Design of an experimental arrangement to study the wind loads on transmission towers due to downbursts

R. Hoxey\textsuperscript{1}, A. Robertson\textsuperscript{1}, N. Toy\textsuperscript{2}, G.A.R. Parke\textsuperscript{2} \& P. Disney\textsuperscript{2}

\textsuperscript{1}Silsoe Research Institute, Silsoe, UK
\textsuperscript{2}School of Engineering, University of Surrey, Guildford, UK

Abstract

High intensity winds (HIW) are associated with severe wind loading patterns on transmission lines and tower failures. These HIWs namely tornadoes and downbursts, are often short-lived, highly energetic, flow fields that are difficult to reproduce for investigative procedures. However, this work outlines an experimental facility for studying the behaviour and characteristics of a downburst in both still air and a cross flow. It is shown that the downburst model produces the three stages of a typical downburst, that is, the contact, an outburst and a cushion stage. The growth of the ensuing ring vortex is captured and initial measurements shows that it expands faster in the radial sense than vertically. In addition to the experimental studies, a finite element analysis has been performed on two geometrically different towers. Although the work is still in progress, early results show that a heavier pylon type of tower is less likely to be affected by non-linearity, whereas a lighter weight, guyed, type of tower may be subjected to buckling modes of failure.
1 Introduction

There are three basic forms of high intensity winds, hurricanes, tornadoes and downbursts (sometimes referred to as microbursts) that may wreak havoc on the structural integrity of buildings and tower arrangements. The occurrence of these high intensity winds can be costly, and it has been reported that many of the utility organizations in the Americas, Australasia and South Africa have provided evidence that between 80 – 100% of all transmission tower failures were due to these types of winds, Dempsey [1]. Although hurricanes and tornadoes may be devastating, their behaviour is, to some limited extent, understandable, and as such, a risk assessment may be determined, Wen [2], Twisdale [3]. However, the production and dissipation of a downburst is not so well known and even fewer have been observed. Fortunately, one such occurrence has been recorded after it had touched down, in which the resulting vortex path was made visible by the ingestion of dust particles into its structure, Fig 1.

![Figure 1: Evolving vortex structure from a downburst.](image)

![Figure 2: Three stages of a downburst.](image)

In broad terms the evolution of a downburst may be described as a contact stage, an outburst stage and a cushion stage, Fig 2. These last two stages of the life of a downburst may give rise to high velocities in which the wind loading onto a transmission tower may be anything but symmetrical. Any off-axis loading could give rise to premature failure of the tower, since this condition is not usually accounted for in the original design configuration, although Krishnasamy [4], McMahon [5], and Oliver [6] have proposed risk assessment models for downbursts. The physical characteristics of HIW events together with our ability to model them adequately, has been an area of wind engineering that has been neglected, Holmes [7]. Work is now in progress to simulate the flow conditions...
of a downburst in order to understand its dissipation and how higher wind loads may occur as a result of this phenomenon. This is being accomplished by designing a downburst model using a number of different size jet effluxes onto a pressure tapped groundboard and evaluating the rate of dissipation, the velocity and turbulence intensity profiles, and the vortical structure of the downburst in the presence of a crosswind.

In addition, a finite element model is also being investigated of the loading characteristics of two types of transmission towers, with the idea of providing evidence of structural damage due to off axis loading patterns.

2 Experimental arrangement

2.1 The Atmospheric Flow Laboratory at Silsoe Research Institute

The Atmospheric Flow Laboratory (AFL) at Silsoe Research Institute (SRI) was used for the downbursts studies. This is a new, large-scale facility for wind engineering research and testing. It comprises a bank of 56 axial-flow fans, each 0.63 m in diameter, arranged in an 8-wide by 7-high matrix and a 6 m wide by 5 m high by 20 m long test area. The fans are frequency-controlled by computer such that their speeds can be fluctuated rapidly as 28 independent pairs. Simulations of turbulent, boundary-layer winds can thus be achieved by direct, computer-controlled, mechanical means. The AFL contains a large (3.5 m high by 12 m long) viewing window that enables photography and image analysis of flows to be undertaken.

A 400 mm diameter ‘downburst’ pipe was installed vertically into the centre of the test area, mounted above ceiling-level. The lower, outlet end of the pipe could receive nozzles of different diameters of up to 400 mm which could be adjusted to different heights above the ground. A variable-speed centrifugal fan was used to provide the downburst airflows via a horizontal pipe mounted above ceiling level that contained a valve that enabled the downburst flow to be switched on and off rapidly.

Downburst tests could be conducted in either still air conditions or with simultaneous wind flow generated by the AFL fans. Experimental variables available for testing in the experimental programme were, therefore:

1. Velocity of downburst
2. Height of downburst nozzle above the ground
3. Diameter of downburst
4. Velocity of simultaneous wind flow

2.2 Instrumentation

Ultrasonic anemometers were used to measure the velocities of the downburst flows once they had impinged on the ground and as they developed away from the downburst pipe. These allowed simultaneous, high-frequency (up to 100 Hz) sampling of the flows in 3 orthogonal directions at each anemometer location.
A floor-mounted pressure-tapping board was prepared comprising sixteen 1.5 mm diameter taps in a line at 100 mm spacings. These were connected via 1.5 mm diameter flexible tubing to 16 Honeywell pressure transducers (± 623 Pa range) with automatic zeroing and calibration facilities that enabled pressures to be measured to a resolution of 0.04 Pa with a 0.16 Pa noise level. A pitot-static probe was mounted in the centre of the downburst nozzle to provide a record of the downburst flow and provide a signal for conditional sampling. All pressures were measured relative to a reference static pressure sensed by a probe mounted centrally in the test area upstream of downburst pipe in relation to the wind flow. In addition, video recordings of the downbursts were made by injecting smoke into the downburst pipe work and illuminating the flows in different planes using light projectors.

