ANNUAL REPORT | 2019-2020

Western

WindEEE Research Institute
Engineering, Energy & Environment

2535 Advanced Avenue, London, Ontario, N6M 0E2, Canada

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Preface

WindEEE Research Institute enters its 10th year.

In accordance with the procedures laid out in the Manual of Administrative Policy and Procedures (MAPP), Section 7.9 for recognition of collaborative research entities at Western, the WindEEE Research Institute was renewed in June 2019 for the third time, until July 2022, by the VP Research.

WindEEE is now towards the end of the IOF funding and enters a period of transition towards a different funding scheme. The IOF funding is projected to end towards the end of the FY 2021 and therefore lasting two years more than the typical CFI projection. This is an important opportunity for WindEEE RI but also for the Faculty and University to look into a transition funding model in view of the need to replace the IOF funding by the end of the FY 2021 as well as in view of long term succession planning.

The COVID-19 pandemic-related measures resulted in WindEEE being shut down between March and July 2020. This period was followed by previously planned repairs that ended August 17th. As a result, WindEEE RI did not operate for a period of almost five months. Aside from the ongoing administrative and client engagement efforts, the remote work period was used towards much needed development work. As a result, data processing capabilities were drastically improved and several testing and calibration procedures have been documented. The gradual re-entry was focused on implementing all new safe-work policies as well as addressing all necessary maintenance and cleanup tasks such that the facility being prepared to return to the planned project work.

WindEEE RI has now matured as a research infrastructure with 3 main strategic research priorities being adopted for the next period:

i. **Drive** *research* and *education* excellence and empower research teams so that they can pursue scientific investigation effectively in a world-class facility, the WindEEE Dome, and to develop real solutions for today's top wind engineering, wind energy and wind environment challenges;

ii. **Enrich** the power of technology and *innovation* and extend collaborations to ensure that the novel infrastructure (WindEEE Dome) is optimally used by internal and external collaborators; and

iii. **Grow** research through *sustainable* financial resources.

Significant progress continues to be made on achieving these objectives. The following are current evidence of this progress:

i / During 2019-2020 year, the WindEEE RI core faculty group produced 36 international journal publications, 23 conference proceeding publications and 2.4M$ in research funding. The core group faculty members at WindEEE RI have collectively supervised 59 students (36 Ph.D; 23 M.Sc) as well as 7 Postdoctoral Fellows.

Notable new research this year has contributed to the 3 main areas of research at WindEEE RI, wind Engineering, Energy and Environment. Some of these contributions are: (i) modal characterization of large scale tornado vortex dynamics with application to new analytical models; (ii) numerical simulations of tornado-like vortices; (iii) new larger (Mode B) tornado simulations with applications to aeroelastic testing of transmission lines; (iv) tornado translation over low-rise buildings and internal pressures measurements with application to code implementations; (v) interaction between downburst and atmospheric boundary layer flows; (vi) interaction between tornadic and downburst winds and aeroelastic models of structures; (vii) the impact of gust, downburst and tornadic flows on wind turbines; (viii) new measurements techniques for canopy studies; (ix) community resilience and sustainability optimization studies; (ix) wind interaction with wood-frame structures; (x) thermal studies for photobioreactors.

WindEEE RI is a driver of the Graduate Program in Wind Engineering at Western which is one of the only two existing programs worldwide.

ii / To expand its pan-Canadian research base, WindEEE RI in consultation with Research Services at Western, continues to invite researchers from across Canada to apply for a WindEEE Innovation Fund. This is meant to provide researchers across Canada with competitive access to the WindEEE RI facilities to prove innovative concepts in wind research. Researchers from University of Victoria (UVic), University of Windsor as well as from UTIAS at University of Toronto have benefited this year from this WindEEE initiative.

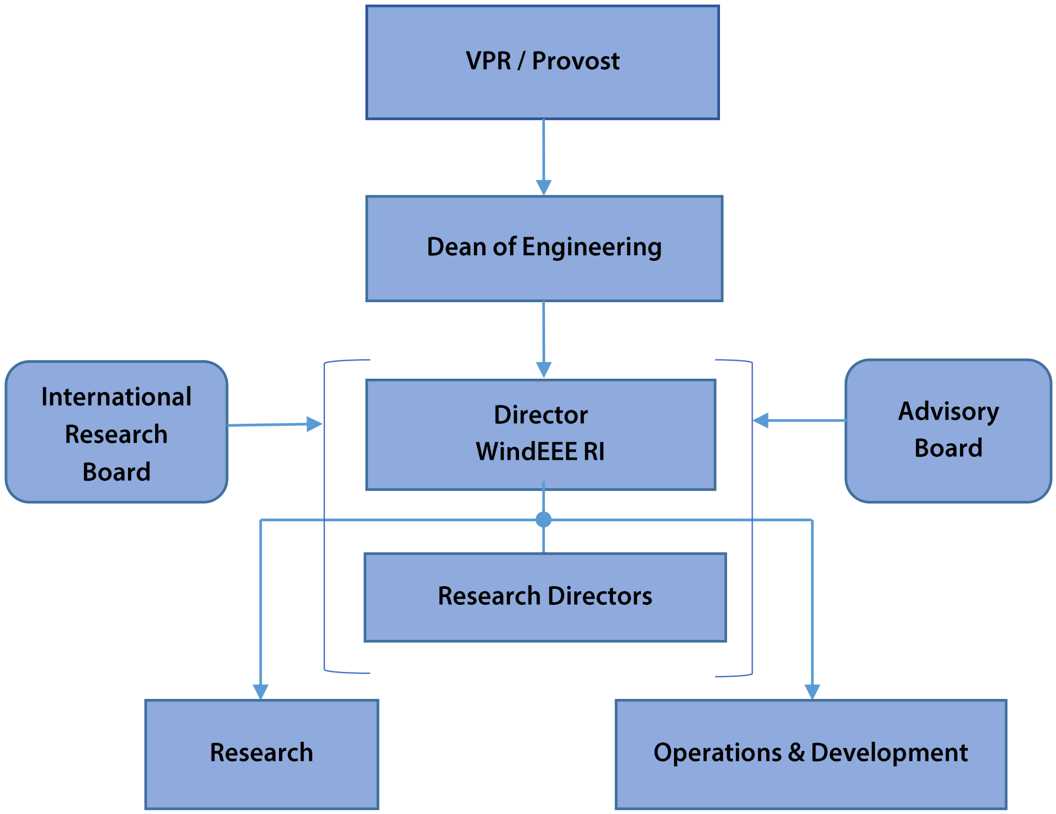
Collaborative graduate programs have continued and expanded internationally with University of Genova with a double PhD Program now approved; Danish Technical University (DTU) with projects and co-supervision of graduate students; through the CONACYT program with Universidad National Autonoma de Mexico (UNAM) and Universidad Juarez Autonoma de Tabasco (UJAT) as well as with Universidad de la Republica of Uruguay. Other such programs are currently under development with Tongji University (China), Chongqing University (China), and the Polytechnic University of Bucharest (Romania

iii / WindEEE had its annual Advisory Board (AB) Meeting in mid-June 2020 to which both the Dean of Engineering and the AVP Research have been invited. The high caliber meeting focused on potential sustainable operating models for WindEEE. Future consultations have been triggered with the VP Research to discuss future funding opportunities. As the term of the Chair of the AB has ended WindEEE RI is actively seeking a new Chair of the Board. New appointments on the Board of Directors of the Institute are also envisaged.

While some of the research activities have been delayed (such as a new research/contract with the University of Genova under ERC Thunder Project), other collaborations continued online (such as the one with the Technical University of Denmark on wind and tree interaction problems). Some contract work was shifted from testing in WindEEE to an expansion in results analysis and computational alternatives (such as the FM Mutual Phase 4 program). A large contract funded by the National Institute for Standards and Technology with ARA in US has been successfully completed. New collaborations have been expanded with S2E Company in London Ontario. An ICLR and MITACS Program in novel hazard estimation for the Ottawa Gatineau tornadoes continues.

The Major Science Initiatives (MSI) funding, which has been identified by WindEEE as a potential target for funding relies on a designation as a national research facility. A national facility supports leading-edge research and provides shared access to substantial and advanced specialized equipment, services, resources, and scientific and technical personnel.
WindEEE conducts unique, leading-edge research and provides access to any Canadian researcher willing to conduct research. Together with a commitment towards the recommended administrative standards, WindEEE RI presents itself as a suitable fit for the MSI program.
With proper attention from the Canada Foundation for Innovation and the University the WindEEE Research Institute will continue to accomplish its Vision: ***to be a global leader in wind research and innovation.***

Horia Hangan
December 31, 2020



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 the figure below. Two external Boards provide the necessary inputs to the Director of the Institute: The Advisory and the International Research Boards.

The **Advisory Board** (AB) advises the Director of the Institute on progress and advancement in areas related to WindEEE activities. The board reports on Industry, International Institutes and Government with a global perspective along with providing advice on potential sources of funding.

Since 2014, the Advisory Board meets once a year and Members from Industry, and Government organizations are nominated for three (3) year terms. They are listed in WindEEE RI Advisory Board.

The **International Research Board** (IRB) 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 International Research Board meets once a year and reviews the research activities of the Institute.

The Members of the International Research Board of the WindEEE RI are nominated for three (3) year term. They are listed in WindEEE RI International Research Board.

People

Faculty

Horia M. Hangan
Professor and Director of WindEEE Research Institute

Girma T. Bitsuamlak
Professor and Research Director WindEEE Research Institute

Ashraf A. El Damatty
Professor and Research Director WindEEE Research Institute

Hassan Peerhossaini
Professor and Research Director WindEEE Research Institute

Kamran Siddiqui
Professor and Research Director WindEEE Research Institute

Staff

Adrian Costache,
Operations Manager

Gerald Dafoe,
Technical Specialist

Tristan Cormier, B. Eng.
Research Engineer

Elisa Yaquian, MSc
Administrative Assistant

International Research Board

Rebecca Barthelmie
Professor, Cornell University, USA

Mark N. Glauser
Professor, Syracuse University, USA

Horia M. Hangan
Professor and Director of WindEEE Research Institute

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Former CEO and Professor, Met Services UK and Cambridge University, England

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Director Natural Hazard Laboratory, Notre Dame University, USA

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Professor, Danish Technical University, Denmark

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Director Wind Energy Center, University of Wyoming, USA

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NIST Fellow, National Institute of Standards and Technology, USA

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Advisory Board Chair / President, Alef Consulting Inc., Canada

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VP Research Area Director, Factory Mutual Global, USA

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Principal, Power Sector, Golder Associates, Canada

Paul Dugsin
Managing Partner, Magnus Associates, Canada

Jon Galsworthy
Managing Director - Canada, CPP Wind Engineering & Air Quality Consultants, Canada

Horia M. Hangan
Professor and Director of WindEEE Research Institute

Paul Kovacs
Executive Director, Institute for Catastrophic Loss Reduction, Canada

Dean Ken Coley
Honorary Board Member / Dean Faculty of Engineering at Western University, Canada

Kevin Shoemaker
Honorary Board Member / Associate Vice-President (Research) Western University, Canada

Postdoctoral Fellows, Graduate and Exchange Students

Dr. D. Romanic – Postdoctoral fellow, Supervisor: Dr. H. Hangan
Dynamics of thunderstorm winds

A. Ashrafi – PhD candidate, Supervisor: Dr. H. Hangan
Experimental simulation of tornadoes and scaling properties

M. Enus – PhD candidate, Supervisor: Dr. H. Hangan
Development of large scale particle tracking methods

A. Gairola – PhD candidate, Supervisors: Dr. G.T. Bitsuamlak and Dr. H. Hangan
Numerical and WindEEE modeling of tornado flow structure and its effect on communities

A. Kassab – PhD candidate, Supervisor: Dr. H. Hangan
Simultaneous pressure and PIV measurements on low-rise buildings

E. G. Narancio – PhD Student, Supervisor: Dr. H. Hangan
Environmental impacts of high intensity winds on communities

J.P. Ortiz – PhD Candidate, Supervisor: Dr. H. Hangan
Non-synoptic wind effects on wind turbines

D. Davalos Arriaga – MESc Student, Supervisor: Dr. H. Hangan
Combined wind and ice loading on transmission lines

K. Shirzadeh Ajirlo – MESc Student, Supervisor: Dr. H. Hangan
Simulation of operational extreme conditions for horizontal axis wind turbines based on IEC standard

Dr. A. Awol – Postdoctoral Fellow, Supervisor: Dr. G.T. Bitsuamlak
Natural ventilation and Enhanced building energy performance evaluation

Dr. M. Kahsay – Postdoctoral Fellow, Supervisor: Dr. G.T. Bitsuamlak
CFD model development for wind engineering and building science application

K. Adamek – PhD Student, Supervisor: Dr. G.T. Bitsuamlak
Adaptive Architectural Forms and Progressive Aerodynamics

T. Alemayehu – PhD Student, Supervisor: Dr. G.T. Bitsuamlak
Drone enabled environmental fluid mechanics modeling

T. Berhane – PhD Candidate, Supervisor: Dr. G.T. Bitsuamlak
Aerodynamic optimization of horizontal (bridge) structures

M. Bezabeh – PhD Candidate, Supervisor: Dr. G.T. Bitsuamlak
Performance based wind design frame work for tall mass timber buildings

A. Gairola – PhD Candidate, Supervisors: Dr. G.T. Bitsuamlak and Dr. H. Hangan
Numerical and WindEEE modeling of tornado flow structure and its effect on communities

T. Geleta – PhD Candidate, Supervisor: Dr. G.T. Bitsuamlak
Performance based design framework for tornado

T. Getachew – PhD Student, Supervisor: Dr. G.T. Bitsuamlak
Performance Based Wind Engineering Methods

C. Howlett – PhD Student, Supervisor: Dr. G.T. Bitsuamlak
Aero-structural optimization of tall buildings

E.R. Lalonde – PhD Candidate, Supervisors: Dr. G.T. Bitsuamlak and Dr. K. Dai (Tongji University, China)
Hybrid numerical and experimental wind and earthquake modeling

A. Melaku – PhD Candidate, Supervisor: Dr. G.T. Bitsuamlak
CFD based aeroelastic analysis of tall buildings

B. Nighana – PhD Candidate, Supervisor: Dr. G.T. Bitsuamlak and Dr. F. Tariku (BCIT, Canada)
Solar thermal and phase material integration with building envelope

M. Younis – PhD Student, Supervisor: Dr. G.T. Bitsuamlak
BIM integrated sustainable and resilient building design frame work

H. Abdallah – MESc Student, Supervisor: Dr. G.T. Bitsuamlak
City growth impact (urban topology change) on the design wind load

K. Current – MESc Student, Supervisor: Dr. G.T. Bitsuamlak
Downburst loading on low-rise structures.

C. Van Der Kooi – MESc Student, Supervisor: Dr. G.T. Bitsuamlak
Wind performance of tall mass timber buildings.

M. Vandewiel – MESc Student, Co-supervisors: Drs. G.T. Bitsuamlak and Miriam Capretz
A.I. assisted building energy consumption estimation

H. You – MESc Student, Co-supervisors: Drs. G.T. Bitsuamlak and A. Sadhu
Wind Induced Fatigue on Tall Building Cladding

Dr. A. Shehata – Postdoctoral Fellow, Supervisor: Dr. A.A. El Damatty
Progressive Failure Software for Transmission Lines under HIW

Dr. A. Enajar – Postdoctoral Fellow, Supervisor: Dr. A.A. El Damatty
Development of Software for the Analysis of Light Frame Wood Buildings

Dr. P. Martin – Visiting Scholar, Dr. A.A. El Damatty
Analysis of communication Towers Under Extreme Wind

E. Abelraouf – PhD Student, Supervisor: Dr. A. A. El Damatty
Behaviour of curved roofs under wind loads

A. Enajar – PhD Competed, Supervisor: Dr. A. A. El Damatty
Nonlinear modeling of retrofitting systems of wood houses under uplift wind

N. Ezami – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Testing of transmission line structures under tornadoes

M. A. Gazia – PhD Candidate, Supervisors: Dr. A.A. El Damatty and Dr. K. Dai (Tongji University, China)
Behavior of Extra Tall Wind Turbines under Extreme Load Events

M. Hamada – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Analysis and testing of transmission lines under tornadoes wind

S. Maheux – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Non-linear flutter behavior of cable-stayed bridges

M. Niazi – PhD Candidate, Supervisor: Dr. A.A. El Damatty
Performance of multi-story wood building under lateral loads

M. Ramadan – PhD Candidate, Supervisors: Dr. A.A. El Damatty and Dr. K. Dai (Tongji University, China)
Performance of wind turbines under tornados and downbursts

T. Sabra– PhD Candidate, Supervisors: Dr. A.A. El Damatty and Dr. Dai (Sichuan University)
Fatigue Behaviour of New Wind Turbine Connections

C. Santos – PhD (Completed), Supervisors: Dr. A. A. El Damatty and Dr. M. Pfeil (University of Rio De Janerio, Brazil)
Optimization of cable-stayed bridges considering wind loads

A. Shehata – PhD (Completed), Supervisor: Dr. A.A. El Damatty
Failure Analysis of Transmission Line Structures under Downbursts

M. Elassaly – MESc Student, Supervisor: Dr. A.A. El Damatty
Behaviour of multi-storey braced frame timber buildings

W. Mohamed – MESc Student (completed), Supervisor: Dr. A. A. El Damatty
Optimization of design of transmission lines under downbursts

C. Peng – MESc Student (Completed), Supervisor: Dr. A. A. El Damatty
Performance based design of buildings under wind loading

K. Dennis – PhD Candidate, Supervisor: Dr. K. Siddiqui
Characterization of three-dimensional flow structure in boundary layers over a heated flat plate

K. Teather – PhD Candidate, Supervisor: Dr. K. Siddiqui
Investigation of pore-scale phase change process in PCM-embedded porous media

E. Blokker – MESc Student, Supervisor: Dr. K. Siddiqui
Investigation of radiation heat transfer in a porous solar thermal receiver

Z. Charran – MESc Student, Supervisor: Dr. K. Siddiqui
Design and characterization of optical guide for concentrated solar energy transmission

C. Kellogg – MESc Student, Supervisor: Dr. K. Siddiqui
Characterization of droplet behavior in the presence of a bluff-body

M. Kuska – MESc Student, Supervisor: Dr. K. Siddiqui
Investigation of aquaculture pond's thermal regulation via geothermal ground loop

M. Mahaffy – MESc Student, Supervisor: Dr. K. Siddiqui
Characterization of droplet dynamics for jets in cross-flow and counter-flow

K. Toxopeus – MESc Student, Supervisor: Dr. K. Siddiqui
Investigation of flow behavior in a PCM-embedded flow channel

S. Jevnikar – Research Associate, Supervisor: Dr. K Siddiqui
Thermal device for the transportation of bio-organisms

M. M. Allaf – Postdoctoral Fellow, Supervisor: Dr. H. Peerhossaini
Active fluid mechanics and biology

Z. Habibi – PhD Candidate, Supervisor: Dr. H. Peerhossaini
Mechanics of active fluids – cell-cell interactions

Z. Samadi – PhD student, Supervisor: Dr. H. Peerhossaini
Active fluids – numerical simulations

M. Shams – MESc Student, Co-Supervisors: Dr. H. Peerhossaini and Dr. C.T. DeGroot, Dr. J. Voogt,
Modelling of urban heat islands

Facilities and Equipment

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.

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 can 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

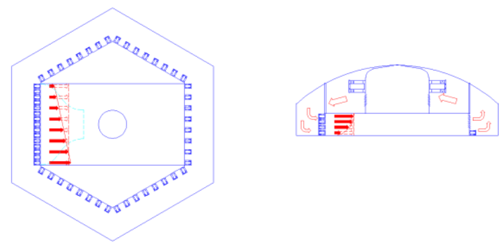


Figure 1 – Straight Flow Closed Loop

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

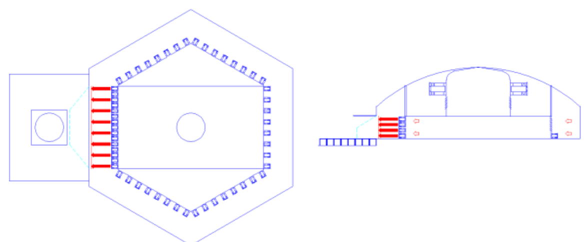


Figure 2 – Straight Flow Open Loop

Tornado

- Replication of EF0-EF3 tornados
- Properly scaled tornado flow
- Geometric scale 1/50 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

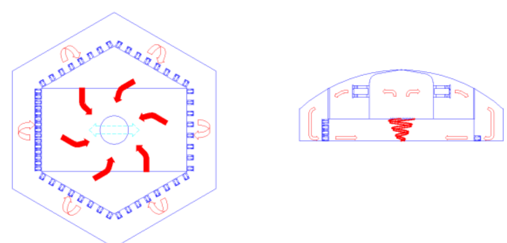


Figure 3 – Tornado

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

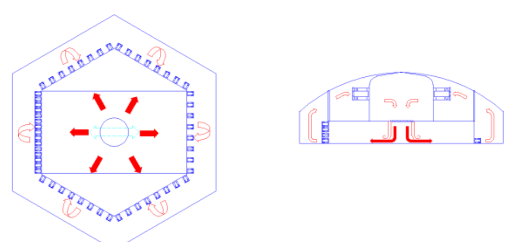


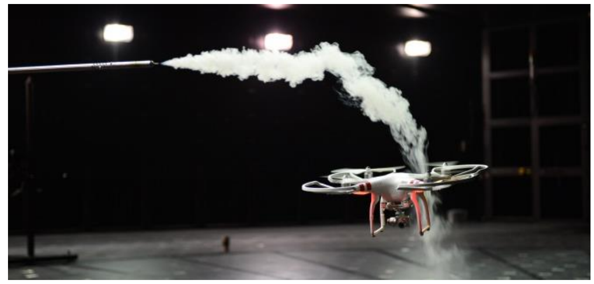
Figure 4 - Downburst

Example Uses

WindEEE Dome 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.

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., 2014. "The Wind Engineering Energy and Environment (WindEEE) Dome at Western University, Canada", Wind Engineers, JAWE, Vol. 39pp.35

Research

Wind Engineering

- Tornado wind loading on essential buildings
- Tornado induced external and internal pressures on low rise buildings
- Downburst effects on utility transmission lines
- Wind loading on full scale roof mounted solar panels
- Wind effects on ground mounted solar panels
- Destructive testing on prototype buildings
- Numerical simulations of tornadic and downburst flows
- Finite Element Analysis of collapse modes due to wind

Wind Energy

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

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 object

Experimental investigation of large-scale tornado-like vortices

Tornadoes are one of the most pressing research topics in wind engineering due to the extensive damages they impact on infrastructure and the environment. The proper scaling of experimentally produced tornado-like vortices (TLVs) against actual tornadoes is, therefore, a quintessential part of assessing tornadic damages on the built environment. The Wind Engineering, Energy and Environment (WindEEE) Dome at Western University has already demonstrated its capacity to generate TLVs characterized by length scales in the range between 1:300 and 1:150 by using only a part of the full potential of this simulator.

This paper introduces a new experimental mode of the WindEEE Dome operation intending to create larger-scale TLVs in the geometric scaling approximately 1:50. In addition to the six upper fans (source of suction) and the peripheral louvers (source of swirl) that were used in the previous TLV simulations, the new tornado mode of the WindEEE Dome also utilizes the peripheral fans situated along the periphery of the testing chamber as an additional source of angular momentum in the inflow.

The simulated TLV is scaled up and compared against published Doppler-radar data of an actual tornado in the United States. Our analyses show that the WindEEE Dome large-scale TLV corresponds to EF0 to EF2-rated twisters in nature. The geometric scale of the produced TLV is ~1:50. This large geometric scale of the TLVs facilitates the experimental investigation of tornadic actions on structures, including aeroelastic testing of wind-structure interactions.

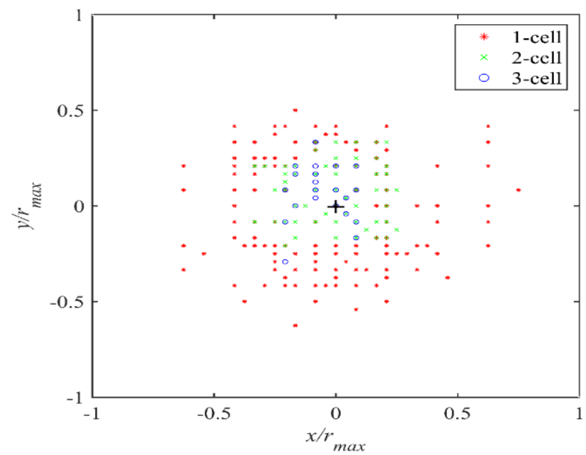


Fig. 1. Distribution of vortex centers in the 1-, 2-, and 3-cell structures of Mode B TLVs around the center of the turntable (the elapsed time from 0 to 30 s with a frequency of 20 Hz for S=0.853 and normalized by r_{max}=1.2 m).

