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NHERI Experimental Facility

SimCenter NHERI
Center for Computational Modeling and Simulation

# Test design and planning using NHERI WOW EF: Aeroelastic, Aerodynamic, Destructive and Wind-Driven Rain Tests

**Speakers: Ioannis Zisis and Amal Elawady**
**(WOW-EF, FIU)**

**August 11, 2020**
**9:00 – 9:20pm PDT**

This workshop is coordinated by the Natural Hazards Engineering Research Infrastructure's (NHERI) Wall of Wind and the NHERI SimCenter and is supported by the National Science Foundation award CMMI 1520853 and 1612843. Any statements in this material are those of the presenter(s) and do not necessarily reflect the views of the National Science Foundation.

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# Outline

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- Existing Testing Capabilities:
  - Aerodynamic Test
  - Aeroelastic Test
  - Wind-Driven Rain Test
  - Destructive Test
- Recent and Scheduled Upgrades:
  - Automated Roughness
  - Robotic Arm
  - PIV (MRI)
  - Downburst Simulator

# Aerodynamic Test

# Aerodynamic Test

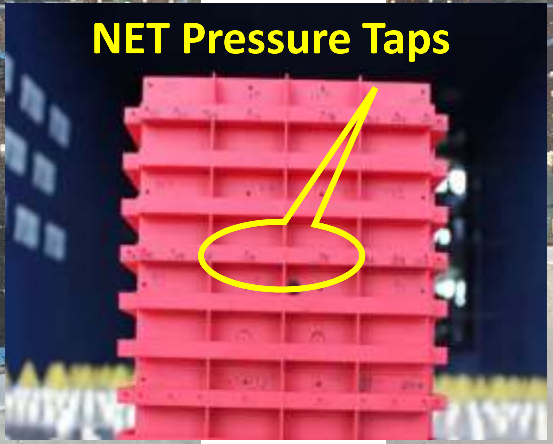


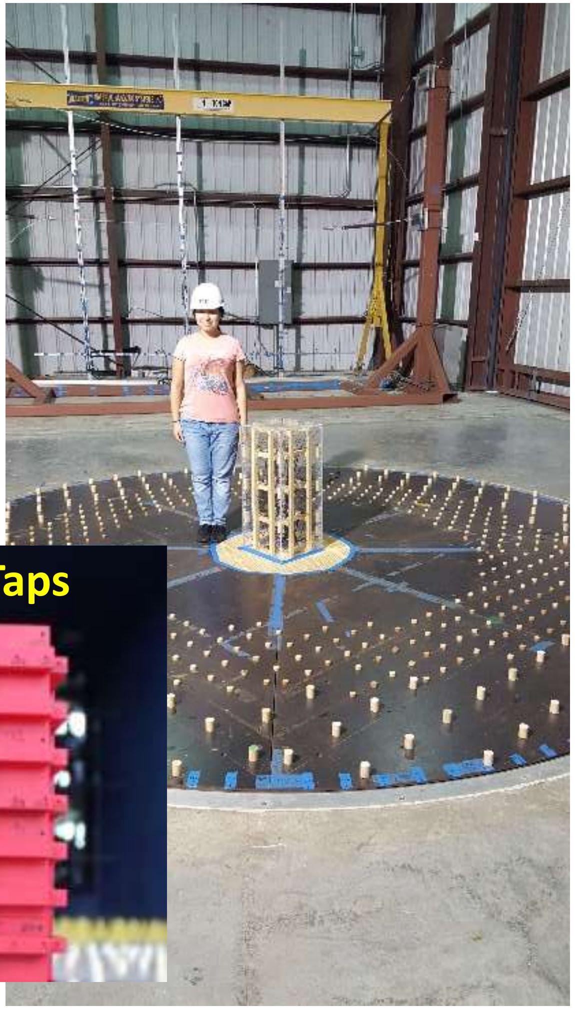
- Example Project: Wind Effects on Canopies Attached to Low/Mid-Rise Buildings
  - ➢ Complex flow: canopy/building interaction
  - ➢ Top/bottom surface taps (differential wind pressure) → C&C loads
  - ➢ ***Net*** wind effect → Overall design

# Aerodynamic Test



- Example Project: Wind Effects on Balconies (Multi-Scale)

