2014 Wall of Wind (WoW) Challenge Informational Workshop

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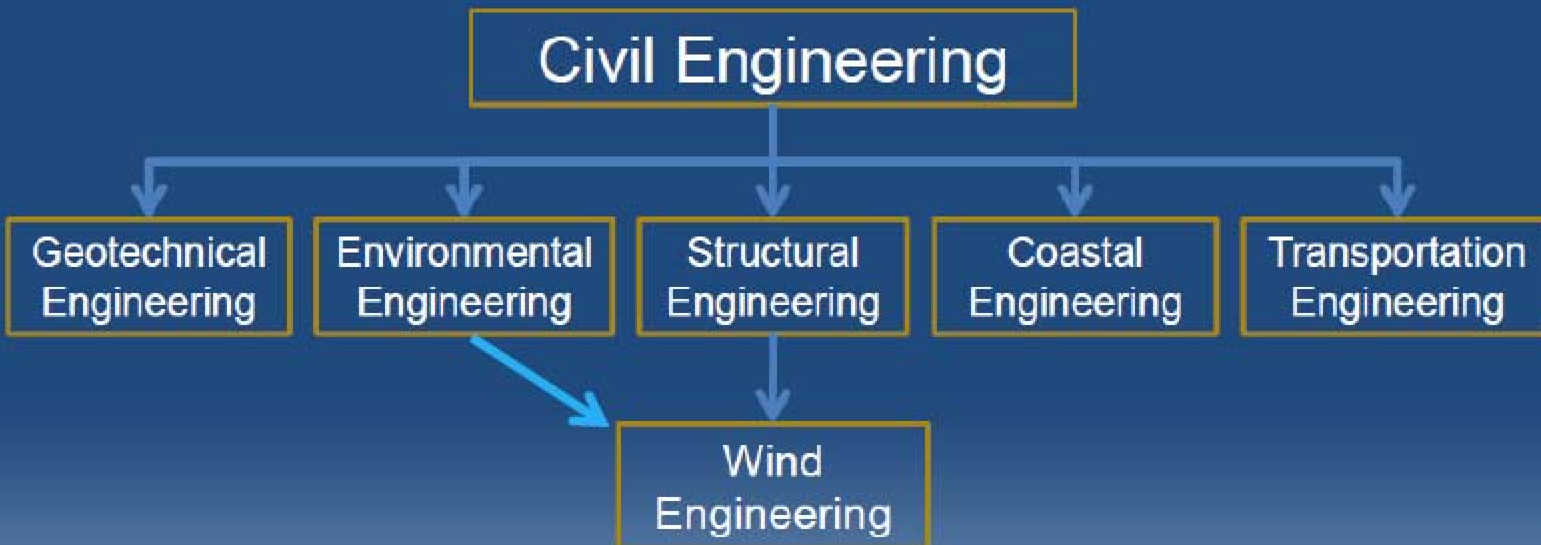
Introduction

What is Wind Engineering?



- Wind engineers study the effects of wind on the natural and built environments

Wind can be a friend…

…or an enemy

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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

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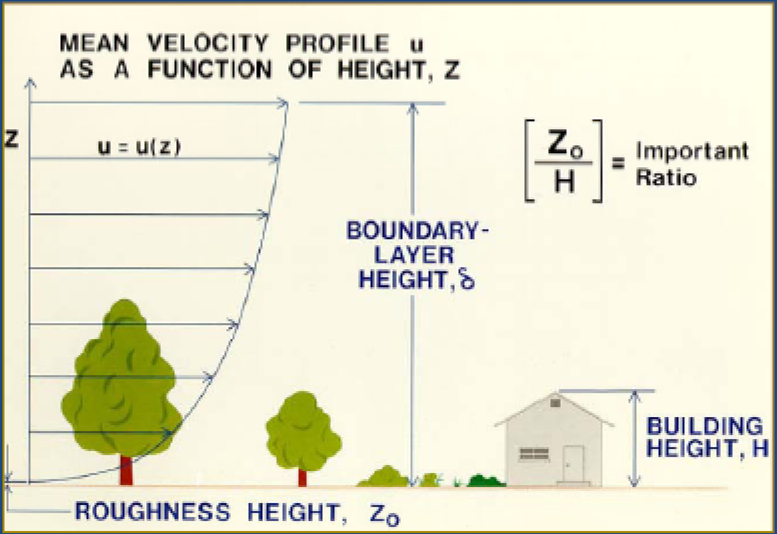
Atmospheric Boundary Layer (ABL)

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):



(Image source: http://mae.ucdavis.edu/~wind/facilities/ablwt.html)

1. The "Logarithmic Law"

$$\bar{U}(z) = \frac{u_*}{k} \log_e \left[\frac{z - z_h}{z_0}\right]$$

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" (≈ ¾ of rooftop height)

2. The "Power Law"

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

$$\alpha = \left(\frac{1}{\log_e(z_{ref}/z_0)}\right)$$

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

where:
$\bar{U}$ = mean wind speed
z = height above ground
$\bar{U}_{10}$ = mean wind speed at z = 10 m (NOTE: 10 m is standard wind measurement height)

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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

