Journal of Wind Engineering & Industrial Aerodynamics 171 (2017) 12–33

Contents lists available at ScienceDirect

Journal of Wind Engineering & Industrial Aerodynamics

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

Novel techniques in wind engineering

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ARTICLE INFO

Keywords:
Full scale measurements
Laboratory simulations
Numerical simulations

ABSTRACT

While the Alan Davenport Wind Engineering Chain is still valid today, the wind engineering techniques and methodologies have evolved. These changes relate to methods of collecting full scale data, physical and numerical modeling techniques, analysis techniques and wind-structure interaction approaches. These methodologies allow us to look at a more diverse spectrum of wind events including non-stationary, non-synoptic winds and their impact on buildings and structures. Spatially distributed full scale data combined with mesoscale and microscale simulations are more fitted today to characterize the local climatic scales associated to these complex wind events. These wind fields are three-dimensional, non-stationary and sometimes non-Gaussian in nature. However, our well-established Boundary Layer Wind Tunnels produce straight and steady wind and are limited in Reynolds number.

The development of larger, multi-fan and sometimes three-dimensional wind facilities has now enabled more realistic laboratory simulations of surface flows for these events. Also, it invites new insight in data analysis and the way we treat the wind-structure interaction problems in a non-stationary context.

In view of all this, we provide a review of new emerging technologies and examples of their applicability in the context of new experiments conducted at the WindEEE Research Institute at Western.

1. Introduction

In a paper dedicated to Hurricanes in United States (US), Pielke Jr and Pielke Sr (1997) define the problem of hazard reduction as minimizing Vulnerability. In turn, Vulnerability can be expressed as a function of: (i) the Incidence of the storm itself, which includes its intensity, frequency and geographical occurrence and (ii) the Exposure to the storm event, which includes the population concentration, the property value and the overall degree of preparedness to withstand such events. By reducing the vulnerability to wind storms, we attempt “to prevent natural hazards from becoming disasters”, NSF- ENH, PD 15-7396, by adopting a risk mitigation approach.

Wind engineering traditionally deals with the Incidence of the storm events and its impact on buildings and structures. The results of wind engineering research can then be translated in new building code implementations which have a direct impact on our degree of preparedness to these events. Alan Davenport's wind loading chain takes into account “the combined effects of the local wind climate, which must be described in statistical terms; the local wind exposure, which is determined by the terrain roughness and topography; the aerodynamic characteristics of the building shape; and the potential for load increases due to possible wind-induced resonant vibrations” in order to determine the wind load and thereafter the wind induced responses on buildings and structures (Davenport, 2002). Fig. 1 provides an interpretation of Alan Davenport's chain with attached practical outcomes at every chain level: the local wind climate provides outputs in terms of statistics (Probability Density Function, PDF) and geostrophic (V_g) and/or gradient wind speed (V_{gr}); the local wind exposure, or the local atmospheric boundary layer provides wind mean, $V(z)$ and turbulence, $I_u(z)$ profiles and typical wind spectra, $S(f)$; the aerodynamics of the building/structure is, therefore, subjected to a space-time pressure field, $P(x,t)$; and the final wind responses (e.g. forces, F; moments, M; displacements, x; accelerations, a) take into consideration the dynamic aspects.

Recent developments in techniques and methodologies have the potential to revisit the practical ways in which the wind engineering chain is employed. These new techniques and methodologies range over: (i) the characterization of the local climate; (ii) the physical (and numerical) modeling and measurement of complex non-stationary wind systems and the terrain, topography and roughness effects; (iii) new data analysis techniques and (iv) new wind structure interaction methodologies as

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http://dx.doi.org/10.1016/j.jweia.2017.09.010
Received 17 June 2017; Received in revised form 11 September 2017; Accepted 11 September 2017

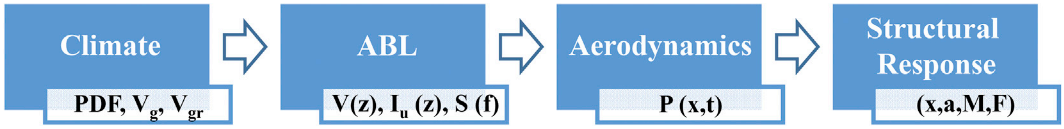

Fig. 1. Interpretation of Alan Davenport wind loading chain.

well as new structural criteria. Herein, we focus our analysis to the first three points (the impact produced by new full scale methods for local climate, novel physical simulators, measurement techniques and data analysis) while only providing some references and thoughts related to the last point.

2. New full scale measurement techniques

The complexity of the flow field generated by non-stationary winds such as tornadoes and downbursts cannot be characterized or merely differentiated by the traditional 10 m height airport measurements. Recent campaigns have employed multiple points anemometers and sonic anemometers combined with LiDARs for coastal harbour measurement of non-synoptic wind events, e.g. Solari (2014), or LiDARs only for canopy and topographic flow measurements, e.g. Mann et al. (2014), Parvu et al. (2015) or mobile Doppler radars (Wurman and Alexander, 2005) for tornado flow measurements, or Dual Doppler Radar and multipoint measurements for various gust events (Gunter and Schroeder, 2015).

