Physical Modeling of Bolund
in an

Atmospheric Boundary Layer Wind Tunnel

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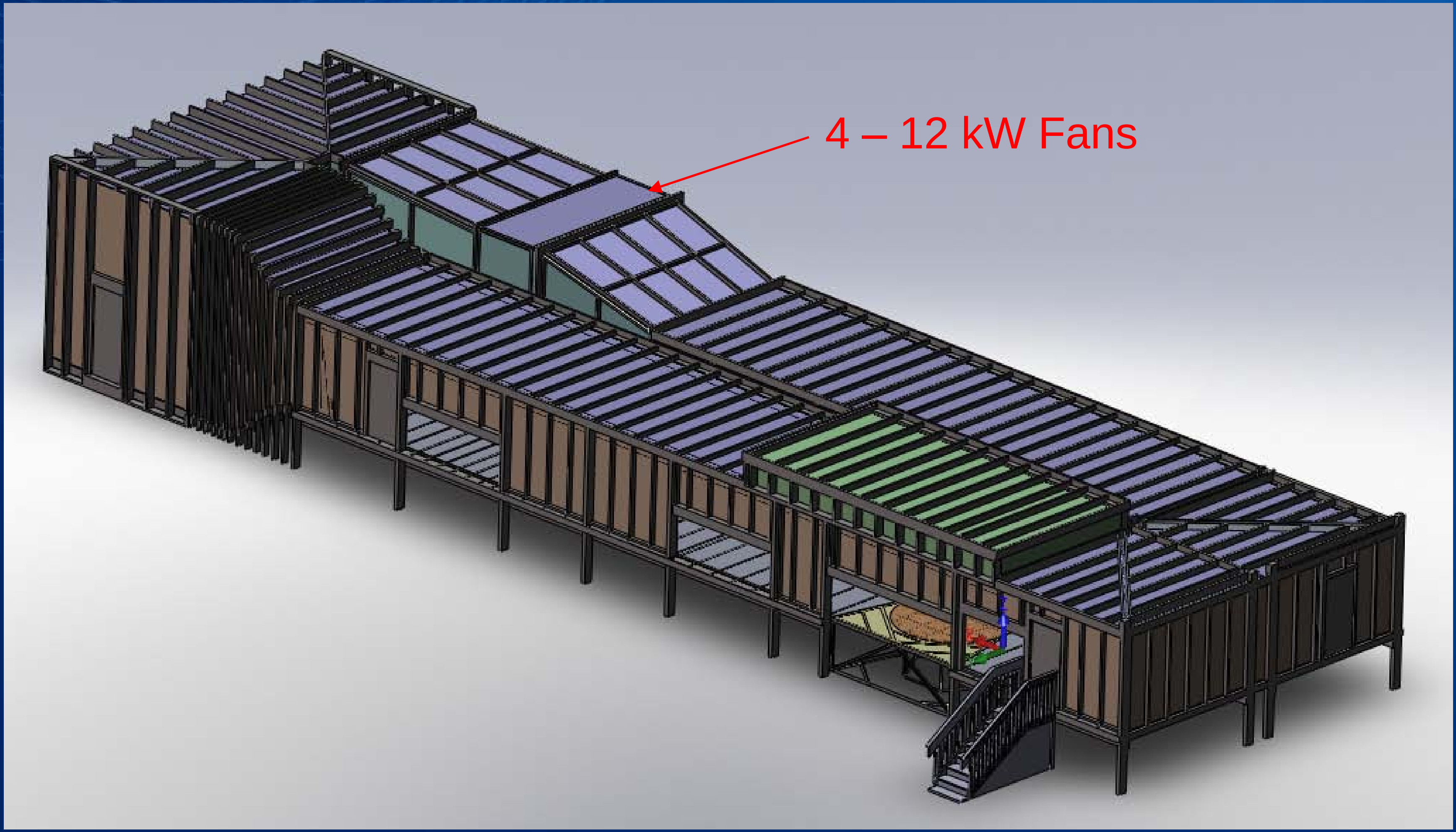
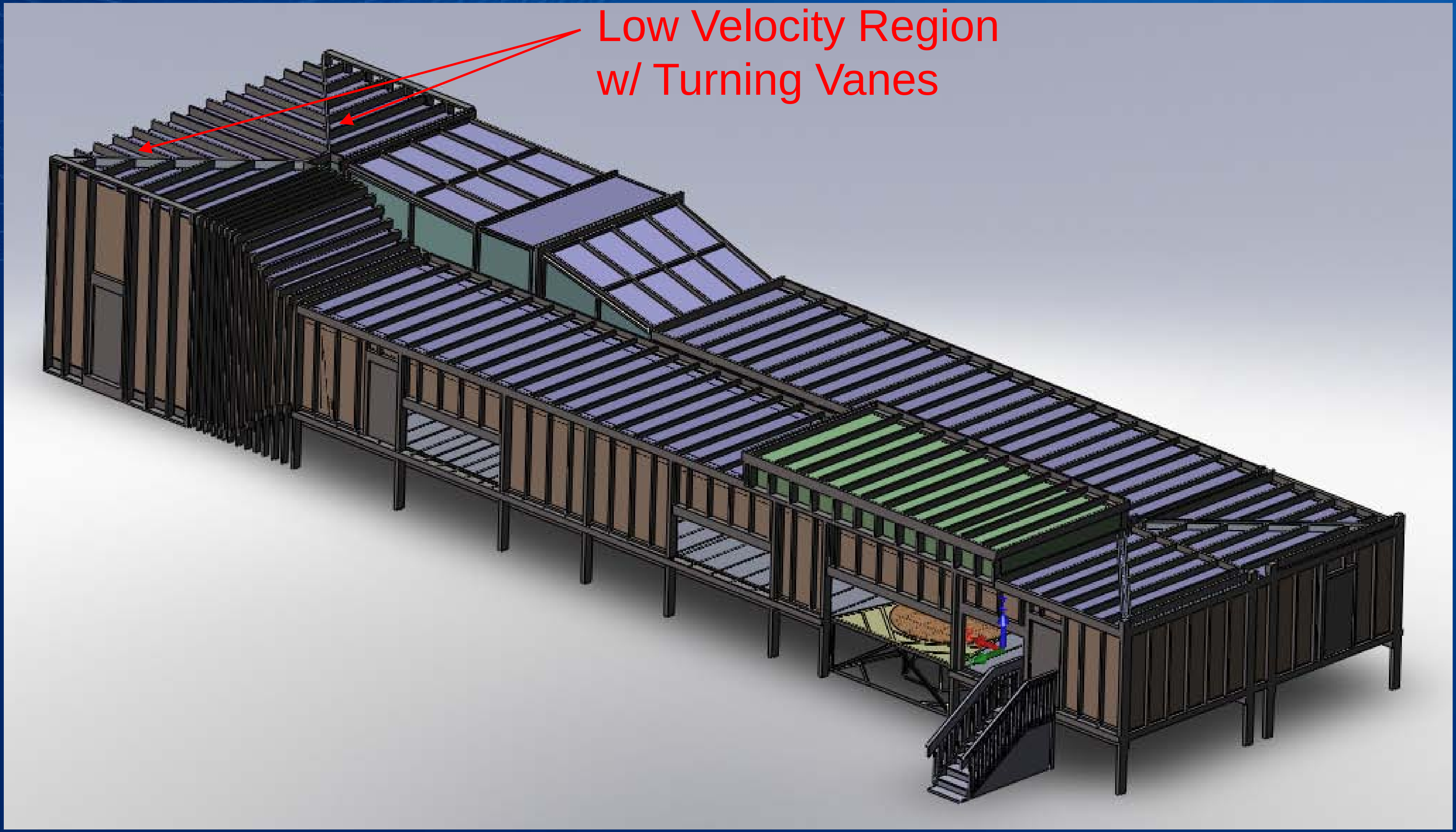
Atmospheric Boundary Layer Wind Tunnel

