
# Challenges and Opportunities in Multi-Hazard Engineering

FIU | Wall of Wind
NHERI Experimental Facility

NSF

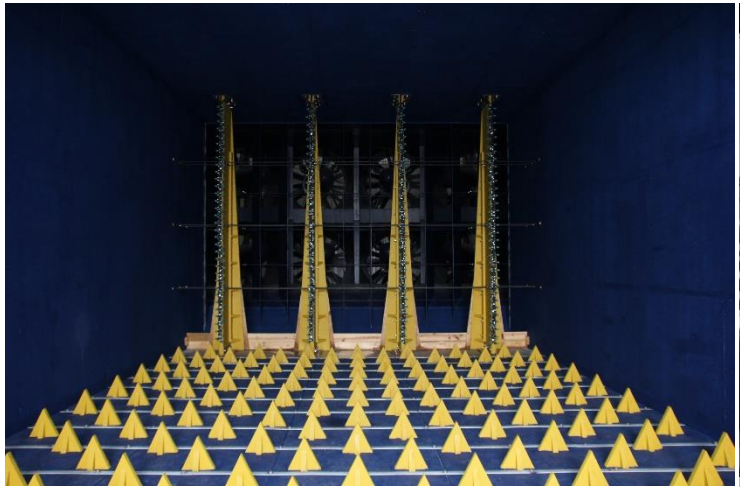
December 2018

# Overview of the Facility

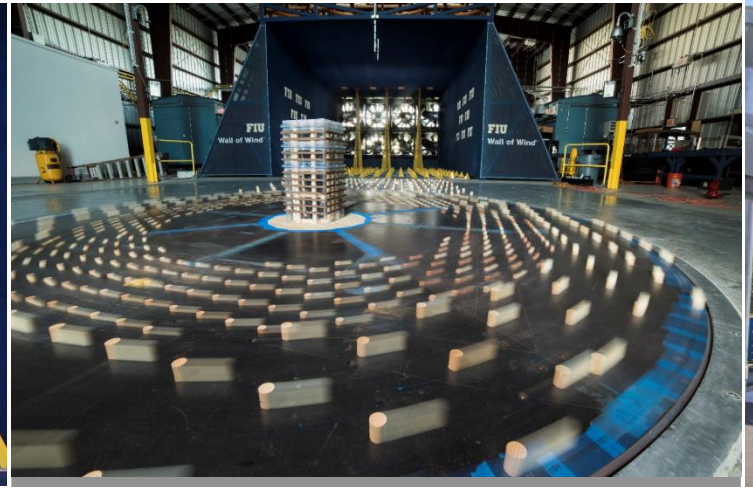
FIU Wall of Wind
NHERI Experimental Facility


Building and Operations and Control Center


Control Room



Flow Management and Rain Nozzles




WOW Turntable (16 ft. Diameter)

Staging Area

# Overview of the Facility

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## Unique Experimental Resources and Testing Capabilities

- Up to Category 5 hurricane winds simulations
- Multi-Scale Testing (full-, large-, small-scale)
- Destructive Testing (to predict progressive failures in buildings and infrastructure elements)
- Wind-Driven Rain simulations (to study water intrusion)
- Various Structures (buildings, bridges, renewable energy systems, lifeline infrastructures)

# WOW-EF Team

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NHERI Experimental Facility

**Arindam Chowdhury, PhD**
Director and PI
*Associate Professor*

**Peter Irwin, PhD**
Co-PI
*Professor of Practice*

**Ioannis Zisis, PhD**
Co-PI
*Associate Professor*

**Amal Elawady, PhD**
Wind Engineering Faculty
*Assistant Professor*

**Laird Kramer, PhD**
STEM Education and Outreach
*Professor*

**TBD**
Site Operations Manager

**Remy Dou, PhD**
ECO Coordinator
*Education Research Specialist*

**Walter Conklin**
Laboratory and EH&S Manager

**Roy Liu-Marques**
Project Engineer

**TBD**
Research Specialist

# Examples of Research Capabilities

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## Topic: Standing seam metal roof testing


**Findings:** Considerably higher suctions with larger non-uniformity for trapezoidal roof; The panel vibrations in the trapezoidal roofs crept into the panel-ribs causing high deflection and failure.

