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Downburst outflow characterization and surface roughness terrain effect

A. Mejia [1], F. Ahmed [2], A. Elawady [3]

[1]Florida International University, Miami, Florida, USA, ameji023@fiu.edu
[2]Florida International University, Miami, Florida, USA, fahme014@fiu.edu
[2]Florida International University, Miami, Florida, USA, aelawady@fiu.edu

SUMMARY:
A downburst event is a meteorological phenomenon that is random, localized, and difficult to capture by traditional anemometer stations. The velocity flow field varies in time and space and can greatly be affected by the terrain conditions and surface roughness length. Due to the difficulty in capturing these systems, the effect of rougher terrain conditions has not yet been studied in downbursts. For this reason, the present study aims to study the downburst flow characterization in different surface roughness lengths. In this study, the downburst is produced by the large-scale downburst simulator at the National Science Foundation (NSF)- Natural Hazard Engineering Research Infrastructure (NHERI) Wall of Wind (WOW) Experimental Facility in different terrain surfaces such as smooth and rougher terrain. It is expected that there will be evident differences in the vertical profiles of horizontal velocities with varying terrain exposures. The rougher terrain caused a reduction in the maximum velocity compared to smoother terrain. Moreover, the rougher terrain caused an increase in the peak height where the maximum horizontal velocities occur as compared to a smoother terrain.

Keywords: Downburst, Characterization, Terrain.

1. INTRODUCTION

Downburst is defined as an intense transient downdraft of airflows that induces an outburst of extreme winds near the ground. The velocity wind profile has a typical nose-shaped resemblance with maximum velocities occurring near the ground as opposed to the Atmospheric Boundary Layer (ABL) profiles which increase exponentially at higher heights. Capturing downbursts in the field is a difficult process due to the localized and random nature of these systems. In the last 40 years, a great number of research methodologies have been conducted to study the flow characterization of downbursts. However, little information from the literature is found regarding different terrain conditions affecting downbursts outflows and subsequently wind actions on structures. Terrain conditions can vary from smooth (ocean) to open, urban, and rougher terrains with escarpments and hills. Rougher terrain conditions will increase the turbulence intensity near the ground considerably and hence create a greater damage extent to any structure. (Aboshosha et al., 2015) conducted several numerical simulations using Large Eddy Simulations (LES) technique to obtain the turbulence characteristics of downbursts impinging on various terrain exposures including open, countryside, suburban, and urban configurations. (Mason et al., 2010) also investigated the effect of speed-up factors for downbursts on different terrains and in comparison to synoptic winds. The studies of downbursts on various terrains are essential to see the effect on the horizontal wind velocity speed-up or retardation. It also will help to understand the turbulence characteristics components such as the turbulence intensities, the integral length scales, the Power Spectral Density and peak factors occurring from the outflow near the ground. These turbulence characteristics are essential to quantify the peak loads on different structures and determine the level of Gaussianity found on these wind and pressure distributions. For this reason, the aim of this paper is to test various downburst outflows on different terrain exposures and determine the possible speed-up or retardation that can potentially occur under these scenarios.

2. EXPERIMENTAL SETUP

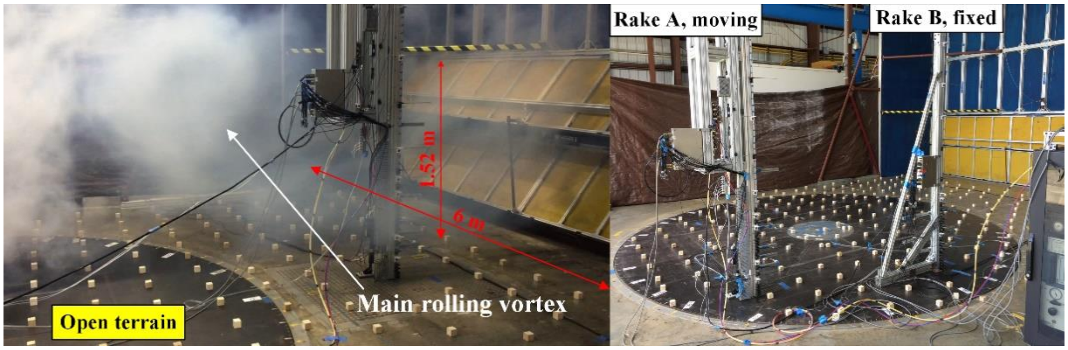
2.1 Wall of Wind Experimental Facility

The NHERI Wall of Wind (WOW) experimental facility is a large-scale, open jet wind tunnel capable of simulating synoptic straight-line winds up to 72 m/s (Chowdhury et al., 2017). The WOW consists of a 12-propeller fan array placed in 2 rows by 6 columns and blowing large volumes of wind capable of testing large- and full-scale models. It contains a large floor testing section with a turntable of 4.88 m diameter. The distance from the exit of the flow management box to the turntable center (TTC) is 6.1 m. The testing section allows the inclusion of roughness elements (type 38.1 mm wooden cubes) attached to the floor in a certain pattern and spacing to obtain the desired surface roughness lengths depending on the scale considered.

