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Atmospheric boundary layer simulation in a new open-jet facility at LSU: CFD and experimental investigations

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ABSTRACT

The purpose of this study is to generate hurricane wind with proper flow characteristics at a new open-jet facility at Louisiana State University (LSU). Numerical investigations via Computational Fluid Dynamics (CFD) are carried out to reduce the effort required for experimentally simulating hurricane wind flows. The purpose of the CFD simulations is to help select among different flow management schemes proposed to create a wind profile with characteristics that mimic certain terrain category. Two basic models are used to do the numerical analysis: 2D and 3D computational domains. The velocities of wind at several locations were taken from the CFD results to provide guidance on the choice of the most appropriate flow management scheme. In parallel to the CFD study, experimental investigations are being carried out in order to validate the computational results. Future research will focus on the generation of hurricane winds with wave. This concept of wind and wave (WAW) simulation is being under development at LSU. The WAW research is thought to push the boundaries of science towards the understanding of the complex hurricane-induced wind and wave loading and their impact on the built environment, with the objective to build the more resilient coastal communities.

1. INTRODUCTION

Atmospheric boundary-layer (ABL) involves wind which can be moderate, strong and destructive. Although hurricanes are large-scale storms, the reproduction of the atmospheric wind characteristics within the lower part of the boundary-layer is very important as the interaction between the wind and the structures occurs in this part of the atmosphere. The physics involved in the ABL are essential for the understanding of wind impact on the built environment and the response of the infrastructure to extreme winds. ABL simulation at a relatively high resolution is very important for wind/structural

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engineering disciplines. The tools used for ABL simulations include wind tunnels, computational fluid dynamics (CFD) models, open-jet facilities, etc. The forces induced by wind on a structure can lead to catastrophic damage, especially in the hurricane and tornado areas (Unanwa et al. 2000). The study of wind impact on the infrastructure is quite complicated as many characteristics of wind have to be taken into account.

1.1 General wind characteristics

Wind blowing over the earth is classified according to its characteristics, strength and location. The most common types of winds that produce significant damage to the built environment are tornadoes, hurricanes (or tropical cyclones) and downbursts. Each type has its sole characteristics and its effect on the built environment is unique. A tornado is a rotating column of air that extends from the base of a thunderstorm. A tornado usually forms a funnel shape with the narrow part near the ground. The main structure of a tornado consists of a single long-lived, nearly erect updraft such intensity that precipitation particles are carried upward into the top. The laws of similitude essential for a laboratory simulation of a tornado are presented in Church et al. (1979). Additional laboratory studies on tornado and other types of non-synoptic winds are reported in the literature (Sengupta et al., 2008).

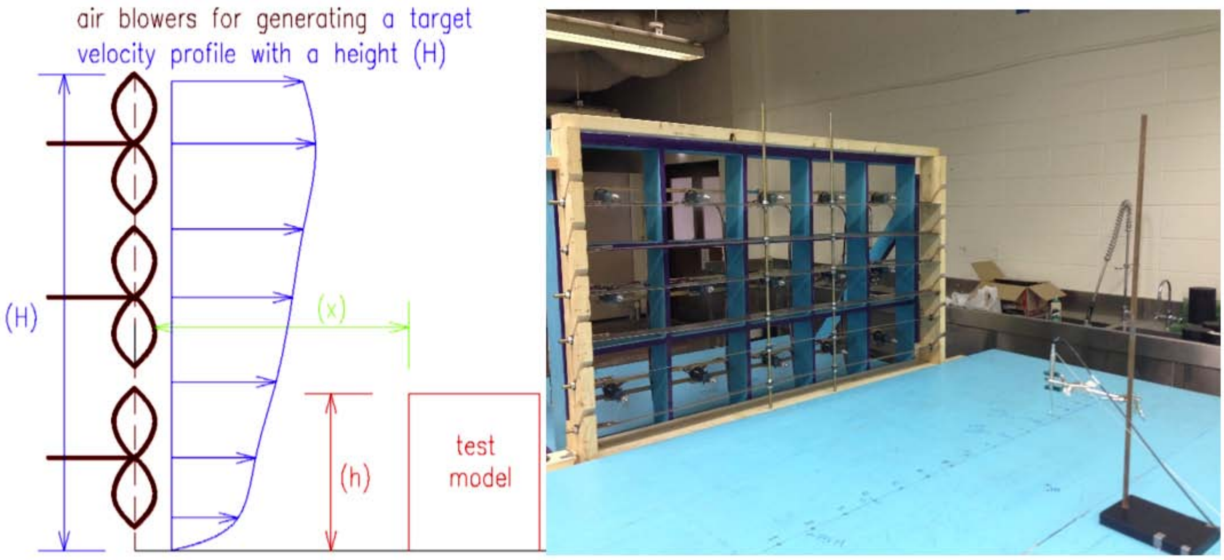
In reality, especially at large scale, straight type of wind does not exist during hurricanes. However, from a localized point of view, a building or a small structure will see a hurricane wind as a straight-line wind. Straight-line wind damage will push debris in the same direction the wind is blowing (hence the term straight-line). Straight-line winds are common with the gust front of a thunderstorm or originate with a downburst from a thunderstorm. The straight-line wind typically has an increasing mean wind speed characteristics within the ABL (from ground surface to around 2000 m). It is worth noting that, although classified as straight-line winds, microbursts have a different mean velocity profiles that are increasing with height to a certain elevation then decreasing. Accordingly, their effects on structures can be different from typical synoptic winds (Chay and Letchford, 2002; Butler et al., 2010). The wind profile of large-size wind events (e.g., hurricanes) in the ABL is logarithmic in nature and it is best approximated using the log law that accounts for surface roughness and atmospheric stability (Tennekes 1973). However, a common mathematical formula that can estimate the change in mean wind speed with height under large size synoptic winds is called the power law (Hellman, 1916 as cited in Simiu and Scanlan, 1996). The power law is often used as a substitute for the log wind profile when surface roughness or stability information is not available. The wind profile power law relationship is:

$$U(z) = U_{ref} \times \left(\frac{z}{z_{ref}} \right)^{1/\alpha} \tag{1}$$

where U(z) is the along-wind mean velocity component at a height z, U_{ref} is the wind speed at a reference height zref. The exponent (α) is an empirically derived coefficient that varies depending on the terrain category (e.g., see ASCE 7-2010, 2010). In addition to variation in the mean wind speed with height, the wind velocity at any location is varying with time. The variation of the wind speed over time can be expressed by the turbulence intensity and the spectral content. The turbulence intensity, Ii, can be expressed as:

$$I_i(z) = \frac{\sigma_i}{U(z)} \tag{2}$$

in which the subscript *i* refers to the different velocity components: *i* = *u* represents the along-wind velocity component; *i* = *v* refers to the cross-wind velocity component; and *i* = w designates the vertical velocity component. The standard deviation of any of the velocity components σ_i is usually obtained from a time history of the velocities that represent 1 hour of records at full-scale. The wind flow near the ground surface is highly turbulent (Lumley and Panofsky, 1964; Kolmogorov, 1941) and usually specified by its turbulence intensity. Atmospheric turbulence can strongly influence the aerodynamic loads as well as causing dynamic motions in flexible structures (Simiu, 2011). The mean wind velocity profiles and the turbulence intensity profiles are the most common properties of straight-line winds in the ABL.