# Examples of Research Capabilities

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## Topic: Aerodynamic mitigation and power system (AMPS)

Patented: US 2015/0345472 A1

**Findings:** AMPS can reduce wind loads by changing the flow structure, disrupting conical vortices; Simultaneous production of wind (green) energy to combat power outages and supplement grid power.

# Examples of Research Capabilities

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## Topic: Aeroelastic and Aerodynamic Responses of Traffic Signal Systems

# Grand Challenges in Multi-Hazard Engineering

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Grand Challenges in the context of *advancing knowledge in natural hazards mitigation, community resilience and sustainability*:

1. Building aerodynamics in high Reynolds number flows.
2. Non-synoptic downburst flows and their effects.
3. Air pollutants dispersion in urban areas.
4. Mechanics of loose-laid particle motions.
5. Active control to improve performance of building systems.
6. Resilient and cost effective renewable energy systems.
7. Civil infrastructure management under wind-storms.

# WOW EF Science Plan and Opportunities

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1. ***Providing Data For Validating Computational and Numerical Simulation Methods:***

- WOW EF has unique experimental resources and ***multi-scale testing capabilities*** to enable cross-disciplinary research on complicated fluid-structure interaction problems.

- Using unique ***PIV capabilities*** the EF can help study the features of the flow-field, turbulence effects, and fluid-dynamics phenomena that lead to pressure patterns and responses.

- EF provides a very useful test bed for validating Computational Fluid Dynamics (CFD) and FEM (including non-linear effects) methods to ***reduce the reliance on physical testing***. [Aligned with the NHERI Vision.]

- Research may also provide means for ***assessing and reducing uncertainties*** in simulation results to foster data-driven modeling. [NSF CAREER project on CFD for Urban Environments – PI: Dr. Catherine Gorle.]

# WOW EF Science Plan and Opportunities

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***2. Performance of Building Envelope***.

- Large- and full-scale tests can facilitate fundamental research pertaining to ***light frame residential structures and retrofit techniques*** (for both steel frame and wood frame structures).

- Understanding multi-stressor effects on building envelopes (including ***multi-layered cladding systems***) can lead to new designs to reduce wind loads and rain infiltration.

- EF can help study the effect of wind and rain on ***air permeable building envelope systems*** which depend on pressure equalization. [NSF project on Physics for Loose-laid Roofing Aggregates -- PI Dr. Nigel Kaye.]

- EF can provide new knowledge on the strength, condition, remaining service life, and ability to resist wind, rain, and debris impacts under single or sequential multi-hazard events.

- New research can predict the ***lifecycle performance of civil infrastructure***, from component to holistic system levels, under hazard events. [Aligned with the NHERI Vision.]

# WOW EF Science Plan and Opportunities

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***3. Innovations in Mitigation Techniques, Engineered Building Systems, New Sustainable Materials***.

- EF can help to translate research into innovative mitigation strategies and technologies to reduce the impact of hazards. [Aligned with the NHERI Vision.] [NSF SBIR Phase II: Telescopic Structural Flood Walls – PI: Mr. Jorge Cueto.]

- Aerodynamic mitigation measures often require the large scale capabilities of the WOW to be properly validated. [NSF project on Smart Morphing Facades – PI: Dr. Alice Alipour.]

- Active control approaches can be studied in high Reynolds number flows. [NSF CAREER project on Control of Vortex Breakdown in High-Reynolds Number Rotor Flows – PI: Dr. Victor Maldonado.]

- Experimentation can inform risk modeling by comparing *fragility curves* for structures with and without mitigation. There are many fragility curves developed for seismic applications, but not so many for wind.

- The EF has been used to explore new types of building systems and materials to improve resilience.

# WOW EF Science Plan and Opportunities

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***4. Non-Straight Line and Short Duration Wind Storms***.

- There is limited information about the loading effects on buildings from ***non-synoptic wind events***, such as thunderstorm downbursts.

- EF will simulate ***downbursts*** with large enough sizes and relative heights of peak wind speeds above ground for different applications.

- Dual simulation capabilities to generate both ***non-synoptic and synoptic winds*** and analyze their effects on structures will attract broader research community and early career faculty. [NSF Project on Downburst Fragility Characterization of Transmission Line Systems – PIs: Abdollah Shafieezadeh and Amal Elawady.]

