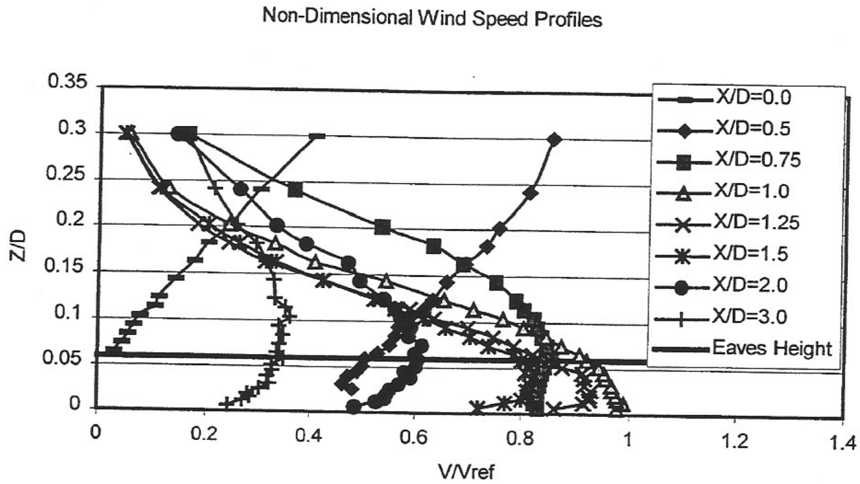

Figure 2. Mean velocity profiles of stationary jet.

A model cube of 30mm side length was constructed for the test. Thirty-eight taps connected to a Scanivalve ZOC33 monitored the surface pressures on the cube. The cube was aligned on the centerline of the path of the translating jet. A Cartesian coordinate system with an origin at the center of the base of the model defined coordinates in the Moving Jet Wind Tunnel. Positive z was defined away from the test surface, while the jet approached laterally from a positive displacement on the x-axis. Division of all distances by the diameter of the outlet of the jet (D) provided a non-dimensional representation of dimensions in the simulation.

The transducer module sampled pressures on the cube with one face normal to the direction of flow and the jet located in the range $0 \leq X/D \leq 3$. Reference pressure was taken as ambient pressure in the laboratory away from the jet. Equation (1) defines a pressure coefficient based on the mean dynamic pressure at the reference location:

$$C_{PJ} = \frac{P - P_{ATMOS}}{\frac{1}{2}\rho \overline{V}_{REF}^{2}} \tag{1}$$

Figure 3 shows the surface pressures over the cube generated by the stationary jet as a function of distance from the stagnation point and indicates two distinct types of pressure distribution. With the jet located in the range 0≤X/D≤0.25, the static pressure field of the wall jet dominates the pressures over the cube resulting in them approaching the stagnation pressure of the jet. With the jet positioned beyond X/D=0.875 the surface pressures were largely a result of the diverging flow over the testing surface as the static pressure field became indistinguishable from ambient pressure. Between these two jet position ranges (i.e. 0.5≤X/D≤0.75) a transition region existed in which both the dynamic and static characteristics of the diverging flow field influenced pressures over the cube.

