Pulsing Jet Simulation of a Thunderstorm Downburst

A study into the viability of using a Pulsing Jet to simulate Downburst flow.

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Introduction

According to studies undertaken in Australia and the United States, thunderstorms are responsible for no less than one third of recorded national extreme gust wind speeds [1]. These winds have also been found to be responsible for more than thirty aircraft accidents since the 1970's and the loss of hundreds of lives [2]. Fujita [3] states that a thunderstorm is capable of producing three different types of wind. The first and usually the most severe is a convergent tornadic wind, the second is a non-divergent straight-line wind, and the third is a highly divergent straight or curved wind of damage causing intensity, known as a 'Downburst'. This research concentrates on downburst winds.

There are essentially two areas of a downburst outflow that can be studied. The first and most intensively researched (in a wind engineering sense) is the mean wind characteristics as simulated by a wall jet, while the second is the transitory phase of an initial roll vortex that is formed at the gust front of the downburst (Figure 1). It is believed that a ring vortex encircles a slow moving microburst [3], this is created by wind shear and, or the effect of the downburst's impact with the ground. Within the downburst, it is this roll vortex that is of interest due to its potential to have extremely high wind speeds, and therefore produce loads which may not have been previously considered in structural design codes.

Previous Studies

Several studies have previously been undertaken on the physical simulation of downbursts; generally there are two driving forces behind this sort of research. The first is a wind/civil engineering study, where the major concern has been with the impact of the downburst winds on a structure. This is generally a post ground impact mechanism. The second type of study is one that is concerned with the downburst structure before and after ground impact. These types of studies are usually produced for the aviation industry. It is the former that is the focus of this work.

Studies undertaken both in Australia and the United States have primarily concentrated on the mean velocity and pressure fields. This research however will be examining the instantaneous velocity and pressure field characteristics at the gust front. It is believed that these instantaneous measurements in the transitory flow will prove to offer significantly different flow and pressure fields on structures than in the mean flow simulations.

Methodology

At Texas Tech University a 'Moving Jet Wind Tunnel' (Figure 2) has been developed, and has been shown by [4] to correlate very well as a mean wind speed downburst model. However the need to translate the whole jet to generate the 'gust front' was clumsy and consequently a mechanism to pulse the jet has been added, so that a ring vortex can be consistently reproduced. The pulsing mechanism works in the same way as a camera iris does. It is a set of 16 blades that can quickly open and close to pulse the flow. The 'shutter' ideally should be opened instantaneously to take advantage of the full diameter of the jet, however since this is not possible, the shutter has been made so that it opens with an almost perfectly circular hole (like an iris) to try and minimize shape effects in the jet.

By using the pulsing mechanism, a roll vortex can be produced at the leading edge of the flow. A helium bubble flow visualization technique has been used so that this structure can initially be quantified (Figure 3). The helium bubble process requires that neutrally buoyant bubbles of soap film be injected into the flow stream of the downburst. The bubbles are then illuminated by a high intensity arc lamp. For each run of this process digital video footage has been taken of the downburst so that its structure and surrounding field could be analyzed in slow motion. Some major structural components that can be determined using this technique are, 1) Vortex size and shape, 2) Horizontal and vertical velocity components within the vortex, 3) Propagation speed of the roll vortex, and 4) Change in vortex dimensions as it propagates. When a high-speed camera (125 fps), with interactive software is used, instantaneous velocities can also be calculated from the video footage. However, due to some lighting and size limitations, the high-speed camera is not always a viable option. Therefore the use of hotwire anemometry is to be used once flow direction is known. A cross film hotwire allows horizontal and vertical velocities to be calculated at the leading face of the roll vortex, but this is not to be used in regions where flow reversal occurs, once the vortex has passed the sensor. Lateral velocity measurements are employed to determine the horizontal propagation profile of the vortex. From this it can be determined whether the vortex is propagating as an expanding ring vortex or if the ring breaks down into several smaller 'rotor' vortices.

