J. Wind Eng. Ind. Aerodyn. 125 (2014) 121–132

Contents lists available at ScienceDirect

Journal of Wind Engineering and Industrial Aerodynamics

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

Thunderstorm characteristics of importance to wind engineering

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ARTICLE INFO

Article history:
Received 3 October 2013
Received in revised form
3 December 2013
Accepted 4 December 2013
Available online 10 January 2014

Keywords:
Thunderstorm
Non-stationary
Turbulence
Time scale
Wind profiles
Gust factor

ABSTRACT

The idea that "wind is wind", irrespective of causal mechanism, allows wind and pressure information collected in wind tunnels to be used in wind load standards. This concept is based on inherently stationary data and validated with field data that are collected from the stationary boundary layer (SBL). Thunderstorms, important events for wind loading, display non-stationary characteristics. Yet thunderstorms are assumed to have the same properties as the SBL, even though differences have been shown, especially in short duration events. In this study, near-surface wind data from thunderstorms which displayed short and rapid wind speed increases (i.e., "ramp-up") were identified and analyzed. Characteristics of the ramp-up events are detailed and compared with SBL data. Analysis revealed averaging times (moving averages) of 15–60 s can be used on ramp-up wind data for comparison to SBL winds and ramp-up events have shorter time scales (1–5 min) than those used in wind engineering practice. Within these shorter time scales turbulence spectra was similar to the SBL. Ramp-up vertical wind profiles rapidly evolve, have a downward transfer of momentum, and show differences from the SBL log-profile. Gust factors of ramp-up events differed from those of the SBL at averaging times greater than 60 s and may differ between thunderstorm types. Overall, properties of ramp-up events also display considerable variability when compared to the SBL, which may need to be considered in wind load standards.

1. Introduction

For most current engineering practice, the properties of wind, no matter the source, are assumed to be homogeneous. The idea that "wind is wind", irrespective of causal mechanism, allows statistics for wind and wind-induced pressure currently collected in wind tunnels to be used in wind load standards. Wind tunnels, without manipulation, inherently produce data with steady mean and variance. Data with invariant moments are classified as *stationary* data. Wind tunnel results are matched, compared (Cook and Mayne, 1979) and validated with full-scale stationary boundary layer (SBL) wind data that has durations that fall within the spectral gap (10–120 min, Stull, 1988). Thunderstorms produce extreme winds relevant for structural design (Holmes, 2001) and are responsible for the majority of wind-induced damage in the United States (Mohee and Miller, 2010). Thunderstorms typically display wind characteristics with unsteady mean and variance and occur over time scales shorter than that for the spectral gap. These events are referred to as *non-stationary*. Current design practices assume non-stationary events such as thunderstorms, have the same properties as stationary events in wind load standards. This assumption has been shown to be questionable in many cases (Fujita, 1985; Kim and Hangan, 2007; Holmes et al., 2008). As a result, Orwig and Schroeder (2007) as well as Choi and Hidayat (2002) state that the wind load standard is not adequately suited for thunderstorm events.

Winds generated from thunderstorms and their associated wind-induced pressure data have been challenging to the wind engineering community due to their transient (i.e., non-stationary, short temporal scale) characteristics. These characteristics render traditional stochastic correlation, spectral analysis and statistical techniques inappropriate. This shortcoming is especially true for thunderstorm events which last over short time periods (i.e., ramp-up events) such as those shown in Fig. 1a–h. Calculation of wind engineering properties (e.g., turbulence intensity, gust factor) and parameters (e.g., power law exponent) used in wind load standards are based on stationary wind data. Due to these transient characteristics and a lack of available field data (Kwon and Kareem, 2009), meaningful comparisons between stationary and non-stationary events are difficult.

Thunderstorm wind flow also shows physical differences from the SBL that may affect wind characteristics and thus wind-induced pressures. Thunderstorm flow has been hypothesized to have lower turbulence and higher lateral correlations than SBL flow (Holmes et al., 2008). Lower turbulence and higher correlations may have implications for pressure distributions on low-rise

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http://dx.doi.org/10.1016/j.jweia.2013.12.004

