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Western

WindEEE Research Institute
Engineering, Energy & Environment

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Contents

Preface

The WindEEE Research Institute has been renewed in July 2014 “recognizing the excellent progress that has been made with the Institute and the research it carries out, as a key strategic priority for Western”. (VP Research). After completing construction in September 2013 and commissioning in September 2014 the Institute has entered its early operational phase. Full attention is now paid to the operational phase ensuring that both high caliber research and industry projects are secured. A Marketing Plan has been completed in collaboration with the Ivey School of Business in March 2016. Currently a detail Business Plan is developed in 2016-2017, again in collaboration with Ivey. Also, a more detailed budgeting process has been started.

WindEEE Research Institute continues to increase its membership of more than 20 researchers from Western, hosted in 3 departments of the Faculty of Engineering (Civil, Mechanical and Electrical Engineering) as well as Faculty of Science (Applied Mathematics and Geography) and the Ivey School of Business. New Research Director positions are presently under consideration. The outside membership expanded with the participation of external researchers in activities at the WindEEE Research Institute through national and international collaborations. Several research programs have been completed or are under development with partners from Europe (3), USA (3) and Asia (3) in which strong research groups and external researchers apply for funding in collaboration with us. WindEEE RI continues to develop MoU’s with Institutes in Europe, the Americas and Asia. Dual Ph.D. programs are presently under development with the Danish Technical University (DTU), University of Genova, Italy, Beijing Joungong Technical University (BJTU) and the Polytechnic University of Bucharest. Based on WindEEE RI collaborations, top international researchers have been attracted to conduct research and teach summer courses, their presence enriching the activities at Western Engineering and at Western in general, complementing the new graduate program in Wind Engineering which is unique worldwide.

Since 2015, WindEEE is recognized by the Group of Senior Officials (GSO) as part of Global Research Infrastructures, a dedicated closed working space established by the European Commission called CIRCABC on which it started collaborating with global members. In 2016, WindEEE RI has become a member of SATA, the world Subsonic Aerodynamic Testing Association. WindEEE RI was also successful in attracting a large base of research collaborations at the national level. We continue our collaboration with the Wind Energy Institute of Canada (WEICan) who started recommending industrial partners to WindEEE RI. Research as well as industrial projects are being developed with UTIAS at University of Toronto and with UOIT in Oshawa with which WindEEE already shared industrial partners on several projects.

During 2015-2016 alone, the WindEEE RI core faculty group increased its research outcomes producing 60 international journal publications, 64 conference proceeding publications and approx. 2.2 M$ in research funding out of which more than 1.7 M$ is non-IOF research funding. The commercial Industry Collaborative Research at WindEEE RI continues. R&D contracts with the insurance industry have been matched through NSERC CRD, and are presently extended. New collaborations with transmission lines design companies have been obtained and matched through OCE funding. New large contract work on wind development problems has started.

The 3rd WindEEE Research Board and the 2nd WindEEE Advisory Board meetings took place in February, 2016. The Research Board advises the Director on research directions of impact helping the process of allocation to WindEEE membership group of a small number of research hours of operation with predilection for high caliber, high visibility research projects. The 2015 Advisory Board suggestion to perform a Marketing Study for WindEEE RI has been now completed in collaboration with the Ivey School of Business in February 2016. This preliminary study has identified some key emerging markets for WindEEE in order to increase its commercial revenue. The 2016 Advisory Board suggestion to perform a Business Plan is currently under development with Ivey.

The WindEEE Research Institute has demonstrated its capacity to continuously increase its world class research, to attract the best groups and scholars internationally and to secure research, R&D and contract work. With sustained growth the Institute strives to accomplish its Vision: to be a global leader in wind research and innovation.

Horia Hangan

November 2016 /London, Canada

Governance Structure

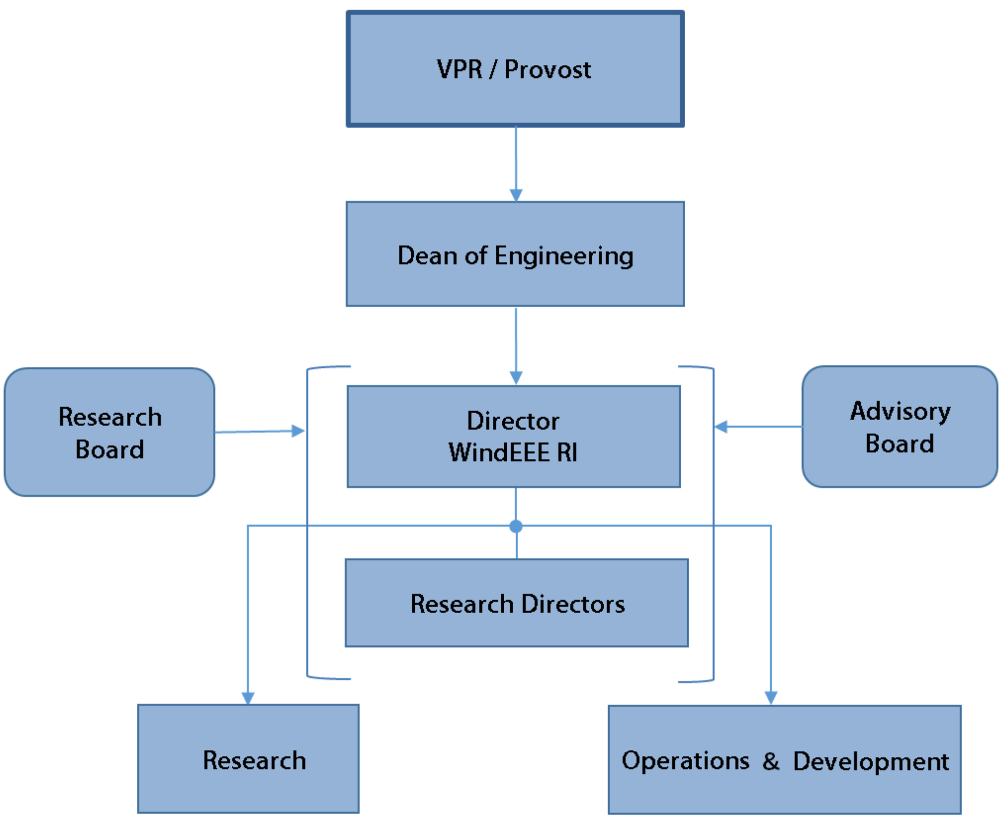
The **Governance Structure** provides both internal and external direction, innovative input and expert advice to the Institute in order to facilitate its development at Western and towards a National and International Institute, see Figure 1. The Director of the Institute reports to the Dean of Engineering. Two external Boards provide the necessary inputs to the Director of the Institute: the Advisory and the Scientific Boards.

The **Advisory Board** (AB) advises the Director of the Institute on progress and advancement in areas related to WindEEE research and services. The board reports on Industry, International Institutes and Government with a global perspective along with providing advice on potential sources of funding in order to primarily address the non-IOF expenditures of the Institute and Facility.

The Advisory Board will meet once a year starting 2014 and Members from Industry, Government and Academia are nominated for three (3) year terms. They are listed in WindEEE RI Advisory Board.

The **Research Board** (RB) advises the Director and the Research Directors on the progress and advancement of the wind engineering, energy and environment sectors, with a scientific perspective. The Research Board normally meets once a year and reviews the Research Proposals to qualify for WindEEE IOF funding.

The Members of the Research Board of the WindEEE RI are nominated for three (3) year terms and have been now approved at the 2nd Annual Research Meeting in January 2014. They are listed in WindEEE RI Research Board.



People

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Wind climatology and wind resource modelling for a modern development situated in “Tornado Alley

M. Karami – PhD Student, supervisor: Dr. H. Hangan and Dr. K. Siddiqui
Extraction of Coherent Structures from Tornado-Like Vortices via POD Method

J. LoTufo – MSc Student, supervisors: Dr. K. Siddiqui and Dr. H. Hangan
Near Surface Measurements Over a Coastal Escarpment: PEIWEE Campaign

J. Lange – MSc Student, supervisor: Dr. H. Hangan

J. Chowdhury – MSc Student, supervisor: Dr. H. Hangan
Analysis and Effects of tornado over urban area

K. Adamek – MSc Student, supervisor: Dr. G. Bitsuamlak
Guidelines for Designers for Predicting Wind Patterns in relation to the Growth of a City

A. Melaku - MSc Student, supervisor: Dr. G. Bitsuamlak
Numerical study of aeroelastic response of tall buildings

B. Nighana – MSc Student, supervisor: Dr. G. Bitsuamlak
Numerical Study of the impacts of air cavity on wall system energy performanc

M. Ayalew – PhD candidate, supervisor: Dr. G. Bitsuamlak

M. Delavar – PhD candidate, supervisor: Dr. G. Bitsuamlak
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M. Kahsav –PhD candidate, supervisor: Dr. G. Bitsuamlak
Numerical study of forced convective heat transfer coefficients on the façade of low-and high-rise buildings

A.Elshaer – PhD Candidate, supervisors: Dr. A. El Damatty and Dr. G. Bitsuamlak
Aerodynamic optimization of tall buildings

A. Awol – PhD Candidate, supervisors: Dr. G. Bitsuamlak and Dr. F. Tariku
CFD determination of external convective heat transfer coefficient of buildings using a consistent UCL velocity profile

T. Hunegn – PhD Candidate, supervisor: Dr. G. Bitsuamlak
Aerodynamic and dynamic optimization of horizontal (bridge) structures

Z. Nasir – PhD Candidate, supervisor: Dr. G. Bitsuamlak
Numerical modeling of tornadic flow structure and its interaction with topography and buildings

A. Gairoloa – MSc Student, supervisor: Dr. G. Bitsuamlak
Tornadic load on structures

C. Howlett – supervisor: Dr. G. Bitsuamlak

M. Hockin - supervisor: Dr. G. Bitsuamlak

M. Aboutabikh – PhD candidate, supervisor: Dr. A. El Damatty
Strength and Stiffness Degradation of Structural Components Subjected to Large Number of Loading Cycles

A. Shehata, Supervisor: Dr. A. El Damatty
Progressive collapse of transmission towers along a line subjected to downbursts

N. Niazi, Supervisor: Dr. A. El Damatty
Structural behavior of lightweight wood buildings under lateral loads

M. A.Gazia, Supervisor: Dr. A. El Damatty

F. Elezaby, Supervisor: Dr. A. El Damatty

A. Ibrahim – PhD Candidate, supervisor: Dr. A. El Damatty
Behaviour of Pre-stressed Concrete Poles under High Intensity Wind

N. El Gharably– PhD Candidate, supervisor: Dr. A. El Damatty
Gust Response Factors for High Intensity Wind Loads

C. Santos – PhD Candidate, supervisor: Dr. A. El Damatty
Optimization of Cable-Stayed Bridges Considering the Wind Action

A. Enajar – PhD Candidate, supervisor: Dr. A. El Damatty
Nonlinear Modeling of Light-Frame House under Uplift Wind Load

J. Rosenkrantz – PhD Candidate, supervisor: Dr. A. El Damatty
Destructive Testing and Validation of a Model LFWS and Roof Harness Subject to Wind Load

M. Hamada – PhD Candidate, supervisor: Dr. A. El Damatty
Transmission Lines Behaviour under Tornadoes Wind Loads

I. Ibrahim, supervisor: Dr. A. El Damatty
Downburst Mitigation Through CFD and Structural Analyses of Electrical Transmission Systems

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Multiple Span Aero-elastic Transmission Line Subjected to Downburst Wind

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K. Toxopeus, supervisor: Dr. K. Siddiqui

A. Kalbfleisch, supervisor: Dr. K. Siddiqui

Facilities

WindEEE Dome

The Wind Engineering, Energy and Environment (WindEEE) Dome, see Hangan (2014), is the world's first 3D wind chamber, consisting of a hexagonal test area 25m in diameter and an outer return dome 40m in diameter. Mounted on the peripheral walls and on top of the test chamber are a total of 106 individually controlled fans and 202 louver systems. Additional subsystems, including an active boundary layer floor and "guillotine" allow for further manipulation of the flow. These systems are integrated via a sophisticated control system which allows manipulation with thousands of degrees of freedom to produce various flows including straight flows, boundary layer flows, shear flows, gusts, downbursts and tornados. A pair of 5m diameter turntables as well as removable contraction systems accommodate a wide variety of test objects and wind speeds for testing inside and outside.

The WindEEE facility is certified LEEDs Silver and includes office space for industry, researchers, staff and graduate students as well as meeting and conference spaces for collaboration. WindEEE is located within the Advanced Manufacturing Park (AMP) in the South East corner of London, ON.

Model WindEEE Dome (MWD)

The Model WindEEE Dome (MWD) is a 1:11 scale version of the WindEEE Dome. The MWD was originally used as part of the design validation for the full scale facility and underwent significant flow studies. The MWD has many of the same features as the full scale WindEEE Dome and is able to produce the same flow scenarios. The model is located on the main Western University campus at the Boundary Layer Wind Tunnel Laboratory. Because of its inexpensive operation and maintenance costs, the MWD will continue to serve as a tool for preliminary test validation/set-up, fundamental tornado research and demonstrations.

Testing Capabilities

The WindEEE Dome can accommodate multi-scale, three dimensional and time dependent wind testing that no other facility can reproduce. WindEEE can be operated in a variety of configurations:

Straight Flow Closed Loop

- Straight flow closed loop utilizing one wall of 60 fans (4 high X 15 wide)
- Up to 30m/s with removable contraction
- Test section 14m wide, 25m long and 3.8m high
- Removable slotted wall assemblies
- All types of naturally occurring horizontal flows including: uniform, gusting, sheared and boundary layer flows
- Active floor roughness control
- Wide variety of scales up to 1:1

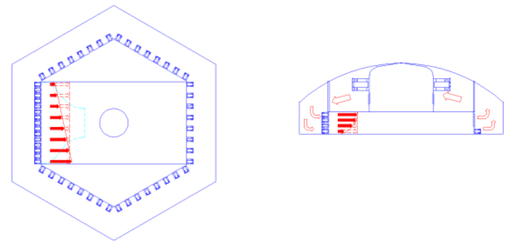


Figure 1 – Straight Flow Closed Loop

Straight Flow Open Loop

- Open mode utilizing 60 fans in reverse
- Uniform, gusting, sheared and boundary layer flows
- Up to 40m/s with removable contraction
- 5m diameter high capacity turntable
- Outdoor test platform with
- Wind driven rain, debris and destructive testing
- Access for very large full scale test objects

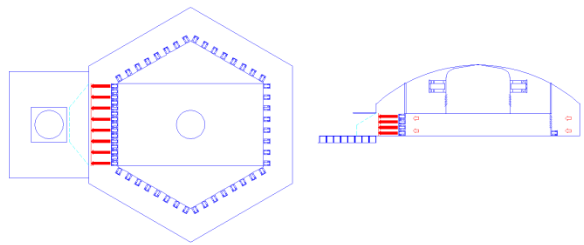


Figure 2 – Straight Flow Open Loop

Tornado

- Replication of EF0-EF3 tornados
- Properly scaled tornado flow-Refan et al. (2014)
- Geometric scale 1/100 to 1/200
- Velocity scale 1/3 to 1/5
- Variable swirl ratio
- Adjustable vortex diameter up to 4.5m
- 2m/s maximum tornado translation speed
- Floor roughness control

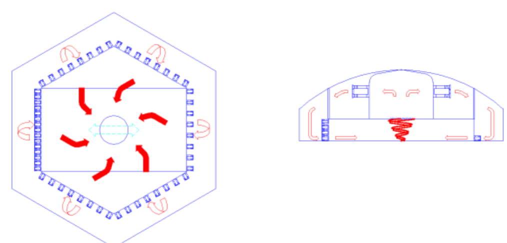


Figure 3 – Tornado

Downburst/Microburst

- Variable jet diameter (max 4.5m)
- Geometric scale ~1/100
- 2m/s maximum downburst translation speed
- Max 50m/s horizontal velocity
- Variable downburst offset and jet angle
- Combined horizontal and downward flows

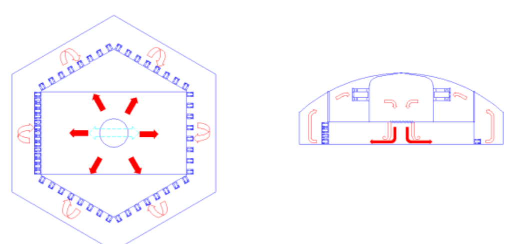


Figure 4 - Downburst

Example Uses

WindEEE has been utilized for many different types of projects and we are always discovering new uses for the facility and equipment. Just like the design of the facility, many of WindEEE's capabilities are unique in the world. WindEEE allows for the first time comparative testing of atmospheric boundary layer, downburst and tornado flows at the same scale. This allows for comparison of loads and responses of a given structure when exposed to these different wind events.

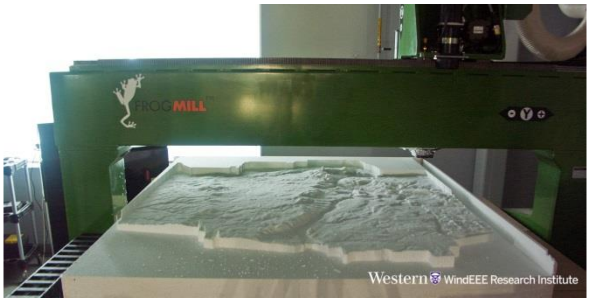
All of WindEEE's different flow configurations can be used to determine pressures and dynamic response of various structures. Scale models of buildings (residential, commercial, industrial, hospital, high-rise), bridges, transmission towers, wind turbines and many others can be tested. Various techniques are used to simulate the effect of surrounding buildings, topography and canopy in order to replicate the local site conditions.

WindEEE can also be used to test large scale, prototype or full scale objects to a wide variety of wind fields. Applications range from testing of full scale solar panels and small wind turbines, large scale topographic and canopy models, large and full scale wind turbine components (blades, towers), building components, environmental measurement devices, unmanned flying vehicles, etc.

Equipment

The WindEEE Facility is furnished with a suite of equipment, instrumentation and data acquisition systems to fabricate scale models and facilitate all types of wind related research and testing, including:

- High speed/high precision pressure scanning system
- Cobra probes
- 6 DOF force balances (multiple ranges)
- Pollution/scent dispersion system
- Multi camera Particle Image Velocimetry (PIV)
- Mobile LIDAR
- Full scale monitoring systems (masts, weather station, anemometers)
- Adjustable rain rake
- 6 DOF probe traverse system
- National Instruments data acquisition systems
- CNC hotwire
- CNC router
- FDM 3D printer



References

Hangan, H., "The Wind Engineering Energy and Environment (WindEEE) Dome at Western University, Canada", Wind Engineers, JAWE, Vol. 39pp.350

Refan, M.*, Hangan, H., Wurman, J., "Reproducing Tornadoes in Laboratory Using Proper Scaling", J. Wind Eng. And Ind. Aerodynamics, Vol. 135pp.

Research

1. Wind Engineering

- Tornado wind loading on essential buildings
- Downburst effects on utility transmission lines
- Wind loading on full scale roof mounted solar panels
- Wind effects on ground mounted solar panels
- Numerical simulations of tornadic and downburst flows
- Finite Element Analysis of collapse modes due to wind

2. Wind Energy

- Aerodynamic testing of smart blades
- Aeroelastic testing of model scale wind turbines
- Topography and canopy effects
- Full-scale campaigns

3. Wind Environment

- Wind resource assessment in complex urban environments
- Smart cities and buildings
- Wind-driven rain/snow
- Pollution-dispersion studies
- Effect of complex flows on unmanned flying objects

Reproducing Downburst Events at the WindEEE Dome – A Case Study

Downburst is a strong downdraft that develops at the upper levels of a thunderstorm. During a thunderstorm, melting of hail and evaporation of raindrops extracts the latent heat from the surrounding air, which consequently cools down the cloud air. As a result, the cold heavy air descends from the cloud base causing the downdraft that upon hitting the ground spreads out radially and produces powerful and damaging winds close to the surface. On October 1, 2012 at about 12:10 UTC (i.e., 1:10 PM Local Italian Time), a downburst struck the coast of Livorno, Italy. Three ultra-sonic anemometers positioned close to the coastline (LI01, LI03 and LI05) recorded the event with the sampling frequency of 10 Hz. The goal of this study was to physically reconstruct the event at the WindEEE Dome.

The downburst reconstruction process was twofold. First, an existing analytical model was used to estimate the location and size of the downburst from the anemometer data. A schematic representation of the Livorno downburst is shown in Figure 1. A3 and A1 represent the locations of anemometers LI03 and LI01, respectively. The angles α β γ and distances d_{3d} and d_{1d} are determined using the analytical model. The distance between anemometers is D = 1561.6 m.

Two cobra probes were placed at the locations of anemometers LI01 and LI03 based on the estimated length scale and the estimated distances of the anemometers from the downburst center obtained from the analytical model. Second, wind measurements were conducted at the WindEEE Dome in order to physically reconstruct the scaled Livorno downburst. The velocity, time and length scales of the reconstructed downburst are determined based on the maximum velocity recorded by anemometers LI01 and LI03, as well as accounting for the time required to reach the maximum velocity (i.e., ramp-up time).

A preliminary analysis has been carried out on the measurements taken in downburst flows at the WindEEE Dome. A comparison between the running mean of wind speeds from the LI01 anemometer reading from the Livorno downburst event and the downburst at the WindEEE Dome is shown in Figure 2.