- Effects of ***non-stationarities*** in the wind events (e.g., sharp changes in wind speed and direction) can be studied.

# User Base and User Support

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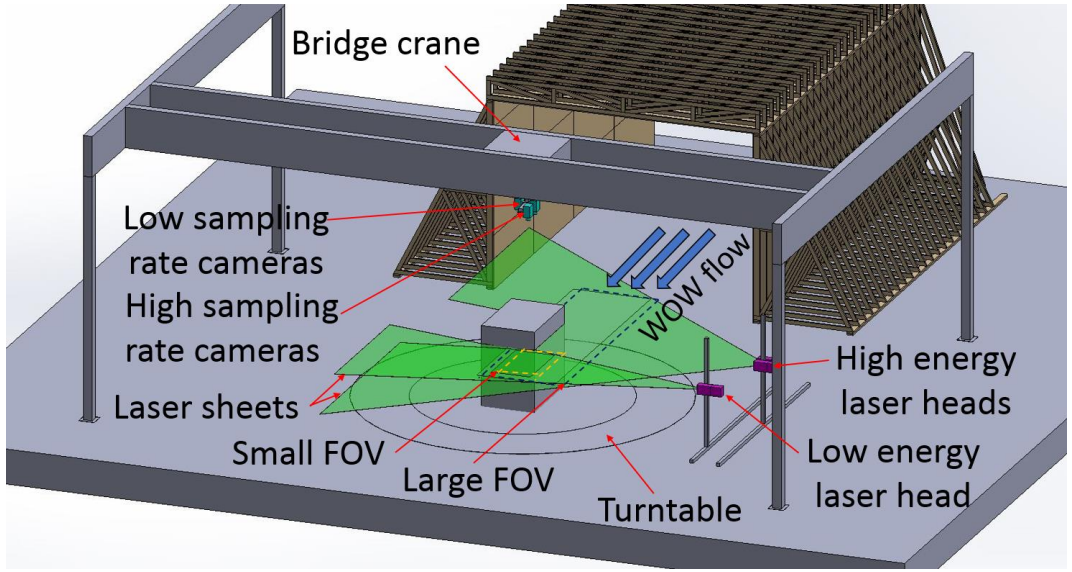
## New Experimental Techniques to Broaden Participation:




***MRI: Acquisition of a Three Component Particle-Image Velocimetry System to Enable Fundamental Research in Wind Engineering and Fluid Mechanics***

1. NSF MRI award (#1828585) to acquire a high spatio-temporal resolution 3-component particle-image velocimetry (PIV) system:
   - Holistic-flow field measurements, fluid-structure interaction at high Reynolds numbers.
   - Validation of numerical models for turbulent flow simulation and fundamentals of fluid-structure interactions.
   - New cross disciplinary research collaborations (pollutant dispersion, energy systems and aerodynamics of unmanned aerial vehicles).

# User Base and User Support

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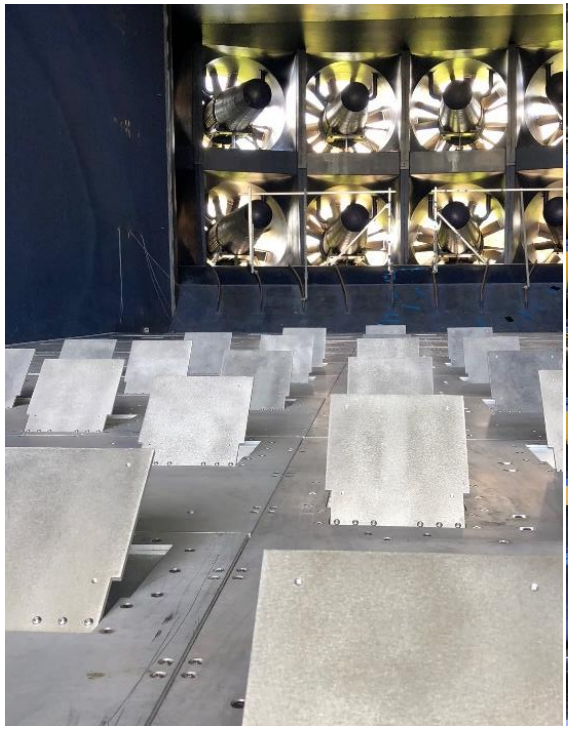
## New Experimental Techniques to Broaden Participation:



