FIU Wall of Wind
NHERI Experimental Facility

SimCenter NHERI
Center for Computational Modeling and Simulation

Hybrid Simulation and Downburst Simulation Capabilities and Research Opportunities

Speakers: Amal Elawady (WOW-EF, FIU)

August 11, 2020
9:20-9:40 PDT

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1. Downburst Simulations at The NHERI Wall of Wind Experimental Facility

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Introduction

Introduction

Microburst

Macroburst

Size: <2.5 miles

Speed: ~170 mph

Duration: 5-15 minutes

Size: >2.5 miles

Speed: ~140 mph

Duration: 5-30 minutes

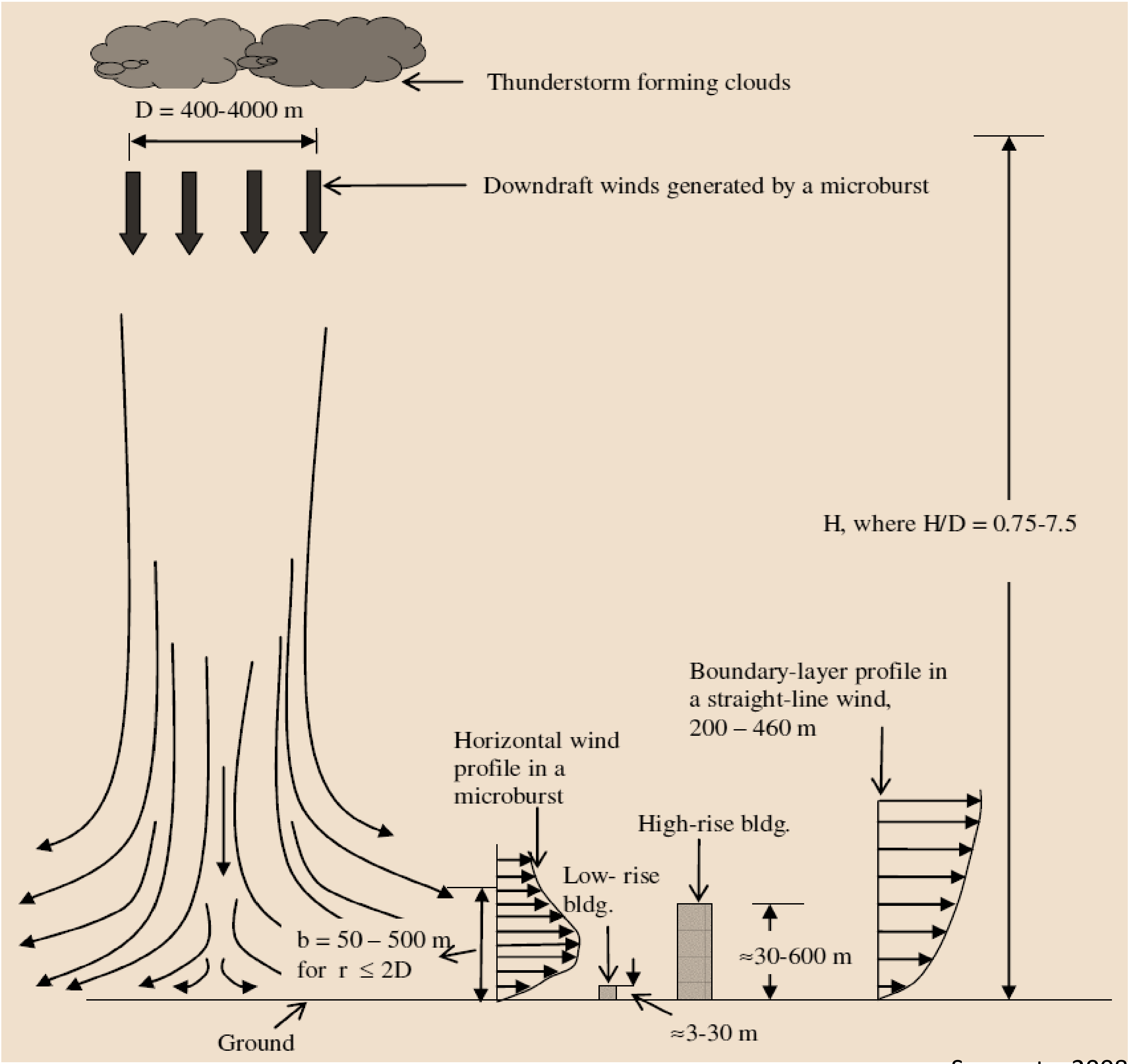
Fujita 1985 and http://noaa.com

Introduction

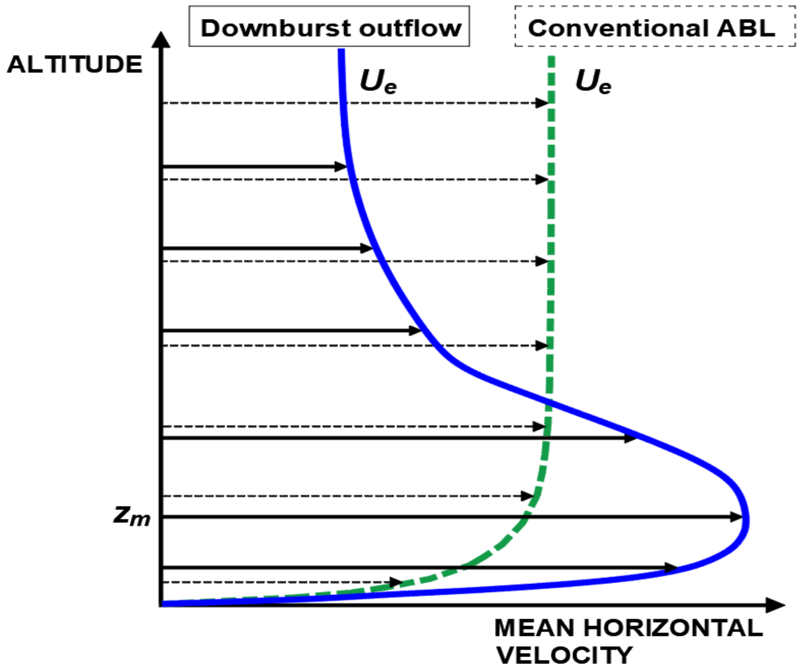
Downburst *vs.* *Tornado*

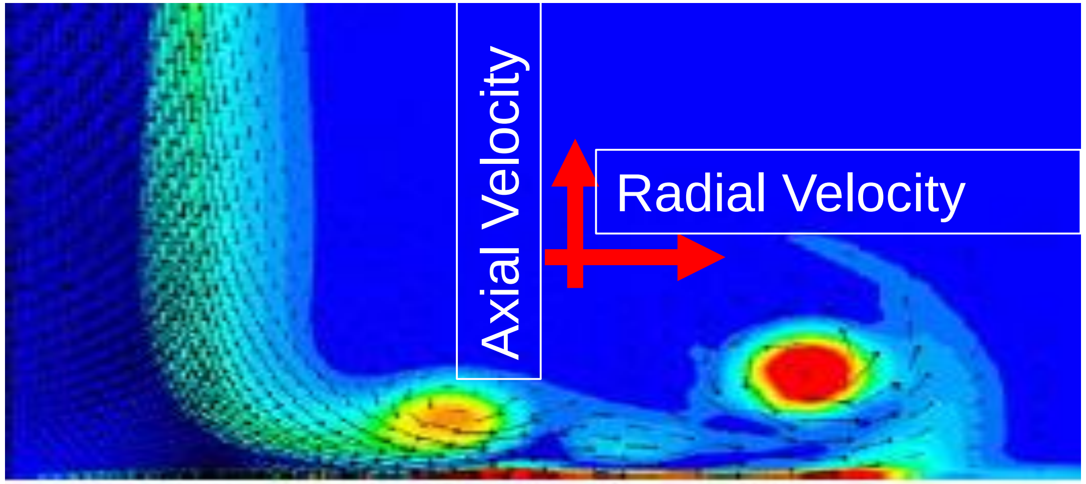
Source: noaa.com

Downburst vs. Synoptic Wind