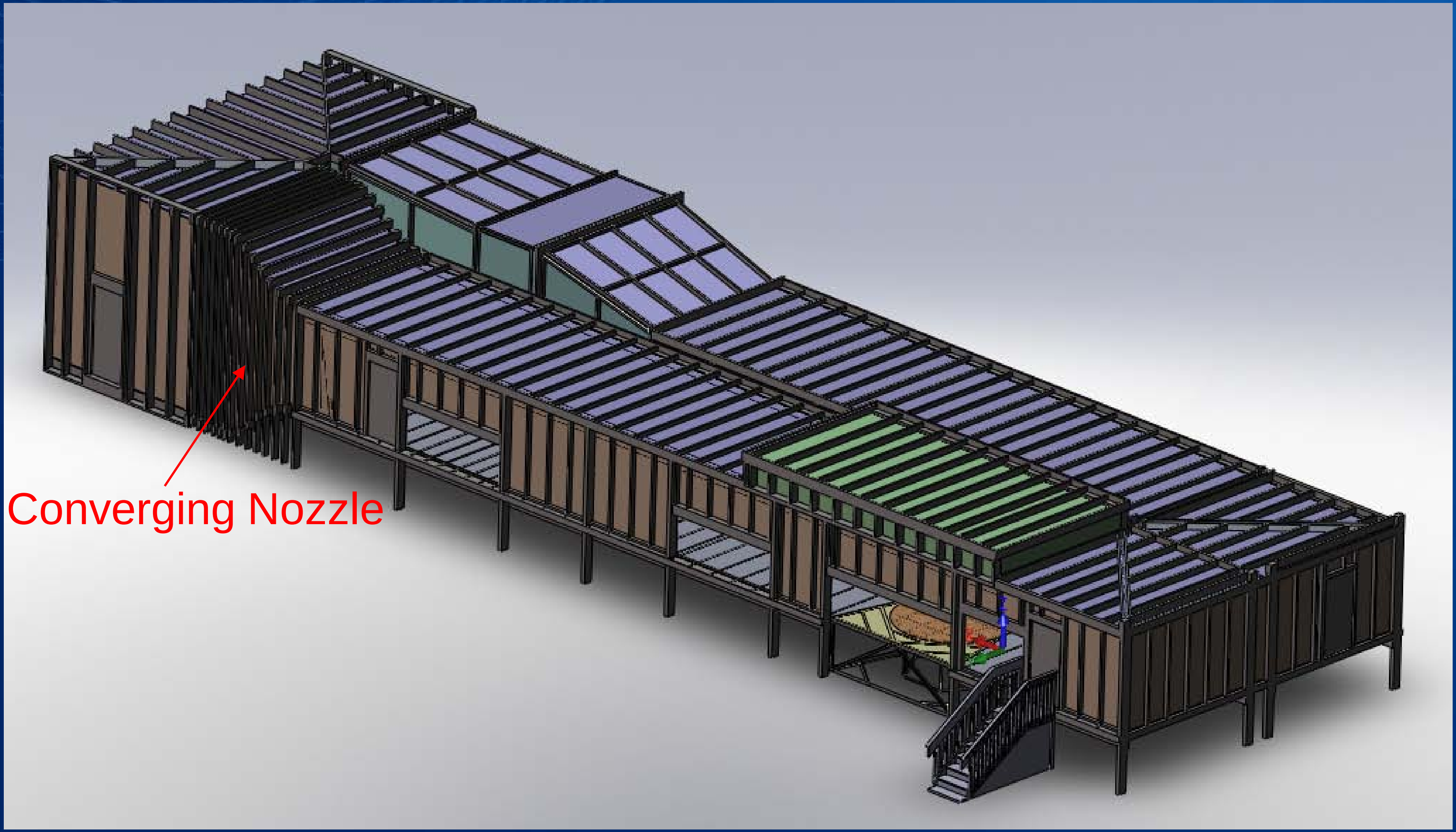
Schematic



Atmospheric Boundary Layer Wind Tunnel
Schematic



Atmospheric Boundary Layer Wind Tunnel
Schematic



Atmospheric Boundary Layer Wind Tunnel
Schematic

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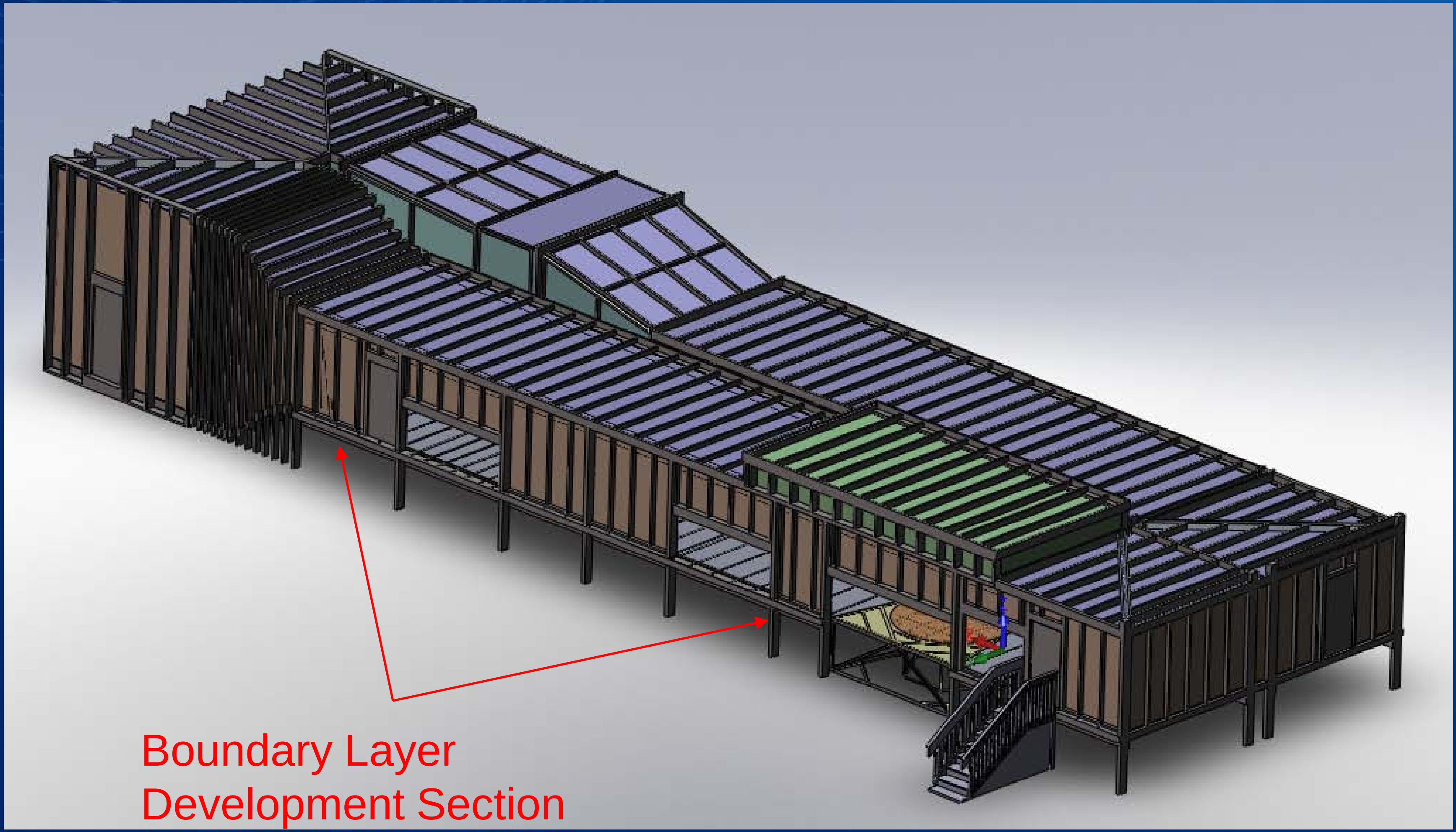
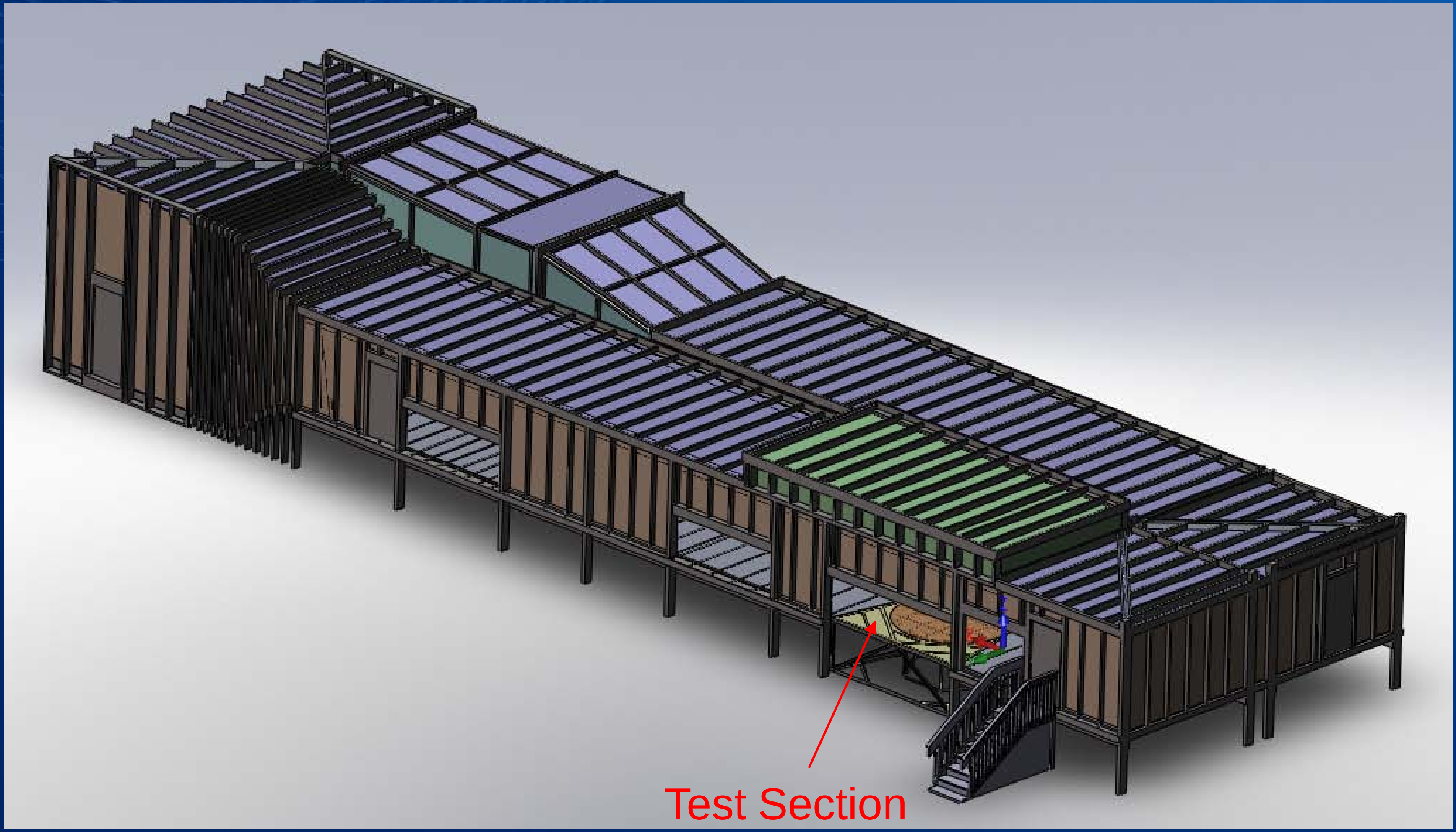


