The Wind Engineering, Energy and Environment (WindEEE) Dome and a New Generation of Wind Engineering Facilities

Horia Hangan

Project Leader, The University of Western Ontario, London, Ontario, Canada, hmh@blwtl.uwo.ca

1 SUMMARY

In June 2009, the Canada Foundation for Innovation and the Ontario Research Fund have awarded 23.7 M$ for the world's first hexagonal wind tunnel, the Wind Engineering, Energy and Environment (WindEEE) Dome. This facility represents a technological break-through in the study of wind-related phenomena as it has the capability to physically simulate both large and local high intensity wind systems over complex terrain and their effects on building and structures, wind turbines, wind and solar farms as well as the transport of pollutants.

2 INTRODUCTION

According to Munich Re America the five-year average insured loss due to thunderstorm activity (tornados and downbursts) in North America is of the order of $6 billion. Thunderstorm activity causes the majority of insured property loss in the U.S. from all natural catastrophes. However at present we do not design or test buildings or structures to this type of local high intensity winds! This is because none of the existing wind tunnels in the world can simulate time dependent and spatially complex storm events.

In order to be able to provide 20% penetration proposed by the Brussels Agreement (2007), Canada as well as many other countries around the world will have to step-up dramatically their wind energy production. However many existing wind farms produce 15% less than their projected annual Capacity Factor of 30%! Errors in modeling of the near-surface wind fields mostly in the presence of complex topography or in estimating wake and array effects are the main factors associated to these errors.

In order to address these important economic problems we proposed to build a totally unique experimental facility at the University of Western Ontario, the Wind Engineering, Energy and Environment (WindEEE) Dome. The facility will be capable of physically simulating wind systems such as tornados, downburst, gust fronts or low level nocturnal currents. The Dome's large scale will allow for high resolution wind simulations representing extended areas and complex terrain. This highly innovative and versatile facility, will have applications to wind energy, wind engineering, environmental impact studies, meso- and micro-scale numerical modeling, risks analysis, economics, policy making.

The lower atmosphere, between 50m-500m above the ground, is the atmospheric layer where the wind energy is harnessed and where wind storms impact our lives. Although significant progress has been made in atmospheric boundary layer modeling, the wind fields in topographically complex and urban terrains, as well as those due to localized storm systems or thermally stratified boundary layers, are extremely difficult to model. Yet, there are several problems with wind technology that relate to the aerodynamic and structural optimization of wind turbines and wind farms such as: better design of the new generation (longer) wind turbine blades, better understanding of rotational wakes, wake interferences and array effects as well as the impact of topography and local storm systems to wind farm and wind turbines siting. In order to address these problems a new trend in wind engineering is to build larger scale, multi-fan facilities. The WindEEE Dome will complement but will be quintessentially different from other international wind related facilities such as the wind tunnels located at NASA Ames and Iowa State University in USA, NRC in Ottawa, Milan Polytechnic, Nantes and the Danish Maritime

Institute in Europe. It will also complement full scale testing capabilities such as those offered at the Silsoe Building in the UK or the Wall of Wind in Florida. WindEEE is based upon a large (25 meter in diameter) hexagonal test chamber (i.e., the inner dome) with an array of specialized fans mounted on the walls and the ceiling, Fig. 1. The fans will be activated using a sophisticated control strategy to provide time-varying and spatially-varying flow fields in the test section. This will enable us to reproduce swirling, sheared, or other flows at appropriate scales similar to what would occur in nature. In addition this new facility will also be capable of testing full scale elements such as solar panels, small wind turbines, or even large wind turbine blades in sheared and time-dependent air flows.