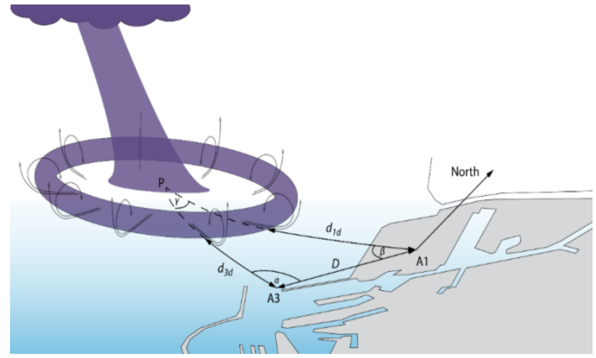


Figure 1. Schematic representation of the Livorno downburst

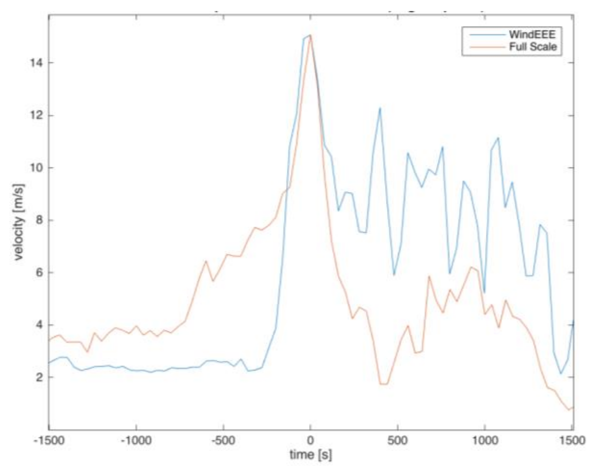


Figure 2. Running mean wind velocities from Livorno downburst event (LI01) and WindEEE downburst

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Effect of downburst on a low-rise building

Downbursts during thunderstorms have gained a lot of attention over the past 50 years since (Whittingham, 1964) recognized the significant damage due to high intensity damaging wind associated with downburst. Significant advancements have been achieved to estimate design wind loads on structures in the ABL from various wind tunnels tests and has been a basis for the building codes around the world (ASCE 7-10, 2013; AS / NZS 1170.2:2011; NBCC 2010, 2012). In contrast, the loading due to extreme thunderstorm events, some of which produce downbursts, is not yet well understood. Downbursts produce strong wind close to the ground and therefore make the low rise structures susceptible to damage.

In this study, wind loads on a typical low-rise building are investigated under a large laboratory simulated downburst-like impinging jet flow produced in the WindEEE Dome at Western University. The WindEEE Dome has the capability to produce both synoptic and non-synoptic wind events. The relative location and orientation of the building with respect to the downburst is varied and the pressure distribution on the surfaces of the building is analysed.

To simulate a downburst at the WindEEE dome, six fans located in a plenum above the test chamber are employed. The upper plenum is connected to the test chamber through a 5 m diameter opening with louvers at the roof of the chamber. To create a downburst like flow, the louvers are closed with the six fans running to build up pressure in the upper plenum. Louvers are then open suddenly to create a downburst in the test chamber. One of the NIST database generic low rise buildings at 1:100 geometric scale was used for this study. Four different building locations and orientations, relative to the downburst, were tested.

Figure 1 is showing the test setup with the building in an offset location (H/D =1, H is the height of the chamber and D is diameter of the downburst) at the WindEEE Dome.

Contours of mean pressure coefficients on the building surfaces for four different building locations and orientations are shown in Figure 2. Mean pressure coefficients are calculated with reference static pressure taken from the center of the bellmouth opening and the reference dynamic pressure was taken at the building height at a distance H/D=1 from the center of the downburst.

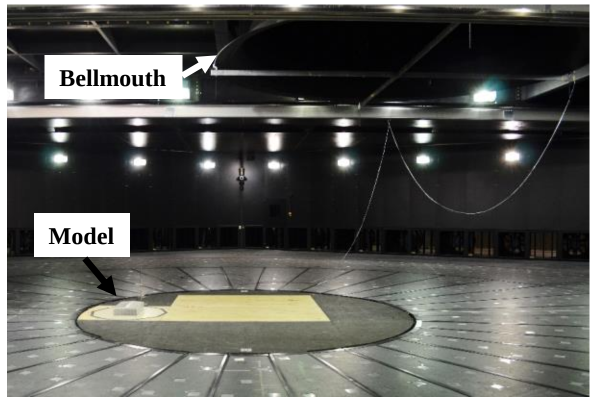

Figure 1. Test setup at the WindEEE dome for one of the offset downburst cases

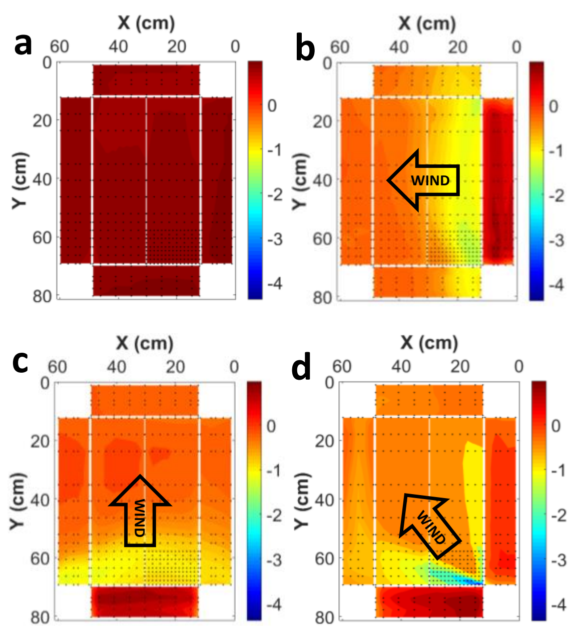

Figure 2. Mean pressure coefficient contours on building surfaces for (location, orientation) (a) H/D = 0, 0°, (b) H/D = 1, 0°, (c) H/D = 1, 90° and (d) H/D = 1, 57°

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Wind Tunnel Modelling of Coastal Escarpment in Prince Edward Island, Canada

An increasing number of wind turbines are constructed in complex terrain such as hills, ridges, valleys, and forest canopies. These types of terrain have an impact on the flow dynamics in the lower portion of the atmospheric boundary layer (ABL). Therefore, the inflow conditions for wind turbines in these types of topography deviate from the ideal and can lead to decreased performance and increased loading and fatigue.

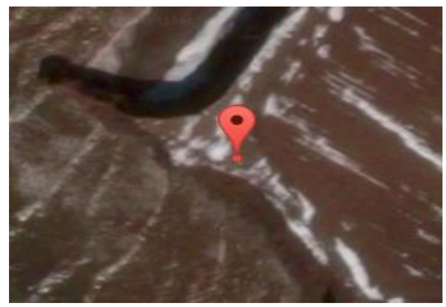
Full-scale field campaigns are done to better understand the underlying physics associated with complex terrains and are often paired with numerical and wind tunnel investigations. However, full-scale campaigns can be very daunting when acquiring useable data is not guaranteed. Hence, there is a need to reduce the overall cost, time and most importantly uncertainty of full scale campaigns while achieving realistic flow physics.

The current study is focused on recreating full-scale measurements at a turbine located on a coastal escarpment. In addition, this study investigates the effect of utilizing standardized versus real inflow conditions on determined flow characteristics. Full-scale data obtained during the Prince Edward Island Wind Energy Experiment (PEIWEE), which was a collaboration between Western, York and Cornell University to investigate multi-scale wake and escarpment effects on the Wind Energy Institute of Canada's research park. WindEEE Research Institute deployed a WindScanner LiDAR developed by DTU to measure inflow conditions over a steep 14 m high escarpment with a wind turbine ≈100m downstream.

A 1:50 scale model is to be tested at the WindEEE dome, investigating mean and turbulent flow characteristics downstream of the escarpment to the turbine location. A rake equipped with cobra probes will be used to traverse the topography in addition to stationary probes at anemometer locations near the site. Two inflow profiles and three wind directions, 240°, 270° and 300° will be used in this experiment.

In the next steps, inflow profiles will be created using the 60 fan wall to match an ESDU open water profile and full-scale measurements from the LiDAR.

North Cape, P.E.I with site and turbine locations.



Coastal escarpment closest to Turbine 4.

Model escarpment to be placed inside the WindEEE dome

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Near Surface Measurements Over a Coastal Escarpment: PEIWEE Campaign

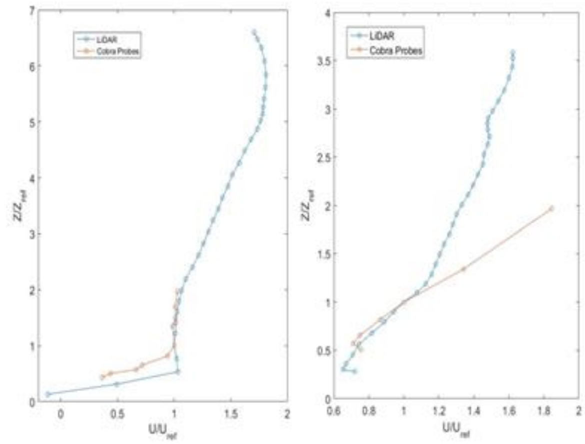
Wind energy has taken great steps forward towards decreasing the use of fossil fuels. In Canada, a growth rate of 23 percent annually from 2011 to 2015 has led to a total increase in capacity of over 5,000 MW.

As this growth rate continues, it will be more commonplace for wind turbines to be built in terrain which is not homogenous. Turbines situated near hills, escarpments and forest will be subjected to more complex inflow conditions. It is important to understand the underlying physics of the flow from a fluid dynamics perspective as turbines in these types of terrain can be subjected to shear across the rotor diameter, increased loading, fatigue and underestimation of generated power.

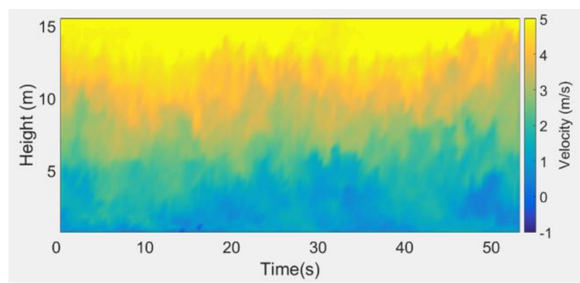
As part of the Prince Edward Island Wind Energy Campaign Western, Cornell and York University collaborated to investigate the effect of the nearby 14 m escarpment and turbine wakes on turbine performance. This study compares the measurements of the taken during the PEIWEE campaign flow field over the escarpment that were conducted using non-intrusive and intrusive techniques. The non-intrusive technique comprised of a Light Detecting and Ranging (LiDAR) device while a set of 4-hole Cobra probes measured the flow field intrusively. One cobra probe was kept at 3.06 m to use as the reference height and velocity.

The two techniques show a good comparison at the edge of the escarpment irrespective of the different flow conditions. On the other hand, at 10 m from the escarpment a good agreement exists beneath 3.06 m but above this height, a deviation of the two profiles is seen. This can largely be explained by the difference in wind speeds between May (6 m/s) and November (12 m/s). The geometry dominates the flow close to the escarpment edge and beneath 3.01 m but the inflow conditions dominate above 3.01 m. A time series of the velocity profile measured from the LiDAR at 5m from the escarpment edge is also shown.

In the next step, these inflow conditions will be recreated in the WindEEE Dome and used to measure mean and turbulent characteristics near a wind turbine located.



Comparison between LiDAR and cobra probes at the escarpment edge (left) and 10m from the escarpment edge (right). Height and Velocity values normalized by cobra probe at 3.06 m



Time series of velocity at 15m from the escarpment edge

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Wind climatology and wind resource modelling for a modern development situated in "Tornado Alley"

The Kansas Project aims to establish a synergetic link between people and weather, as well as to explore different ways to harness the weather for its sustainable resources. The site is located in the South Central Kansas, US. This case study presents a wind climatology analysis coupled with a wind resource assessment study for this modern development. The analyses are conducted on the wind data obtained from a weather station located in Medicine Lodge and for the period 1984-2015.

The wind climatology study shows that the mean wind speed at 10 m above ground is 4.45 m s-1. The highest winds occur in January and July, whereas the lowest wind speeds are observed in December and transitional seasons. The two prevailing wind directions at the site are from south and north. These directions are also associated with the strongest winds. Statistically insignificant, but nevertheless positive trends of the mean annual wind speeds are found for the period 1984-2015 (0.2 m s^{-1} over the analyzed period). The extreme value analysis is performed on the annual maximum 5-second gusts and annual maximum 2-minute mean wind speeds.

The wind resource assessment analysis performed using WAsP package demonstrates good wind potential at the project site, particularly in the hilly south region of the site (figure on the right). The three tentative locations were identified for installing wind turbines on the site. The estimated mean wind speed at 100 m above ground is above 7 m s^{-1}. The power density at two reference sites exceeds 420 W m^{-2}.

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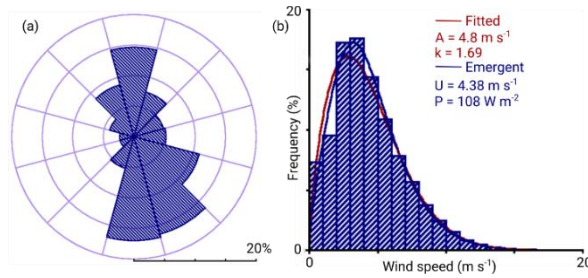
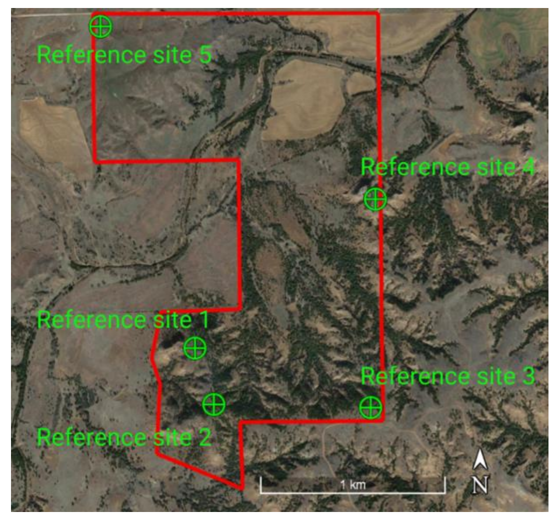
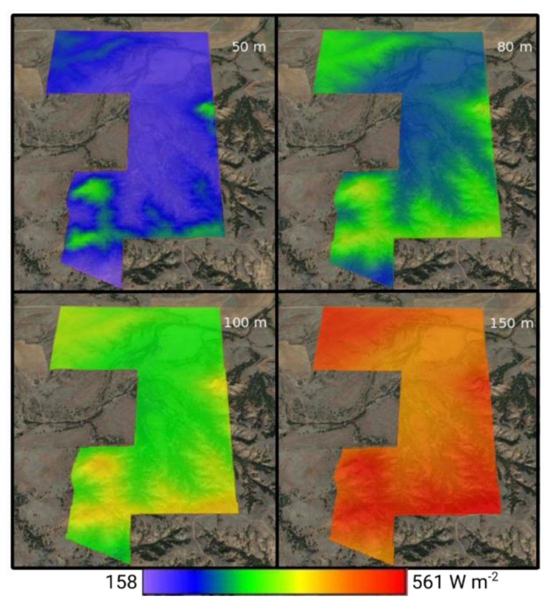


Wind rose and all-sector Weibull distribution based on the wind data from weather station in Medicine Lodge.



Locations of five reference sites placed across the project site.



Wind resource maps at 50 m, 80 m, 100 m and 150 m above ground.

Extraction of Coherent Structures from Tornado-Like Vortices via POD Method

Tornadoes as a serious threat to the large regions of the world cause fatalities and billion dollars damage. The near-surface tornado flow dynamics is of high interest as most of the human and natural habitat resides one hundred meters above the ground.

Although there are some standardized measuring technique, the choice of mathematical methods for data processing and physical interpretation is a challenging task. Coherent structures, which are present in the flow for a relatively long time, provides a simplified understanding of the overall flow geometry. The classical method for extraction of dominant features is proper orthogonal decompositions (POD). For more information about this method, see Ref. [1].

Here, surface pressure fluctuation of a tornado-like vortex is investigated by POD method. The experiment was carried out by Refan [2]. Figure 1 shows the first 8 eigenvalues of pressure field. It can be observed that the first 3 eigenvalues are much greater than others. Since the eigenvalues are proved to be related to turbulent kinetic energy, the first three modes represent approximately 80% of mean kinetic energy. Moreover, the first three eigenvalues at S=0.25 is significantly higher than the corresponding eigenvalues at other values of swirl ratio. This suggests that we have more vortex instability at S=0.25.

Figure 2 presents the first three dominant POD modes at the different swirl ratios. The core radius expands as the swirl ratio increases from S=0.25 to S=0.52 and then remains constant for the range of 0.52≤S≤0.82. This shows that vortex break down touched the surface at S=0.52. We can also see a non-symmetrical pattern (mode 2) at S=0.25 which is not the case for other values of S. Therefore, we have more instability at this swirl ratio number which is attributed to the wandering effects of vortex; this was also obtained by analysis of the eigenvalues (Figure 1). The recurrence of dipole modes corresponds to the rotation of pressure field. In the next step, POD method will be used to extract the coherent structures from the velocity field.

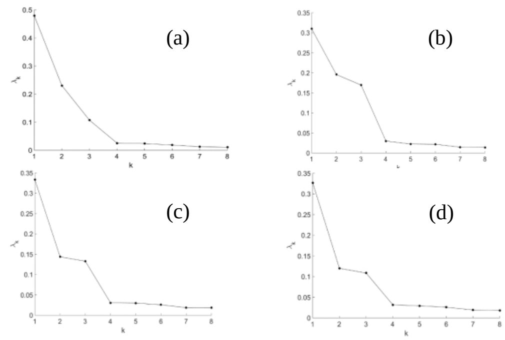


Figure 1. Eigenvalues of POD at different swirl ratio numbers (a) S=0.25 (b) S=0.52 (c) S=0.65 (d) S=0.82.

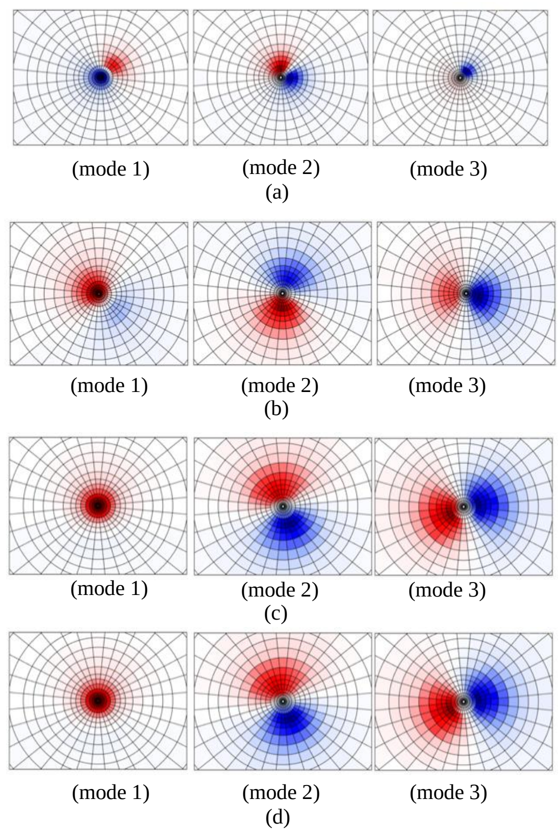


Figure 2. The first three POD modes at different swirl ratio numbers (a) S=0.25 (b) S=0.52 (c) S=0.65 (d) S=0.82.

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Description of Surface Pressure Fluctuation Generated by Tornado Using ICA Technique

As mentioned earlier, proper orthogonal decomposition (POD) is a classical method for extraction of coherent structures out of turbulent flows. Sometimes the results of the analyses appeared encouraging, but the general opinion that POD modes is unable to identify physically-meaningful coherent structures was derived by several authors. A major reason of this failure is believed to derive from the orthogonality constraint of the modal shapes that is intrinsically present in POD and has no physical justification.

Recently, another method as a feature recognition tool, called independent component analysis (ICA), has been introduced. ICA does not have the non-justified orthogonality restriction which is embedded in POD. In ICA, which is close to the method of blind source separation (BSS), the independent components (ICs) are obtained under the assumption that they have nongaussian distributions.

The choice of the model order in ICA is crucial compared to POD. Here, mutual information between pairs of ICs is considered as a measurement of the statistical dependence between pairs of ICs. The values of mutual information between different pairs of ICs are shown in Figure 1. As we can see, the values of mutual information are small which proves the appropriate choice of our model order (n=6).

Figure 2 shows the six ICA modes at S=0.25 and 0.82. At S=0.25, the non-symmetrical patterns represents the instability of the flow. As the swirl ratio increases, the core radius extends (compare the nodal diameter between patterns) which shows that the vortex break down touched the surface. We can infer the rotation of pressure field from dipole modes. Moreover, we can see that radial pressure gradient (∂p⁄∂r) increases with swirl ratio. This trend was not obtained by POD.

In the next step, ICA method will be used to extract the coherent structures from the velocity field.

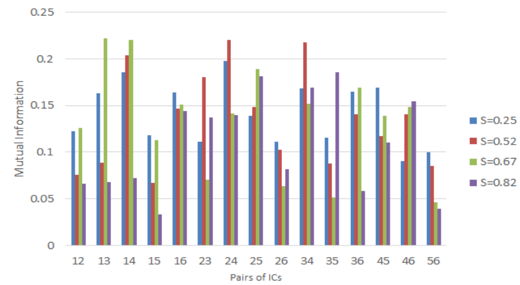

Figure 1. Mutual information between pairs of ICs for different values of swirl ratio number.

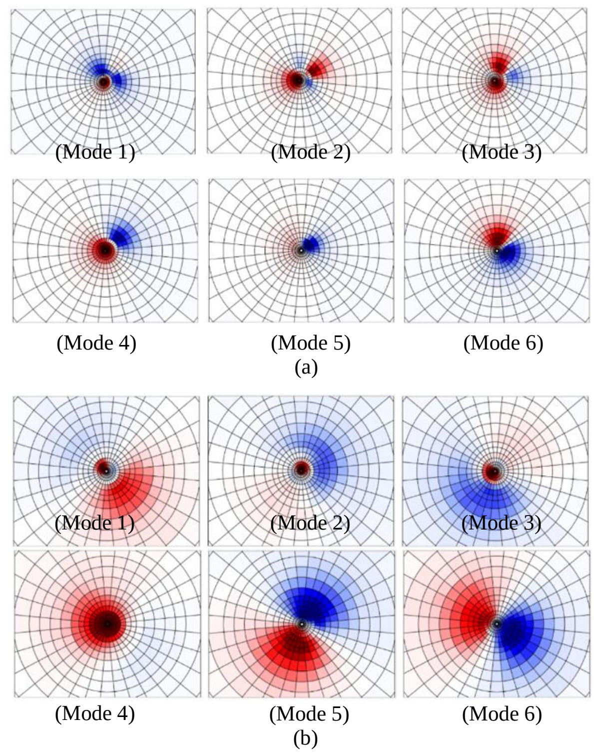

Figure 2. The six ICA modes at different swirl ratio numbers (a) S=0.25, (b) S=0.82.

