August 27-31, 2023
FLORENCE - ITALY
16th International
Conference on
Wind Engineering

Current field perspective of thunderstorm-generated near-surface winds

Franklin T. Lombardo [1]

[1]*University of Illinois Urbana-Champaign, Urbana, IL, US, lombaf@illinois.edu*

SUMMARY: (10 pt)
This abstract describes the state of field measurements for thunderstorm generated near-surface winds. A brief summary of field data collection is shared with critical gaps in the data collection highlighted based on the summary and with an eye toward furthering wind engineering. New insights into the role thunderstorm winds play in wind engineering based on current research and a potential path forward to gain further insights will also be discussed.

Keywords: extreme wind, downburst, thunderstorm

1. SUMMARY OF FIELD DATA COLLECTION

There have been a number of thunderstorm wind measurement campaigns that have contributed to better understanding of thunderstorms from an *engineering perspective*. A short survey of those campaigns are discussed in the next paragraph. The focus in this abstract is on near-surface wind data collected by anemometers. Radar is a critical tool for assessing various thunderstorm wind properties but not looked at in depth in this abstract.

Thunderstorm wind (i.e., downburst, microburst) induced aircraft accidents in the 1970s inspired Fujita to lead both JAWS and NIMROD to rigorously document their occurrence with detailed field campaigns. Fujita continued his work on thunderstorm winds culminating with the 1983 Andrews Air Force Base (AAFB) event (Fujita, 1985), which produced peak winds of approximately 75 m/s. Data collected from these campaigns have been used to validate and/or inform numerous experimental and numerical approaches in engineering (e.g., Sengupta and Sarkar, 2008) including the foundational thunderstorm wind field model used in engineering (Holmes and Oliver, 2000) and its descendants (e.g., Xhelaj et al., 2020).

Nearly 20 years after AAFB, field projects directly aimed at engineering aspects of thunderstorm winds began to commence. Orwig and Schroeder (2007) placed 7 towers collecting data at multiple heights, where two severe thunderstorm wind events were collected. Wind data from a number of strong thunderstorm wind events were collected at multiple levels of a 200 m tower and found peak wind speeds at elevations as low as 4 m and a large variability from event-to-event (Lombardo et al., 2014). Gunter and Schroeder (2015) identified a handful of strong events using both radar and surface measurements, which showed complex thunderstorm wind behavior which differed from engineering models. Solari (2012) began an ambitious campaign to measure thunderstorm winds in Italy using an anemometer network and led to multiple studies ranging from extreme wind climate to structural response.

Figure 1 summarizes these experiments by illustrating the average horizontal spacing and vertical resolution of *anemometer* measurements. The fixed ASOS measurement network in the U.S. is also included as it the data source for the current ASCE 7 wind maps. A non-exhaustive list of studies are included here, others such as Stengel and Thiele (2017) could be valuable for wind engineering purposes.

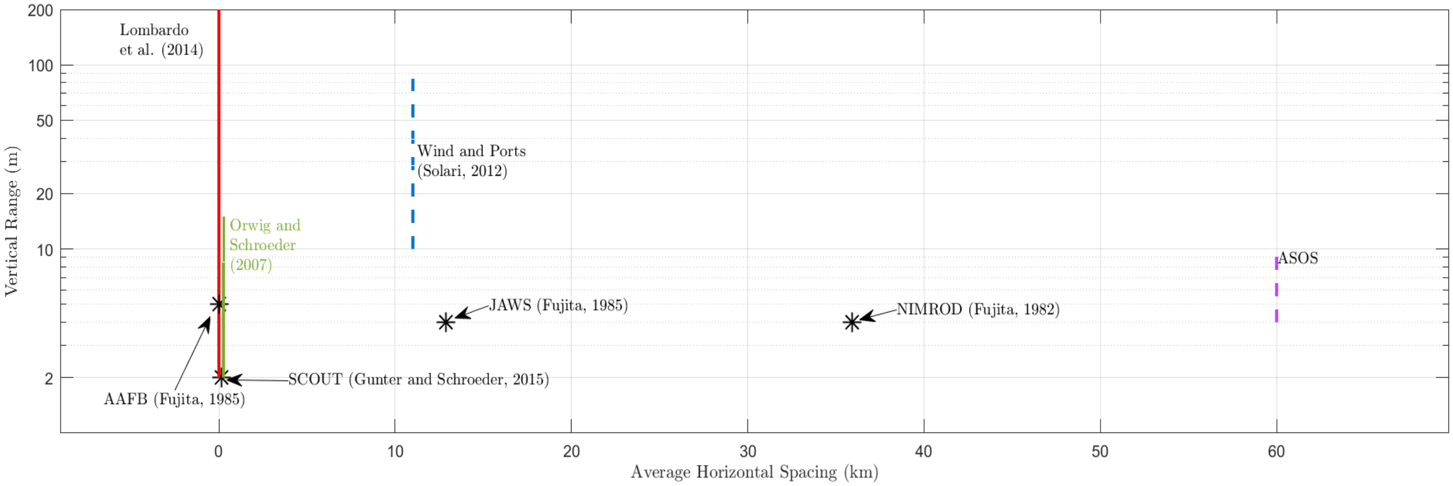

Figure 1. Illustration of field data collection for thunderstorms (anemometry only).