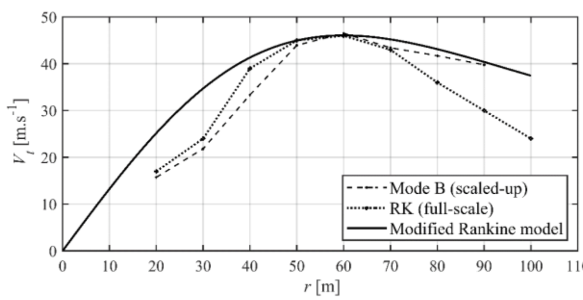


Fig. 2. Comparison of radial profile of the tangential velocity in scaled-up Mode B TLV (1:6.5 for velocity and 1:50 for length) and RK tornado. Vertical profiles are matched at r_{max}=60 m.

Arash Ashrafi / aashra22@uwo.ca
Horia Hangan / hmhangan@uwo.ca

Wind and ice effects on transmission lines

Atmospheric icing on mountainous terrain can produce catastrophic damages to transmission lines when incoming particles impinge and accrete on the cable surface of the system. For instance, in Quebec and Ontario, during the winter of 1998, a severe ice storm without precedents in recent history produced the collapse of 1,300 power-line towers and 35,000 distribution towers leaving millions of people without electricity for weeks and severely affecting their lifestyles. In Sweden in 1999, the power supply was interrupted for several hours in a 130-400 kv system due to ice accumulation on an insulator. In 1990, 20 cm of radial ice accretion were reported in a 400 kv system located in the United Kingdom which produced several incidents and failures during the icing event. In 2010 in Catalonia, where transmission lines are usually not design to withstand severe ice storms due to the low probability of the events, the extra vertical load produced by the ice accretion resulted in costly repairs which took six weeks to complete.

The first challenge in wind-ice loading is determining joint statistics of wind and ice accretion on transmission lines. With those statistics it is possible to estimate the joint hazard and build joint hazard contours. The hazard contours indicate the probability of exceedance for a given mean year recurrence interval (MYRI) and are usually represented by the following example: 2%, 50. The second challenge of wind and ice loading is to deal with the wind induced vibrations when the iced conductors present complex asymmetrical shapes. The vertical galloping, characterized by high amplitude and low frequency motions, produce extra tension to the transmission towers which is not considered in the Canadian standard (CSA-C22.3) for the design of wind and ice loads for overhead transmission lines. For the dynamic analysis, the Den Hartog's principle is applied to identify potential instabilities and the linear theory of free vibrations of a suspended cable is performed for the estimation of the extra tension produced by the free stream velocity acting on the one-degree-of-freedom iced conductor. The static and dynamic loading resulting from the present study are compared with the wind and ice design cases based on the Canadian standard (CSA-C22.3) and for three reliability levels related to the 50, 150, and 500 year return periods, respectively. For this report, the results of the analysis using a 10 m/s wind velocity and for the first reliability level related to the 50-year return period are shown.

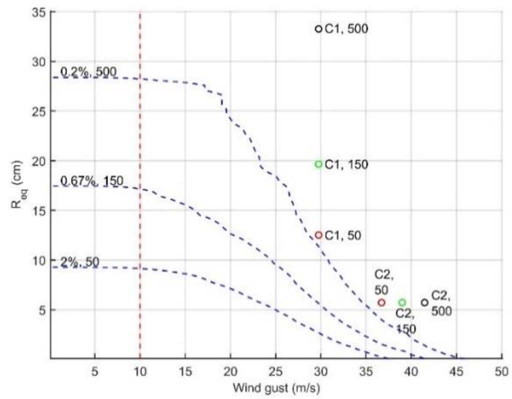


Fig.1. Hazard contours representing three different reliability levels and the radial ice accretion data pair for a 10 m/s wind speed

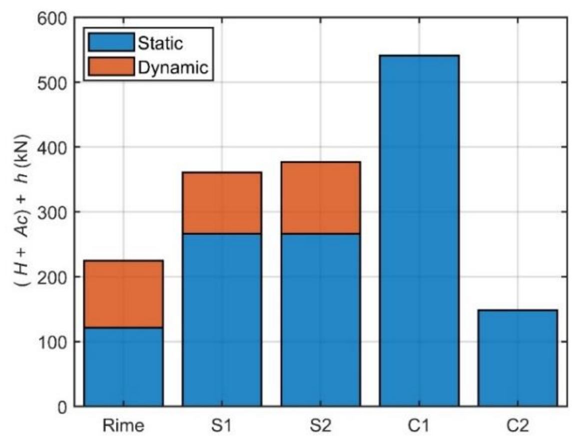


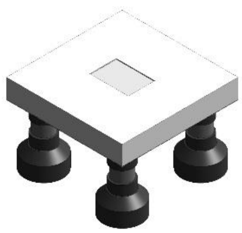
Fig 2. Static and dynamic effects transmitted to the tower due to wind and ice loading

Nomenclature: **Rime**: Static and dynamic effects for a rime ice accretion profile. **S1, S2:** Static and dynamic effects for complex glaze ice accretion profiles. **C1, C2**: Combined wind and ice effects considered in the Canadian code. **H**: Tension transmitted to the tower due to vertical loads. **Ac**: Tension transmitted to the tower due to horizontal loads. **h**: Tension transmitted to the towers on the onset of galloping

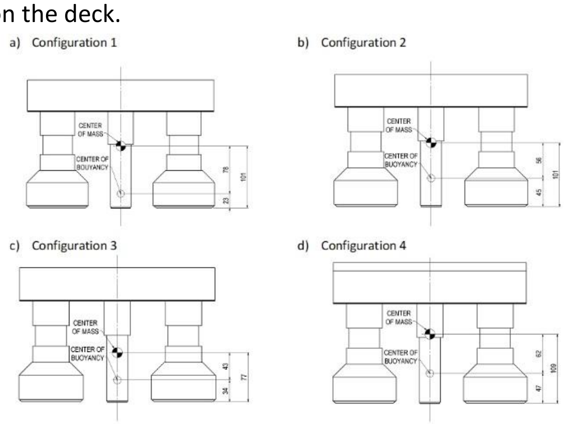
Daniel Davalos / ddavalos@uwo.ca
Horia Hangan / hmhangan@uwo.ca

Experimental Investigation of the Movement of an Offshore Floating Platform in Straight Wind, Tornadic Wind, and Downburst Conditions

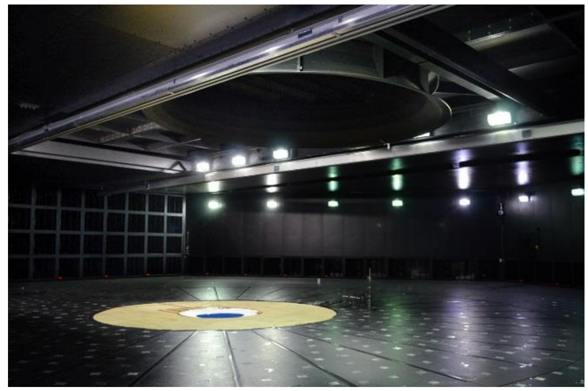
There is growing interest in multi-purpose offshore floating platforms that: harvest energy from the sun, wind, water, and waves; desalinize water; host agriculture and aquaculture; and house residents. While there are some basic commonalities with well established, oil and gas platforms, lighter variants are functionally different with little wind research coverage. Here we investigate a floating, multi-purpose, light duty platform under 1:150 scaled straight atmospheric boundary layer wind (ABL), tornado like vortices (TLV), and downburst (DB) conditions.



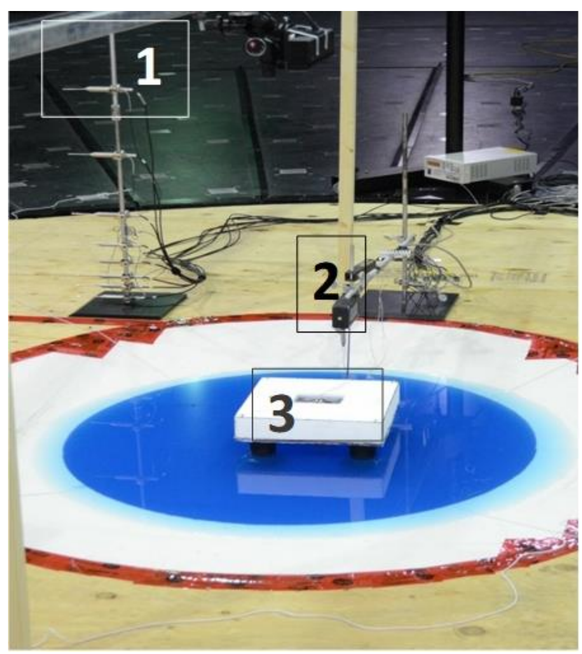
The experiments examined the movement of a 1:150 geometrically scaled platform with six degrees of freedom and two mooring Configurations. Four Configurations are studied, (1) Loosely moored platform, (2) Tightly moored platform, (3) Platform with ballast, and (4) Platform with ballast and weight on the deck.



These experiments marked the first time that water was brought into the WindEEE wind chamber at Western University. Since testing within water had not been done here before, a custom water tank was configured and brought into the wind chamber.

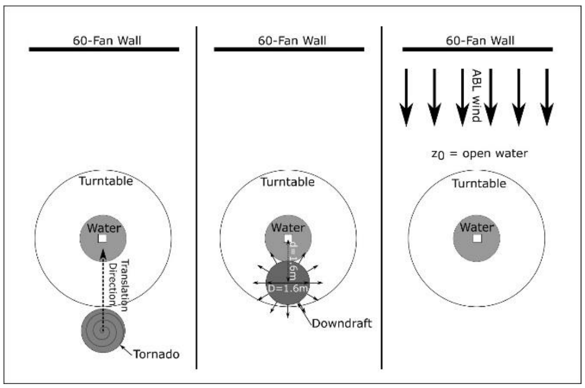


Various customized instrumentation was also used during these experimental tests, including accelerometers to measure the linear acceleration of the platform, an IMU device to record the platform rotations, a wave probe to measure the wave height at one location within the water tank, and cobra probes to record the wind profile data.

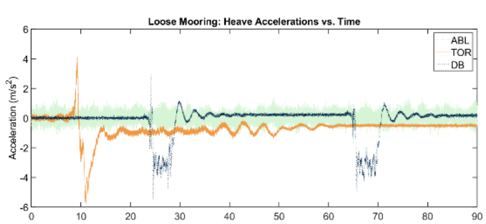


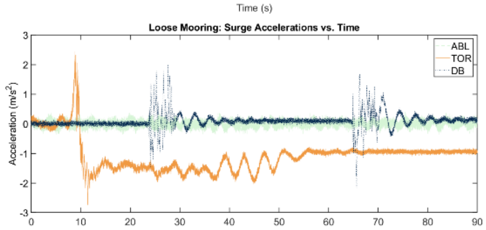
Instrumentation Set-up: (1) Cobra Probes, (2) Resistance wire wave probe (3) Floating platform with the IMU and accelerometers. The ABL wind is coming from left.

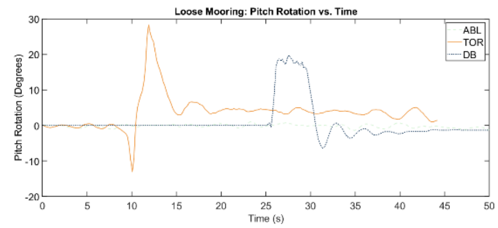
It was found that continuously, the TLV cause very large, sharp movements in the platforms when the tornado first hit. The downburst caused large, high frequency oscillations of acceleration for each platform configuration during its duration. The downburst did cause the loosely moored base platform to remain at an angle during its duration as well. The tightly moored configuration experienced much lower magnitudes of motion for every wind profile, compared to the loosely moored system with the same platform configuration. The tight mooring lines also lead to the greatest rotational stability.



Adding ballast to the platform generated lower magnitudes of motion following the initial peaks when the winds first hit the platform. The ballasted platforms also experienced lower magnitudes of rotation, but they had more sharp back and forth rotations than the platforms without the ballast addition. The greatest heave stability was found in the platform with ballast and a top-heavy deck.







Taken together, these studies provided initial insight to the differences in platform dynamics during various extreme winds and demonstrate the need to test offshore structures in harsh conditions, and to consider the findings for design standards. These experiments also proved the ability to test water within the WindEEE Wind chamber at Western University, allowing the utilization of their unique abilities for offshore structure testing.

Sarah Nichol / nicho11b@uwindsor.ca
Rupp Carriveau / rupp@uwindsor.ca
Lindsay Miller / ljmiller@uwindsor.ca
D. S-K. Ting / dting@uwindsor.ca
Djordje Romanic / djordje.romanic@mcgill.ca
Adrian Costache / acostach@uwo.ca
Horia Hangan / hmhangan@uwo.ca

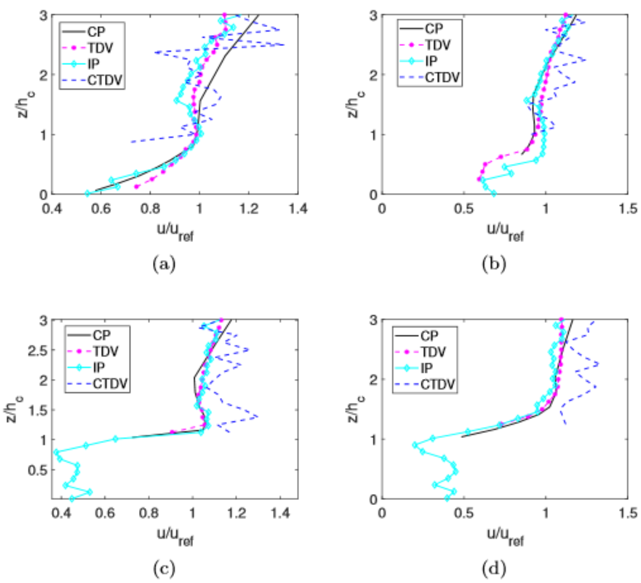
Trace Detection Velocimetry methods for large scale experimental flow field measurements

Two new methods for measuring flow fields in wind tunnel facilities are advanced. The methods presented here have the potential to provide measurements over larger volumes and be cost efficient compared to other frequently used particle imaging techniques. The two new measuring methods are called here Trace Detection Velocimetry (TDV) and Colored Trace Detection Velocimetry (CTDV). The equipment used for the tests consists of a digital camera, a light source and tracer particles.

The first method allows for a rapid extraction of two dimensions - two components (2D-2C) of the flow field while the second method adds a three-dimensional visualization of the particles in the volume with the addition of color to the test volume.

The two methods are applied for flow over a forest edge model for which previous point measurements and CFD simulations were available. The advantages of both Trace Detection Velocimetry and Colored Trace Detection Velocimetry are their capacity to produce 2D-2C and 3D-2C velocity vector fields respectively without requiring complex 3D optical-geometric calibration prior to the experiments.
Given enough streaks and a relatively small illuminated depth the TDV method can yield accurate two-dimensional flow speeds. Colored TDV is at this stage a general visualization technique that can be improved by using carefully chosen colors, higher reflecting tracer particles and better color capturing cameras.

Marilena Enuş / menus2@uwo.ca
Horia Hangan / hmhangan@uwo.ca



Impact probe (IP) and Cobra probe data (CP) versus TDV and CTDV results - normalized *u* component in (a) *x=-1.5hc*; (b) *x=0*; (c) *x=1.5hc* and (d) *x=3.375hc.* The variable *hc* is the forest canopy height which is 400 mm

Tornado-Induced Internal Pressures on Low-Rise Buildings

Tornadoes pose a huge threat to life and properties. Every year, tornadoes claim the lives of 60 people in the United States, on average, and leave more than 1000 injured according to NOAA. Moreover, the damaging behavior of tornadoes to properties, either partially or totally, leads to economic losses reaching billions of dollars. This destruction is attributed to the net induced wind loads on buildings. The effects of atmospheric pressure deficit (APD) due to the high negative pressure in the tornado vortex as well as the tornado flow-structure interaction add together to form the resultant tornado-induced wind loading. The tornado interaction with the structures is divided into two main components, (a) the external pressure loading, and (b) the internal pressure.

The internal pressure plays a significant role in determining the overall wind loading on buildings, therefore their precise measurement is crucial. Most of the studies on tornadic flow concentrated on external pressures and few studies examined the role of internal pressure in rising or supressing the net wind loads. Studies of induced internal pressures inside buildings in tornadic flow-field have started only recently in 2009, unlike internal pressure studies in atmospheric boundary layer (ABL) flows which have been studied extensively since the seventies. One of the main reasons for the lack of internal pressures in tornado-like vortices is the size of most of the simulators which does not allow a model size that is large enough to be properly instrumented. Hence, a need for a more comprehensive study about internal pressure loadings inside low-rise buildings with taking into consideration the effect of building size, building offset from tornado translation path, building orientation, opening configurations, higher translation speed as well as higher resolution using appropriate-sized models is crucial for better understanding the tornado-structure interaction for low-rise buildings.

Two generic low-rise building models from the NIST aerodynamic database with a geometric scale of 1:100 and a gable roof slope of 1:12 (4.76°) were employed in this study (Fig. 1). The two building models have dimensions of (572 mm × 365.8 mm) and (191 mm × 122 mm), respectively. The eave height of both buildings is 73.2 mm. The models were located along the path of translating tornadoes equivalent to EF-1 and EF-2 tornadoes with a translating speed of (≅ 1.5 m/s).

Results show that It is found that for all the cases of the current study, the internal pressure taps' measurements are highly correlated with correlation coeffecient $R_{xy} > 0.9$. In addition, building offsets were found to have an important effect on the peak internal pressure (Fig. 2). Peak internal pressure were shown to decrease by 2/3 in the outer core compared to the core region of the translating TLVs.. In addition, the relation between the offset distance and the peak internal pressure is not linear.

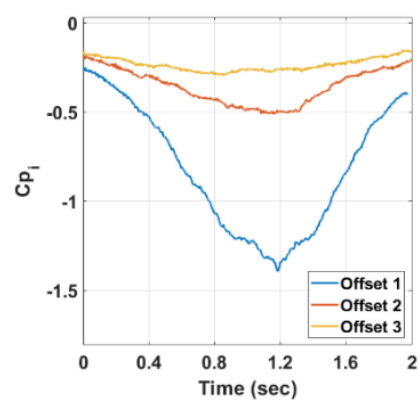
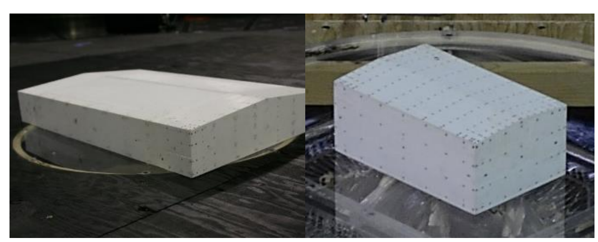


Figure 1. Effect of offset on internal pressure for S=0.76 (EF-2)



(a) (b)

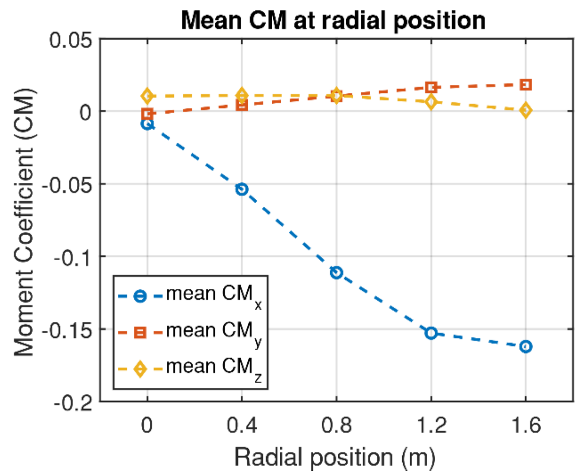
Figure 1. Building models (a) Large building, and (b) Small building

Aya Kassab / akassab@uwo.ca
Jubayer Chowdhury / cjubaye@uwo.ca
Horia Hangan / hmhangan@uwo.ca

Experimental study of tornado-induced loads on a wind turbine model.

Wind energy has become the fastest-growing energy source in the world, and according to the International Renewable Energy Agency, the global installed wind capacity has increased by a factor of 75 in the last two decades, and new large-scale wind turbine installations are expected to continue growing. However, to maximize the profitability of large-scale investments in wind farms, wind turbine rotors have been continuously increasing. As a result, the loads produced by the driving torque, the thrust force, and the gravitational weights of the wind turbine elements under extreme weather event effects can generate simultaneous loads and dangerous cumulative effects. Inevitably, large wind turbines are elastic structures, and according to the simple beam theory, increasing the length of the blades will cause more flexibility and dynamic stresses due to wind loads. Additionally, new wind farms extend over large areas with abundant wind resource capacity, exposing new large-scale wind turbines to extreme weather events such as tornadoes.

Although wind turbines are designed to withstand high-speed winds, international standards only evaluate scenarios produced by Atmospheric Boundary Layer (ABL) flows. Therefore, these codes exclude events related to tornadoes, which possess three-dimensional winds with significant tangential and vertical velocity components. A study of proper scaled tornado-induced loads on a rigid wind turbine model was performed in The WindEEE Dome at Western University. Preliminary results showed a high dependency on the thrust and bending moment on the wind turbine with respect to the vortex center distance of the tornadic flows for time-average loads taken for a stationary tornado case. Furthermore, loads on a parked rotor are lower in contrast to an idling rotor. Future work concerns deeper analysis of the aerodynamic response on blades using a servo elastic wind turbine model. Results from this research can improve load prediction models, international standards, as well as wind turbine control strategies during tornadoes, and consequentially reduce operational and structural failures.



Mean CM at different radial locations with respect to the tornado vortex center for the parked rotor mode. CM_x is the bending moment and CM_z is the twisting moment of the wind turbine.

Juan Pablo Lopez / jlopezor@uwo.ca
Horia Hangan / hmhangan@uwo.ca

Environmental impacts of high intensity winds on communities

Although research on tornadic flows has been extensive in previous decades, the understanding of its effects on buildings and structures is limited. In particular, the pressure distribution on facades of buildings and loadings on them are poorly understood. In order to improve tornado resilience and reduce the damage associated with these events, research must be done to evaluate the loadings on real communities. On the other hand, it is important to quantify the loss that a certain tornado can create in a community. For that purpose, fragility curves must be developed.

In this project, the calculation of pressures and loadings under different extreme wind events are made for two real communities. One situated in Kansas, in the heart of "Tornado Alley" and the other in Dunrobin, Ontario. The latter location was hit by an EF3 tornado in September 21, 2018. This is done through physical simulation at WindEEE. As mentioned before, the other objective of this project is to combine the loading on buildings with fragility curves to quantify the loss in property value. Finally, the results will be compared with data from real events compiled by ICLR.

The enveloped pressure coefficients obtained on the zones indicated in ASCE 7-16 on one low-rise building from the Dunrobin community indicate that the original provisions developed for straight line winds are not safe in case of EF1 to EF3 tornado-induced loads. By using the tornado factor incorporated in ASCE 7-16 the provisions provide safe recommendations in zones near the corners and edges of the roof but fail on the central part of the roof.

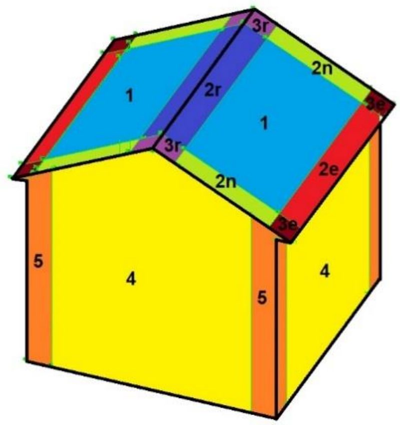


Fig.2. Low-rise residential building from Dunrobin community with ASCE 7 zones indicated.

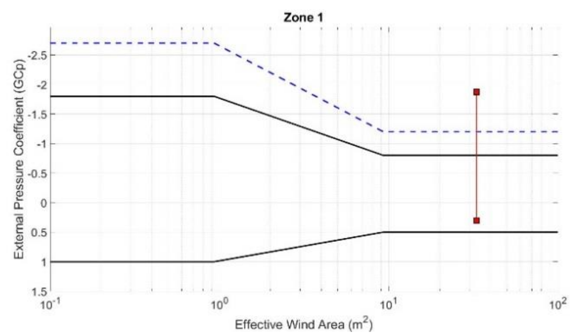


Fig. 3. Maximum and minimum enveloped pressure coefficient in zone 1 compared to ASCE 7 provisions.

