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In this issue:

An Investigation of In-Field Blockage Effects in Closely-Spaced Lateral Wind Farm Configurations

Sean McTavish, Daniel Feszty, Fred Nitzsche

Department of Mechanical and Aerospace Engineering, Carleton University, Ottawa, Canada

Wind energy is currently one of the fastest growing sources of renewable energy, but sustained development of wind resources necessitates new approaches to improve the performance of wind farms. Wind farm efficiency typically suffers on an annual basis due to the observation that mean annual wind speeds can be 50% lower than the wind speeds required for a farm to generate its maximum rated capacity. A method of augmenting the performance of wind farms in mean annual wind conditions has been established by capitalizing on the effects of reduced lateral wind turbine spacing and the associated wake behavior. The benefits of closely-spaced wind turbine configurations were identified by conducting a parametric study of lateral and longitudinal wind turbine separation distances in the atmospheric boundary layer wind tunnel at Carleton University. Custom-designed 20 cm diameter wind turbines were arranged such that the outer turbines were separated by a gap (G) and adjacent rotors had a tip-to-tip separation distance (S_{tip}), as shown in Figures 1(a)-i and 1(b)-ii. The downstream setback of the center rotor was also varied for each upstream gap width. The power output from each turbine was calculated using the voltage output of their respective DC generators and the mean velocity in the turbine wakes was characterized using a single-normal hot-wire probe.

A beneficial in-field blockage effect can be generated between two laterally-aligned rotors arranged as shown in Figure 1(a). The in-field blockage effect is caused by the relative proximity of the rotors and their wakes and results in the flow acceleration between adjacent rotors highlighted by the velocity contours in Figure 1(a)-ii. The region of increased flow speed through the gap extends from the upstream rotor plane to

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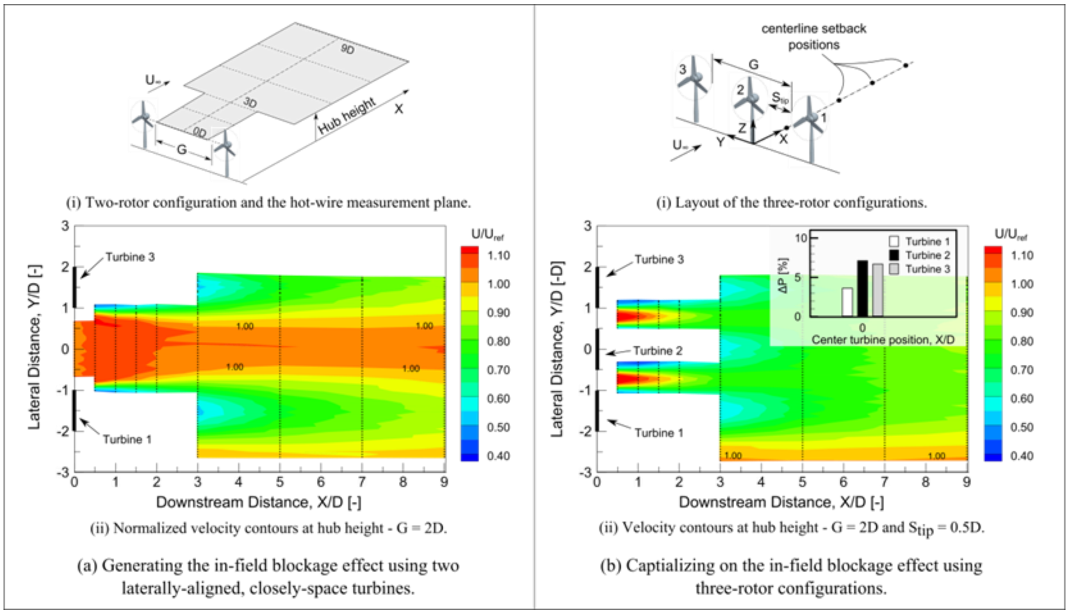

(i) Two-rotor configuration and the hot-wire measurement plane.

(ii) Normalized velocity contours at hub height - G = 2D.

(a) Generating the in-field blockage effect using two laterally-aligned, closely-space turbines.

(i) Layout of the three-rotor configurations.

(ii) Velocity contours at hub height - G = 2D and S_{tip} = 0.5D.

(b) Captializing on the in-field blockage effect using three-rotor configurations.

Figure 1: Identifying and analyzing the in-field blockage effect using two- and three-rotor wind farm configurations

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more than 3D downstream. The velocity contours in Figure 1(a)-ii have been normalized by the mean reference speed (U/U_{ref}) at the turbine hub height and contour lines where the speed is equal to the freestream speed have been identified.