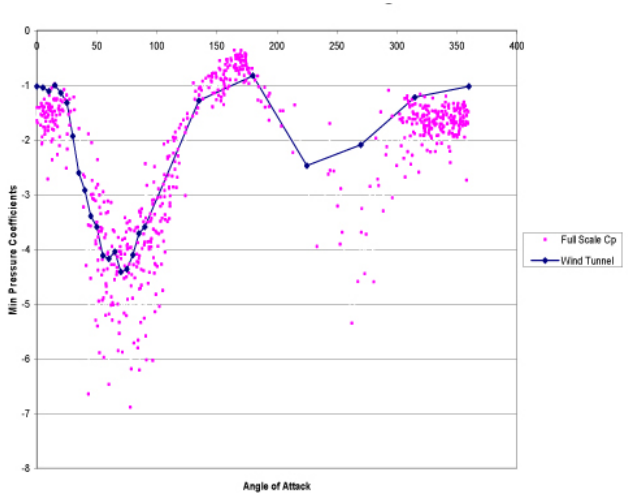
2. New Automated Roughness System and an Automated 3-Axis Traverse System (robot arm) will significantly reduce the test time setup.

3. A preliminary investigation phase to assess the feasibility of producing non-synoptic downburst wind flow at large scales appropriate for downburst-structure interaction studies.