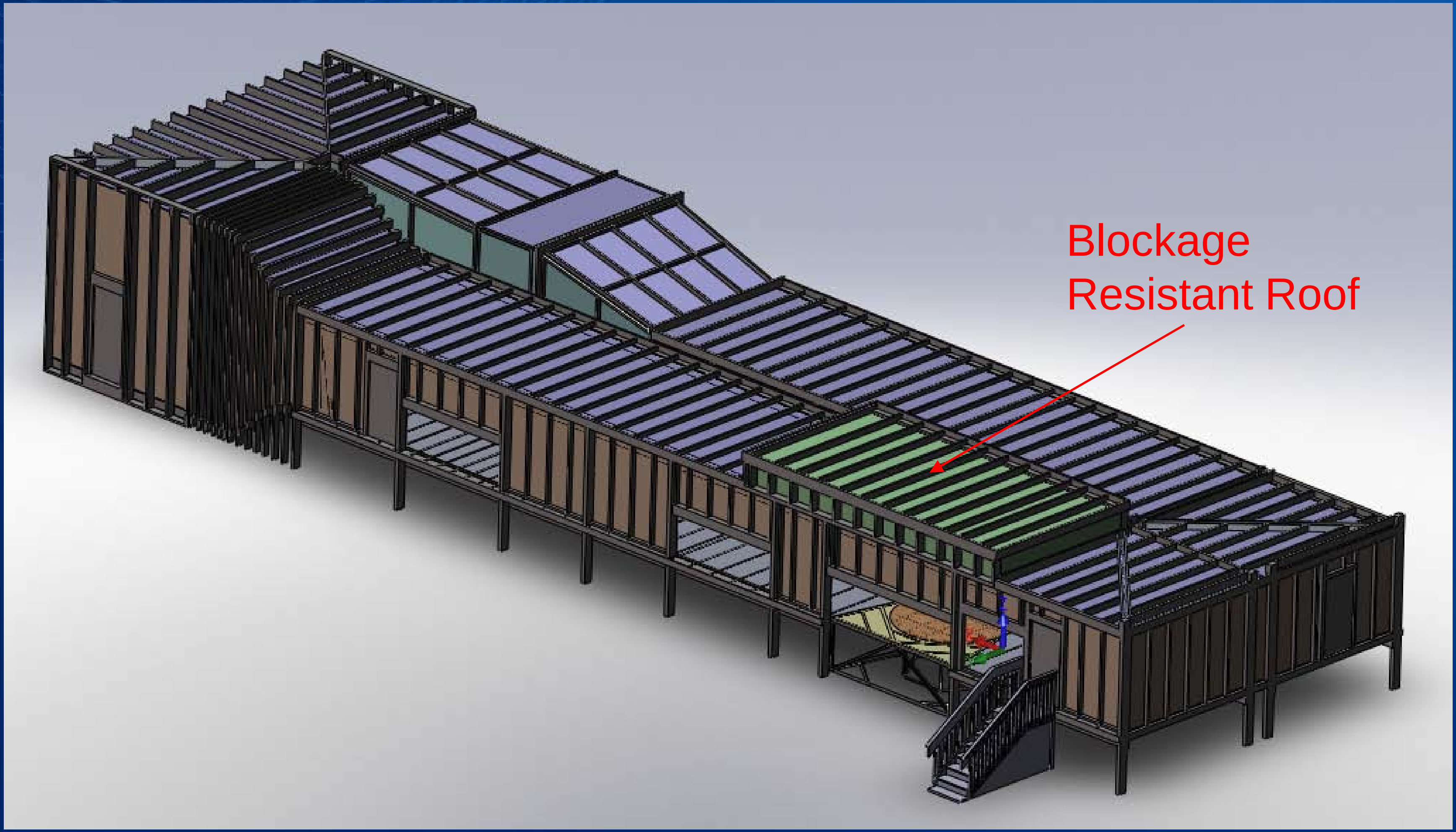
Atmospheric Boundary Layer Wind Tunnel

Schematic

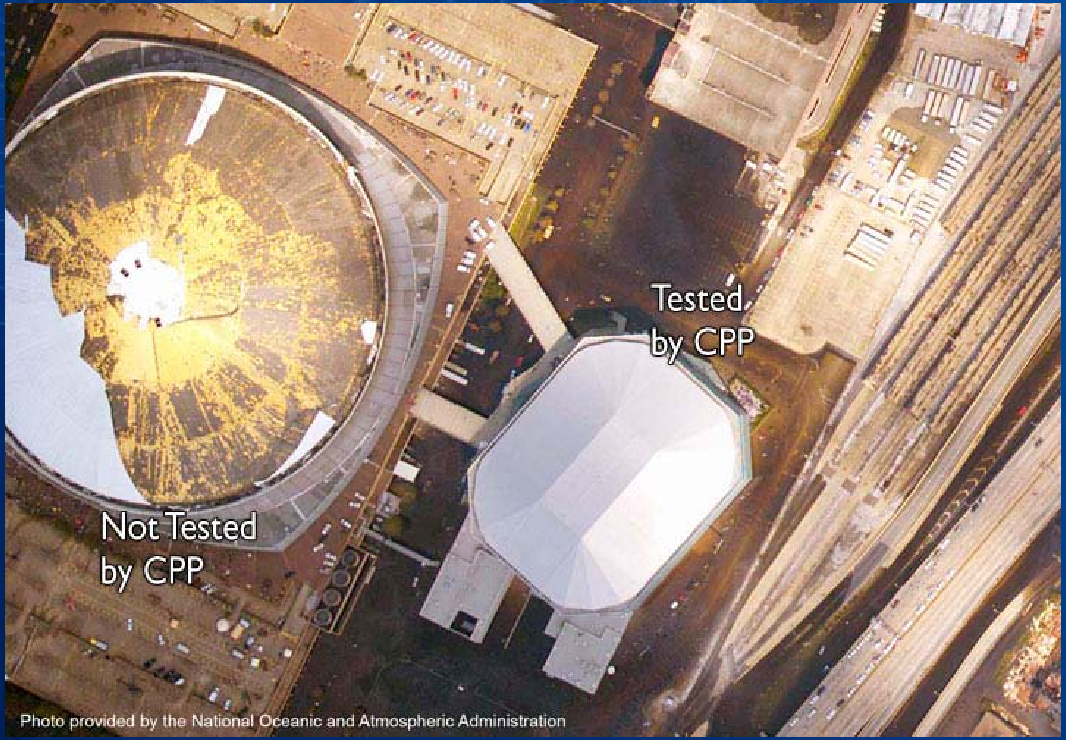


Atmospheric Boundary Layer Wind Tunnel

Schematic



Typical Applications
Wind Induced Building Loads



Superdome and New Orleans Arena

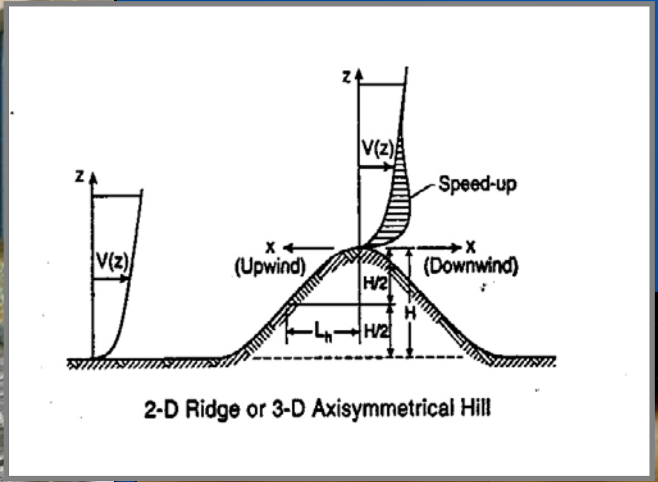
John Hancock Building - Boston

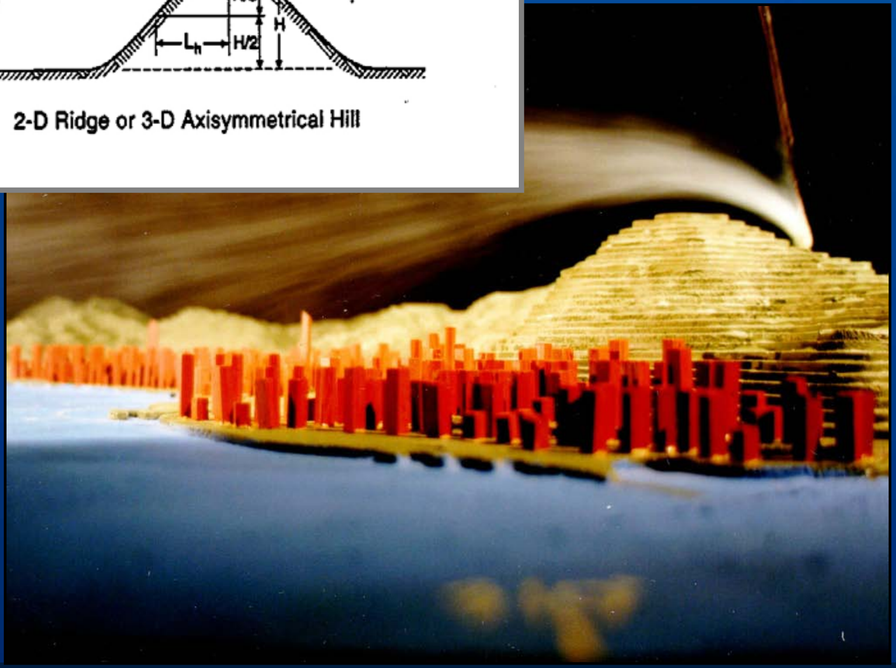
Typical Applications
Pedestrian Level Wind Environment

Typical Applications
Plume Dispersion

Typical Applications

Airflow in Complex Terrain Environments





Physical Modeling
Theory

Navier-Stokes Equations

Continuity

$$\frac{\partial}{\partial \mathbf{t}}(\rho \mathbf{v}) + \nabla \cdot (\rho \mathbf{v}\mathbf{v}) = -\nabla \mathbf{p} + \nabla \cdot \tau + \rho \mathbf{F}$$

Momentum

$$\frac{\partial}{\partial \mathbf{t}} + \nabla \cdot (\rho \mathbf{v}) = 0$$

Energy

$$\frac{\partial}{\partial \mathbf{t}}(\rho e) + \nabla \cdot (\rho \mathbf{v} e) = -p \nabla \cdot \mathbf{v} + \tau : \nabla \mathbf{v} - \nabla \cdot \mathbf{q}$$

Physical Modeling
Scaling Parameters

- **Undistorted scaling geometry**
- **Equal dimensionless boundary and approach flow conditions**
- **Equal Rossby number – $U/L\Omega$**
- **Equal gross Richardson number – $[\Delta T/T](L/U^2)g$**
- **Equal Reynolds number – UL/ν**
- **Equal Prandtl number - $n/(k/rC_p)$**
- **Equal Eckert number – $U^2/[C_p(\Delta T)]$**

Physical Modeling
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Coriolis effects minimal in the near field

Physical Modeling

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Neutral Stratification

Physical Modeling

Scaling Parameters

$$\left(\frac{UL}{\upsilon}\right)_{\mathrm{model}} = \left(\frac{UL}{\upsilon}\right)_{\mathrm{fullscale}}$$

$$(L)_{\mathrm{model}} = (L)_{\mathrm{fullscale}} / 100$$

$$(\upsilon)_{\mathrm{model}} = (\upsilon)_{\mathrm{fullscale}}$$

NOT POSSIBLE!

$$\downarrow$$

$$\cancel{(U)_{\mathrm{model}} = (U)_{\mathit{fullscale}} \times 100 = 1{,}000\, m/s}$$

Physical Modeling

Reynolds Number Independence

- Ensure a fully turbulent wake flow

  Terrain or Building Reynolds Number greater than 11,000 ($R_{e_T} = UH_T/\upsilon$)