Once the velocity field has been determined, a judgment as to whether this is a representative model can be made. This will not be an easy step as most of the full scale data that has been collected is presented as time averaged mean velocity profiles, and does not specifically show the effect of the initial roll vortex.

Pressure measurements on a 30mm x 30mm cube have been obtained and overall drag, lift and pressure coefficient values have been calculated. This data is then compared with data taken on the cube immersed in the steady and moving jet flows to ascertain the difference of the transitory roll vortex.

Results and Discussion

It has been determined from helium bubble visualization that the flow field created by the pulsed jet does not exactly match that of a natural downburst. It can be seen that the flow produced by the jet is entrained and forms the roll early in the jet's decent. This is in conflict with what is believed to actually happen in nature. The conflict can be attributed to the fact that in this simulation only one fluid is employed whereas in a natural downburst a colder, more dense parcel of air descends through less dense air, which allows the flow to be less entrained and the roll is not formed until ground impact occurs. However, since this research only considers the effects of the roll vortex after it has interacted with the ground, the model is acceptable as long as the flow field within the vortex is represented correctly. The velocity profiles within the vortex are yet to be taken, though it is expected that these velocities will be shown to be greater than the mean velocities calculated by [4] using this same simulator.

Even thought velocity measurements are yet to be undertaken, initial pressure readings have been recorded. Figure 4 shows an initial pulse (time history) drag force for the cube. From this time history it is seen that there is great variability in the initial pulse size (attributed to a non constant shutter opening speed). The graph shows that a maximum drag force coefficient of 5.5 is obtained for a single run (obtained using Eqn. 1), while a moving average of less than four is shown for the group of tests. Many more tests of this nature must be undertaken to determine a true average peak value.

$$C_D = \sum \frac{C_P \delta A}{A} \qquad \text{Equation 1.}$$

Equation 1 shows the process employed to obtain the drag force coefficient, where C_D represents the Drag force Coefficient, and C_P represents the Pressure coefficient normalized using a constant jet velocity (located at 0.5D above the outlet). Also delta A is the small area that a particular pressure tap on the model is assumed to represent, while A is the total area of the cube face. A summation of the front and back face drag effects is then calculated to determine the overall cube drag.

One impact that is yet to be determined (or understood) is the effect of the shutter opening speed on the velocity field. It is possible that the shutter may not be able to be opened fast enough to enable a vortex to be produced that is representative of the jet diameter; this would then lead to measurements of a vortex that is essentially produced by a smaller jet. Effectively the vortex is created by the shear induced by opening the shutter. For this to be remedied a faster opening device is required to be developed, or a different pulsing mechanism developed.

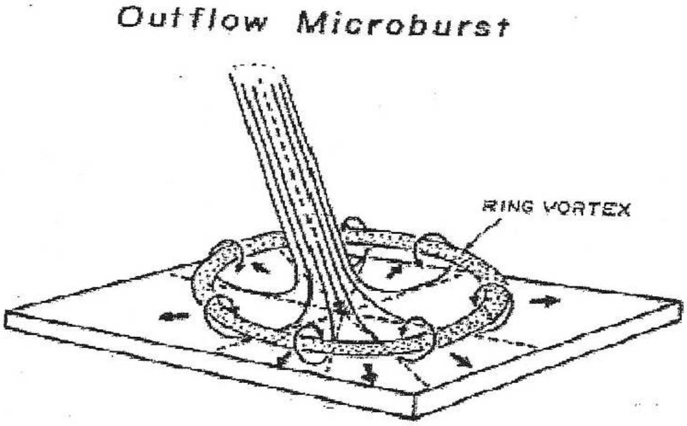

Figure 1. Encircling roll vortex around microburst.