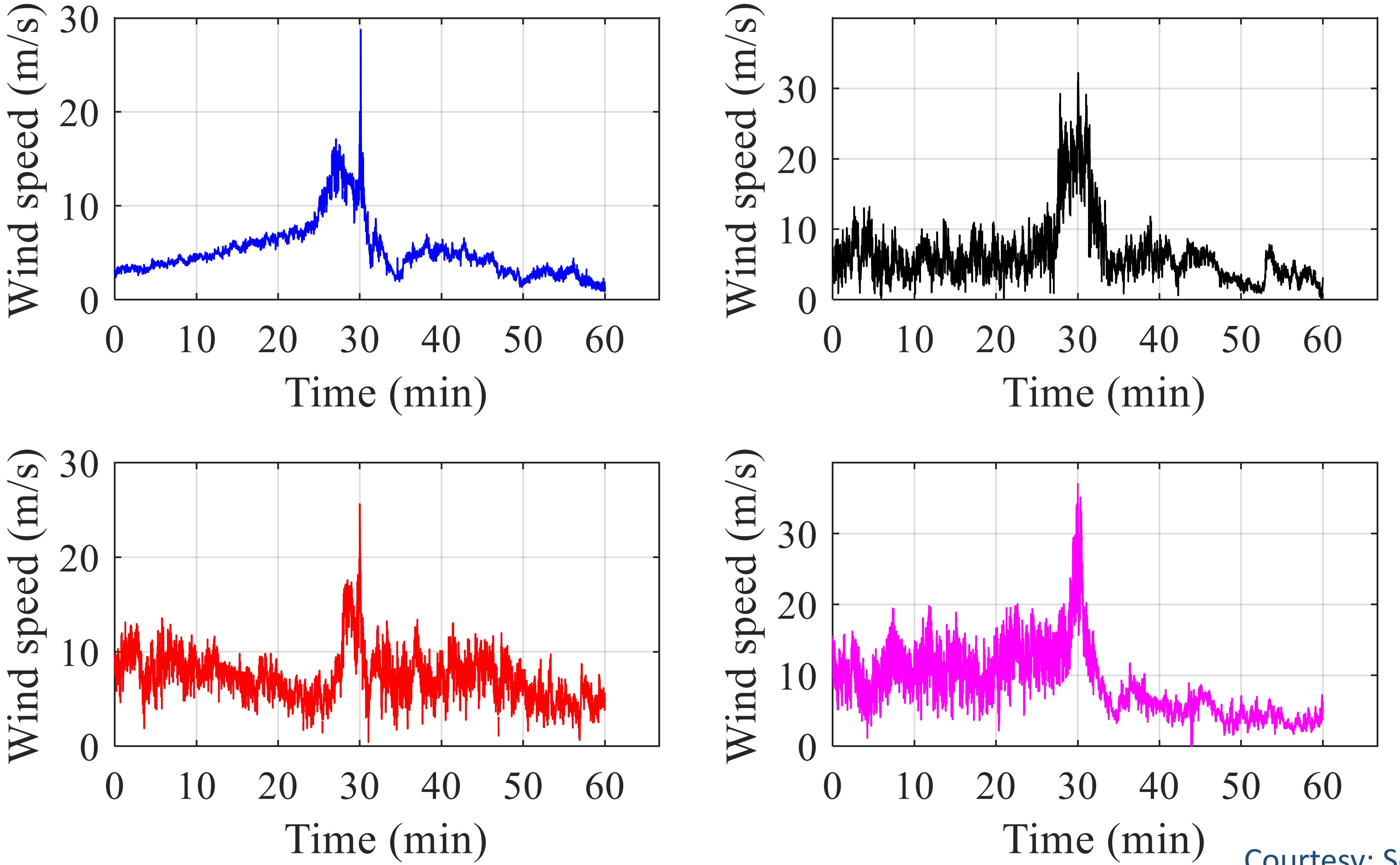


Sengupta, 2008





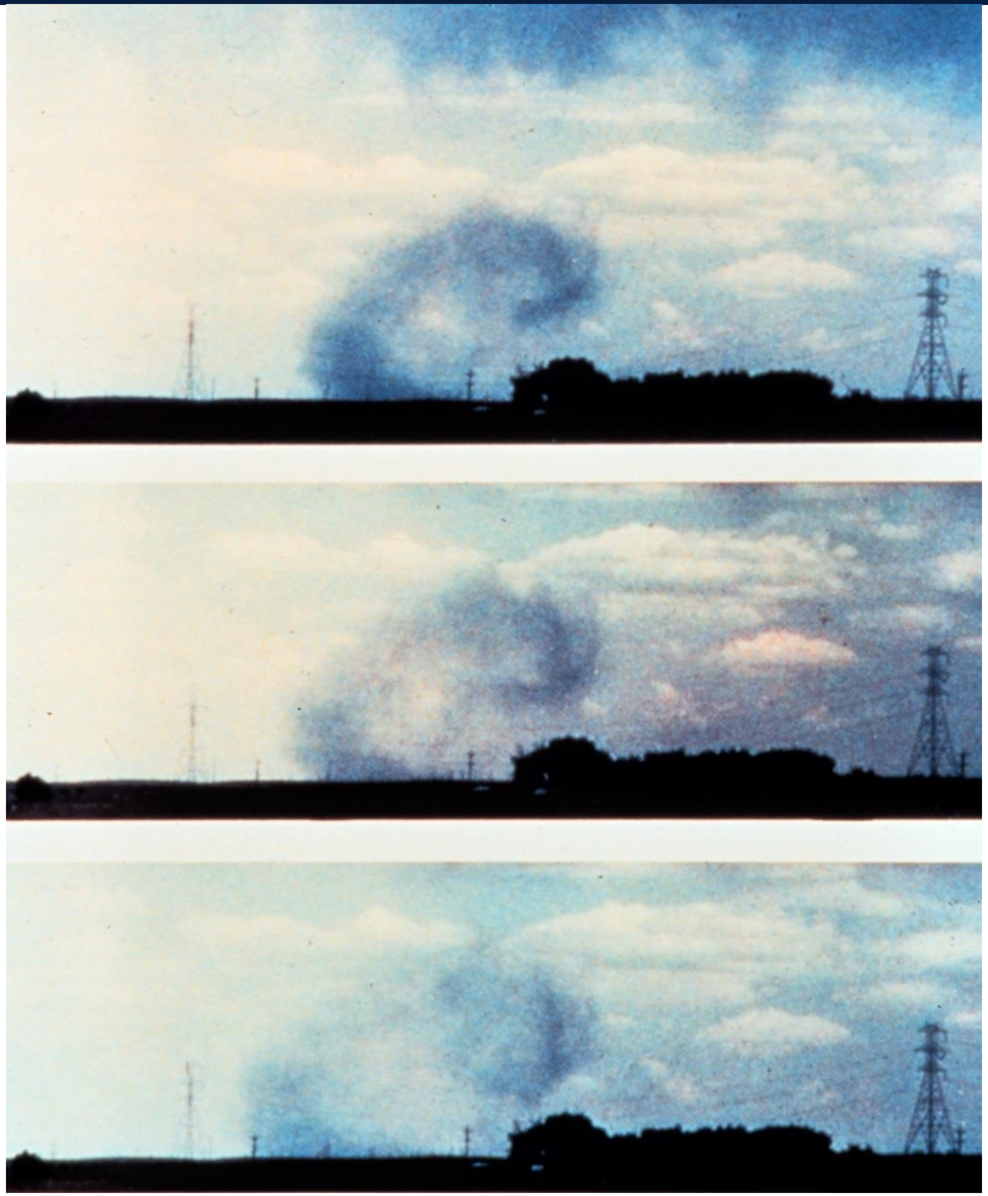
Downburst vs. Synoptic Wind



Courtesy: Solari et al. 2015

Challenges

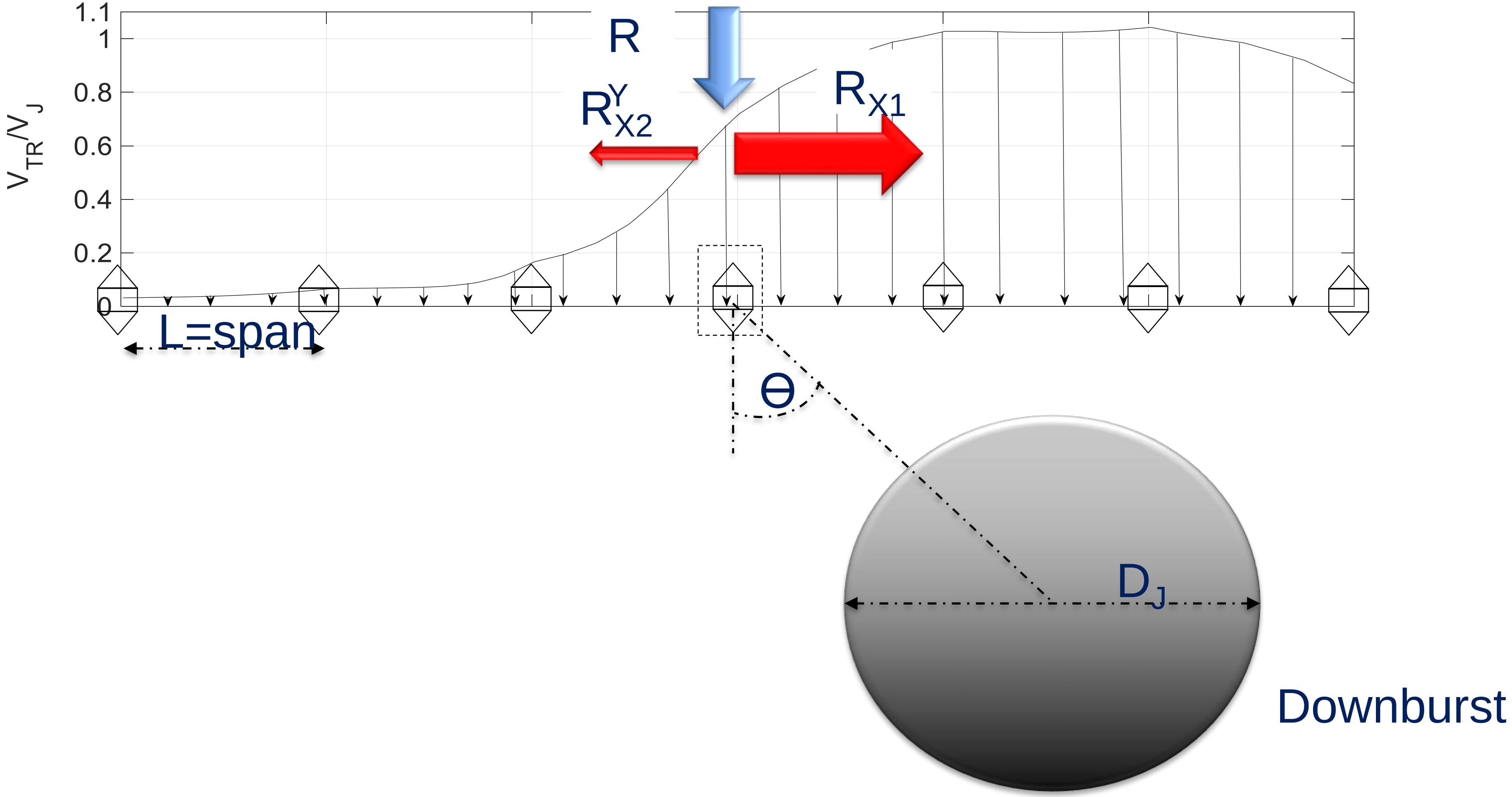
- Design guidelines are based on conventional boundary layer profile.
- Wind profiles and time histories are substantially different compared to synoptic winds.
- Localized nature both in Space and Time
  - ✓ difficult to forecast or measure.
  - ✓ Non-uniform loading on long span structures



Source: OAR/ERL/National Severe Storms Laboratory (NSSL) (NOAA Photo Library, NOAA Central Library)

Challenges

✓ Non-uniform loading on long span structures



Source: Elawady, A., and El Damatty, A., (2016)

Downburst Damages to Structures

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Source: Manitoba Hydro (1996) – 20 towers failed