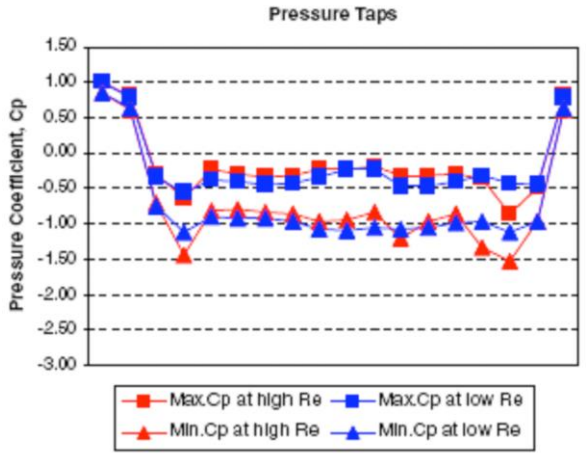
# Wind Engineering Challenges



- ***Reynolds number issues warrants large-scale testing***




*Courtesy: TTU*




*Courtesy: Dr. P. Irwin*

- ***Blockage constraints precludes testing of entire structures***

- ***Hybrid Simulations can be the answer!***

# User Base and User Support

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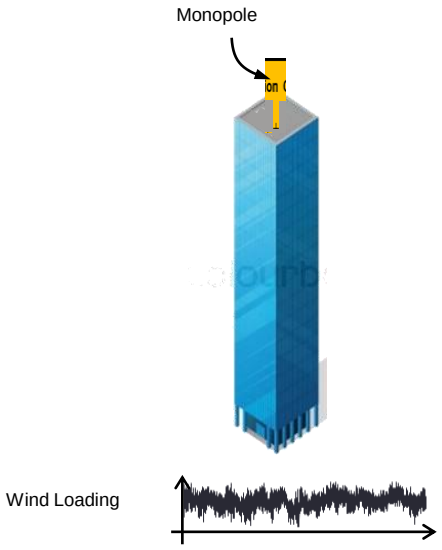
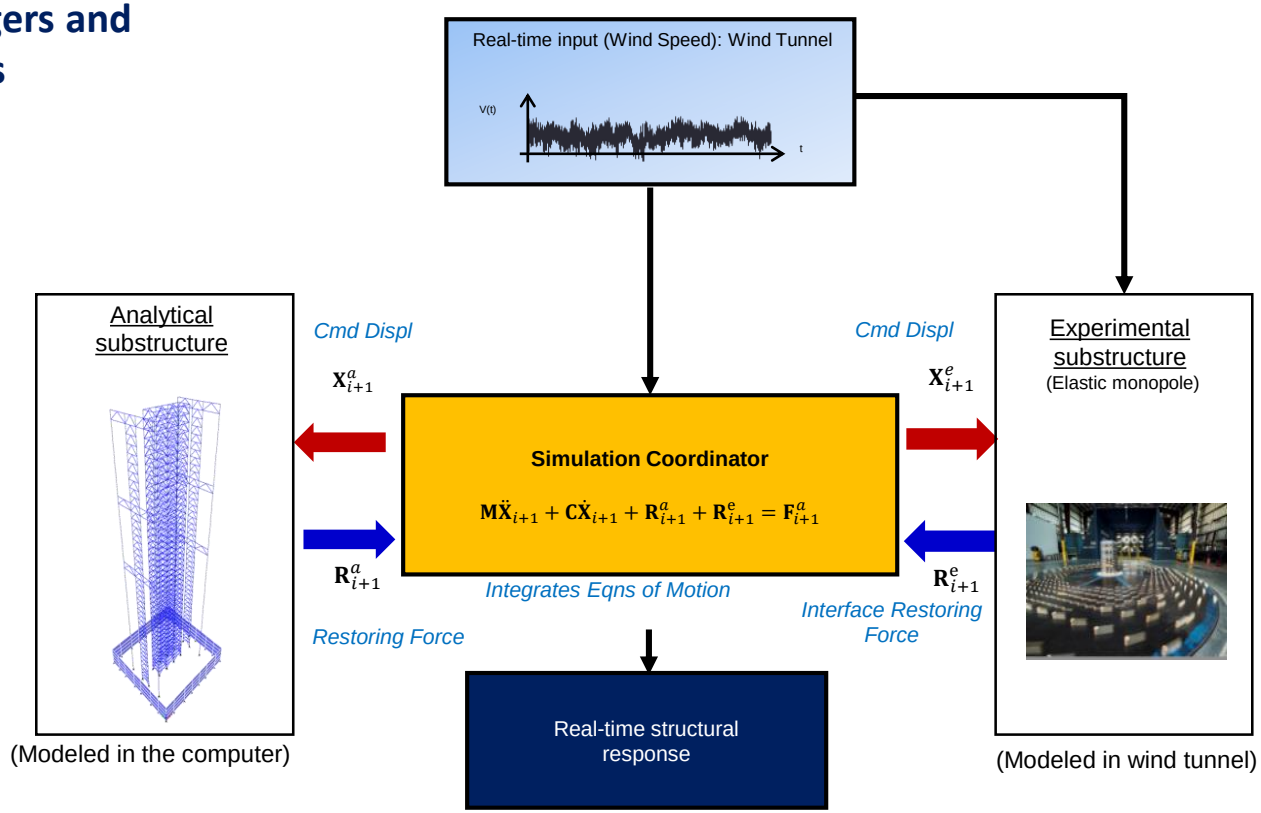
## Partnerships Facilitated to Broaden User Base:

Lehigh RTMD EF – FIU WOW EF Collaboration: Advancing wind testing using RTHS technology.

**Structural System**
**40-Story Building with Outriggers and Supplemental Dampers**




**Hybrid Wind Simulation Experiments**



# Wind Engineering Challenges



**Challenges in RTHS**:

Similarity requirement yields that the prototype time interval is:

$$\Delta t_p = \frac{D_p}{D_m}\frac{U_m}{U_p}\Delta t_m$$

where the subscripts $p$ and $m$ stand for prototype and model, respectively, $D_m/\ D_p$ is the geometric scale, $U_m/\ U_p$ is the velocity scale, and $\Delta t_m = 1/n_m$.

- For example, for geometric scale $D_m/D_p$ = 1:300 and velocity scale $U_m/U_p$ = 1:5, time scale $\Delta t_m/\Delta t_p$ = 1:60.
- 1 sec. in wind tunnel represents 1 minute at full scale; 60 Hz in wind tunnel represents 1 Hz at full scale.

- ***Time and frequency scaling issues pose challenge: Numerical simulations of full structure residing on computer may not be 'fast' enough; Actuators to apply deflections on physical sub-structure in wind tunnel may not have adequate frequency response.***

**Large Scale Tests**:

- For geometric scale $D_m/D_p$ = 1:20 and velocity scale $U_m/U_p$ = 1:5, time scale $\Delta t_m/\Delta t_p$ = 1:4.
- 1 sec. in wind tunnel represents 4 sec. at full scale; 4 Hz in wind tunnel represents 1 Hz at full scale.