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Field Data Analysis and Weather Scenario of a Downburst Event

There is a wide body of literature on the subject of extreme weather events in the Mediterranean basin. Downbursts, although being an extreme weather phenomena, have not been extensively researched in the Mediterranean region. In this study, the downburst event that struck the Livorno coast on October 1, 2012 at about 12:10 UTC (i.e. 1.10 p.m. local Italian time) is investigated as a test-case.

The present work is part of a longer collaboration between Windyn (University of Genoa) and WindEEE (Western University) carried out as an interdisciplinary effort between two groups involving atmospheric scientists and wind engineers, with the objective to conduct a comprehensive analysis of field measurements and weather scenarios related to non-synoptic wind systems in the Mediterranean.

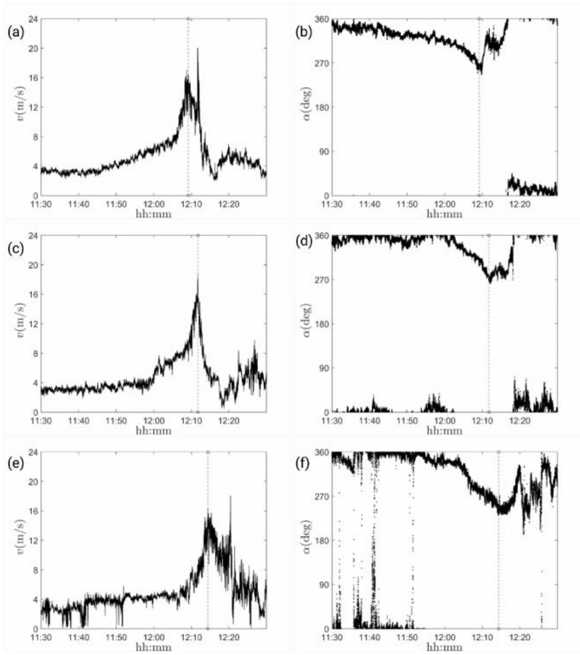
The wind speed records detected by ultrasonic anemometers, part of a monitoring network created for the European Projects “Wind and Ports” and “Wind, Ports and Sea”, are analyzed and decomposed in order to inspect the main statistical features of this transient event. The analysis of the meteorological precursors to this event is carried out making use of model analyses, standard in-situ measurements, remote sensing techniques (radar and satellite data), proxy data, and direct observations. The results obtained bring new insights on downburst’s onset and detection in the Mediterranean, its evolution at the local scale, and possible connections to specific synoptic-scale weather conditions like a secondary cyclogenesis in the lee of the Alps.

Despite some peculiar aspects of this event, first of all the double peak registered by two of three sensors, its properties match rather closely the basic features of the whole database generated by the monitoring network. In particular the set of the slowly-varying mean wind velocity components provides, in its whole, a clear picture of the movement of the gust front from the sea to the inland; in addition it supports a robust separation between the dominant features of the large scale flow and the random turbulent fluctuations. Despite the residual fluctuation has strongly nonstationary random properties, the set of the diagrams of the slowly-varying turbulence intensity confirms that this quantity is not strongly time dependent; it also provides a partial confirmation that the time evolution of a downburst is so rapid and short that its wind field does not reach an equilibrium condition over the roughness of the terrain, thus turbulence intensity is not much affected by this parameter. The probability density functions of the rapidly-varying reduced turbulent fluctuation exhibit classical Gaussian features as many other authors observed in literature; moreover, its power spectral density tends to decrease in the high frequency range with a slope that is typical of the inertial sub-range of synoptic-type winds.

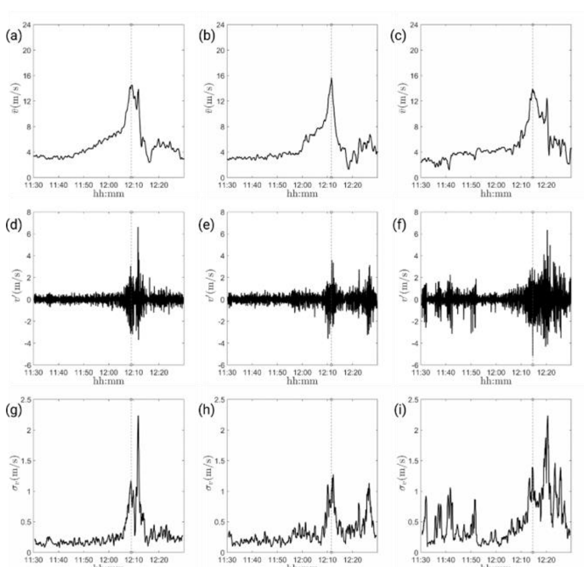
The analysis of the meteorological conditions concurrent with this event has been carried out by gathering all the meteorological data available in this area, making use of model analyses, standard in-situ measurements (stations and radio-soundings), remote sensing techniques (radar and satellite), proxy data (lightning), and direct observations (from the European Severe Weather Database). All this information contributed to reconstruct the comprehensive weather scenario that occurred on October 1, 2012, over the City of Livorno, confirming that the strong wind event detected by the high-sampling rate anemometers of the local monitoring network was most probably a wet downburst.

This is an important result as it demonstrates the role of specific synoptic-scale conditions over Western Europe, e.g. the formation of a secondary cyclone in the lee of the Alps, as a necessary meteorological prerequisite and precursor to the occurrence of local-scale convectively-forced strong wind events in the northern Mediterranean Basin. Moreover, the downburst position seems to be detectable, at least in the present case, by some local signals like higher values of storm-relative helicity, as well as using standard storm-specific indexes, like the WINDEX and the Lifted Index.

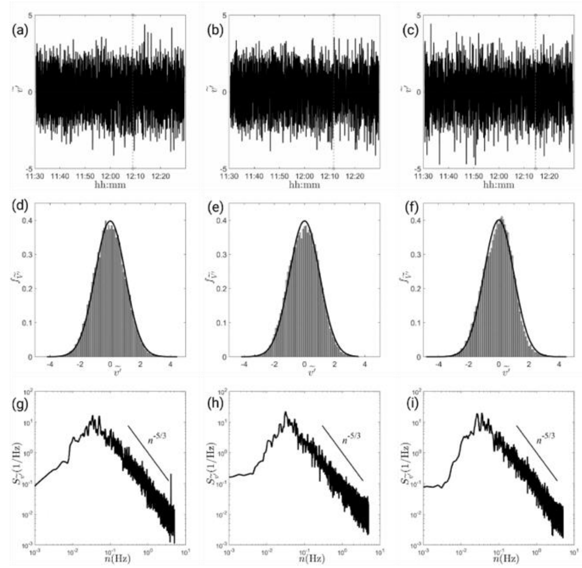
It is worth noting the interest in bringing together the two different viewpoints provided by wind engineering and atmospheric sciences. In this case, the high-sampling rate wind speed records detected in a typical wind engineering framework have proven to be an excellent tool which can correlate to a meteorological event further investigated through a typical meteorological approach. Several outcomes from the atmospheric science framework evaluations were later refined using the information provided by the local anemometric network and signal analysis.



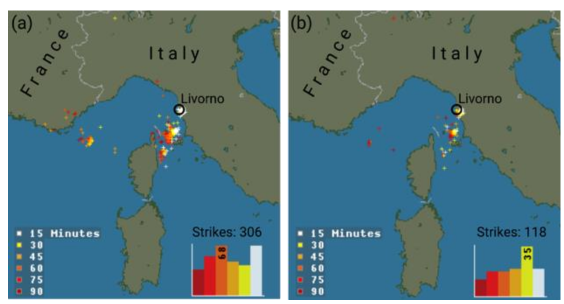
Wind speed (left) and direction (right) measured by three anemometers (top, center, bottom) of the Port of Livorno monitoring network from 11:30 to 12:30 UTC on October 1, 2012. Vertical dashed lines show the approximate time of the gust front passage.



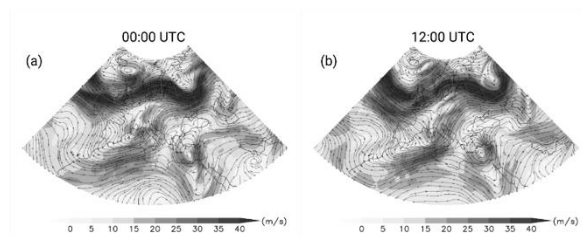
Slowly-varying mean wind velocity (top), residual fluctuation (center), and slowly-varying standard deviation (bottom).



Rapidly-varying reduced turbulence fluctuation (top), histogram compared with a reference Gaussian PDF (thick line) (center), and PSD (bottom).



Strikes recorded on October 1, from 11:00 to 12:30 UTC (left) and from 12:00 to 12:30 UTC (right), by means of the Blitzortung network for lightning and thunderstorms.



Wind speed (shaded contours) and streamlines at 300 hPa. Left (right) panels correspond to October 1, at 00:00 (12:00) UTC.

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Effect of Reynolds Number and Inflow Parameters on Mean and Turbulent Flow over Complex Topography

Wind turbines represent an effective and reliable means of extracting energy from the wind to produce clean, renewable electricity. Optimizing wind farm layout and design for maximum production relies on accurate forecasting of wind speeds and turbulence levels at prospective wind farm sites. While this is a fairly straightforward process in flat, open terrain, the task becomes much more complicated in regions of highly variable, or complex terrain.

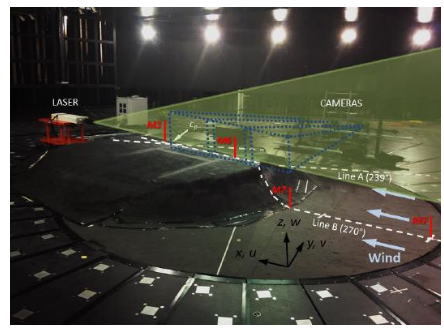
An improved understanding of how complex terrain affects the three dimensional structure of the wind is required, and one approach to achieving this involves developing new predictive models, and validating these models against full-scale and wind tunnel testing. Bolund Hill, a 12 metre high hill located near Roskilde, Denmark, and characterized by a steep escarpment on its windward side, has over the last ten years become a test case for validation of numerical models for wind resource assessment.

A 1:25 scale model of Bolund Hill was tested at the WindEEE dome, and the mean and turbulent flow behavior were analyzed under various inflow conditions. Measurements were conducted using Particle Image Velocimetry (PIV) in the vicinity of the escarpment as well as Cobra Probe measurements at select locations corresponding to the mast locations of the full-scale experiment.

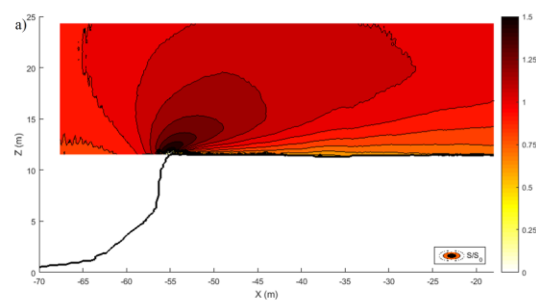
Various parameters including Reynolds number, inflow surface roughness, and inflow shear profile were altered, generating eight different test cases, and the resulting behavior on mean and turbulent flow above the surface of the hill was observed.

The results showed that mean flow behaviour was generally unaffected by changes to the Reynolds number, however an increase in wind speed over the escarpment was observed for cases with lower inflow roughness. The shape of the inflow wind shear profile also had a minor impact on the mean flow near the escarpment.

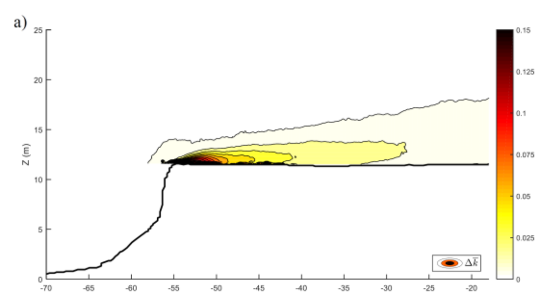
More significant effects were observed in the turbulent flow behavior, where the turbulent kinetic energy (TKE) over the escarpment was found be a strong function of inflow roughness and a weak function of the Reynolds number. The local change in the upwind shear profile was found to have the most significant influence on the TKE magnitude, which more closely approximated the full-scale TKE data, and which had not been previously observed in wind tunnel modelling of this topography. This work has recently been accepted for publication in the journal Wind Energy Science.



WindEEE experimental setup



Contours of speed-up ratio S/S_0 over the escarpment



Contours of TKE increment $\Delta\bar{k}$ over the escarpment

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Analysis of Turbulent Coherent Structures in a Flow over an Escarpment using Proper Orthogonal Decomposition

The present study extends the wind modelling of the flow over Bolund Hill to include the use of the Proper Orthogonal Decomposition (POD) technique to analyze the turbulent coherent structures present in the flow and the relative influence of the inflow conditions. The WindEEE facility allows for customized control of fan speed and roughness element height. As part of the overall experiment, various combinations of wind speeds, upstream roughness, inflow profiles and model geometries were tested. This study presents a direct comparison of two such cases, whose key parameters are indicated in Table 1. The two cases, denoted “uniform” and “shear”, were tested with the same model geometry and upstream roughness configuration, at roughly the same Reynolds number. The cases differed only in the shape of the inflow wind profile.

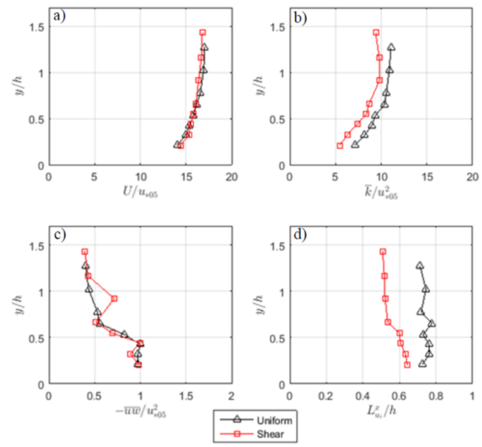
In the study of general mean and turbulent flow behavior over the escarpment, an increase in Turbulent Kinetic Energy (TKE) of over 200% was observed for the shear case, compared to the uniform case, in the region close to the hill surface, just downwind of the escarpment leading edge. This large increase occurred despite what could be described as only minor differences between the two sets of inflow profiles. Furthermore, the TKE measurements for the shear case more closely approximated the full-scale TKE measurements in the same region, providing an incentive to investigate the turbulent mechanisms and structures in the flow field.

Through the POD technique, the turbulent velocity field is decomposed into ortho-normal basis functions in time and space, and the method is optimized such that the energy of the signal is represented using the fewest number of modes. Lower modes correspond to larger, more energetic structures, while higher modes are associated with smaller structures with lower energy. Previous efforts have documented relationships between the POD modes and the underlying physical turbulent structures present in the flow.

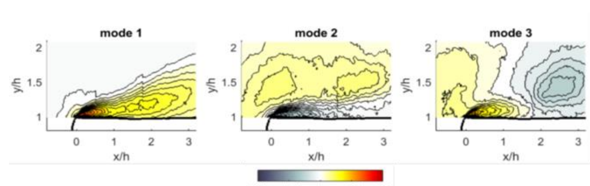
Results of the POD analysis revealed different scales of turbulent coherent structures present in the flow depending on the inflow wind profile. The most significant differences between the two profiles were observed in the lowest POD modes, corresponding to the largest and most energetic structures.

The strongest structures in the measurement region were those associated with the separated flow region at the escarpment leading edge. The results also indicate that the larger, energy-containing turbulent vortices grow in size as they move downwind. When a wind turbine is installed in the downwind region of a topographic feature such as an escarpment, these vortices are expected to dynamically interact with the turbine blades and tower and may induce transient loading on the turbine. This may affect the structural integrity of the turbine as well as induce low-frequency noise that may cause discomfort for residents living nearby.

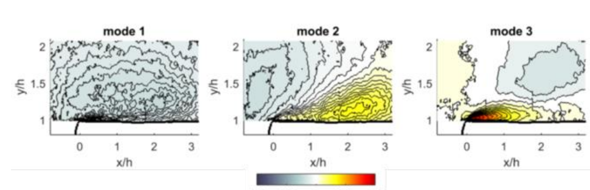
This work was presented at *The Science of Making Torque from Wind* conference held in Munich, Germany, October 5 – 7, 2016.



Inflow profiles for uniform and shear cases: a) mean speed, b) Turbulent Kinetic Energy (TKE), c) Reynolds shear stress, d) Streamwise integral length scale



Contours of streamwise POD energy, uniform case



Contours of streamwise POD energy, shear case

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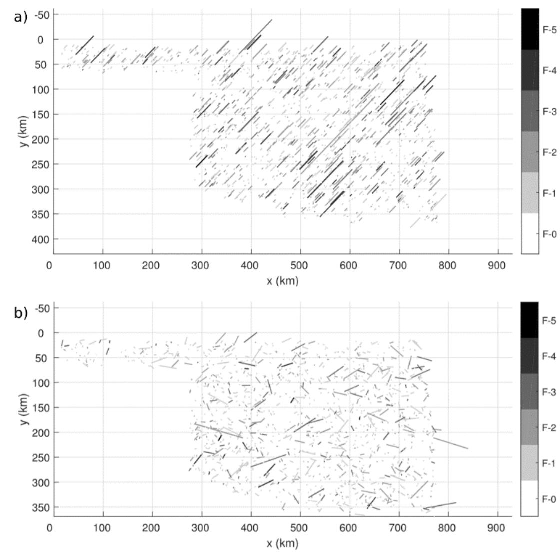
Oklahoma Tornado Risk and Variability: A Statistical Model

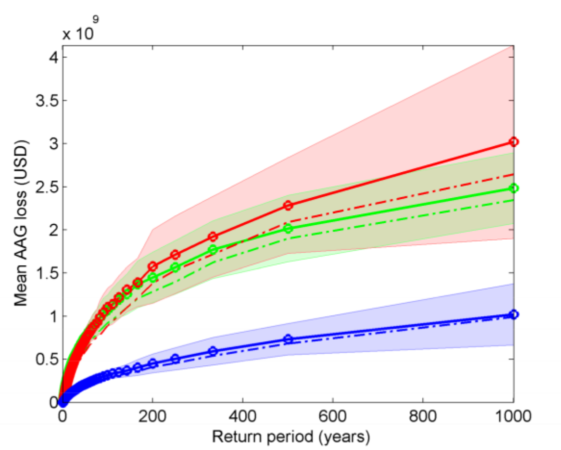
Every year, tornadoes cause damage to property and loss of life in the US. Although a single tornado does not cause the same damage a single hurricane produces, the sum of losses of dozens of tornadoes in a year can surpass hurricane losses. In 2011, tornadoes in the US created US$ 27 billion of insured property loss, which is about five times the loss generated by hurricane Irene, the most damaging hurricane that occurred in the same year.

Here, an existing catalog of registered tornadoes over the territory of the US is used to construct a numerical model for tornado loss assessment for the state of Oklahoma (OK). The model incorporates the following input parameters: (1) tornado occurrence, (2) tornado intensity, (3) exposure, (4) vulnerability, and (5) spatial distribution of tornado tracks. Three different variations of input variables are considered: (1) all input parameters except for the annual number of tornadoes are derived based on their mean values excluding variability around the mean, (2) variability of house prices, footprint orientation and vulnerability values is included in addition to (1), and (3) same as (2), but variability of tornado intensity along footprint length and width is introduced. Hereafter, the cases (1), (2) and (3) are named "NoVar" (No Variability), "HOV" (House-Orientation-Vulnerability) and "HOVI" (House-Orientation-Vulnerability-Intensity), respectively.

The calculated aggregated (AGG) losses from independent model runs show high level of convergence for 1000 years of simulated tornadoes. The largest differences in the exceedance probability loss curves result from introducing variability in intensity along the tornado tracks (HOVI). We ran proxies for calculating Risk-Based Capital in order to understand the impact of these findings for policy makers and/or the insurance industry. Modelled losses are compared against results from a commercial tornado risk assessment model as well as against the 2013 Moore tornado event. The NoVar and HOV cases predict the 2013 Moore twister to be 1 in 10 and 1 in 12.5 loss event, respectively, whereas the HOVI case estimates the return period of this event at 58 years. Probability of being hit by a tornado in OK is calculated to be 0.039%, which is in accordance with literature. The limitations and uncertainties of developed model are also discussed.



Representation of tornado footprints in a) NoVar case, b) HOV and HOVI cases. The plots are based on a 50-year RP model run



Aggregated (full lines) and occurrence (dot-dash lines) loss profiles associated with NoVar (green), HOV (red) and HOVI (blue) cases. The profiles are based on an average of 25 model runs. The shaded regions bounded by the dashed lines represent the standard deviation around the mean estimated losses.

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Wind Climatology of Toronto and its Potential Relation to Solar Activity

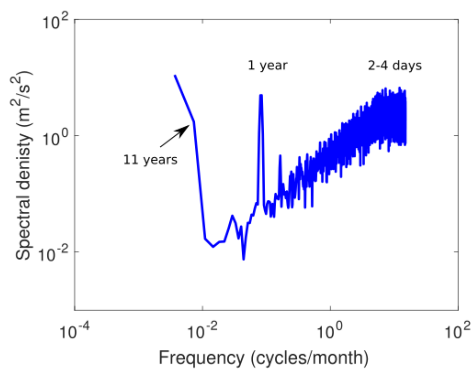
The goal of this study is to investigate the wind climatology of the city of Toronto, Canada from the regional scale perspective. To be more specific, the study is focused on the following subjects: (1) wind speed and wind direction climatology, (2) wind power analysis, (3) wind speed and wind occurrence trends (4) spectral analysis of wind speed time series, and (5) wind speed autocorrelation analysis. The results could have practical implications in various areas of urban sustainability of Toronto.