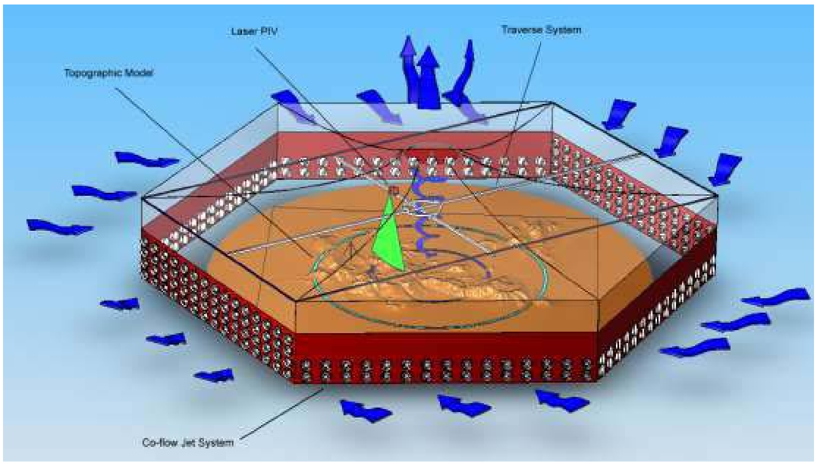

Fig. 1: WindEEE Dome Conceptual Drawing

3 PROPOSED RESEARCH

The main research themes are presented below. They all relate to necessary improvements in the simulation of surface winds in the lower 500 meters of the atmospheric boundary layer where most of the natural and human activities take place.

3.1 Theme 1 – Physical Simulation of Complex Wind Fields and their Impact on Structures and the Environment

Boundary layer wind tunnels such as the one at Western have mastered the simulation of large, meso-scale wind systems as well as the measurement of pressures and loads generated by these straight winds on buildings and structures. Recently at Western's Insurance Research Laboratory for Better Homes the research team of the Three Little Pigs (3LP) Project applied, for the first time, the wind pressures obtained in the wind tunnel to *full scale* buildings and building components in order to study damages and collapse modes. However, even the best equipped wind tunnels cannot currently simulate with high enough resolution the localized winds which present a sharp time and space variability.

To conduct these physical simulations and generate the desired wind fields, we will use arrays of fans that will be operated through a sophisticated non-linear control system. Computational Fluid Dynamics (CFD) simulations employed during the conceptual design phase suggested using a matrix of Ø0.8m diameter direct drive axial fans with downstream guidevanes each providing 30 m/s air speed distributed in rows of 8 fans each at the base of each of the walls of the hexagonal test chamber. A set of larger 6 fans will be installed in the ceiling and connected to a plenum box. The opening of the plenum can be fast triggered and it is mounted on a guillotine fast traversing systems that will translate over ± 2.5 m at a maximum speed of 3 m/s.

The ceiling fans combined with the system of fans on the six peripheral walls can be manipulated to produce a variety of axysimmetric wind fields. Combining inflow at the ceiling level and radial outflow at the peripheral walls downburst-like wind field can be produced. Alternatively by combining outflow at the ceiling and radial and tangential inflow at the peripheral boundaries tornado-like wind fields can be produced.

In addition one of the six peripheral walls will have a matrix of 60 fans (4 rows of 15 fans each. This wall of fans will be operated in conjunction with two sets of porous side wall to provide “wind-tunnel type” flows at large scale (approx. 14 meters across and 3.8 meters in height). These fans are capable of producing 1 Hz gust winds with a nominal turbulence intensity of the order of 17% thus simulating full scale atmospheric conditions. Moreover these fans are 80% reversible and using an opening in the dome can produce reversed outside flow which will be used to test large-size full scale components, solar panels or wind turbine blades

3.2 Theme 2 – New Methods to Characterize Wind Fields over Complex Topographic and Urban Terrains

The most common way presently used to numerically simulate or predict wind systems is based on mesoscale and microscale wind numerical models as they produce good prediction for *large* wind systems over *flat* surfaces. However, the current models fail when it comes to simulating near-ground local storms or the effects of complex topographic landscape and urban terrains. We will be able at the WindEEE Dome to reproduce various landscapes at large scales and then investigate the characteristics/behaviour of different wind fields in great detail. For this purpose, the test chamber floor will be divided into concentric circular zones around the central test zone of ~5m (at ~5m increments) to allow for progressive floor model detail. In the central zone, representative terrain models will be produced by using CNC machining; the next zone will have a set of 36 adjustable sector plates to adapt from the periphery of the central zone to a planar circular section; the next zone (as well as zone 2) will be instrumented with roughness elements while the last zone is just a mixing zone.

In addition we will also use new “Particle Image Velocimetry (PIV),” to determine the wind field over extended topographic areas with exceptional spatial resolution (approx.10 meters full scale). The use of a time-resolved PIV system sampling velocity fields at 2000 Hz will make possible to resolve the necessary timescales of the flow. The PIV system will be adapted to map the flow using a traversing system thus, forming a mosaic of velocity fields over the required region.