1:180

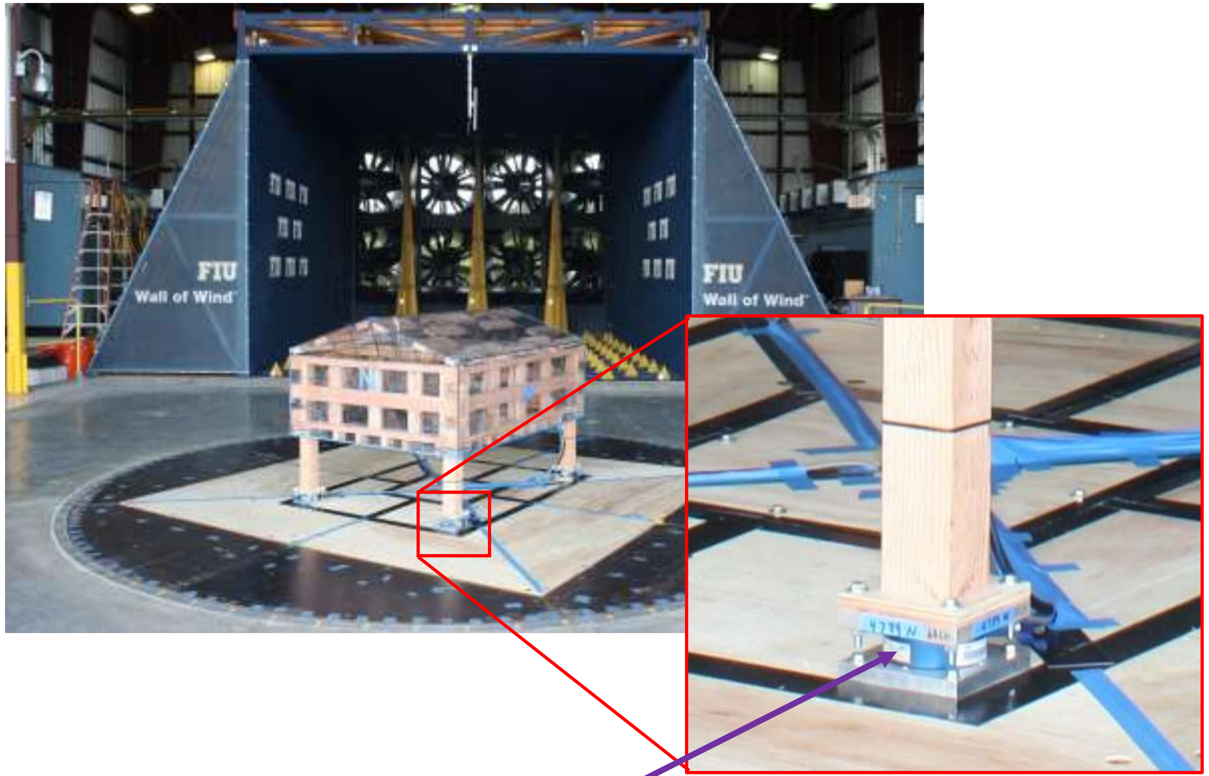
1:67

1:25

# Aerodynamic Test



- Example Project: Wind Effects on Elevated Houses




MDOF Load Cell

# Aerodynamic Test

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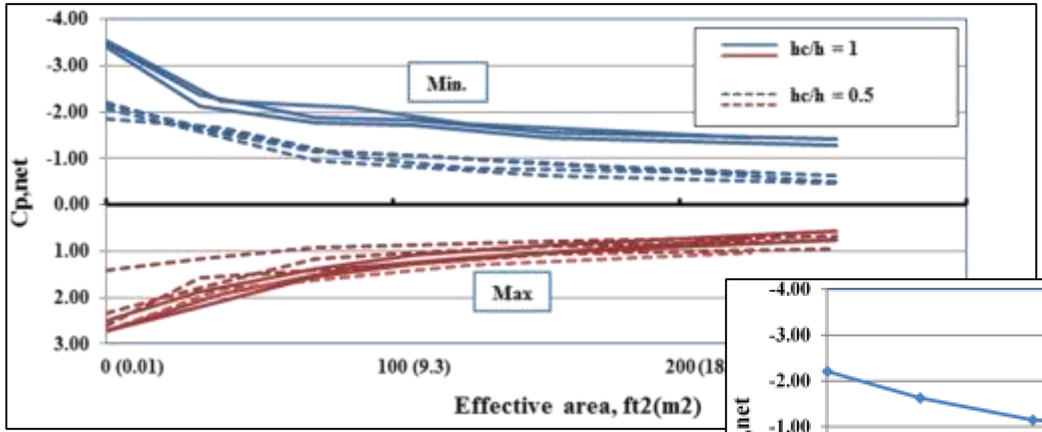
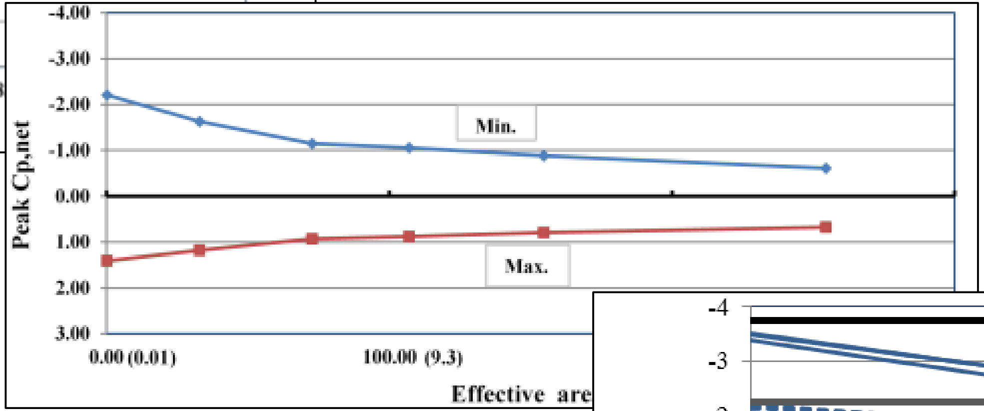
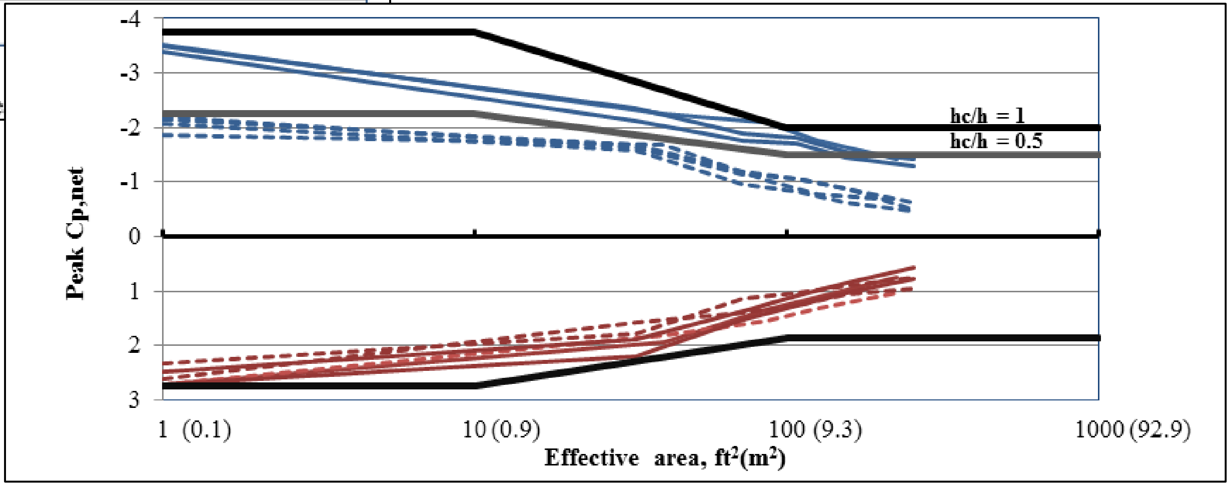
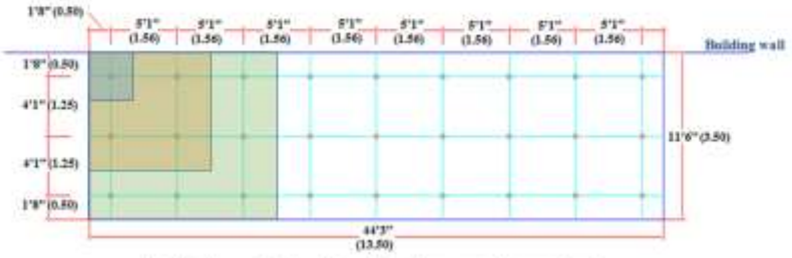
- Sample Results (used for Codification):




Full length canopy tap layout (same location for upper and lower surfaces)

# Aeroelastic Test

# Why we need aero-elastic testing?

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- Certain structures may experience significant aerodynamic forces generated by structural motions.
- These motions, called self-excited, are in turn affected by the aerodynamic forces they generate.
- The structural behavior associated with self-excited motions is called aeroelastic.
- Aero-elastic testing is the most reliable approach to predict the structural deformation and aeroelastic feedback under wind actions.

# Aero-elastic Model Design

Motivations

Length Scale (shape of building)

↓

Mass, mass moment of inertia, damping

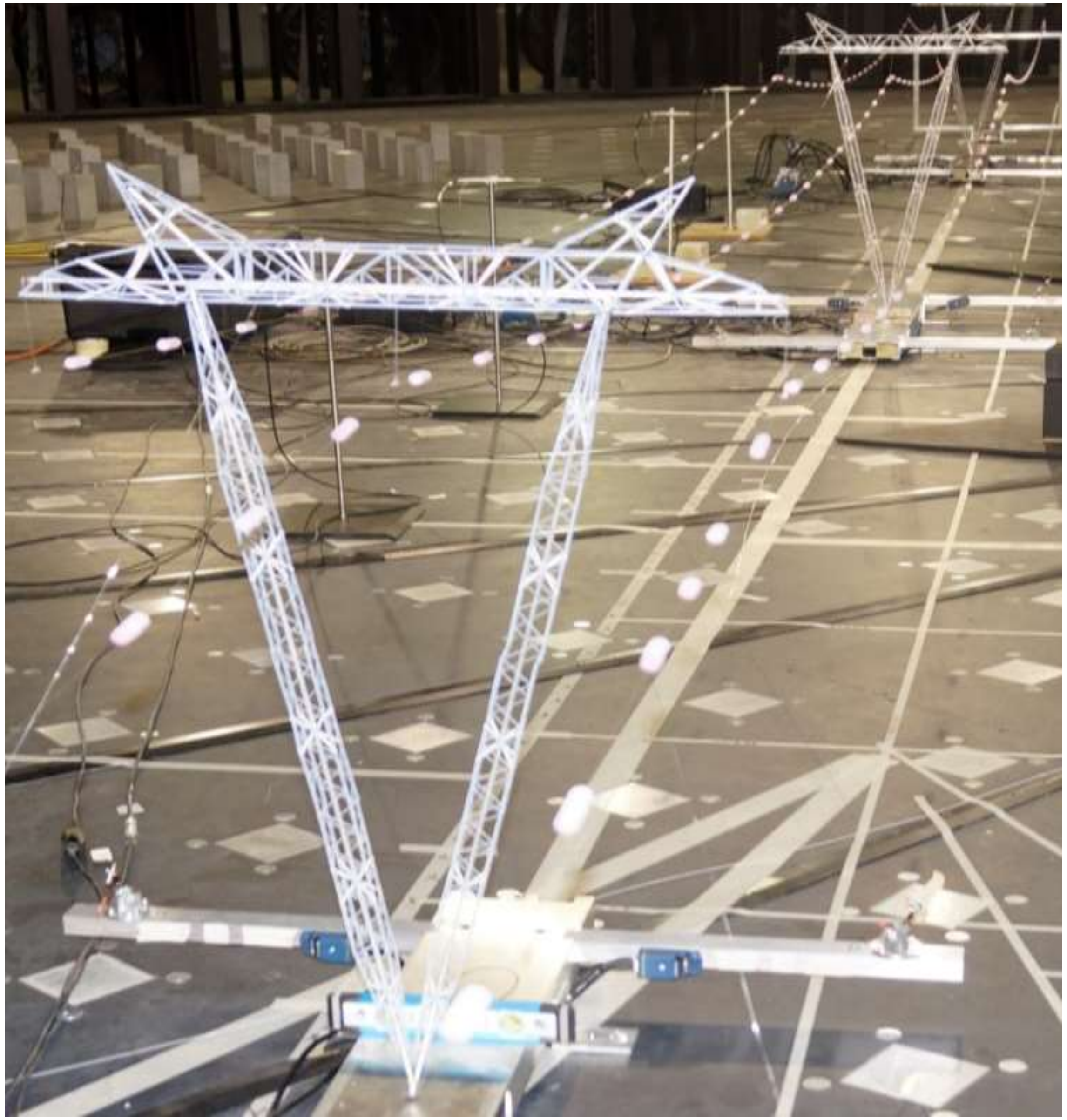
↓

Velocity Scale

↓

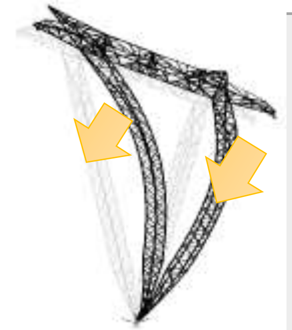
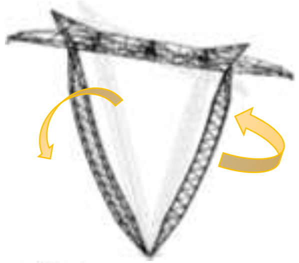
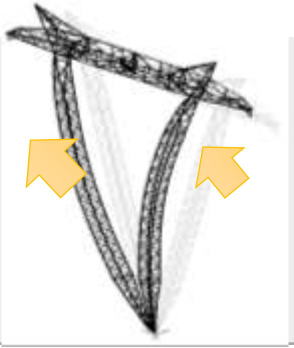
Moments, shear forces, and accelerations

| Parameters | Similitude Requirements | Scaling Ratio |
|---|---|---|
| Length | $\lambda_L = L_m/L_f$ | 1: 50 |
| Velocity | $\lambda_V = \lambda_L^{0.5}$ | 1: 7.07 |
| Time | $\lambda_T = \lambda_L/\lambda_V$ | 1: 7.07 |
| Density | $\lambda_\rho = \rho_m/\rho_f$ | 1: 1 |
| Mass | $\lambda_M = \lambda_\rho \lambda_L^3$ | 1: 125,000 |
| Mass Moment of Inertia | $\lambda_I = \lambda_M \lambda_L^2$ | 1: 312,500,000 |
| Acceleration | $\lambda_a = \lambda_V/\lambda_T$ | 1: 1 |
| Damping | $\lambda_\zeta = \zeta_m/\zeta_f$ | 1: 1 |
| Axial Stiffness | $\lambda_{EA} = \lambda_V^2 \lambda_L^2$ | 1: 125,000 |
| Bending Stiffness | $\lambda_{EI} = \lambda_V^2 \lambda_L^4$ | 1: 312,500,000 |
| Force | $\lambda_F = \lambda_V^2 \lambda_L^2$ | 1: 125,000 |
| Force / m' | $\lambda_f = \lambda_V^2 \lambda_L$ | 1: 2500 |
| Bending and Torsional Moment | $\lambda_{BM-TM} = \lambda_V^2 \lambda_L^3$ | 1: 6,250,000 |
| Warping Stiffness | $\lambda_{CW} = \lambda_V^2 \lambda_L^6$ | 1: 781,250,000,000 |