Source: Hydro One Company, 2006


Source: www.srh.noaa.gov

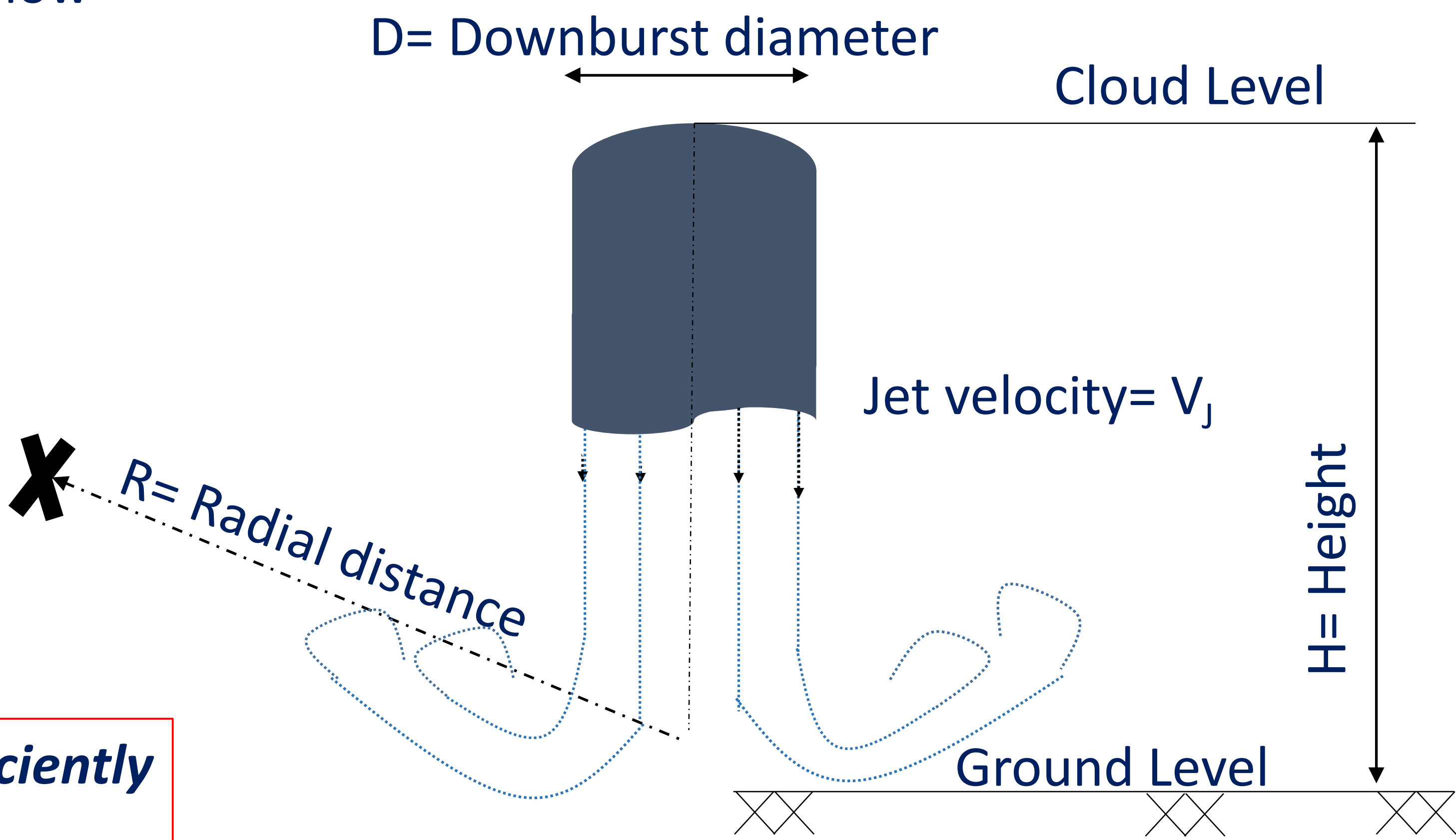

https://www.weather.gov

https://www.weather.gov/


https://bowmanextra.com/

Parameters Affecting Downburst Intensity

- **Height ratio H/D**: at H/D > 1.0, the flow becomes independent of H/D.
- **Distance ratio R/D**
- **Jet velocity**



The Main Challenge is to a achieve a sufficiently large flow for structural applications

Downburst Simulations at the WOW

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1:15 Small-Scale WOW

The FIU Downburst simulator is supported by a grant from the National Science Foundation (#1762968).

Downburst Simulator Alternatives

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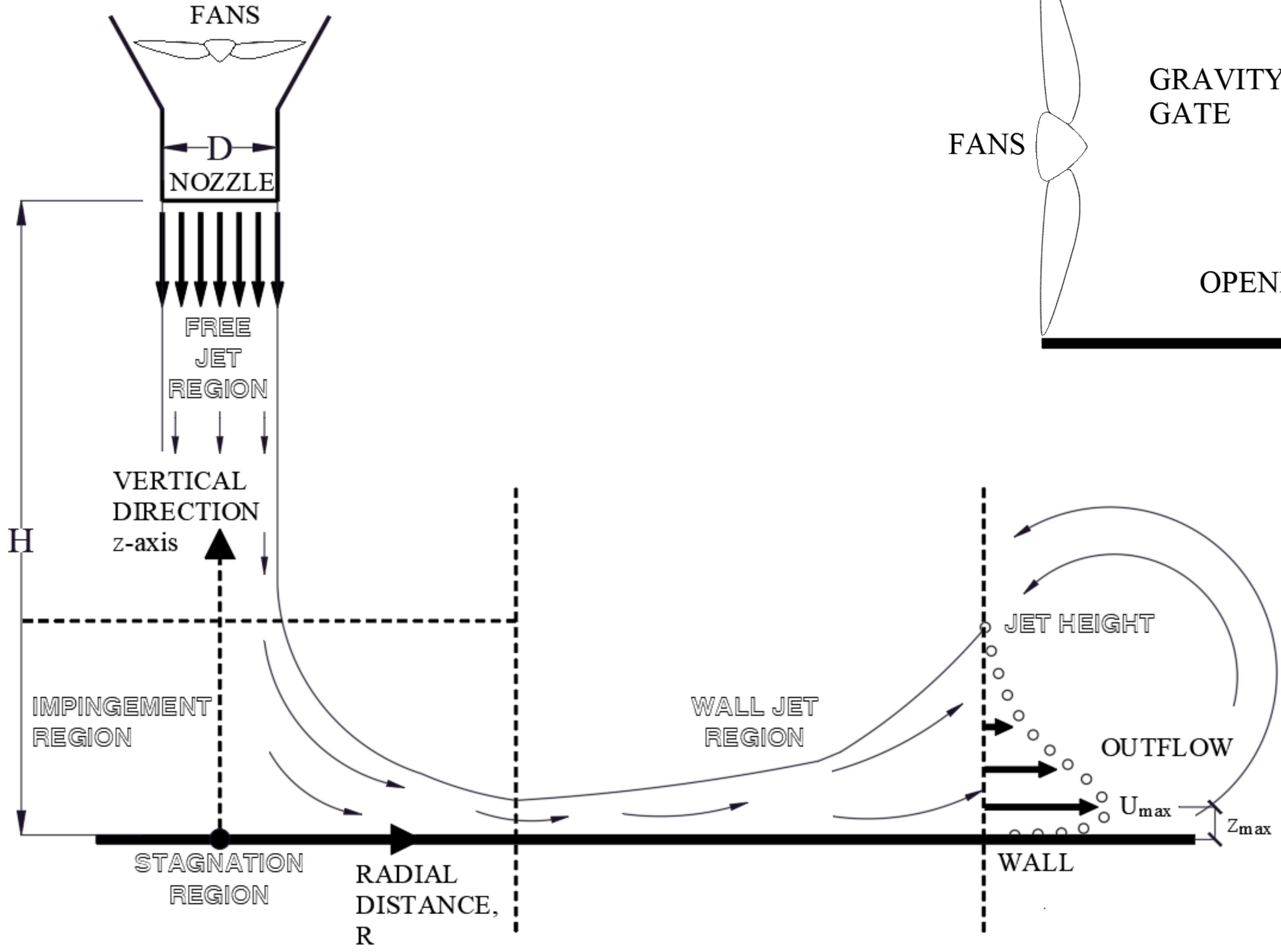
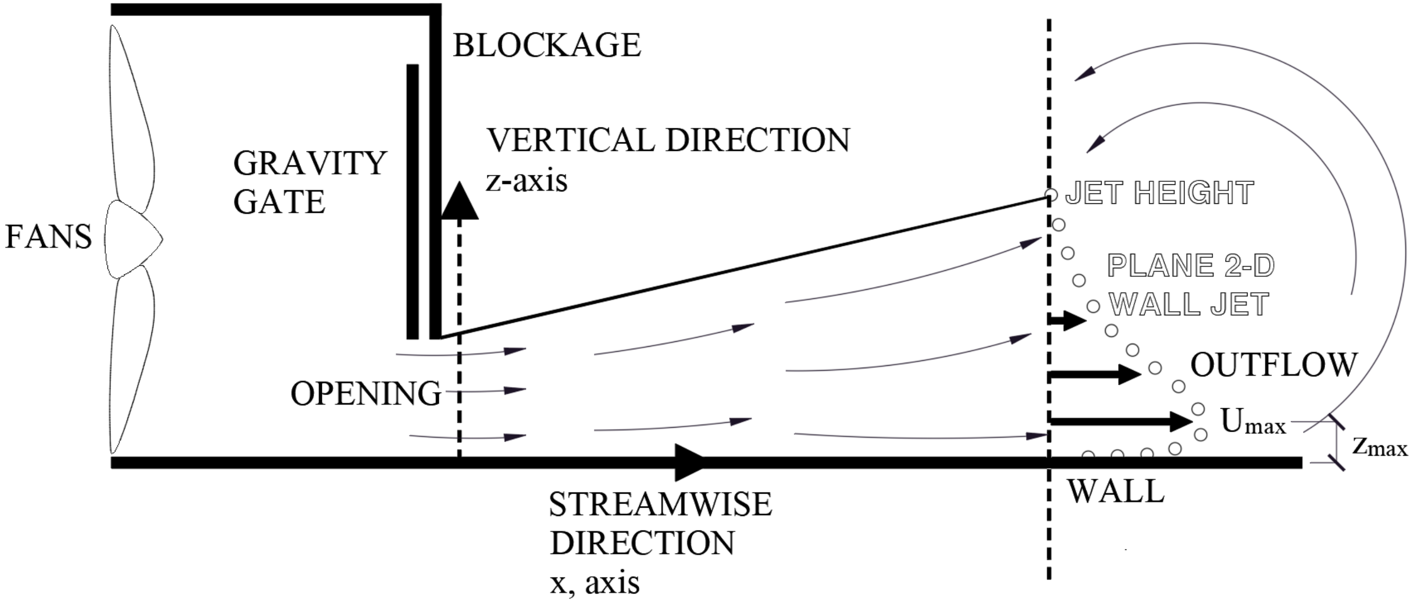
(a) Impinging Jet