2.3 Experimental results

At present a preliminary investigations has been undertaken to evaluate the experimental arrangements. This work has already highlighted areas that will require further investigation of the downburst phenomena. As an example, fig 3 shows 3 frames from a video record taken with a vertical plane of light that bisects the downburst pipe. They show a 5 m/s velocity downburst through a 300 mm diameter nozzle positioned one diameter above the floor with no simultaneous wind flow (i.e., still air conditions along the test area of the AFL). The frames were taken 1, 3, and 6 s after the start of the downburst. They show the formation of an initial tight, anti-clockwise-rotating vortex structure close to the nozzle edge that migrates radially, increasing in diameter and reducing in vorticity. The frames portray one radius of an annular vortex structure.

1 second after impingement
2.2 D in radial extent, 0.8 D high
For comparison, Fig 4 shows 3 frames of a 10 m/s velocity downburst through the same nozzle, positioned at the same height, but with a simultaneous 2 m/s wind flow (at 200 mm height) passing from right to left. The frames were taken 1, 1.75, and 2.5 s after the start of the downburst. In this case, there is no lateral migration of the vortex. Instead, it remains as a relatively tightly rolled-up, anti-clockwise-rotating vortex of fluctuating diameter and vorticity, located just upwind of the downburst. The frames portray the apex region of a horseshoe vortex structure.
More quantifiable measurements using the instrumentation described above will be undertaken to describe in much greater detail the sorts of phenomena illustrated in the two figures, and extend these measurements over ranges of the experimental parameters also listed above.

### 3 Finite element analysis

As part of this research, two types of tower have been modelled. Initial work was carried out on a CEGB type Blaw Knox L6 standard height lattice tower. Although such a tower is not normally located in regions of regular HIW occurrence, it is adopted here simply as a representation of a generic lattice tower. The second type of tower is a type A-402-0 guyed suspension tower used by Manitoba Hydro in Canada. A line of nineteen of these towers suffered failures during a windstorm in September 1996.

The L6 tower, which has a height of 44m, a square base of side length 9.1m is illustrated in fig 5. The mean height of the conductors above ground level is 30m and the average distance between adjacent towers is 340m. In contrast, the lighter guyed suspension tower is typically of 44 m height with an average distance between towers of 488 m, fig 6.
To-date, a simple analytical downburst model has been developed to determine the effect of such a HIW as it passes close to a pylon, Savory et al [8]. This model has provided the basic flow parameters and loading conditions for the finite element analysis of the above towers. In the case of the L6 tower, the finite element code ABAQUS was used with the three-dimensional beam elements, type B31, being modelled, and included a small value for the moment of inertia in order to keep the bending and torsional stiffness at both ends close to zero. For the A-402-0 tower, the finite code ANSYS has been used and a greater emphasis has been placed on accurately modelling the buckling of individual members, including non-linear material effects.

3.1 Structural response of the tower

The lifetime of a downburst is very transitory and may be as short as 5 minutes or less once it has touched down, Fujita [9], [10]. Given that representative figure for the core radius of a downburst may be 650 m with a maximum radial velocity of 80 m/s and a translational velocity of 20 m/s, an analytical model has been proposed, Fig 7. Here the downburst is approaching perpendicular to the conductor lines, some 1500m upstream of the lines, such that the tower will have to respond to off axial loading.

For this particular case, a finite element analysis of the L6 tower has been developed and the results are shown in fig 8. Here it can be observed that the displacement remains proportional to the applied load throughout the time history and reaches its maximum at the same time as the wind load, with no significant non-linearity occurring in the structure.
In the case of the suspension tower, the tower is divided into six vertical sections, of approximately equal proportions. The overall loadings for these sections in the longitudinal or X-direction, that is, normal to the conductors, as well as the transverse or Y-direction, that is, parallel to the conductors and including the cross-arms, has been computed using ANSYS, fig 9. The analysis of the tower under this loading shows that the tower is prone to overall buckling. In addition, members in the crossarm fail together with the complete failure of the primary members in the tower above the guy fixings, fig 10. This appears to be in agreement with full-scale failures of these types of towers as shown in fig 11.
4 Conclusions

This paper outlines some preliminary studies into developing a physical model to investigate the characteristics of a downburst. The three stages of its lifespan has been captured in laboratory environment, that is, the contact, outburst and
cushion stages. Furthermore, the effect of a crossflow on a downburst has also been captured and shows evidence of a horseshoe vortex being formed that restricts the downburst from expanding into the oncoming wind. Further work is planned to explain the fundamental characteristics of this flow regime.

In addition, two finite element analyses have been performed on two geometrically different transmission tower arrangements. The results indicate that for the heavier (L6) lattice tower, no significant non-linearity occurs on the structure, whereas for the lighter suspension type tower (A-402-0) buckling of the primary compression members in the tower and cross-arm can occur. Further results will be discussed after the studies are concluded.

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6 References