# Free Vibration Analysis

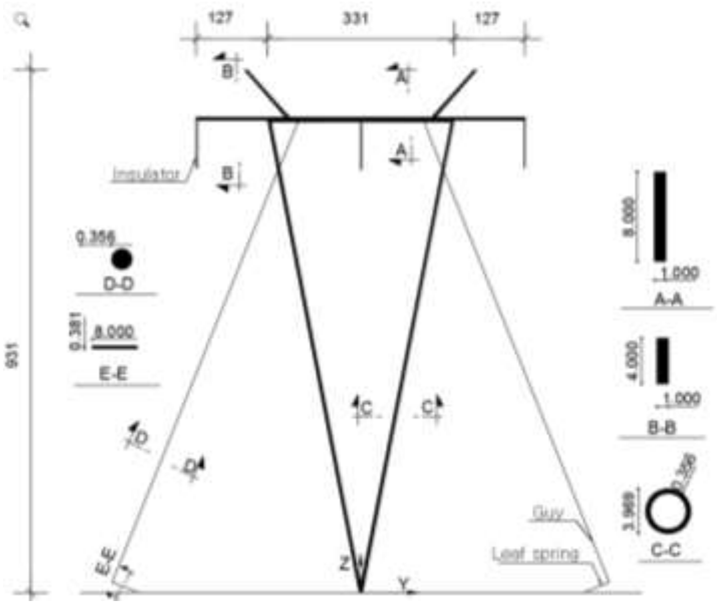


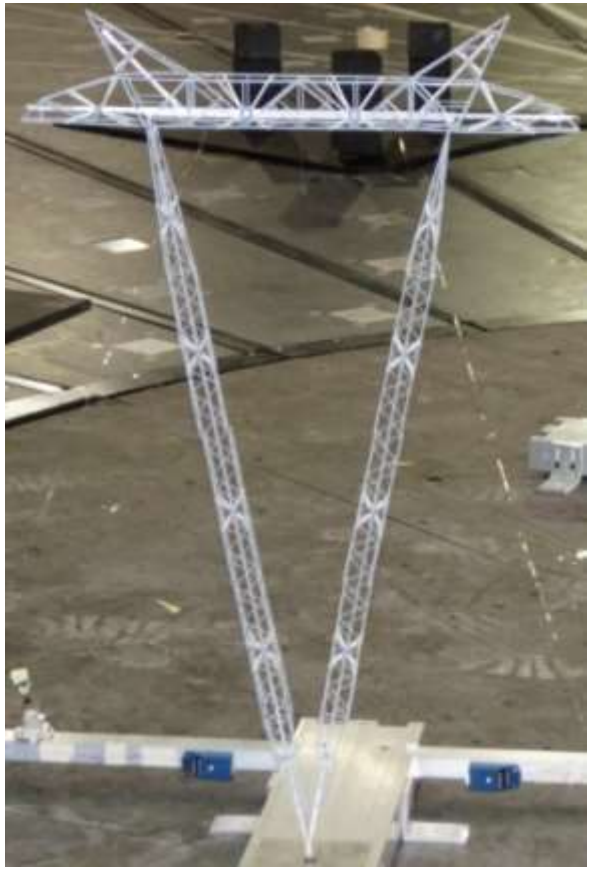
| Mode | Shape | Prototype Frequency (Hz) | Frequency scale | Target Frequency (Hz) |
|---|---|---|---|---|
| 1 |  | 1.44 | | 1.44*7.07=10.18 |
| 2 |  | 1.88 | 1/Time Scale=7.07 | 1.88*7.07=13.3 |
| 3 |  | 2.44 | | 2.44*7.07=17.25 |