The wind analyses are based on the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis 1 dataset for the period 1948-2014 (67 years). The mean daily wind speed and direction are given at the sigma-995 level (the level where the pressure is 99.5% of the surface pressure), which is calculated to be positioned at 41.1 m above ground.

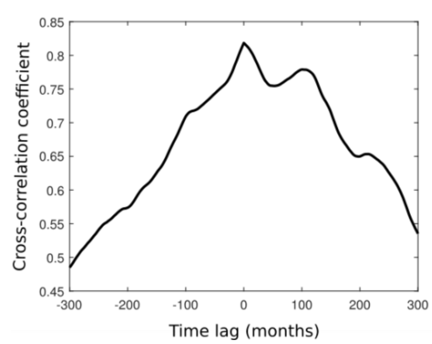
Winds coming in from 240°, 270° and 210° were the most frequent. On an annual bases, these three wind directions were present in about 50% of the time. The windiest season is winter with an average wind speed of 5.61 m s^{-1} and the wind power density of 190.7 W m^{-2}. The mean annual wind speed above Toronto is found to be 4.83 m s^{-1}. Besides being the most frequent, the 240° wind direction is also associated with the strongest winds. The windiest season after winter is fall, followed by spring and summer, respectively.

Mean annual wind speeds above Toronto increased for 0.2 m s^{-1} and this trend is statistically significant at the 95% confidence level. The strongest positive trends are observed in the fall and winter seasons. The fall winds increased their speed for 0.8 m s^{-1} in the 67-year-long period. Negative wind speed trends in the summer and spring seasons are statistically not significant with very small values of Sen's slope. The windiest directions, 240° and 270°, have also experienced statistically significant upward wind speed trends.

Spectral analysis of wind speed series in the low-frequency domain reveals three distinguished peaks. One of the peaks corresponds to the passage of the low pressure systems (cyclones and depressions) with a period of 2 to 4.5 days. The second peak has a period of 1 year and corresponds to the annual cycle of seasons. This peak is also evident in the autocorrelation analysis which resembles 1-year statistically significant periodicity. The striking feature, however, is the existence of the third peak with the period of 11 years. Cross-correlation analysis between smoothened wind speed series and the total monthly number of sunspots indicates that the 11-year peak in wind spectrum might be due to the solar activity that manifest as the famous 11-year solar cycle. The highest correlation between these two time series is observed at zero time lag and reaches 0.82.



Low-frequency wind speed spectrum for Toronto based on the mean daily wind speeds.



Cross-correlation between the 13-month moving averages of the mean monthly wind speed above Toronto and total monthly number of sunspots

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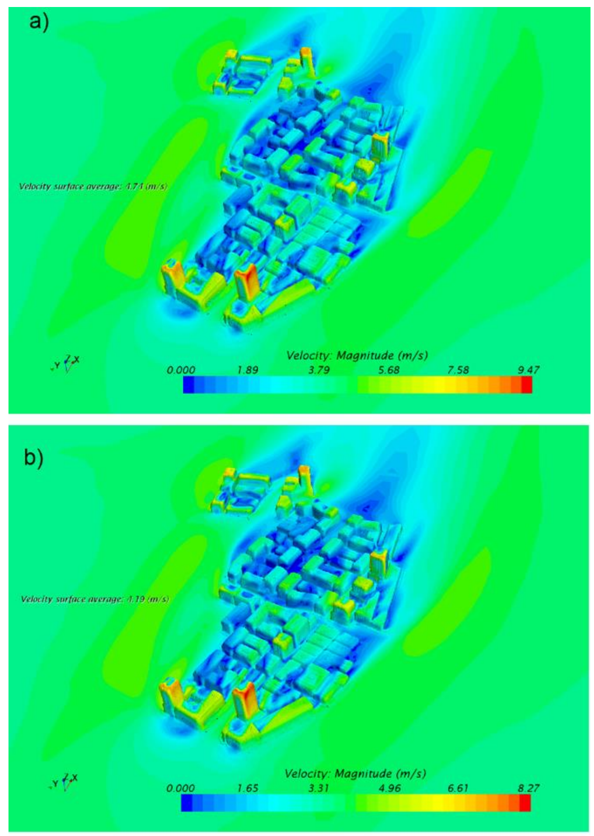
Urban Wind Resources in Changing Climate

Rapid urbanization is a global phenomenon. In mid-2015, the world population reached 7.3 billion, out of which 53.9% lived in cities. The percentage is even higher in Canada, where 82% of Canadians in 2015 inhabited urban environments; mostly the Toronto, Montréal and Vancouver regions. Harvesting and modifying weather, and wind in particular, will be one of the key factors in transforming modern cities into sustainable and more resilient ones.

In this regard, the possibility of installing small-scale wind turbines in an urban environment is investigated in this study. This problem is addressed in two steps. First, a new methodology for urban wind resource assessment is introduced in an earlier study. Second, the proposed methodology is placed in the framework of the current climate change and the available wind resources are analyzed.

The methodology to estimate the climate change influence on available wind resources in based on the magnitude and sign of the linear trends of the near-surface winds, i.e. winds at the sigma-995 level (the level where pressure is 99.5% of the surface pressure). The methodology is applied for a specific urban development in downtown Toronto. The Mann-Kendall test for trend and Sen's slope technique are used to detect and estimate the strength of wind speed, signma-995 level geometric height and air density trends for the period 1948-2015. In the next step, the obtained trend lines are used as the inputs for computational fluid dynamics (CFD) analyses. Namely, one CFD simulation of wind resources is performed using the wind speed, sigma-995 level height and air density values at the beginning of each of the three trend lines. The second CFD analysis is conducted utilizing the wind speed, sigma-995 level height and air density values at the end point of the three trend lines. The differences between the calculated wind resources in these two CFD simulations are an estimate of the climate change influence on the wind potential above downtown Toronto. The methodology, however, does not take into consideration the changes in urban planning during the same period of time.

Figure on the right shows that the long-term wind speed trend does not profoundly affect the mean velocity field above downtown Toronto. It has been shown that the maximum speeds are more affected by the climate change than the mean speeds. This finding is in accordance to with literature. It has been demonstrated that randomly spaced and located objects in urban environments are factors that have to be accounted for in urban wind resource studies in changing climate.



Velocity field at 5 m above building and ground surfaces calculated using the two end points at the near-surface wind speed trend lines; i.e., a) the last value on the near-surface wind speed trend line and b) the first value on the trend line. Flow is along *x*-axis.

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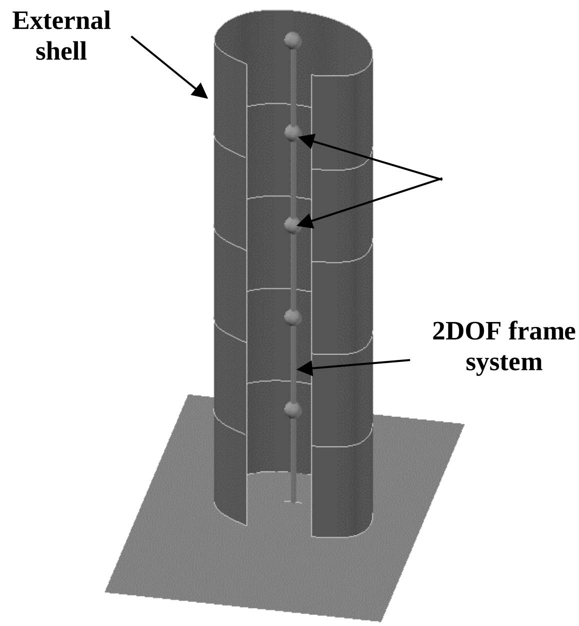
Numerical study of aeroelastic response of tall buildings

Lightweight and flexible structures are extremely susceptible to wind induced vibration and aeroelastic instability due to their low natural frequency. Design of these structures for wind, particularly tall buildings, has been mainly carried out using wind tunnel experiments. In the past few decades, however, due to the increased computational power, aerodynamic modeling employing CFD has shown considerable progress in evaluating wind loads on tall buildings.

The objective of this research is to study the aeroelastic response of tall buildings numerically using fluid-structure interaction. The wind flow around the building will be simulated using unsteady CFD and the structural response of the building will be modeled by a linear FEM model. In order to couple the wind flow with the deformation of the structure, a partitioned and strongly coupled fluid-structure interaction scheme is adopted. Similar to the experimental aeroelastic models, in the numerical simulation also, the mechanical property of the building is modeled as a lumped mass two-degree-of-freedom “Stick” model and the exterior shell of the building was allowed to translate as a rigid body following the deformation of the core FEM model. This numerical simulation is implemented by coupling two open source packages, OpenFOAM for the wind flow simulation and OpenSees for structural analysis.

The developed method has the potential to be used as a tool in the initial design stage of tall buildings for assessing wind induced vibration for occupant comfort, and in structural optimization of tall buildings to better the aeroelastic performance. It can also be easily extended for studying wind induced stress on flexible components and cladding of both high and low rise buildings.



Implementation of fluid-structure interaction method: frame system for the structure with dummy external shell translating with internal frame structure.

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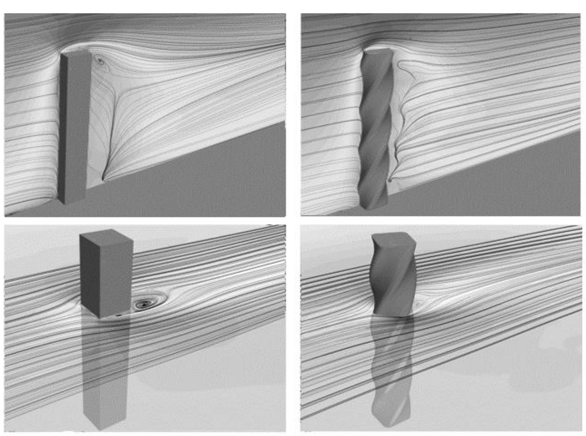
Aerodynamic optimization of tall buildings

Improving the aerodynamic performance of a building by local and/or global mitigations can result in a significant reduction in the lateral loads and limit the vibrations caused by wind, which leads to a more economic and comfortable tall building. The target of the current research is to develop a multi-scale and multi-physics climate responsive design framework that accounts for the complex interaction between buildings and wind.

Recently, an aerodynamic optimization procedure (AOP) was developed by our research group. The procedure couples the genetic algorithm with the artificial neural network (ANN) model trained by a database resulted from CFD analysis in an automated process to estimate the optimal tall building shape that result in the best aerodynamic performance. AOP is adopted to optimize tall buildings locally (i.e. corners) to reduce a single-objective function (either drag or lift forces) using three dimensional large eddy simulation (3D-LES) models of a 2D flow [1–3]

Rectangular building Optimized building



Building on that benchmark, the use of AOP is further extended to conduct multi-objective optimization (i.e. minimizing base moments in both the along- and across-wind directions) for a tall building with three through openings and for a building with helical twisting [4]. This type of mitigation requires a 3D-LES of an atmospheric boundary layer (ABL) flow to capture the aerodynamic improvement. The AOP is adopted to identify the Pareto Front (PF), which is the set of optimal shapes that achieves the best fitness (improving the aerodynamic performance) among the whole search space. The main advantage of defining the PF is having the flexibility of choosing from a set of optimal building shapes rather than obtaining only one optimal shape in the case of single-objective optimization.

Wind load reduction though use of “openings”

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[3] Elshaer A, Bitsuamlak G, El Damatty A. Enhancing wind performance of tall buildings using corner aerodynamic optimization. Eng Struct 2016.

[4] Elshaer A, Bitsuamlak G, El Damatty A. Aerodynamic shape optimization of tall buildings using twisting and corner modifications. 8th Int. Colloq. Bluff Body Aerodyn. Appl. Boston, USA, 2016.

CFD determination of external convective heat transfer coefficient of buildings using a consistent UCL velocity profile

Consistent urban canopy layer (UCL) velocity profile is sought to characterize local flow around arrays of buildings. And hence, based on these local characters; such parameters like convective heat transfer, pedestrian comfort, and pollution transport parameters can be determined in a reliable manner. In the current study, the characters needed are those that are the most relevant references to discuss coefficients of convective heat transfer on the external surfaces of the buildings. This approach produces a more realistic representation of the heat transfer phenomenon by convection, unlike previous cases whose basis are formulations directly on reference velocities at metrological station scale or non-consistent local states. Moreover, most relations for external convective heat transfer coefficient are obtained from wind tunnel or CFD simulations of an isolated building.

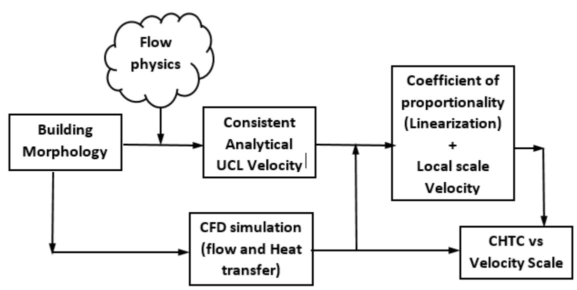
There are several research outputs claiming convective heat transfer coefficient to be in linear, or power law proportion to either the wind velocity at 10 meter height from ground or local velocity scale. Review of literature indicates, there is no consistency in the determination of the location of reference for local velocity scale. As a result, reported correlations for evaluation of convective heat transfer coefficient show wider discrepancy among them.

In light of these, this research aims to perform simulations on array of buildings and determine convective heat transfer coefficient. It considers reference states based on reference velocity scale locations; such as lines and planes of symmetries for various morphological scenarios. More importantly, the reference characteristic velocities will be determined using consistent analytical velocity profile derived by the authors for urban canopy layer of defined morphological state.

Preliminary attempts indicate the present UCL profile displays some advantages, in terms of the physical essence than conventional relations found in literature. The present profile is able to satisfy the vital conditions such as no-slip near wall, back flow or separation under dense settlements and matching the ABL conditions under sparse array scenarios. CFD simulations of several conditions are then utilized to ascertain the consistency of the relation and hence determination of a coefficient; currently named coefficient of linearization.

The profile obtained is the used to define flow characters near building in the array system, which are again employed in the determination of a consistent heat transfer coefficient correlations. The local characters will be based on reference locations which are easy to infer; such as symmetry lines or planes of the array system.

The aforementioned procedure is considered to give appropriate heat transfer correlations; thereby improving the heat transfer and energy evaluation in performance analysis of buildings in a complex setting. The present study is supposed to contribute a share in the bridging of what is known as *the sustainable performance gap*.



Work flow to obtain consistent convective heat transfer coefficient relations

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Numerical Study of the impacts of air cavity on wall system energy performance

Field experiments were conducted by the Building Science center of excellence (BCSE) to test the impact of airflow through an air cavity on the hygrothermal performance of wall systems[1]. To do this, three test panels were instrumented and monitored in field-experimental setting: one with no air gap, another with air gap but restricted airflow (vented) and the third with air gap and unrestricted airflow (ventilated). The test panels were instrumented and installed in the Building Envelope test facility (BETF) at the British Columbia institute of Technology. Experiments were monitored for 15 months and the temperature and moisture contents of the sheathing membrane were compared for wall system performance.

Preliminary results revealed that air flow in the air cavity did not significantly improve the drying of the sheathing membrane. However, the air gap in the vented wall system increased the thermal resistance of the wall that keeps the sheathing boards slightly warmer than the other wall assemblies in the winter. Also, the solar radiation-induced airflow is beneficial during the cooling season. Following, the implications of airflow on the heating and cooling loads calculations of different orientations, wall configurations and climate will be numerically investigated in COMSOL.

The numerical results are benchmarked against field experimental data. Given, the measured interior and exterior boundary conditions as inputs, the temperatures of the various wall assembly layers and the air cavity are compared. Following, a satisfactory agreement between experiment and numerical simulation, a parametric analysis is conducted to investigate the impact of cladding (Fibre cement, Metal cladding, Brick cladding), Cavity spacing (6 mm, 19 mm, 25 mm), climate and vent opening area. The project is currently in the benchmarking phase.

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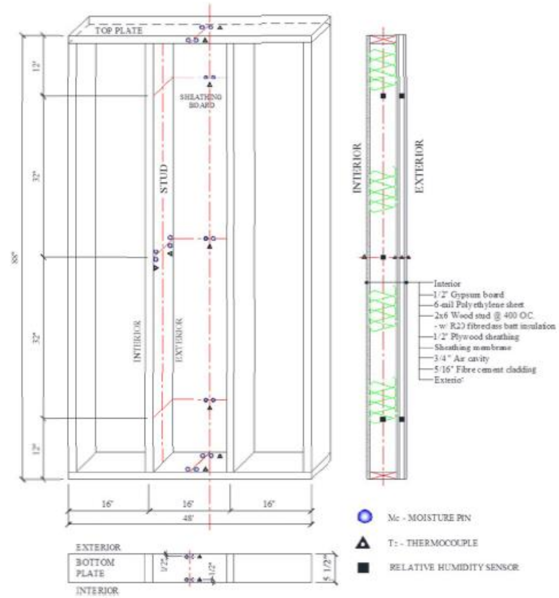

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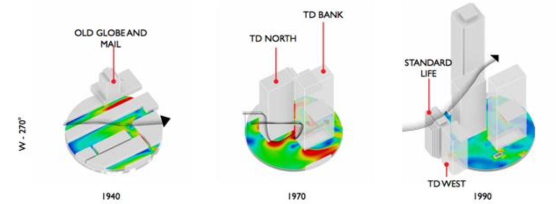
Guidelines for Designers for Predicting Wind Patterns in relation to the Growth of a City

Cities all over the world are growing as more people move to live in urban areas. In fact, more than 50% of the world's population lives in cities, and this number is expected to only increase with time. As taller buildings are constructed, pedestrians can begin to experience disruptive wind-related events at grade level that challenge their safety, comfort and health. Disruptive wind events in Toronto 1970, Leeds 2014, and London 2015 are amongst the most significant and dangerous wind events caused by the orientation, placement and shape of buildings in the recent years. As new cities are planned and older cities continue to develop, the relationship between winds and the structures that make up the city must be considered carefully.

With few visual guidelines and tools accessible to them, designers are not only limited in their ability to understand architectural aerodynamics but also lack the knowledge to properly make use of available modes of software and testing. While other elements of design such as day lighting, can be verified through sight, the invisibility of wind makes deciphering its effects a difficult and perpetual task.

Using five case studies of the development of winds in relationship to the growth of a city, the plan is to create guidelines for the planning stages of a city that take into account the comfort, safety and health of the pedestrian. The guideline will be for the new Schuylkill yards project that is a 20 year development plan in West Philadephia. The figure below shows the change in winds with the development of the Financial District in Toronto, Ontario.

In the next step, the changing winds of 4 other major cities will identify patterns and common wind occurrences and their links to building form, placement and orientation.



Example of Toronto Development from 1940, 1980 and 1990 and changing winds associated with buildings.

Planned Development in West Philadelphia

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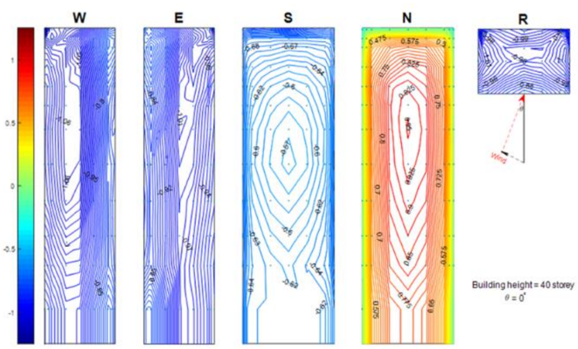
Towards Performance Based Serviceability Risk Assessment of Tall Mass Timber Buildings

The recent worldwide surge in research to enhance the sustainability of the current urban-form draws the attention of construction stakeholders towards the use of timber buildings. To this end, several mid- and high-rise timber-based buildings are constructed in Europe, North America, and Australia. In Canada, the 2015 edition of the National Building Code has raised the height limits for wood-frame buildings from four to six storeys. Also, new design provisions for Cross laminated Timber (CLT) have been included in the 2016 to supplement the 2014 CSAO86, the Canadian Standard for Engineering Design in Wood. Using CLT and other mass-timber construction techniques, tall timber buildings could be economically feasible.

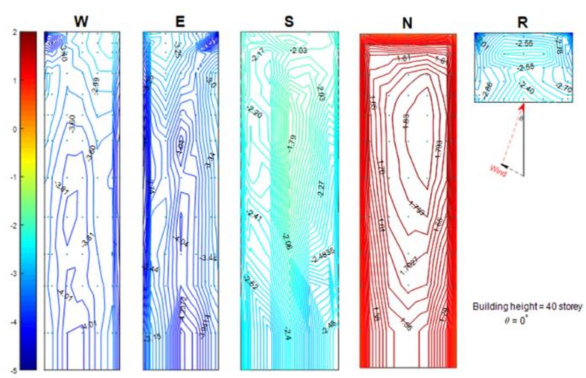
In general, mass-timber buildings are lightweight and slightly more flexible than buildings made from conventional construction materials. While their flexibility helps them to resist strong earthquakes, it limits their lateral stiffness, thus making them vulnerable to high along- and across-wind loads. Recent studies indicate the socio-economic consequences related to the inadequate serviceability of tall buildings. Moreover, frequent exposure to excessive building vibrations can cause serious physiological problems and discomfort to occupants. Major international building codes and standards use the floor acceleration demand as a reliable indicator of the wind induced human discomfort. In the following, the aerodynamic database development effort to calculate the serviceability risk of tall mass timber buildings is presented.