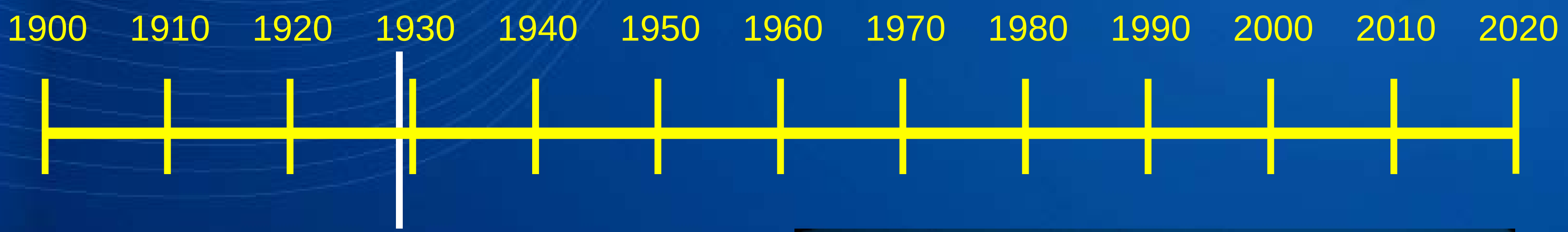
$$U = 10 \text{ m/s}$$

$$H_T = 0.25 \text{ m}$$

$$\upsilon = 1.15\text{x}10^{-5} \text{ m}^2\text{/s}$$

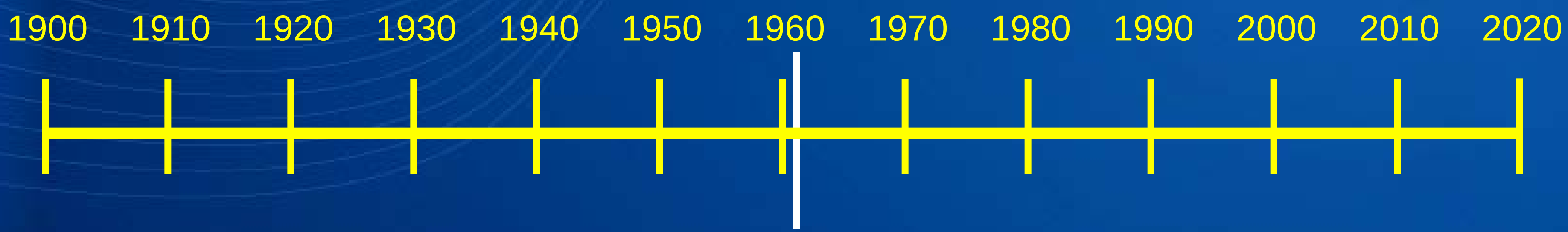
$$R_{e_T} = 217{,}391$$

History
Timeline



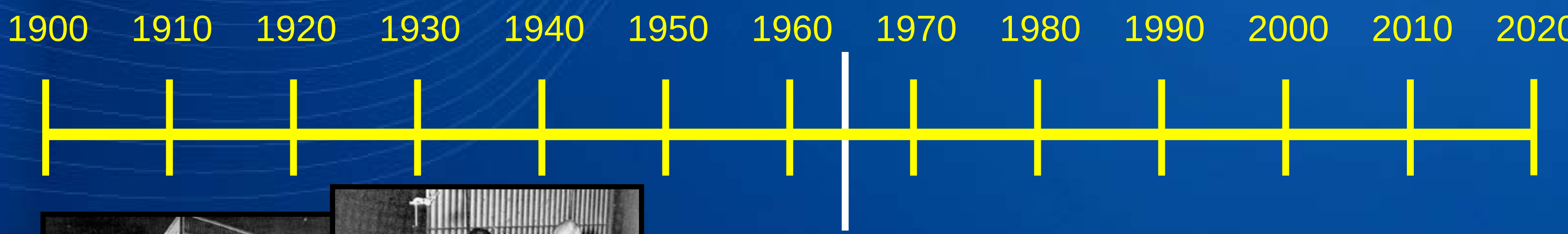
Abe (1929) studies air flow over a scale model of Mt. Fuji

History
Timeline



Golden (1961) Defines minimum acceptable Reynolds number to achieve Reynolds number independence

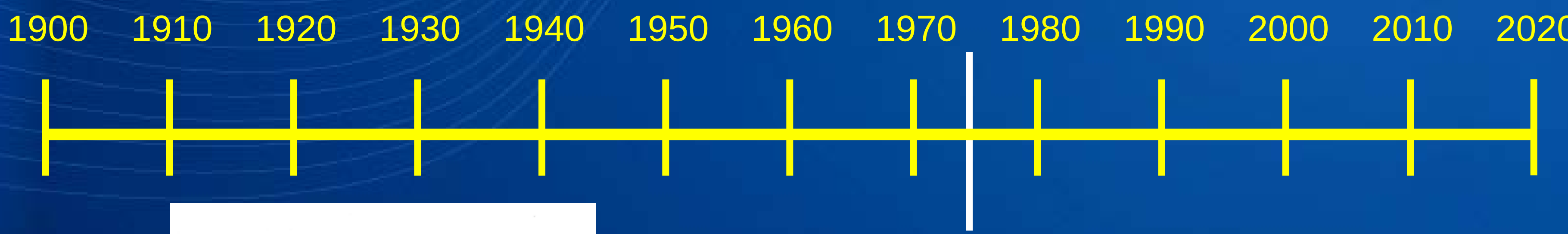
History
Timeline

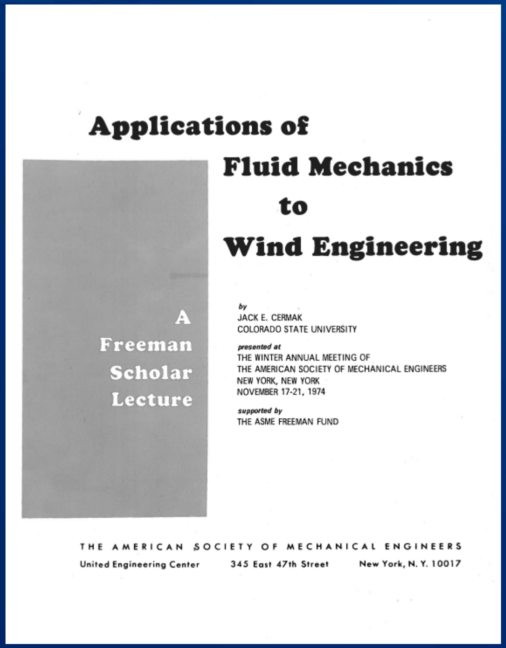


Cermak and Davenport (1964) measured wind loads on a scale model of the World Trade Centers in New York

History

Timeline





Applications of Fluid Mechanics to Wind Engineering

A Freeman Scholar Lecture

by
JACK E. CERMAK
COLORADO STATE UNIVERSITY

presented at
THE WINTER ANNUAL MEETING OF
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
NEW YORK, NEW YORK
NOVEMBER 17-21, 1974

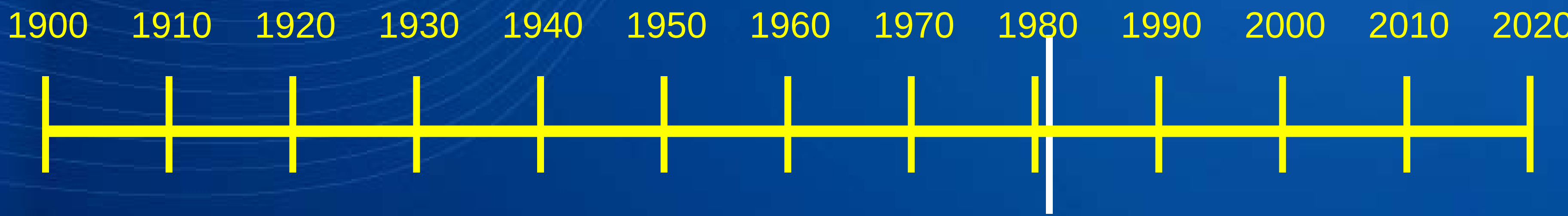
supported by
THE ASME FREEMAN FUND

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center 345 East 47th Street New York, N. Y. 10017

Cermak (1975) Publishes Freeman Scholar Lecture on wind tunnel simulation methods

(Resulting in wind tunnel modeling being accepted by most building codes)

History
Timeline



US EPA (1981) Publishes
Fluid modeling guideline
for wind tunnel simulations

History

Timeline

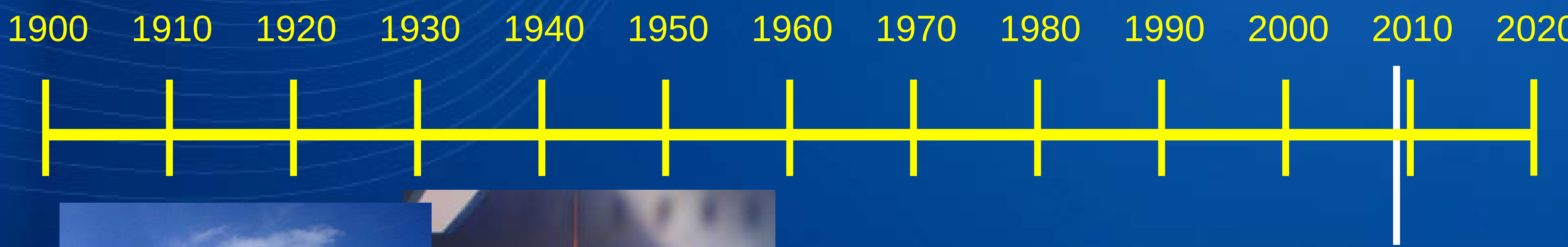
A properly executed wind tunnel study is, in effect, equivalent to an analog computer with near infinitesimal resolution and near infinite memory.