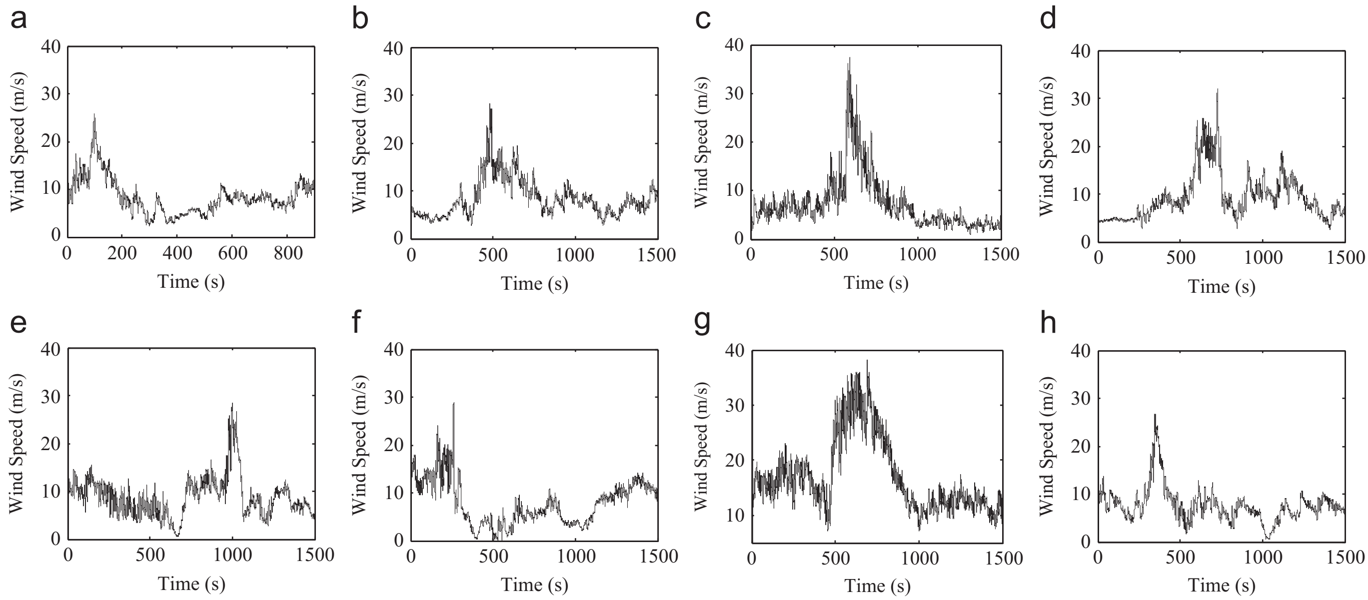

Fig. 1. (a–h) Time histories of the eight ramp-up events described in Table 1.

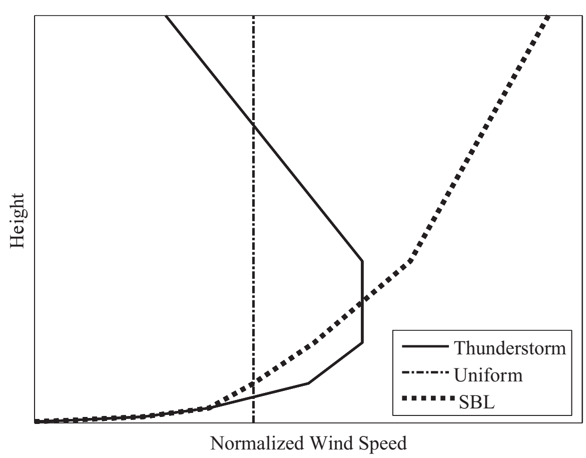

Fig. 2. Generalized vertical profiles for thunderstorm (ramp-up) and SBL winds. The word "normalized" would refer to some characteristic height.

buildings. Rapid changes in wind speed may also hide frequency content important for structural response (Juhásová, 1997) as this information is poorly understood for thunderstorm events (Kim and Hangan, 2007).

Thunderstorm wind profiles, based on wind tunnel (e.g., Mason et al., 2005) and limited full-scale data (e.g., Holmes et al., 2008), can (in some cases) show substantial differences with respect to the expected logarithmic profile exhibited by SBL winds (Fig. 2). Due to strong downward velocities striking the ground surface and spreading out (Fujita, 1985), maximum horizontal wind velocities are expected to occur at heights 100 m (300 ft) or lower (Kim and Hangan, 2007) which has implications for high-rise buildings. As the mechanics associated with convective gusts differ significantly from the SBL in both its kinematics and dynamics (Kwon and Kareem, 2009), rapid changes in wind speed and direction may cause rapid spatiotemporal pressure fluctuations on a structure (Kareem, 2008). Murgai et al. (2006) used computer simulation and found effects of non-stationary gusts on surface pressures, concluding that there were larger peak suction pressures than produced by a stationary flow. Due to the difference in the generation mechanisms and the non-linear dependence on certain meteorological parameters (Wakimoto, 2001), thunderstorm properties also are expected to display greater variability than the SBL (Choi, 2000; Choi and Hidayat, 2002; Lombardo, 2009). The lack of quality full-scale data adds to the uncertainty in the engineering properties and parameters of thunderstorm winds.

One approach to quantifying non-stationary thunderstorm wind characteristics (Holmes et al., 2008; Chen and Letchford, 2005) is to use a time-varying mean wind speed rather than a constant mean wind speed over the duration of the record. This time-varying mean wind speed data is then compared with the stationary mean wind speed data of the SBL through the computation of wind engineering parameters. The time varying means are then subtracted from the original record to generate "residual turbulence". This approach was initially used for loading coefficients in Mayne and Cook (1980). The values of both time-varying mean and residual turbulence will be used throughout this paper to compare thunderstorm wind speed data to that of the SBL. The averaging times used in the computation of time-varying means are shown in Table 2 and are discussed in more detail in Section 3.

2. Background information

For this study, full-scale thunderstorm wind data was collected at Texas Tech University and field campaigns from 2003 to 2010. A listing of ramp-up events that were collected as well as supporting information is found in Table 1 and information about the collection sites are discussed in this section.

As a note to the readers, the terms "microburst" or "downburst" will be referred to in this paper as simply "downdraft" and is used in synonymity with the ramp-up and thunderstorm terms in the context of this paper. The term thunderstorm will be used unless specifically referring to an event studied in this paper. In the latter case, the term "ramp-up" will be used.

2.1. Site characterization/instrumentation

Nearly all of the wind data analyzed for this work were collected at the Wind Engineering Research Field Laboratory (WERFL) at Texas Tech University. The original WERFL site included a 50 m (160 ft) tower with meteorological instrumentation at five levels. The original WERFL site was generally considered to be in "open" exposure (Levitan and Mehta, 1992), representative of "Exposure C" in ASCE (2010). In fact the mean