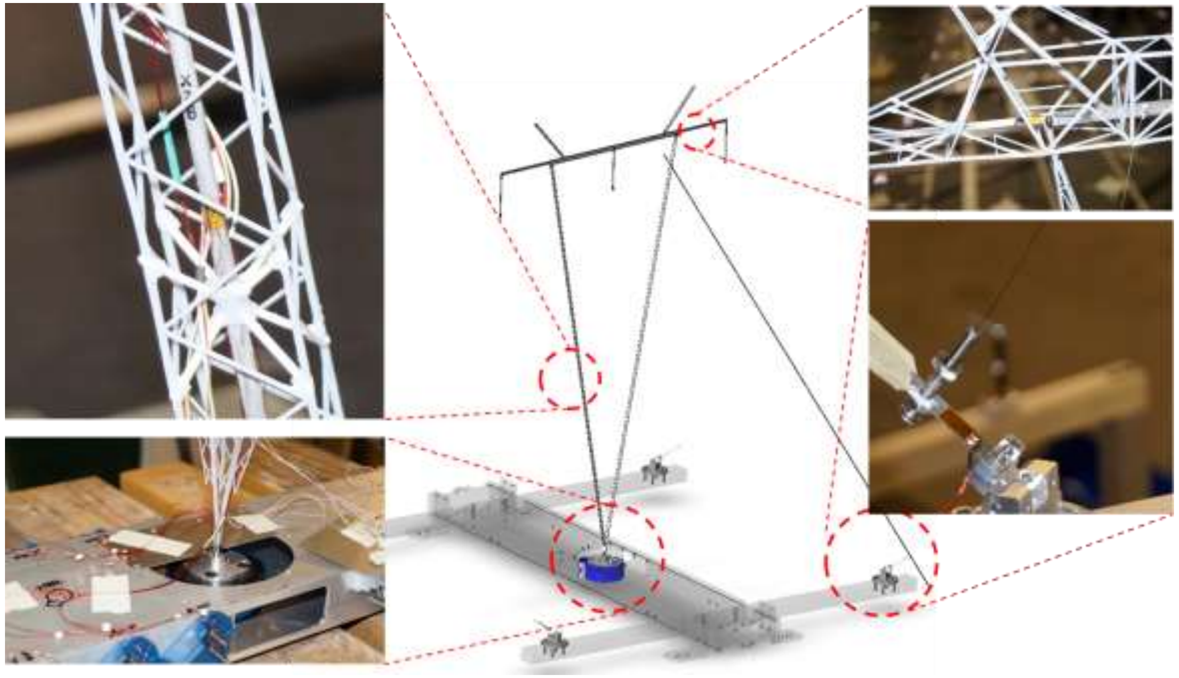
# Aero-elastic Model Design



## Equivalent Reduced Scale Model





# Expected Outcomes from an aero-elastic testing

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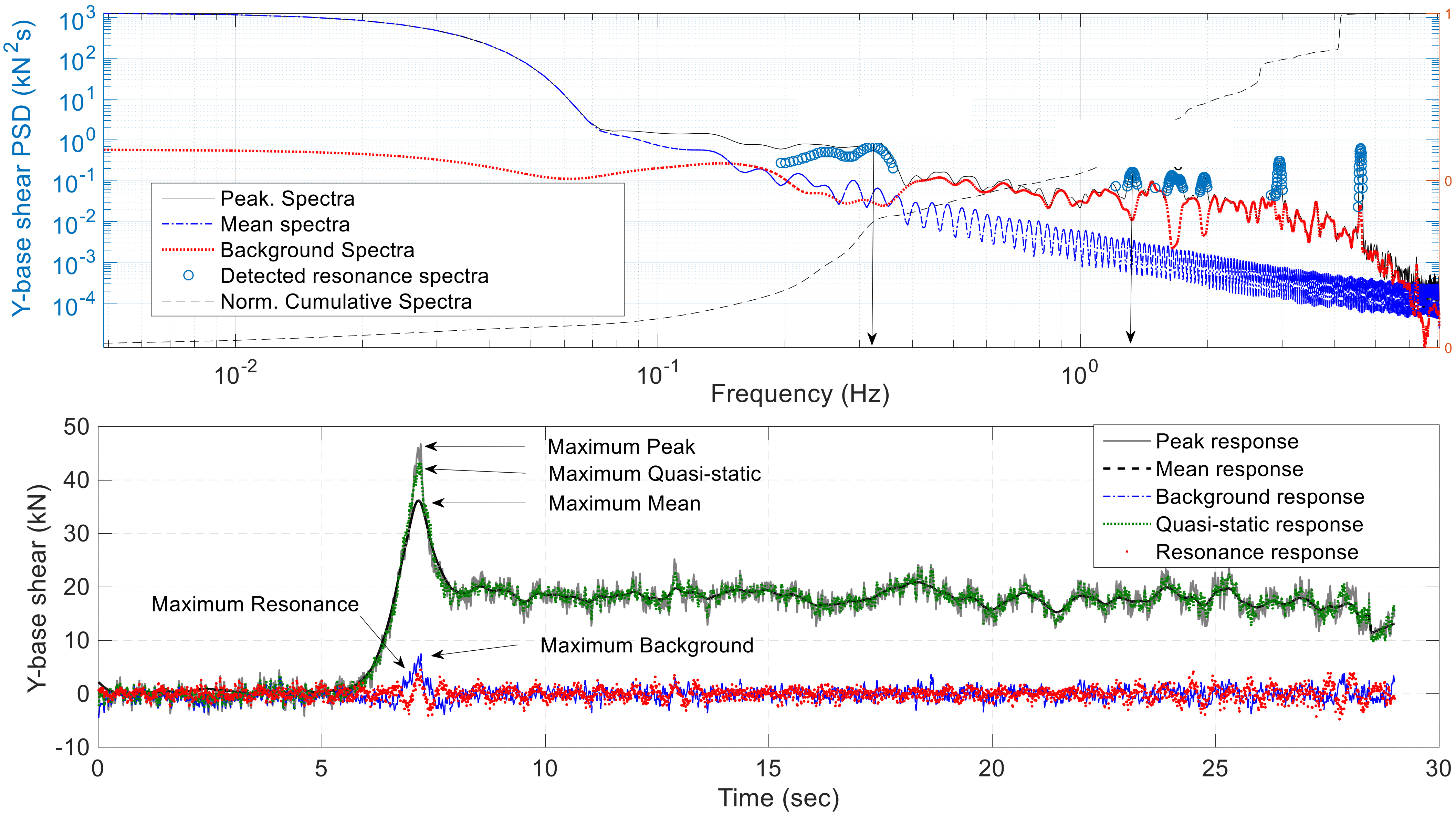

# Expected Outcomes from an aero-elastic testing

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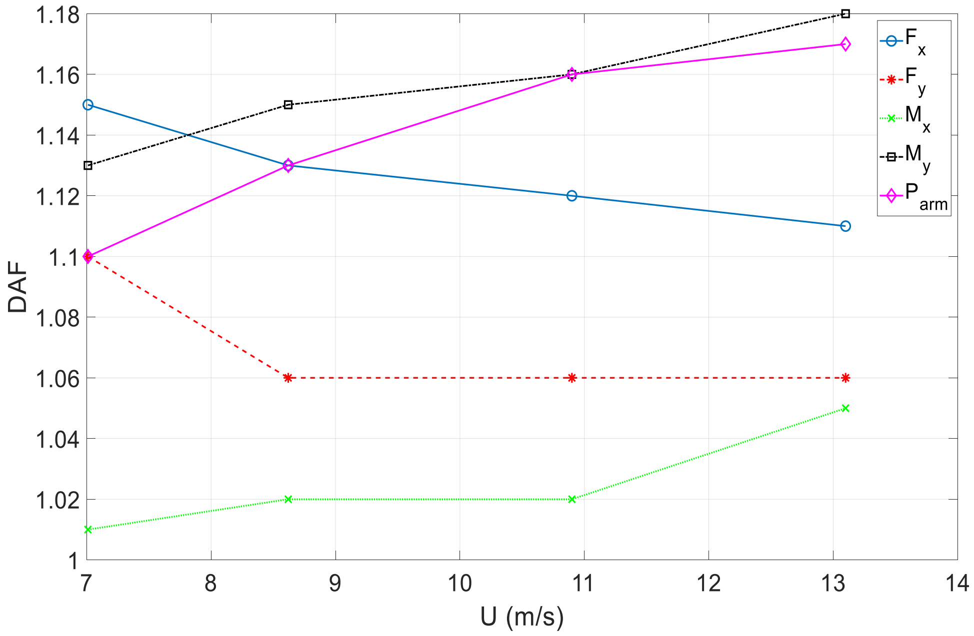
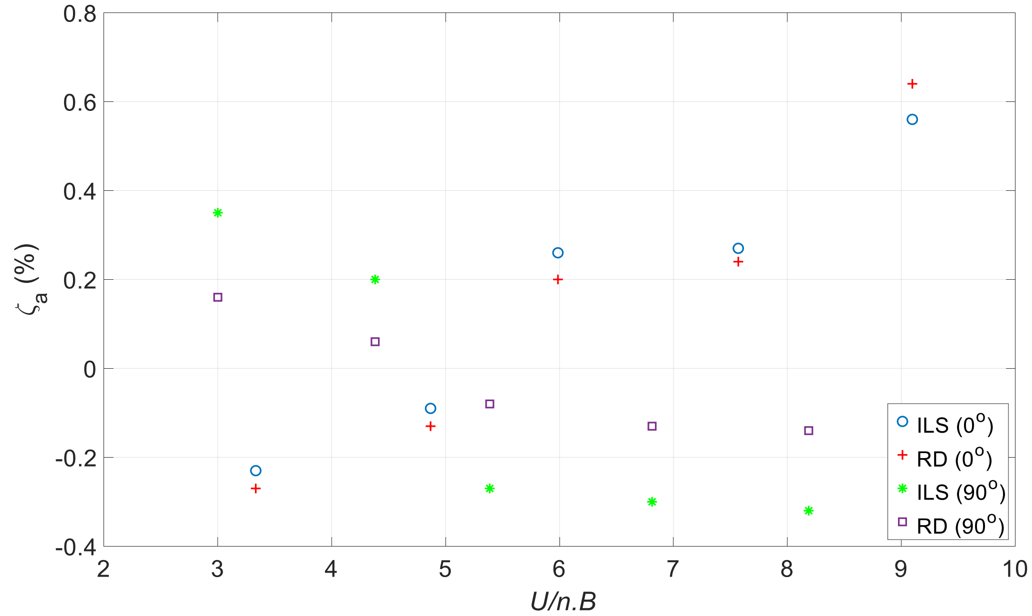
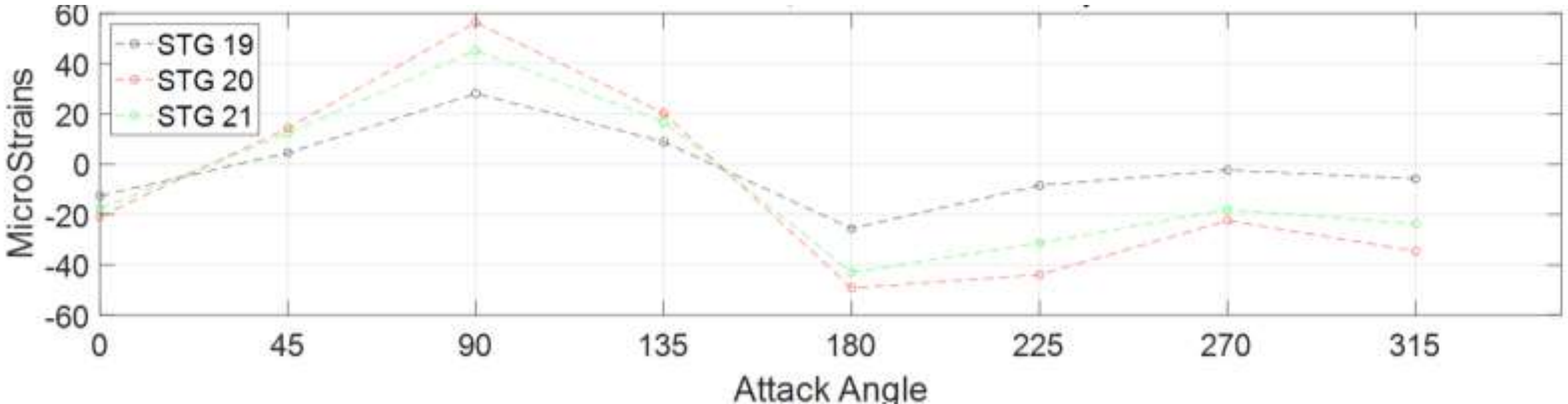
$$\text{DAF}=\frac{\text{(Maximum Peak Response)}}{\text{Maximum Quasi static Response)}}$$




## Damping and aerodynamic damping




## Strain Measurements



# Wind-Driven Rain Test

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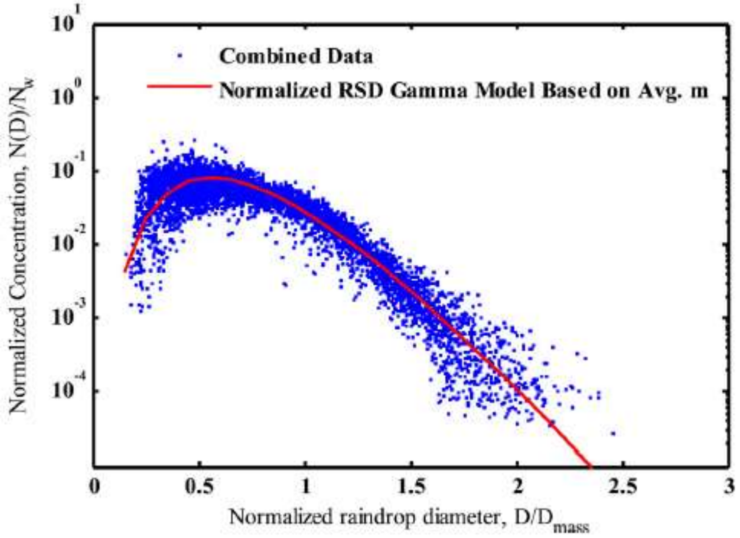
Steps:

