Introduction

What is Wind Engineering?

Civil Engineering

- Geotechnical Engineering
- Environmental Engineering
- Structural Engineering
- Coastal Engineering
- Transportation Engineering

Wind Engineering

- Wind engineers study the effects of wind on the natural and built environments
Wind can be a friend…

...or an enemy
Wind engineering is best described as the rational treatment of interaction between wind in the atmospheric boundary layer and man and his works on the surface of Earth.

Synthesis of knowledge from
- fluid mechanics
- meteorology
- structural mechanics
- physiology

Aerodynamics is of central importance but most applications are non-aeronautical in nature.
Atmospheric Boundary Layer (ABL)

**Mean wind speed profile:**
- Shape of profile is created by friction between moving air and the earth’s surface.
- Two mathematical expressions are commonly used to describe the mean wind speed profile over various terrain (Holmes, 2001):

1. The “Logarithmic Law”

\[
\bar{U}(z) = \frac{u^*}{k} \log\left(\frac{z-z_h}{z_0}\right)
\]

where:
- \( \bar{U} \) = mean wind speed
- \( z \) = height above ground
- \( u^* \) = “friction velocity” = (surface shear stress/density of air)^0.5
- \( k \) = von Karman’s constant (= 0.4)
- \( z_0 \) = roughness length (obtained from a table)
- \( z-z_h \) = “zero plane displacement” (= ¼ of rooftop height)

2. The “Power Law”

\[
\bar{U}(z) = \bar{U}_{10} \left(\frac{z}{10}\right)^\alpha
\]

where:
- \( \bar{U} \) = mean wind speed
- \( z \) = height above ground
- \( \bar{U}_{10} \) = mean wind speed at \( z = 10 \) m
- \( \alpha \) = (1/\log\left(\frac{z_{ref}}{z_0}\right))

\( z_{ref} \) = reference height
\( z_0 \) = roughness length (obtained from a table)

(NOTE: 10 m is standard wind measurement height)
Atmospheric Boundary Layer (ABL)

Turbulence:
- The “gustiness” of the wind
- Turbulence intensity is mathematically equivalent to the standard deviation of a given wind speed time history
- Like the mean wind speed profiles, turbulence profiles vary for different types of terrain

Example of a typical wind speed record.

Turbulence describes the relationship between fluctuations in the wind speed with respect to the mean wind speed over a given time period.

Image Source: (http://miamiweatheralert.com/history.htm)
Simplified 2-D diagram of wind acting on a tall building

- Equivalent free body diagram
- Equivalent wind force, $F_e$
- Reaction shear force, $F_R$
- Reaction moment ($M_R = F_{eq} \times h$)
Wait a minute!

Wind loading is not that simple....
Basic Bluff Body Aerodynamics

• Generally speaking, the way that wind flows around an object is dependent upon the object’s shape.
• Bluff bodies may be defined as objects that do not have a streamlined shape.
• Most buildings can generally be classified as bluff bodies located in ABL flows.

(Image source: http://suberic.net/~avon/mxphysics/Ame%20and%20Debbie/web%20page.htm)
Basic Bluff Body Aerodynamics

- The flow around bluff bodies is typically defined by flow separation, reattaching shear layers, and vortex formation.


Aerodynamics: Bernoulli’s equation

- Bernoulli’s equation is the basis which allows determination of pressures.
Aerodynamics: Bernoulli’s equation

- Pressure coefficient:

\[ C_p = \frac{\Delta P}{\frac{1}{2} \rho V_o^2} \]

\( \Delta P \) is the pressure induced by wind (above or below ambient atmospheric pressure); commonly \( \Delta P \) is called \( P \).
Aerodynamics: Pressure Coefficient

Common features of pressure distributions on buildings:

- Pressures over the front face are positive but reduce rapidly as the flow accelerates around the sides and upper edge of the face.
- Pressures decrease downwards along the face centre (decreasing velocity in boundary layer).
- Pressures on the rear face are negative.
- Roof and side pressures are mostly negative with very large localized suctions (eaves, corners).
Basic Bluff Body Aerodynamics

- Fluctuating forces on bluff bodies may be caused by:
  - Natural turbulence in the flow
  - Unsteady flow caused by wind moving around the body itself → Example: Vortex Shedding
  - Fluctuating forces due to movement of the body itself.

(Holmes, 2001)
Basic Bluff Body Aerodynamics

Vortex Shedding:
- A series of alternating vortices form as the wind flows around a bluff body.
- The vortices correspond to regions of low pressure, and the object (building in our case) will tend to move toward the low pressure region.
- The result is a significant cross-wind loading on the object.
- Tall, slender objects are particularly vulnerable to vortex shedding.
- Video of vortex shedding: [http://www.youtube.com/watch?v=_AJgEa2dbJU](http://www.youtube.com/watch?v=_AJgEa2dbJU)

Image Source: http://www.vibrationdata.com/Tacoma.htm

If there are fluctuating forces on buildings...

...how do we determine the wind loads?
Determining Wind Loads on Buildings

- Modern building codes give engineers guidance to estimate the extreme wind loads on both low-rise and high-rise buildings.
- However, tall buildings are typically tested in a Boundary Layer Wind Tunnel (BLWT) during the design phase:
  - BLWTs can:
    - Accurately measure base (reaction) loads on a tall building model
    - Measure loads on buildings with unique and irregular shapes that are not covered by building codes
    - Determine and mitigate a building’s sensitivity to aerodynamic phenomena
    - Help reduce material costs for the full-scale structure
Example of small-scale BLWT models

CASE A

CASE B

RWDI wind tunnel models

(Dagnew and Bitsuamlak, 2010).
Computation Fluid Dynamics (CFD) Modeling

(Dagnew and Bitsuamlak, 2010).

CASE A

Mean velocity

Inst. velocity
Large and Full Scale Testing
Now we have the wind loads on the building... 

...isn’t that all we need to design the building?

Yes, but we can still enhance the design to mitigate the wind loading (i.e. there can be economic gains by reducing the wind loads).
Aerodynamic/shape mitigation, optimization

- Low-rise roofs/wall corners
- High-rise buildings
- Energy infrastructure (wind farm optimization, wind load mitigation on solar panels etc.)
Real-world Tall Building Mitigation Example

Taipei 101
- Located in Taipei, Taiwan
- 101 floors

Basic shape modification yielded a 25% reduction of the base moment (Irwin, 2006)
Shape/architectural modifications

Original  Modified
Mechanical Room

Original  Modified
2013 WoW Mitigation Challenge

• Each team will be given a top portion of a cubic-shape building

• Building dimensions:
  3 x 3 x 3 ft

  WoW → 3 x 3 x 2.5 ft

  School → 3 x 3 x 0.5 ft
2013 WoW Mitigation Challenge

Objective:

Design simple and inexpensive aerodynamic devices to suppress vortices along roof and wall edges.
2013 WoW Mitigation Challenge

• Physical tests will occur on the cube; these cubes are to represent a single story building;
• Sand or kitty litter will be applied on top of the flat roof;
• Students must design a mitigation solution that will stop the sand or kitty litter from blowing away when subjected to hurricane winds

• Mitigation solutions should be realistic, aesthetic, marketable, practical and PERFORM WELL!
2013 WoW Mitigation Challenge

Students will prepare three components to address the mitigation problem and solution:

- physical test,
- oral presentation
- written paper
Thank you

Questions??