The basic equations are solved by simulating the flow at a reduced scale, then measuring the desired quantity

- U.S. EPA Fluid Modeling Guideline

History

Timeline



By 2009 over 5000 building have been testing in an atmospheric boundary layer wind tunnel, including the worlds tallest Burj Dubai

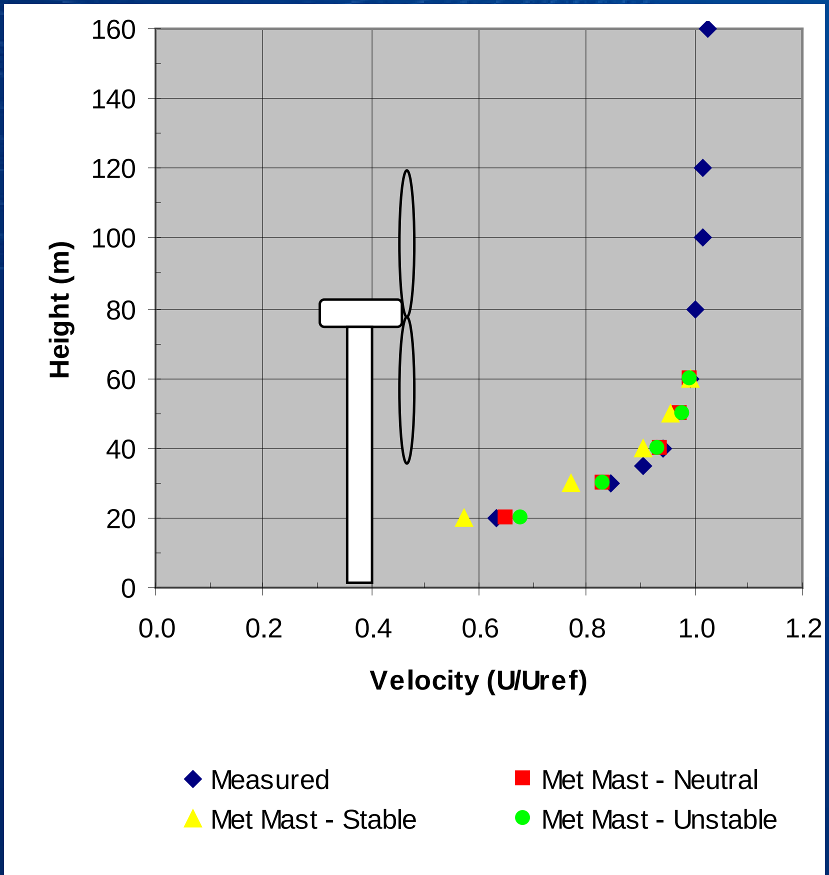
History
Validation in Wind Energy Applications