High frequency pressure integration wind tunnel tests were carried out to evaluate the top floor acceleration demands of 10-, 15-, 20-, 30-, and 40-storey mass-timber buildings with a typical rectangular floor plan that has an aspect ratio of 1:1.5. Pressure readings were taken using simultaneous multi-pressure sensing systems using 495 distributed taps on a large model (1:200 scale). This was possible due to a large test section of the newly constructed WindEEE Dome at University of Western Ontario.

Following the test, signal processing and statistical data analysis were performed to interpret the obtained results. Mean and root mean square maps of pressure coefficient were developed for all building models. Probability distribution plots of the pressure signals show the non-Gaussianity of the pressure field in the vortex shedding and wake regions. To support the finding, kurtosis and skewness contour maps were also produced. Moreover, to study the local load correlations, cross-covariance and auto-covariance matrices were computed from the pressure coefficient time series. The non-Gaussian peak pressure coefficients were evaluated using a standard signal translation process. Both Gamma and Normal probability distribution types were used as a parent probability distribution of the measured pressure signals. Extreme value I (Gumbel) distribution was used to characterize the probability of the peaks. The obtained pressure coefficients from this research can be used for quantify the serviceability risk of tall mass timber buildings. Moreover, future extensions of this research aim to quantify the wind induced losses due to cladding failure.



(a)



(b)

Contour plots of pressure coefficient for 40 storey building under 0° wind angle of attack; a) mean b) peak

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Numerical study of forced convective heat transfer coefficients on the façade of low- and high-rise buildings

Optimal fenestration configuration is one of the most important passive strategies or saving energy in buildings, and it has to be optimized for more than one objective due to its influence on heating, cooling, and daylighting performances. This is particularly for high-rise buildings having a large window-to-wall ratio. Previous studies have shown that fenestrations are configured mainly by their aesthetic value, however, local Convective Heat Transfer Coefficient (CHTC) distribution over the facade of a buildings are vary as a function of building height. In this study, it is observed that as height increases from 10m to 100m, the surface average-CHTC on the windward façade increases by about 55%.

This study is intended to investigate on high-resolution average-CHTC distribution over the surface of a high-rise building and to provide detail information on analyzing of overall heat transfer coefficient (U-value) of glazing and fenestration configurations. In the next step, fenestration configuration optimization for better thermal comfort and energy saving will be investigated.

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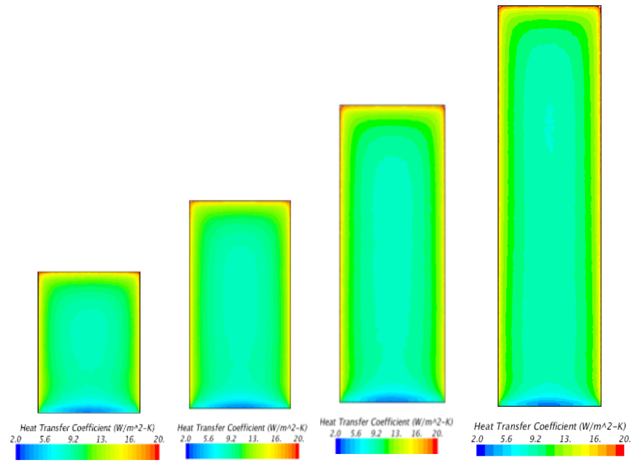
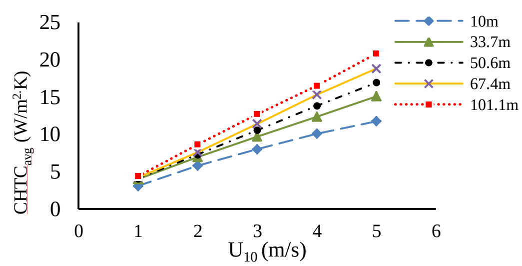
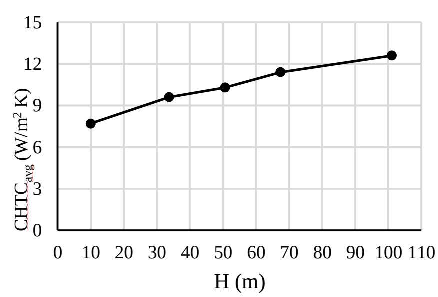


Windward CHTC distribution at a wind speed of 3m/s for a height of: a) 33.7 m, b) 50.6 m, c) 67.4 m, and d) 101.1m



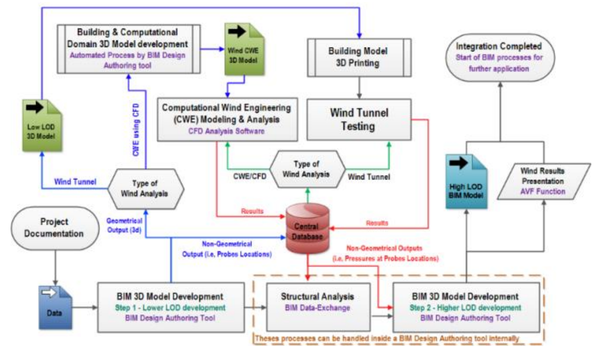
Surface average CHTC correlation as a function of U_{10}



Surface average CHTC as a function of building height.

Automated BIM process for wind design collaboration: A pre-engineered building example

Building Information Modeling (BIM) is a collaborative design process. In this study, an integrated BIM structural design environment for wind has been developed. A pre-engineered building case is considered. BIM integrated system which can collaborate with computational fluid dynamics (CFD) simulation or wind tunnel experiments using a central database is developed. The 3D model of the building and the computational domain has been seamlessly exported to CFD environment, and results from CFD passed to the BIM environment for structural design.



Detailed process-map/workflow defining the 3D models/data exchange strategies and the application of the "central database" in BIM and Wind Engineering integration (For both Wind Tunnel and CFD based approaches)

A BIM-based application program interface (API) and a stand-alone software were developed to evaluate the proposed system and its feasibility. The results suggest a successful integration which could significantly reduce the cost of the design by cutting down the geometric modeling time during wind evaluation process, and the design efficiency by facilitating the engineering collaboration during different design phases.

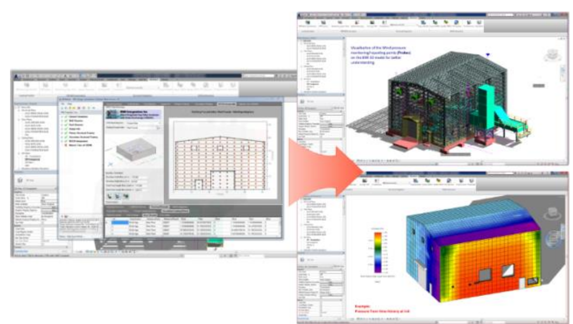


Illustration of the BIM-based API interface and its processes in Wind Engineering Collaboration. (The system was evaluated using an example PEB project).

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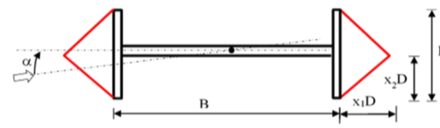
Computational aerodynamic shape optimization of long-span bridge decks – a numerical search for optimal fairing shape

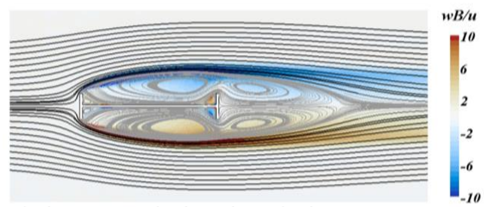
In the wake of Tacoma Narrows Bridge failure, considerable great advancements have been achieved in enhancing the aerodynamic performance of long-span bridges through deck shape modifications. Shape modifications to existing long-span bridges as in the case of White Bronx Bridge or development of aerodynamically efficient bridges as in the case of the proposed Messina Straight Bridge have been mostly carried out through the traditional experimental based "cut and try" procedure (King et al. 2000, Larsen et al. 2012 Diana et al 2002). This procedure is believed to be both time consuming and costly as compared to computational tools. For example, to improve the critical flutter wind speed of Nanjing 4th Bridge of China from 45m/s to the design speed limit of 60.8m/s, more than 60 shape modification cases were tested using 1:50 scale section models (Wang et al. 2011). For identifying the best aerodynamic retrofitting option for Bronx-Whitestone Bridge, 45 shape modification cases were tested at BLWTL, UWO (King et al. 2004).

Though the identification of aerodynamic mitigation measures in wind engineering applications has been guided by the series of wind tunnel tests, computational tools have been applied effectively to design optimum aerodynamic shapes in aeronautical and automobile industries. However, a framework for applying such tools for long-span bridges needs to be developed and to be tested for practical implementation. We developed a computational aerodynamic shape optimization (CASO) framework which involves a coupled use of computational fluid dynamics (CFD) and numerical optimization routines. The framework is applied for aerodynamic fairing design of a typical plate-girder stiffened deck with the objective of reducing the lateral wind load and improving its aerodynamic stability under smooth flow.

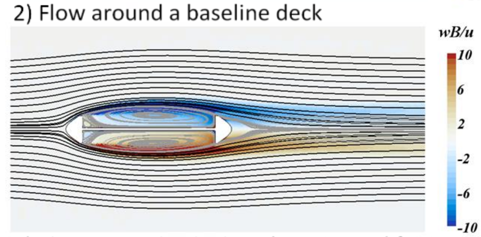
Typical results from the optimization process are presented in the figure. The Figure shows the parametric definition of the triangular fairing; the flow structure around the bassline deck and modified deck with optimal fairing shape; and aerodynamic force coefficients. The CFD simulation was carried out using two-dimensional steady *SST* turbulence model and a static section model of a generic plate girder deck that mimics the shape of the First Tacoma Narrows Bridge deck having breadth-to-depth ratio of 5. The optimization is carried out with the objective of minimizing the drag coefficient under a constraint function defined by setting the pitch-slope to 0.5. While the bassline deck (x_1 = 0 & x_2 = 0.5) has wider wake, higher drag, and a negative pitch and lift slopes; the deck with the optimized fairing shape (x_1 = 0.6 & x_2 = 0.5) has a narrow wake, a reduced drag and a mild positive pitch and lift slopes. It is also found that while an elongated sharper fairing (x_1 = 1 & x_2 = 0.5) leads to reduced drag, imposition of flutter stability constraint produces shorter fairing (x_1 = 0.6 & x_2 = 0.5).



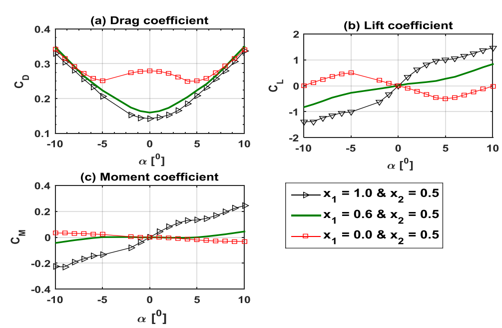
1) Parametric definition of fairing shape



2) Flow around a baseline deck



3) Flow around a deck with optimized fairing



4) Aerodynamic force coefficients

Improving the aerodynamic performance plate-girder stiffened bridge deck using optimized fairing shape.

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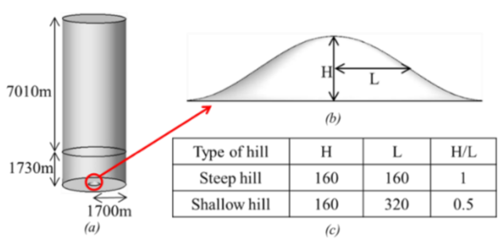
Numerical modeling of tornadic flow structure and its interaction with topography and buildings

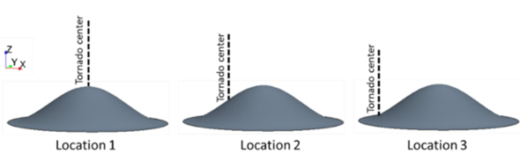
Tornado has a very complex flow structure; especially near the ground where most of the engineering structures are present. Laboratory and numerical studies have been used in the past to analyze the impact of tornadic flow-structure. Field studies are limited due to the difficulty of gathering actual tornado data. Although some efforts have been made to gather data from actual tornadoes, still the field data are not sufficient enough to analyze the flow structure completely. Here, numerical simulations are carried out to assess the effects of topography on tornado and simulate the interactions with porous bluff bodies.

Topography effect: The effect of the presence of small sizes hills (steep and shallow) over tornado flow structure has been simulated for three different locations of tornado with respect to the crest of the hill.



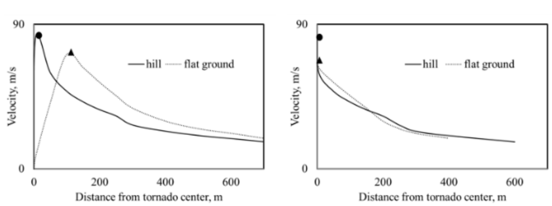
Type of hill	H	L	H/L
Steep hill	160	160	1
Shallow hill	160	320	0.5

Dimensions for Numerical model



Location	Tornado center
1	At hill crest
2	At half-height of the hill
3	At foot of the hill

Location of tornado center

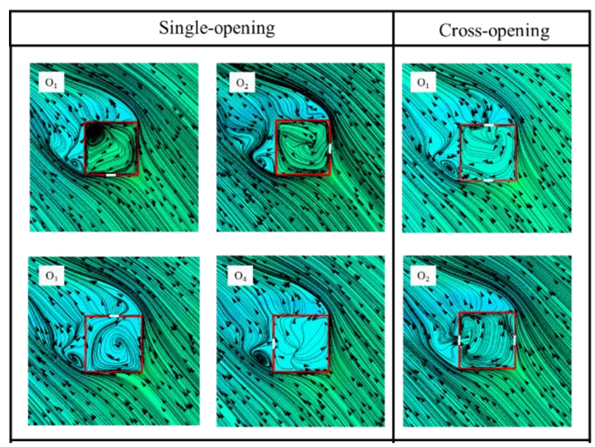


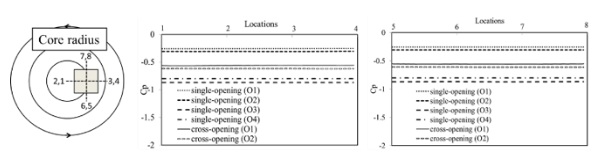
Velocity field distribution with and without the presence of the hill.

Fractional Speed-up Ratios were obtained for both steep and shallow hill types. New ways of obtaining FSUR calculations has been developed that is commensurate with the complexity of tornadic flows. This includes shifting of peaks and providing FSUR for regions as opposed to point on space.

Porous bluff body: The impact of tornadic load over short building with single and cross openings for three different locations has been investigate. It was obtained that, although the overall pressure inside the building is dominated by the ground suction, the location where building is located at the core radius shows variation in internal pressure with respect to the location and number of openings.

At core radius location, suction inside the building is maximum for single opening on the leeward side of the wall and minimum for opening on the windward wall. For cross-opening case, internal suction falls within the maximum and minimum values observed in the earlier cases.





Internal Cp distribution

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Behavior of Pre-stressed Concrete Poles under High Intensity Wind

Transmission line structures play a great role in electrical energy transmission. The major components of a transmission line are conductors, ground wires, insulator strings and supporting towers. Pre-stressed concrete transmission poles are becoming widely used due to low installation and maintenance costs, appropriate delivery time and corrosion resistivity. The pre-stressed concrete poles are mainly subjected to dynamic normal (synoptic) and high intensity wind loading (downbursts and tornadoes), ice loads and maintenance loads. The behavior of this type of poles under local high intensity wind -such as tornadoes and downbursts- has not been studied before despite the fact that significant failures have occurred for this type of poles under severe localized wind events.

This research is considered as part of a large scale research program that has been conducted by a number of investigators at Western University during the last decade.

A numerical technique which accounts for material and geometrical nonlinear behavior due to the stress strain relationship of reinforced concrete, pre-stressing strands and time dependent changes that occur in the pre-stressed concrete, such as: shrinkage, creep and relaxation of strands is developed and validated. The non-linear behavior of the conductors under high intensity wind loading is included in this simulation using a closed form technique previously developed at Western University. The high intensity wind forces induced from the tornado and downburst events acting on the concrete poles and the conductors are calculated based on previously conducted computation fluid dynamics.

The behavior of the poles under the effect of various probable tornado and downburst events is examined using the developed numerical model. The tornado and downburst locations and configurations leading to maximum straining actions and deformations in the poles are identified through an extensive parametric study. Provisions for the design of concrete poles always recommend that the poles remain un-cracked throughout under synoptic wind loading. However, existing poles are found to be subjected to plastic deformations, cracks and even failures when subjected to the critical tornado and downburst configurations.

It is concluded that the existing design procedures and practices for the pre-stressed concrete poles are inadequate to keep the pre-stressed concrete transmission pole structures un-cracked while being subjected to those local high intensity wind events.

Prestressed concrete transmission pole.

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Multiple Span Aero-elastic Transmission Line Subjected to Downburst Wind

Despite the fact that downbursts are responsible for more than 80% of the weather-related failures of transmission lines, most design guidelines do not provide enough details about the analyses of transmission lines under downbursts including their dynamic behaviour. An aero-elastic model, shown in Figure 1, is designed and tested at the WindEEE dome, which is a one-of-a-kind three-dimensional wind-testing chamber. The downburst wind field simulated at the WindEEE is characterized. A number of test configurations have been used to assess the dynamic response of the line of the current study. The tests are also carried out at various wind speeds to assess the effect of the aerodynamic damping of the conductors on the dynamic response of the line. A decomposition approach is developed in order to differentiate between the resonance and the background components of the structural response. Hence, the contribution of the measured resonance to the peak responses is evaluated. The results show that the resonance contribution represented by DAF factor shown in Figure 2 ranges between 10% and 15% of the peak response for the tower sections regardless of the wind speed. On the other hand, the contribution of the conductor-induced forces is responsible for more significant dynamic effect, which can reach up to 30% at low speeds and up to 15% of the peak response in high speeds. To the best of the authors' knowledge, this study represents the first aero-elastic multi-spanned transmission line to be tested under downburst-induced loads.

Figure 1 Multi-spanned aero-elastic model of a transmission line structure

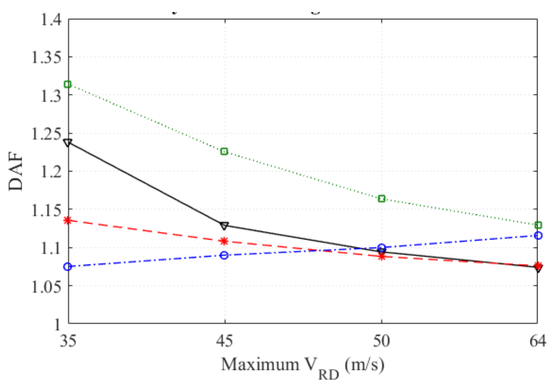

Figure 2 Built in-house Finite Element Model validation using the test results

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Destructive Testing and Validation of a Model LFWS and Roof Harness Subject to Wind Load

Load paths in light-frame wood structures (LFWSs) are historically nailed connections between the sheathing and rafters, and toenail connections between the rafters and stud walls. However, these connections have poor resistance to uplifting forces, as occurs in high wind speed events, causing sheathing or roof-to-wall-connection (RTWC) failures. The improvements made to building codes after Hurricane Andrew affected only new construction, and the economic losses caused by roof failures in homes built prior to 1992 from Hurricane Katrina pointed to a need to retrofit older structures.

The roof harness is one such retrofitting option that involves a temporary net of cabling that is placed over the roof and secured to piles around the structure in advance of a high wind speed event. It improves LFWS performance by increasing the mean wind speed at which cladding damage, RTWC separation and ultimate failure occur, and by preventing total loss of roof.

The roof harness design proposed by Jacklin and El Damatty (2013) is the subject of this study. The efficacy of this design is measured as improvement in RTWC performance, as it is the most critical failure precipitating total roof loss. Improvement is comparatively measured, where an unretrofitted model LFWS is first subjected to increasing wind load until RTWC failure, after which an identical model LFWS with the retrofit is similarly tested.

The tests were conducted on the outdoor platform of the WindEEE dome to mitigate the risk of damage during the destructive tests. This was achieved by exhausting the flow through the dome in an open circuit configuration. A three dimensional contraction was developed to increase the available incident wind velocity to a maximum of approximately 40 m/s uniformly over the 2 m high by 6 m wide wind field.

To meet various geometric and RTWC uplift constraints, the LFWS model produced was a 1:3 scale adaptation of the simple gable roof structure tested in the Three Little Pigs experiment (Morrison and Kopp, 2011). Changes made to the model included reducing the roof slope to 3:12 to improve flow separation, reducing the number of trusses from 16 to 4 to induce greater RTWC uplift, and simulating the end gable trusses as interior trusses to prevent load unrealistic load distribution.

To achieve realistic structural behaviour, the roof truss member cross-sections and sheathing thickness were selected to reach stresses at failure similar to the corresponding components of a full scale structure at failure. Further, 2D common nails were used as toenails in the RTWCs to provide a reduced ultimate withdrawal capacity while retaining the nonlinear behavior of the full scale toenail connection.

Significant improvement in RTWC performance was observed, delaying the onset of initial RTWC failure from $\boldsymbol{v} = 20$ m/s to $\boldsymbol{v} = \mathbf{32}$ m/s, and preventing total roof failure at sustained maximum velocity. Further, good agreement was observed between experimental results the results predicted through FEA exercises, which were improved through post-failure analysis of RTWC failure modes.