2.1. Doppler radar measurements

Doppler radar field measurements are of utter importance for the wind engineering community mostly for characterization of non-synoptic wind events such as tornadoes and downbursts. Measurements are now available for tornadoes (Wurman and Gill, 2000; Bluestein and Pazmany, 2000; Wurman, 2002; Lee and Wurman, 2005; Wurman and Alexander, 2005) and for gust fronts/downbursts at different scales (Järvi et al., 2007; Pistotnik et al., 2011; Gunter and Schroeder, 2015; Burlando et al., 2017).

Two main field campaigns, namely the Verification of Rotation in Tornadoes Experiment (VORTEX) and Radar Observations of Tornadoes and the Thunderstorms Experiment (ROTATE 2012), have gathered data related to tornado-genesis and tornado low-level wind fields, respectively. Detailed field data from these campaigns has been obtained and analysed by the Center for Severe Weather Research (CSWR), in Boulder Colorado using a new technique the Ground-Based Velocity Track Display (GBVTD) analysis. Recently a first database extracting and analysing the velocity fields for several EF0, EF1- and EF2-rated tornado events has been generated, Refan et al. (2017).

The VORTEX1 project (1994 and 1995) sought to understand how tornadoes are generated and how some supercells produce no-tornadoes, weak tornadoes or violent tornadoes. 18 Doppler Radar on Wheels vehicles have been deployed in this ambitious campaign and managed to document the entire life cycle of a tornado for the first time (Bledsoe, 2009). The VORTEX2 project was an expanded second VORTEX project with field measurements from 10 May until 13 June 2009 and 1 May until 15 June 2010. This project was by far the largest and most ambitious tornado study ever with over 100 scientific participants from many different universities and research laboratories. For the first time, one of the quests of the campaign was to identify the structure of tornadoes, how strong are the winds near the ground and how exactly do they cause damage?

The ROTATE2012 was the most ambitious project ever to probe the inner workings of tornadoes. The questions driving ROTATE were even more specific to the interest of the wind engineering community: How do tornadoes cause damage? What is the role of changing winds, and airborne debris?

While successful at documenting tornadoes, nevertheless some limitations apply to full scale data sets: the dangerous environment near the tornado region and unpredictable path of a tornado limit the access. Most importantly, the characteristic of radar waves, not following the topographic features on the surface, affects the accuracy of the near ground measurements. It should also be noted that radar only measures the along the beam component of velocity.

Thunderstorm data has been targeted by the research group of Professor Schroeder at Texas Tech University (TTU) through the years using Met masts (Orwig and Schroeder, 2007), portable tripods for surface measurements and more recently mobile Doppler radars. The most recent campaign by the TTU group aiming at thunderstorm flow observations, Project SCOUT (Severe Convective OUtflow in Thunderstorms), was designed to combine radar wind profiles and surface SickNet (providing wind speed and direction at 2.25 m height) measurements, see Gunter and Schroeder (2015). Combining two Dual-Doppler radars, wind speed and direction profiles can be retrieved. Despite the large variability in wind profiles registered for a variety of thunderstorm events resulting from a variety of inflow conditions, the large majority of events displayed maximum velocities in the proximity of the ground.

This data set together with data sets from other campaigns such as "Sea and Ports" (Solari et al., 2012), "Wind, Ports and Sea" (Repetto et al., 2017) are important in providing a calibration between various physical and numerical simulations and full scale thunderstorm events. Besides these comprehensive data sets, time records of individual downburst events also provide a valuable quantitative description of this thunderstorm-related phenomena above the US (e.g., Fujita, 1985; Hjelmfelt, 1988; Atkins and Wakimoto, 1991; Holmes et al., 2008; Lombardo et al., 2014; Gunter and Schroeder, 2015), Asia–Pacific (e.g., Gomes and Vickery, 1977; Sherman, 1987; Choi, 2004), and Europe (e.g., Järvi et al., 2007; Pistotnik et al., 2011; Burlando et al., 2017).

Besides the research campaigns, such as the ones described above, the radars are today used in everyday meteorological and weather forecasting routines. An example is the NEXRAD (Next-Generation Radar) network in the US made out of 159 S-band Doppler radars managed by the National Weather Service. This network of high-resolution radars in combination with the ground measurements is used by meteorologists to issue tornado and severe weather warnings across the US. It is important to note that the radar technology and measuring techniques have evolved over the time providing more usable information about the state of the atmosphere compared to the first generation of radars. The most significant enhancement that took place in the 1990s is the introduction of dual polarization technology. Dual-polarization radars enable distinction between rain, snow, hail, and airborne debris, which is of particular importance for tornado monitoring and tracking. The number of weather radars in the US in the 1970s—time period when the ground-breaking research in wind engineering was conducted—was only 71, whereas today their number is more than two times larger than that (Whiton et al., 1998).

2.2. LiDAR measurements

Ground-based LiDARs can be either a continuous wave type or a pulsed type. These instruments detect the backscatter from airborne particles and various algorithms are used to determine wind velocities in the atmosphere. While the pulsed types are used for long range detection