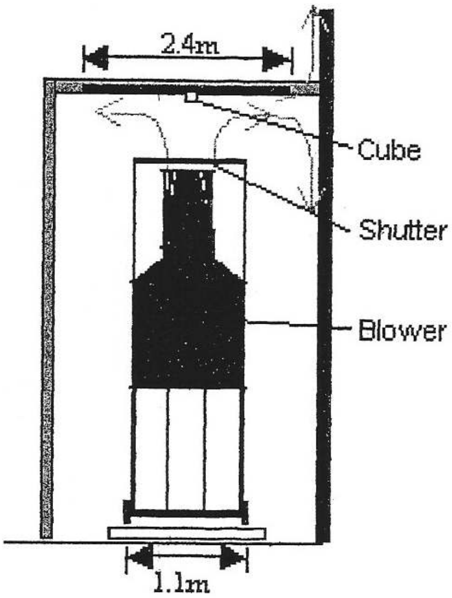

Figure 2. Moving Jet Wind Tunnel with Shutter attachment and Cube placement.

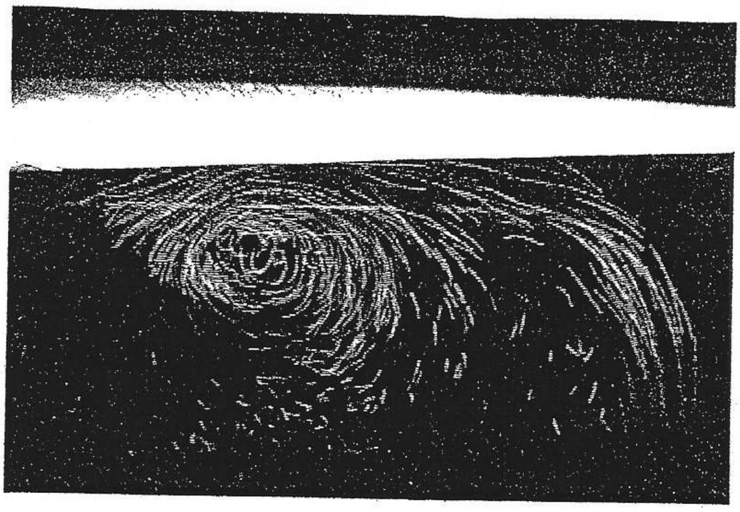

Figure 3. Helium Bubble Flow Visualisation of downburst/ground impact.

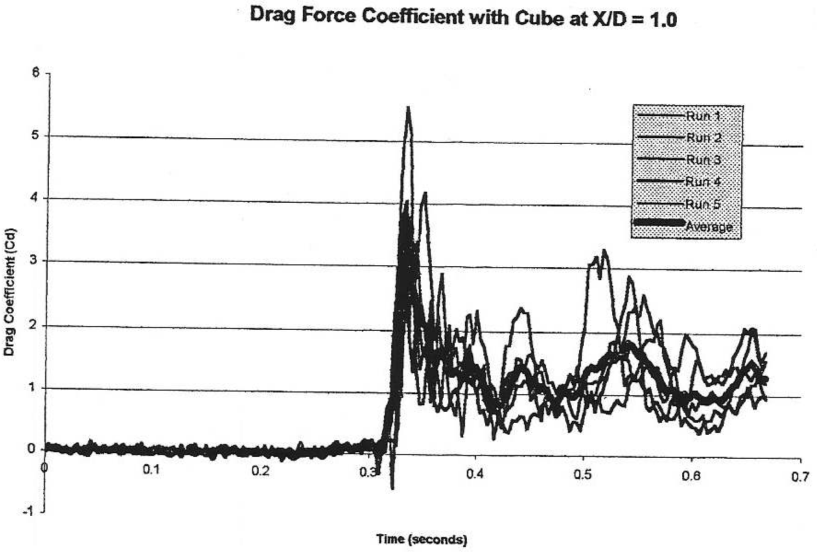

Figure 4. Time dependent Drag Force.

References

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