Windward face of the reduced scale retrofitted test specimen on the exterior platform of the WindEEE Dome

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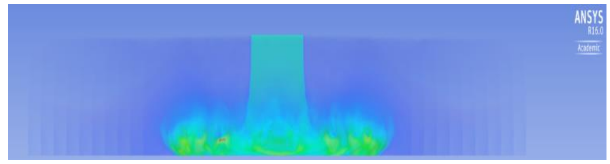
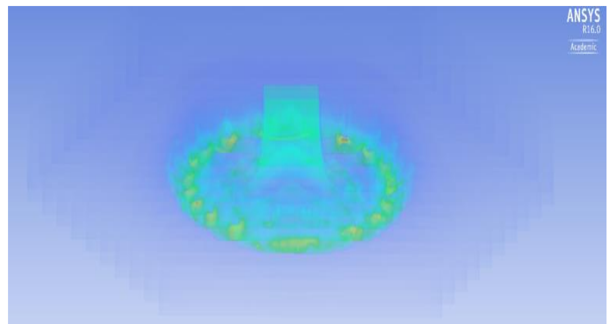
Downburst Mitigation Through CFD and Structural Analyses of Electrical Transmission Systems



Elevation view of velocity contour for a downburst



Isometric view of velocity contour for a downburst

Being one of the few territories worldwide that experience severe thunderstorms, Canada suffered the consequences of numerous HIW (high intensity wind) events through the past decades. Among those, power outages and their complications stood out as a major symptom that needed the expertise of researchers to help their partners in the industry.

The University of Western Ontario has been a key participant in the efforts of mitigating the structural hazards associated with HIW events. The research teams lead by some of the world’s most established scientists, and built of innovative young researchers, broke ground years ago with their research, providing better understanding of the phenomenon, along with creative solutions that were implemented by both the industry and building codes committees in and outside of Canada.

Coherently, the WINDEEE dome is a clear demonstration of the cutting-edge facilities that researchers in Western University utilize towards refined visualization, and thus understanding of phenomena like downbursts. The experimental path paves the way for numerical approaches like CFD (computational fluid dynamics) to yield accurate predictions of wind fields associated with downburst events.

Finally, a representing wind field is then applied, under various conditions and circumstances, to investigate the behavior of transmission systems under such conditions. The introduction of validated numerical simulation’s output certainly adds more variables that can be investigated, aiming towards sustainable structures that can withstand such events during its lifetime.

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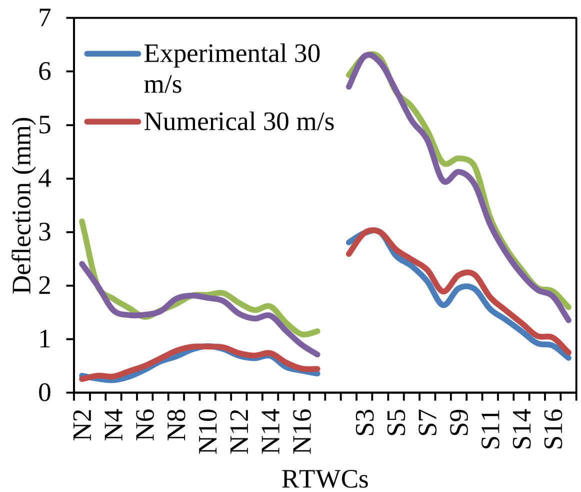
Nonlinear Modeling of Light-Frame House under Uplift Wind Load

Light-frame wood structures have the ability to carry gravity loads. However, their performance during severe wind storms has indicated weakness with respect to resisting uplift wind loads exerted on the roofs of residential houses. A common failure mode observed during almost all main hurricane events initiates at the roof-to-wall connections (RTWCs). The toe-nail connections typically used at these locations have weak withdrawal capacity with regard to resisting uplift loading. The withdrawal capacity of RTWCs is dependent on the properties of the wood, such as water content, specific gravity, and penetration depth of the nails. As a result, some connections are characterized by a higher degree of stiffness than others, and a stiffer connection can absorb a greater load.

When a weak connection fails, the extra load is transferred to the adjacent connections, leading to increased demand on the connections that have not failed. The consequence of increases in the applied uplift load is that the remaining connections become unable to sustain that uplift load, resulting in additional connection failures. This issue has been investigated at the Insurance Research Lab for Better Homes located at the University of Western Ontario, where full-scale testing was conducted of a house under appropriate simulated uplift wind loads.

The goal of this research was to develop detailed and sophisticated finite element simulation performed for this full-scale test, following which the numerical predictions were compared with the experimental results. The comparison was performed regarding the deflections at RTWCs as shown in the next figure.

The next step of the research is to provide an effective solution for existing light-frame wood houses located within hurricane regions through the utilization of retrofit systems, such as the installation of steel net wires on roofs, which is considerably less expensive than strengthening existing connections with strong hurricane straps, the installation of which requires the removal of nonstructural elements. Based on the findings of this research, a library of suitable retrofit systems will be suggested for a variety of wood-frame architectures.



Experimental and numerical deflection values for all RTWCs on the north and south sides under the maximum global uplift

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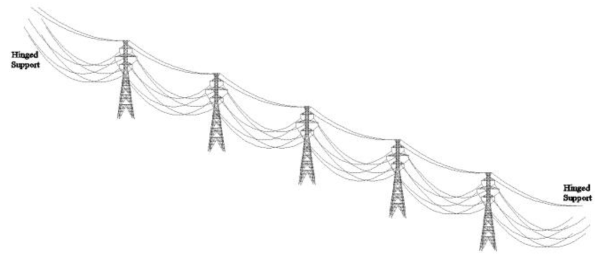
Transmission Lines Behaviour under Tornadoes Wind Loads

Electrical energy plays a vital role in many aspects of daily life. United States and Canada are active zones for tornadoes with approximately 800 to 1,000 tornadoes per year (ASCE 2010). Severe wind events in the form of downbursts and tornadoes are referred to as High Intensity Winds (HIW). Such events are responsible for more than 80% of all weather-related transmission line failures worldwide



Schematic layout of the transmission line system model.

Despite this fact, the current codes of practice for transmission line structures do not account for wind loads resulting from tornadoes events. In these codes, the specified design wind loads are based on large scale storms with conventional boundary layer wind profile, which is different than the tornado profile{{}}. The forces acting on the structure depend on the location of the storm relative to the structure. Therefore, it is important to identify the tornado and downburst locations that lead to the maximum structural responses. This is challenging for transmission lines, where the wind forces resulting from tornadoes vary along the span of the lengthy conductors and along the height of the towers. Thus, self-supported and guyed aero-elastic tower models will be tested under a simulation of the tornadoes wind in WINDEEE to understand the behavior of both transmission lines systems under the complex wind profiles of the tornadoes. Finally, the behavior of angle and end lattice transmission towers will be assessed under tornado wind loads. The research proposed in this study will build on the findings, developments and experience gained during the previous research program. The objective is to develop guidelines for designing transmission line structures to resist HIW events and to use these findings in codes of practice.

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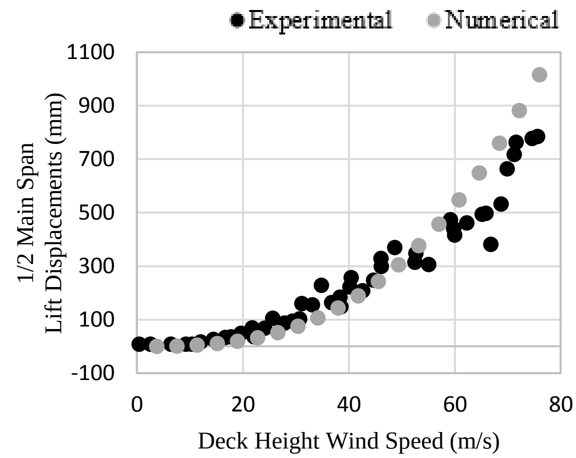
Optimization of Cable-Stayed Bridges Considering the Wind Action

Cable-stayed bridges are an economical option for the range of medium to long-span bridges. Compared to the suspension bridges, the cable-stayed bridges are stiffer, require less material and are easier to construct due to the balanced cantilever method. Besides, the different options of deck cross sections, tower types and cable arrangements leads to a wide assortment of design considerations [2].

Due to their complexity, many studies were previously carried out to optimize the geometry and the pretension forces of cable-stayed bridges considering the action of the dead loads. Although, long-span cable-stayed bridge deck design is frequently controlled by aerodynamic analysis because of their light weight and high flexibility. Moreover, once the bridge is considered stable, buffeting effects evaluation is needed because its response provides the envelopes of internal forces, and consequently the size of the structural members [1].

Considering all that, equivalent static forces were applied to the numerical design tool to take into account the action of the turbulent wind flow. The validation was made by comparing two different approaches. The first approach was based on a sectional model test, that provides the aerodynamic coefficients, the equivalent static forces due to the buffeting loads, and a finite element model. The second approach was only based on a full aeroelastic model test. The sectional model and the full aeroelastic model, were tested at the Boundary Layer Wind Tunnel Laboratory at University of Western Ontario. Displacements of both approaches were compared enabling the validation of the equivalent static forces due to the turbulent wind flow, as shown in the figure below.

The next stage consists in the optimization of cable-stayed bridges considering the wind action. Parameters such as number and diameter of the stay-cables, main span length, height of the pylons, and the dimensions of the deck cross section will be optimized.



Comparison between numerical (1st approach) and experimental (2nd approach) lift displacements on the deck.

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[1] Davenport, A. G. 1966. The action of wind on suspension bridges. Keynote Paper, Intl. Symp. Suspension Bridges.

[2] Troitsky, M.S. (1988). Cable-Stayed Bridges: Theory and Design, 2nd Edition, BSP, Oxford.

Strength and Stiffness Degradation of Structural Components Subjected to Large Number of Loading Cycles

Non-linear design of building is becoming the benchmark approach for the design of modern structures. In structures subjected to seismic loads, inelastic behavior is allowed by different codes for a safe and more economic design. On the other hand, buildings subjected to wind loads which induce a large number of loading cycles are usually designed considering elastic analysis and equivalent static lateral loads. Generally, there is no established framework for consideration of inelastic response of buildings under such loads. However, the concept of allowing a controlled inelastic response can be particularly beneficial if it is applied to the analysis and design of tall, slender buildings subject to wind loads.

This study focuses on the inelastic behavior of structural components of tall buildings subjected to cycling loading. Modeling and experimental testing will be performed on ductile reinforced concrete shear walls in order to study the degradation in strength and stiffness under large number of loading cycles. This research can be a first step towards a realistic and reliable evaluation of non-linear behavior of structures subjected to wind loads.

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Structural behavior of lightweight wood buildings under lateral loads

The 2015 edition of the National Building Code of Canada has recently allowed the construction of multi-storey buildings using structural systems made entirely from wood without imposing limits on the number of stories. The use of wood in construction has the advantage of reducing greenhouse gas emissions and the carbon prints of structures. In addition, wood frame construction has the advantage of being usually less expensive than concrete or steel, which would allow the expansion of the supplication of mid-rise building development.

While, the construction of wood buildings is spreading, there is a significant lack in the scientific knowledge about the behaviour of those structures, especially under strong wind storms and earthquake excitations. In addition, there is no computer tools currently existing in the market, not only in Canada but worldwide, that can perform proper three-dimensional finite element analysis and design of wood buildings under the lateral loads resulting from wind storms and earthquake excitations.

The objective of this research program is develop a numerical tool that can perform this task and to use it to understand and quantify the behaviour of multi-storey wood buildings under seismic and wind loads.

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Progressive collapse of transmission towers along a line subjected to downbursts.

Most of transmission line structures failures during natural disaster events are due to localized high intensity wind (HIW) loads associated with downbursts. Research related to high intensity wind loads and their effects on structures in general is very limited and on transmission line structures in particular is rare. Previous failure investigations were limited to individual towers and on stationary HIW.

However, an incremental progressive failure analysis must be considered since failures of transmission lines occur in the form of a cascade failure progressing from one tower to another. Therefore, there is a pressing need to develop a nonlinear finite element model for predicting the progressive failures of transmission towers along a line subjected to downbursts.

Some of the key features in the model:

- Incorporating the downbursts translation motion and modifying the load instantly on different towers depending on their locations to the downburst center.
- Predicting nonlinear effects resulting from steel yielding, buckling as well as connection failures.
- Conductor's behavior during the initiation of a tower's collapse and the effects on the adjacent towers.

In the next step, a unique model will be tested at WindEEE for the validation of the progressive failure model in order to understand the failure mechanism of the entire line.

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Progressive failure of Transmission lines occurred in South Australia during Sept 2016 Thunderstorms.

Development of Three-Dimensional Modelling Technique for Mid-Rise Wood Buildings

Light-weight wood framed construction has gained significant popularity over the past decade as a sustainable, cost-effective solution for low-rise multi-residential buildings. Recently, the wood construction trend is moving towards extending the use of light wood framing to mid-rise construction. In 2009, British Columbia amended their building code to allow five and six story residential wood-framed buildings, and in early 2014 the Province of Ontario passed legislation to permit wood-framed buildings up to six stories.

A five stories wood-frame building in British Columbia.

The numerical modeling of the structure behavior of light frame wood buildings (LFWB) is complicated as each component of the LWFB (either walls or floors) consists of multiple elements that are connected using mechanical fasteners (usually nails). The behavior of the wood and nails are both nonlinear, which complicates the numerical modelling.

The main objective of the current research is to develop equivalent structural elements that are capable to simulate the complex behavior of the walls and floors of light frame wood buildings. Those equivalent elements can be incorporated into a commercial finite element package to perform structural analysis of LFWB.

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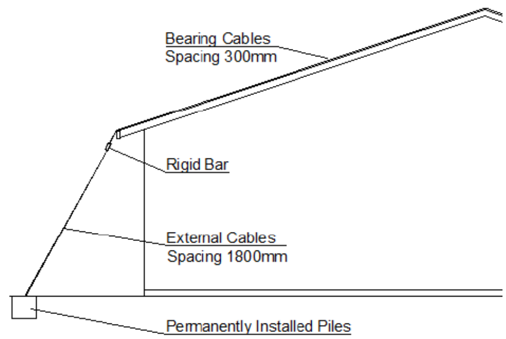
Optimization of Retrofit System for Light-Framed Wood Structures under Wind Loadings

Light-framed wood houses are commonly used in North America due to the availability of materials as well as ease of construction. Previous wind events caused catastrophic human and economic losses. For instance, the economic losses by Hurricane Andrew in 1992 were estimated by (HUD, 1993) to be US$20-25 billion, with approximately 95% of those losses resulting from the failure of light-framed wood structures (Baskaran and Dutt, 1997).

A retrofit system was developed by (Jacklin and El Damatty, 2012) to increase the uplift capacity of light-framed wood structures under wind loadings. This system consists of a set of bearing and external cables as well as rigid bars. The system provides the uplift forces an alternate load path and reduce the applied forces on the nailed roof-to-wall connections.

In the next step, the retrofit system will be optimized to determine the cables cross sections, spacing, and arrangements as well as the rigid bars sections corresponding to the most economical solution. A genetic algorithm will be implemented in a finite element model that utilizes a three-dimensional frame element. The study will be extended to develop design guidelines of the retrofit system for different light-framed structures with a wide range of practical dimensions.



Elevation view of retrofit system as applied to a light-framed wooden house.

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Non-Linear Analysis for High-rise Buildings subjected to wind loads

Buildings subjected to wind forces are designed using elastic analysis and equivalent static loads. In the traditional design strategies, the inelastic behavior of members wasn't considered. However, the implementation of a performance-based approach can be very beneficial, where inelastic behavior of members and dynamic effects of the natural hazards are taken into consideration.

In traditional procedures for design of buildings for wind loads, the response of a building was considered only in the elastic stage in members of its lateral load resisting system under strength level load combinations in ASCE 7. It hasn't been considered before to push the limit to the inelastic range of members as there is no established framework for inelastic behavior of the building under wind loads. On the other hand, when designing buildings for seismic, the inelastic deformations and ductility of members are taken into account aiming for a more economic design without jeopardizing the safety of members. This concept can be extended also to wind engineering, especially in tall buildings (taller than 400 feet) where wind loads are governing rather than seismic loads.

One motivation for a nonlinear wind analysis is that the prescribed code method for wind design may result in overly conservative design. An additional motivation for a nonlinear analysis is to determine collapse capacity of buildings by exploring how the members in the lateral load resisting system of a tall building will behave nonlinearly

In the next step, the effect of reduction of the resonant component of wind loads on the response and natural frequency of tall buildings will be investigated, which will yield reduced cross-sections for critical elements in the lateral load resisting system. Furthermore, a non-linear dynamic analysis for the reduced-cross sections will be conducted to assess the ductility demand of members.

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Simultaneous Failure of Transmission Towers Subjected to Tornadoes

High wind intensity events including tornados are strong three-dimensional flow fields which may cause significant damages on the structures. Wind resistant design of structures requires proper consideration of tornado-induced wind loads, which need detailed information of the three-dimensional flow field of a tornado [1]. Many researchers have performed the experimental and numerical simulations to obtain the detailed information of the flow field. Flow fields of tornado-like vortices generated by a numerical tornado simulator have been investigated using the LES turbulence model.

Numerical models that can combine the data of computational fluid dynamic (CFD) simulations of tornado wind fields with three-dimensional nonlinear structural analysis modelling is developed.

To consider simultaneous failure effects of transmission towers, first, the failure analysis of only one transmission tower and then a sophisticated model of three transmission towers system are designed and developed. In order to consider the effect of tornado loads acting on conductors and for taking into account the flexibility of the supporting towers and insulators, the support provided to the conductors through the towers and the insulators is modelled using a three-dimensional nonlinear spring system with stiffness dependent on the rotation experienced by the insulators [2].

Eventually, the structural behaviour of transmission line systems subjected to tornado loading considering the effect of simultaneous failure of towers is investigated.

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Strength and Stiffness Degradation of Structural Components Subjected to Large Number of Loading Cycles

Non-linear design of building is becoming the benchmark approach for the design of modern structures. In structures subjected to seismic loads, inelastic behavior is allowed by different codes for a safe and more economic design. On the other hand, buildings subjected to wind loads which induce a large number of loading cycles are usually designed considering elastic analysis and equivalent static lateral loads.

Generally, there is no established framework for consideration of inelastic response of buildings under such loads. However, the concept of allowing a controlled inelastic response can be particularly beneficial if it is applied to the analysis and design of tall, slender buildings subject to wind loads. This study focuses on the inelastic behavior of structural components of tall buildings subjected to cycling loading. Modeling and experimental testing will be performed on ductile reinforced concrete shear walls in order to study the degradation in strength and stiffness under large number of loading cycles.

This research can be a first step towards a realistic and reliable evaluation of non-linear behavior of structures subjected to wind loads.

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Developing Uncertainty: Renewable energy policy and Wind generation in Ontario.

As global environmental priorities have shifted towards finding more sustainable ways to produce energy, there has been a rise in the focus on renewable technologies. The Ontario government first publically announced renewable power targets in 2003, and began its first renewable energy supply program in 2004. In 2009 the Government of Ontario enacted the Green Energy and Green Economy Act (GEA), which centralized renewable energy project approvals processes in the provincial government while restricting the powers of municipalities – in order to promote more and faster development. This included streamlining project construction and application processes, establishing a feed-in-tariff (FIT) program with guaranteed prices under long-term contracts, and creating a Renewable Energy Approval (REA) process that exempted some projects from requirements for approval under existing legislation. Together these measures were intended to incentivize the development of renewable energy technologies, create new jobs, and attract private investment. In the intervening years, interest in renewable electricity generation capacity and the importance of wind power both for electricity generation and in public debate has grown dramatically in Ontario. Since the first announcement of renewable power targets in 2003, electricity generated by wind power has grown in Ontario from essentially zero to 6% of total electricity production and 10% of installed energy capacity in 2015.

This research project assesses whether the 2009 GEA had a measurable impact on the duration and outcomes of regulatory approval and project development processes. In an effort to quantify these and other effects of renewable energy policies and rapid wind generation growth, the Ivey Energy Policy and Management Centre has undertaken a comprehensive data collection project with the goal of capturing project development information for each of 198 proposed, operating, withdrawn, or cancelled onshore, commercial wind power projects in Ontario. The first report summarizes the main insights that emerge from the construction of a database following all such identifiable projects through the regulatory process, construction, and operation and including related media coverage and legal proceedings. The resulting database is unique and can be used for a variety of policy, project financing, and project feasibility studies.

Initial analysis indicates that the government's 2009 goal of streamlining the regulatory approval process for renewable energy generation projects did not translate into tangible gains in the rate or ease of developing wind generation capacity. For instance, comparisons of the duration of the regulatory process and the number of projects successfully reaching commercial operation after 2009 fail to show significant differences from the prior regulatory regime before 2009. Future research will provide a rich analysis of the patterns of wind farm development since 2003, and the impact of local community resistance on siting decisions and regulatory approvals.

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International Collaborations

Dynamics of tornado-like vortices: a collaboration between WindEEE and the WindFluX Lab at UT Dallas

The WindFluX Lab of the Mechanical Engineering Department at UT Dallas, directed by Dr. G. Valerio Iungo, has been working actively for the last five years in developing techniques for the detection, characterization and prediction of dynamics and instabilities of swirling flows. The research approach consists of using synergistically statistical, spatio-temporal, and modal decomposition techniques, together with linear stability analysis. These techniques are now available for investigations on morphology and dynamics of tornado-like vortices.

Since Fall 2015, a collaboration exists between WindEEE and UT Dallas, with the aim of investigating dynamics and instabilities of tornado-like vortices. Dr. Horia Hangan and Dr. G. Valerio Iungo co-advised the M.Sc. thesis of a UTD student in Mechanical Engineering, Ryan Ashton, who defended successfully his thesis in July 2016. That thesis focused on the correction of 2D Particle Image Velocimetry (PIV) measurements of a tornado-like vortex acquired at the down-scaled WindEEE dome facility from wandering smoothing effects. PIV measurements were performed along the axis of a tornado-like vortex and for different swirl ratios. It was observed that the tornado-like vortex undergoes significant oscillations from the time-averaged vortex location. This phenomenon is referred to as vortex wandering, and it occurs for swirling flows reproduced in down-scaled facilities. These vortex oscillations do not occur at full scale flow conditions; thus, wandering can compromise accuracy of the measurements by leading to smoothing effects of the peak velocities and to larger vortex dimensions than for the actual tornado. Therefore, procedures must be developed for correcting wandering effects on PIV measurements

For the M.Sc. thesis of Ryan Ashton, two different procedures were developed for the characterization of tornado wandering and correction of the velocity measurements. The first procedure is based on the re-centering of the PIV measurements as a function of the instantaneous vortex location, while the second procedure corrects wandering effects on the time-averaged velocity field through a statistical approach. Main results of this research will be included in a scientific publication, which is currently under preparation.