(a) (b)

Fig. 1 Open-jet simulations: (a) main concept of the open-jet testing: the test model's height (h) and its location from the exit of the blowers (distance x) are important parameters that depend dominantly on the height of the open-jet (H); (b) small-scale open-jet simulator in construction at LSU (part of a WAW simulator).

In addition to mean velocity and turbulence intensity profiles, the spectral characteristics of the wind are very important, especially to simulate fluid structure interaction and peak aerodynamic loads. The turbulence structure in a wind flow can be specified by its spectral content. Low-frequency side of a velocity spectrum designates large scale turbulence (which corresponds to large air buckets in the flow and hence defines the integral length scale). The high frequency part of the spectrum, however, corresponds to small eddies in the flow (small-scale turbulence). These high frequency vortices are responsible for energy dissipation and more importantly the proper formation of the flow patterns around a bluff body (Tieleman et al., 1997). Large eddies in a flow contribute significantly to peak aerodynamic loads. In fact, the generation of turbulence in a flow with a certain spectral content presents a challenge for both experimental and numerical simulations of ABL winds.

1.2 ABL simulation

The tools used for ABL simulations include wind tunnels, computational fluid dynamics (CFD) models, open-jet facilities, etc. (Aly, 2014). The current study however focuses on ABL simulation in a new open-jet facility at LSU which is a part of a WAW simulator.

<u>Open-jet simulators as a tool for large-scale testing</u> Post-disaster investigation of areas affected by severe winds has been useful for understanding of the performance of structures under extreme events, however, the design parameters and the flow conditions affecting the performance of the structures cannot be controlled during an actual wind event (Lacy and O'Brien, 1997). To alleviate this problem, a windstorm testing facility that can replicate actual storm conditions in a controlled manner on full-size structures was thought (Lacy and O'Brien, 1997). In 1999, the Idaho National Engineering and Environmental Laboratory (INEEL), through the U.S. Department of Energy (DOE), proposed that a large-scale wind test facility would be constructed to study the behavior of low-rise buildings under simulated extreme wind conditions. However, the cost for the proposed facility was extremely high, and therefore it would be uneconomical and inappropriate (National Research Council, 1999; Leatherman et al., 2007). In 2003 the research team at the International Hurricane Research Center (IHRC) of Florida International University (FIU) started planning a large-scale open-jet testing facility (Leatherman et al. 2007). With this vision, the IHRC first developed a 2-fan hurricane simulator (named Wall of Wind (WoW)) and then a 6-fan WoW (Bitsuamlak el al. 2009). However, to allow for a better understanding of hurricane-induced effects on structures through large-scale and destructive testing, a 12-fan WoW was built (Aly et al., 2011a, 2011b, 2012, 2013a, 2013b). Full-scale testing permits the determination of aerodynamic loads by eliminating scaling requirements and Reynolds effects in particular (Kopp et al., 2012). Blockage effects are usually minimized by using the open-jet concept (Aly et al., 2011a). Fig. 1(a) shows the main concept of open-jet testing. The test model's height (h) and its location from the exit of the blowers (distance x) are important parameters that depend dominantly on the height of the open-jet (H). The distance (x) should be relatively short to allow for high testing wind speeds. Longer the distance x lower the wind speed that can be achieved at an open-jet simulator. In addition, the test model's height (h), say for a building model, should be within one third of the wind field height (H) to allow for realistic pressures on the roof (Aly et al., 2011a). Fig. 1(b) shows a photograph of a small-scale open-jet simulator that is currently in construction at LSU (part of a proposed WAW simulator). Active control systems are often used to create the required turbulence

levels and turbulence spectra. Similar concepts are used at the Hurricane Simulator of the University of Florida (Salzano et al., 2010) which is only intended to test small structures or components within windward walls. The Insurance Institute for Business and Home Safety (IHBS) Research Center is another example of large-scale testing facilities with details given in Liu et al. (2009) and Brown et al. (2011). This is in addition to the Wind Engineering, Energy and Environment (WindEEE) dome at the University of Western Ontario (UWO) (Natarajan and Hangan, 2010).

The current study focuses on the simulation of hurricane winds to create flows with similar characteristics to those of open and suburban terrain. First the mean wind velocity profile is the focus. Later the focus will be on the turbulence characteristics (both the intensity and the spectral content). Once the dray wind is simulated, wind profiles on sea will be generated and the simulator’s capabilities will be extended to include the simulations of waves with proper correlations with the wind.

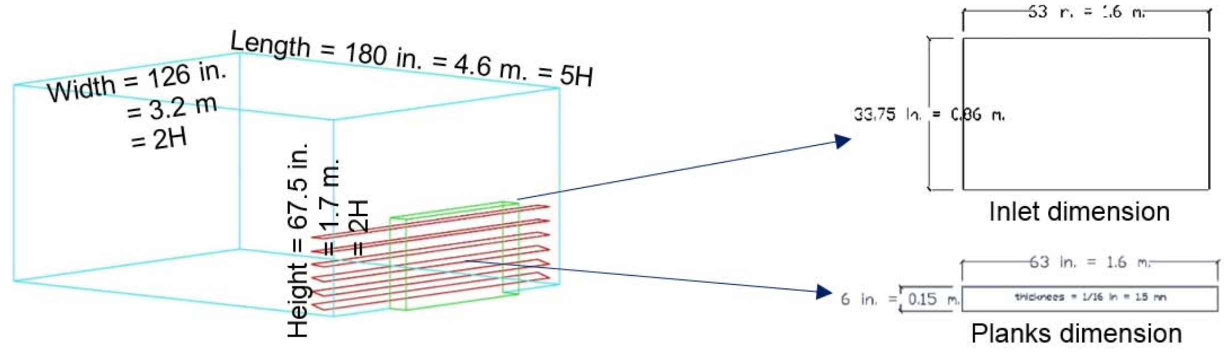


Fig. 2 Model of the open-jet wind generator with planks: (a) computational domain; (b) inlet and planks dimensions

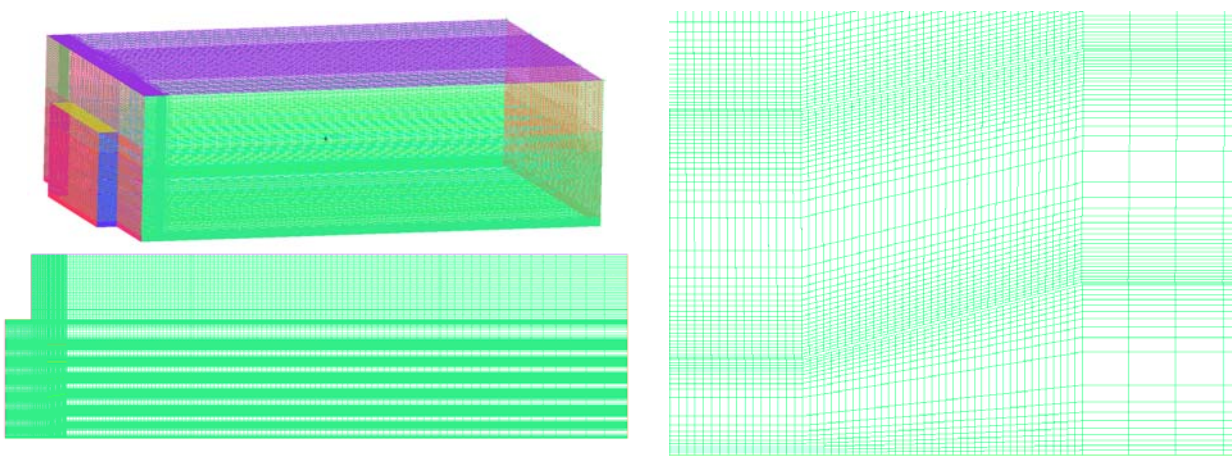


Fig. 3 3D structured mesh (hexagonal elements)