# FIU and Lehigh Collaboration

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# User Workshops

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## User Workshops to Broaden User Base:

- Live demonstration of testing capabilities and EF tour for NHERI User Workshop participants.

- Telepresence used for broadcasting experiments in real time for user broadening during each NHERI WOW EF User Workshop and the Summer Institute to showcase EF capabilities.

# NHERI WOW EF Workshops Around The Year

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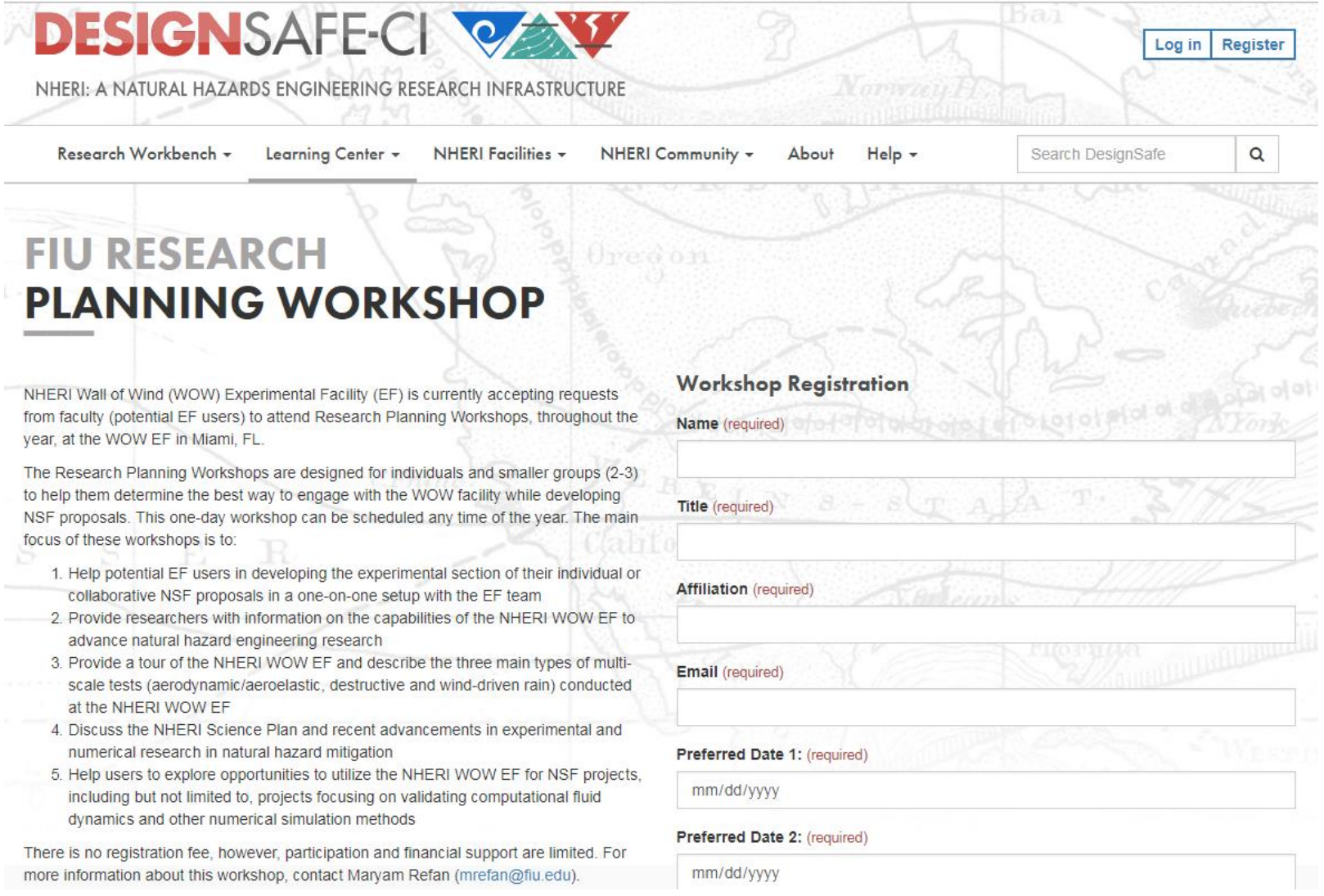
https://fiu.designsafe-ci.org/

https://https://www.designsafe-ci.org/learning-center/training/workshops/fiu-ef/research-planning/



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## FIU RESEARCH PLANNING WORKSHOP

NHERI Wall of Wind (WOW) Experimental Facility (EF) is currently accepting requests from faculty (potential EF users) to attend Research Planning Workshops, throughout the year, at the WOW EF in Miami, FL.