Other interesting physical mechanisms were also observed during that study, such as the one depicted in Figure 1. It has been observed that by increasing the tornado swirl ratio, the azimuthal velocity field transitions from a pure isotropic rotation to a spiral-like motion over horizontal planes. This is a consequence of the enhanced radial velocity generated for higher swirling ratios. The occurrence of this spiraling motion is clearly detectable through the maps of the horizontal shear stress reported in Figure 1. The consequences of the physical mechanism on the morphology and dynamics of the tornado-like vortex are not completely understood. Therefore, this topic will be the focus of future investigations.

The collaboration between WindEEE and UT Dallas has been strengthened by a bilateral Memorandum of Understanding between the two institutions, which is finalized to the cotutelle of two raduate students. This official collaboration will be the framework for continuous exchange of know-how between the University of Western Ontario and UT Dallas and a great opportunity for international exchanges among students of these two universities.

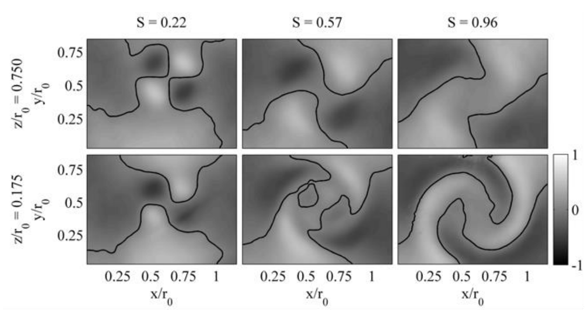

Figure 1: Horizontal shear stress estimated at different heights along the axis of the tornado-like vortex and different swirl ratios, *S*.

Dr. Hangan and Dr. Iungo are currently working on the preparation of a scientific proposal to be submitted to the US National Science Foundation. In case of a successful review, this project will provide the opportunity to fund two graduate students, who will work on numerical simulations and experiments of tornado-like vortices. The experiments will be carry out at the WindEEE dome facility.

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Modal representation of pressure in the tornado footprint

Tornadoes are complex atmospheric phenomena characterized by an intense vortex with vertical axis and a highly-correlated fennel-shaped flow field. It is the result of several fluid-dynamic mechanisms occurring within and in the neighborhood of the vortex, which reflect into a series of different time and space scales that are observed in the measured data.

The knowledge of the effects of tornadoes at the ground level has obviously the greatest importance in terms of life and property protection. This knowledge can be incremented through experimental investigations in which pressure and velocity fields are measured within specifically-designed facilities such as WindEEE.

The pressure field on the tornado footprint is the composition of a nearly time-invariant pressure distribution, whose shape and intensity is determined by the nature of the tornado, plus a time-fluctuating component. This latter component results from a number of different factors, including the velocity fluctuation within the vortex core, the wandering of the vortex tip, the interaction of the flow with the terrain and with the still air outside the vortex. The composition (and possible interaction) of these physical mechanisms reflects into very complicated pressure fields that make interpretation and modelling challenging tasks.

A long experience in aerodynamics teaches that the dominant features of complex flow fields can be often represented as a superposition of characteristic flow patterns referred to as coherent structures. Once the coherent structures are known, they can be used for interpretation purpose or to construct reduced-order models of the observed phenomenon to be used in digital simulation. The idea of coherent structure is intimately related to the concept of modal representation. According to these techniques, a flow quantity, e.g. the pressure p in a 2D domain parametrized through the coordinate (x, y) can be represented as:

$$p(x,y,t) \approx \sum_{k=1}^{n} \phi_k(x,y)\,\xi_k(t)$$

where the ϕ_k are functions called modes and interpreted as coherent structures, while ξ_k are the respective amplitude as function of the time t.

The first and most popular technique for the extraction of coherent structures is the Proper Orthogonal Decomposition (POD). It provides modes that are orthogonal with respect to the Euclidean product and coefficients that are mutually uncorrelated. Besides, POD is optimal in an energetic sense, i.e. among all the linear representations, it has the best possible velocity of convergence in terms of variance. The limitations of POD suggested the development and application of alternative techniques whose formulation was established in the context of the Blind Source Separation (BSS) problem. One of these techniques, the Independent Component Analysis (ICA), was successfully applied in bluff-body aerodynamics obtaining modal representations that are more physically-consistent than representations based on POD.

ICA uses a modal representation similar to POD, but its modes are non-orthogonal and its coefficients are not simply uncorrelated, but are as much statistical independent as possible. ICA modes are usually extracted after having applied some de-noising filter. A typical choice is to apply POD as a pre-conditioner for ICA. This treatment is also necessary since mode numbering in ICA is conventional and does not have any energetic nor importance meaning like in POD.

As a first attempt to derive modal representations of the pressure field in a tornado footprint, some pressure datasets acquired in WindEEE have been processed through POD and ICA. Figure 1 shows the ICA modes extracted from the subspace of the measurements defined through the first 6 POD modes. Modes 1 and 2 are axis-symmetric and may represent the pressure fluctuation within the core of the vortex. Modes 3 and 4 have a dipole shape, which probably represents the wandering of the tip vortex. Modes 5 and 6 have a spiral structure, which may represent the footprint of fluid-dynamic structures generated in the shear layers around the vortex. Non-symmetric modes appear in pairs due to the statistical symmetry of the flow.

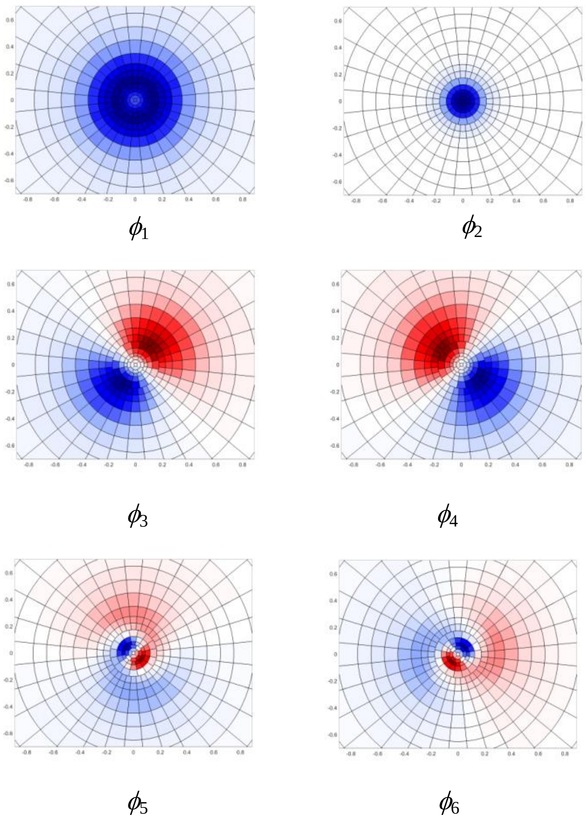

Figure 1. ICA modes extracted from a data subspace defined by the first 6 POD modes.

Figure 2 shows the Power Spectral Density function (PSD) and the coherence function of the ICA coefficients. It is worth noting that symmetric modes are characterized by low-frequency peaks. Dipole-type modes have peaks at about 1.3 Hz, and around this frequency, they are fully coherent and have phase angle equal to $\pi/2$. This means that these two modes represent a single traveling mode rotating at their peak frequency. Spiral-type modes have peaks about 2-2.5 Hz. In terms of amplitude, they are weaker that the dipole-type ones, but like these, they are well correlated and have a $\pi/2$ phase delay. Like for the previous case, they represent a traveling pressure structure.

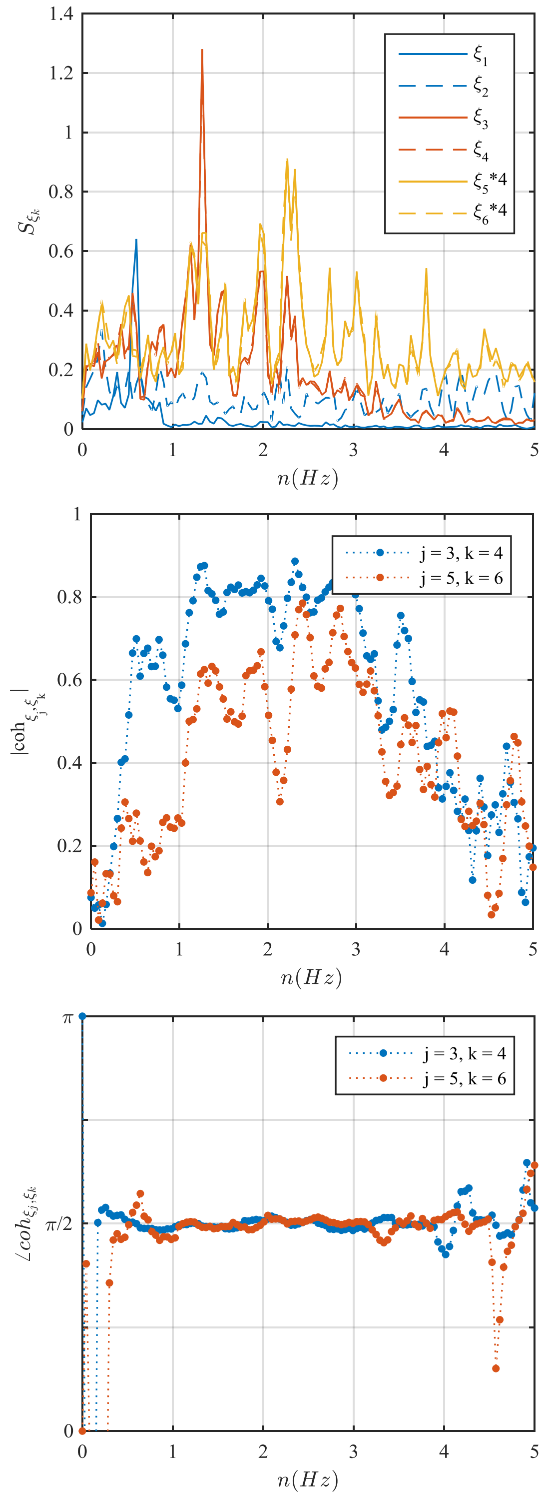

Figure 2. PSD and coherence of the coefficients in ICA representation.

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The Single-Tree Experiment Project (2016-2020)

The Single-Tree Experiment project is a collaboration between the Technical University of Denmark (DTU), Western University and INRA Bordeaux in France. The project brings together experimentalists and modelers as well as tree and wind experts.

One scientific motivation for the Single-Tree Experiment project is that trees are notoriously difficult to represent and model correctly due to their multi-scale nature. This makes their effect on the wind flow quite different than houses and other man-made structures. Furthermore, how to include the contribution of trees and smaller forests into state-of-the-art flow modeling tools is an unsolved problem in the fields of fluid dynamics and nearsurface meteorology. To properly understand and account for the effect the trees have on the wind - and the effect the wind has on the trees - also has a strong societal relevance. For example, a small to medium sized wind turbine will produce less downwind of small-scale tree configurations during storms, falling trees are both dangerous and cause economic losses for land-owners. Althought the project has the fundamental science in focus, the knowledge gained in the project will be directly made useful in wind models for wind energy and in forest management tools concerning wind risk.

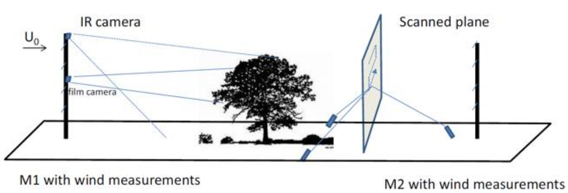

Figure 1. Sketch of single-tree full scale field experiment, which will also be performed in WindEEE using a smaller tree and different observational techniques.

The main experiments will be conducted at DTU (full-scale experiment around a solitary tree on campus, Figure 1) and Western Univeristy (scaled experiments in the WindEEE dome). The scaled experiments at UWO will also start with a single tree and then we will study different constellations of a few trees. In order to assess the wind measurements in relation to the tree structure, a detailed model of the investigated tree is needed. Figure 2 shows a model of an oak tree at the DTU campus, which is based on laser scanning point cloud data. This model will be used as input in wind models, where we will test different parameterizations for optimal modeling of the effect that the tree has on the wind.

Figure 2. Tree model based on an oak tree at DTU Campus.

The collaboration has started with on-line virtual meetings, with the focus of preparing the experiments and creating a common frame of reference by discussing relevant scientific literature together. DTU researchers will visit Western for the scaled experiments and vice versa. Apart from the experimental collaboration, DTU and Western are exploring the possibility of a joint PhD programme, which will allow for a longer-term scientific collaboration. A joint UWO-DTU PhD will spend at least one year at both universities and fulfill the criteria for the PhD degree at both universities. We hope to have the first joint UWO-DTU PhD student graduate within the Single-Tree Experiment project.

The Single-Tree Experiment is funded by the Danish research council for fundamental research and the funding for UWO in project covers the expenses for running the facility during the experiment, travels and the salary and benefits as well as the salary and costs for a joint PhD student.

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Terrain Experiment for Wind Energy in WindEEE

The cost of energy produced by onshore wind turbines is among the lowest forms of electricity generation; however, onshore wind turbines are often positioned in a complex terrain where the wind resources and wind conditions are quite uncertain, because of the surrounding topography or vegetation. In this study, we use a scaled terrain model in WindEEE to show how minor changes in the terrain can result in significant differences in the flow at turbine height. These differences affect not only the power performance but also the life-time and maintenance costs of wind turbines, and hence, the economy and feasibility of wind turbine projects.

The scaled model of an escarpment called the Bolund peninsula shows that the mean wind, wind shear and turbulence level are extremely sensitive to the exact details of the terrain. A modification of the escarpment of the Bolund model to give a sharper edge has dramatic consequences for a wind turbine positioned close to the edge.

The energy production is much less in the sharp edge case than in the round-edge case, while the turbulence level is increased by a factor of five. Our findings imply that detailed full-scale measurements are very important and that physical modeling can be an important tool for quantifying terrain effects.

In order to investigate the WindEEE modeling of Bolund in more detail, Reynolds number, inflow shear and turbulence, and upstream roughness was changed. Mean flow behavior was generally not affected by Reynolds number, but a slight increase in speed-up over the island was observed for cases with lower upstream roughness.

Trees constitute a fundamental part of our landscape but the understanding of how they affect the wind field in the lower part of the atmosphere is insufficient. This lack of understanding undermines our ability to predict accurately the wind energy potential in forested terrain. Also, the understanding of the flow around tress is important for wind throw. The project will both use scaled trees to study the flow in WindEEE, and full-scale field test using meteorological masts and scanning lidars.

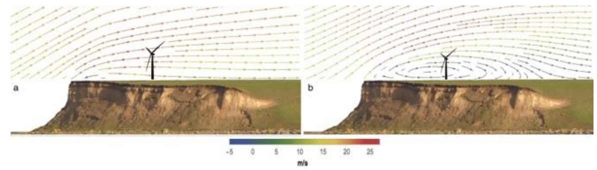

Figure 1 Mean flow field measured in WindEEE with rounded escarpment edge (a) and sharp edge(b).

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Collaboration Between WindEEE and Université Paris Diderot (2014-2016)

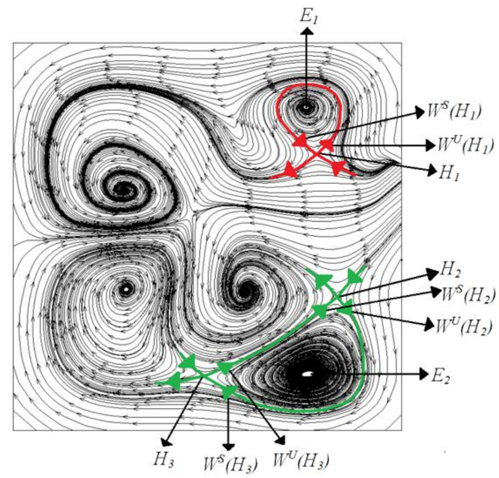
Analysis of Vortical Flows

Tornados are complex vertical flows, unsteady and meandering in space. They interact strongly with their immediate environment and attract or repulse debris which can cause heavy damages to built environment and inhabitats on their pathway. Deformation of tornado's axis causes complex fluid flow trajectories that contribute to mixing or segregation of solid debris in the flow. Therefore, understanding of flow topology, attraction manifolds and formation of periodic points give interesting clues for prediction and eventual control of the flow outset.

Collaborative work on this subject focused on theoretical analysis of a vertical flow which encounters drastic external perturbation to its axis and/or interacts with another vertical structure. For the sake of simplicity, Dean vortex which result from an imbalance between centrifugal force and pressure gradient in a curved flow was opted as vortex model. Dean vortices in practice can be generated in flows with curved streamlines. External perturbation was imposed by turning the flow curvature plane at a given angle with respect to its initial position. The effect of axial pulsating motion was also taken into account. Therefore, the simultaneous effects of flow pulsation and geometrical perturbation in curved bounded flows were numerically studied by three different metrics: analysis of the secondary flow patterns, Lyapunov exponents and vorticity vector analysis.

In the steady axial flow case, analysis of secondary flow patterns showed that homoclinic connections appear and become prominent at large Reynolds numbers. In the pulsatile flow, homoclinic and heteroclinic connections appear by increasing β, the ratio of the peak oscillatory velocity component of the axial mean flow velocity. Moreover, sharp variations in the secondary flow structure are observed over an oscillation cycle for high values of β. These variations are reduced and the homoclinic connections disappear at high oscillating frequencies.

We show that small and moderate values of flow pulsation frequency and high values of velocity amplitude ratio ($\beta \geq 2$) provide a strong mixing in the vortex core than that in the steady axial flow. These results correlate closely with the analysis of vorticity vector.



Singularity points in the secondary flow structure for β=1

Natural Walls

Residential and office buildings count for more than 40% of the total energy consumption in industrialized countries. They are challenged to reduce their energy consumption and also GHG emissions. Of course new buildings are concerned with this challenge but the existing buildings constitute a larger part of this energy consumption; in Europe more than 85% of the buildings have been built before 1990. More than 80% of energetic cost of a building in general is related to its operation phase.

In highly well isolated positive energy buildings of today air-conditioning becomes a crucial element for ensuring interior air quality and comfort of the inhabitants. Many residential or office buildings (new or existing) are already equipped with central air-conditioning systems. However, recent surveys have shown that their energy efficiency can be largely improved by modifying the architecture of the system and decentralizing their installation. Decentralized air conditioning system improves human comfort, increases energy efficiency (and reduces GHG emission), reduces the lost space in the building construction and is applicable to new as well as existing buildings.

In this collaborative project façade elements were designed which intake air from outside through small openings on the building façade and after passing through air channels embedded in the wall thickness is delivered directly to the indoor space. While air passing through the channels its temperature is adjusted to the desired temperature by passive means such as phase change materials (PCM). Air can also be evacuated from the indoor space through the same façade elements. In this case the hot or cold evacuated air can also be used for bringing the intake air to the desired temperature. Globally, the façade element is comprised of an external glass collector panel isolated from the back and covered with a thermo-chrome layer to avoid summer over-heating. An air layer separates this wall from PCM storage part of the wall. Another air layer separates the storage part from the isolated indoor face of the façade element. All openings to the indoor and outdoor zones are controlled by servo-motors.

In the framework of this collaboration Professor Horai Hangan spent two months in 2014 as visiting professor at Université Paris Diderot. Also a PhD student is currently co-supervised by Professor Hassan Peerhossaini and Professor Horia Hangan on the interaction of tornado and debris.

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UNIGE and UWO Joint Cooperative Research on Downbursts

A climatologic condition in which different wind phenomena coexist is referred to as a mixed climate. Many parts of the world are dominated by extra-tropical cyclones and thunderstorm outflows (Figure 1).

Figure 1: Synoptic extra-tropical cyclone and mesoscale thunderstorm.

The polar front theory, advanced by Bjerknes and Solberg in 1922, explains the genesis and life cycle of extra-tropical cyclones. They are synoptic-scale phenomena that develop in a few days on a few thousand kilometres. Their velocity field is endowed with a mean profile in equilibrium with an atmospheric boundary layer (ABL) with depth of about 3 km. Here, in time intervals between 10-min and 1-h, turbulent fluctuations are stationary and Gaussian. Wind actions on structures are usually evaluated by the method introduced by Davenport in the '60s; it identifies strong winds with extra-tropical cyclones.

The modern study of thunderstorms started in 1946, when Byers and Braham showed that they are meso-scale phenomena that develop in a few kilometers. They consist of cells that evolve in about 30 minutes through three stages in which an updraft of warm air is followed by a downdraft of cold air. In the '70s and '80s Fujita proved that the downdraft that impinges over the ground produces intense radial outflows (Figure 2). The whole of these air movements is called downburst. Radial outflows exhibit a non-stationary and non-Gaussian speed with a "nose profile" that increases up to 50-100 m height, then decreases above.

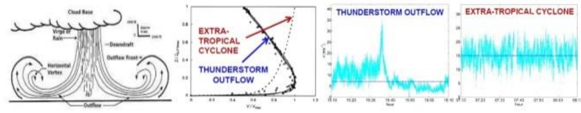

Figure 2: Downburst scheme, outflow velocity profile and time-history (compared with synoptic winds).

In the same period in which atmospheric sciences produced an extraordinary fervor of research on downbursts, wind engineering realized that design wind speed is often due to thunderstorms (Figure 3). Hence, a striking research arose along four main directions: wind statistics in mixed climates; monitoring and data analysis; modelling and simulation by experimental, numerical and analytical methods; wind loading on structures. In spite of an impressive amount of research, however, there is not yet a shared model of thunderstorm outflows and their actions on structures like that for cyclones. This happens because the complexity of thunderstorms makes it difficult to establish physically realistic and simple models. Their short duration and small size make few data available. There is a large gap between wind engineering and atmospheric sciences. Thus, wind loading on structures is still evaluated by the model established by Davenport over half century ago. This is non-sense because cyclones and thunderstorms are different phenomena that need separate assessments.