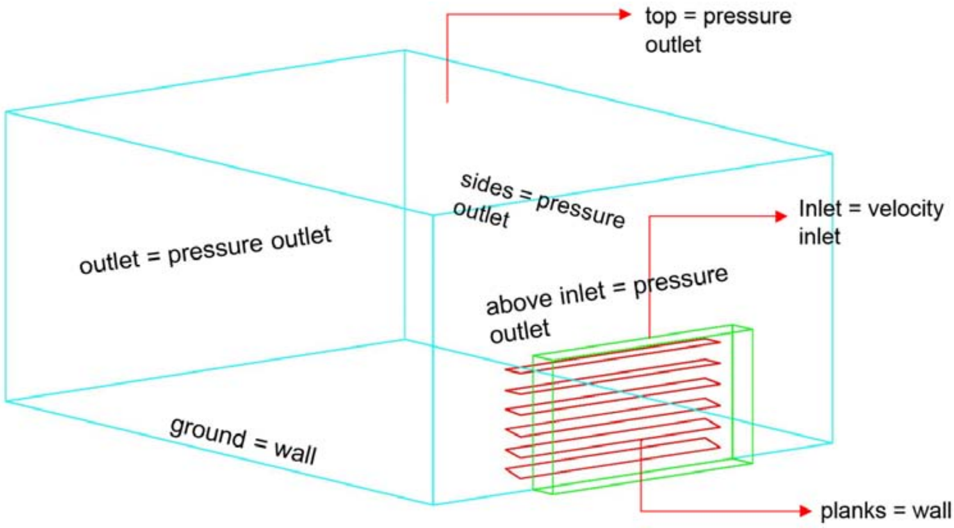


Fig. 4 Boundary conditions in ANSYS FLUENT

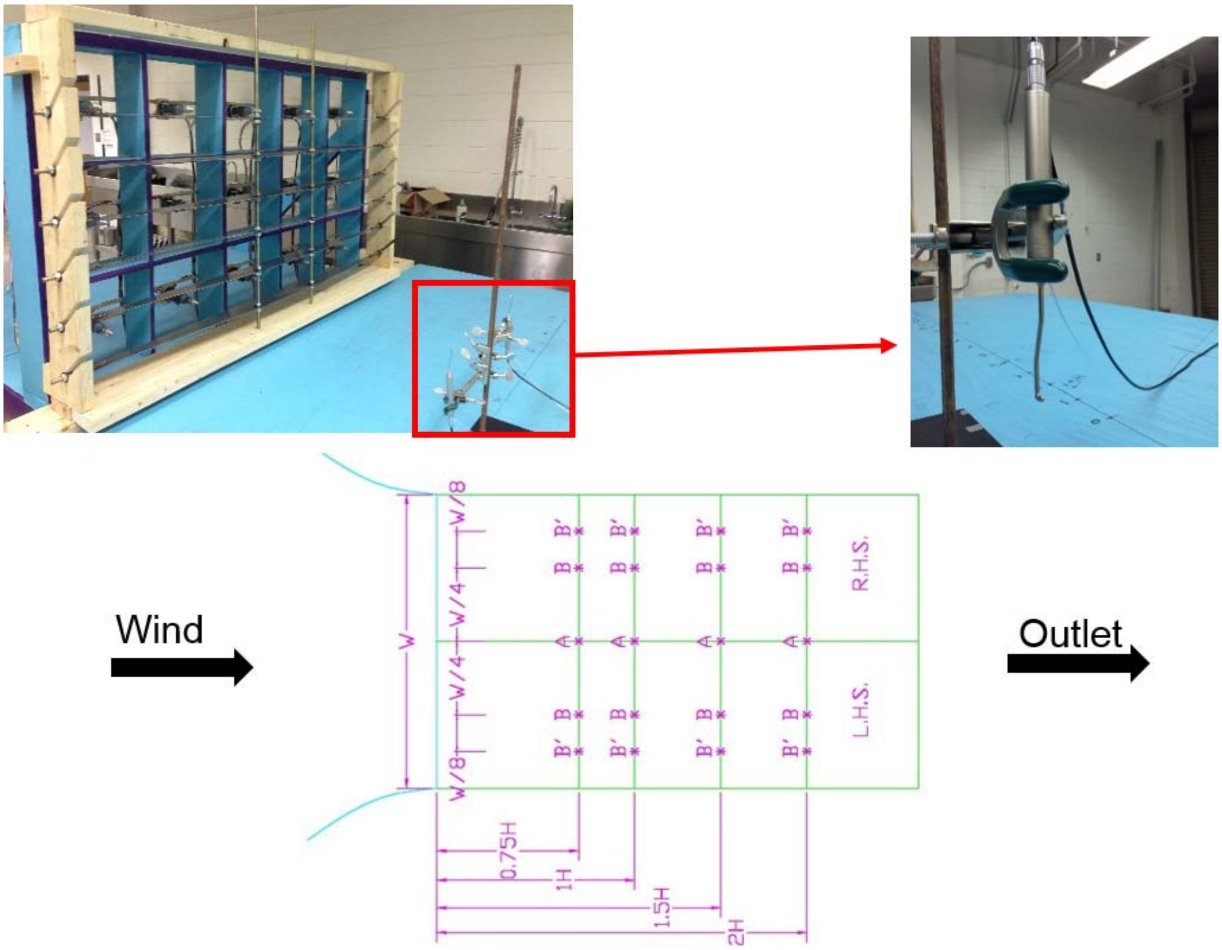


Fig. 5 Cobra probe was used to measure the velocity profile at certain locations

2. METHODOLOGY

CFD simulations are used to help reduce the experimental efforts by allowing for verifications of several arrangements of a flow management setups. ICEMCFD was used to generate the computational meshes and ANSYS FLUENT with the standard k-ϵ model was used as the solver. The standard k-ϵ model is still the most popular model used in general-purpose CFD codes, which was proposed by Launder and Spalding in 1972 (see Sengupta and Sarkar 2008). The standard k-ϵ model is a semi-empirical model based on model transport equations for the turbulence kinetic energy (k) and viscous dissipation rate (ϵ). The objective of the CFD simulations is to generate wind profiles with a power law profile that mimic suburban terrain (power law exponent α = 0.25) and open terrain (power law exponent α = 0.15) by examining certain planks setup (inclination angles). The 15 fan open-jet wind generator's computational domain was generated in AutoCAD (Fig. 2). The geometric models were exported to ICEMCFD in order to create a computational mesh. Multi-block surface structured grids were created (Fig. 3). To get the accurate result, bluff body aerodynamics has to be considered. The edge of the planks need to be assigned with a high quality mesh by using function spline mesh in order to catch vertices formation by rolling up of shear layer as the action of bluff body aerodynamics as well as the ground of the system near the planks (Makris et al. 2012). After the structured grids are generated on the domains, a fluid dynamic simulation was carried by means of ANSYS FLUET. The boundary conditions were defined, for instance, the boundary condition of the inlet is velocity inlet which is 10 m/s (uniform), the sides, top and area above inlet are pressure outlet, the planks and the ground are walls, and outlet is pressure outlet (Fig. 4). The results of the CFD simulation were analyzed in terms of velocity profiles at specific measuring points (Fig. 5).