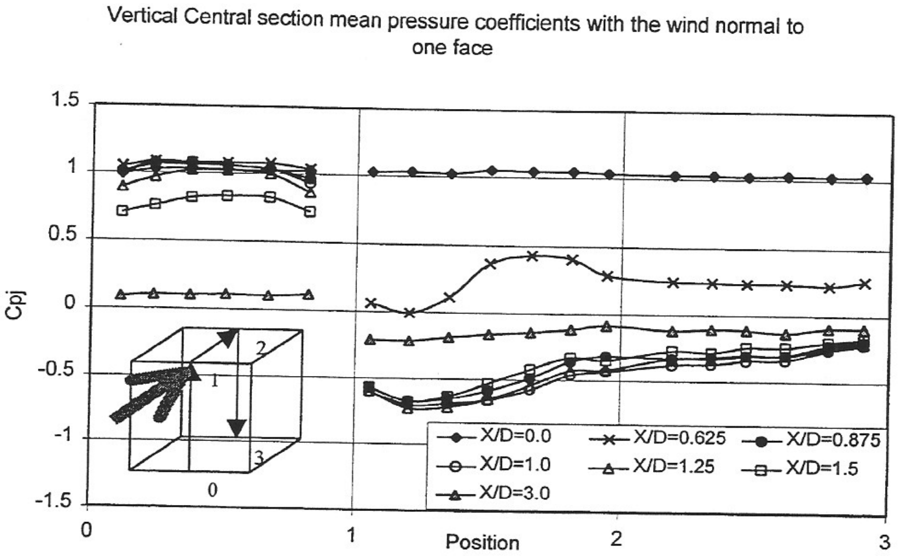

Figure 3. Mean surface pressures over cube for stationary jet

The largest mean pressures on the cube occurred for 0.875≤X/D≤1. The mean pressure profiles on the cube tended to show greater similarity to a uniform flow pressure distribution than a boundary layer pressure distribution in this range of jet locations. The relatively uniform velocity profile over the height of the cube in this region of the diverging flow produced the resemblance to the uniform flow pressure distributions. When pressures were expressed as a ratio of the maximum eaves height dynamic pressure, pressure coefficients on the windward face of the cube proved greater in the stationary jet flow than in reported uniform and simulated atmospheric boundary layer flows (Castro and Robbins, 1977). The stationary jet produced weaker suctions at the windward edge of the roof than previous boundary layer studies on cubes, but greater suctions over the roof as a whole.

Simultaneous pressures over the cube when then measured while the jet traversed the testing surface at an approximately 2m/s (≈0.2 V_{ref}). Pressure coefficient time histories were obtained by dividing by the jet outlet dynamic pressure. A 10-point moving average smoothed the data somewhat and repeated runs were undertaken to obtain phase-averaged pseudo mean pressure coefficient at each location. The time axis was also non-dimensionalized by the jet translation speed and diameter. The stationary jet mean pressures tests also provided a quasi-steady estimate of the moving jet pressure coefficient time histories. However, the quasi-steady estimate excluded the affect of the increase in wind speed resulting from jet translation. A typical time history is shown in Figure 4.

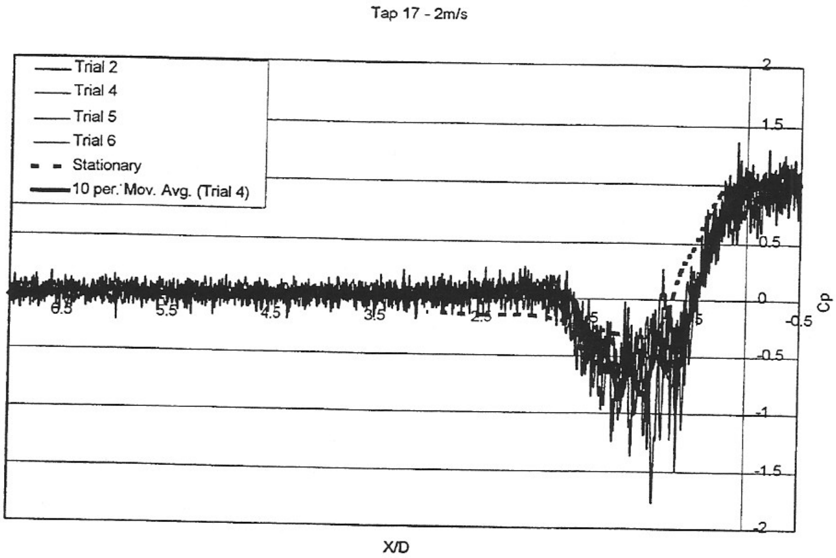

Figure 4. Transient pressure coefficient time history

The transient pressure coefficient time histories show an increase in magnitude as the jet approaches, and then converge to the stagnation pressure of the jet. The 2m/s moving jet tests yielded significantly stronger smoothed transient pressure coefficient time histories than the quasi-steady profile. Furthermore, the shape of the smoothed time histories varied significantly from the stationary mean pressures. The transient pressure coefficient time histories at the higher translational speed reflected the later arrival of a pseudo gust front formed under these conditions, and the pressure readings decayed to stagnation later than the stationary trials.

References:

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