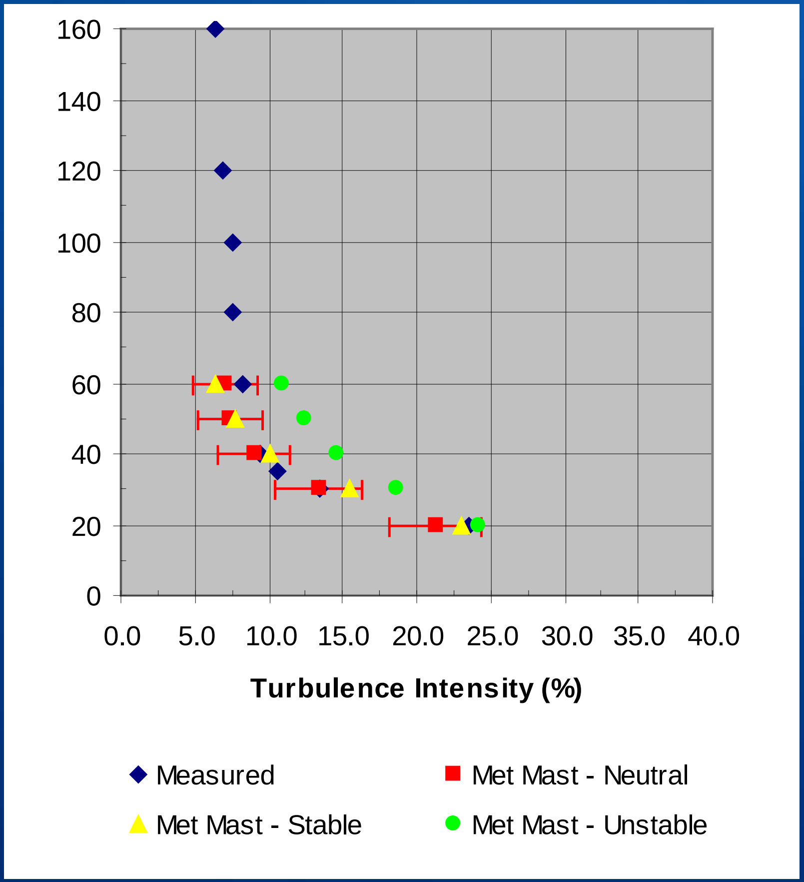
History

Validation in Wind Energy Applications

History

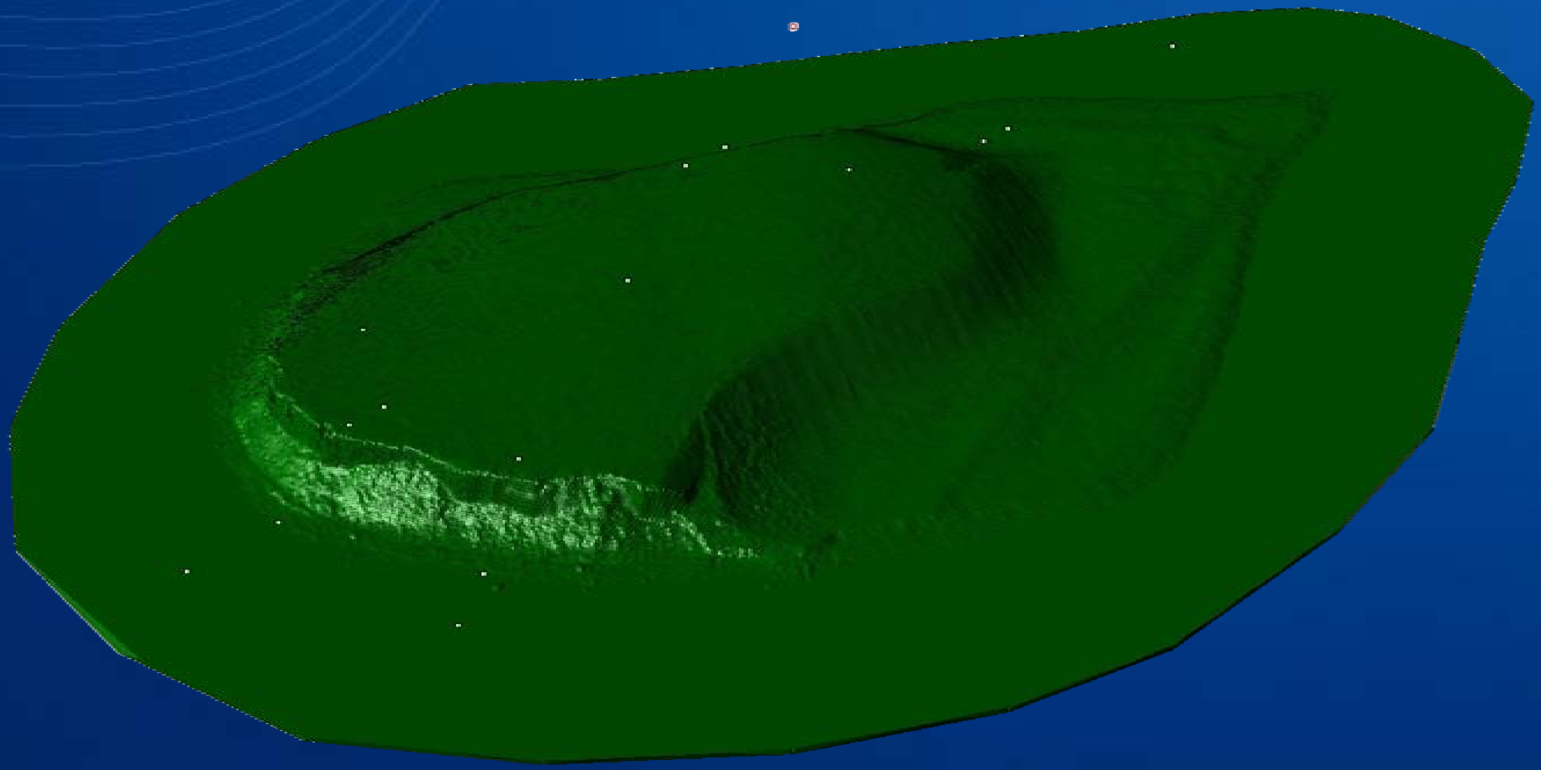
Validation in Wind Energy Applications





Conducting a Wind Tunnel Study

Create 3-D representation in CAD



Conducting a Wind Tunnel Study

Create Physical Model using a 3-D Mill

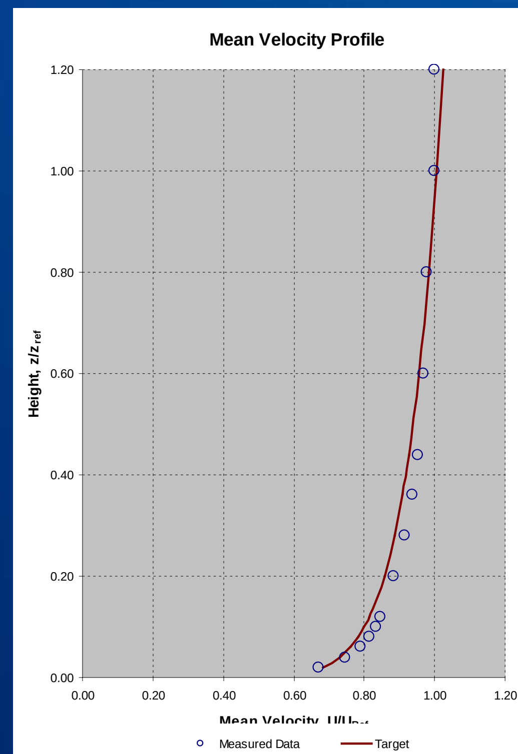
Conducting a Wind Tunnel Study

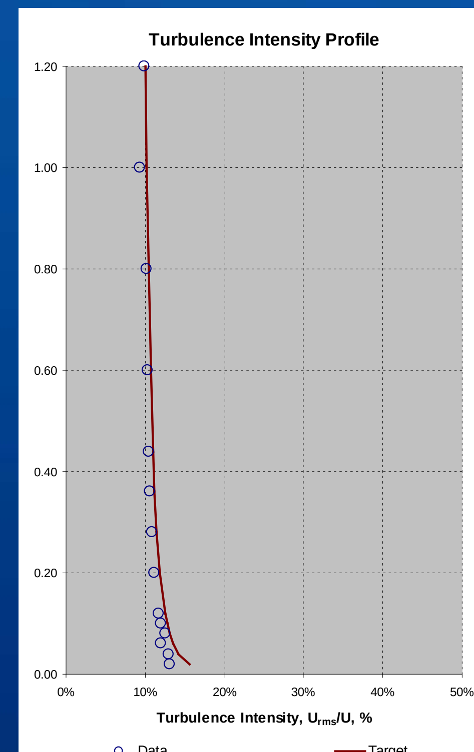