- Determine target wind-driven rain parameters (characteristics of rain associated with tropical storms and hurricanes have been studied by many researchers)

- Selection of nozzles to simulate the target WDR parameters



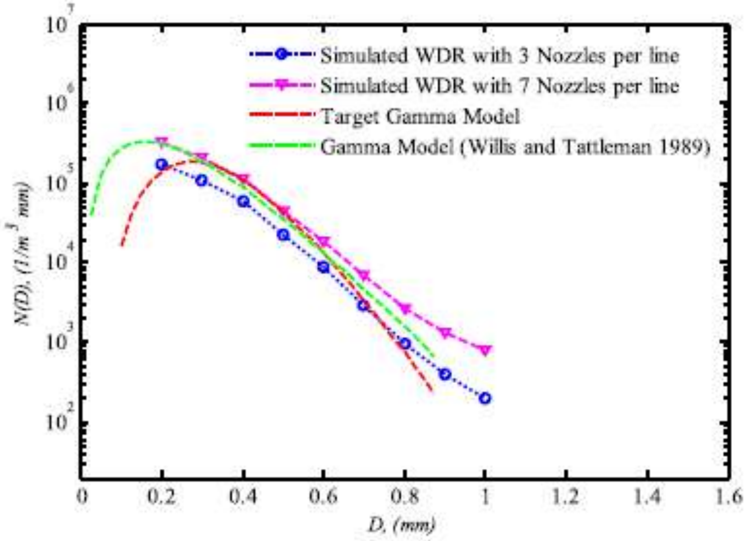




**Fig. 10.** RSD of simulated WDR using *TEEJET 8008 – E* nozzles.

# Wind-Driven Rain Test

Wind-Driven Rain Test of Full-Scale Model

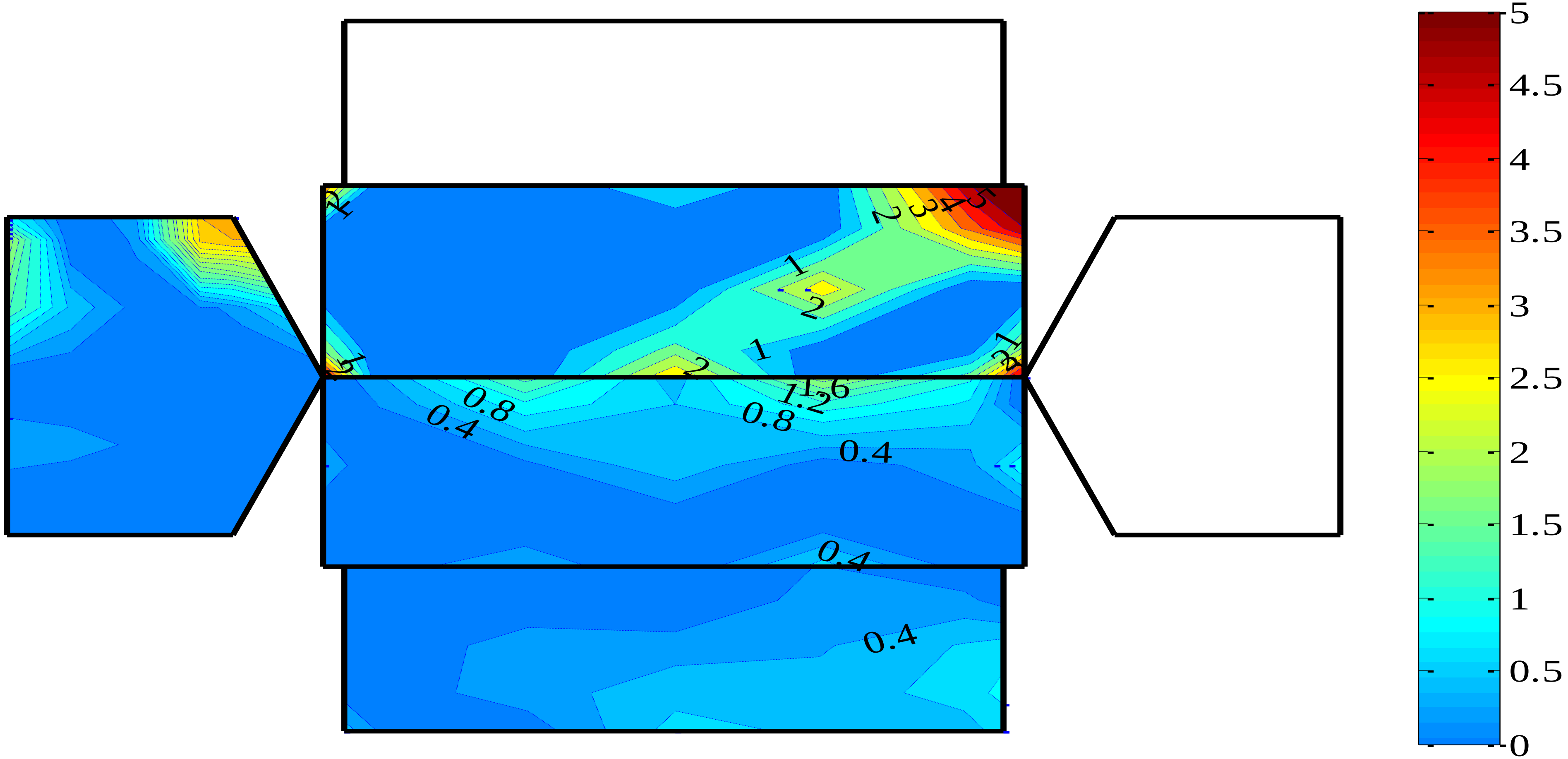
Large-Scale Model with Rain Gauges

Water-Injection System for Wind-Driven Rain

# Wind-Driven Rain Test



- Sample Results (Exterior)




**Findings: The leading edge/corner regions receive less volume surface runoff rainwater; The rain water accumulation increases toward the leeward roof surfaces.**

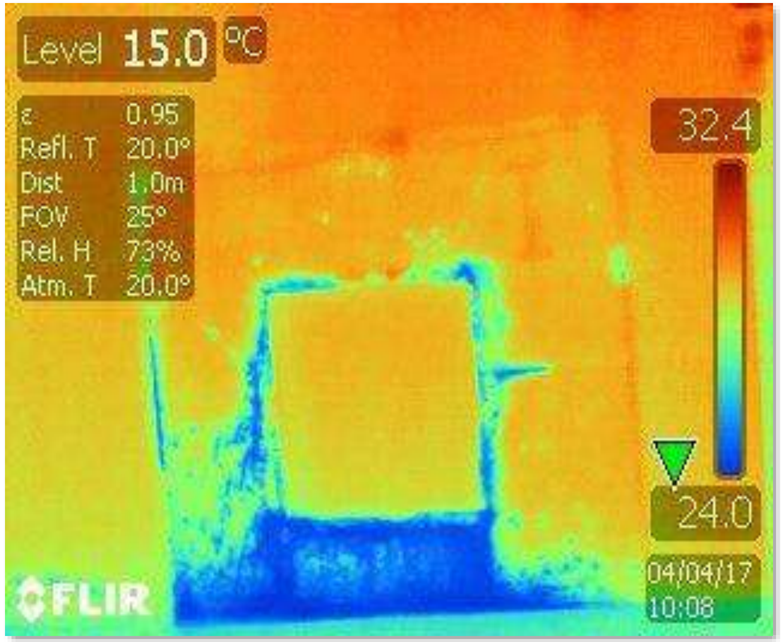
# Wind-Driven Rain Test



- Sample Results (Interior)