The 15-fan wind generator with speed controller was built at the wind engineering laboratory, LSU. The wind speed at the exit of the simulator is about 10 m/s. Cobra probes were used to measure wind velocity in specific along-wind locations (Fig. 5). The planks were arranged as specified in Fig. 6, which was a result of trial and error adjustments to create velocity profiles that can mimic open and suburban terrain. Once a certain planks arrangement was setup, velocity measurements for 30 seconds were carried out at each point for each location. Two minutes measurements were also carried out for spectral analysis. The data were analyzed by extracting the mean velocities and turbulence intensities at each location point to create the profiles.

Fig. 6 Planks' setup angles 15, 12, 10, 5, 0 and 0 from bottom to top

3. RESULTS

To create a wind profile, the adjustable planks were used to adjust the direction of the wind as shown in Fig. 1. Several set of angles or configurations have been trialed to get a proper wind profile. Fig. 7 presents a contour plot of the velocity at a central plane that shows the influence of the planks inclination angle on the velocity gradient. The configuration from CFD that matched open terrain (target α = 0.15) is the set of angle 15, 12, 10, 5, 0, 0 from the ground (Fig. 6). There were two cases of model created to conduct the experiment namely 3-dimensional model with the boundary condition of pressure outlet (CFD_3D_PRES), and 2-dimensional model (CFD_2D). The wind profiles at points A in Fig. 5 of all of those cases were plotted together along with the target wind profile of both suburban terrain (target α = 0.25) and open terrain (target α = 0.15).

Fig. 8 show that the CFD wind profile at a distance 0.75H and 1H match the wind profile of open terrain (target α = 0.15) at height under 35 inch from ground but at height above 35 inch wind profile has tendency to decrease speed. At a distance 1.5H and 2H (Fig. 9), the CFD wind profiles were quite out of range of the target wind profile but they still maintained the same shape of the profile as distance 0.75H and 1H.

The angle of the plank from CFD was used to do the experiment in the laboratory. First trials considered analyzing the profile at 0.75H form the exit of the simulator (Fig. 8(a)). However, the wind profiles obtained at this location were non homogeneous and repeated experiments never gave the same results as the measuring distance was too close to the inlet. Accordingly, the wind profiles at farther distances were measured (Fig. 8(b)). The profile got better than the previous one in the case of matching the open terrain wind profile. The wind profiles at 1.5H and 2H were also measured (Fig. 9). The results show that the profile at distance 2H is the best match to the open terrain wind profile. In order to confirm that wind profiles at cross-section of the distance 2H are still match the open terrain wind profile, the wind profile at point B and B' in were measured (Fig. 10).

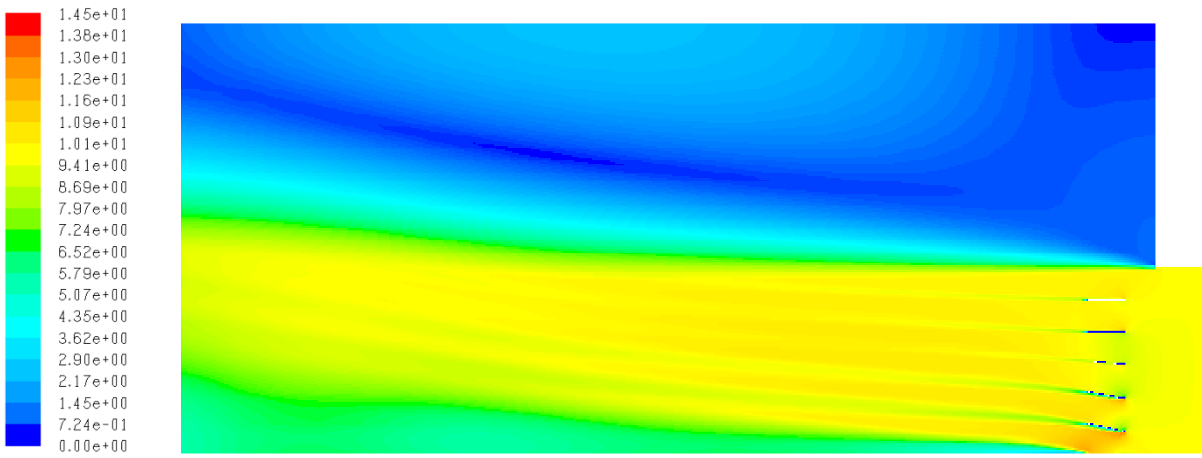


Fig. 7 Contour plot of velocity at a central plane showing the influence of the planks inclination angles on the velocity gradient

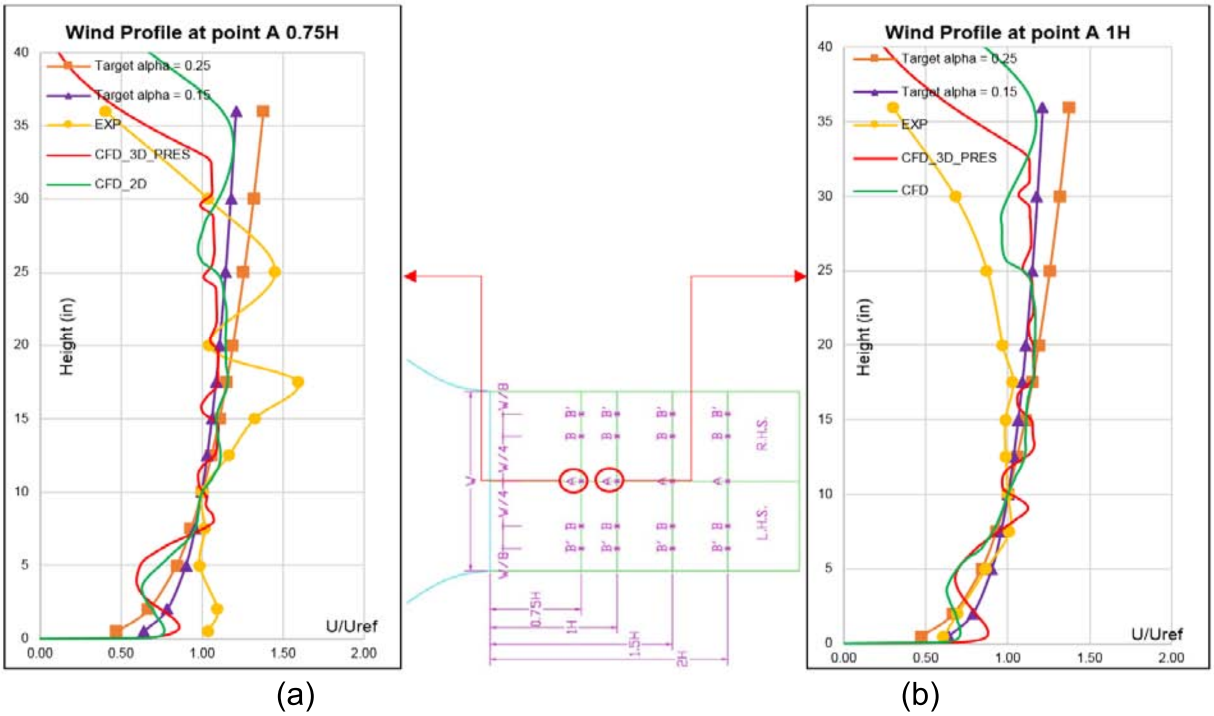


Fig. 8 Mean velocity profiles: (a) at a distance of 0.75H; (b) at a distance of distance 1H