Establish an Atmospheric Boundary Layer

Data Power Law	
n=	0.09
intercept =	0.006

Data Log Law	
n=	0.12
U* =	0.320
zo =	0.0001

Target	
n=	0.10
zo =	0.0003



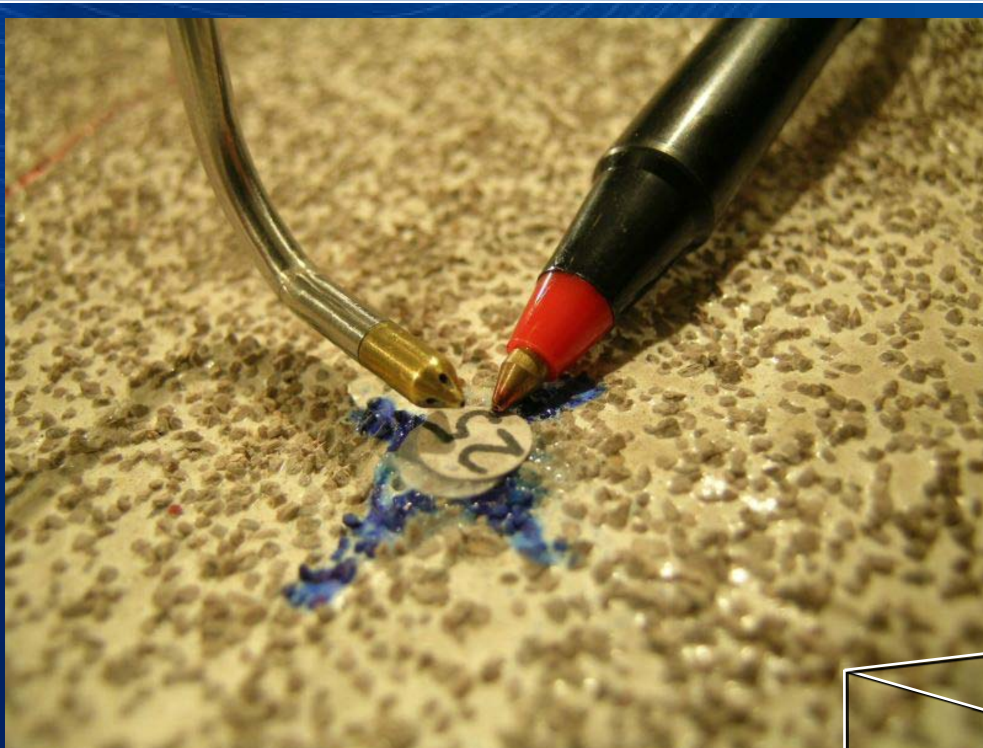


Conducting a Wind Tunnel Study

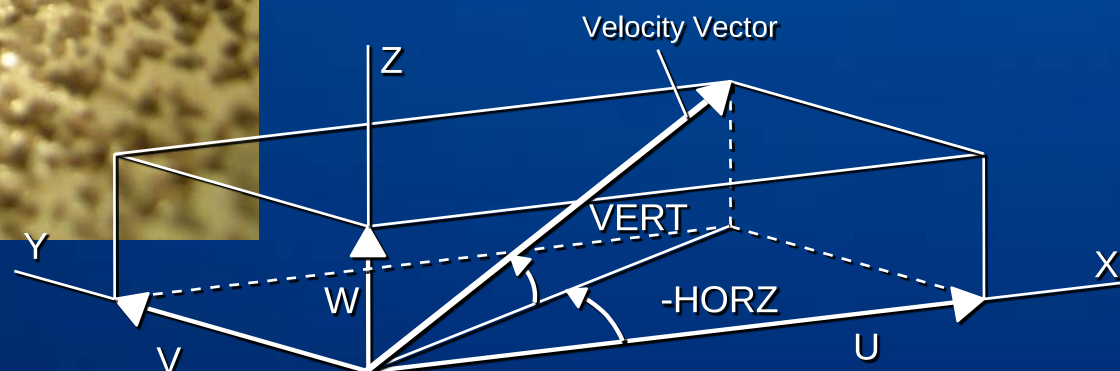
Install Model in the Wind Tunnel

Conducting a Wind Tunnel Study

Measure wind speeds using a 5-holed probe mounted on a 3-D traverse



5-Holed Probe Used to Measure the Local Wind Vector and Turbulence Intensity