The Research Planning Workshops are designed for individuals and smaller groups (2-3) to help them determine the best way to engage with the WOW facility while developing NSF proposals. This one-day workshop can be scheduled any time of the year. The main focus of these workshops is to:

1. Help potential EF users in developing the experimental section of their individual or collaborative NSF proposals in a one-on-one setup with the EF team
2. Provide researchers with information on the capabilities of the NHERI WOW EF to advance natural hazard engineering research
3. Provide a tour of the NHERI WOW EF and describe the three main types of multi-scale tests (aerodynamic/aeroelastic, destructive and wind-driven rain) conducted at the NHERI WOW EF
4. Discuss the NHERI Science Plan and recent advancements in experimental and numerical research in natural hazard mitigation
5. Help users to explore opportunities to utilize the NHERI WOW EF for NSF projects, including but not limited to, projects focusing on validating computational fluid dynamics and other numerical simulation methods

There is no registration fee, however, participation and financial support are limited. For more information about this workshop, contact Maryam Refan (mrefan@fiu.edu).

### Workshop Registration

**Name** (required)

**Title** (required)

**Affiliation** (required)

**Email** (required)

**Preferred Date 1:** (required)

mm/dd/yyyy

**Preferred Date 2:** (required)

mm/dd/yyyy

# Facility Use by NSF-Supported Awards

FIU Wall of Wind
NHERI Experimental Facility

| 7-digit NSF grant number | PI name | Project Title | Status |
|---|---|---|---|
| **1541142 (I-Corps)** | Arindam Chowdhury | Innovative Hurricane Damage Mitigation Systems | Complete |
| **1234004 (Collaborative)** | Steve Cai and Arindam Chowdhury | Progressive Failure Studies of Residential Houses towards Performance Based Hurricane Engineering | Complete |
| **1151003 (CAREER)** | Arindam Chowdhury | CAREER: Full-Scale Simulation of Peak Responses to Reduce Hurricane Damage to Low Buildings and Use of Related Research to Develop Hurricane-Engineering Expertise | Complete |
| **1443999 (EARS)** | Kemal Akkaya (Former PI: Ismail Guvenc) | Pervasive Spectrum Sharing for Public Safety Communications | Complete |
| **1455709 (CMMI)** | Guirong (Grace) Yan | Damage and Instability Detection of Civil Large-scale Space Structures under Operational and Multi-hazard Environments based on Change in Macro-geometrical Patterns/Shapes | Complete |
| **1605091** | Liang Chung Lo | Variability of wind effects on natural ventilation and pollutant transport in buildings | Complete |
| **1635378 (CMMI)** | Youngjib Ham | Uncovering Potential Risks of Wind-induced Cascading Damages to Construction Projects and Neighbouring Communities | Ongoing |
| **1635569 (CMMI)** | Abdollah Shafieezadeh | Experimentally Validated Stochastic Numerical Framework to Generate Multi-Dimensional Fragilities for Hurricane Resilience Enhancement of Transmission Systems | Ongoing |
| **1635137** | Catherine Gorle | Quantifying Uncertainties in Computational Fluid Dynamics Predictions for Wind Loads on Buildings | Ongoing |
| **1727401** | Chris Letchford | Model to Full-Scale Validation of Peak Pressure Mechanisms in Buildings that Cause Cladding Failures and Windstorm Damage | Ongoing |
| **1661621** | Shirley Dyke | Research Coordination Network in Hybrid Simulation for Multi-hazard Engineering | TBD |