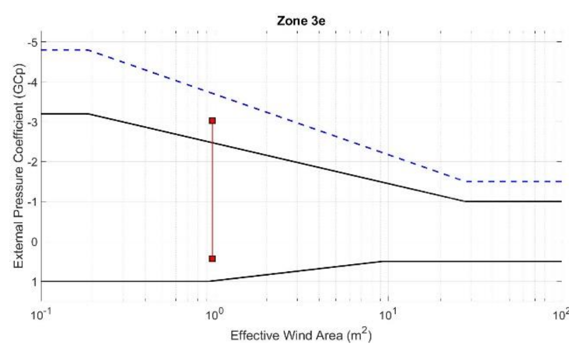


Fig. 4. Maximum and minimum enveloped pressure coefficient in zone 3e compared to ASCE 7 provisions.

Gabriel Narancio / enaranci@uwo.ca
Horia Hangan / hmhangan@uwo.ca

Experimental Investigation of the Interaction Between Near-Surface Atmospheric Boundary Layer Winds and Downburst Outflows

Coupling between ambient atmospheric boundary layer (ABL) and downburst winds is one of the pressing questions in atmospheric sciences and wind engineering. This research investigates the interplay between these two wind systems through a set of physical experiments carried out inside the WindEEE Dome. The coupling between downburst and ABL winds was investigated for five different radial distances from the undisturbed downdraft center, seven different azimuth angles in respect to the incoming ABL winds, and six different heights above the floor. This study also introduced a methodology for the segmentation of velocity records of physically produced downburst into transient and steady-state parts.

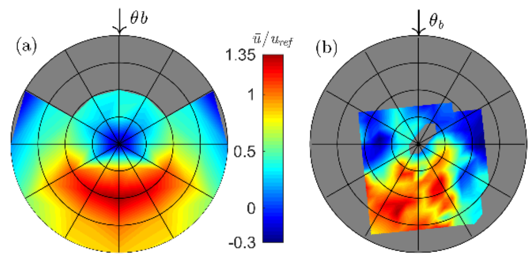
We demonstrated through a series of different analyses that isolated downbursts (DB); i.e., downbursts without background (ABL winds) and DBABL downbursts (i.e., downbursts immersed into background ABL winds) are profoundly different in terms of mean and peak velocities, as well as turbulence intensities. The discrepancies between the two outflows highly depend on the position in the outflow and the time.

The study also demonstrated that the vector addition of downburst radial velocities and ABL winds is inaccurate throughout the flow field, i.e.:

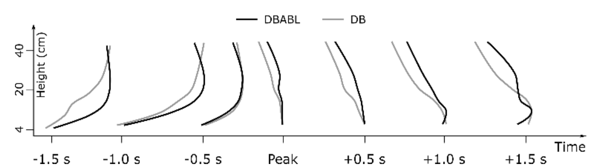
$$\overrightarrow{\mathrm{DBABL}} \neq \overrightarrow{\mathrm{DB}} + \overrightarrow{\mathrm{ABL}}.$$

In some regions of the DBABL outflow, this simple vector addition of DB and ABL winds produces enveloped peaks that are more than two times smaller than the observed values in the DBABL outflow. Moreover, this region of peak underestimation is situated in the highly turbulent part of the DBABL outflow.

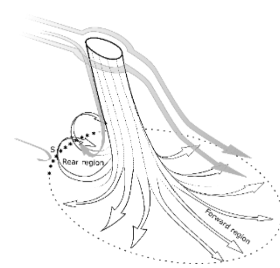
This study also compared the enveloped peak and instantaneous maximum radial velocity profiles in the DBABL outflow to several Doppler radar measurements of real thunderstorm winds from the United States and Australia. The similarity between enveloped peaks in the experiments and reality is higher than the similarity between the instantaneous profiles in the outflows. The results were also benchmarked against numerical simulations of DBABL winds. The experimentally produced DBABL flow field showed the beam-shape spatial pattern similar to that of the real downbursts in ABL winds. The overall resemblance between the experiments and reality warrants high fidelity results.



Normalized radial velocities in the DBABL outdlow in the WindEEE Dome (a) and real downburst observed using Doppler radars (b). The incoming direction of background ABL winds denoted with θ_b.



Evolution of DB and DBABL radial velocity profiles at a fixed position in the outflow. Velocities are normalized with the maximum velocity, while the height (in cm) and time (in s) are not normalized.



Conceptual model of the DBABL outflow. The symbol "S" in the rear region indicates the stagnation point in the flow due to the opposite vorticity in the DBABL outflow and ABL winds. The frontal line made of the star symbols in the rear region indicates the maximum radial distance to which the primary vortex can advance.

Djordje Romanic / djordje.romanic@mcgill.ca
Horia Hangan / hmhangan@uwo.ca

A Novel Approach to Scaling Experimentally Produced Downburst-Like Impinging Jet Outflows

This study introduces a novel scaling technique of downburst outflows aiming to reproduce specific downbursts detected at the full-scale, or families of these, in an experimental facility. Scaling of downburst events is a key aspect of wind engineering, both with regard to laboratory simulation of the flow as well as to the investigation of downburst wind loading, wind-induced response and aeroelastic effects on structures. We demonstrated through a series of different analyses that isolated downbursts (DB); i.e., downbursts without background (ABL winds) and DBABL downbursts (i.e., downbursts immersed into background ABL winds) are profoundly different in terms of mean and peak velocities, as well as turbulence intensities. The discrepancies between the two outflows highly depend on the position in the outflow and the time.

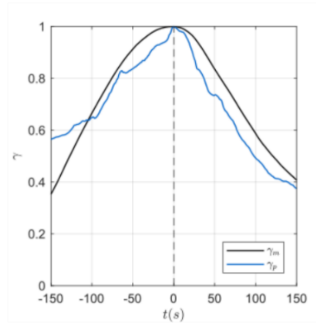
The proposed method compares the γ functions of modelled downbursts in a wind simulator (*m* downbursts) and full-scale downburst events (*p* downbursts). The γ function, defined as a ratio of the slowly-varying mean and the maximum value of the slowly-varying mean, describes in non-dimensional form the highly transient downburst time series characterized by velocity ramp-up, peak, and slowdown of wind speed. The best match between γ_p and γ_m is obtained through a parametric procedure which finds the best averaging window of *m* data.

The scaling method was tested on 1400 *m* downburst records experimentally simulated in the WindEEE Dome and on 17 *p* records from the Mediterranean in Italy. The *p* downbursts are measured under the scope of the European project "Wind and Ports". This dataset is the largest collection of *p* and m downbursts analyzed so far.

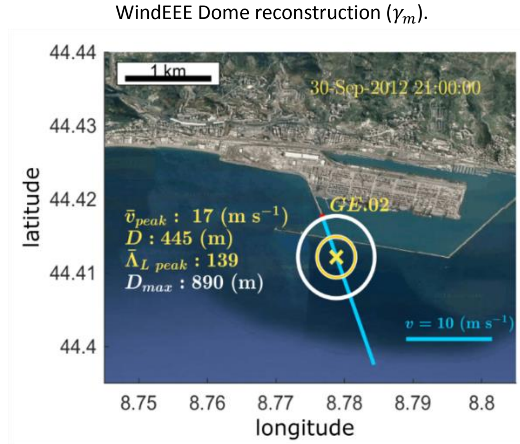
The simulated downbursts in the WindEEE Dome closely resemble the transient features of *p* downbursts both qualitatively and quantitatively. This similarity is demonstrated by comparing the γ functions of *p* and *m* records and by inspecting their slope and symmetry for different averaging times. In addition, the μ functions (i.e., a ratio of the slowly-varying turbulence intensity in time and its mean value) between *p* and *m* records are also analyzed and their similarity is confirmed. While γ describe the mean feature of the flow, the μ functions describe the fluctuating (turbulent) properties of downburst outflows. It was concluded that each γ function can be represented as a sample of a highly transient random process, whereas the μ functions are quasi-stationary and deterministic.

The typical velocity and time scales between the investigated *p* and *m* records are found to be between 2:1 to 4:1 and 40:1 to 70:1, respectively. However, significant deviations from these values are also observed. The resulting length scales are obtained as the product of velocity and time scales and they are in typically around 100:1 to 250:1, and similar.

The proposed scaling method was validated on several *p* downburst events from the Mediterranean. In addition, the scaling method enabled a partial reconstruction of the selected *p* events in terms of evaluating the radial distance of downburst touchdown and the radius of the maximum wind speed in the downburst outflow in respect to the anemometer positions.



The γ function of the full-scale downburst event (γ_p) and the WindEEE Dome reconstruction (γ_m).



Reconstructed location of a full-scale downburst close to Genoa (Italy) using WindEEE Dome simulations

Djordje Romanic / djordje.romanic@mcgill.ca
Edoardo Nicolini / edoardonicolini1993@gmail.com
Horia Hangan / hmhangan@uwo.ca
Massimiliano Burlando/ Massimiliano.burlando@unige.it
Giovanni Solari / giovanni.solari@unige.it

Investigation of the Transient Nature of Thunderstorm Winds from Europe, United States and Australia Using a New Method for Detection of Changepoints in Wind Speed Records

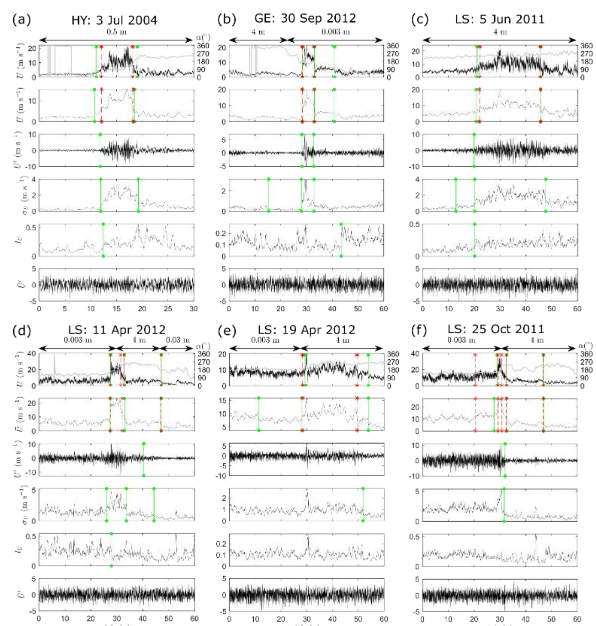
This study investigated the transient characteristics of thunderstorm winds by using an objective method for the detection of changepoints in velocity records. The method seeks changepoints in anemometer records based on the statistical properties of different segments of time series. The investigated wind statistics were the mean (M) and standard deviation (SD). We considered 41 velocity records from 19 thunderstorm wind events from Europe, the United States (US) and Australia. The changepoint analysis was applied not only to the instantaneous velocity records but also to the decomposed time series in the form of slowly-varying moving mean, moving standard deviation and moving turbulence intensity, as well as the residual turbulent fluctuations.

The proposed methodology separated the central thunderstorm wind peak from the rest of the velocity records. The M and SD changepoints in the instantaneous velocity records coincide with the location of changepoints in the records of slowly-varying velocity. This result demonstrated that the abrupt changes in the velocity records caused by the thunderstorm passage are predominantly associated with the changes in the mean (i.e., large scale) flow features. The SD segments that encompass the thunderstorm peak are usually longer than the M segments.

This systematic observation suggests that the changes in velocity fluctuations often precede and proceed the abrupt changes in the mean flow. This study did not find any methodical relationship between the time occurrence of changepoints in either M or SD statistics and the surface roughness changes associated with the shifts of wind direction during the thunderstorm wind episodes. It seems that the thunderstorm outflows might be too localized and transient to establish the flow equilibrium with the underlying surface. The absence of systematically detected changepoints in the records of slowly-varying turbulence intensity and SD for continually changing wind direction during some thunderstorm episodes partially supports the conclusion that the time evolution of thunderstorm winds is rapid to the point the flow field does not reach equilibrium with the terrain roughness.

The study further showed that the maximum velocity during the thunderstorm peak in the events from Europe is usually between 2 and 4 times larger than the mean wind speed before the event. This ratio seems to be higher for US events, but the analyzed sample was too small to conclude this result firmly. Also, the US events were more organized thunderstorm systems than the isolated thunderstorms in Europe, and this difference in thunderstorm morphology is probably an important factor that governed the above ratios. The duration of the thunderstorm velocity peak was 2–5 min in approximately 60% of the records segmented using the M cost function and 5–10 min long when the records were partitioned using the SD statistic.

Also, the ramp-up times of the mean flow were below 2 min in approximately 50% of the analyzed velocity records. Here, the ramp-up time was defined as the time interval between the velocity peak in the slowly-varying velocity record and the first changepoint before the velocity peak. The ramp-up time was longer when the records were analyzed using the SD cost function.



Change points detected using the M (red line) and SD (green line) methods applied to decomposed velocity records (subplots) of the several (a–f) thunderstorms from Europe.

Djordje Romanic / djordje.romanic@mcgill.ca
Junayed Chowdhury / cjunayed@uwo.ca
Jubayer Chowdhury / cjubayer@cppwind.com
Horia Hangan / hmhangan@uwo.ca

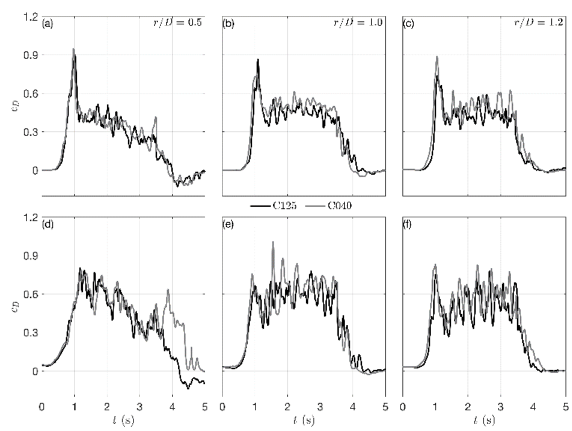
Aerodynamic Coefficients and Pressure Distribution on Two Circular Cylinders with Free End Immersed in Experimentally Produced Downburst-Like Outflows

This experimental study analyzed the surface pressures and aerodynamic coefficients on two circular cylinders with free end immersed in three different wind fields. The diameters of these two cylinders were 12.5 mm (C125) and 4 mm (C040). The investigated flow fields were (1) a downburst outflow (DB), (2) a downburst outflow supplemented by atmospheric boundary layer (ABL) winds (DBABL), and (3) the steady ABL wind. The motivation to conduct this research came from the continually increasing wind engineering interest to better quantify the wind effects of non-synoptic winds, such as thunderstorm downbursts, on various structures. Circular cylinders—being the classical bluff body that was most studied in the classical fluid mechanics literature—was, therefore, also the starting point of this research. The study provided the first comparisons between surface pressures and aerodynamic coefficients that resulted from these three different wind systems. The flow fields of experimentally produced DB and DBABL outflows were also examined.

The ABL winds caused a higher drag coefficient (c_D) than the two DB-like outflows on the C040 cylinder. The results are more height-dependent in the case of the C125 cylinder. The c_D overshoot—defined as the ratio of the peak c_D in the DB-like outflow and the mean c_D in the ABL wind—was higher in DB than in DBABL wind at the lower elevations and vice versa (or similar values) close to the top of the cylinders. At r/D=1.0 and 1.2, the c_D overshoot in the DB outflow around the C125 cylinder was consistently higher than one between z/L=0.1, and 0.4 (r is the radial distance from downdraft center, z is the height, D is the downdraft diameter, and L is the height of the cylinders). Also, the c_D overshoot in the DBABL outflow in the same height interval was below unity. Therefore, the inclusion of ABL winds in the DB simulations significantly influenced the aerodynamics of low-rise structures in the outer regions of the DB-like outflows.

The lift coefficients (c_Ls) during the passage of the primary DB-like vortex were negative at the base of the cylinders and approached zero or slightly positive values close to the cylinders' top. The change in a c_L sign was previously observed in high-shear flows in which there is a strong interplay between the inviscid and the wake effects on a cylinder's aerodynamics. In the study of ABL winds, the mean c_Ls are effectively zero. The location of the cylinders in the DB-like outflows is aerodynamically more significant than the diameter of a cylinder. This finding is profoundly different from the case of stationary ABL winds.

While the surface pressures for the windward and leeward taps at r/D =1.0 and 1.2 were symmetric around zero in the DB case; the symmetry line was shifted towards the positive value of the ABL wind pressures in the DBABL outflow. The pressure distribution at r/D =0.5 was profoundly different from that at the other two radial locations. The symmetry between positive and negative pressures at tap #1 (windward tap) and tap #7 (leeward tap in the wake region) that was observed at larger r/Ds was gone at r/D =0.5. The positive surface pressures everywhere around the cylinders at r/D =0.5 were due to the predominantly downward orientation of the DB and DBABL outflows at this location. The traditional notation of windward and leeward sides of a structure is not meaningful in the regions close to the downburst center.



Time histories of drag coefficient (c_D) on C125 (black) and C040 (grey) cylinders immersed in the DB and DBABL outflows (two rows) at three different r/Ds (three columns). The values are provided at z/L = 0.056 (i.e., 5 cm) above the ground.

Djordje Romanic / djordje.romanic@mcgill.ca
Andrea Ballestracci / andrea.ballestracci46@hotmail.it
Federico Canepa / federico.canepa@edu.unige.it
Giovanni Solari / giovanni.solari@unige.it
Horia Hangan / hmhangan@uwo.ca

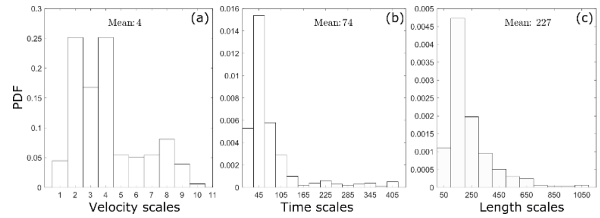
Scaling of Tornadoes and Downbursts: Relation between Full Scale and Model Data

This book chapter published by the Oxford University Press discusses recent results aiming to compare full scale data and simulations of tornadoes and to establish a framework through which simulations of tornado-like vortices (both physical and numerical) can be compared to full scale data. It is shown that the tornado geometric scaling involves two length scales corresponding to the height and the radius corresponding to the maximum tangential velocity. When plotted against a varying swirl ratio the two scales merge to a common scaling value. This frame for establishing a tornado scaling can be applied for any numerical and physical simulations and it allows for proper translation of results from model to full scale results.

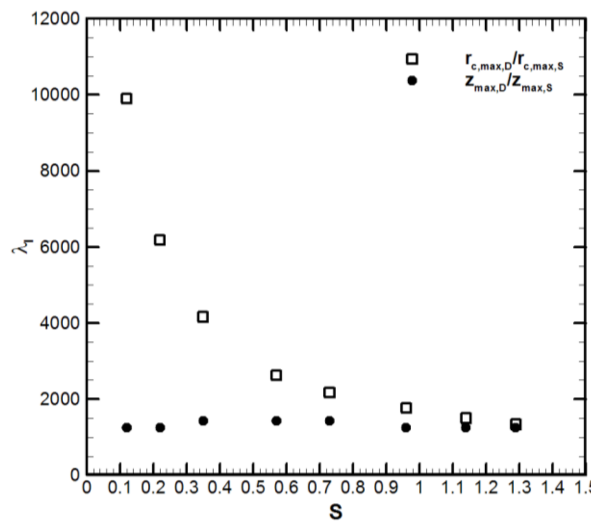
The chapter also introduces the last results related to the scaling of downburst events. A statistical approach proposed by Romanic et al. (2019b) compares the γ functions (defined as a ratio between the slowly-varying mean velocity and its maximum value) between modelled and full scale downburst events. The best match between γ_p and γ_m is obtained through an iterative procedure which finds the best averaging window of the modeled data (*p* stands for "prototype" and *m* stands for "model").

This scaling method is then tested on 1400 *m* downburst-like records experimentally simulated in the WindEEE Dome, and on 17 *p* records from the Mediterranean in Italy measured under the scope of the European project "Wind and Ports." The same scaling method can then be used to correlate the position and spatial extent of real and simulated events.

While the presented methodologies for scaling tornadoes and downbursts are quite different, they both focus on the main flow field. Once more full scale and simulation data will become available for the fluctuating velocity fields it is important to incorporate turbulence scaling in the two frameworks. In addition, the current methodologies of downburst scaling will have to be modified or new methodologies developed in order to account for physically produced downburst outflows embedded into atmospheric boundary layer winds.



The WindEEE Dome downburst scales: (a) velocity (mean flow), (b) time and (c) length scales.



Geometric scaling ratio as a function of swirl ratio for Happy, Texas (United States) 2007 tornado from 0203:20 to 0204:17 UTC.

Horia Hangan / hmhangan@uwo.ca
Maryam Refan / maryam.refan@rwdi.com
Djordje Romanic / djordje.romanic@mcgill.ca

Analytical and Semi-Empirical Models of Tornadoes and Downbursts

Experimental and numerical simulations of non-synoptic winds are many times complemented by analytical and semi-empirical models. These models are inexpensive to run and produce mostly mean flow fields that can be further used in several types of applications spanning from risk analysis, guidelines and codes as well as in estimating further effects such as debris flight passes and damage and losses to buildings and structures.

In this book chapter, published by the Oxford University Press, we presented a review of most of these models for tornadic and downburst flows. Some of these models are developed by employing simplifying assumptions in the Navier-Stokes equations and searching for exact, but many times inviscid solutions sometimes complemented by boundary layer equations to take into account the surface effects. Other use simple superposition of generic, canonical flows, for which the individual solutions are known. These solutions are then ensembled together by empirical or semi-empirical fitting procedures. Very few of these models try to address the turbulent or fluctuating flow fields. All models have a series of constants that are fitted against experiments or numerical simulations.

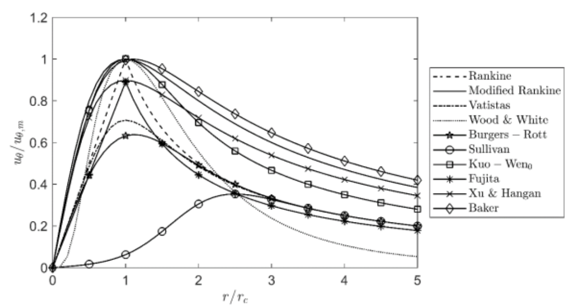
We have made an effort to present these models in an organized manner and to underline their assumptions and limitations.

The reviewed tornado models are:

- Rankine and modified Rankine vortex models
- Various improvements to the initial version of the modified Rankine vortex model
- Burgers-Rott model
- Sullivan model
- Kuo-Wen model
- Fujita model
- Xu and Hangan model
- Barker model
- Karami and Hangan model

The reviewed downburst models are:

- Oseguera-Bowles model and the modification proposed by Vicroy (OBV model)
- Various improvements to the original OBV model
- Verhoff model
- Wood moodel
- Mason model
- Holmes and Oliver model
- Xu-Hangan-Yu model
- Zhu and Etkin model
- Ivan model
- Schultz model



Radial profiles of tangential velocity calculated using different analytical models of tornadoes. Apart from Rankine and modified Rankine vortex models, the shape of all other profiles can be manipulated depending on the choice of model parameters.

Djordje Romanic / djordje.romanic@mcgill.ca
Horia Hangan / hmhangan@uwo.ca

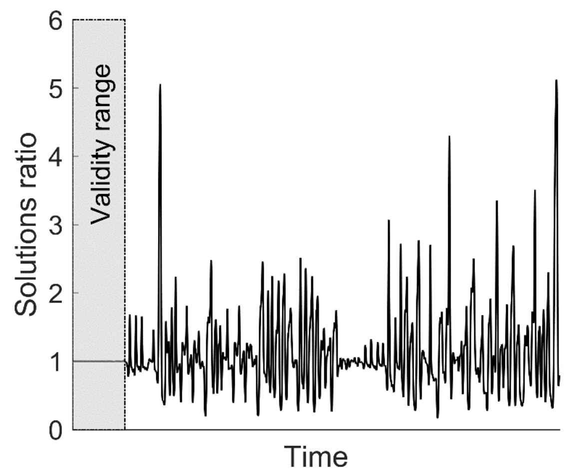
Forecasting of Tornadoes and Downbursts: Challenges, Prioritization, and Progress

This chapter published by the Oxford University Press summarizes the current state-of-the-art of tornado and downburst forecasting (TaDF). We first described the factors that prevent more reliable weather forecasts for the long prognostic periods. The discretization of partial differential equations (PDEs) that describe the atmospheric processes on a coarse grid is one of the main challenges for TaDF. This difficulty is due to the relatively coarse grid resolution (3 km or larger) in comparison to what would be needed (approximately 25–50 m) for the explicit modeling of TaDs. A simple increase of grid resolution is not a solution due to the limited computational power that is at our disposal. The effectiveness of nesting a finer grid inside a coarser grid was described in the context of TaDF. However, the research in this field is still new and restricted to specific and idealized case studies.