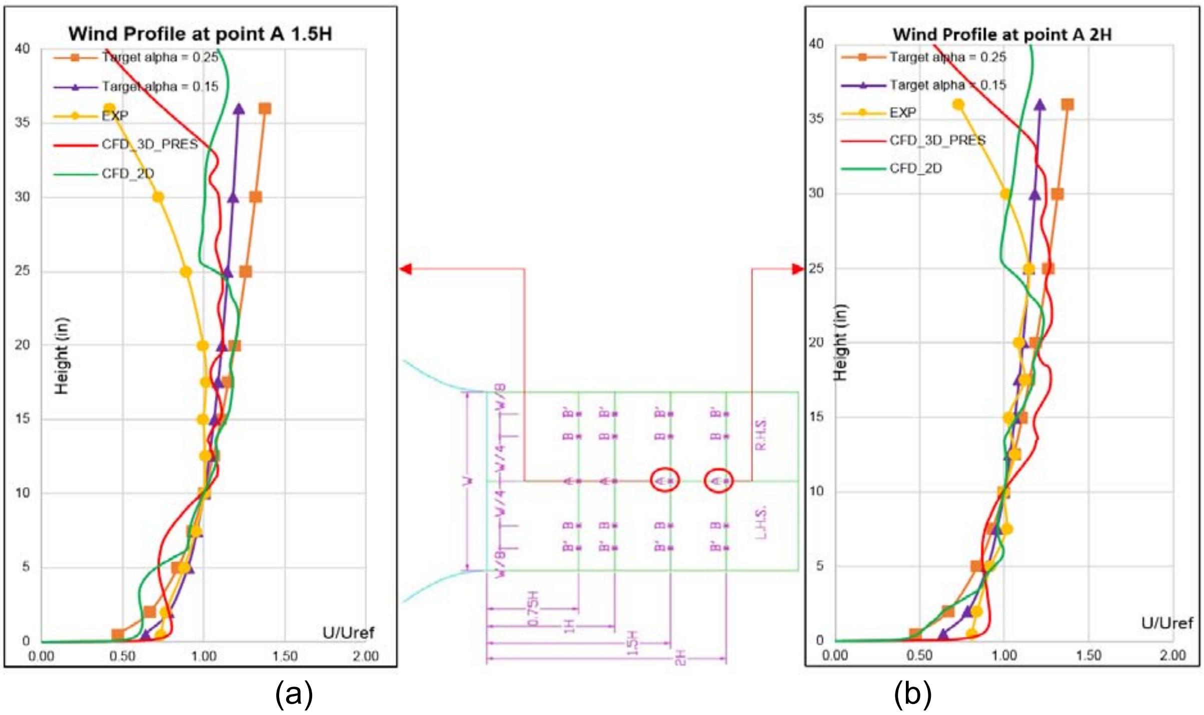
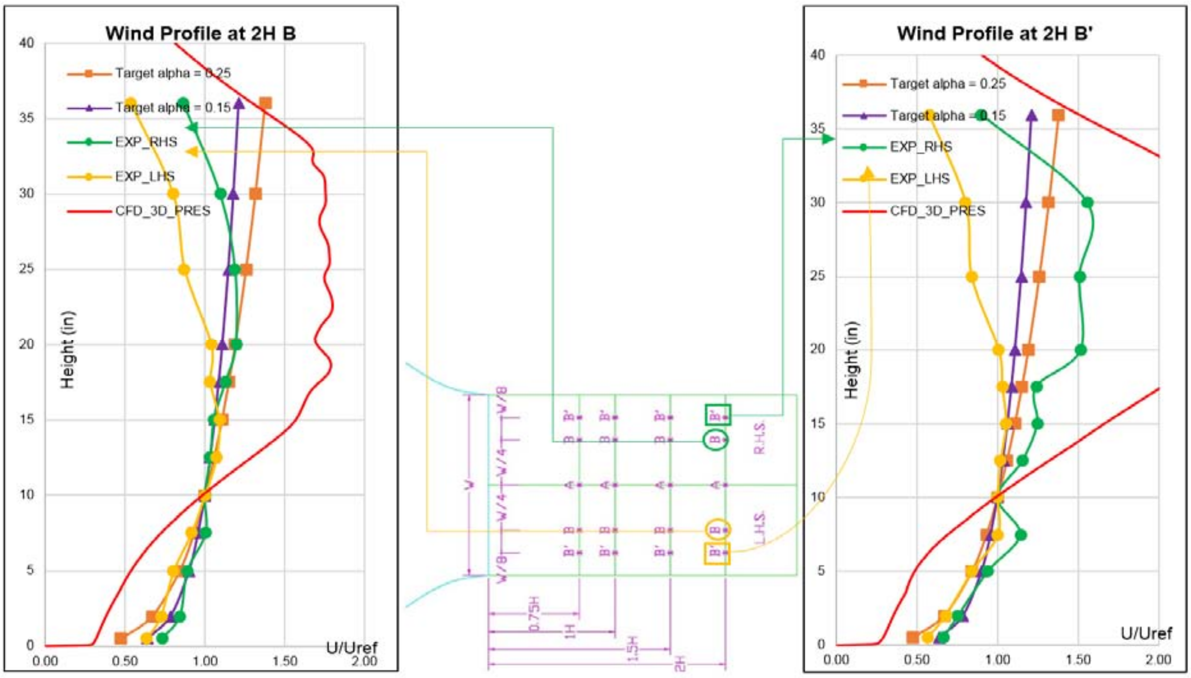


Fig. 9 Mean velocity profiles: (a) at a distance of 1.5H; (b) at a distance of distance 2H



(a) (b)

Fig. 10 Mean velocity profiles at two different points located 2H from the exit of the simulator: (a) location B and (b) location B' as designated on the CAD drawing