2.2 Downburst simulator at the Wall of Wind

A large-scale downburst simulator is placed directly in front of the existing WOW flow management box outlet as seen in Figure 1(a). The downburst simulator can produce large-scale downburst-like outflows traveling through the test section of the WOW. The downburst simulator at the WOW adopted the 2-D wall jet redirection method (Lin and Savory, 2006) to convert a classical straight-line wind tunnel to downburst winds. More information about the WOW downburst simulator design can be found in (Mejia et al., 2022). In Figure 1(b), it is shown a dense rake containing 64 pitot tubes and 6 Cobra probes. The dense rake is split into two rakes, one moving and one fixed, and with half of the number of probes going on each rake to measure the spatiotemporal differences found in the same outflow in different terrains: smooth and open.

(a) (b)

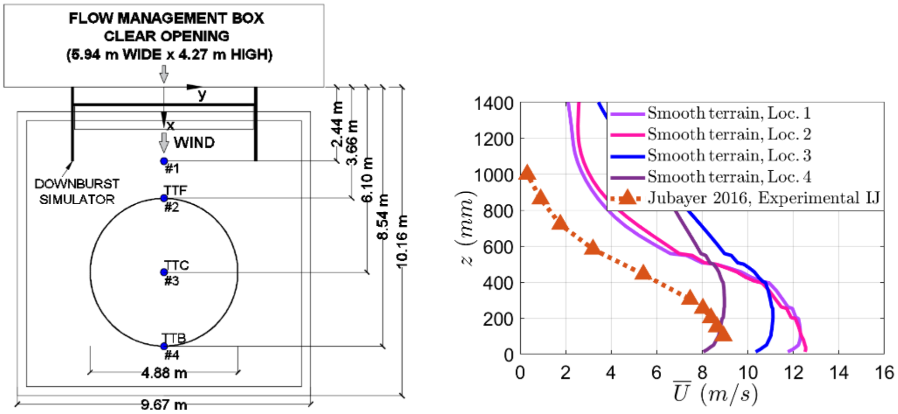


(c) (d)

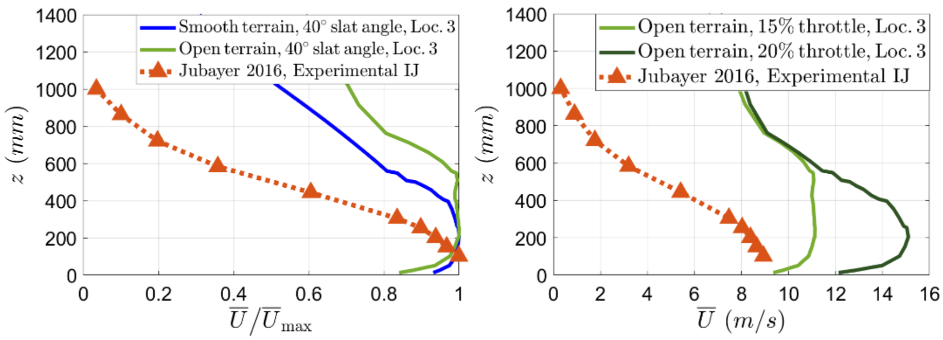
Figure 1. (a) Downburst simulator at WOW (b) dense rake in smooth terrain (c) main rolling vortex (d) open terrain configuration.

3. RESULTS

In Figure 2, it is shown the (a) plan view of the WOW testing section and strategic positions where the flow was measured by cobra probes; (b) the downstream distance effect. It can be seen that the peak height increases with the increased downstream distance while the velocity is reduced; (c) a comparison between a smooth terrain (no roughness elements on the floor) and an open terrain showing that the peak height is higher in the open terrain than the smooth terrain but with a lower maximum local velocity; (d) a comparison of the same terrain but with two different inlet velocities indicated as fan throttle of 15% and 20% respectively. The vertical velocity profile with higher initial wind velocities tends to provide a sharper nose shape compared to the lower velocity. More discussion and results will be provided at the conference.



(a) (b)



(c) (d)

Figure 2. (a) Plan view of test section (b) downstream distance effect (c) Surface roughness length effect (d) Velocity effect.

4. CONCLUDING REMARKS

The surface terrain effect is a fundamental aspect of understanding downburst outflows. So far, a smooth and open terrain has been tested in the present study. Analyzing various terrain configurations such as smooth (e.g., ocean), open, urban, suburban, and rougher terrains with escarpments and shallow hills will shed light on the uncertainties found in downburst outflow turbulence characteristics and variations of peak height and horizontal velocity.

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