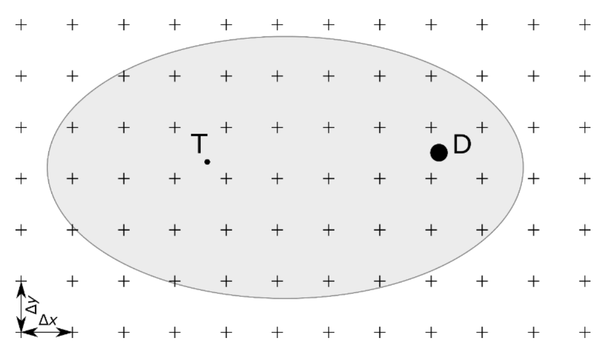
In weather forecasting, it is possible to distinguish between intrinsic and practical predictability of weather. The intrinsic predictability is related to the chaotic nature of the PDEs and that even small errors in initial conditions and inaccurate approximations will eventually grow to be arbitrarily large—the so-called chaotic nature of PDEs. Because this challenge is an intrinsic mathematical property of the system, there is very little that can be done to change it. The practical predictability is what currently can be done to improve the quality of weather forecasts. These include better meteorological measurements, more accurate numerical approximations, and, most importantly, more complete knowledge of natural phenomena (e.g., tornadogenesis and downbursts). Another factor related to practical predictability is data assimilation methodologies, which are techniques that combine observational data with numerical model outputs to generate an optimal estimate of the evolving state of weather.

Warn-on-Forecast (WoF) is one of the most recent TaDF attempts that combines rapid data assimilation of surface measurements, radar observations, and satellite data with high-resolution numerical models. The WoF system works towards issuing severe weather warnings based on model results supplemented with forecasters' supervision. Currently, the operational severe weather forecasts rely on the prediction of severe weather parameters and instability indices that are used as a proxy for the likelihood of a TaD occurrence.

The chapter also briefly summarized our current understanding of TaD formation. The goal was to familiarize the reader with the complexities of TaD development. While substantial progress has been made in this field over the last several decades, it is also necessary to recognize that one of the fundamental problems of TaDF is our inadequate understanding of TaD physics.



The ratio of two solutions to the system of differential equations that describe a certain atmospheric process. One solution was initiated with the number π = 3.142, while the other solution was initiated with the number π = 3.141593. Since π is an irrational number that never ends, we will always have to make rounding at some point and thus introduce an error into the system. After some finite time, the error will grow and result in an arbitrary inaccurate solution of the system. In this case, the validity range schematically represents the time interval over which weather forecasts are reliable



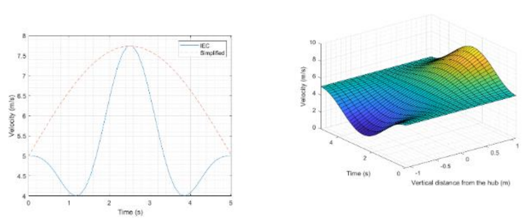
A 3-km grid is represented with black crosses. The symbols T and D represent a 300-m and a 1000-m wide tornado and downburst, respectively. The shaded ellipse is an idealized contour of a thunderstorm cloud. In this case, both tornado and downburst are sub-grid processes that cannot be directly resolved on this coarse grid.

Djordje Romanic / djordje.romanic@mcgill.ca

Simulating Operational Extreme Wind Conditions for Horizontal Axis Wind Turbines Based on the IEC Standard

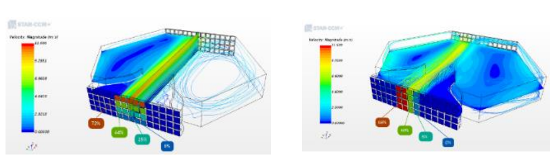
The possibility of simulating some of the deterministic extreme operational wind conditions for horizontal axis wind turbines based on the IEC 61400-1 at WindEEE dome was investigated. Using the 60 individually controlled fans and their adjustable Inlet Guiding Vanes (IGV), simulation of Extreme Operational Gust (EOG), Extreme Wind Shears (EWS) are considered (scaled for a 2.2 m HAWT, representing a full scale, 1:42). All these cases are deterministic and transient. This study is in three stages. Firstly, developing a numerical model for the test chamber. Secondly, experimentally simulating the extreme conditions based on the numerical model. The final step is to investigate the effect of these conditions on power generation and loading of the model wind turbine.

This study demonstrated the potential of the current setup for testing new design concepts for mitigating the effect of extreme conditions in future.



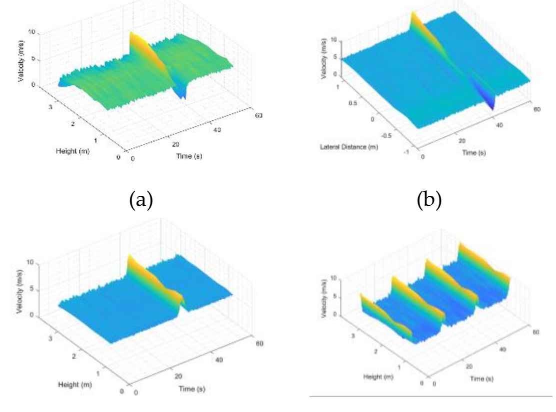
(a) (b)

The scaled extreme conditions for simulations and experiments based on the micro wind turbine and capability of the fans, (a) extreme operating gust, (b) extreme vertical shear



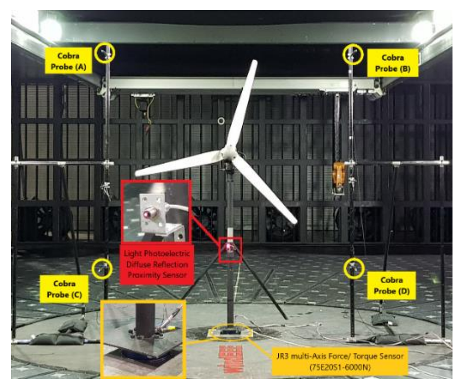
(a) (b)

Simulating the fan set-ups for peak stages of extreme shears (a) vertical and (b) horizontal, prescribed for the micro HAWT identical to full scale condition.

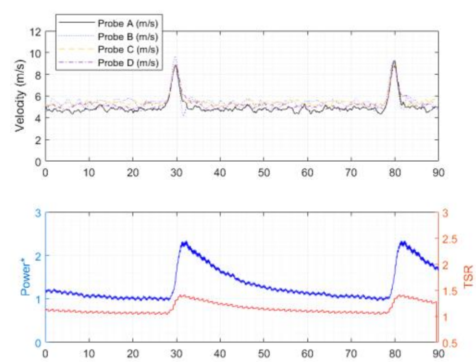


(a) (b) (c) (d)

3D pictures of the time history of the turbulent velocity field, (a) EVS, (b) EHS, (c) EOG generated with changing fan powers, (d) EOG generated with IGVs



(a)



(b)

The effect of extreme conditions on the wind turbine, (a) the setup, (b) the effect of EOG on power generation and rotor speed

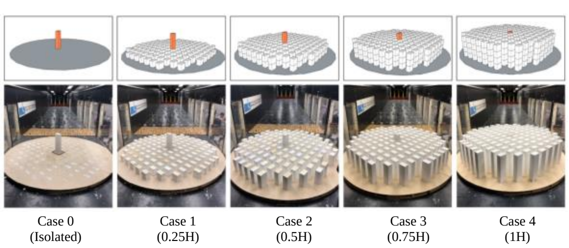
Kamran Shirzadeh / kshirzad@uwo.ca
Horia Hangan / hmhangan@uwo.ca
Curran Crawford / curranc@uvic.ca

Implications of city development on high rise buildings behavior

High rise buildings in growing cities can become more vulnerable to variations in wind flow due to the continuous changes in urban topology. This in turn can lead to changes in the wind pressure distribution on buildings surface. In this research, boundary layer wind tunnel tests are conducted to investigate the impact of city growth on cladding load of tall buildings. A typical tall building adopted from the Commonwealth Advisory Aeronautical Council (CAARC) building model (Melbourne, 1980) was used in this experimental program. The city growth is represented by five different generic surrounding configurations, varying in height ratios compared to the study building. The configuration includes quarter (C1), half (C2), three quarters (C3) and full height (C4) surrounding buildings, along with an isolated case scenario (C0). The results show a significant increase in pressure fluctuations on cladding elements as the surrounding building grow in height subjecting the building to more fatigue related wind-hazards.

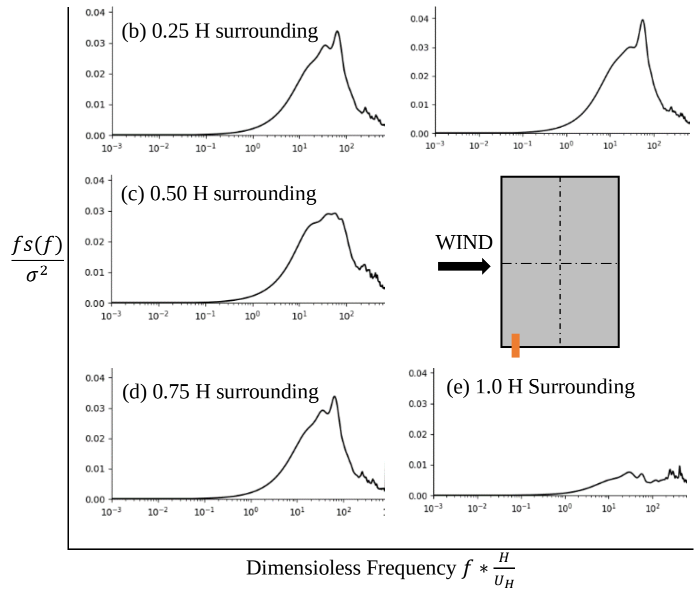
The highest peak suctions were also examined at different wind directions for all cases showing an extensive increase in the peak negative pressures for cases configurations C1 and C2

In the next step, the effect of city growth on the structural behavior of tall buildings will be investigated. This will give a vision on the impact of city behavior on the global behavior of structures.

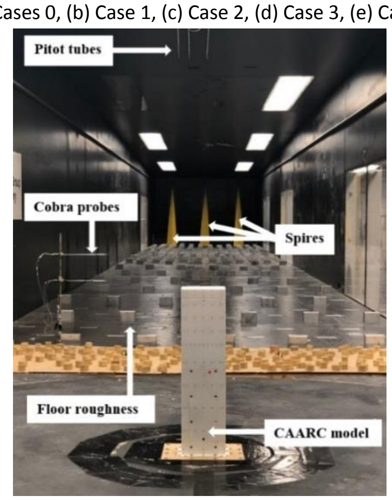


Different test configurations used in the experiments

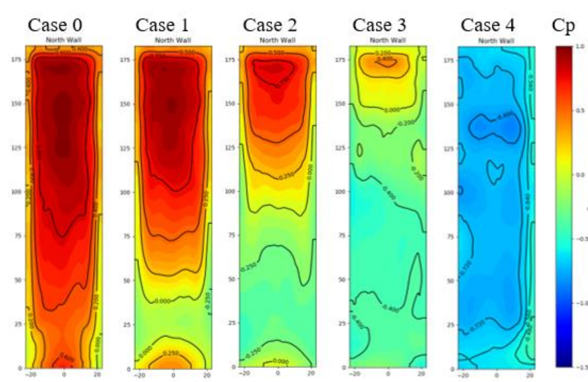
Hadil Abdallah / habdall4@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca



Power spectral densities of pressure at model height of 0.96H for (a) Cases 0, (b) Case 1, (c) Case 2, (d) Case 3, (e) Case 4 in Suburban



Experimental model installed at (UWO WIND TUNNEL) for the Isolated case 0 at AoA=0°



Mean pressure coefficients (Mean Cp’s) on the Northern wall for 0° angle of attack

A wind-based workflow for the multi-scale design of sustainable communities

In recent years, society has begun to notice how tall buildings redirect or block winds that challenge the comfort, health and safety of people all over the world. In some cases, fast winds can create windy conditions that can blow people off their feet, so we try to add wind walls and other mitigating elements but similarto all things, this has a cost, takes time and alters original designs in many cases. On the other hand, slow winds, blocked by the density of buildings may not be able to clean the pollutants in the air from cars or buildings that accumulate outside. Areas may have slow enough winds to walk safely, but become unsafe in a different sense. If these pollutants accumulate for long enough, they have the potential of seeping indoors. And since people spend 90% of their time indoors, a long exposure time (even with minimal pollutants) can be unhealthy. Buildings can increase their reliance on mechanical/ filtration systems to try to combat these pollutants, but this also contributes to large quantity of Co2 emissions caused by the overall building sector in Canada. In the end, dealing with wind from the start can help mitigate these problems before they become more serious. T workflow is needed to relate the building design across multiple wind issues at many scales.

To create this workflow, a combination of computational and physical testing methods will be utilized. The study will analyze the ventilation, air quality, and pedestrian level winds on and around different geometries at 4 different building scales: a room scale, a building scale, a canopy scale and a block scale. The computationally results will be validated with wind tunnel tests. At each iteration, the relationship between the buildings will be identified, setting the bounds to this workflow.

Kimberley Adamek / kadamek2@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca

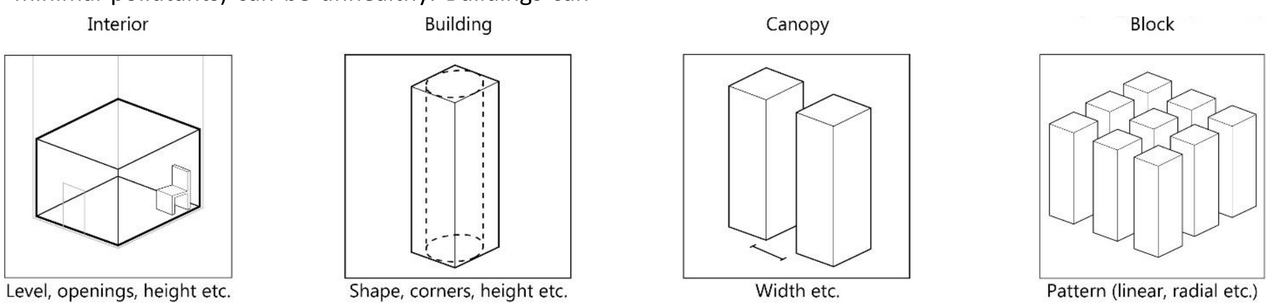


Figure 1. Architectural scales to be tested

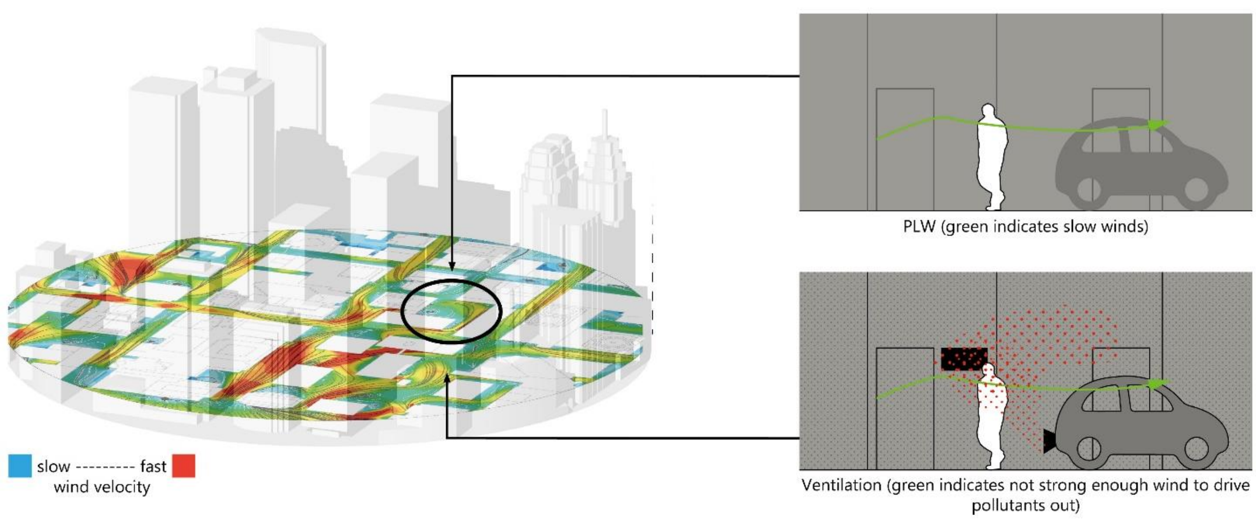


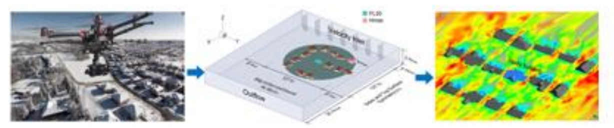
Figure 2. Competing wind topics (pedestrian level winds and ventilation)

LiDAR point cloud & drone imagery automated urban geometry and airflow modeling: A machine learning approach

Embracing sustainability and maintaining resiliency of Canada's built environment against natural hazards is necessary to sustain the wellbeing and prosperity of our communities. Sustainable building design in Canada, the second largest country in the world with diverse geography characterized by climate extremes, mostly revolves around energy efficiency and resiliency (i.e. ability to withstand the climate loads and re-bounce quickly after climate induced interruptions).

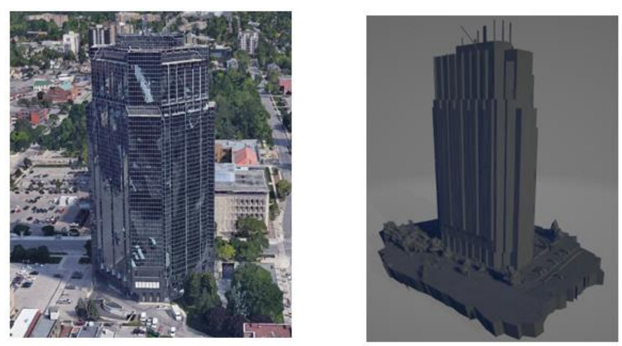
Accurate site and building specific information are required to assess climate loads such as wind, for example, during structural or natural ventilation design or for building energy simulation. The main objective of this project is to develop an automated site-specific 3D urban modeling useful for urban climate studies. For this purpose, various remote sensors installed on Unmanned Aerial Vehicle (UAV) will be used to collect topology and surface data

Figures illustrating the workflow, polygon extraction and 3D building geometry generation, respectively are shown below. The urban topology generated will then be use to model the local microclimate that can be used for pedestrian level wind assessment and other urban flow applications. Downwash and channeling effects which results due to high-rise buildings in city corridors will be assessed using a computational fluid dynamics (CFD). Both Reynolds Averaged Navier Stokes (RANS) and Large Eddy Simulation (LES) approach will be used mean flow and transient characteristics, respectively using STARCCM+.



General automated workflow for computational fluid dynamics

Building polygon extraction using deep learning approach



3D building model generation from satellite imagery

Tewodros Alemayehu / talemaye@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca

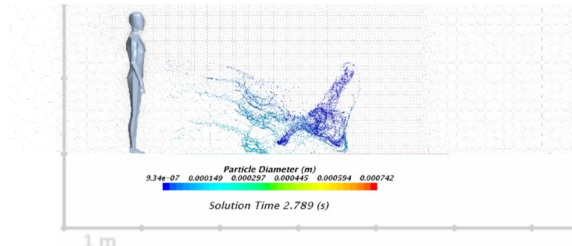
A social distancing computational model for open spaces during a Covid-19 pandemic

Social distancing is necessary to control the spread of viruses during pandemics like COVID 19 and SARS. Based on research carried out on SARS, a distance of 5 ft. (1.5m) between individuals is recommended widely for COVID 19. However, recent cough studies predicted larger distances. Nevertheless, most of these recommendations are applicable when the cough source is stationary, and when there are no prevailing winds or obstructions.

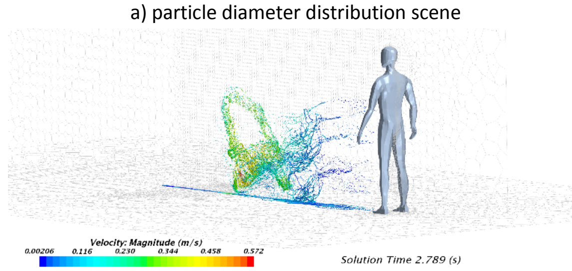
Various expiatory physiological processes result in the dispersion of the virus capsules into the air. Cough and sneeze get the attention in social distancing research due to the intensity of virus count during a single expiatory event. However, the non-violent expiatory process like breathing or speech play role in the spread of the virus. The mixture, released close to the body temperature, has liquid mist/parcel that would serve as a vector for the viruses. The diameter distribution of the parcels in a single event depends on the expiatory event. Each of the processes are highly transient events and are completed in a very short duration. Moreover, the volume flow released from the body source is fundamentally non-uniformly distributed transient flow.

The temporal distribution is often assumed to be close to the normal or log-normal fit. The droplet suspension and propagation physics must account for buoyancy and thermodynamic processes on top of inertial and drag considerations. All these are further complicated by additional environmental factors. When people are walking or running in a park or streets (self-movement) exposed to direct prevailing winds (e.g. cross or along wind effect) or obstructed by trees or building (body generated wake). Hence, the current social distancing recommendation based on stationary conditions most likely is not enough.

Therefore, the objective of the proposed research is to perform high-resolution computational modeling of cough droplet propagation under different environmental conditions. The following specific environmental considerations will be made a) human activities, b) prevailing winds, and c) obstruction conditions to come up with social distancing recommendations applicable for parks.



a) particle diameter distribution scene



b) particle velocity distribution scene

Figure 1. Preliminary unsteady cough jet propagation model

The development of land use class based CHTC correlations are expected to reduce the bias resulting from using correlation based on isolated building studies.

Anwar Awol / ademsis@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca

Predicting Residential Energy Consumption Using Wavelet Decomposition with Deep Neural Network

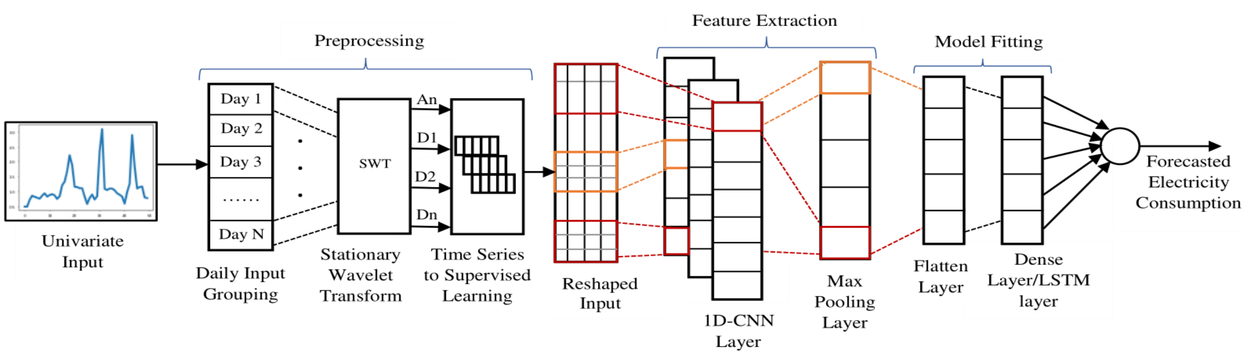
Electricity is one of the primary energy sources in today's world, and its rate of consumption continues to accelerate due to economic and population growth. The residential building sector consumes 27\% of global energy generated. Therefore, energy consumption forecasting is crucial for residential energy demand management, electricity price market design, energy efficiency, and maintenance scheduling of large-scale complex smart power grids.

Recently, large amounts of high-resolution consumption data are becoming available from smart electric meters. The availability of this information has motivated (data-driven) studies on forecasting energy consumption for residential and commercial buildings.

