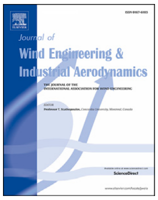
Journal of Wind Engineering & Industrial Aerodynamics 172 (2018) 12–30

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

journal homepage: www.elsevier.com/locate/jweia



Numerical investigation of the flow field around low rise buildings due to a downburst event using large eddy simulation

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ARTICLE INFO

Keywords:
Turbulent inlet
Impinging jets
LES
Downbursts
Non-stationary analysis

ABSTRACT

The transient lift and drag coefficients around a low rise cube of dimension 60*mm* and a portal building of dimensions $240 \times 130 \times 53mm$ with eaves height of 42*mm*, which arise from the numerical simulation of an impinging jet or downburst are investigated. The numerical results were validated against a experimental results from a laboratory impinging jet simulator operating at the same scale. Having found the CFD simulation to match well with the laboratory scale the CFD was then used to visualise and interpret the flow field around the buildings. Common transient atmospheric boundary layer flow features, such as conical vortices, vortices on the rear face of a building, flow separation and vortex shedding were observed and could be used to explain the lift and drag results obtained. In particular, motion of the primary vortex from the downburst and its effect on the transient pressures on the building were identified, with strong pressure gradients observed for a number of configurations. Aspects of the flow phenomena were identified, which along with the strong pressure changes on the building surfaces, indicate areas of further research due to their potential impact on building and cladding design.

1. Introduction

In recent years, Wind Engineering researchers and practitioners have become increasingly interested the effects of extreme wind events, and particularly thunderstorm downbursts. During a downburst, an intense downward movement of air is formed by falling precipitation, buoyancy effects and intensified by other cloud processes such as the melting of ice and hail. This downwards moving column of air impinges on the ground, with the vortex ring being formed as the air is displaced radially outwards from the point of impingement. As the ring vortex translates along the ground away from the stagnation point, causing rapid changes in velocity, from which a very different flow field is produced, compared to those usually considered when assessing wind loads on structures (Sengupta and Sarkar, 2008; Zhang et al., 2013; Chay and Letchford, 2002b). Thunderstorm downbursts are therefore important from a wind engineering perspective as they are strongly non-stationary (Fig. 1a), and also produce a different vertical velocity profile to the traditional “synoptic” winds characteristic of the logarithmic atmospheric boundary layer (ABL) profile (Fig. 1b).

This difference to ABL flow complicates the investigation of pressure, drag and lift coefficients around buildings. The traditional ABL coefficients are usually normalised by the mean velocity of the wind field striking the building, but given the non-stationary nature of the downburst the idea of a mean velocity field is more problematic to define. There have been a number of approaches used including normalising the pressure coefficient time history by the 50 point running mean of the velocity time history on the roof face (Chay and Letchford, 2002b). Lombardo (2009) took a similar approach but normalised the velocity by a 3*s* mean instead of a 50 point moving average. However, regardless of the method used there are difficulties with direct comparison to existing ABL pressure coefficients because of the different methods that are required to calculate the coefficients for the two wind field types.

In order to investigate wind loading around buildings due to downburst flows, engineers generally have to resort to simulations (experimental or numerical) of the phenomena, as they are difficult to forecast and cover only a small area. The most common of these is the impinging jet simulator, either constructed in a laboratory, for example Holmes (1992) and Xu and Hangan (2008) or modelled numerically, for example (Selvam and Holmes, 1992) and Kim and Hangan (2007). These models can then be scaled to the limited full scale data (Jesson et al., 2015) and then model buildings placed in the flow with the resulting pressure fields analysed (although there are difficulties with selecting appropriate

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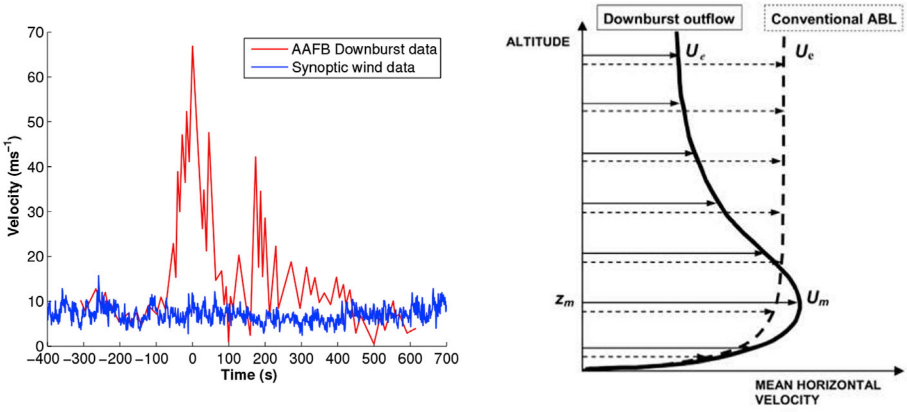
https://doi.org/10.1016/j.jweia.2017.10.028
Received 4 July 2017; Received in revised form 18 October 2017; Accepted 30 October 2017



(a) Downburst velocity time history

(b) Vertical velocity profile

Fig. 1. a) Velocity time history comparison of a rural synoptic wind at $3m$ height (Sterling et al., 2006) and the Andrew's air force base (AAFB) downburst over rural terrain, $4.9m$ height, Fujita (1985); b) Schematic illustration of the mean streamwise velocity profile corresponding to a 'typical' downburst and a typical boundary layer or "synoptic" wind (Lin and Savory, 2006).

scaling for the simulations). While impinging jet models are not perfect they provide a simple way of analysing pressures around buildings without having to resort to time consuming full scale experiments and given the computational resources required to undertake numerical simulations of full scale data downburst events.