(b) Wall Jet

Downburst Simulator Alternatives

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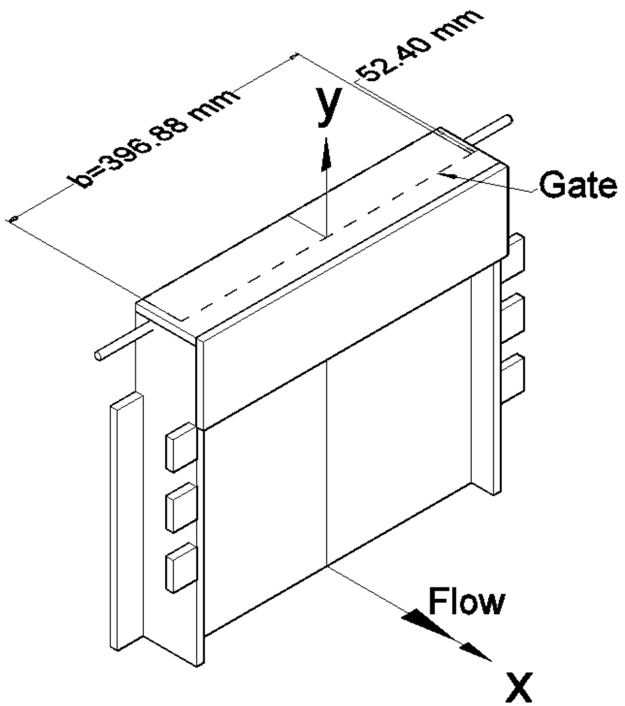
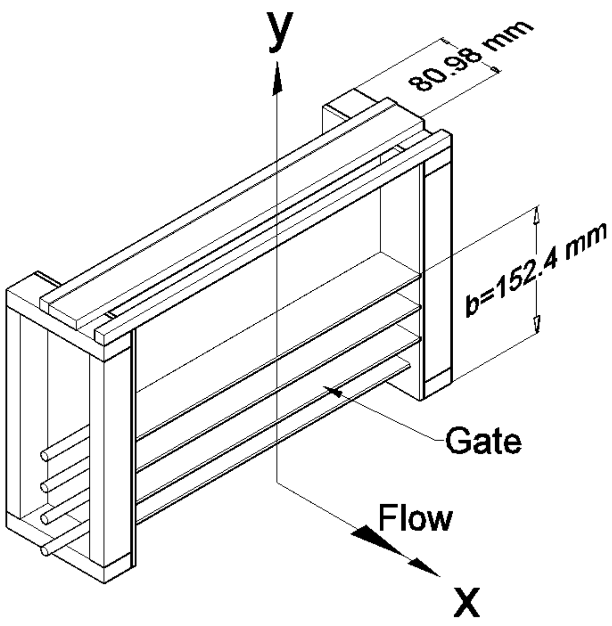
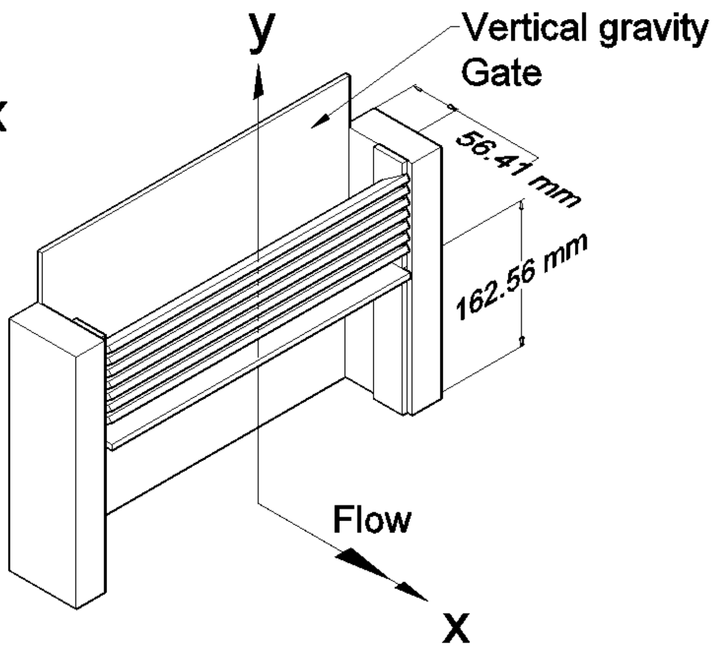


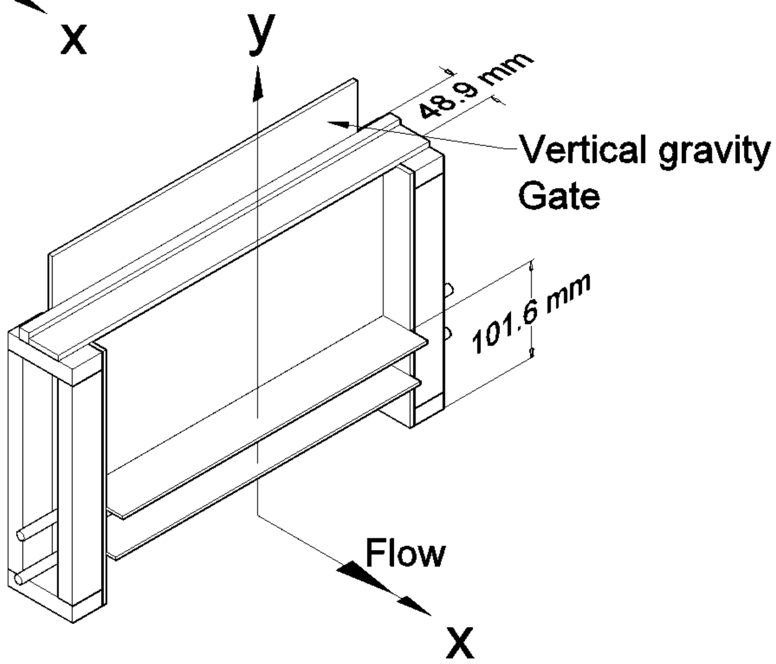
Option A



Option B



Option C



Option D

Option D: 2-Slat Louver

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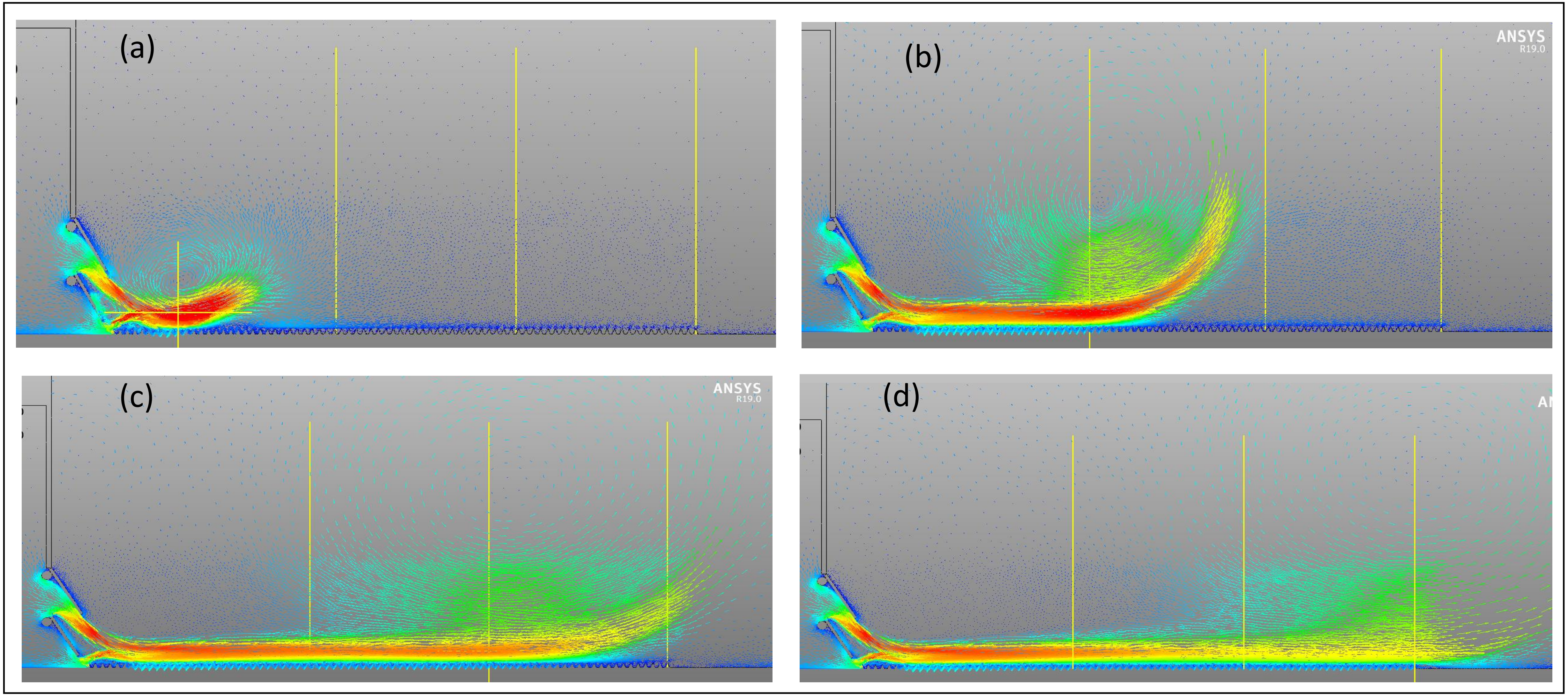
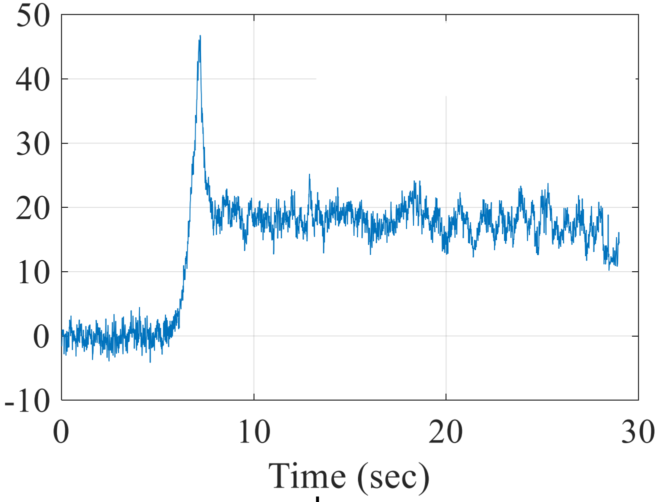
Option D: 2-Slat Louver



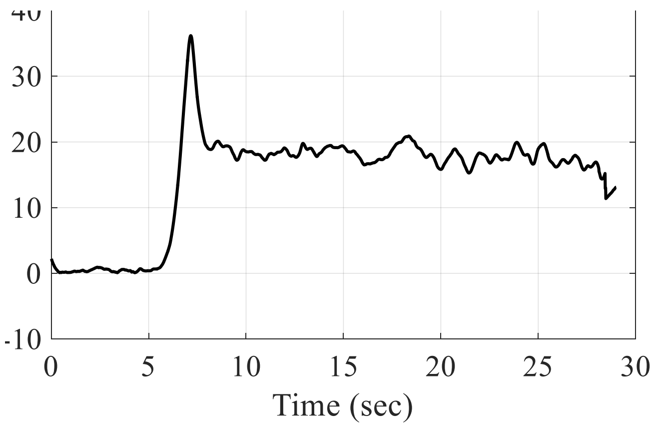
Development of the vortex throughout the domain (Roughness 1); (a) t=0.04 s; (b) t=0.185 s; (c) t= 0.395 s; (d) t=0.525 s

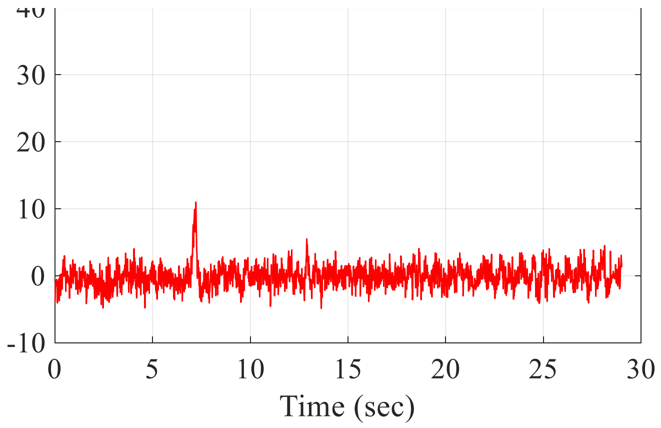
Downburst Velocity Decomposition



Mean (M)