2. CRITICAL GAPS

Figure 1 illustrates several key items. Larger more ‘fixed network’ studies have relatively large average horizontal spacing with the smallest being around 10 km. Although ranges of vertical heights are shown for these studies (dotted lines in Fig. 1), all these experiments had anemometry for a given tower at a *single* height (i.e., no profile information available). Engineering focused field studies have small spacing all along a single dimension (e.g., either horizontal or vertical) and a limited number of observing stations. Figure 1 also reveals a clear gap in spatial scales studied. Coincidentally, dimensions of microbursts fit within this gap as suggested by Fujita to be 0.4-4 km in diameter. Recent field studies also suggest the scale of intense thunderstorm winds are less than 1 km (Skinner et al., 2015). In summary, all current studies lack the ability to better understand the full spatial dimension and hence life cycle of near-surface thunderstorm winds.

The latest work has also shown the large *variability* inherent in thunderstorm winds. This variability, in part, stems from the different types of thunderstorm winds (e.g., isolated downburst, RFD, derecho) which have different *temporal and spatial scales, wind generation mechanisms and probabilistic characteristics* (e.g., Lombardo, 2012). These distinctions are important for later sections of the abstract which discuss new insight into thunderstorm winds.

Given the lack of data collection and the ‘gaps’ discussed above, robust physical targets are missing. Experimental/numerical studies suggest there are certain flow parameters and parameter values unique to thunderstorm winds that have engineering importance and need reasonable targets. These parameters are, but not limited to, vertical angle of attack, wind profiles, flow accelerations and direction changes (e.g., Yang and Mason, 2019). Current ‘unofficial’ targets such as the profile in Hjelmfelt (1988) have significant temporal and spatial smoothing well above the surface and does not represent wind characteristics from a design perspective (i.e., 10 m, 3-s gust). The time history from AAFB does not have a comparable recorded event in both ramp-up/ramp-down character and magnitude. Although it is surmised that these parameters are important, a lack of full-scale loading data inhibits complete knowledge of each parameters general importance.

3. NEW INSIGHT

There are a number of existing field projects may shed additional insight. The group at Genoa is continuing the work Solari began and are continuing to generate valuable research related to thunderstorm winds. Texas Tech continues their work integrating field and radar measurements with computational modelling and the Illinois group will continuing field measurements of wind speed and wind loading through an NSF CAREER grant.

Computational simulations that incorporate realistic physics including environmental wind shear and buoyancy is also capable of generating new insight (Orf et al., 2014). Figure 2 illustrates some results from the simulations first discussed in Orf et al., (2014). At the time of the peak overall speed (lower right; 7 m height) the thunderstorm generated winds are asymmetric and the maximum speed is located within a small crescent shaped feature with a spatial dimension similar to those discussed in the summary section. A wind profile at the location of the maximum speed shows the 7 m peak and a distinctive nose profile. The small area of the maximum, if similar to real events, should spur questions on downburst risk, the accuracy of existing engineering models and the ability to capture these features with field measurements.

Other new insights have and can be gained understanding the engineering differences of various storm types (e.g., supercell vs. derecho). Ongoing work following the 2020 derecho in the United States which likely produced peak wind speeds in excess of 45 m/s is looking at the extreme wind climate in certain locations of the U.S. and determining if there is a dominant thunderstorm type. Events that contribute to design level wind speeds and their flow properties should be of highest consideration for design of buildings and other structures to withstand these events. Field measurements will continue to be difficult to capture and so information gained from damage surveys, especially those that damage trees and/or crops should be used to gain insight of extent of damaging winds.

4. CONCLUDING THOUGHTS

This abstract contains a summary of field projects that measure thunderstorm-generated winds. Based on an initial assessment, there is a clear need to rethink how these types of experiments are done. This call has been echoed in the literature (Solari, 2020). A new NIMROD or JAWS field type project with focus on engineering is likely ideal. A coordinated effort with all interested parties is needed to really make a difference which includes a set of common and stated goals and open sharing of data. The computational simulations as well as the existing field data have produced a significant amount of data and so do field measurements. A deep dive into data that has been collected from these experiments is also needed.