The main objective of this research was to develop a data-driven electricity consumption forecasting model (next-hour consumption) for residential buildings, solely based on analyzing electricity consumption data. Therefore, we proposed an end-to-end forecasting framework that combines the stationary wavelet transform and deep neural networks, as shown in Fig. 1. The stationary wavelet transform operation is employed to decompose the single-source (smart-meter) readings into low-frequency and high-frequency components. After the wavelet decomposition, a single layer of convolution followed by a pooling operation is used to extract abstract features. Furthermore, the proposed approach can generate the final prediction from a single model by aggregating wavelet features through convolution and pooling operations.

Thus, unlike existing wavelet-based methods, modeling each wavelet sub-sequence and inverse wavelet transform is not required.

The proposed method was evaluated using six years of electricity consumption data from ten residential buildings. The results have proved that the proposed architecture can accurately forecast residential building's energy consumption while automating the feature extraction process.



In the future, multiple layers of convolution, max-pooling, and flexible window size will be investigated for residential buildings that use mixed energy sources (gas, electricity, and other local renewable energy sources).

Dagimawi Eneyew / deneyew@uwo.ca
Miriam A. M. Capretz / mcapretz@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca

On the comparison of numerically generated tornado flow-field with experimental, analytical and full-scale data

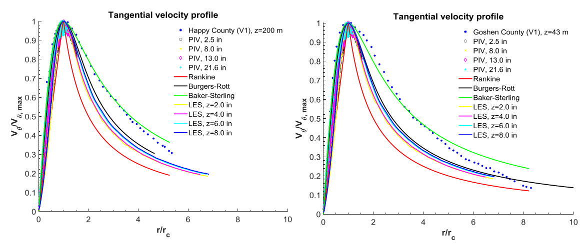
Ideally, near ground radar measurements along with in situ intercepts of a tornado should provide enough data for time-varying three-dimensional mapping of tornadic wind field. However, the localized, transient, unpredictable nature of tornadoes along with the danger associated with such intense storms makes it extremely treacherous to obtain good quality field measurements. In fact, reliable measurements within the first 40 m above ground level (AGL), a region of high interest for wind engineering applications, is extremely rare and usually unavailable. Considering the shortage of good quality near ground field measurements, analytical, experimental and numerical modelling of tornadoes have proven to be viable alternatives for understanding the end-wall flow dynamics of tornadoes. Analytical solutions of the relevant equations are elegant and offer a mathematical insight into the nature of such flows. They also form a basis for estimating tornado wind speeds from post damage surveys, particularly tree fall patterns and boundary conditions for numerical simulations. However, these solutions are obtained under highly idealized constraints and may not capture the reality.

In fact, the closed form solutions are often not possible beyond relaxing some of the simplifying assumptions due to the complexity, particularly the non-linearity, of the Navier-Stokes equations.Therefore, with the objective of evaluating wind loads and responses of structures, the use of simplified tornado simulations (numerical and experimental) is prevalent in the wind engineering community. In fact, much of our present state-of-the art understanding of tornado flow dynamics is attributed to experimental and numerical simulation of “tornado-like” vortices. However, making accurate measurements with high resolution for rotating flows remains a challenge in an experimental set-up. Numerical simulations of tornado-like vortices offer an opportunity to study the flow-field at higher resolution. But, limited domain numerical simulations of tornado-like vortices suffer from the uncertainties associated with the application of simplified, artificial boundary conditions. It is therefore desirable to compare the flow-field generated by these means to full-scale data and assess their performance. In this work, two full-scale events are selected as representative tornadoes, i.e. Happy county V1 (single-cell structure) and Goshen county V1 (two-cell structure) reported in Refan et al [1]. For the purposed of this study, the radial profiles of tangential velocity at various heights are compared. The three analytical models used for the comparison are-the Rankine, the Burgers-Rott and the Baker-Sterling vortex models as given below.

$$u_\theta = \begin{cases} \left(\dfrac{\Gamma_\infty}{\pi r_c^2}\right) r \text{ , } r \le r_c \\ \left(\dfrac{\Gamma_\infty}{2\,\pi}\right) \dfrac{1}{r} \text{ , } r > r_c \end{cases}$$

$$u_\theta = \frac{\Gamma_\infty}{2\,\pi r}\left(1 - e^{-ar^2/2v}\right)$$

$$u_\theta = u_{\theta,max}\left(\frac{2r/r_c}{1+(r/r_c)^2}\right)$$



Particle Image Velocimetry (PIV) measurements of tornado-like vortices from WindEEE Dome for swirl ratios deemed representative of the Happy county (V1) and Goshen county (V1) tornadoes based on the scaling technique developed by Refan et al [2] are used for comparing the experimentally generated flow-field. High fidelity Large Eddy Simulations (LES) of tornado-like vortices are also conducted using a simplified cylindrical computational domain with uniform, steady input velocity.

The plots show a good agreement between the analytical, experimental, numerical and full-scale data in the inner, rotational region. However, a considerable scatter is observed in the irrotational tail of the profile. It is noted that the experimental data (PIV) is limited in the radial direction and does not extend all the way out. The numerical results appear to align with the tail of the Burgers-Rott model while the Baker-Sterling model aligns well with the tail of the full-scale data. In the future, we plan to include more full-scale events for comparison, along with the radial and axial velocities.

Anant Gairola / agairola@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca
Horia Hangan / hmhangan@uwo.ca

Flow around a flat-roof low-rise building: LES vs PIV

Extreme wind load on low-rise buildings with flat-roofs depends on the flow dynamics close to the building surface. Strong suction occurs at locations of flow-separation for cases where wind perpendicular to the one of the edges. Fundamental fluid dynamics studies have covered broad aspects of flow around a plate-mounted prizm type of setup. Therefore, for a method to be proven effective in predicting the surface pressure on the prism (i.e. wind load on the building), proper replication of the separated flow is very important.

In the current study, flow details from Large Eddy Simulation (LES) models is validated agains PIV measurements in Boundary Layer Wind Tunnel (BLWT) experiments conducted by (Akon and Kopp, 2016). The case-study building is the widely studied Texas Tech University's field study building.

Inflow generation for the LES model was done by a syntethic method called CDRFG. All the simulations were conducted using OpenFOAM on HPC's provided by Compute Canada. The PIV measurement was conducted at a scale of 1:50, which was also adopted for the simulation.

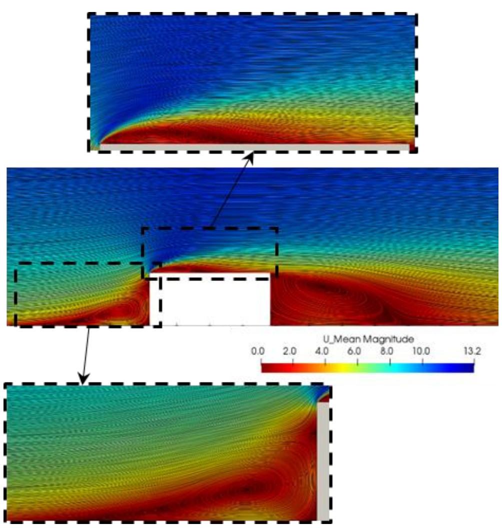


Fig. 1: Mean velocity streamlines of LES results

Figure 1 shows the mean streamlines of the longitudinal velocity colored with the velocity magnitude. It shows the major aerodynamic features of a low-rise building such as the stagnation point at approximately two-thirds height of the upstream wall, separation bubble, and wake recirculation. Figure 2 shows the comparison of these stream lines against those obtained from PIV measurements. The comparison shows that the results are matching well. A follow-up of this study will jointly compare the surface pressure and the velocity field.

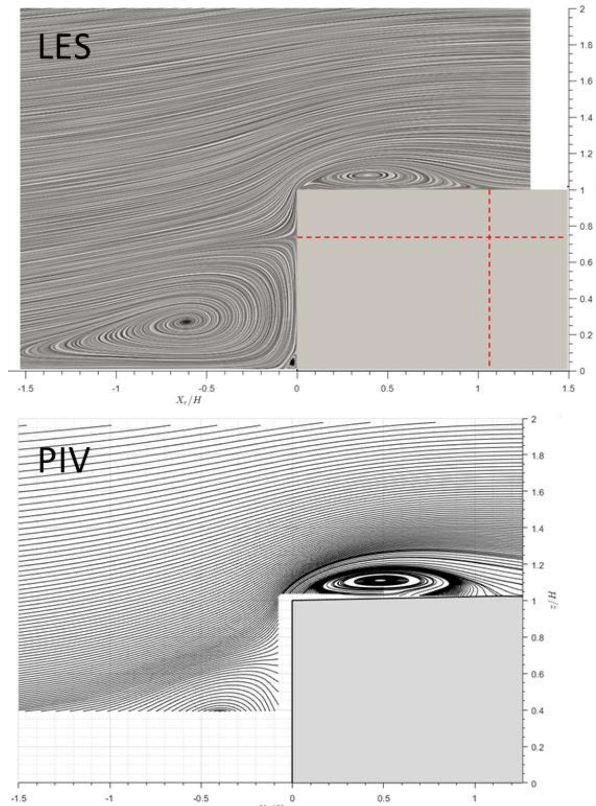


Fig. 2: Mean velocity streamlines comparison between LES and PIV measurements over a vertical section cutting through the centerline of the building in the flow-direction

References:

Akon, A.F., Kopp, G.A., 2016. Mean pressure distributions and reattachment lengths for roof-separation bubbles on low-rise buildings. J. Wind Eng. Ind. Aerodyn. 155, 115–125.

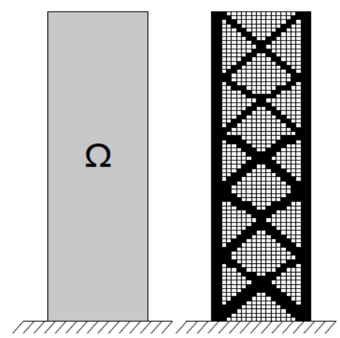
Tsinuel Geleta / tgeleta@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca

Aero-Structural Optimization of Tall Building

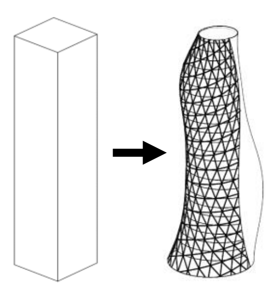
Recent trends in city development have shown a dramatic increase in the construction of tall buildings. Buildable space within cities is becoming limited, forcing designers to expand upwards by creating taller and more slender buildings. These buildings are more susceptible to wind-induced forces, and the design for wind performance commonly govern the structural systems. Designers have been pushing the limit of the current design practices and structural systems in order to create taller buildings. A key limitation within the current design process of tall buildings is the separation of disciplines. The exterior shape, i.e. the architecture, and structural system are designed separately from each other while the dynamic response of the structure is affected by both. Tall building design problems are multidisciplinary. A design framework which combines the exterior form and the internal structural system and optimizes them as a single unit is needed to address the limitations within the current design practice.

Topology optimization has been used to improve structural systems and exterior forms within aerospace engineering. Topology optimization determines the optimal material distribution to resist the applied loads while using less material. This method is adopted to produce structural systems for tall buildings in order to improve stiffness while remaining lightweight. The framework optimizes both the structural system and the exterior form while conforming to the architectural and structural engineering constraints.

The multidisciplinary aspect of the optimization process is managed within the BIM environment. BIM allows data from different designers (architects and engineers) to be collected in a single model and then be accessed by everyone. The optimization objective(s) and constraints from each designer can be indicated within the model, using the parties' respective terminology. The 3D model, along with the micro-climate and structural parameters required will be exported to both the simulation methods. The wind loads, and the aerodynamic responses will be determined using CFD. The structural system of the tall building will be represented using FEM. Through the optimization process, any alterations made to the exterior form or the structural system will update the BIM model. Connecting the CFD and FEM simulations to the BIM model ensures that the exterior form and structural system are coupled, creating the aero-structural dynamic optimization framework. The proposed framework will outline the importance of multidisciplinary aero-structural optimization while designing tall buildings. Rather than optimizing separate components (exterior geometry and structural system) of the building, the different components will be optimized as a single unit enhancing the performance at a system level. Designers will be able to use the framework to create safer, cost-effective tall buildings which reach greater heights while using less material.



Vector maps showing horizontal velocity field obtained from 4 cameras at 33 cm above the ground and for S=0.35



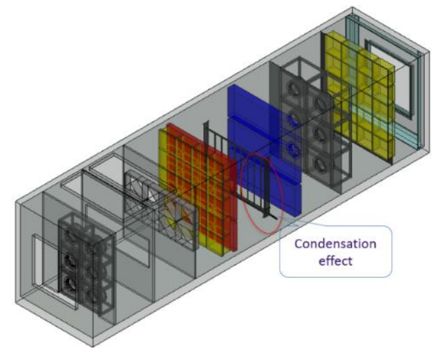
Conceptual Aero-Structural Optimization for Tall Buildings

Christopher Howlett / chowlet5@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca

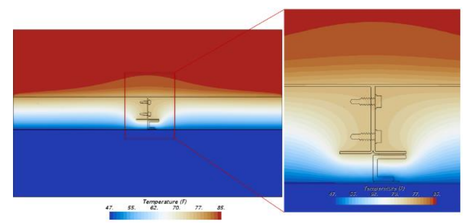
Numerical analysis of condensation on the surface of Air Handling Unit

Condensation on the surface of an Air Handling Unit (AHU) can interfere with energy efficiency, air quality and cause damage to the mechanical equipment and building. The fundamental calculation of condensation is complicated due to the intricate interaction between the AHU surface and its environment. Realistic modeling of conduction through the AHU walls or roof and convective heat transfer distribution over the surface of the AHU is crucial to assess to avoid condensation occurrence. The present study investigates thermal bridging effects across the walls or roof of panel joints and condensation occurrence on the surface of the AHU, considering the effect of thermal insulation, temperature difference, and air velocity. The momentum and heat transfer in the AHU is evaluated using high-resolution 3D steady Reynolds-Averaged Navier-Stokes (RANS) computational heat transfer and fluid dynamics simulations. The airflow inside the unit is considered turbulent forced convection, and the external airflow is assumed natural and forced convection. The conditions for the condensation occurrence are assessed, and the vertical temperature distribution on the panel shows that at the panel joint, a lower temperature distribution (see Fig. 4). Based on this, further research study aims to minimize the thermal bridging and its effect on the surface condensation will be performed.

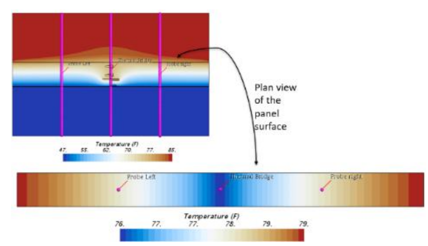
Meseret Kahsay / mkahsay@uwo.ca
Anwar Awol / ademsis@uwo.ca
Babak Solati/ babak.solati@xnrgy.com
Girma Bitsuamlak / gbitsuam@uwo.ca



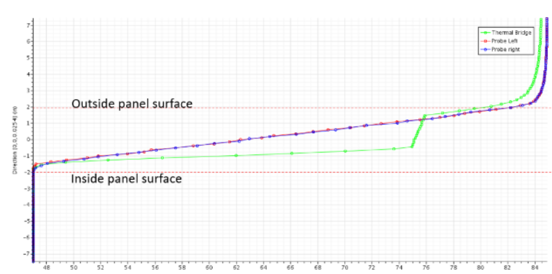
CAD: Air Handling Unit



Vertical temperature distribution on the AHU panel



Horizontal temperature distribution on the AHU panel
Temperature distribution on the vertical surface of the AHU panel



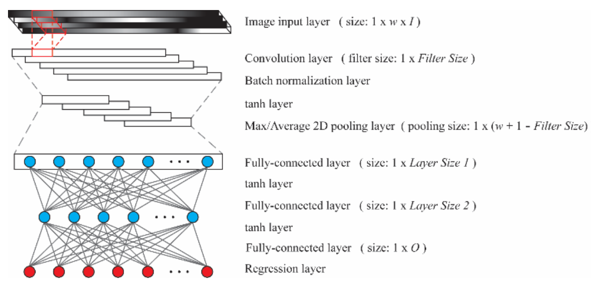
Neural network-based surrogate aerodynamic wind turbine blade models based on CFD data

Due to the Reynolds number-sensitivity of wind turbine airfoils, wind tunnel testing is limited for predicting the aerodynamic loads on operational turbine blades. Alternatively, numerical aerodynamic models are limited by lower accuracy (such as when using the common blade element momentum (BEM) technique) or long computation times (such as when using CFD). This research is in the process of investigating the use of a trained neural network as a surrogate aerodynamic model that is able to achieve high accuracy in reasonable computation times.

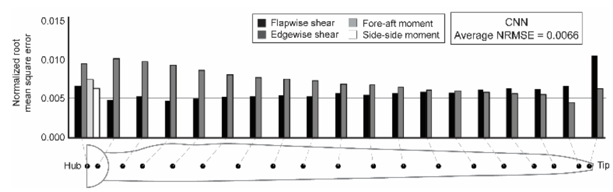
Preliminary optimization of the neural network has been performed using BEM-generated data. 30M time steps of data were extracted from 115 turbine simulations of a 5 MW wind turbine, recording the wind speed, geometric information, structural displacements, and wind loads at the hub and at 18 points along one of the turbine blades. This data was then used to optimize and train six different neural networks including multilayer perceptron, long short-term memory and convolutional neural network types. This training consists of optimizing hyperparameters using an external Bayesian optimization algorithm followed by direct network training using a back-propagation algorithm. These neural networks were trained using MATLAB on Compute Canada supercomputing clusters.

Ultimately, it was found that the optimized convolutional neural network (CNN) was the most effective at predicting the wind loads on the turbine blade when provided with geometric, wind speed and structural displacement information. As shown in the first figure, the network consisted of supplying time histories of input data as 1D images followed by convolution, activation, pooling and fully-connected layers to the output. As shown in the second figure, across all outputs, the overall normalized root mean square error between the wind loads predicted by the network and the true values supplied in the testing data was found to be only 0.66%, an accuracy that exceeds that of previous neural networks of this size used in turbine research.

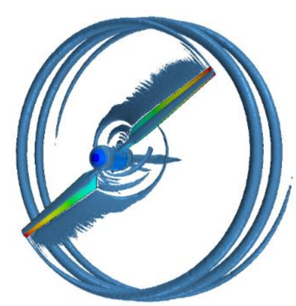
With an optimal architecture identified, the next step is to generate higher-accuracy aerodynamic data of operational wind turbines using CFD simulation. The third figure shows the vortices around a 2-bladed wind turbine from a preliminary simulation. Using CFD simulations validated against previous experimental and numerical studies, similar aerodynamic information as used previously will be extracted; blade geometry, wind speeds, structural displacements, and resulting wind loads. Using this higher-accuracy data to train a CNN-based surrogate model should deliver a numerical aerodynamic blade model that achieves both high accuracy and reasonable computation times.



Convolutional neural network architecture



Normalized root mean square error of the CNN-predicted aerodynamic wind loads on the turbine blade

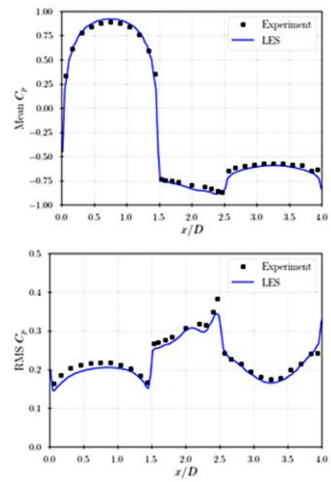

Vorticity surface of operation NASA Phase VI turbine under 5 m/s mean wind speeds

Eric Rowland Lalonde / elalond3@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca

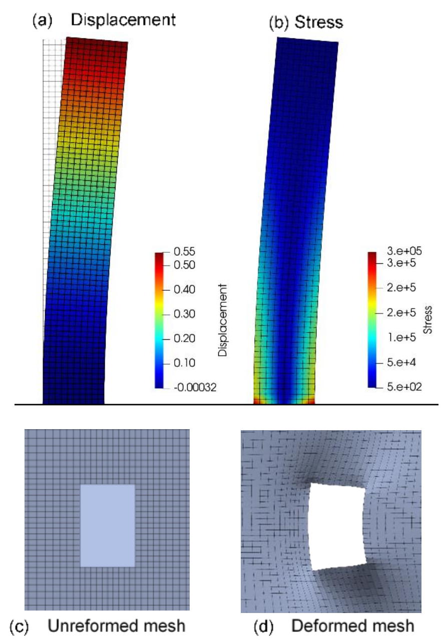
Computational aeroelastic modeling of tall buildings using fluid-structure interaction

Tall buildings are prevalent in cities of the world because of the advantage they provide in using land space efficiently. The current trend in the evolution of these structures has been primarily driven by the need to build higher. Complemented by the advancements in use of lightweight construction material, new structural systems and design methodologies, the current generations of tall buildings are becoming lightweight and flexible. As a result, they are becoming highly vulnerable to wind induced dynamic actions due to the reduced mass, stiffness and damping. The current state-of-the-art approach to assess the dynamic action of wind on such structures is to undertake aeroelastic experiment in the wind tunnel. In the past few decades, however, coupled with growing computational power, Computational Fluid Dynamics (CFD) has been extensively used to study tall building aerodynamics. In the current study, high fidelity multi-physics simulation is proposed to include the prediction of the aeroelastic response of tall and slender buildings. To demonstrate the performance of the proposed approach, the numerical models will be validated against full aeroelastic experiments in boundary layer wind tunnel.

The proposed research work aims to contribute to the development of computational framework to estimate the aeroelastic response of tall building using fluid-structure interaction algorithms. This is achieved by developing efficient fluid-structure interaction algorithm that is optimized for aeroelastic response prediction of tall buildings. Initial aerodynamic wind load evaluation and wind repose prediction using fluid-structure interaction showed promising result as shown in the figures.



Mean (top) and rms (bottom) at 2/3 height of the CAARC building



Result of fluid-structure interaction for CAARC model under wind load: structural response (a), stress (b), unreformed mesh(c) and deformed mesh (d)

Abiy Melaku / amelalu@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca

Assessing the impact of transverse roughness ribs on the turbulent natural convection in a BIPV air channel: A CFD study

Building integrated Photovoltaics (BIPV) are typically installed on the building envelope with an air gap for thermal regulation. The air flow in the gap is driven passively by natural convection. The heat transfer effectiveness is limited due to low flow rates. Appending transverse ribs on back surface of BIPVs may enhance the convective heat transfer in that they excite turbulent mixing in the air channel. Hence, this study numerically investigates the impacts of ribs on the turbulent natural convection heat transfer coefficient in BIPV channel.

The parameters considered were the rib shape (i.e. square, triangle and semi-circle), relative rib height (i.e. $0.01 \leq e/D \leq 0.30$) and relative pitch ratio (i.e. $5 \leq p/e \leq 50$); where e is the rib height, D is the channel depth and p is rib spacing. In each instance, the heat flux is varied from 100 – 1000 W/m^2 and the channel inclination angle from 0 – 75 degrees. The heat transfer enhancement factor is the ratio of the convective heat transfer coefficient of the roughened air channel and the smooth channel. A value greater than 1 indicates a heat transfer improvement and vice versa.

The triangular rib section showed the most heat transfer enhancement due to the more enhanced turbulence mixing in the channel. This is depicted in Fig 1a by a stronger vortex in the immediate downstream of the rib. The optimal roughness height that maximizes the convective heat transfer is 0.20 (Fig 1b). The optimal rib spacing is p/e – 10 for the range of parameters considered (Fig 1c). At higher channel inclination angles, the heat transfer enhancement is sustained up till 60 degrees. For $\vartheta >$ 60 degrees, the ribs are detrimental to the natural convective heat transfer.

