Modelling of downbursts based on physical experiments

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SUMMARY:

During the last two decades, the wind engineering debate was dominated by the issue of non-synoptic wind storms (Hangan and Kareem, 2021). This type of winds (e.g. tornadoes, downbursts, gust fronts) are more complex, from a spatio-temporal perspective, compared to the synoptic-scale winds in the atmospheric boundary layer. Downbursts involve complex vortex structures, instabilities, translation and surface effects.

Herein, a first attempt is made to characterize downburst-like flows (DLFs) through the superposition of stationary mean flow fields with the effects of translation, surface roughness and the effect of the parent storm. The proposed modelling equations are calibrated on a set of experiments conducted during the last decade in the WindEEE Dome at Western University culminating with a campaign under the project THUNDERR (Canepa et al., 2022b, 2022c, 2022a). In this sense the modelling equations are semi-empirical in nature but are based on simplifications of the flow physics. The proposed model provides a frame for bringing together sets of experiments on DLFs with the aim to further the understanding of these flows and their further action on buildings and structures.

Keywords: Downburst-like Flows Modelling, Translation, Roughness

1. INTRODUCTION

Non-synoptic wind systems are the result of relatively small, meso-gamma to micro-beta scales thermal instabilities of spatial extent of the order of a couple hundred meters and duration of minutes. Of particular interest for wind engineering are the high intensity winds such as tornadoes and downbursts due to their destructive action on man-made and natural habitat.

Downbursts are characterized as downflow jets of cold and moist air impinging on the surface. The superposition of this impinging jet and the surface layer creates a mean vertical velocity profile with a maximum (nose) very close to the ground. The intense shear between the descending air and the surrounding air generates vorticity which once reflected by the ground surface generates a dynamic separation-reattachment of the flow resulting in intense wind speed near the ground. The flow field measured at a certain location is highly non-stationary, with an intermittent aspect correlated to the passage of the main vortex. As a result of asymmetry and translation the measured flow is also accompanied by directional change. The turbulent field is characterized by large non-stationarity and non-Gaussianity. Figure 1 shows a flow visualization in the WindEEE Dome of a

DLF investigated in Canepa et al. (2022b, 2022c).

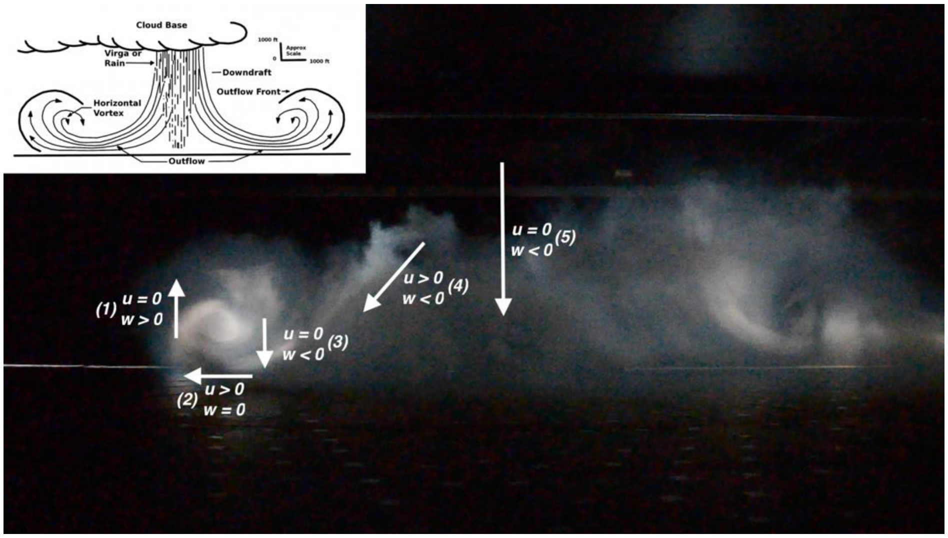

Figure 1. Flow visualization of a DLF in the WindEEE Dome and flow schematic (from Canepa et al., 2020)

2. MODELLING OF DLF

The modelling of DLFs is attempted based on a superposition of stationary flow plus the effects of translation, roughness and interaction with the parent storm (Xu and Hangan, 2008; Hangan et al., 2019; Junayed et al., 2019; Romanic and Hangan, 2020; Romanic et al., 2020; Canepa et al., 2022b, 2022c, 2022a).