Fluctuating





Downburst Velocity Decomposition

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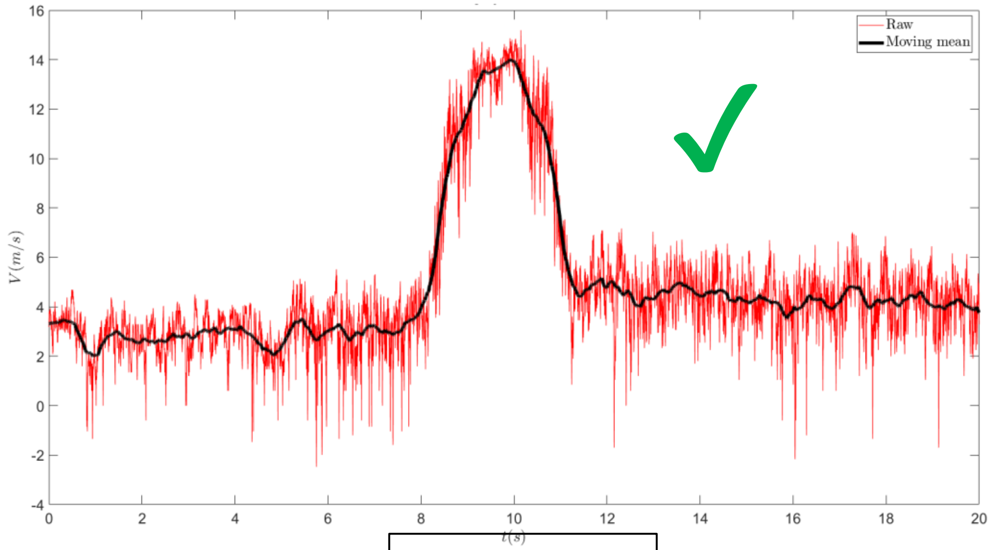
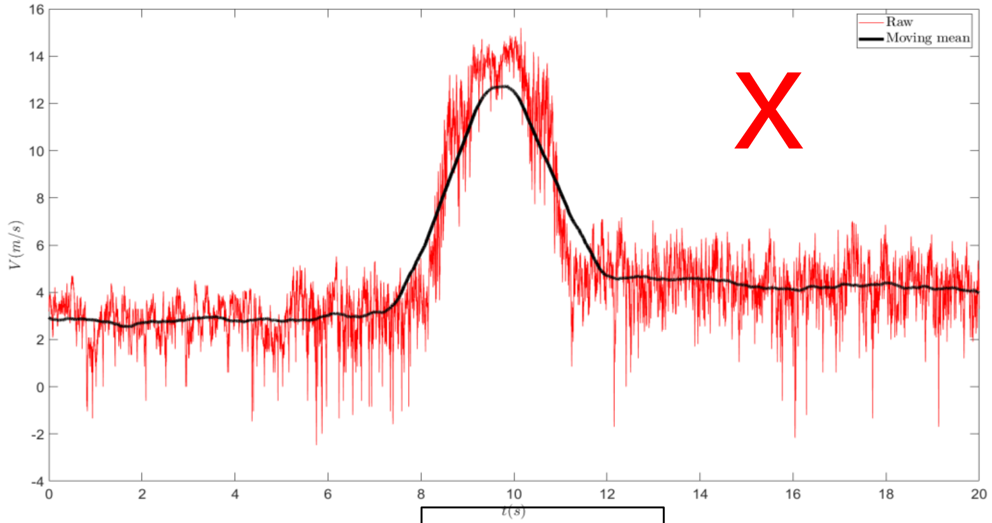
- A suitable time average is required to extract the moving mean that follows the trend and sharp step of the instantaneous wind speed time history.



T_{ave}=0.5 sec



T_{ave}=2 sec

Validation

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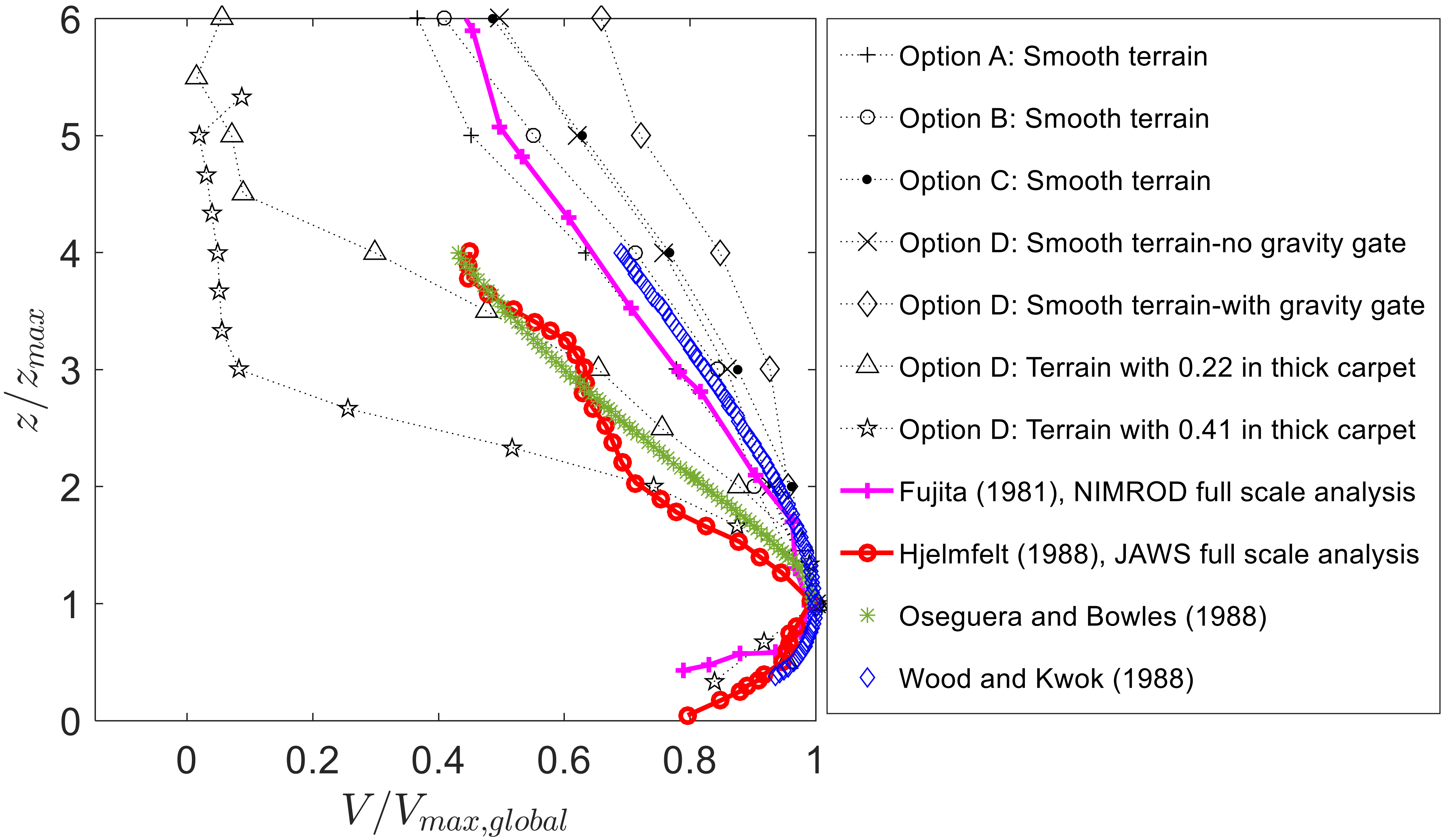
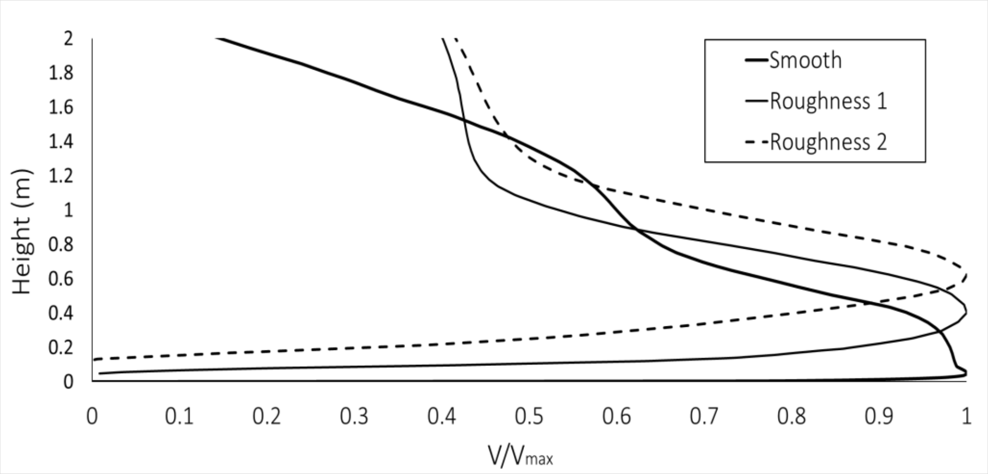
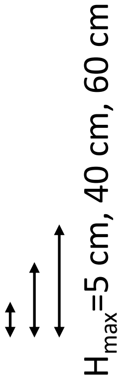
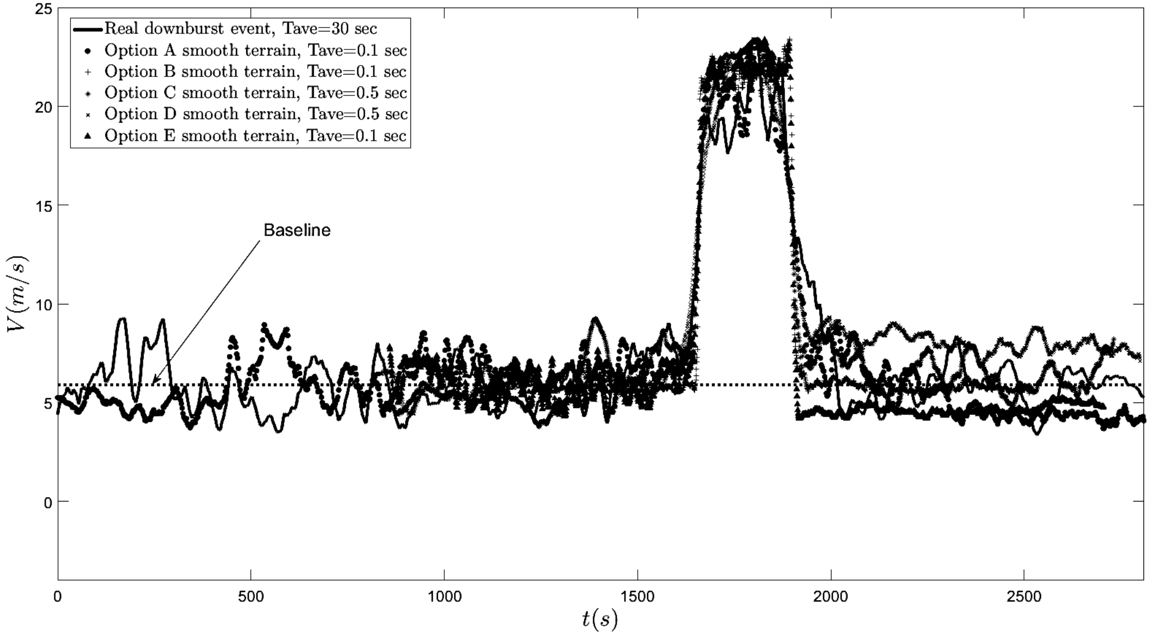


Downburst Scaling







$H_{max,real\ Downbursts}$ = 5 m to 100 m $\Longrightarrow$

$$\lambda_L = \frac{0.05}{100} = 1/2000$$

$$\lambda_L = \frac{0.6}{5} = 1/8.3$$

Parameter	Scaling ratio
Length	$\lambda_L = \frac{L_m}{L_p} = \lambda_V \lambda_t$
Velocity*	$\lambda_V = \frac{V_m}{V_p}$
Time	$\lambda_t = \frac{t_m}{t_p} = \frac{\lambda_L}{\lambda_V} = \frac{L_m}{L_p}\frac{V_p}{V_m}$

Downburst event	Acceleration of ramp-up (m/s^2)	Deceleration of ramp-down (m/s^2)
Real event	0.26	-0.25
Option A	0.43	-0.12
Option B	1.25	-0.86
Option C	0.46	-0.34
Option D	0.12	-0.12
Option E	0.69	-0.90

Recent NSF Project Utilizing the Downburst Simulator at WOW

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Title: Collaborative Research: Downburst Fragility Characterization of Transmission Line Systems Using Experimental and Validated Stochastic Numerical Simulations

PI: Amal Elawady (FIU), Abdollah Shafieezadeh, Ohio State University

NSF Program: Engineering for Natural Hazard (ENH)

Experiment: A series of aeroelastic wind tunnel studies on the downburst response of multi-span transmission systems at the NHERI Wall of Wind EF at FIU.