Figure 3: Consequences of the thunderstorm downburst occurred in the Port of Genoa on 31 August 1994.

Two unprecedented and recent facilities may offer a radical advancement of knowledge in this field.

The first is the wind monitoring network created for two European projects, "Wind and Ports" and "Wind, Ports and Sea", funded by European Territorial Cooperation Objective, Cross-border program "Italy-France Maritime 2007-2013". They involved the five main Port Authorities of the North Tyrrhenian Sea - Genoa, La Spezia, Livorno, Savona and Bastia - and DICCA as the only scientific partner, giving rise to a monitoring network made up of 28 ultrasonic anemometers, 3 weather stations, each one equipped with an additional ultrasonic anemometer, a barometer, a thermometer, and a hygrometer, and 3 LiDARs (Figure 4). 13 ultrasonic anemometers installed autonomously by Port Authorities are becoming part of the network. 3 ultrasonic anemometers are going to be installed in the channel area of Livorno for the San Paolo Project. Sensors are located aiming to register undisturbed wind speeds. Ultrasonic anemometers are mounted from 10 to 84 m above ground; their sampling rate is 10 Hz except in the Port of Bastia whose sampling rate is 2 Hz. LiDARs detect vertical speed profiles at 10 levels between 40 and 250 m with sampling rate 1 Hz. Local port servers receive the data and transfer it to DICCA. Here the data is checked and stored in a dataset including raw data and statistical estimates. A semi-automated procedure separates cyclone from thunderstorm records.

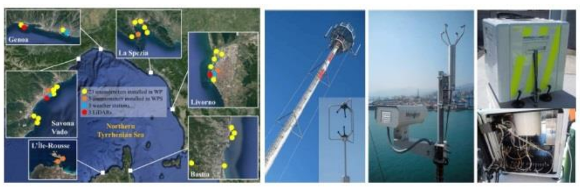

Figure 4: WP and WPS wind monitoring network, three-axial and bi-axial ultrasonic anemometers, LiDAR.

The WindEEE (Wind Engineering Energy and Environment) Dome is a three-dimensional time-dependent laboratory (Figure 5) opened in 2013. Its core is a huge hexagonal chamber 25 m in diameter, surrounded by a return circuit with the same hexagonal shape 40 m in diameter. A wide variety of non-synoptic winds may be created by varying the configuration, wind speed and direction of 106 fans. 100, situated on the peripheral walls of the inner testing chamber, are 0.8 m in diameter. The other 6 fans are 2 m in diameter and are placed above the testing chamber ceiling. Downbursts are created by having the upper fans feeding air down into the main chamber through the bell-mouth and evacuating air through peripheral walls, thereby creating all kinds of impinging jets. The flow field of the downburst is about 5 m in diameter; its translation is up to 5 m with a maximum velocity of 2 m/s. The space-time structure of the wind speed is measured at two different scales: the overall structure is detected by a novel stroboscope based technique; the detailed structure near the ground is detected at high resolution by time resolved PIV measures using new seeding techniques.

Figure 5: Inner chamber of the WindEEE Dome and a simulated downburst.

These facilities involve complimentary merits and limitations. Thanks wind monitoring network provides a high-resolution description of the local time structure of thunderstorm outflows and, at LiDAR sites, also their vertical profile. Availing of almost 6 years measures and continuing to accumulate data, the statistical analysis of extreme wind speeds is now possible. Thanks to a plan grid of nearly 1 km, this set of sensors furnishes enough information to estimate the touchdown position, size, velocity and direction of downbursts. Instead, it is not enough to derive a detailed description of the time-space structure of a phenomenon that runs out in a few kilometers in horizontal and in a few hundred meters in vertical. Moreover, it captures only those phenomena that occur in the monitored area. The WindEEE Dome can simulate and detect the time-space structure of large-scale downbursts, capturing flow details that cannot be seen elsewhere. It produces unprecedented set of downbursts on varying parametrically a wide spectrum of characteristic quantities such as the downdraft diameter, translational speed and terrain roughness. Instead, the possibility of reproducing real phenomena and their laboratory scaling are open issues whose investigation needs reference measures.

Considering the longstanding co-operation and friendship between the University of Genova (UNIGE) and the University of Western Ontario (UWO), and the huge potential of joining unique complimentary data, a number of common initiatives have been undertaken to develop advanced research and educational programs at the frontier of the state of the art and beyond.

In 2015 the writer was invited to join the Research Board of WindEEE and an Agreement for International Research Collaboration was signed between UNIGE and UWO. In this framework

UNIGE supported a scholarship for a master student who spent over six months at UWO and WindEEE developing a thesis titled “Physical modelling of a real thunderstorm outflow at the WindEEE Research Institute”. Some applications for funding research on downbursts were also submitted by writer claiming this co-operation. Taking a cue from these preliminary initiatives, this year Prof. Hangan visited DICCA delivering the lecture “Wind Engineering: Time for change?” His stay at UNIGE was an excellent opportunity to discuss a coordinate a research project involving scientists of UWO and UNIGE. In particular, the downburst event occurred in the Port of Livorno, Italy, on October 1, 2012 (Figure 6) was selected as a case study around which to build a research project.

In parallel the writer was appointed Adjunct Professor at UWO, and here he spent one month to deliver the official course on “Wind-Excited and Aeroelastic Response of Structures”, follow student projects, and give the guest lecture “Art, engineering and perfection: the Endless Column of Constantin Brancusi”. His presence at UWO was also an excellent opportunity to focus on the Livorno downburst and compile a detailed plan aiming to write and submit to international journals a series of three linked papers.

The first provides an interpretation of the weather scenario in which the downburst occurred throughout a broad band of tools including field measurements, satellite and Doppler radar images, and lighting maps.

The second proposes a new method to evaluate the touchdown position and motion of the downburst.

The third provides the first attempt to simulate a real downburst in the WindEEE laboratory and calibrate its scaling laws. It was also decided that the next step will be using this framework as a reference point to repeat analyses systematically on a broader class of events, providing also a statistical interpretation of the randomness and uncertainties involved.

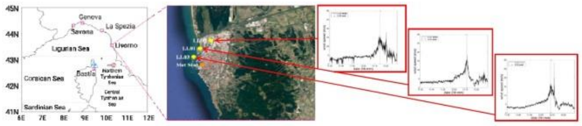

Figure 6: Downburst event in Livorno, Italy on October 1, 2012.

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WINDIA : Integrating 3D Wind Field Scanning with Wind Tunnel and Open Air Field Test Research Infrastructures

WINDIA will mobilize a consortium of 13 key research facilities from Europe, Canada and the US in close co-operation with the new unique emerging ESFRI supported research infrastructure in the field of performing experimental research in wind and turbulence fields for wind energy research.

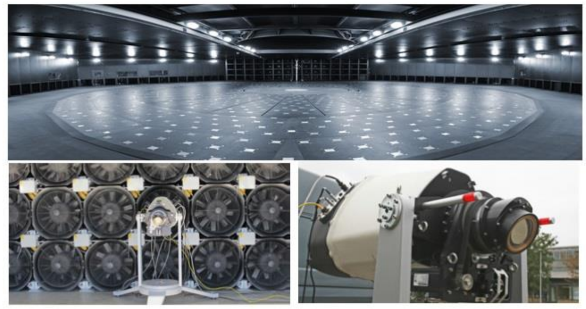
WINDIA will also collaborate within other ongoing EU research activities including the European Energy Research Alliance EERA; JRC and FP7 projects such as IRPWind, InnWind,; and more.

WINDIA's integrating activities will disseminate and co-operate the new WindScanner remote-sensing based wind field scanning methodology into similar key research infrastructures in closely related research fields, i.e. infrastructures such as wind tunnels and open air test fields by operating 3D wind field scanning for wind measurements within the research topics for Wind Energy and Wind Engineering.

WINDIA will open up access by pursuing integration with other key European research infrastructures to create a cohesive consortium playing a leading role in the European and also in the global community of world-class research in experimental wind and turbulence with focus on wind energy research.

WINDIA's integration activities will support all three components of the knowledge dissemination triangle: research, education and innovation. To ensure social impact as well the partners of WINDIA consortium will address collaboration and awareness with national and regional policy-makers. WINDIA will also through innovation and education continue to contribute to the creation of new jobs in the wind industry and research.

The WINDIA partner in Canada is WindEEE Research Institute at Western University (London, Ontario, Canada), hosts the world's first hexagonal wind tunnel - the Wind Engineering, Energy and Environment (WindEEE) Dome. It is a large- scale structure (25 meters diameter for the inner dome and 40 meters diameter for the outer return dome) able to perform scaled wind simulations over extended areas and complex terrain.



Short-range WindScanner at WindEEE Dome.

WindEEE brings key contributions to WINDIA by offering access to world-class unique capabilities in terms of reproducing special wind flow fields:

- downbursts and ABL flows at large scales, and even tornadoes,
- combinations of straight and updraft/downdraft winds,
- spatio-temporal correlations of inflow conditions
- Reynolds numbers which are between typical wind tunnels and full scale, addressing Re number dependency problems.

Given these characteristics it can be a perfect complement to full scale (LiDAR) measurements as it can generically reproduce LiDAR measurements of flows which are non-straight and dynamic. It can therefore be used to test model wind turbines to these unique conditions.

Full scale and experimental infrastructure can play an exceptional role in improving numerical models for users. Having a common shared budget helps both the infrastructures and the research community at large.

WindEEE sees a great potential for WINDIA: WINDIA can become a model of solving wind-related problems in general. WINDIA can open researcher's access to multiple tools: full scale, experimental and computational facilities. Therefore researchers can address complex, multiscale problems that cannot be address by one single tool or one single approach.

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53. Kilpatrick, R., Siddiqui, K. and Hangan, H. "Experimental Characterization of Flow around an Escarpment", Canadian Congress of Applied Mechanics, London, ON, May 31-June 4, 2015.

54. Ibrahim, A., El Damatty, A.A., "Case Study to Assess the Sensitivity of Prestressed Concrete Poles to Tornadoes", CSCE Conference, London, ON, Canada, June 1-4, 2016.

55. Rosenkrantz, J.D., Enajar, A., and El Damatty, A.A., "Structural Modeling and Verification Methods to Develop a Cable Roof Harness Retrofit System", CSCE Conference, London, ON, Canada, June 1-4, 2016.

56. Elawady, A., El Damatty, A. and El Ansary, A., "Critical Load Cases Simulating Downbursts: Economical Implications for Design of Transmission Lines.", CIGRE-IEC Colloquium, Montréal, QC, Canada, May 9-11, 2016.

57. Aboshosha, H., Ibrahim, A. M., El Damatty, A. A. and Hamada, A., "Dynamic Behaviour of Transmission Lines Structures under Synoptic Wind Loads", CIGRE-IEC Colloquium, Montreal, Canada, May 9-11, 2016.

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59. El Damatty, A.A. and Elawady, A., "Load Patters Simulating Downburst Wind Acting on Lattice Transmission Lines", 14th International Conference on Wind Engineering (ICWE14), Brazil, June 2015.

60. El Damatty, A.A., Hamada, M. and Hamada, A., "Load Cases for Transmission Line Structures", 14th International Conference on Wind Engineering (ICWE14), Brazil, June 2015.

61. El Damatty, A.A., Bitsumalak, G. and Elshaer, A., "Aerodynamic Shape Optimization for Corners of Tall Buildings using CFD", 14th International Conference on Wind Engineering (ICWE14), Brazil, June 2015.

62. Musa, A. and El Damatty, A.A., "Seismic Behaviour of Steel Liquid-Filled Conical Tanks Designed under Hydrostatic Pressure", 25th Canadian Congress of Applied Mechanics, CANCAM, London, Canada, 2015.

63. Elansary A. and El Damatty A.A.,"Seismic Analysis for Composite Conical Tanks", 25th Canadian Conference of Applied Mechanics, CANCAM, London, Canada, 2015.

64. Elshaer, A., Bitsuamlak, G. and Damatty, A.A., "Vibration Control of Tall Buildings using Aerodynamic Optimization", 25th Canadian Congress of Applied Mechanics, CANCAM, London, Canada, 2015.

Grants

NSERC CRD/ $ 540,000 / 2015-2018
Determination of load differences between straight winds and tornadoes in the WindEEE Dome
Hangan

OCE / $ 75,000 / 2016
Design wind speeds in complex terrain
Hangan

Western Strategic / $ 40,000 / 2015-2016
Wind sustainability and resilience index
Hangan

Joint Usage Center for Wind Engineering Grant / $ 3,927 / 2015-2016
Calibration of tornado simulators
Hangan

NSF / $ 4,000,000 / 2015-2020
Natural Hazards Engineering Research Infrastructure: Experimental Facility with Twelve-Fan Wall of Wind
Bitsuamlak

Wasau Tiles / $ 72,000 / 2015-2016
Pressure equalization on roof pavers
Bitsuamlak

NSERC CRD / $ 180,000 / 2015-2017
Numerical and Experimental Study of a New System for Retrofitting Roofs Subjected to Extreme Wind Loading
Bitsuamlak

Hydro One / $ 300,000 / 2016-2020
Progressive Failure Analyses of Transmission Line Structures under the Action of Downbursts and Tornadoes
El Damatty

NSERC Discovery Grant /$ 225,000 / 2016-2021
Performance Based Design of Transmission Line Structures Under Tornadoes and Downbursts
El Damatty

SBM Engineering / $ 66,000 / 2015-2016
Development of Software for Analysis of Multi-Storey Wood Buildings
El Damatty

NSERC CRD/ Steelcon Engineering / $ 180,000 / 2015-2017
Numerical and Experimental Study of a New System for Retrofitting Roofs Subjected to Extreme Wind Loading wind
El Damatty

Hassco Industries Inc / $ 75,000 / 2015-2016
Efficient Alternative for Material Handling in Rice Straw Power Generating Prototype
El Damatty

NSERC Engage / $ 25,000 / 2015-2016
Finite Element Modelling aspects of Mid-Rise Light Frame Wood Buildings

El Damatty

Connect Canada / $ 50,000 / 2015
Comprehensive Software for Analysis of Transmission Line Structures under High Intensity Wind
El Damatty

MITACS Accelerate Internship / $ 40,000 / 2015-2016
Accelerate development of new technologies and applications for advanced water treatment
Siddiqui

Trudell Medical International / $ 7,200 / 2015
Ventilator aerosol delivery system performance measurements
Siddiqui

NSERC (Engage) / $ 25,000 / 2015
Investigation of wake and topography effects on a wind farm performance
Siddiqui

NSERC (Engage) / $ 25,000 / 2015
Thermal characterization of polyurethane-cement composites
Siddiqui

Awards

2015

Whitman Wright Award for Excellence in information Technology in Civil Engineering, CSCE
Ashraf El Damatty

Fellow, American Society of Mechanical Engineers (ASME)
Kamran Siddiqui

2016

Horst Leipholz Medal, for outstanding contributions to engineering materials and mechanics in Canada, CSCE.
Ashraf El Damatty

Fellow, Canadian Society of Mechanical Engineers
Horia Hangan

Terry Base Award for Excellence in Teaching (MME)
Kamran Siddiqui

Events

WindTech2015 - 2nd International Conference on Future Technologies in Wind Energy

The generation of electricity via wind has grown rapidly, in Europe, in North America, and now worldwide with China having the largest amount of installed capacity of any country in the world. Despite the success of the wind energy industry to date, many challenges still exist including reliability, overall wind farm performance, and offshore wind to name just a few. The International Conferences on Future Technologies in Wind Energy focus on addressing those technology developments necessary for wind turbines and wind farms to continue improving.

WindEEE Research Institute hosted the second edition of this new series of conferences - WindTech2015. Organized in collaboration with Cornell University, University of Wyoming and Danish Technical University, the conference was focused on measurements (at all scales) and the evaluation of numerical models using measurements, encompassing all areas of wind energy from resource assessment through power quality. The conference also showcased impact research related to new technologies and their applications. Session topics included:

National and international overviews

- Support and funding strategies
- National/international campaigns
- Field testing facilities

Wind resource & full scale testing

- Remote and in situ measurements
- ABL and freestream measurements
- On- and off-shore/complex terrain
- Model development/validation needs

Wind tunnel and field measurements

- Flow field and wakes
- Steady and unsteady aerodynamics
- Scaling issues
- Reconciling models and measurements
- Unique facilities and instrumentation

Control and performance

- Wind turbine and wind farm control
- Fatigue and extreme loads
- Aeroacoustics
- Structural health/condition monitoring

Components and materials

- Blade/drive train/generators
- Blade materials, components and manufacturing
- Future materials
- Multi-scale testing: laminates and structures
- Environmental effects on components
- Defects and damage

Analysis and design methods for wind turbines

- Full-scale and sub-structural testing
- Foundation and tower design

Enabling technologies for wind energy integration

- Grid connectivity issues for wind energy
- Wind energy technologies for o"-grid applications
- Policy issues for promotion of wind energy
- Wind farm design

Bringing the latest in wind energy research to London, WindTech2015 confirms Western’s position as a leader in wind-related research. Western’s strength comes from strong, interdisciplinary teams of researchers from several faculties, including Engineering, Science, Social Science and the Richard Ivey School of Business. The University is also the only institution in Canada currently offering a graduate program in wind engineering.

SHAD at WindEEE

Western University is the latest top university to join with SHAD, a prestigious program which brings the best and the brightest high school students to university campuses across the country every July for an intense program that helps them reach their full potential. SHAD, founded in 1980, has become known as an incubator for innovation and entrepreneurship among these students who specialize in STEAM (Science, Technology, Engineering, Arts and Math). With an impressive list among its 15,000 alumni which includes 30 Rhodes Scholars, SHAD has seen a record number of applications for two years straight.

Western becomes the 12th host university campus around the country for the one-month residential program with places highly sought after by students who go through a rigorous competition and application process.

Each year, the program has a specific theme, built around a current economic and social problem. The students collaborate to develop a unique innovative product or service that addresses the issue. As part of this engineering and design challenge, teams are taught how to build a business and marketing plan, and design and build working prototypes. Winning projects advance to national judging and results are celebrated each fall.

A typical day at SHAD includes experiential learning, from class to labs and beyond. Students are inspired by university professors, business leaders, entrepreneurs and innovators, who help them set aspirational goals and envision their own extraordinary potential.

This summer, WindEEE Research Institute had the privilege to be one of Western's hosts for the SHAD group. The day at WindEEE started with a presentation about the Dome's capabilities, followed by facility tour and a tornado simulation.

A technical presentation on wind turbine designs and technologies introduced the students to the hands-on session. The students, divided in groups, designed and assembled small wind turbines to be tested inside the WindEEE test chamber. With plenty of construction materials at hand and keeping the rules of the game to a minimum, it did not take long until the innovative prototypes were ready to be tested. The competition was equally fun and exciting, bringing everything from entertaining failures to amazing performances.

Chronicle

2015.09

Custom DLR Drone Testing at WindEEE Dome

2015.10

WindEEE hosts
WindTech2015 - 2nd International Conference on Future Technologies in Wind Energy

2015.11

Installation and commissioning of outdoor contraction system

Field Measurements at the WEICAN Wind Farm Site in Prince Edward Island

2015.12

NIST low-rise building testing in tornado and downburst

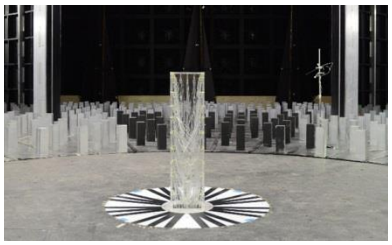
2016.01

Horia Hangan's presentation at United Nations Office for Disaster Risk Reduction, Geneva, Switzerland

Flow conditioning for special Atmospheric Boundary Layer flows

First automotive testing at windeee

NIST Low-rise building testing in Atmospheric Boundary Layer flows

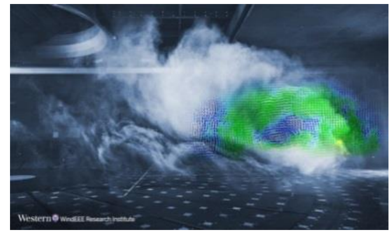


2016.02

Testing of CAARC tall building in tornado and downburst

CAARC tall building testing in Atmospheric Boundary Layer flows

2016.04



WindEEE Participates in the Research Showcase at the Western University

Presentations at the 1000 Islands Fluid Dynamics Conference

First full-scale downburst event reproduction at WindEEE

2016.05

WindEEE welcomes new research scientist, Dr. Jubayer Chowdhury

Outdoor roof loading testing

2016.06

Certificate of Membership

This Certifies That

WindEEE Research Institute

Is Hereby An Active Member In Good Standing Of The

Subsonic Aerodynamic Testing Association

SATA

And Has Met All Requirements Outlined By Its Constitution

2016

Jorge L Martinez, Chairman — Klaus Muthreich, Vice-Chairman — Peter Skinner, Secretary

WindEEE RI becomes active member of Subsonic Aerodynamic Testing Association

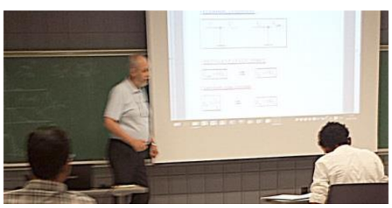
Presentations at the 8th International Colloquium on Bluff Body Aerodynamics and Applications

Presentations at the CSME International Congress

2016.07

SHAD program day at WindEEE

Presentations at ASCE/SEI Committee for Wind Speed Estimation in Tornadoes, Norman OK, USA



Presentations at Wind-Excited And Aeroelastic Vibrations Of Structures

Professor Giovanni Solari's course (co-organizaed by WindEEE and CEE)

2016.08

Professor Giovanni Solari's seminar: Art, Engineering and Perfection: The Endless Column of Constantin Brancusi

Special testing of tall building in the Atmospheric Boundary Layer flow

Ashraf El Damatty, invited keynote speaker, The 2016 World Congress on Advances in Civil, Environmental, and Materials Research (ACEM16), Jeju Island, South Korea

2016.09

Presentations at First International Conference on Urban Physics, Ecuador

Notes

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