Internal walls covered with dried absorbent pads


Remove and weight the wet pads after each test

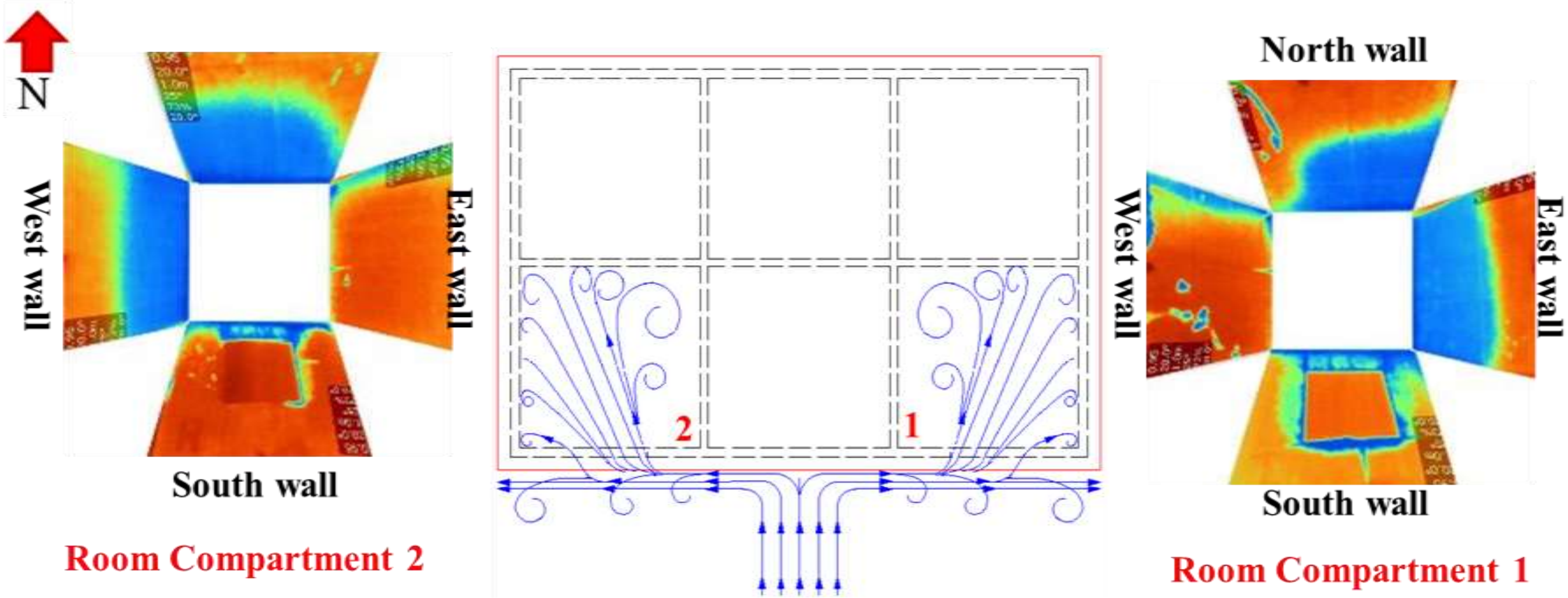



Take thermographic pictures

# Wind-Driven Rain Test



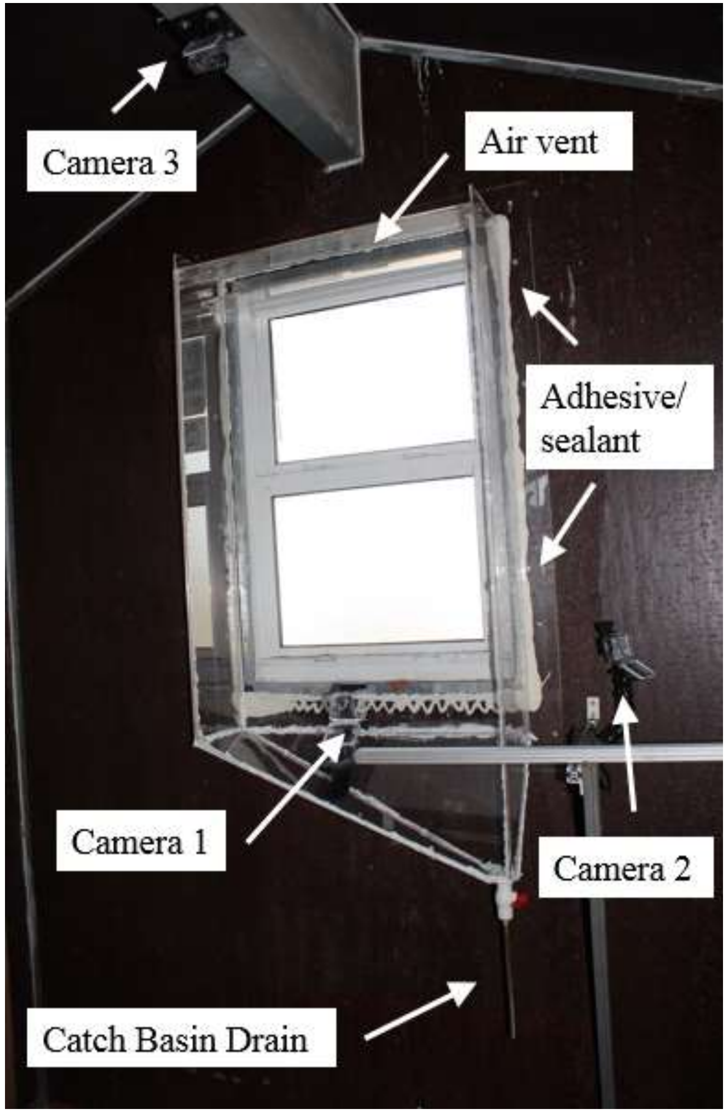
- Sample Results (Interior)



# Wind-Driven Rain Test



- Instrumentation and WDR Intrusion Results:






Comparison of water intrusion collected in catch basin for 0° wind direction, 62 mph test case.

a) Nonimpact window,

b) Accordion shutter.

# Destructive Test

# Example Project -- Performance of Traffic Signal Assemblies

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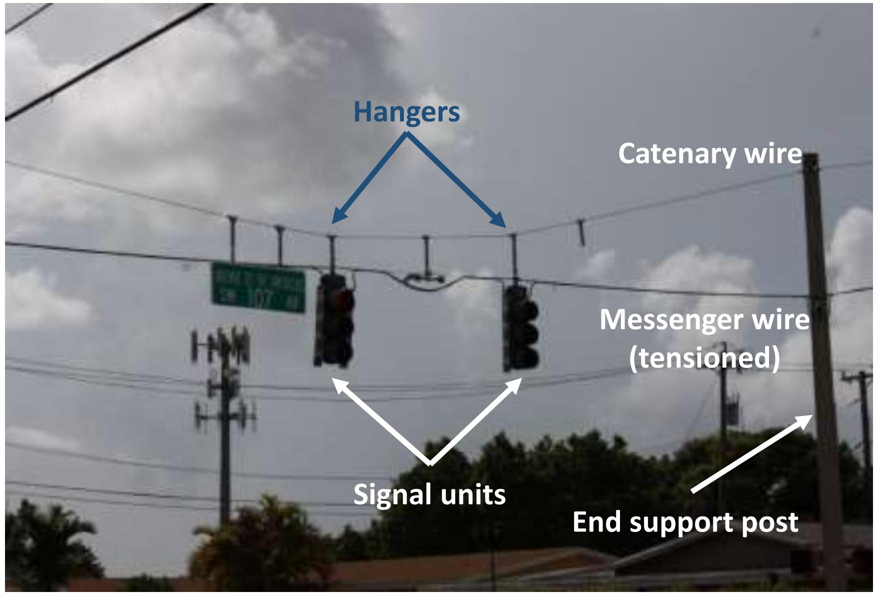
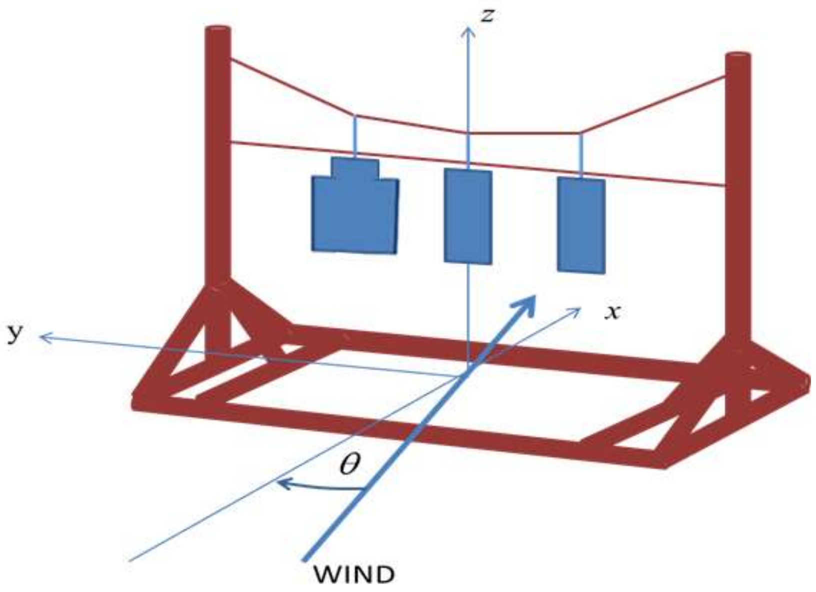
- Traffic signals are an important part of civil infrastructure
- In 2003-2004, hurricanes with wind speeds exceeding 100 mph caused considerable damage to traffic signals in Florida and other states
- Failure of the signal systems results in unsafe traffic conditions during and after a storm, and the time taken for repairs delays recovery
- Span wire traffic signals are widely being used in the state of Florida and other states in USA



# Example Project -- Performance of Traffic Signal Assemblies

- Test rig with a span of approx. 21 ft
- Objective: span-wire possesses the same deflection versus force relationship as the field span
- Springs added at the ends of the messenger/catenary wires