NSF Projects Utilizing the Downburst Simulator at WOW

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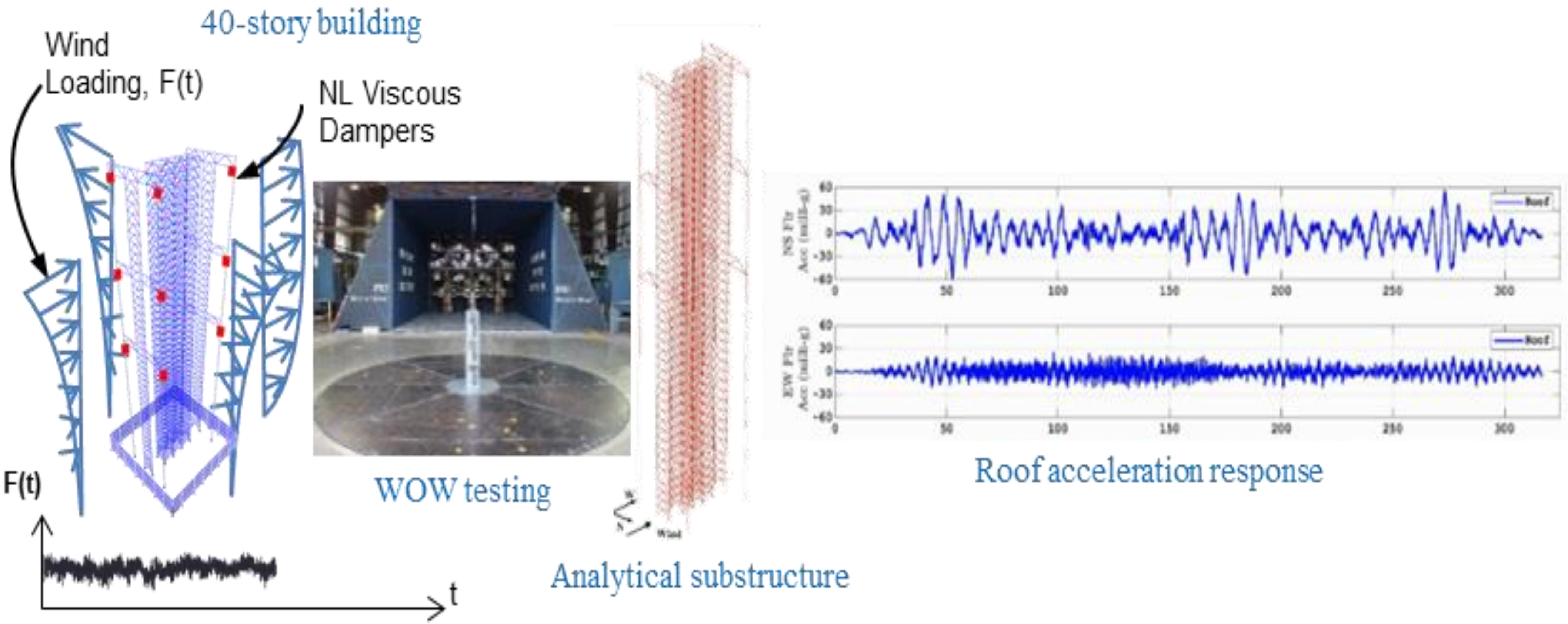
Title:	Structural Response in Transient Winds of Hurricanes and Downbursts
PI:	Teng Wu (Buffalo)
NSF Program:	NEES RESEARCH

Experiment: Aerodynamic wind testing studies on the synoptic and downburst response of tall buildings at the NHERI Wall of Wind EF at FIU.

2. Hybrid Simulation Capabilities and Research Opportunities



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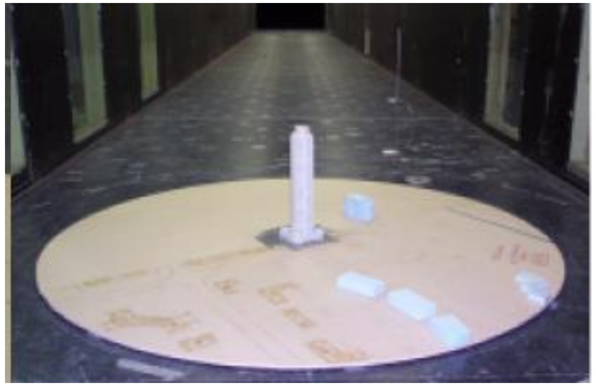
LEHIGH UNIVERSITY

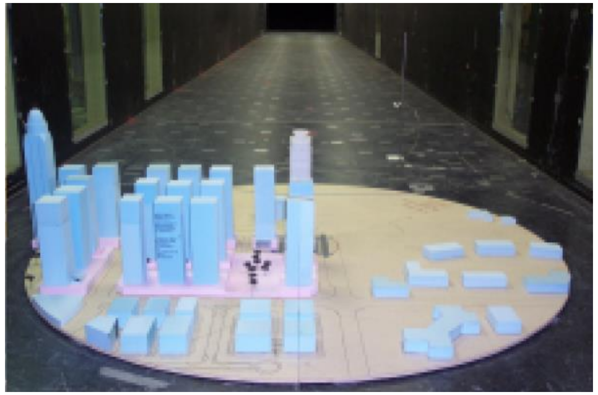
RTMD
REAL-TIME MULTI-DIRECTIONAL SIMULATION
NATURAL HAZARDS ENGINEERING RESEARCH INFRASTRUCTURE

NSF-MECHS

Individual Capabilities vs. Hybrid Simulation

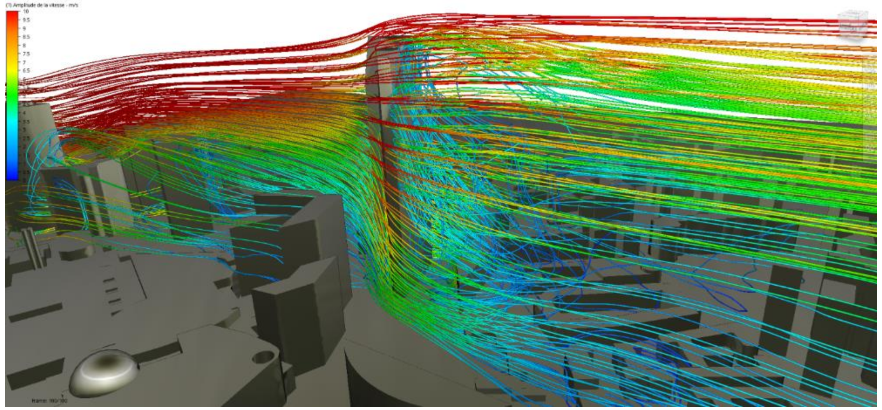
Wind Testing (WT)





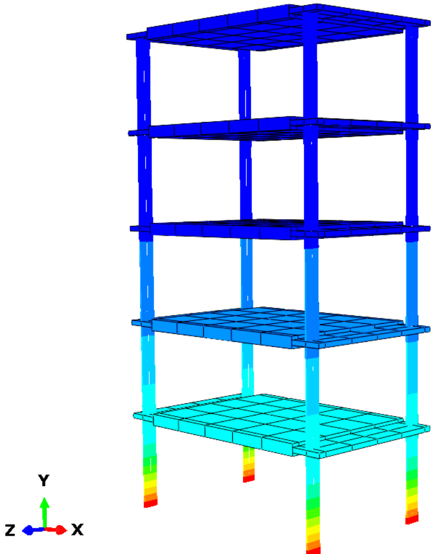
Tamani, Tower Dubai, UAE; Courtesy of BLWT, UWO

CFD Simulation



http://www.inex.fr/

Finite Element Modeling + WT or CFD



Hybrid Simulation?

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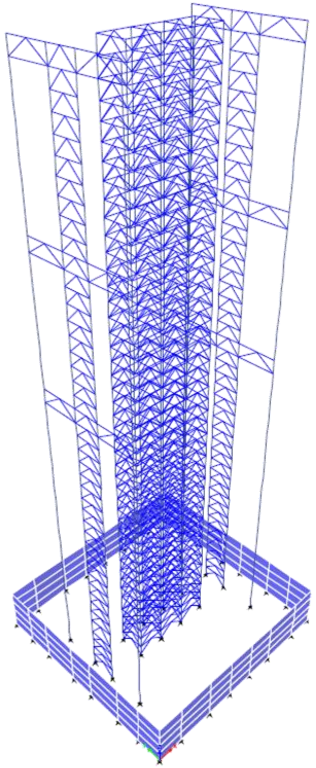
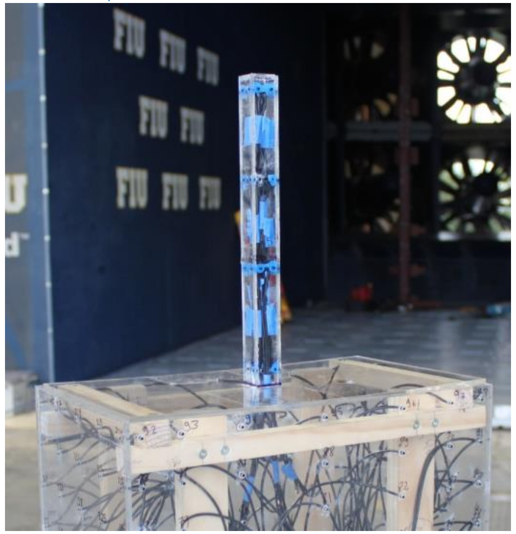
Numerical Substructure