Lombardo (2009) examined the response of the Wind Engineering Research and Fluids Laboratory (WERFL) building a pressure tapped $9.14 \times 13.7 \times 4.0m$ cuboid, to full scale downburst winds. The peak pressure coefficients were compared to the building design codes given in ASCE (2006) and it was found that the peak pressures did not generally exceed the values in the code. However, in some instances there was a rapid increase in suction on the roof of the WERFL building which then exceeded the values given by ASCE (2006). It was hypothesised that when the downburst winds struck the edges of the building they were ideally suited to producing conical vortices which extended from the roof edges (Wu, 2001). However, it should be kept in mind that the choice of formula and gust duration greatly altered the number of events where design values were exceeded and differences in the formulae between the code and downburst pressure coefficients may make comparisons unreliable.

There have also been studies using impinging jet simulators to simulate downbursts, notably Chay and Letchford (2002b) who examined the pressure and drag coefficients around a cube in a translating impinging jet. Comparing these results with the ABL work of Castro and Robins (1977) revealed that the impinging jet flow did exceed the ABL flow pressure coefficients (1.5 compared to 0.9 on the windward face), but only briefly. On average the ABL coefficients were still higher over a similar time period. For the impinging jet the drag and lift coefficients also showed little difference to individual point pressure measurements, indicating that the flow was well correlated across the surface of the cube.

Sengupta and Sarkar (2008) also examined the flow around a cube, using a large eddy CFD simulation and laboratory based translating impinging jet simulator. The results from both simulations matched each other well and like Chay and Letchford (2002b) found to exceed ABL values with a maximum drag exceeded on the building front face (1.4) and maximum lift exceeded (−1.0) on the roof. However, neither of these studies attempted to visualise, or indeed hypothesise the causes of these pressures around the buildings.

Zhang et al. (2013) examined pressures around a portal building with two roof pitches (16° and 35°), at five distances from the centre of impingement ($\frac{r}{D} = 0.0$, $\frac{r}{D} = 0.5$, $\frac{r}{D} = 1.0$, $\frac{r}{D} = 1.5$ and $\frac{r}{D} = 2.0$) and three yaw angles (0°, 45° and 90°) and also used flow visualisation to try and identify the flow phenomena responsible for producing the pressures. In the simulated downburst winds the surface pressures on the portal buildings exceeded or matched those defined for ABL winds by ASCE (2010), which would lead to greater wind loads. The maximum exceedance occurred at $\frac{r}{D} = 0.5$ when loadings were almost twice the pressures defined by ASCE (2010). The flow visualisation revealed that the causes of these exceedances varied depending on the yaw angle of the building. At the 45° yaw angle with the 16° roof pitch conical vortices were formed on the roof which increased the risk of damage to roof edges. However, at the 90° yaw angle low pressure bands were formed across the roof for both building pitches, formed by the flow separating at the windward/roof face edge.

Jubayer et al. (2016) investigated the wind loads on a low-rise building due to a laboratory simulated downburst, using the WindEEE Dome at Western University, Canada. A jet diameter of $3.2m$ was used with a generic low rise portal type building, scaled geometrically at $1:100$, corresponding to a full scale size of approximately $57m \times 37m \times 12m$. Pressure taps were included on the side faces and the roof, with readings taken for various building orientations. Varying loads on the roof, upward or downward, were found depending on building orientation and also corner vortices were identified at the eaves leading edges for some angles. Differences in magnitude between downburst and ABL pressures were also noted, again highlighting the necessity of considering non-synoptic type flows.

Jesson et al. (2015) further examined the pressures around a portal building with dimensions $240 \times 130 \times 53mm$, and with eaves height of $42mm$ at three yaw angles, 0°, 45° and 90° and also at different heights. A cube building at different heights was also examined so a comparison could be made to Chay and Letchford (2002b). Firstly it was found that there were stronger pressure gradients on the roof of the portal building than the cube building, especially at the 0° yaw angle where the cube distributions were relatively uniform across the roof face. Adjusting the yaw angle caused sharp gradients of pressure to form on both buildings, extending from the windward edge across the roof. These were assumed to be formed from conical vortices as they were in Zhang et al. (2013).

Unfortunately because of the location of the simulator within an open laboratory, Jesson et al. (2015) could not use the flow visualisation to confirm these hypotheses. Instead the data from the simulations of Jesson et al. (2015) were used to verify an LES simulation, the details, results and limitations of which are described in Haines et al. (2015).

This paper expands upon the work of Haines et al. (2015) using the numerical model developed to examine the pressure fields around two model buildings, a cube and portal building, with the same experimental setup and scale of Jesson et al. (2015). Firstly the simulation methodology is described, the results section then examines the match between the