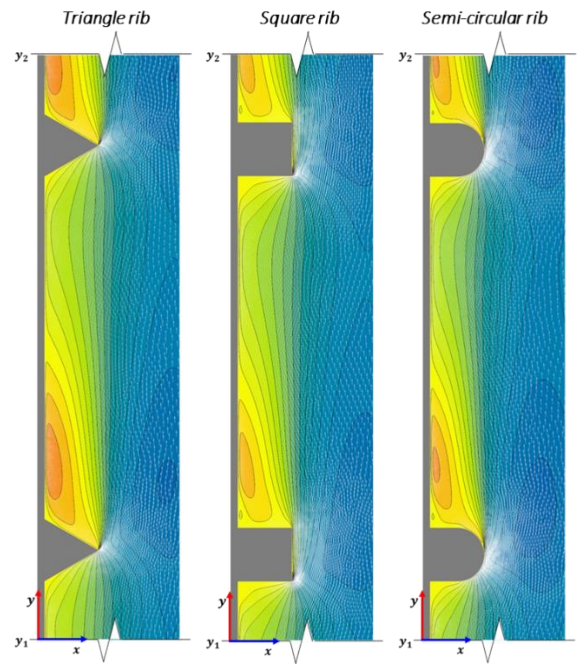


Fig 1a. Typical flow structures between consecutive ribs

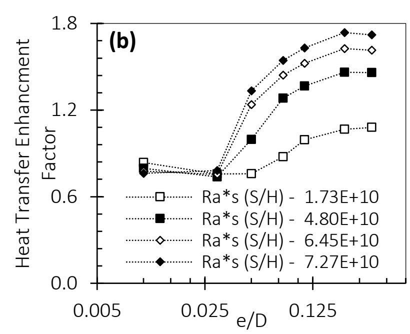


Fig 1b. The effect of roughness height

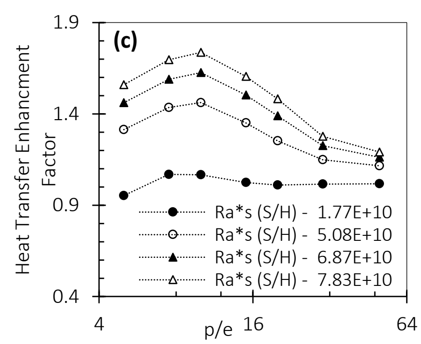


Fig 1c. The effect of roughness spacing

Barilelo Nghana / bnghana@uwo.ca
Fitsum Tariku / fitsum_tariku@bcit.ca
Girma Bitsuamlak / gbitsuam@uwo.ca

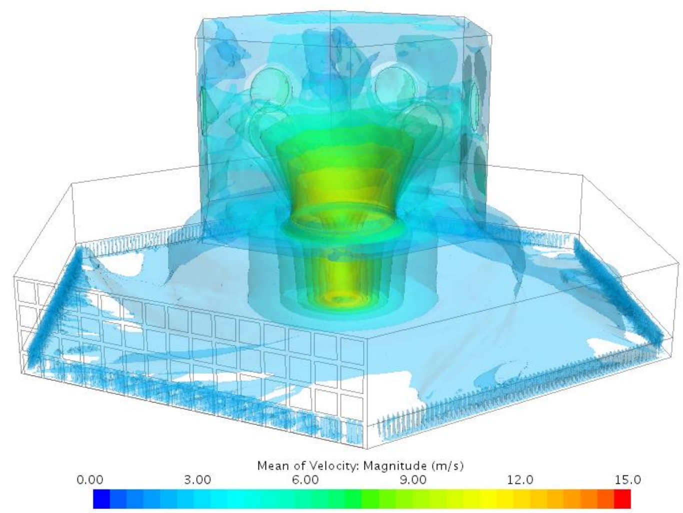
Low-rise building performance assessment under tornadic wind loads

Tornadoes are an extreme weather phenomenon that can cause severe damage to communities. In the United States, over 1000 tornadoes occur annually [1] that can cause significant damage and risk to human life, such as the April 2011 "super outbreak" that resulted in $11 billion in damage along with 321 fatalities [2]. Canada also experienced around 60 verified tornadoes annually [3], with a notable event being the 2018 Dunrobin tornado that caused $300 million in insured losses [4].

There is a growing interest in designing structures for tornado wind loads. Numerous numerical and experimental studies have been conducted to evaluate the pressure distribution on low-rise buildings subjected to tornado loads [5]. Building codes have also started to include tornado wind load provisions, such as those found in the commentary of ASCE 7-16 [6]. Understanding the difference in the structural performance of buildings between the building code provisions and experimental loads from simulated tornadoes would be of value to the engineering community.

Experiments will be conducted at the WindEEE Dome on a HFPI model of a low-rise building. The model will be subjected to both translating and stationary tornadoes of various sizes, and 480 pressure taps will be used to extract measurements on both the building surface and ground plane.

From a numerical modeling standpoint, computational fluid dynamic (CFD) simulations of tornado-like vortices have been developed. These simulations will be validated against the wind tunnel experiments and used to simulate other tornado flow conditions. Further, a finite element model of a low-rise steel structure is being developed. By subjecting the model to both static loads from the building code and time histories from both WindEEE experiments and CFD simulations, the structures performance in tornado wind events will be assessed.



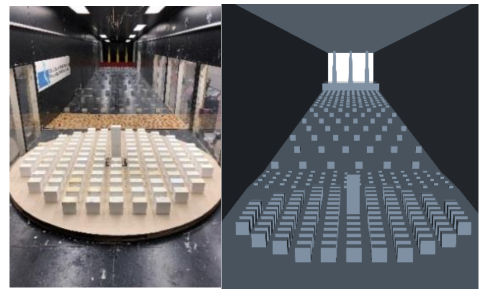
CFD Simulation of a tornado-like vortex in the WindEEE Dome

Cody Van Der Kooi / cvande89@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca

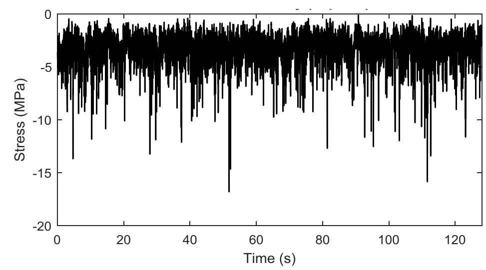
Effect of city growth on tall building cladding fatigue

As city develops there will be changes in the aerodynamic characteristics due to varying building surrounding and topology. For example, the city growth around a tall building can cause an increase in wind load due to venturi or wake effects or decrease due to sheltering effects depending on the type of surrounding. The densification of cities will also increase the turbulence level due to wake effects. In the present study, the implication of these changes on the aerodynamic forces on cladding connections is investigated. With increased fluctuations in the wind loads, the cladding connections will also experience stress fluctuations, which may result in fatigue problems in its lifetime. The growth of an urban area is represented by placing surrounding buildings with different height around the study building and testing them in a boundary layer wind tunnel. Five surrounding conditions were investigated including isolated, surrounded with 1/4H, 1/2H, 3/4H, and H, where H is the height of the study building. The wind tunnel measured cladding pressure was then used to estimate the stress in the connections. Additional CFD simulations were carried out to explain aerodynamic mechanisms and results. Finally, fatigue damages were evaluated for different city development stages using two methods (i) direct wind time history method developed as part of this study and (ii) Weibull wind distribution methods adopted from literature. The highest fatigue loads are found to occur in the following order 1/4H, 1/2H, 3/4H, and H.

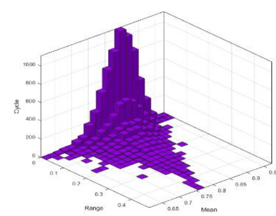
Hang You / hyou24@uwo.ca
Ayan Sadhu / asadhu@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca



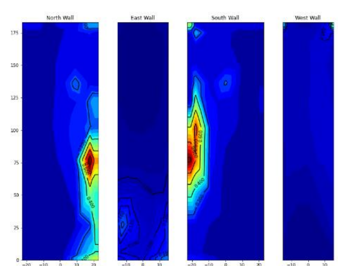
Wind Tunnel Testing and CFD Simulation



Connection stress time history



Stress Cycle Histogram Counted from Time History



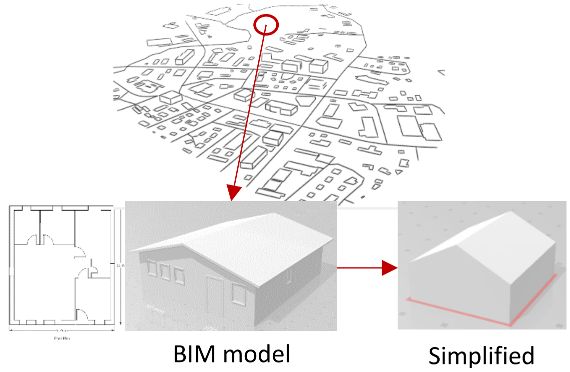
Overall Fatigue Damage at ¼ H Surrounded Case

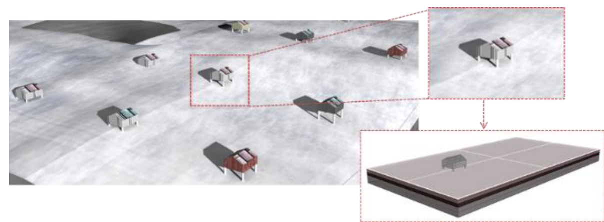
Permafrost Integrated Buildings Design Framework

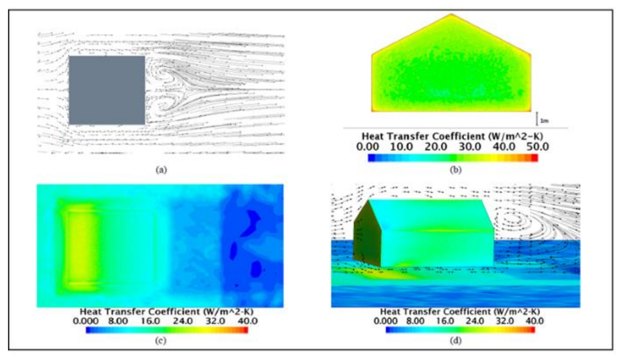
The Northern communities are exposed to many challenges such as remoteness, significant infrastructure deficit, and extreme climate and environmental conditions. Within this frame and to overcome such challenges, urban and infrastructure design has become a vital requirement for a sustainable and resilient future in the Northern climate.

Buildings in the north are subjected to extreme environmental stressors: above-grade thunderstorms, snow, extreme wind, rain, thermal stress, and sub-grade permafrost degradation. Under these multi-stressor design conditions, numerical and experimental simulations of permafrost integrated buildings are considered essential and valuable approaches to provide a better understanding of the relation between permafrost buildings and microclimate, considering the lack of related research in this field.

This report presents some results of a study in which Building-permafrost with different wind magnitude and direction are simulated using computational fluid dynamics (CFD). The study reveals that the heat transfer from structures causes ground warming which leads to permafrost degradation. To overcome such a problem, the study proposed and examined a solution to raise the building above the ground. This, in turn, creates an open space underneath to reduce thermal stress on the permafrost ground. The significance of this work highlights the ability to quantify the impact of raising buildings from the ground. The authors are currently extending this work by developing a framework to study the effect of buildings on permafrost thermal regimes.







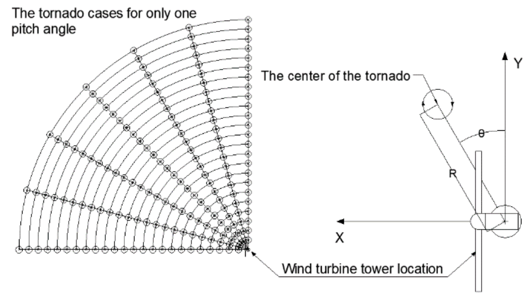
(ii) Scenario 2: $h = 1m, V = 7m/s, 0°$

Muna Younis / Myounis4@uwo.ca
Girma Bitsuamlak / gbitsuam@uwo.ca

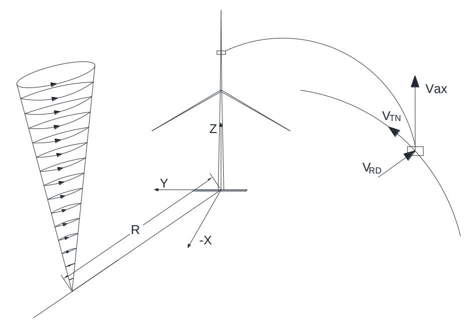
Numerical Model for Analysis of Wind Turbines Under Tornadic Wind Fields

The installation rate for wind turbines is accelerating around the world, leading to the introduction of new wind turbine farms in regions where wind is abundant. As a result, the number of wind turbine towers prone to severe wind loads is increasing, as is the rate of failure due to unexpectedly strong wind loading. Wind turbines are typically designed to resist the synoptic wind loads specified in current International Electro-technical Commission (IEC) guidelines, but these standards fail to include consideration of High-Intensity Wind (HIW) events such as tornadoes or downbursts. Because such HIW events stem from localized natural events, identifying critical locations that result in peak forces acting on the tower and blades is a challenging task. For this reason, a built-in- house numerical model has been developed for simulating a three-blade horizontal-axis wind turbine tower exposed to 3D tornado wind fields. An extensive study has been conducted with the goal of determining both the critical location of a tornado that will cause peak straining actions on the tower and blades, and the optimal pitch angle that will minimize the effects of that tornado.

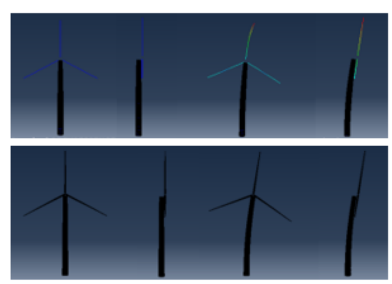
Validation of a numerical model for predicting the response of wind turbines to tornado loading. The developed HIWWT numerical model incorporates a wind field that was generated from a previously developed CFD model. The analyses are based on moving the tornado in space around the wind turbine in order to determine the critical tornado locations for both the tower and the blades for a variety of blade pitch angles. The developed numerical model was applied for the tornado analysis of a case study of an actual wind turbine. It has been found that an F2 tornado wind field presents a hazard for wind turbine towers and must therefore be taken into account if the negative impact of this type of unexpected load on tower elements is to be avoided. The effects of tornado loads on tower's height and airfoil sections have been investigated, alongside with studying the effect of different tornado wind fields on the tower and blades. New detailed ABAQUS models have been developed to account for the geometric imperfections as well.

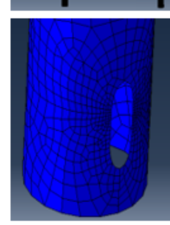


Schematic of tornado locations for the current study relative to the centerline of the wind turbine



Velocity components of the tornado wind field for a random element in the coordinate system





Detailed ABAQUS models have been developed with different approaches considering the geometric imperfections to study the behavior of the wind turbine tower and blades under tornado wind fields

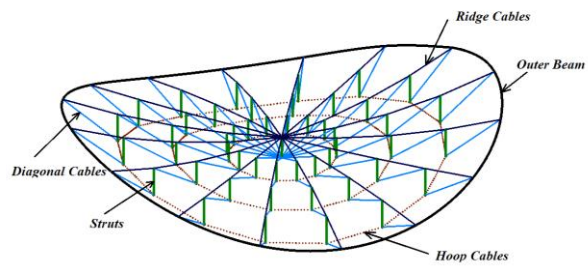
Mohamed AbuGazia / Mabugazi@uwo.ca
Ashraf El Damatty / Damatty@uwo.ca

Dynamic Analysis of a Negative-Gaussian Curvature Cable Dome

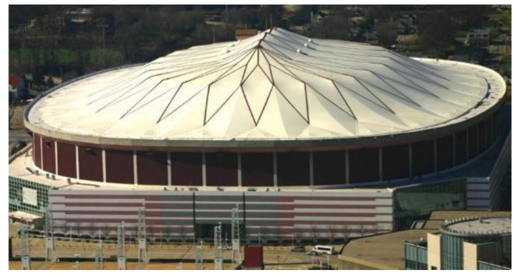
During the last decades, most architectures has adopted the use of cable structures for covering large areas such as arenas, stadia, and open squares because of their lightweight and versatile forms. Cable domes are considered one of the most widely used cable structures in practice. However, research is needed to understand the wind behavior of these structures. The current research involves investigating the wind-induced response of cable roofs, taking into account the influence of curvature and flexibility. The study will focus on doubly curved cable domes which have better stability than the corresponding positive-curvature cable domes and better stiffness than cable net structure.

The large deformations of this type of structures require considering the interaction that occurs between the structure deformations and the wind forces. This will be carried out experimentally using wind tunnel testing and numerically by coupling Computational Fluid Dynamics and Finite Element Modeling.

The study will also involve the development of coupled finite element-optimization technique that can be used to determine the optimum cable shape and the pre-stressing cable forces that achieve the best aeroelastic behavior of doubly curved domes.



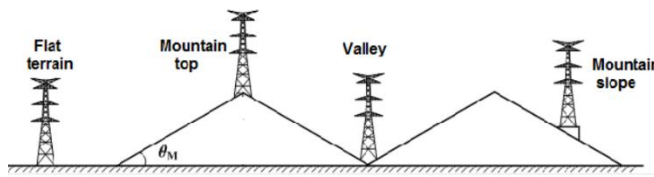
Components of a negative-Gaussian curvature cable dome



Georgia Cable Dome

Elshaimaa Ahmed / eahmed23@uwo.ca
Ashraf El Damatty / damatty@uwo.ca

Progressive Failure of Transmission Line Towers under Synoptic Wind Fields



Transmission line on different terrains and topography

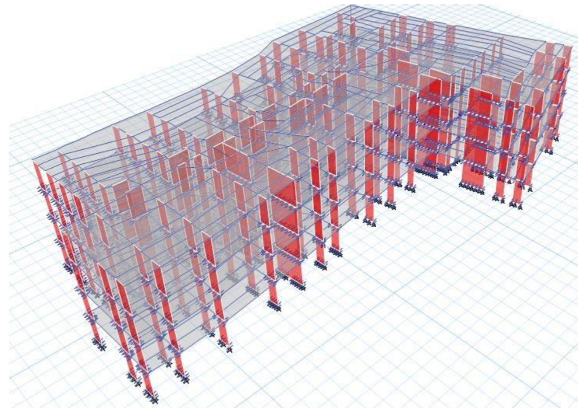
Transmission lines (TL) have become corner stone for any civilization because electricity constitutes the major element of our daily activities. TL have shown vulnerability to progressive failure in many transmission systems collapses around the world during extreme wind events. The failure of one tower overloads the system, which may lead to new state of equilibrium, and initiates a failure sequence that can cause the collapse of the whole system.

This study aims to investigate progressive failure of a line consisting of multiple transmission towers considering the variation of the terrain and topography from tower to another under synoptic wind fields. Computational Fluid Dynamics (CFD) simulations are carried out to obtain the wind field in an area where multiple terrain exist using real site conditions. Wind tunnel test will be carried out for TL model to validate the CFD simulations of progressive collapse.

Finally, prediction of the TL progressive collapse under synoptic wind events will be provided in addition to recommendations and precautions for the design of TL based on the study outcomes.

Abdelrahman Ahmed / aahme377@uwo.ca
Ashraf El Damatty / Damatty@uwo.ca

Analysis of Mid-Rise Timber Buildings



Numerical model showing the formulation of CLT panels as shear walls

Heavy timber has been gaining strong popularity worldwide. The use of heavy timber has been increasing exponentially due to its improved properties over light frame wood structures. The objective of this study is to assess, the structural behavior of various heavy timber systems used in a multi-story building in comparison with the light-frame wood (LFW) system.

The reference structure is a real 4-storey L-shaped LFW building recently constructed in Canada. The same building layout is remodeled and redesigned using four different heavy timber structural systems: Moment resisting frames (MRF), braced frames (BF), and shear walls using Cross laminated timber (CLT) panels. The four structural systems are numerically modelled. In order to be able to compare between the different systems, the layout and dimensions of the structural system of the three heavy timber buildings are selected such that those buildings have almost the same lateral stiffness as the reference LFW building.

The four numerical models are exposed to the same gravity and wind loads according to the NBCC. Also, wind tunnel test data are considered for application to the mid- rise structures using a nonlinear time-history analysis A key element that governs the behavior of timber structures is the connection between various elements. Connections with known mechanical characteristics based on test results available in the literature are used in the study. The choice of the members of the heavy timber systems is restricted to those used in the tested connections. In addition, all members are designed to satisfy the strength requirements under the combined effects of gravity and lateral loads.

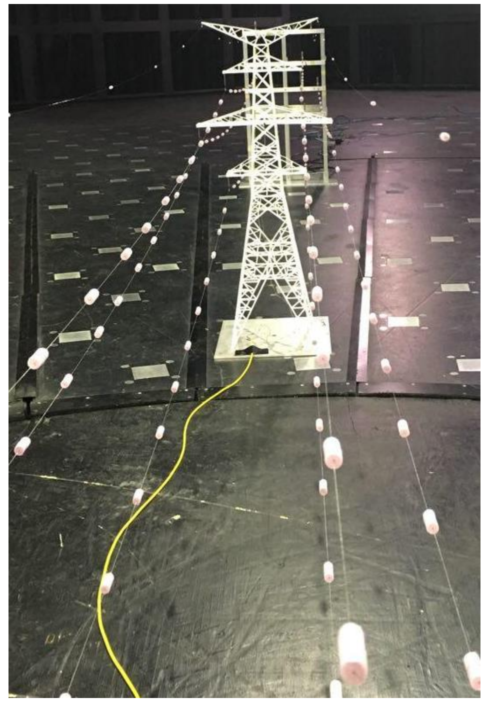
Moustafa El-Assaly / melassal@uwo.ca
Ashraf El Damatty / damatty@uwo.ca

Dynamic Investigation of Transmission Line Structures Subjected to Tornado-Induced Loads

Tornadoes are localized wind events with narrow width and certain path. For transmission line structures which are responsible for conducting electrical power from a generation source to cities and usually expand for thousands of kilometers exposed to different weather conditions, such localized loading should be considered. The United States and Canada are among the most active zones for tornadoes. Failures of transmission lines during tornadoes have been occurring more frequently, especially in Ontario, including incidents near Sarnia in 2003, 2006, and 2011, near Wawa in 2013, Woodstock 2016 and Ottawa 2018. Therefore, a comprehensive study has been triggered to mitigate such failures. The research includes numerical and experimental simulations of tornadoes and transmission line structures.

An extensive set of integrative experimental examinations is conducted in WindEEE research institute, a facility of Western University, to assess the structural response of a multi-span aeroelastic self-supported transmission line under a set of laboratory simulated tornadoes. The structural responses are recorded in terms of base shear forces and overturning bending moments due to the tornado-induced aerodynamic forces at various radial distances of the tower of interest with respect to the tornado centre.

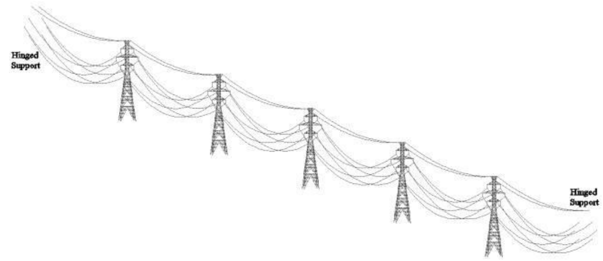
To determine the contribution of resonant component to the total response, the zero-mean response power spectral density of the tower of interest is derived for each tornado configuration. The background response is calculated by integrating a straight line connecting the lower points of the spectral density results. Based on the resonant peaks obtained from spectral density of the free vibration test, the contribution of the resonant component relative to the background component are calculated within the frequency band of each resonant peak. The results are utilized to understand the dynamic behavior of transmission lines duo to tornado-induced loads



Aeroelastic multi-span transmission line model under a simulated tornado conducted in WindEEE research institute

Nima Ezami / nezami@uwo.ca
Ashraf El Damatty / damatty@uwo.ca

Angle and End Transmission Lines Towers behavior under Tornado Wind Load



Schematic layout of the transmission line system model

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. 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 (TL) failures worldwide. Previous studies conducted TL under HIW focused on tangent towers. Those studies led to the development of a set of critical load cases that were recently incorporated into the ASCE(2020) guidelines. This study is the first to assess the behavior of angle and dead-end lattice transmission towers under tornadoes. This is very important since such towers serve to contain the failure from progressing when a one or multiple tangent tower collapse during a HIW event. The study has three objectives: (1) extend the numerical model developed to the analysis of angled and dead-end transmission towers under tornadoes, (2) assess the behavior of such towers and determine the critical tornado location leafing to peck internal forces, (3) assess the adequacy of the newly developed load cases for tangent towers to their application to both angled and dead-end towers.