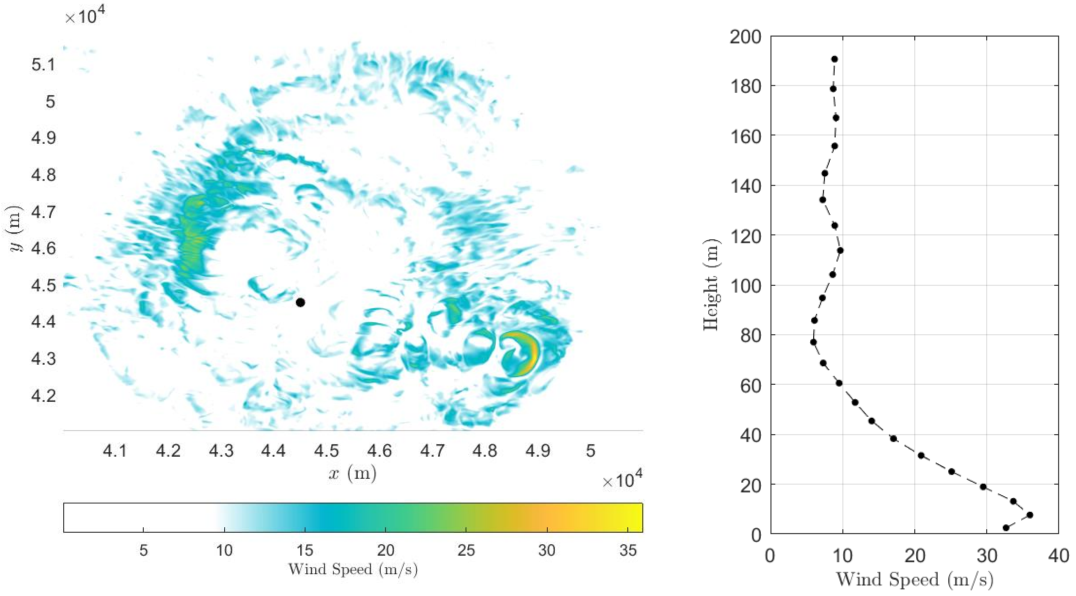

Figure 2. *Left:* Contour plot of wind speeds at the time of the maximum speed (36 m/s). *Right:* Wind profile at the location of the maximum in the lowest 200 m. Black dot represents approximate downburst center.

ACKNOWLEDGEMENTS

The author would like to gratefully acknowledge NSF CAREER and NIST DRRG grants for support of this work.

REFERENCES

Fujita, T. T. (1985). The downburst. SMRP, 210, 112.

Hjelmfelt, M. R. (1988). Structure and life cycle of microburst outflows observed in Colorado. Journal of Applied Meteorology and Climatology, 27(8), 900-927.

Holmes, J. D., and Oliver, S. E. (2000). An empirical model of a downburst. Eng. Struct., 22(9), 1167-1172.

Lombardo, F. T. (2012). Improved extreme wind speed estimation for wind engineering applications. Journal of Wind Engineering and Industrial Aerodynamics, 104, 278-284.

Lombardo, F. T., Smith, D. A., Schroeder, J. L., and Mehta, K. C. (2014). Thunderstorm characteristics of importance to wind engineering. Journal of Wind Engineering and Industrial Aerodynamics, 125, 121-132.

Orf, L. G., Oreskovic, C., Savory, E., and Kantor, E. (2014). Circumferential analysis of a simulated three-dimensional downburst-producing thunderstorm outflow. J. Wind Engineering and Industrial Aerodynamics, 135, 182-190.

Orwig, K. D., and Schroeder, J. L. (2007). Near-surface wind characteristics of extreme thunderstorm outflows. Journal of Wind Engineering and Industrial Aerodynamics, 95(7), 565-584.

Sengupta, A., and Sarkar, P. P. (2008). Experimental measurement and numerical simulation of an impinging jet with application to thunderstorm microburst winds. J. Wind Engineering and Industrial Aerodynamics, 96(3), 345-365.

Skinner, P. S., Weiss, C. C., Wicker, L. J., Potvin, C. K., and Dowell, D. C. (2015). Forcing mechanisms for an internal rear-flank downdraft momentum surge in the 18 May 2010 Dumas, Texas, supercell. Monthly Weather Review, 143(11), 4305-4330.

Solari, G., Repetto, M. P., Burlando, M., De Gaetano, P., Pizzo, M., Tizzi, M., and Parodi, M. (2012). The wind forecast for safety management of port areas. J. Wind Engineering and Industrial Aerodynamics, 104, 266-277.

Solari, G. (2020). Thunderstorm downbursts and wind loading of structures: Progress and prospect. Frontiers in built environment, 6, 63.

Stengel, D., and Thiele, K. (2017). Measurements of downburst wind loading acting on an overhead transmission line in Northern Germany. Procedia engineering, 199, 3152-3157.

Xhelaj, A., Burlando, M., and Solari, G. (2020). A general-purpose analytical model for reconstructing the thunderstorm outflows of travelling downbursts immersed in ABL flows. Journal of Wind Engineering and Industrial Aerodynamics, 207, 104373.

Yang, T., and Mason, M. S. (2019). Aerodynamic characteristics of rectangular cylinders in steady and accelerating wind flow. Journal of Fluids and Structures, 90, 246-262.