Numerical Simulation Data

Physical Substructure



Physical Response Data

RTHS Advantages in Wind Engineering

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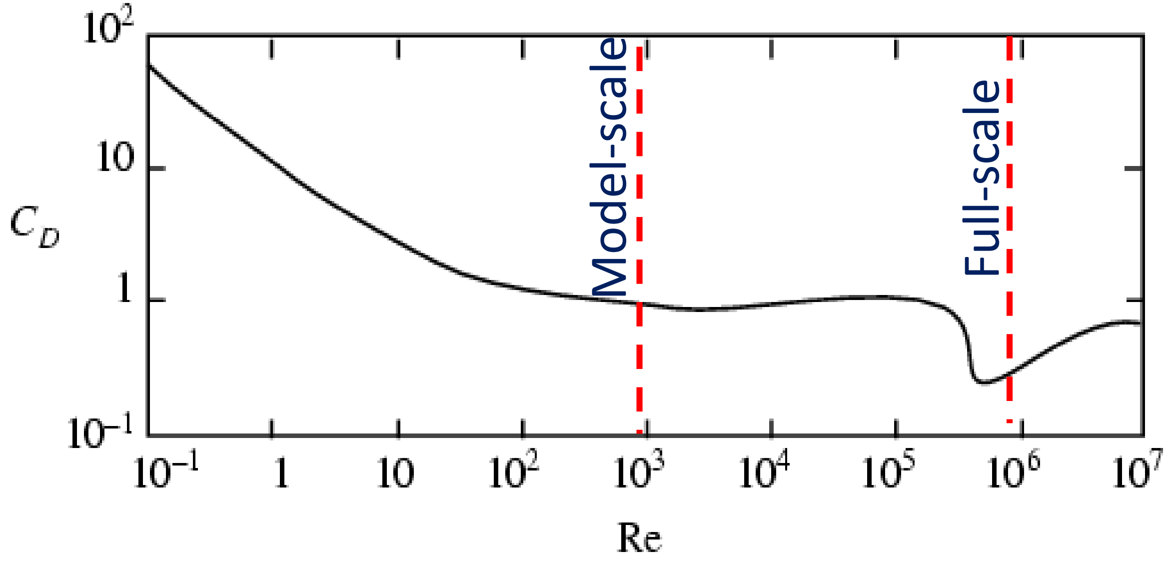
Large scales testing	Eliminate possible scaling effects.
Coupling wind testing with a numerical modeling	Capture nonlinear effects for the entire structure
Simulation of wind-structure interaction	Understand wind-induced response, aerodynamic damping effects using large-scale experiments
Allows combining different loading scenarios	Study multi-hazard effects (e.g. wind and flooding effects)

Scaling Effects Challenges

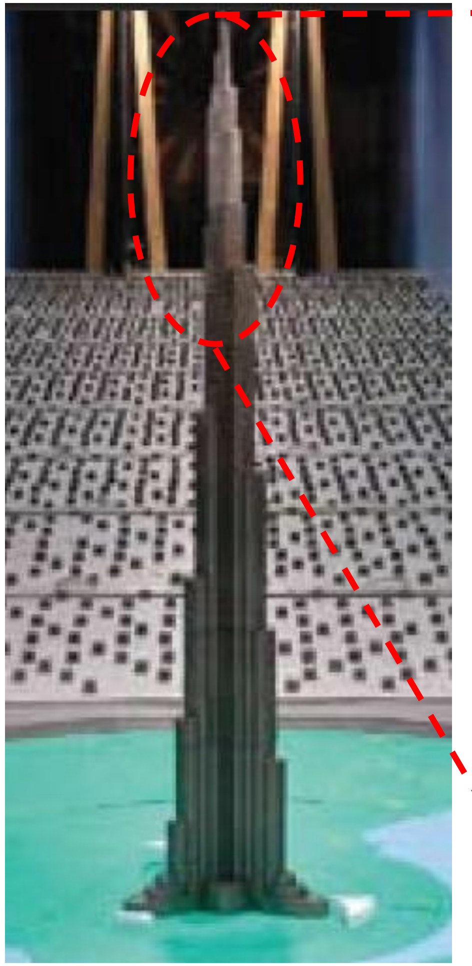
Drag coefficient for a cylinder



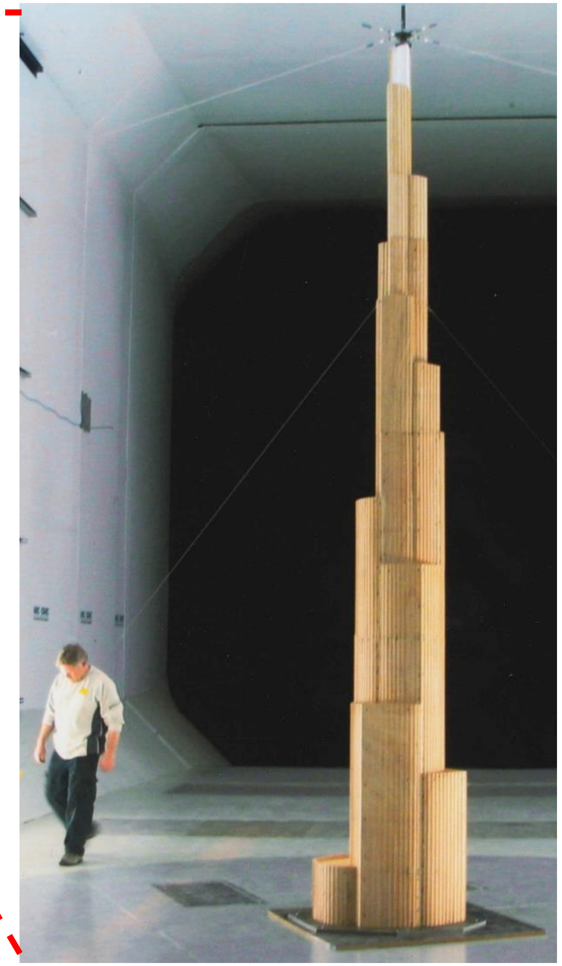
Full-scale Re:
V=50 m/s
D=2 m
Re=6.7x10^6

1:500 length scale
1:10 velocity scale

Model-scale Re:
V=5 m/s
D=0.004 m
Re=1.3x10^3



A 1:500 scale rigid model of the Burj Dubai



A 1:50 scale model

RTHS Challenges in Wind Engineering

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Small Scale Tests:

Length scale D_m/D_p = 1:300;
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 min at full scale;
60 Hz in wind tunnel represents 1 Hz at full scale.

Time and frequency scaling issues pose challenge:

- Numerical simulations 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:

Length scale D_m/D_p = 1:20 ;
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.

Case Study: Tall building with Rooftop Mast

Prudential Tower, Boston, MA

One World Trade Center, NY

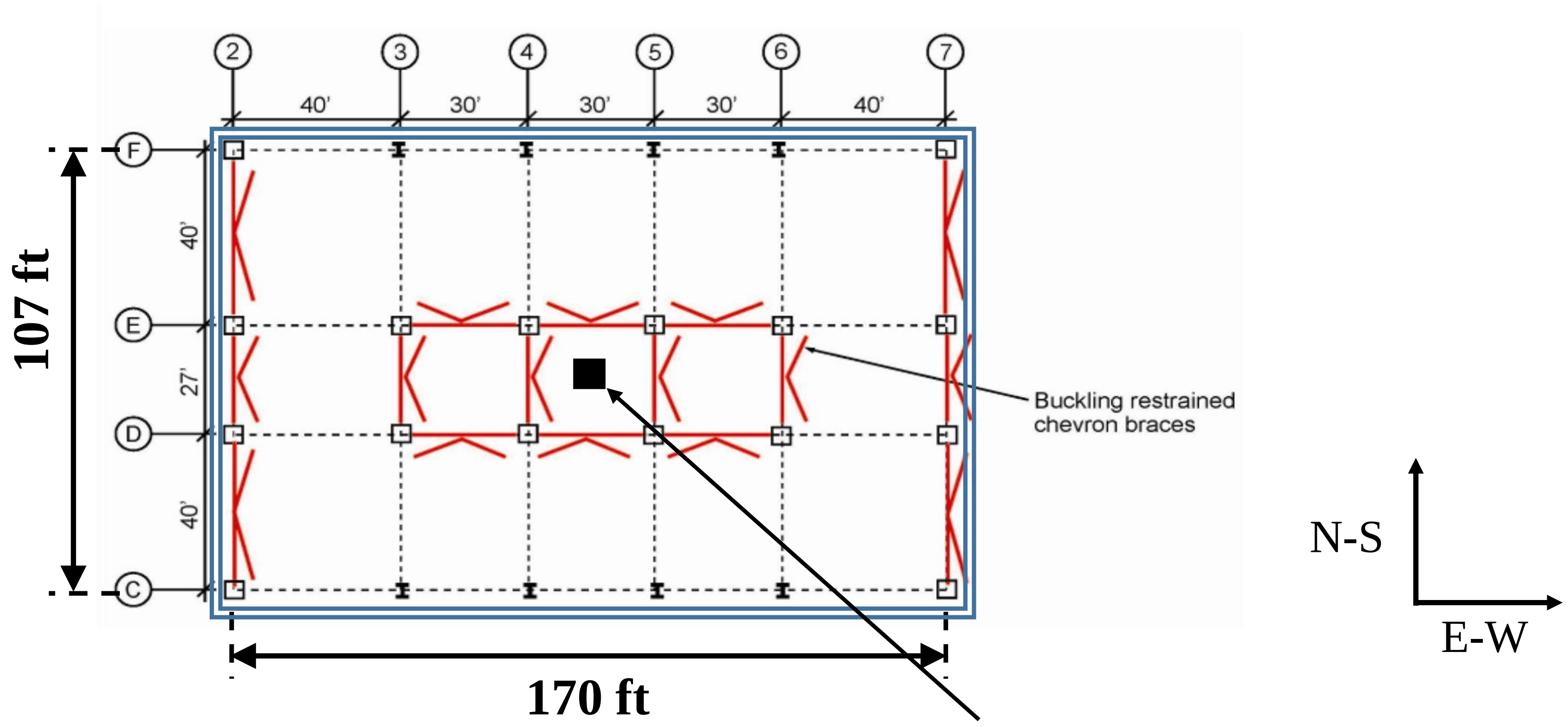
Taipei, Taiwan

Willis Tower, IL

Selected Case Study

Prototype: 40 Story Building:

- Located in Los Angeles designed by SGH for PEER Tall Building Initiative.
- The current study adopts a rooftop monopole communication structure.