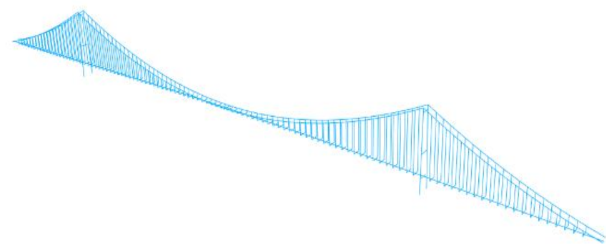
Mohamed Hamada / mhamada2@uwo.ca
Ashraf El Damatty / damatty@uwo.ca

Effect of Structural Nonlinearities on Flutter of Cable-Supported Bridges

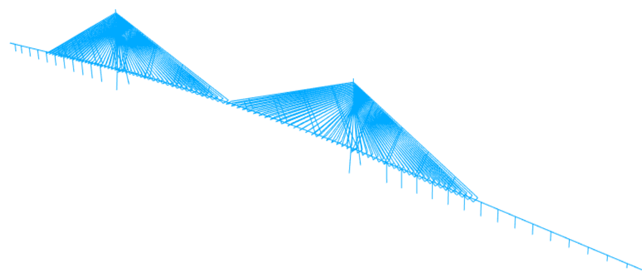
Flutter, an aeroelastic instability, is a determining factor for the design of suspension and cable-stayed bridges. This is even more critical for super long-span bridges such as the Messina Strait Bridge with a main span of 3.3 km. The assessment of flutter is currently based on a linear structural behavior due to the ease of usage of frequency-domain analysis. However, such bridges could exhibit structural nonlinearities at high wind speeds, especially geometric nonlinearities. As demonstrated by mathematicians, nonlinear geometric effects in cable-supported bridges could lead to nonlinear structural dynamic phenomena that are not considered in the design of long-span bridges. These phenomena could interact with the aeroelastic forces that are responsible of flutter, hence they could influence flutter stability. Therefore, this project aims at evaluating the effect of structural nonlinearities on the dynamic and flutter stability of cable-supported bridges.

Numerical and experimental approaches are considered for evaluating the susceptibility of long-span bridges to nonlinear dynamic instability phenomena. So far, eleven finite element models have been developed for existing bridge design of suspension and cable-stayed bridges. Using these models, a simplified and practical approach has been developed in order to provide initial information on nonlinear structural dynamic phenomena. Afterwards, nonlinear time-domain analysis will be utilized for validating the simplified analyses and confirming the susceptibility of these bridges to nonlinear dynamic phenomena. Then, nonlinear time-domain flutter analysis will be used to assess numerically the effect of structural nonlinearities on flutter stability. These analyses will be validated experimentally.

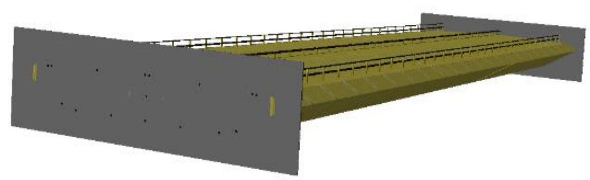
This project will provide analysis techniques to bridge engineers for assessing nonlinear dynamic phenomena and their interaction with aeroelastic effects in long-span bridges. This will allow safer bridge designs with respect to flutter, especially in the case of super long-span bridges.



Finite element model of a suspension bridge



Finite element model of a cable-stayed bridge



3D rendering of a suspension bridge section model

Sébastien Maheux / smaheux@uwo.ca
Ashraf El Damatty / damatty@uwo.ca
J. Peter C. King / jpck@blwtl.uwo.ca

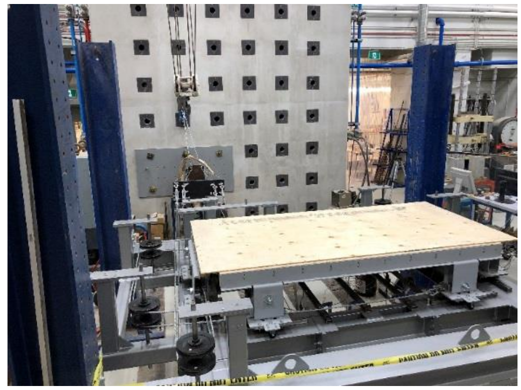
Shear Buckling Testing of Wood Sheathing Panels

As wooden sheathing panel in Light-Framed Wood Shearwalls usually is stiff in in-plane deformation, it plays an important role to resist lateral loads. The typical size of the sheathing panel in the construction industry is 1220×2440 mm and panels connect to studs and rails by nails. One of the failure modes of shear wall segments under lateral loads is the out-of-plane deformation of sheathing panels where the nail-based connections do not reach their ultimate capacity. The experimental research on this topic is limited to the small size of the plywood and different edge loads.

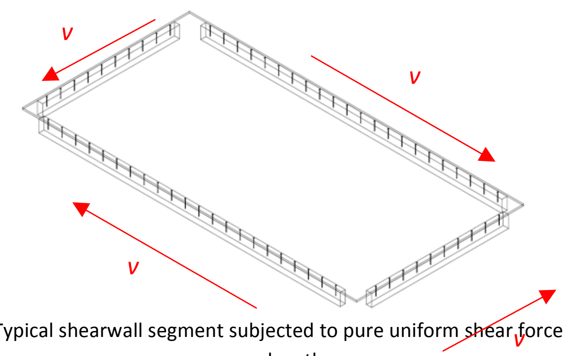
The current Canadian wood design code (CSA O86-14) presents the usual buckling theoretical equation for determining the critical shear stress for a sheathing panel with simply supported boundaries along all edges with the assumption that the sheathing panel is experiencing uniform shear stress along the edges.

In this study, a typical sheathing panel size (1220×2440 mm) is selected which is connected to four edge typical studs (38×89 mm) with typically spaced nails. The shear buckling test is carried out in a specially designed frame at the structural laboratory, Western University. Also, a nonlinear finite element model is developed and validated with the test results to simulate the shear bucking and post bucking behavior of sheathing panels.

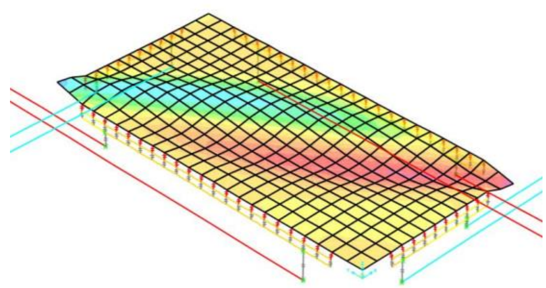
The objective of the research is to verify that the sheathing panel with intermittent nail supports subjected to pure shear follows the usual buckling theories but not necessary the equation proposed by the code. Moreover, the instability of the sheathing panel as a failure mode of LFW walls under which circumstances will be governed and some recommendations are proposed for design purposes.



Shear buckling test set up



Typical shearwall segment subjected to pure uniform shear force per length



Out of plane deformation of sheathing panel due to pure shear – Finite Element Model

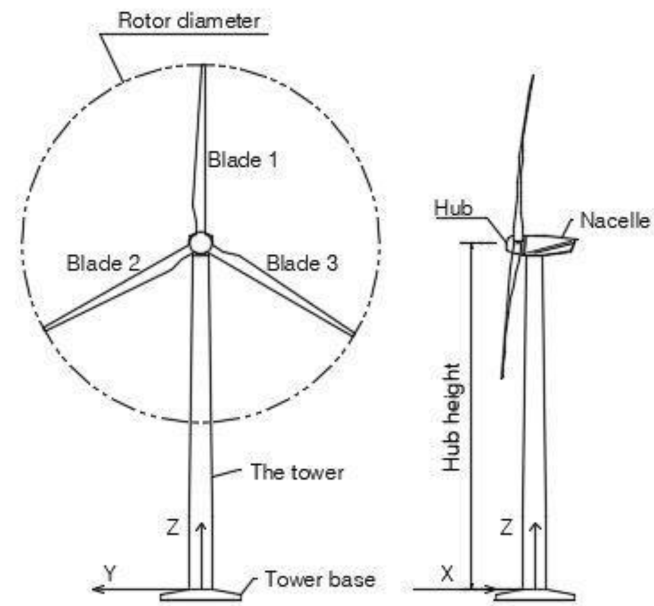
Mohammad Niazi / mniazi6@uwo.ca
Ashraf El Damatty / damatty@uwo.ca

Behavior of Wind turbines under Downburst wind loading

A numerical model is developed to study the performance of wind turbines under downbursts. The numerical model simulates both the wind turbine tower and the blades and incorporates downburst wind fields based on Computation Fluid Dynamics (CFD) simulations. The model considers the variation of the location of the downburst relative to the tower as well as the variation of the blades pitch angles. After validating the numerical model, a real wind turbine is considered for analysis. An extensive parametric study is conducted to determine the peak moments at the tower base and the roots of the blades considering 38,808 load cases including 5,544 downburst configurations for 7 different blades pitch angles. Critical configurations of the downburst which produce maximum stringing actions on the tower and blades for different blades pitch angles are identified. The optimum blade pitch angle which minimizes the downburst effect on both the tower and the blades is then determined.

Downburst design criteria and critical wind profiles are developed to determine the critical downburst loadings on wind turbines. A comprehensive parametric study is carried out including all possible downburst configurations on a variety of wind turbines which are commonly used worldwide. Based on the results obtained from this parametric study, critical load cases are identified to obtain the critical downburst configurations on both the wind turbine tower and blades. These critical load cases are then represented by both equivalent uniform and nonlinear design wind profiles which are shown in a reasonable format that can easily be used by designers and implemented in the design codes. The proposed profiles are then compared to the extreme wind profile recommended by the design codes.

Dynamic analysis of wind turbines under downbursts is currently under investigation considering the fluid-structure interaction effect. A comparison between the wind turbine quasi-static and dynamic responses is conducted under various downburst configurations and the dynamic amplification factor (DAF) is then assessed. The aerodynamic damping of the blades is also estimated under the critical downburst configuration.



Mostafa Ramadan / mramada2@uwo.ca
Ashraf El Damatty / damatty@uwo.ca

Detailed and Simplified Numerical Analysis of Multi-Storey Light-Frame Wood Buildings and Introducing an Optimization Scheme for Minimizing the Cost of Light-Frame Wood Buildings

Wood possess high levels of strength and durability corresponding to its lightweight, which makes it a perfect choice as a construction material for mid-rise buildings. Modeling Light-Frame Wood (LFW) floors is complicated as the typical LFW diaphragm is composed of studs, sheathings, nails, and concrete cover. The non-linear behaviour of the nails with the orthotropic nature of wood makes the modelling of LFW building challenging. Moreover, LFW floors are neither fully rigid nor flexible which imposes more challenges when modelling. As such, modeling detailed LFW floors are very computationally expensive and makes it not practical for practitioners. Therefore, developing a simplified LFW floor model that is able to capture the behaviour of the detailed LFW floor model is of high importance. The current study aims to develop and validate simplified LFW floor models, as well as developing an optimization scheme to minimize the cost of LFW structures.

The first stage of the current study will include the development of detailed numerical models for the floor diaphragm including all of its individual components. Those detailed models will be used as a benchmark for simplified LFW floor models, developed by either link elements or thin orthotropic shells, which can simulate accurately the stiffness of the floors. The developed models will be then be validated against a controlled experiment at WindEEE, where a one-story LFW building will be constructed and tested under wind loads.

While the second stage in the current study will incorporate an optimization scheme based on the Genetic Algorithm method that allows optimizing the design of all LFW walls and floors, in order to minimize the cost of the building while achieving all strength and serviceability requirements. The independent variable in the optimization scheme will be the geometric configuration of all the walls and floors (such as number of studs, dimensions of studs, number of nails, size of nails and number and dimensions of tie rods). While the objective function will be minimizing the cost of the building, and the constraints will be satisfying all the design requirements for the walls and the floors as well as the serviceability criteria.

Mohamed Sadek / msadek6@uwo.ca
Adnan Enajar / aenajar@uwo.ca
Ashraf El Damatty / damatty@uwo.ca

Structural Behavior of Composite Conical Water Vessels Under Hydrostatic Loading

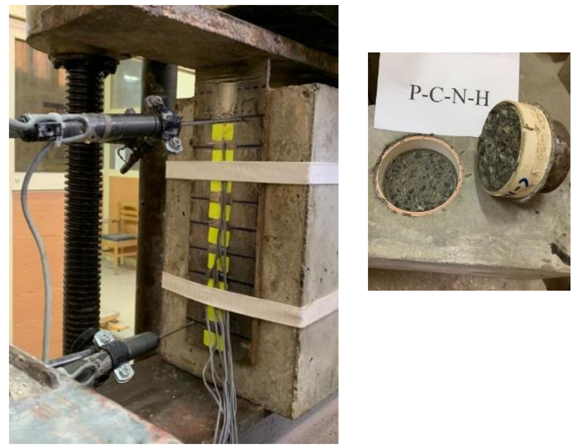
Vessels with truncated conical shapes are commonly used as liquid containments around the globe because they provide large storage capacities with relatively small footprints. In addition, the conical shape provides a more aesthetically pleasing look compared to rectangular and cylindrical shapes.

The conical vessels can be made of steel or reinforced concrete. Recently, composite steel-reinforced concrete construction has been used for conical vessels. In this type of construction, the vessel consists of an external steel shell, made of curved steel panels, and an internal reinforced concrete shell that is cast-in-situ. The steel and reinforced concrete shells are connected together using steel studs that are welded to the steel shell and embedded into the reinforced concrete wall.

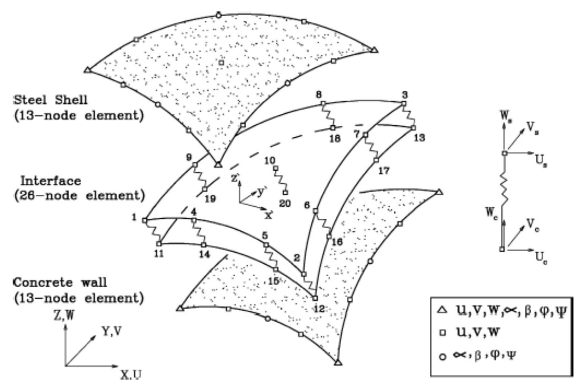
The current research aims to study the behavior of composite conical tanks under hydrostatic loading without using studs or any other local connection between the steel shell and the concrete wall. In this case, the composite action relies on the mechanical interlock obtained through the existence of embossments rolled into the steel shell. This will lead to a significant reduction of the material and labor costs, ease of construction and acceleration of the construction process.

An experimental program was conducted to study the shear and peel behavior of different grades of concrete and various patterns of embossed steel plates available in the market. The obtained results were then used to model the concrete – embossed steel interface in an in-house numerical model (CFEM) to study the effect of using this new technique on various conical vessels under hydrostatic loading.

Embossed steel patterns used in the experimental program



Experimental shear lap and pull-off tests used to study the shear and peel behavior of concrete – embossed steel plates



Elements used to model steel and concrete walls in addition to interface between concrete and embossed steel plate (after Elansary and El Damatty 2017)

Maryam Seleemah / maryam.seleemah@f-eng.tanta.edu.eg
Ahmed Elansary / aelansa2@uwo.ca
Ashraf El Damatty / Damatty@uwo.ca

Cascade failure of transmission towers along a line subjected to downbursts.

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

Transmission line's cascades have played a major role in several serious accidents around the world, as they are particularly prone to occurring in the presence of strong winds. The failure of a line component overloads the system, inducing a progressive failure that can involve many transmission line (TL) supports. Due to their localized nature, downbursts, in particular, cause unequal wind forces on various towers of a transmission line; the collapse of one tower can affect the adjacent towers through the unbalanced forces that develop in the conductors, which can lead to a cascaded-type of failure along the entire line. 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. 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, a nonlinear finite element model was developed to assess the capacity of transmission lines under downbursts. The numerical model can predict (i) the tower's post failure geometry by capturing the plastic hinge formation and the failure mechanism until a state of equilibrium occurs (ii) the tension developed in the new conductor's profile by utilizing the extensible catenary approach in solving three-dimensional conductors with moving boundary conditions under horizontal and vertical loads.

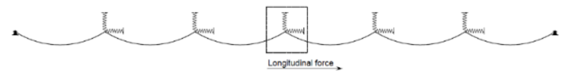
In the next step, a model will be tested at WindEEE for the validation of the progressive failure model in order to understand the failure mechanism of the entire line.

Ahmed Shehata / ashehat7@uwo.ca
Ashraf El Damatty / damatty@uwo.ca

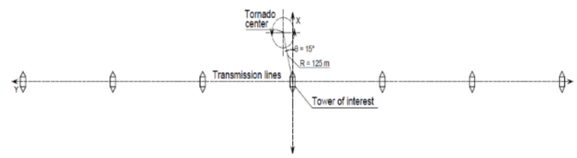
Longitudinal Force on Transmission Lines Towers due to Tornado Wind Load

Transmission lines (TL) structural failures caused by tornadoes have been observed in multiple countries around the globe. More than 80% of worldwide weather-related transmission lines failure are caused by high intensity wind events such as downbursts and tornadoes. When tornado occurs in the vicinity of a transmission tower, an uneven wind velocity distribution will develop along the conductor spans adjacent to this tower. This generates differences of tension force in the adjacent spans. The longitudinal reaction caused by these differences is believed to be one of the reasons of towers' failure under tornadoes.

The ASCE(2020) incorporated for the time some guidelines for tornado and downburst wind loading on TL structures. However, the guidelines pertaining to tornadoes still need refinement, especially for the estimation of conductors longitudinal forces. Therefore, the objective of this study is to provide a procedure that can be used to estimate the maximum longitudinal force acting on transmission towers under tornadoes accurately. This is challenging since the generated force depends on the position of tornadoes due to the localized nature of tornado. The geometric and material parameters of conductors will also influence this force. Thus, a study is first conducted to identify the tornado position that generates the largest longitudinal reaction. Then based on the critical position, a parametric study is conducted on two different transmission line system to access the influence of conductor parameters on the longitudinal forces. Results of this parametric study are used to develop a set of charts that can be used to estimate the longitudinal forces using three-dimensional linear interpolation.



Schematic layout of the 6-span transmission line mode

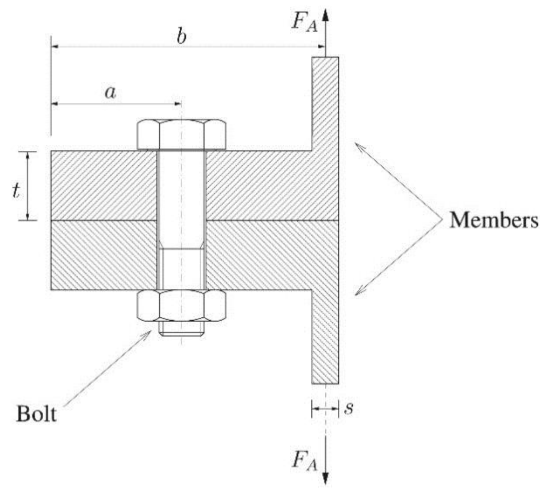


Tornado configurations with respect to the tower of interest

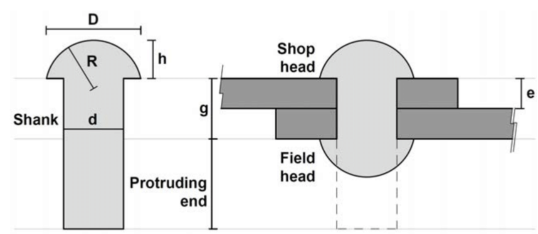
Dingyu Yao / dyao43@uwo.ca
Ashraf El Damatty / damatty@uwo.ca

Local Fatigue Analysis for a Wind Turbine with Riveted and Bolted-Flange Connection

Wind energy harvested from wind turbine has been widely used in many regions around the world. In Canada, the wind generation capacity has been gradually increasing since 2000. As of December 2019, wind power generation capacity reached 13,413 megawatts (MW), which provides nearly 6% of the Canadian electricity demand. In the near future, 2025, the capacity would be expected to meet 20% of the country's energy needs.



Bolted flange connection



Riveted connection

Since wind turbines are frequently exposed to wind load with various wind speed from various directions, fatigue failure of the connections should be thoroughly considered during the design stage. The usual fatigue assessment approach for riveted or bolted joints consists of using the global S-N curves with net or nominal stresses. However, this approach could lead to excessive conservative predictions since it does not recognize the need for detail categorization.

In the current study, a series of detailed riveted and bolted-flange connections finite element model (FEM) will be created. With those models, local concept will be applied to obtain the specific S-N curve for each connection numerically. Fatigue experiments will also be carried out in lab facility in order to validate the S-N curves obtained above. In the end, with the help of software "FAST" and the detailed FEMs, local fatigue assessment will be conducted to compare the fatigue endurance of various connections.

Shaoqing Yu / syu367@uwo.ca
Ashraf El Damatty / damatty@uwo.ca

Active Fluids for Green Energy-Physical Properties

Microalgae and cyanobacteria can be used for the production of "3rd generation" biofuels, which do not require the use of food crops or arable land for their production. Essentially, these photosynthetic microorganisms are able to convert inorganic carbon (e.g., CO_2) to biomass using solar energy to support their metabolism.

In industrial applications, microorganisms are cultivated in dedicated reactors, referred to as photobioreactors (PBRs). Design of photobioreactors for microalgae and cyanobacteria cultivation involves the interplay between fluid flow, microbe biokinetics, and radiative transport phenomena, in which the physical and rheological properties of the active fluid play a crucial role. In this research, we focus on the variation of physical and rheological properties of dilute suspensions of bacterium *Synechocystis* sp. CPCC534 with the shear stress applied to the fluid.

Experiments were carried out at three different stirring rates in well-controlled conditions and the results were compared with stationary conditions where only molecular diffusion and cell motility govern the transport phenomena and cell growth. During the exponential growth phase and in the presence of sufficient light, cell density increases as a result of nutrient up-take. The growth rate and doubling per day were calculated during this phase for samples subjected to different average shear stresses and are plotted in FIGURES 1A and 1B. The results revealed a significant difference between the cultures grown under stationary conditions and those grown under shear ($p < 0.05$). Exerting turbulent shear on the cultural system, causing the suspension to be mixed, improved the growth rate as well as doubling per day in comparison with the stationary condition where only molecular diffusion and cell motility govern the transport phenomena and nutrient up-take.

The viscosity of *Synechocystis* suspensions, subjected to different shear stress levels, was also measured with two different methods. The viscosity data showed shear stress independent Newtonian behavior. However, the viscosity of *Synechocystis* suspensions increased moderately with cell volume fraction up to 10%, beyond which it increased more rapidly. Nevertheless, the correlation between viscosity and bacterial volume concentration did not satisfy the Einstein equation, arising the question of the influence of bacteria motility on the apparent viscosity of suspensions, FIGURE 2. The shear stress history of the cell suspensions did not show any effect on the fluid viscosity.

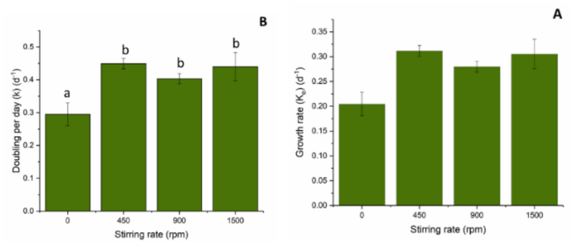


Fig 1: Profiles of growth rate (K_e) (A) and doubling per day (k) (B) for *Synechocystis* sp. CPCC 534 under stirring rate. Same lowercase letters indicate no significant effect at the level of 0.05 among different shear rates. Values are expressed as means ± standard deviation.

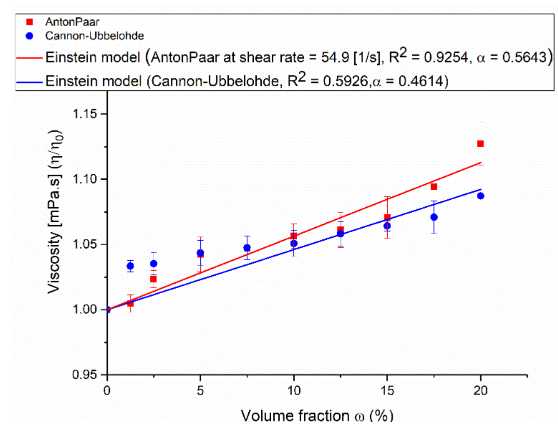


Fig 2: Variation of the viscosity of *Synechocystis* suspensions as a function of concentration measured by two methods. Solid lines show the Einstein equation with adapted intrinsic viscosity values for each method.

Mali Mehdizadeh Allaf / mmehdiz@uwo.ca
Zahra Habibi / zhabibi@uwo.ca
Hanssan Peerhossaini / hpeerhos@uwo.ca

Temperature Regulation in Photobioreactors using Phase Change Materials

Modern urbanization has necessitated innovations in vertical urban growth. High rise buildings provide a good alternative to horizontal urban expansion in terms of space management/utilization. However, consumption of a considerable portion of non-renewable energy by the building sector results in atmospheric emission of a significant amount of carbon dioxide. In light of the increasing concern for climate change, considerable effort has been made to adopt renewable energy sources. One such sustainable energy source with a potential use in the building sector is algal biofuel.