The increased speed resulting from the close lateral placement of the turbines creates a unique opportunity to increase the power output of wind farms. In order to capitalize on the flow acceleration created by the in-field blockage effect, a multi-rotor study was conducted using three wind turbines arranged as shown in Figure 1(b)-i. Although this particular case used three laterally-aligned rotors, the downstream position of the center turbine was systematically varied in other tests. The increase in power of a turbine in a three-rotor configuration (ΔP) was calculated by comparing the power output of a particular rotor in a multi-rotor test to its power output in stand-alone, isolated conditions. A positive ΔP therefore indicates that the turbine generates more power in the multi-rotor configuration compared to the amount of power generated by a single turbine in isolation. The effect of adding a third turbine in the region of increased velocity is illustrated in Figure 1(b)-ii, where G = 2D and S_{tip} = 0.5D. The velocity contours highlight regions of accelerated flow between the blade tips and a broad wake behind the three rotors. This arrangement leads to the beneficial power increase observed in the bar chart inset in Figure 1(b)-ii. The power output of all three rotors is increased relative to their respective isolated power outputs and Turbines 2 and 3 each exhibit a significant increase in output of approximately 7%. The in-field blockage effect identified with closely-spaced lateral wind turbine configurations may offer the potential to increase the annual capacity factor of a wind farm by increasing the energy yield in mean wind annual wind speeds while also requiring less land for a wind farm.

Analytical Function for Low-Rise Buildings Vulnerability

Gonzalo Pita [a] and Jean-Paul Pinelli [b]
[a] Johns Hopkins University, Baltimore, MD, USA
[b] Florida Institute of Technology, Melbourne, FL, USA

This paper presents the use of a Verhulst 6-parameter function coupled with a hyperbolic tangent function to fit a set of wind vulnerability curves obtained from engineering simulations. The parameters of the proposed function provide valuable insight into the relevance and interaction of key components of the overall building wind vulnerability. The dependency between the parameters of the analytical function and the building features has been explored with regression trees. The simulation-based vulnerability functions, provided by the Florida Public Hurricane Loss Model, are characterized by key building components. The model proposed expresses damage ratio r contingent upon wind speeds v_w as:

$$r(v_w) = k(v_w) + r_M\left(1 - \frac{1}{\left(1+\left(2^n-1\right)\cdot\exp\left(\frac{v_w - v_{1/2}}{\tau}\right)\right)^{1/n}}\right)$$

with $k(v_w)$ water intrusion damage; r_M damage ratio at 250 mph on top of $k(v_w)$; $v_{1/2}$ wind velocity at half of $r(250)$; n curve asymmetry factor; and τ building damage growth rate (Figure 1). The function parameters provide useful insights about the vulnerability of the buildings. The wind velocity $v_{1/2}$ is mostly determined by strength and number of stories. Because of the curve asymmetry, $v_{1/2}$ does not coincide with the inflection point velocity v_{IP}. In general, the smaller $v_{1/2}$, and also the closer $v_{1/2}$ and v_{IP}, the more vulnerable is the building. The difference $v_{IP} - v_{1/2}$ could be interpreted as a proxy for a reserve of capacity. The damage growth rate τ will grow faster in weaker buildings. Consequently in weak buildings, a large amount of damage occurs over a relatively short interval of wind speeds. Damage growth rate τ is contingent upon building strength, number of stories (for weak and medium strength buildings) and roof shape for strong buildings. The asymmetry of a vulnerability curve is measured by n, which is also related to the difference of wind speeds $v_{IP} - v_{1/2}$. The asymmetry of a vulnerability curve is indicative of the strength of the structure, with stronger buildings having more asymmetric vulnerability curves.

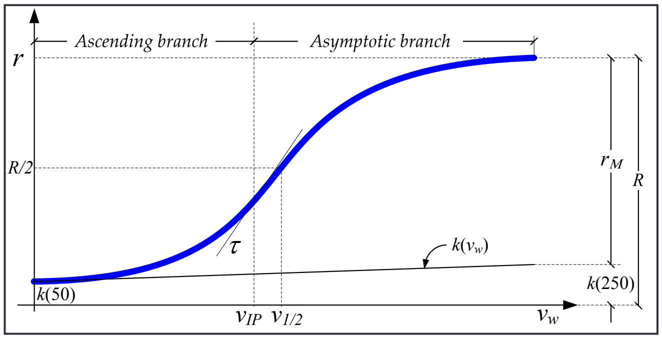

Figure 1: Vulnerability curves, and their derivatives (i.e. t), of weak and strong types

The approach accurately fitted a significant number of very different vulnerability curves with an error that is significantly smaller than the inherent margin of uncertainty of the curves produced by engineering simulation (Figure 2). The proposed function seems promising as it conveys interesting insights about the relationships between building features and building wind vulnerability. It also hints at a possible method for generating vulnerability curves analytically.