# 2018 NSF-Awarded Projects

FIU Wall of Wind
NHERI Experimental Facility

| 7-digit NSF grant number | PI name | Project Title | Status |
|---|---|---|---|
| **1751918 (CAREER)** | Victor Maldonado | CAREER: **Control of Vortex Breakdown in High-Reynolds Number Rotor Flows with Secondary Vortex Structures** | Ongoing |
| **1749610 (CAREER)** | Catherine Gorle | CAREER: Quantifying Wind Hazards on Buildings in Urban Environments | Starts Jul 2018 |
| **1751844 (CAREER)** | Alice Alipour | CAREER: Resiliency of Electric Power Networks under Wind Loads and Aging Effects through Risk-Informed Design and Assessment Strategies | Starts Aug 2018 |
| **1762968 and 1762918 (Collaborative)** | Abdollah Shafieezadeh and Amal Elawady | Collaborative Research: **Downburst Fragility Characterization** of Transmission Line Systems Using Experimental and Validated Stochastic Numerical Simulations | scheduled for Oct.2018 |
| **1758544** | Jorge Cueto | SBIR Phase II: **Telescopic Structural Flood Walls** | TBD |
| **1760999 (CMMI)** | Nigel Kaye | Understanding Particle Scale Motion Initiation **Physics for Loose-laid Building Rooftop Aggregates in Severe Windstorms** | TBD |
| **1824995 and 1825908 (Collaborative)** | Dorothy Reed and Arindam Gan Chowdhury | Collaborative Research: Hybrid Experimental-Numerical Methodology and Field Calibration for Characterization of Peak Wind Effects on Low-Rise Buildings and Their Appurtenances | TBD |
| **1826356 (Collaborative)** | Alice Alipour | Collaborative Research: Rethinking the Role of Building Envelopes with **Smart Morphing Facades** | TBD |
| **1819785 (SBIR)** | Benjamin Storm | SBIR Phase I: Lowering Wind Power Costs Through **Robust Vertical-Axis Turbines** | TBD |

# Successful Proposals

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## *DesignSafe-CI* Announcements on NSF Awards to Inform Potential Users:

designsafe-ci.org/community/news/2018/august/alipour-career-award-electric-power-wall-wind/

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### ALIPOUR TO ENHANCE RESILIENCY OF ELECTRICAL POWER NETWORKS USING NHERI FIU WALL OF WIND

Published on August 23, 2018

**Related Links**

- Alice Alipour
- National Science Foundation Fac Early Career Development (CARI Award
- CAREER Project
- Wall of Wind

designsafe-ci.org/community/news/2018/may/another-nsf-career-award-wall-wind-gorle/

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FOR IMMEDIATE RELEASE:

### ANOTHER NSF CAREER AWARD AT THE NHERI-FIU WALL OF WIND EXPERIMENTAL FACILITY

Miami, May 24,2018 — Catherine Gorlé, assistant professor of civil and environmental engineering, recently received a 2018 National Science Foundation (NSF) CAREER Award. The award recognizes early career faculty who show equal dedication to research and education within their departments and institutions.

The research will use the NSF-supported Natural Hazards Engineering Research Infrastructure (NHERI) Wall of Wind facility at Florida International University and archive project data in the NHERI Data Depot. The Data Depot is a repository of hazards engineering information where researchers upload, organize, collaborate, analyze, visualize and formally publish their data with a Digital Object Identifier (DOI).

Gorlé leads Stanford's Wind Engineering Lab, where she and her team research and assess complex environmental issues in urban environments. The lab's research seeks to quantify the uncertainties facing designers and policymakers in their efforts to grow sustainable cities by developing predictive computational fluid dynamics (CFD) frameworks that model or solve wind flow and transport problems. She and her team work to apply these findings to resilient and breathable cities, improved ventilation systems, and energy optimization around the world.

**Related Links**

- Stanford Wind Engineering Lab
- NHERI Wall of Wind Facility
- NSF Faculty Early Career Developm Program (CAREER)

# National Recognition and Achievement

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The American Society of Civil Engineers (ASCE) selected the NHERI WOW EF as the winner of the:

***2018 Charles Pankow Award for Innovation***

*"The NHERI WOW is recognized for opening up a realm of research and education opportunities, never before possible, to enhance the safety and resiliency of new and existing buildings and infrastructure."*

# Acknowledgement

The FIU NHERI Experimental Facility is supported by a grant from the National Science Foundation (#1520853).