The modeling of the stationary DLF is split between the mean flow field and the fluctuating flow field. Mean flow modeling will be presented based on several existing models in literature and comparison with experimental results will be provided. The fluctuating flow field will be analyzed based on a separation between a moving average component and a turbulent component made out of a slowly varying variance and a random turbulent flow field. The spectra and probability density functions of the DLF will also be presented and model results will be compared with experiments.

The effect of translation will be added mostly based on an inclination of the DLF axis and as an alteration of the axis-symmetry of the flow. Further effects of roughness will be added by testing different rough surfaces. Finally, effects of the embedding of the main DLF into a parent storm dominated by atmospheric boundary layer winds will also be introduced.

2. MODELLING FOR DLF–STRUCTURE INTERACTION

The DLF fields will be analysed from the perspective of their use to determine the Main Wind Force Resisting Systems (MWFRS). While different as approach, both the Gust Front Factor (GFF) (Kwon and Kareem, 2009, 2013, 2019) and the Thunderstorm Response Spectrum Technique (TRST) (Solari, 2016; Solari et al., 2015; Solari and De Gaetano, 2018), decompose the DLF flow field into a time and a space variation.

The GFF expresses the fluctuating mean and the variance of the DLF field as:

$$\text{a) } V_{G-F}(z,t) = V_{G-F}(z) \cdot V_{G-F}(t)$$
$$\text{b) } \sigma_{G-F}(z,t) = \sigma_{G-F}(z) \cdot \sigma_{G-F}(t) \tag{1}$$

where G–F stands for the abbreviation of gust-front wind; V and σ are the time-varying mean wind speed and standard deviation, respectively.

For the fluctuating mean a sinusoidal wave is used for the time component and the Vicroy model (1991) is used for the variation with height:

$$\text{a) } V_{G-F}(t) = \sin(\frac{\pi}{t_d} t)$$
$$\text{b) } V_{G-F}(z) = A \cdot V_{\max}[e^{b_1\left(\frac{z}{z_{\max}}\right)} - e^{b_2\left(\frac{z}{z_{\max}}\right)}] \tag{2}$$

where t_d is the pulse duration of the excitation, whereas A, b_1 and b_2 are model constants. $V_{\max}$ and $z_{\max}$ correspond to the peak velocity and its height of occurrence, respectively.

It is shown that for the effects taken into consideration in Section 2 these two simple expressions fit to a certain extent the experimental results. Figure 2 shows this for the superposition of the stationary DLF and the atmospheric boundary layer wind flow.

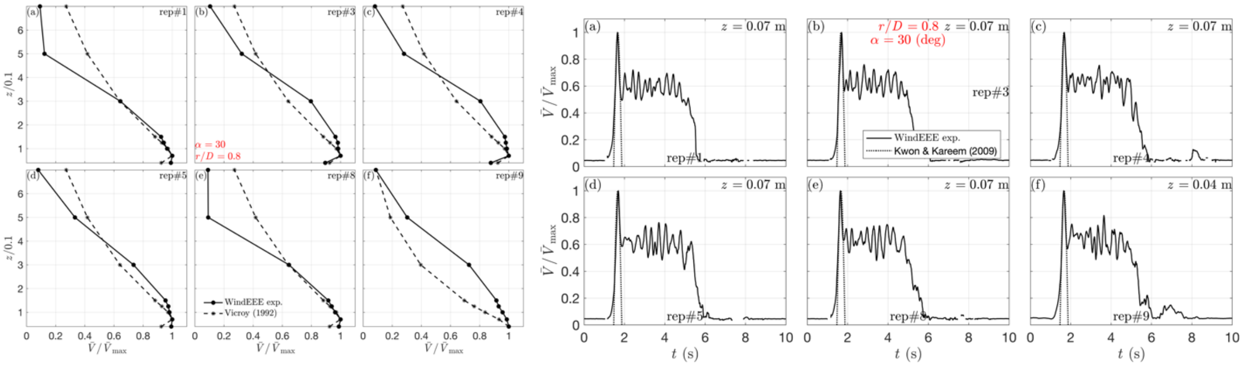

Figure 2. Mean varying DLF velocity with a) height and b) time and the fit with Eq. (2).

The problem of the more complex variation of DLF with space and time will be analysed. Also, the variation of the fluctuating flow field, according to Eq. (1b) will be further investigated.

3. CONCLUSIONS

For the first time an experimental flow field model of downburst-like flows (DLFs) is attempted. The modelling is based on the superposition of the flow field of a stationary DLF (including both mean and turbulent fields characterization) with the effects of translation, roughness and the accompanying storm front.

The model has the potential to be used in conjunction with a Main Wind Force Resisting Systems (MWRS) framework to model the effects of thunderstorms on buildings and structures.

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