# Example Project -- Performance of Traffic Signal Assemblies

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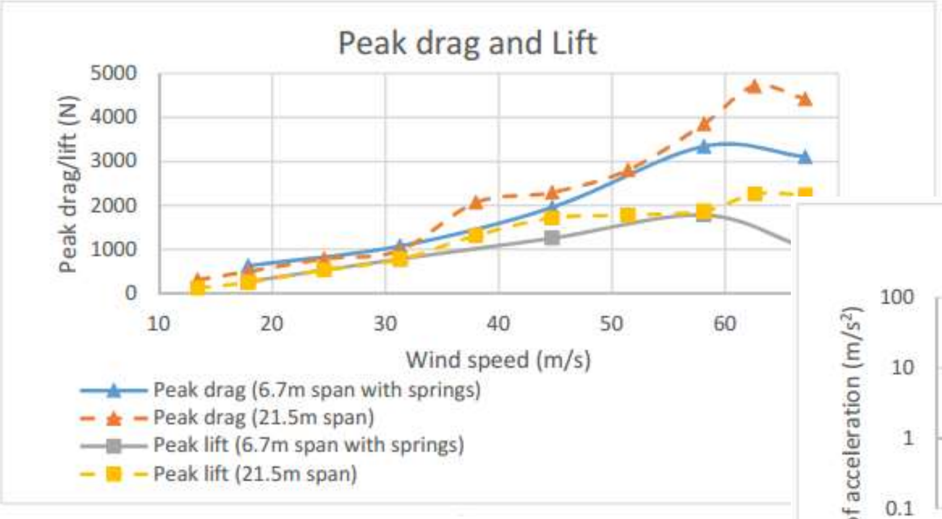
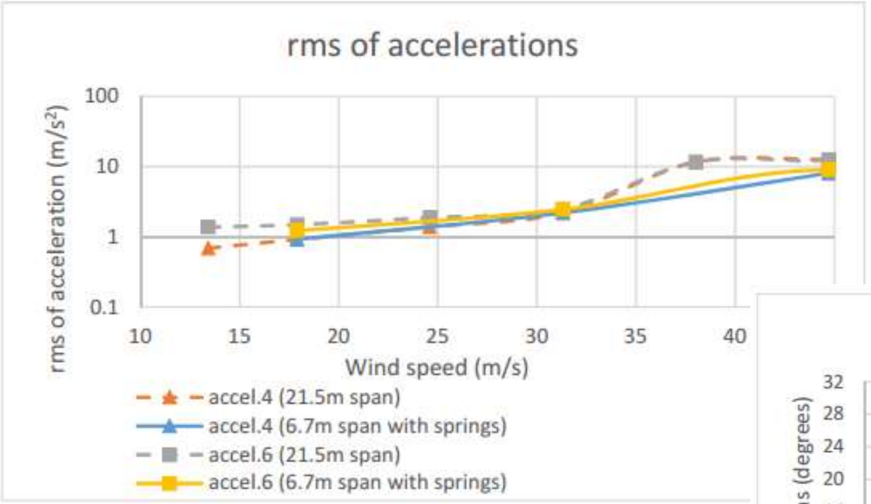
- Test rig with a span of approx. 75 ft
- Objective: validate short-span test rig

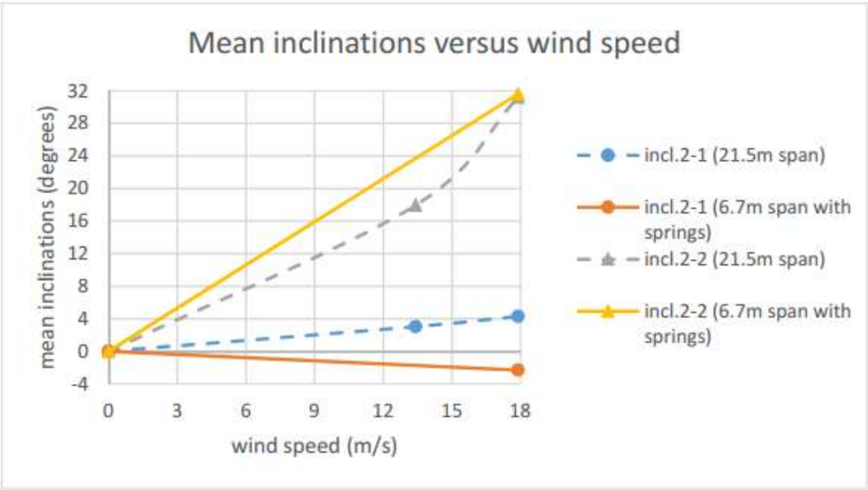
# Example Project -- Performance of Traffic Signal Assemblies



- Vast amount of data was collected



# Example Project -- Performance of Traffic Signal Assemblies

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- Removed all instrumentation and increased wind speed up to Cat-5 hurricane (157 mph)

# Full-scale Destructive Test – Roof Paver Lift-off Speed

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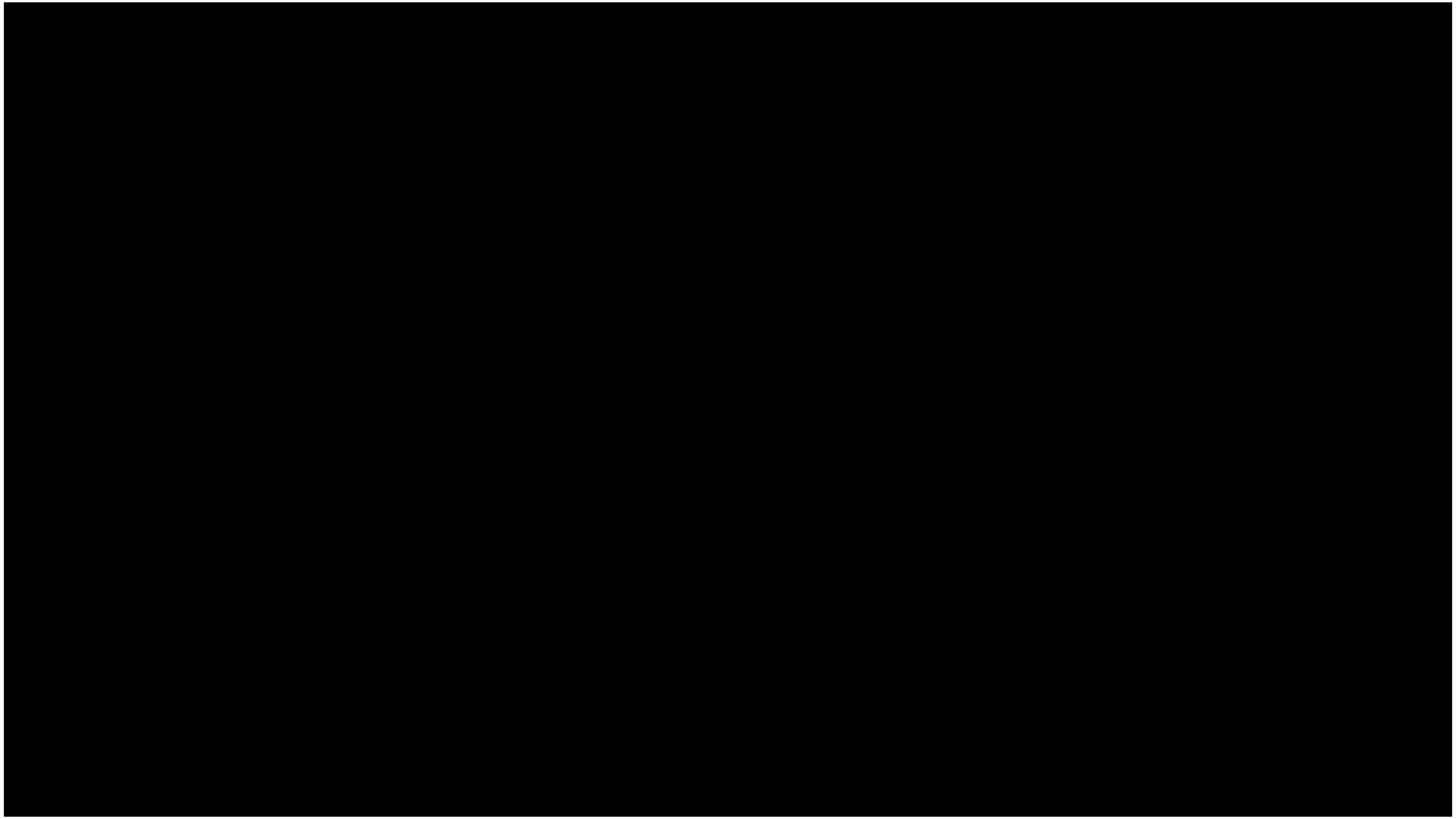
**Live Streaming of Experiments using Telepresence at WOW EF**