Definition of flow angles; x axis defines the approach wind direction

Conducting a Wind Tunnel Study

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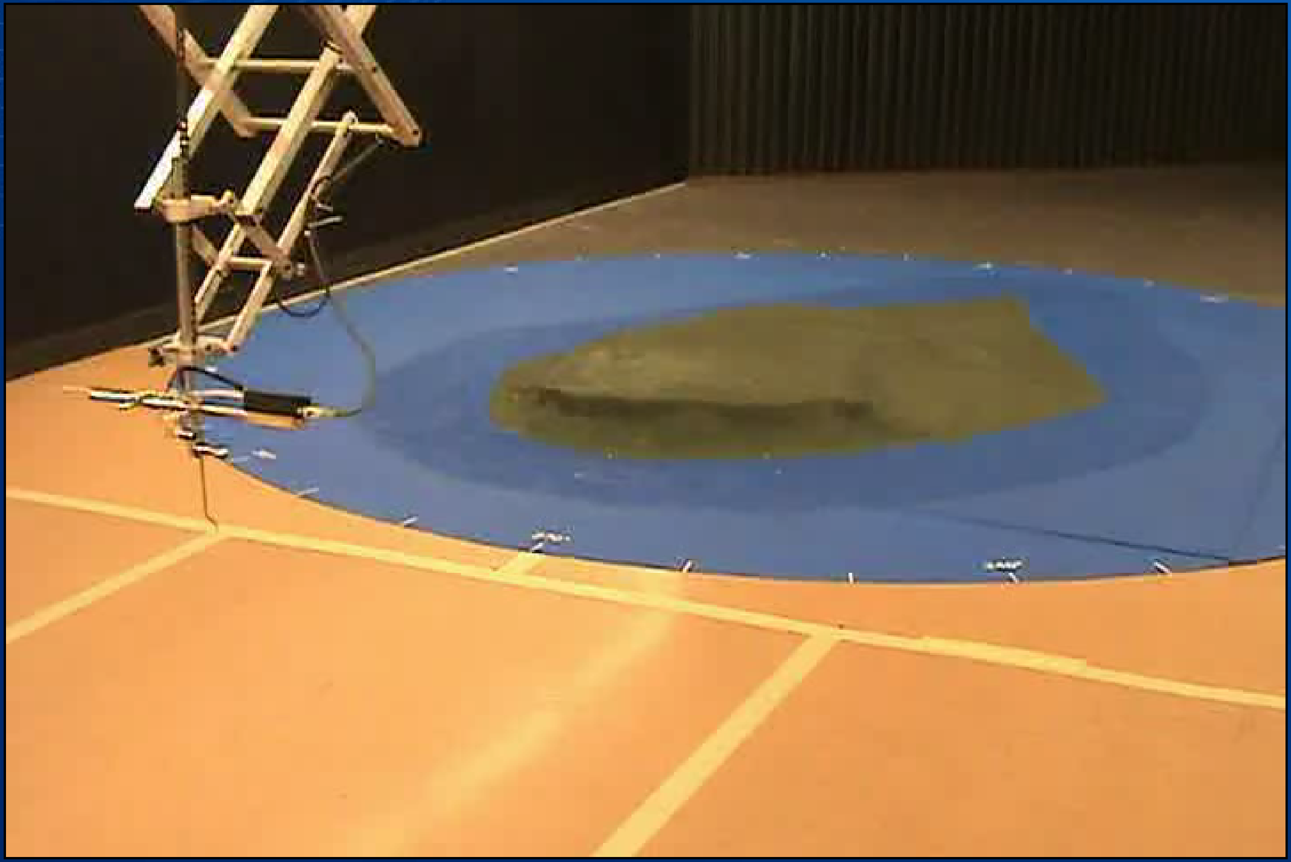
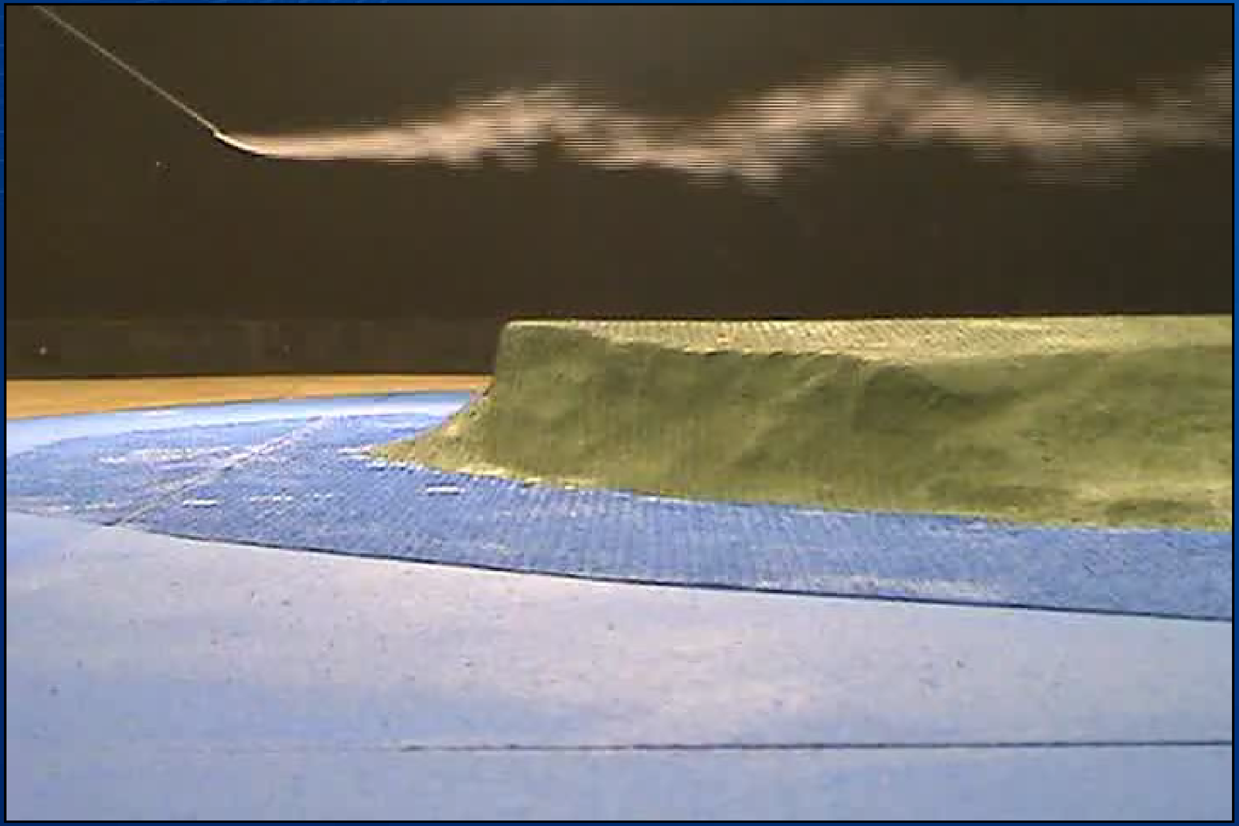


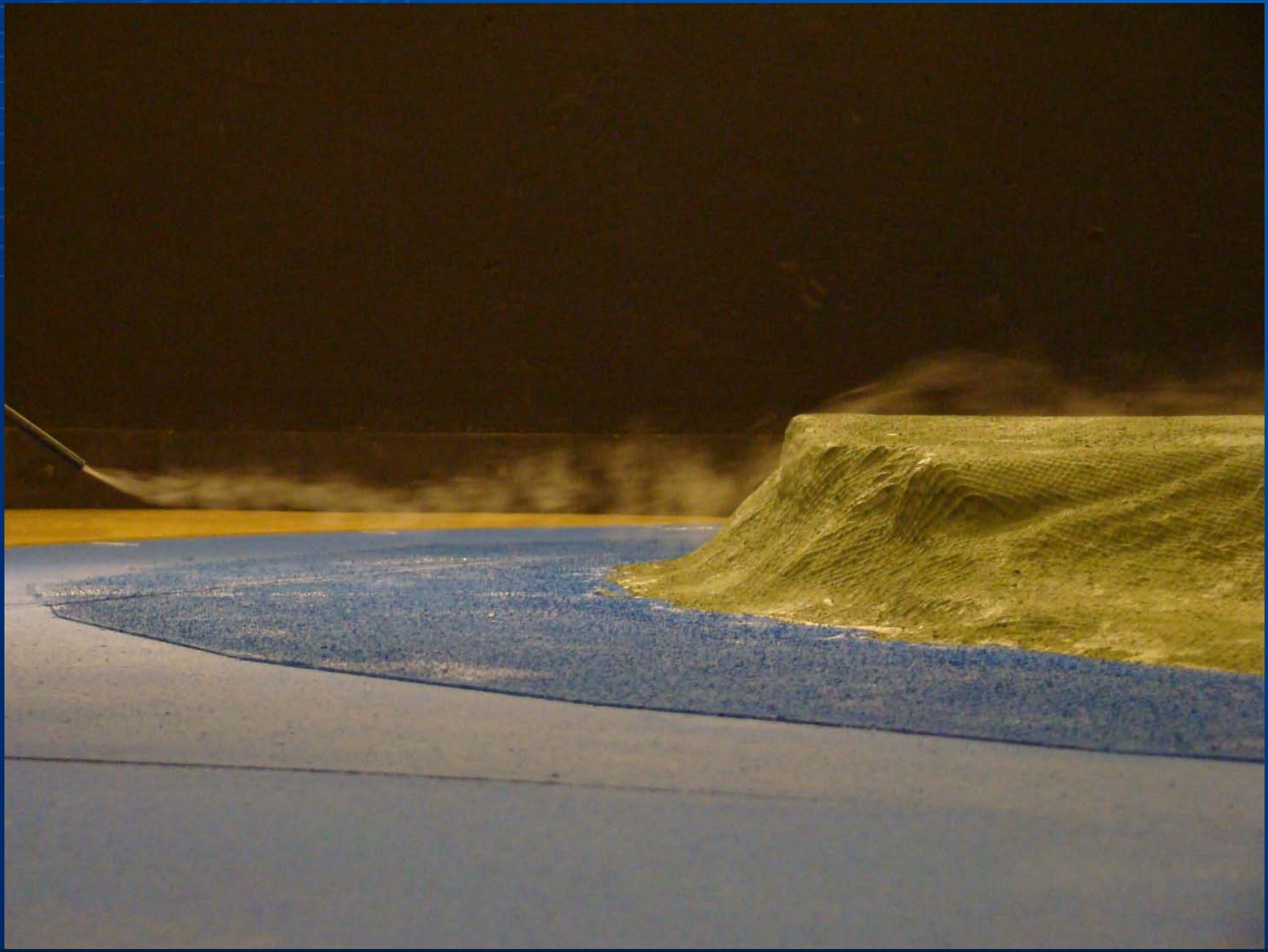
Flow Visualization

270 Degree Wind Direction



Results

239 Degree Wind Direction



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