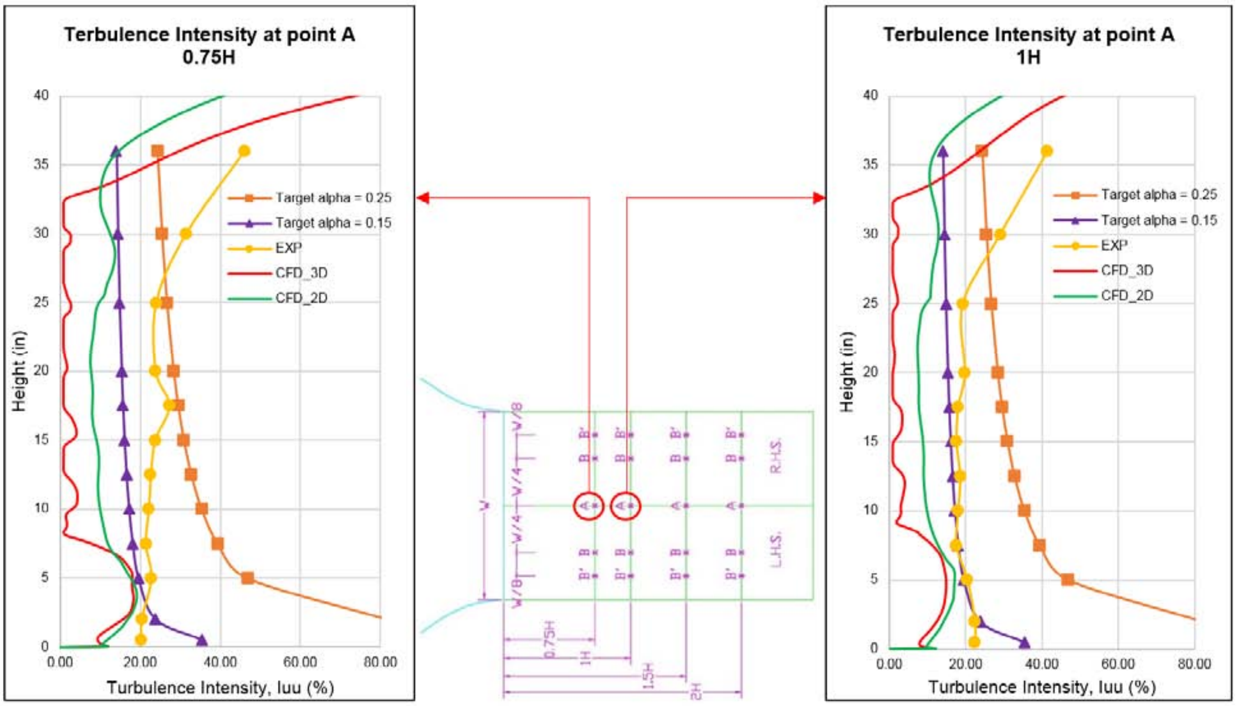


Fig. 11 Along-wind turbulence intensity profiles: (a) at a distance of 0.75H; (b) at a distance of distance 1H

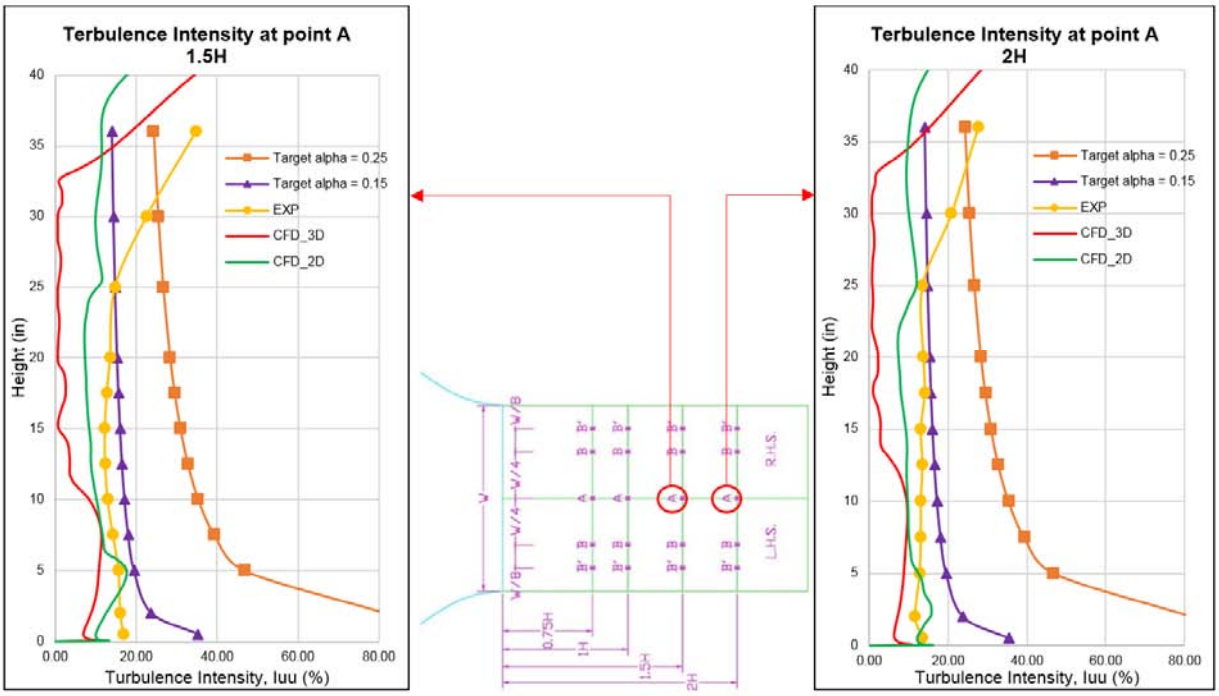


Fig. 12 Along-wind turbulence intensity profiles: (a) at a distance of 1.5H; (b) at a distance of distance 2H

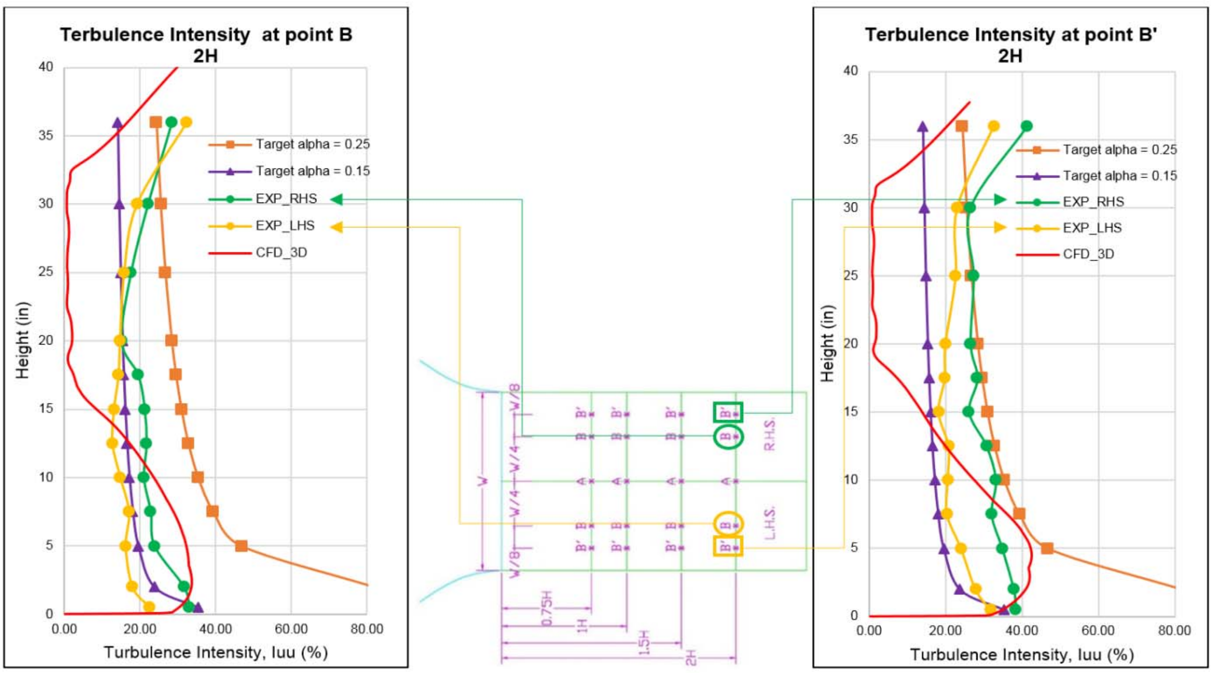


Fig. 13 Along-wind turbulence intensity profiles at two different points located 2H from the exit of the simulator: (a) location B and (b) location B' as designated on the CAD drawing