Rooftop Telecommunication tower

Ref.: Moehle et al., PEER 2011/05

WOW testing: Aero-elastic-Numerical

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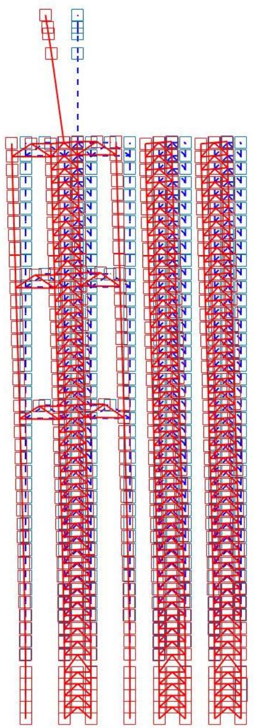
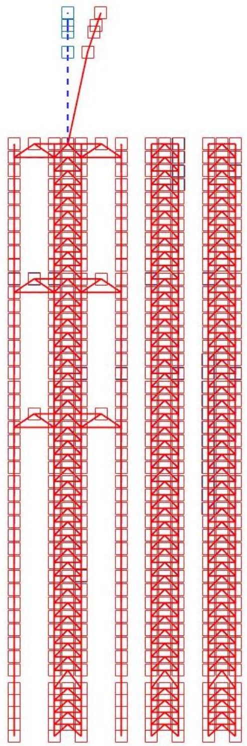
Building + Rooftop tower



Mode 1: 0.17 Hz



Mode 2: 0.52 Hz

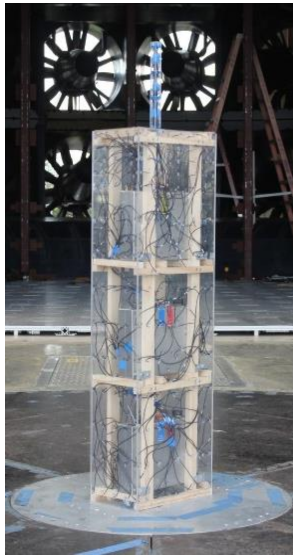
Rooftop tower

Mode 1: 0.55 Hz

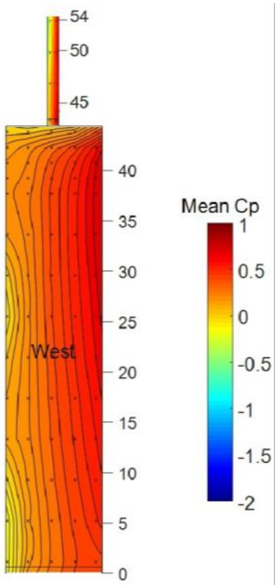
Mode 2: 3.8 Hz

Project Description-Phase I

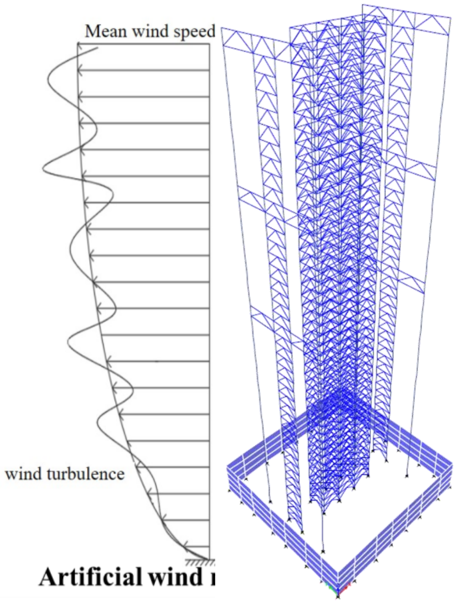
- Aerodynamic wind pressure testing at NHERI WOW to establish baseline.
- Developing a 3D Finite Element Model for the building with the mast



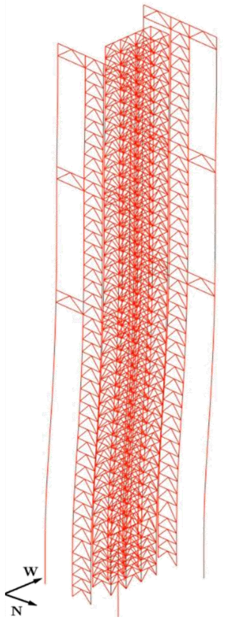
Aerodynamic model



Peak Cp contours



FEM wind input

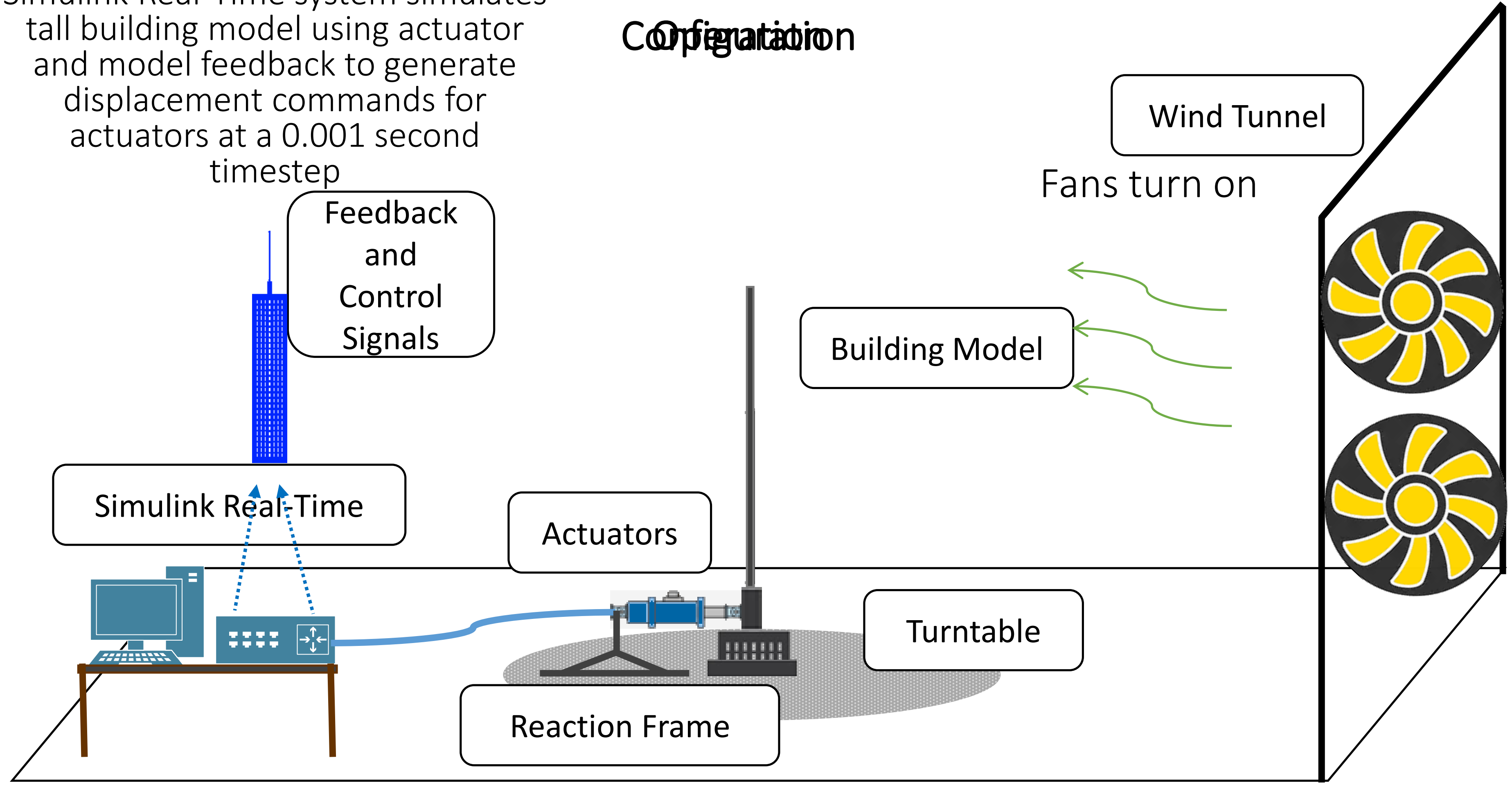


FEM response

WOW testing: Aeroelastic-Numerical

Real-Time Multi-Hazard Simulation

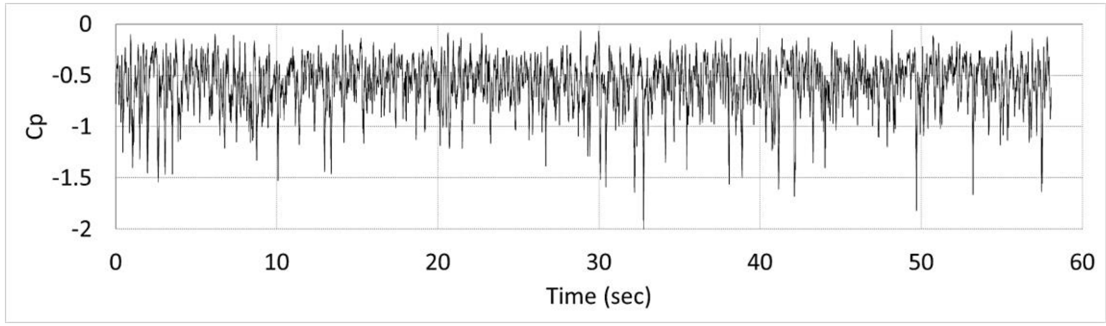
Simulink Real-Time system simulates tall building model using actuator and model feedback to generate displacement commands for actuators at a 0.001 second timestep



Research Questions

- Forcing function may not be repeatable from test to test.

This poses a challenge related to the definition of the forcing function in the numerical simulation with respect to the wind tunnel loading imposed on the physical substructure.



<u>Forcing function discrepancies sources:</u>

1. The variability of the peak pressure coefficient because of the random nature of the peak.
2. The uncertainty in the relevant statistics of the peak because of the limited size of the record.
3. The uncertainty with respect to the actual value of the roughness length.
4. The uncertainty associated with the measurement of the wind speeds.
5. The sampling errors in the estimation of the wind speed with a specified mean recurrence interval.

Possible HS Applications in Wind Testing

- Transmission tower systems: conductors are modeled as substructure.
- Cladding systems vibrations and water penetration: cladding panel as a substructure.
- Offshore structures (wind turbines; floating substructures): wave actions on submerged system modeled using actuators and WT as substructure.
- Damping systems on a tall building: damper system and building potion as substructure.
- Communication infrastructure, Traffic signals, Variable Message Signs.

Committee on RTHS in Fluid-Structure Interaction (FSI) Applications

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MULTIHAZARD ENGINEERING COLLABORATORY ON HYBRID SIMULATION
A RESEARCH COORDINATION NETWORK

DESIGNSAFE-CI
A NATURAL HAZARDS ENGINEERING COMMUNITY

- Recently, the MECHS Coordination Network has established a new committee on RTHS in Fluid-Structure Interaction (FSI).
- The committee brings together researchers from different institutions around the world: USA, Canada, Denmark, Norway, Colombia; with expertise in RTHS, Wind Engineering, Wave Engineering.
- The committee aims to leverage the RTHS techniques to include FSI applications to foster the capabilities of traditional wind and wave testing methods.

Name	Affiliation
Amal Elawady (CHAIR)	Florida International University
Arindam Gan Chowdhury	Florida International University
Richard Christenson	University of Connecticut
James Ricles	Lehigh University
Oh-Sung Kwon	University of Toronto
Denis Istrati	University of Nevada, Reno
Steven Wojtkiewicz	Clarkson University
Pedro Fernandez-Caban	Clarkson University
Thomas Michel Sauder	SINTEF
Pedro Lomonaco	Oregon State University
Barbara Simpson	Oregon State University
Wei Song	University of Alabama
Jacob Waldbjørn	University of Denmark
Amin Magahareh	Purdue University
Brian Phillips	University of Florida
Teng Wu	University at Buffalo
Peter Thomson	University of Cali, Colombia
Shirley Dyke	Purdue University

Thanks you!