The database of surface wind field measurements generated out of this research will be then used in conjunction with available full scale data by numerical modelers (using WRF and micro-scale CFD) to improve their simulations.

3.3 Theme 3 – Improving the Performance of Wind Turbines and Wind Farms

Wind energy is one of the major sources of alternative energy that will drastically expand and is expected to capture 20% energy penetration by 2020. WindEEE will investigate the aerodynamics of wind turbine blades, the structural response of wind turbines to local storm events, the scaling and the interference of rotating wakes. We will also improve/facilitate wind farm optimization (siting and arrays effects) and try to reduce acoustic noise.

We plan to use the WindEEE Dome to investigate the structural performance of large Horizontal Axis Wind Turbines (HAWT) under localized wind storm conditions such as Low Level Currents (LLC) or thunderstorms in order to increase the accuracy of the Maximum Foreseeable Loss (MFL) estimations. As described in # 3.1, WindEEE will be able to generate realistic, time- and spatially-varying wind fields via the peripheral fan arrays and control systems, in conjunction with realistic scaled terrain and structural models. With an improved understanding of the time-varying load on these structures, design strategies can be refined to avoid catastrophic failures at one extreme, and over-engineering at the other extreme, both of which can have negative economic impacts on power generation and distribution

Currently, the blades of wind turbines are only tested under straight flow conditions. WindEEE will enable the testing in wind flows spatially and temporally similar to the real wind conditions. Full scale and/or large sections of wind blades will be tested under sheared and turbulent conditions. We will attempt to control the fan system so that we can produce accelerations similar to the ones occurring due to rotation-induced Coriolis effects which are responsible for ill-understood local (blade tip) stall effects.

In order to investigate and solve the problems associated with complex terrain, wake interference and array effects, we will conduct experiments that focus on the scaling of rotating wind turbines. With the Dome's capability to simulate an entire wind park at an approx. scale of 1:500 it will entail rotor models of approximately 15–18 cm diameter for 1.5–3.0 MW utility scale machines. Simultaneous scaling of the Reynolds number for the scale of the site topography and the rotor blades themselves might prove being challenging and therefore we will develop new special mesh rotor models

The research that will be conducted through the WindEEE projects will help support several other collateral research areas such as the improvement of grid connectivity, new business models for wind farm operation and development of new models for public policy in the wind power sector.

4 PROJECT DEVELOPMENT

Based on the conceptual design proposed by Western, AIOLOS has completed the preliminary design of the facility. This involved extensive CFD simulations to address 6 test cases: 1) straight flow for uniformity; 2) boundary layer flow by vertical shear; 3) horizontally uniform shear flow; 4) downburst-like flow with translation; 5) tornado-like flow with translation and 6) reversed outside flow for full scale testing. Fig. 2 a and b show CFD results for cases 3) and 5), respectively.

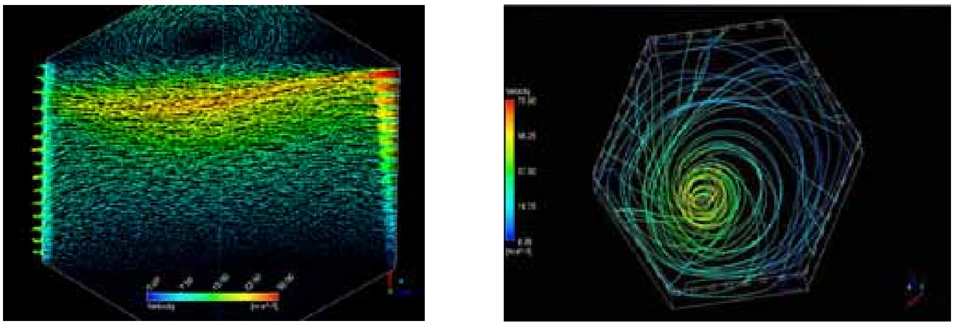

Fig. 2: CFD simulation results a) Horizontally sheared flow, b) Tornado-like flow

The testing of a 1/10 scale model facility is currently undertaken as a proof of concept, benchmark of the CFD results and in order to firm up the control system. The process is continued through the engineering design phase conducted in collaboration with NORR architects and the Fan-Drives-Motors-Electrical manufacturers.

The construction start-up is planned for November 2010 with commissioning following at the end of 2011.