Figures 11-13 show along-wind turbulence intensity profiles obtained at 0.75H, 1H, 1.5H and 2H from the exit of the simulator. Unlike the velocity profiles, the turbulence intensity profiles obtained by CFD simulations are far from those obtained experimentally. This indicates that while the k-epsilon turbulence model can predict the flow velocity gradient (profile), it is not accurate for turbulence prediction. Generally speaking, the turbulence intensities obtained by the open-jet simulator are close to the turbulence in an open terrain. Additional turbulence generation mechanisms (for instance actively changing the RPM of the fans) are required for generating high intensity turbulence.

4. DISCUSSION

The focus of the current paper is the ABL simulation for wind engineering applications. Large-scale testing facilities capable of generating hurricane wind and wave with proper characteristics to allow better understanding of extreme winds and their effects on offshore and onshore infrastructure are needed. These facilities shall be large enough to engulf full- and large-scale models of buildings and other types of structures built using actual construction materials to allow for a comprehensive research program that can improve the resiliency and the sustainability of the built environment under extreme wind events. This will help improve environmental sustainability, mitigate the devastating effects of extreme winds, and produce solutions which bridge the disciplines of atmospheric sciences, wind engineering and structural engineering. A number of thoughts have been raised that can allow for improving the flow characteristics at open-jet simulators:

(i) *Actively controlling the fans:* this approach usually allow for the generation of turbulence in the along-wind with no control on the vertical and cross-wind components of velocity. The active control of the fans requires knowledge about the fan system with its all components (transfer function), in addition quick responding motors with speed controllers which may present additional cost to the system.

(ii) *The use of an easy adjustable planks mechanism:* this approach allows for creating different velocity profiles (e.g., open country and suburban terrain velocity profiles) with minimal control on turbulence. Although this mechanism can alert the turbulence intensity, it does not allow for a control of the turbulence structure (Aly et al., 2011a).

(iii) *Hybrid simulators:* a hybrid wind tunnel/open-jet facility can be an option to allow for turbulence management (from a spectral perspective) at open-jet facilities. That is to generate a flow with desired characteristics and at the same time to allow for testing under wind and rain with minimal blockage, and possibly to permit destructive testing at large scale. Fig. 14 shows two proposed techniques for a hybrid simulator. There are two options: (a) open-jet with a short test section, spires and roughness elements introduced at the exit of the blowers and (b) open-jet with a ducted section containing spires and roughness elements. These options require experimental/computational investigations. The spires and roughness elements presented in the first option (a) may cause the flow of the open-jet to significantly deviate to the sides and hence a significant reduction in the velocity at the test section. The second option may require additional increase in the power to drive the blowers and hence maintain a relatively high testing wind speed. A sufficiently long ducted section is required to allow for the turbulence to be fully developed.

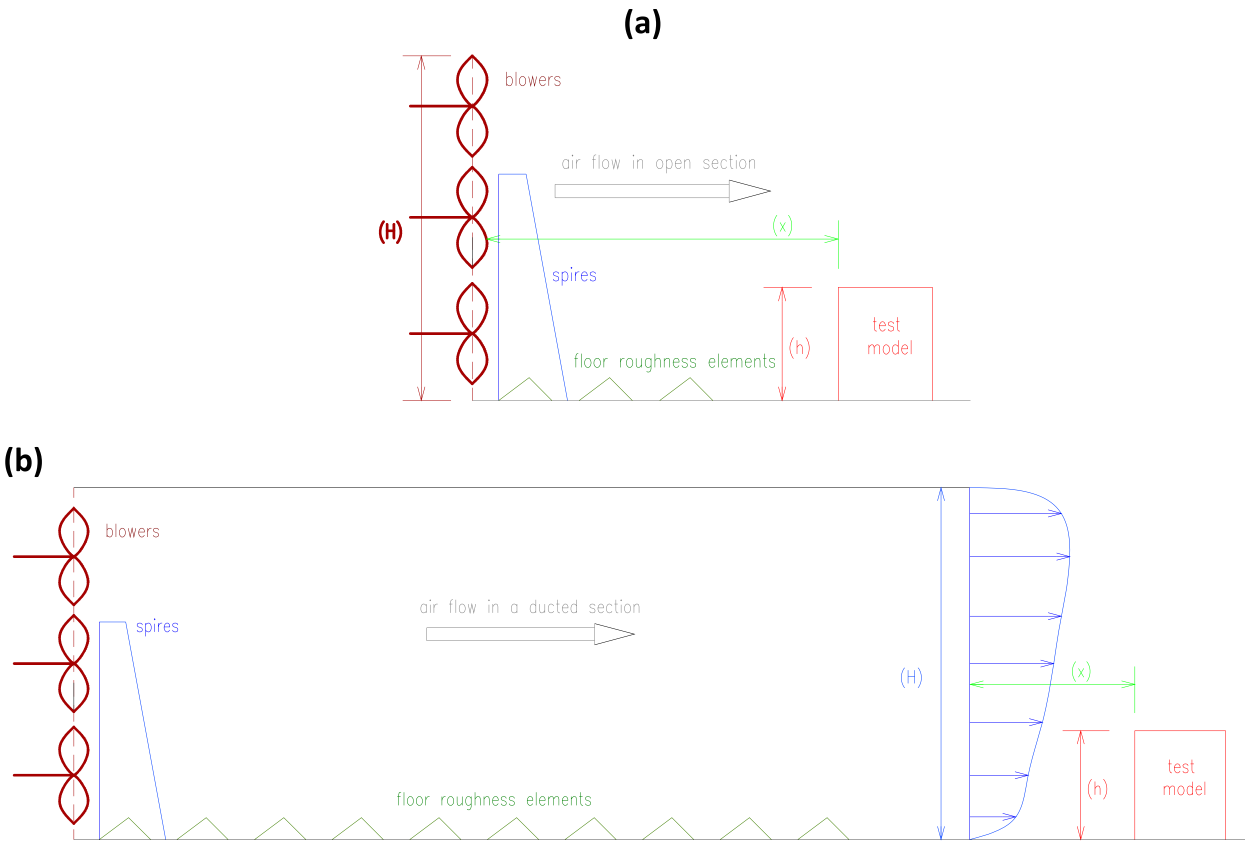


Fig. 14 A proposed hybrid open-jet simulator: (a) short section with spires and roughness elements to generate turbulence; (b) a longer ducted section with spires and roughness elements. Note that the test model location distance (x) and height (h) can be different for short and ducted sections (w.r.t. the wind field height, H)

5. CONCLUSIONS

The focus of the current paper is the ABL simulation for wind engineering applications. A small-scale open-jet hurricane simulator representative of a larger wind and wave (WAW) simulation facility was presented as phase 1. CFD simulations were used to reduce the effort required to experimentally create wind profiles that mimic open and suburban terrain. Experimental results show that the planks arrangement suggested by CFD simulation can create wind speed profiles with desired characteristics. The turbulence intensity profiles expected by the CFD simulations are different from those obtained experimentally. Additional turbulence generation mechanisms like actively controlling the fans are needed. The full-scale WAW facility shall be large enough to engulf full- and large-scale models of buildings and other types of inland/offshore structures built using actual construction materials to allow for a comprehensive research program that can improve the resiliency and the sustainability of the built environment under extreme wind events. This will help improve environmental sustainability, mitigate the devastating effects of extreme winds, and produce solutions which bridge the disciplines of atmospheric sciences, wind engineering and structural engineering.