# Studies of Light Frame Residential Structures and Retrofit Techniques



- Link to IMAX Video



# New Capabilities

# NHERI WOW EF Upgrades

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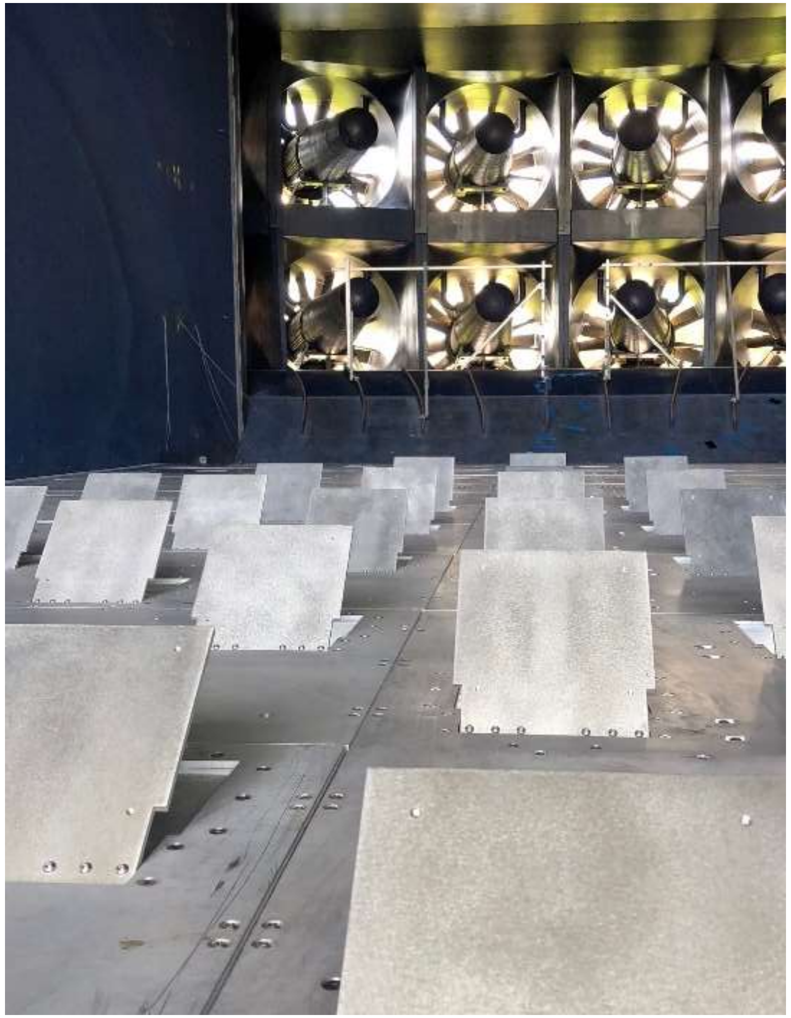
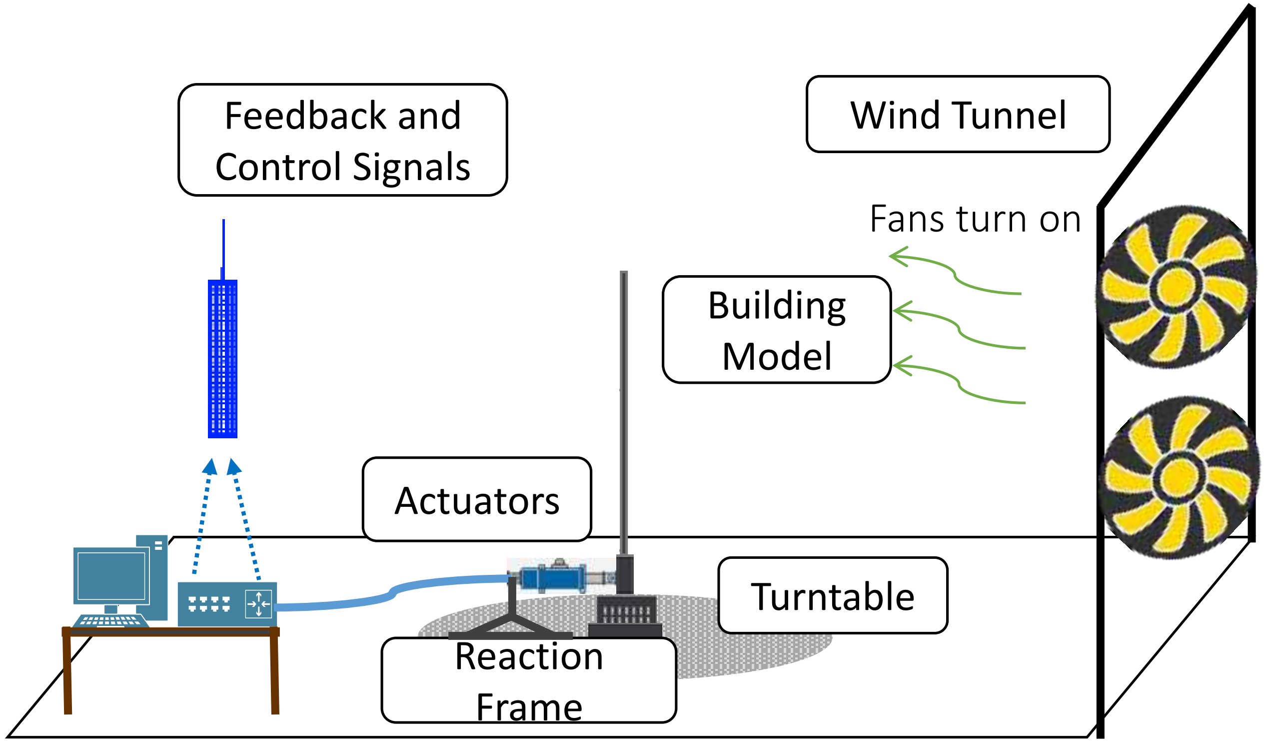


New Automated Roughness System will significantly reduce the test time setup.

New Automated 3-Axis Traverse System (robot arm) will help to quickly characterize wind field.

# NHERI WOW EF Upgrades

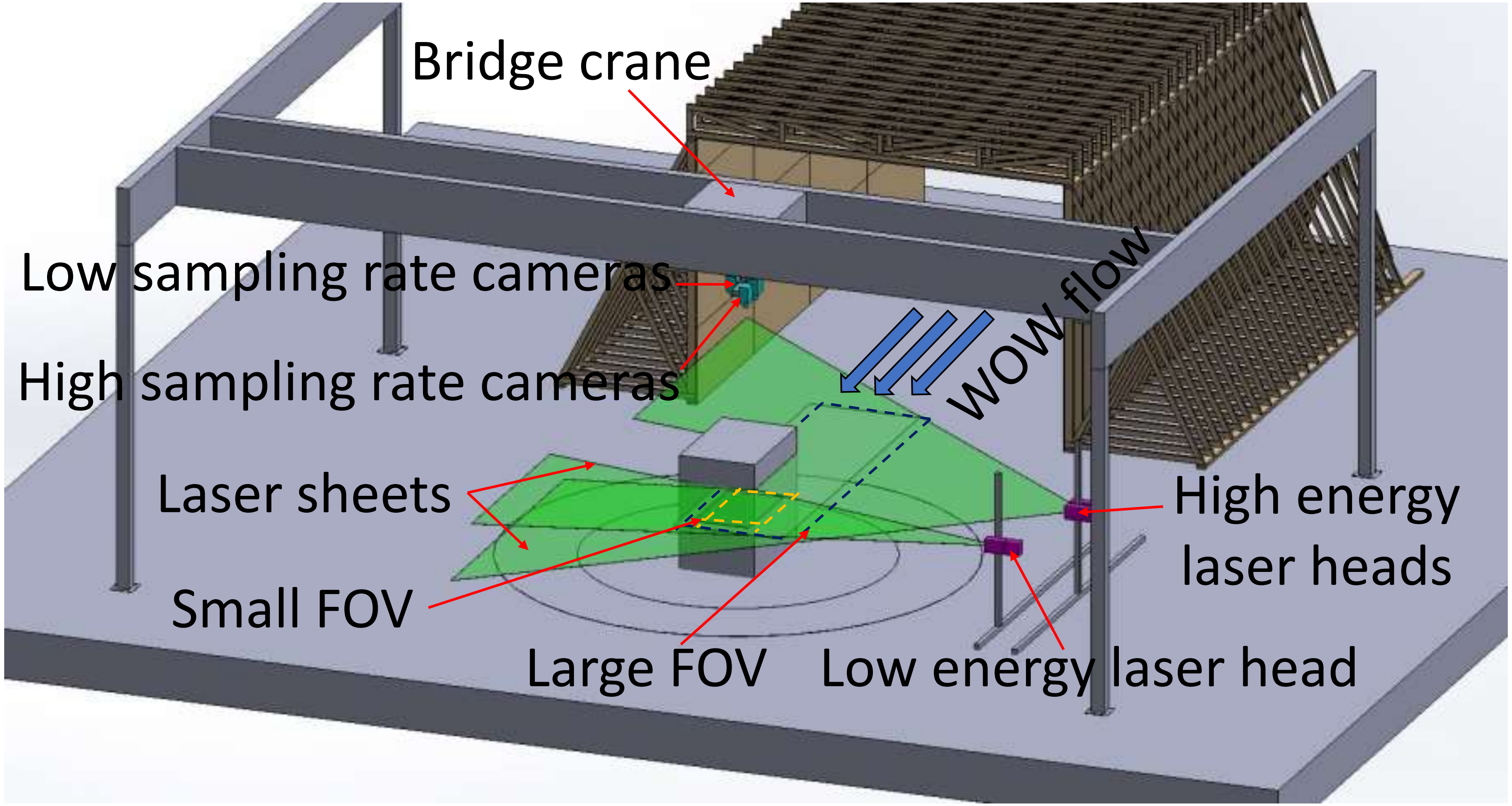





Simulation of non-synoptic downburst wind flow at large scales for downburst-structure interaction studies.

Hybrid Simulation capabilities will be implemented.

## Acquisition of a Three Component Particle-Image Velocimetry System to Enable Fundamental Research in Wind Engineering and Fluid Mechanics (NSF MRI award #1828585)




(a) Horizontal Plane Setup

# Q&A Session