Microalgae is incubated inside photobioreactors to produce biofuel. Photobioreactors have the potential to be structurally integrated into buildings with the aim of carbon dioxide mitigation and biofuel production. Optimal growth of most microalgae species can be sustained under relatively narrow temperature ranges only. Therefore, in order to facilitate algae growth in real world conditions where temperature varies across the day and throughout the year, a temperature regulation system must be present in the photobioreactor. Phase change materials (PCM) have the ability to absorb or release large amounts of latent heat during phase change to provide useful heating or cooling to maintain temperature of a system. The objective of this study is to characterize temperature regulation in a prototyped photobioreactor containing a phase change material.

An insulated open channel flow apparatus containing algal culture and PCM (placed in vertical columns) is created to simulate flow within a photobioreactor. Temperature readings from thermocouples placed at various locations in the channel are used to characterize heat transfer within the system. Microalgae health and growth is characterized at regular time intervals by green saturation values and average algae movement velocity. Algae health and temperature field data are used to gauge effectiveness of PCM and extract optimal PCM placement configuration.

Sameed Akber / sakber2@uwo.ca
Kamran Siddiqui / ksiddiq@uwo.ca
Chris DeGroot / cdgroo5@uwo.ca

Optimization of Porous Geometry for Collecting Concentrated Solar Energy

Fossil fuel usage is resulting in global warming. There is a need to switch to renewable energies, but existing technologies lack the efficiency for widescale adoption. Concentrated solar power (CSP) is a renewable energy that could aid in the transition to a low carbon future by harvesting the abundant heat from the sun. CSP directs sunlight to a single focal point which is used to create energy. A challenge with the current design is that the surface of the thermal receiver reaches a high temperature and does not efficiently transfer the heat due to re-radiation losses. There is a need to re-design the thermal receiver to maximize the efficiency of CSP.

This project investigates the impact that a gradually decreasing porous receiver would have on the efficiency of solar radiation heat capture. A receiver that has a low porosity at the entrance allows for more solar radiation to penetrate into the receiver, reducing re-radiation losses. Moving deeper into the receiver, the porosity increases, resulting in more internal reflections of radiation and a higher percentage being absorbed.

An experimental setup was created that measures the temperature of an aluminum model porous block under the light of halogen lamp. This model block can be seen in Figure 5. The block has a hole down the centre with a gradually decreasing size, modelling a gradually decreasing porous medium. The outer temperature of the porous block mesh was measured using a FLIR infrared thermal camera. For accurate readings, the block was painted with high temperature black spray paint. The readings taken by the infrared camera were verified against measurements taken by surface thermocouples. The internal temperature of the block was taken at each pore size by inserting a thermocouple into the side holes leading to the internal pores of the block.

This experimental setup has been modelled using ANSYS Fluent, using the discrete ordinance (DO) radiation model. Figure 6 shows this computational domain. Currently, experimental results are being used to validate the computational model. Once this validation is achieved, a more complex gradually decreasing porous geometry will be modelled computationally. This geometry will be iterated upon until the optimal heat capture is achieved in the thermal receiver.

Figure 5 Model porous geometry with a gradually decreasing hole size down the centre, and viewing holes in the side through which thermocouples are inserted

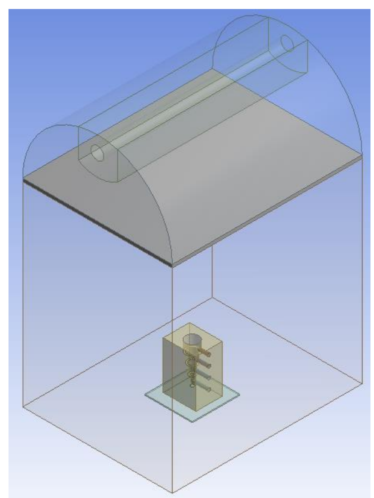


Figure 6 Computational domain containing model porous geometry

Elizabeth Blokker / eblokker@uwo.ca
Kamran Siddiqui/ ksiddiq@uwo.ca
Anthony Straatman / agstraat@uwo.ca

Characterization of Dual-Jet interaction in an Afterburner-like geometry

The fluid interactions in the current fuel injectors of fighter jet afterburner systems are not fully predictable and require further study to better understand. The fuel injectors are of complex design containing numerous holes that inject fuel in varying directions into the high-speed air travelling through the engine. By improving the understanding of these interactions, the afterburner system can be improved to operate more efficiently.

To study these characteristics, a spray bar with two holes oriented in the same direction will be used to model a simplified version of the fuel injector. This spray bar will be placed in a square 25.4cm reduced section of the wind tunnel with a 35m/s wind velocity, to simulate the jet engine duct, and be positioned to spray in different directions relative to the air flow. Water will be sprayed from the bar using momentum fluxes of q30, q60, and q120 as reference points for comparisons.

In order to capture the behaviour of the fluid particles as they exit the spray bar and interact in the wind tunnel, a high-speed camera and Particle Image Velocimetry (PIV) system will be used. This setup will record thousands of back-to-back pairs of images for processing to determine the particle movements between images and convert this into relevant data to be used for finding the desired characteristics. The figure below is an example of one of these images.

Once these tests are completed, this same setup and procedure will be used for observing the liquid particles' behaviour after passing a triangular bluff body used to depict the flame holder within the afterburner system.

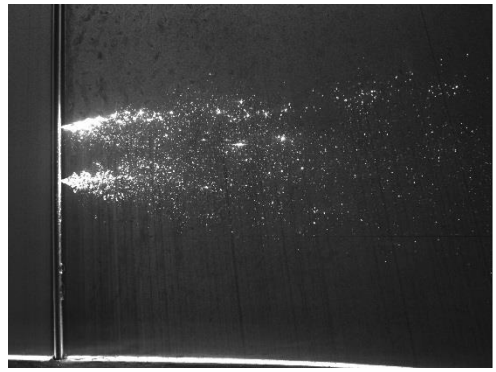


Figure 1: High-speed camera image illuminated by the PIV system of the two liquid jets for a momentum flux of q30.

Complimenting this experiment, a second experiment will be performed to study the behaviour of fuel droplets in an air flow. The droplet detachment sizes as well as their evaporation rates will be observed.

To conduct these tests, the droplets will be inserted into the middle of a square 10.16cm vertical tube using a needle fed from a pressurized tank containing either water or jet fuel. The test section will recirculate the air at different velocities traveling up the tube to carry the droplets upwards.

Performing these tests will be done using the high-speed camera and PIV system to capture the droplets at two locations to observe evaporation rates, while a high-speed video camera will record the droplet separations.

Cody Kellogg / ckellog@uwo.ca
Kamran Siddiqui / ksiddiq@uwo.ca

Mixing of Liquid Droplets in High Speed Air Crossflow

Liquid jet-in-crossflow (JIC) is a liquid injection process which atomizes a liquid jet using a gaseous crossflow. JIC has applications in agriculture, industrial processes, and aerospace. In particular, gas turbine aeroengine afterburners use the simplicity of JIC fuel injection to reduce part weight and complexity. Understanding the behaviour of the droplets resulting from JIC atomization is important in predicting combustion behaviour in the afterburner. Droplet size, distributions, and trajectories have been studied under a number of crossflow conditions including subsonic and supersonic flow, and high and low ambient pressures and temperatures. These crossflow conditions and their effect on droplet dynamics has been investigated at a bulk level. This research further investigates the interaction between gas and liquid phases by examining the influence of local turbulence on the droplet dynamics. The flow of droplets around a bluff body was also of interest for aeroengine applications.

Experiments were performed in a closed-loop wind tunnel with a 27cm × 27cm test section, 69cm long with walls made of clear acrylic for flow visualization. The freestream air velocity was 35m/s (126km/h) in the test section with turbulence of ~1.5%. Water is injected into the crossflow through a 0.8mm orifice in a 4mm diameter spray bar. This JIC spray is investigated for a range of momentum flux ratios, which is defined as the ratio of fluid-to-gas kinetic energy. The gas turbulence was investigated using 2D particle image velocimetry (PIV) and droplet size, D_{32}, and distribution was determined through image processing of the PIV images. The flow of droplets around a bluff body was examined using high-speed imaging.

The adjacent figures illustrate the wind tunnel test section (Figure 7), a PIV image of the JIC process (Figure 8) and the spatial distribution of droplet size (Figure 9).

Figure 7 - Wind tunnel contraction and test section containing a 4mm spray bar

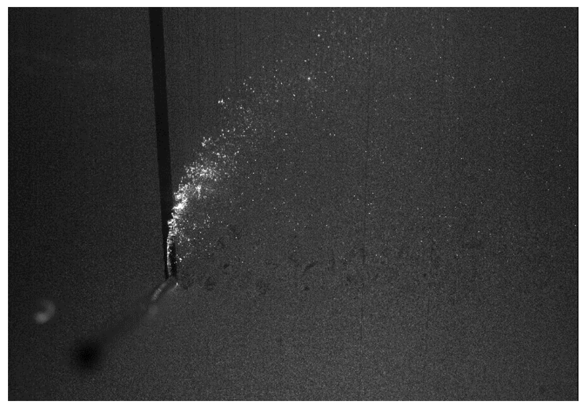


Figure 8 - Particle image velocimetry image of the JIC (crossflow direction: left-to-right)

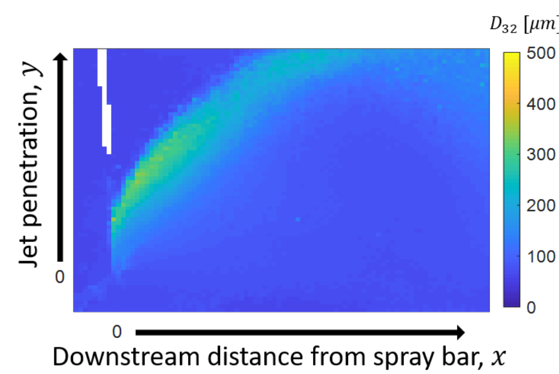


Figure 9 – Spatial distribution of droplet size (D_{32}) which shows that the larger droplets give the JIC its characteristic shape

Matthew D. Mahaffy / mmahaffy@uwo.ca
Kamran Siddiqui / ksiddiq@uwo.ca

Thermo-fluid characterization of Melting PCM in a Circular Cavity

The continued reliance on fossil fuels to generate power has a significant detrimental effect on the environment. However, they continue to be the primary source of energy, and in the current situation will continue to be for the foreseeable future. It is imperative that the integration of renewable energy sources be increased in the near future.

One of the main barriers to renewable energy sources is energy storage. Many renewable sources are intermittent in nature, such as solar and wind. Without effective means of storing this energy until it is needed it is difficult to compete with fossil fuels which provide energy on-demand.

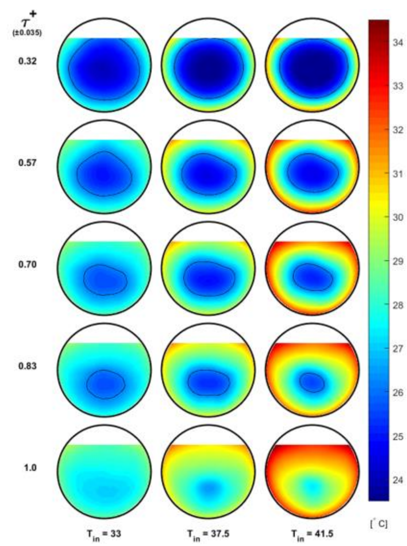
Thermal energy storage is an effective candidate for this purpose, as it is relatively cheap, easy to scale, has high cyclic efficiency and long life. Systems that use materials that melt and freeze during a storage cycle, called latent heat thermal energy storage systems, make use of the large energy associated with phase change and are a better alternative to conventional (sensible) energy storage which relies on a change in temperature alone. These latent heat thermal energy storage systems have greatly increased energy density and have a lower range of operating temperatures due to the isothermal nature of phase change.

The major challenge with latent heat thermal storage is that the storage media it uses, called phase change materials (PCMs) have a very low thermal conductivity which makes heat transfer inefficient. In order to design efficient systems that use PCMs, the underlying physical mechanisms of phase change must be well understood.

The most effective methods to increase heat transfer to PCMs involve encasing it in a spherical cavity with high heat transfer at the boundaries. This could be accomplished with a material with high thermal conductivity, such as a porous media composite, or by other means such as a packed bed of microencapsulated PCM. Therefore, characterizing melting in a spherical geometry was the objective of this study.

The velocity behaviour of the PCM during melting was captured using particle image velocimetry (PIV), a state-of-the-art technique in which a sheet of laser light illuminates particles within the flow, and the movement is captured with a synchronized camera. The temperature behaviour during melting was captured using a high-resolution grid of thermocouples, supplemented by a novel technique using thermal imaging.

In this case, the PCM was fixed in place during melting. In future work, the PCM will be allowed to sink and float, more closely representing a practical scenario. Freezing behaviour in the same geometry and the effect of convective heat transfer in the transient liquid region is also currently being investigated.



Temperature fields at multiple values of non-dimensional time (τ^+) for different heating conditions

Kyle Teather / kteather@uwo.ca
Kamran Siddiqui / ksiddiq@uwo.ca

WindEEE RI's and COVID-19 Pandemic

An unprecedented year at WindEEE Research Institute due to COVID-19 pandemic. WindEEE RI was not spared from the negative effects that the pandemic caused for the scientific research not only in Canada but around the globe. WindEEE RI followed all regulations set forth by Western University and Ontario government. As a result, measures resulted in WindEEE being shut down between March and July 2020. Despite the closure, the institute continued its activities. Aside from the ongoing administrative and client engagement efforts, we efficiently used the remote work period towards much needed development work. As a result, we significantly improved our data processing capabilities and caught up on documenting several processes and procedures. The gradual re-entry was focused on implementing all new safe-work policies as well as addressing all necessary maintenance and cleanup tasks such that the facility was prepared to return to project work as soon as possible.
While some of the research activities were delayed, other collaborations continued online. Some contract work was shifted from the test chamber to an expansion of data analysis and computational alternatives.

Postdoctoral researchers, Graduate Students and WindEEE's staff along with dedicated Directors ALL continued to work and adapted seamlessly, transitioning to working remotely and virtually to the best of their capabilities due to the closure of Western University's offices, labs and WindEEE dome. Research productivity was affected in some areas but exceeded expectations in others. This can be shown by the number of publications being churned. Inevitably numerous projects have been postponed/delayed but many positive effects have surfaced and became clear, one being, WindEEE's entire team's resilience and perseverance. This too has proved to be a period of growth within the team.

Publications

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Patents

1. Jevnikar, S., Siddiqui, K., Sener, A., Jevnikar, A. and Jevnikar, J. "Dynamic Temperature Regulating Device" PCT/CA2020/050836, June 17, 2020 (pending)

Grants

Multi-hazard Risk and Resilience Interdisciplinary Development Interdisciplinary Development Initiatives Program (IDI) – Western University / $400,000 / 2020-2023
Goda, K. plus 20 Co-PIs; Hangan.H. (5%)

Multi-hazard Risk and Resilience (IDI) – Western University / $22,500 / 2020-2021
Urban Disaster Reduction from Tree Failure under Windstorm
Hangan H. (P.I.), Way D., Peerhossaini H

EVE park Wind Study – Environmental and Structural Impacts of Wind at Neighborhood Scale. / $75,000 / 2020-2021
Voucher for Innovation and Productivity (VIP)
Bitsuamlak G., Hangan H.

Mitacs Accelerate & Institute for Catastrophic Loss (ICLR) / $110, 000 / 2019-2020
Tornado Hazards and Exposure Model for Canadian Communities
Hangan, H.

Tornadic Loads Research with FM Global Phase3 / $71,400 USD / 2019-2020
Chowdhury, J., Romanic D., Hangan H.

Performance test of HVAC unit of Bluewater Technology / $7,500 / 2019
Chowdhury, J., Hangan, H.

Regional Power – Long Lake Hydroelectric Project / $57,300/ 2019-2021
Hangan, H.

S2E London, Ontario Development / $25,000 / 2019
Optimal Orientation for Pedestrian Level Wind Comfort and Mitigation Snow Drift for S2E Development
Chowdhury, J., Bitsuamlak G.T., Hangan, H.

Theakston Environmental and Mitacs / $110,000/ 2020-2022
Urban microclimate modeling for sustainable building design, London, ON.
Bitsuamlak G.T. (PI, 100%)

S2E and Ontario Center of Excellence / $75,000/ 2019-2020
Optimal orientation for pedestrian level wind comfort and mitigating snow drift for S2E development, London, ON.
Bitsuamlak G.T. (CoPI)

NSERC Discovery + Accelerator +DND Supplement Award / $130,000 / 2019-2020
Novel computational and experimental wind engineering approaches for community level performance assessment
Bitsuamlak G.T. (PI)

Next Tracker / $15,000 / 2019
Solar System Aeroelastic Testing Review

Bitsuamlak, G.T.

Compute Canada / $7,683 / 2019-2020
Climate Reslience and Sustainable Cities of Tomorrow. Computational Resources Allocation
Bitsuamlak, G.T.

Natural Sciences & Engineering Research Council of Canada (NSERC) Discovery Accelerator / $ 120,000 / 2018-2020
Novel Computational and Experimental Wind Engineering Approaches for Community Level Performance Assessment
Bitsuamlak, G.T.

Natural Sciences & Engineering Research Council of Canada (NSERC) Discovery / $120,000 / 2018-2020
Department of National Defense Supplement Award
Novel Computational and Experimental Wind Engineering Approaches for Community Level Performance Assessment
Bitsuamlak, G.T.

Ontario Centre of Excellence (OCE) /$300,000 / 2020-2022
Development of Software for Analysis of Wood Buildings
El Damatty, A. A.

The Centre for Energy Advancement through Technological Innovation (CEATI) / $56,000 / 2019-2020
Performance Assessment of Transmission Line Structures under Downbursts and Tornadoes
El Damatty, A. A.

Ontario Centres of Excellence (OCE) VIP1 and Centric Engineering / $ 20,000 / 2018-2019
Assessment of Application Heavy Timber Construction for Low-Rise Buildings
El Damatty, A. A., Hamada, A.

Natural Sciences & Engineering Research Council of Canada (NSERC) Engage / $25,000 / 2018-2019
Assessment of Application Heavy Timber Construction for Low-Rise Buildings
El Damatty, A. A.

The National Natural Science Foundation of China (NSFC) / $458,000 / 2018-2020
Effects of Tornado and Downbursts on Network-like Infrastructures
Yang, Q., El Damatty, A.A., Backer, C.

Multi-hazard Risk and Resilience Interdisciplinary Development Initiative (IDI) UWO / $22,500 / 2020-2021
Urban Disaster Reduction from Tree Failure under Windstorm.
Hangan H. (P.I.), Way D., Peerhossaini H

Multi-hazard Risk and Resilience Interdisciplinary Development Initiative (IDI) / $22,500 / 2020-2021
Urban heat islands in London (ON): effects of anthropogenic heat emissions on urban temperature and consequent risks.
Dr. H. Peerhossaini (P.I.), Dr. C.T. DeGroot, Dr. J. Voogt

Western University Start-Up / $ 300,000 / 2018-2022
Peerhossaini, H.

Natural Sciences &Engineering Research Council of Canada (NSERC) – Research Tools and Instruments (RTI) / $ 143,280 / 2020-21
Advanced Particle Image Velocimetry System
Siddiqui, K. (PI) and six others

Natural Sciences &Engineering Research Council of Canada (NSERC) – Idea to Innovation (I2I) / $ 124,400 / 2020-21
Passive Thermal Regulator for Bio-organisms
Siddiqui, K. (PI), Sener, A. and Jevnikar, A.

Western Innovation Fund (WIF)/ $100,000 / 2020-21
Passive thermal regulator for bi-organisms and vaccine transportation
Siddiqui, K.

Natural Sciences &Engineering Research Council of Canada (NSERC) / $ 195,000 / 2018-2023
Characterization and Development of PCM-based Thermal Energy Storage Systems
Siddiqui, K.

Honors and Awards

Honors and Awards

Proposed by Western University for Fellow of the Canadian Academy of Engineers
Hangan, H.

Doctor Honoris Causa – University of Construction. Bucharest, Romania
Hangan, H.

Invited Professor, Short Course, Wind Engineering: Classical and New Concepts, Universidad de Granada, Spain
Hangan, H.

Invited Speaker, Computational wind engineering application for architectural engineering, webinar presentation for Thornton and Tomasetti Engineers and Scientists, July 24 2020.
Bitsuamlak G.T

Invited Speaker, Application guide for wind-speed up factors for transmission line towers, Transmission overhead line design and extreme event mitigation program training webinar, CEATI International, May 28, 2020.
Bitsuamlak G.T

Invited speaker, Wind effects on low-rise structures, webinar presentation for WSP Engineers and Scientists, April 23, 2020.
Bitsuamlak G.T

Invited Speaker, Wood Rise 2020 Webinar.
Bitsuamlak, G.T.

Invited Speaker, Reducing the risk of extreme wind induced damage, Institute for Catastrophic Loss Reduction - Friday Forum Webinar, September 20, 2019.
Bitsuamlak G.T

Driving the Standard: Wind Testing, Solar Trackers, and Peer Review, Green Tech Media Webinar, December 2019.
Bitsuamlak G.T

Member of National Digital Research Infrastructure Organization (NDRIO) - Research Council
Bitsuamlak G.T.

Invited speaker, Physics Colloquium, Western University
Bitsuamlak, G.T.

Invited Keynote Speaker, Wood Rise 2019 Conference, Quebec, Canada.
Bitsuamlak, G.T.

Invited Speaker, Wind-resilient and Sustainable Architectural Engineering. University of Michigan

Bitsuamlak, G.T.

Invited Speaker, Synoptic and Non-Synoptic Wind Loading on Buildings. Stephenson, Engineering Inc.
Bitsuamlak, G.T.

Invited Speaker, Computational Wind Engineering and Building Science, Theakston Environmental Inc.
Bitsuamlak, G.T.

Invited Speaker, A Community Outreach. Mr. Ken Whitnall Residence
Bitsuamlak, G.T.

Changjiang Award, China (Highest Academic Award Offered by the Ministry of Education in China)
El Damatty, A.A.

Keynote Speaker, World Congress on Advances in Civil, Environmental, and Materials Research (ACEM20), Seoul, South Korea.
El Damatty, A.A.

Keynote Speaker, Certificate Presentation Ceremony, Professional Engineers of Ontario
El Damatty, A.A.

Invited Visiting Professor, Seoul National University, Seoul, Korea
El Damatty, A.A.

Chair Professor, South China University of Technology, Guangzhou, China
El Damatty, A.A.

Invited Keynote Speaker, the 2nd International Conference on Civil Engineering and Architect (ICCEA). Seoul, Korea.
El Damatty, A.A.

Invited Keynote Speaker, the 2019 International Conference on Engineering Education and Innovation (ICEEI), Seoul, Korea.
El Damatty, A.A.

Invited Keynote Speaker, The ASME-JSME-KSME Joint Fluids Engineering Conference. San Francisco, USA
Peerhossaini, H.

Vanguard Award (WORLDiscoveries)
Siddiqui, K.

Invited Speaker, 9th International Mechanical Engineering Conference. Karachi, Pakistan.
Siddiqui, K.

Events

Student Tours at WindEEE

Western University is recognized as the leading university in wind engineering and wind-related research. It is also the only institution in Canada that currently offers a graduate program in wind engineering. For WindEEE it is a prosperous opportunity to inspire our impending engineers towards a future in wind by demonstrating our operating capabilities.

This year the WindEEE Research Institute had the opportunity of hosting some of our first year civil engineering students. Their visit at WindEEE included a presentation about the dome's capabilities, past projects, and accomplishments. Following the presentation the students were invited into the WindEEE dome test chamber to experience a tornado and downburst simulation.

Western Formula Racing Unveiling

Western Engineering students are among the most active students on campus when it comes to extracurricular activities, participating in faculty-based groups, clubs and teams. The Western Formula Racing (WRF) team is for students who are interesting in all things automotive and would like to become involved in the world of Formula SAE cars. Students use their engineering skills along with university and external resources available to them to fabricate and compete a formula-style race car in an annual competition with approximately 120 other vehicles from colleges and universities around the world.

WindEEE was geared for its usual involvement, as in previous years, to host the exciting event while the WRF team was to unveil their 2020 formula race car. Unfortunately, due to COVID-19, this years' event didn't take place. However WindEEE RI is looking forward to hosting the 2021 WRF team's car unveiling event and we will ensure the event will be as exciting and as well received as it was last year, as the image below depicts.

Notes

Notes

WindEEE Research Institute
Western University

2535 Advanced Avenue
London, ON N6M-0E2
Canada

t: +1 (519) 661-2111 x89143
f: +1 (519) 661-3339
windeee@uwo.ca
www.windeee.ca

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Western University

2535 Advanced Avenue
London, ON N6M-0E2
Canada

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