REFERENCES

Aly, A.M. (2014), “Atmospheric boundary-layer simulation for the built environment: Past, present and future,” Build. Environ., **75**, 206-221.

Aly, A.M., Bitsuamlak, G.T., and Chowdhury, A.G. (2012), “Full-scale aerodynamic testing of a loose concrete roof paver system”, Eng. Struct., **44**, 260-270.

Aly, A.M., Bitsuamlak, G., and Chowdhury, A.G. (2011b), “Florida International University’s Wall of Wind: a tool for the improvement of code provisions and design criteria for hurricane-prone regions”, Vulnerability, uncertainty, and risk: analysis, modeling, and management–proceedings of the ICVRAM 2011 and ISUMA 2011 conference, 352-359.

Aly, A.M., Bitsuamlak, G., Chowdhury, A.G., and Erwin, J. (2013a), “Design and fabrication of a new open jet electric-fan Wall of Wind facility for coastal research,” Coastal Hazards, (2), 137.

Aly, A.M., Chowdhury, A.G., and Bitsuamlak, G. (2011a), “Wind profile management and blockage assessment for a new 12-fan Wall of Wind facility at FIU,” Wind Struct., **14**(4), 285-300.

Aly, A.M., Fossati, F., Muggiasca, S., Argentini, T., Bitsuamlak, G., Franchi, A., Longarini, N., Crespi, P., and Chowdhury, A.G. (2013b), “Wind loading on trees integrated with a building envelope,” Wind Struct., **17**(1), 069-085.

ASCE 7-2010, (2010). Minimum design loads for buildings and other structures, ASCE Standard, ASCE/SEI 7-10, American Society of Civil Engineers, Reston, Virginia.

Bitsuamlak, G., Chowdhury, A.G., and Sambare, D. (2009), “Application of a full-scale testing facility for assessing wind driven rain intrusion,” Building Environ., **44**(12), 2430–2441

Brown, T.M., Liu, Z., Morrison, M.J., Cope, A.D., and Smith, D.A. (2011), “Comparison of field and full-scale laboratory pressure data at the IBHS research center,” Proceedings of the 13th International Conference on Wind Engineering, Amsterdam, Netherlands, July 10-15.

Butler, K., Cao, S., Kareem, A., Tamura, Y., and Ozono, S. (2010), “Surface pressure and wind load characteristics on prisms immersed in a simulated transient gust front flow field,” J. Wind Eng. Ind. Aerodyn., **9**, 299-316.

Chay, M.T., and Letchford, C.W. (2002), “Pressure distributions on a cube in a simulated thunderstorm downburst. Part A: stationary downburst observations,” J. Wind Eng. Ind. Aerodyn., **90**, 711-732.

Church, C.R., Snow, J.T., Baker, G.L. and Agee, E.M. (1979), “Characteristics of Tornado-Like Vortices as a Function of Swirl Ratio: A Laboratory Investigation,” Am. Met. Soc., **36**, 1755-1776.

Hellman, G. (1916) “Über die Bewegung der Luft in den untersten Schichten der Atmosphäre,” Met. Z., **34**, 273.

Kolmogorov, A., (1941), “The Local Structure of Turbulence in Incompressible Viscous Fluid for Very Large Reynolds Numbers”, Doklady Akademiia Nauk SSSR, **30**, 301-305.

Kopp, G.A., Morrison, M.J., and Henderson, D.J. (2012), “Full-scale testing low-rise, residential buildings with realistic wind loads,” J. Wind Eng. Ind. Aerodyn., **104–106**, 25–39.

Lacy, J.M. and O'Brien, C.C. (1997), “Design Considerations for a National Windstorm Test Facility,” In Proceeding of The Eighth U.S. National Conference on Wind Engineering, Dept. of Civil Engineering, The John Hopkins University, Baltimore, Maryland, USA, June 5-7.

Leatherman, S.P., Gan Chowdhury, A. and Robertson C.J. (2007), “Wall of Wind full-scale destructive testing of coastal houses and hurricane damage mitigation,” J. Coastal Res., **23**(5), 1211-1217

Liu, Z., Prevatt, D.O., Aponte-Bermudez, L.D., Gurley, K.R., Reinhold, T.A., and Akins, R.E. (2009), “Field measurement and wind tunnel simulation of hurricane wind loads on a single family dwelling,” Eng. Struct., **31**(1), 2265–2274

Lumley, J.L., Panofsky, H.A. 1964. The Structure of Atmospheric Turbulence. Wiley, New York.

Makris, E., Neofytou, P., Tsangaris, S., and Housiadas, C. (2012), “A novel method for the generation of multi-block computational structured grids from medical imaging of arterial bifurcations,” Medical engineering and physics, **34**(8), 1157-1166.

Natarajan, D., Hangan, H. (2010), “Preliminary numerical simulation of axi-symmetric flows in WindEEE dome facility,” In The Fifth International Symposium on Computational Wind Engineering (CWE2010), Chapel Hill, North Carolina, USA May 23-27.

National Research Council (US), 1999. Review of the Need for a Large-Scale Test Facility for Research on the Effects of Extreme Winds on Structures. Washington, DC: National Academy Press, pp. 1–40.

Salzano, C.T., Masters, F.J., and Katsaros, J.D. (2010), “Water penetration resistance of residential window installation options for hurricane-prone areas,” Build. Environ., **45**(6), 1373–1388

Sengupta, A., and Sarkar, P.P. (2008), “Experimental measurement and numerical simulation of an impinging jet with application to thunderstorm microburst winds,” J. Wind Eng. Ind. Aerodyn., **96**(3), 345-365.

Sengupta, A., Haan, F.L., Sarkar, P.P., and Balaramudu, V. (2008), “Transient loads on buildings in microburst and tornado winds,” J. Wind Eng. Ind. Aerodyn., **96**, 2173-2187.

Simiu E, Scanlan R. 1996. Wind Effects on Structures. John Wiley & Sons, New York.

Simiu E., 2011. Design of Buildings for Wind – A Guide for ASCE 7-10 Standard Users and Designers of Special Structures. 2nd Ed., John Wiley & Sons, Inc., NY.

Tennekes, H., (1973), “The Logarithmic Wind Profile,” J. Atm. Sc., **30**, 234-238.

Tieleman, H.W., Reinhold, T.A., and Hajj, M.R., (1997), “Importance of turbulence for the prediction of surface pressures on low-rise structures,” J. Wind Eng. Ind. Aerodyn., **69**(71), 519-528.

Unanwa, C. O., McDonald, J. R., Mehta, K. C., and Smith, D. A. (2000), “The development of wind damage bands for buildings”, J. Wind Eng. Ind. Aerodyn., **84**(1), 119-149.