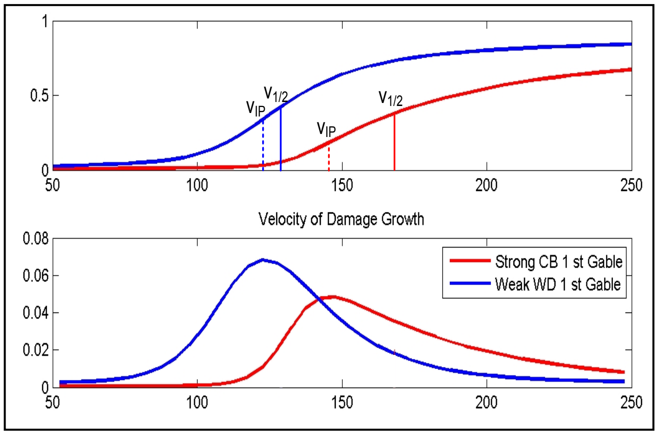

Figure 2: Percentage error between modeled and actual values of vulnerability curves (dots), average of absolute error (solid)

An Estimate of Tornado Loads on a Wood-frame Building using Database-Assisted Design Methodology

David B. Roueche [a], David O. Prevatt [a], Fred L. Haan [b], Peter L. Datin [c]

[a] *University of Florida, Gainesville, FL, USA*
[b] *Rose-Hulman Institute of Technology, Terre Haute, IN, USA*
[c] *Risk Management Solutions, Inc., Newark, CA, USA*

Thunderstorms and related tornadoes in 2011 caused over $25 billion in damages [1], the majority of which was to residential structures, with over 13,000 damaged or destroyed homes in Tuscaloosa and Joplin alone. Despite the general knowledge of the vulnerability of homes to tornadoes, it has been assumed that methodologies to mitigate tornado damages are not economical. However this assumption has been made primarily from observations of catastrophic damage to structures with minimal engineering attention and structural capacity. Without specific knowledge of tornado loads on buildings, it is difficult to estimate the possibilities for mitigation of tornado damage through improvements to residential building design. Since 94% of reported tornadoes are EF-2 or less, and even in violent tornadoes as much as 85% of the damage path can be attributed EF-2 or less wind speeds [3], cost-effective structural designs may in fact be possible. Testing this hypothesis requires knowledge of tornado pressures, structural load paths in a representative building, and the structural resistance of components and their connections. For this study, tornado pressures were obtained from previous work by Haan et al [2], which used a physical tornado simulator at Iowa State University to pass a tornado vortex directly over an instrumented, completely enclosed gable-roof building. Three-dimensional structural load paths were quantified using a Finite Element model, calibrated to match the structural behavior of a 1/3rd scale light wood-frame structure [4].

To estimate structural reactions in light wood-frame structure during a tornado, the Database-Assisted Design (DAD) approach was utilized [4], albeit simplified in that only a single building orientation of 0° (corresponding to the orientation at which in general the highest pressures were observed) in relation to the approaching tornado was used. Structural reactions were estimated for a low-end EF-3 tornado with maximum horizontal gust wind speed of 140 mph. This selection was deemed appropriate due to the fact that over 98% of reported tornadoes are EF-3 or less. The results were compared to structural reactions from straightline winds of the same magnitude, obtained using the same DAD methodology but with design wind pressures from ASCE 7-10 Main Wind Force Resisting System and Components and Cladding methods. Results demonstrated the two distinct loading mechanisms present in a tornado, as the estimated total shear load on the building from ASCE 7-10 MWFRS was similar to the total shear from tornado winds when the building was located at the edge of the tornado vortex, where the highest wind speeds occur. However, as the center of the tornado moved closer to the building, the static pressure drop within the vortex began to dominate the loading pattern, resulting in peak lateral and uplift reactions in roof-to-wall connections of 1.5 kips and 3.4 kips respectively, which were 62% and 28% higher than those predicted using ASCE 7-10 wind pressures. Peak shear and uplift reactions observed in roof-to-wall connections are shown in Figure 1. In both shear and uplift, the maximum observed load in both roof-to-wall and wall-to-foundation connections occurred under tornado pressures. However, the results indicate that it is feasible to design residential buildings to withstand the direct impact of an EF-2 or low-end EF-3 tornado using existing construction methods. Providing strengthened vertical and lateral load paths can prevent damage from the direct impacts of less violent tornadoes, as well as significantly reduce damages away from the center of the tornado vortex in even the most violent tornadoes.

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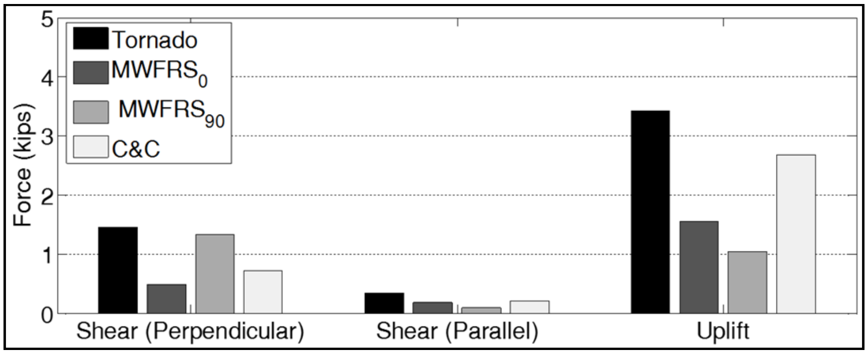

Figure 1: Peak Roof-to-Wall Reactions in Light Wood-frame Structure under Tornado and Straightline Wind Loads

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john.schroeder@ttu.edu

American Association for Wind Engineering

1415 Blue Spruce Drive
Fort Collins, CO 80524
Phone: 970-221-3371
Fax: 970-221-3124
www.aawe.org
aawe@aawe.org