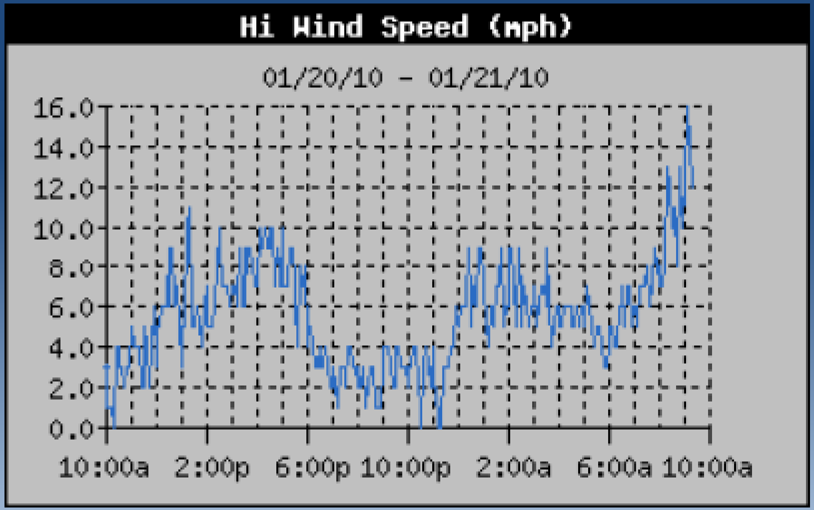

Image Source: (http://miamiweatheralert.com/history.htm)

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.

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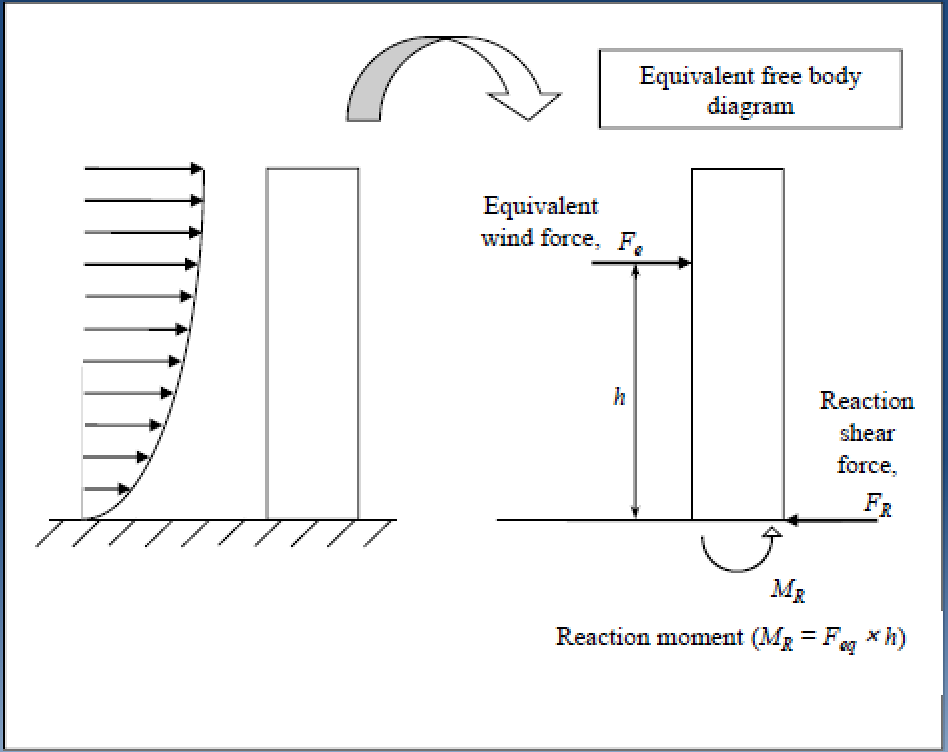
Simplified 2-D diagram of wind acting on a tall building



Wait a minute!

Wind loading is not that simple....

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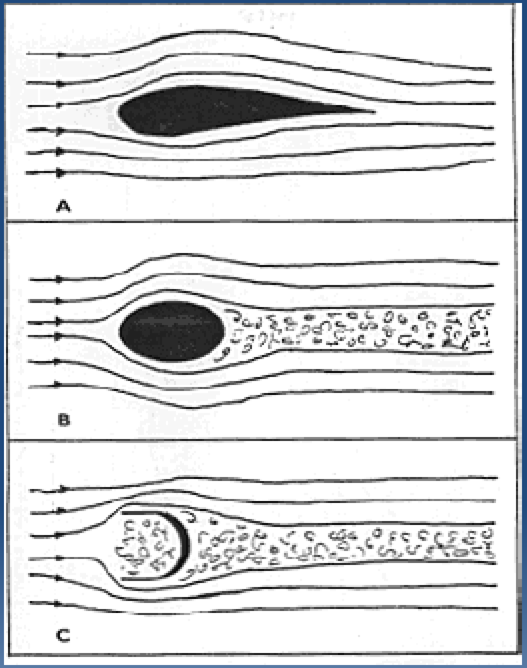
Basic Bluff Body Aerodynamics

- 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.



Aerodynamic (streamlined) object

Bluff Bodies

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

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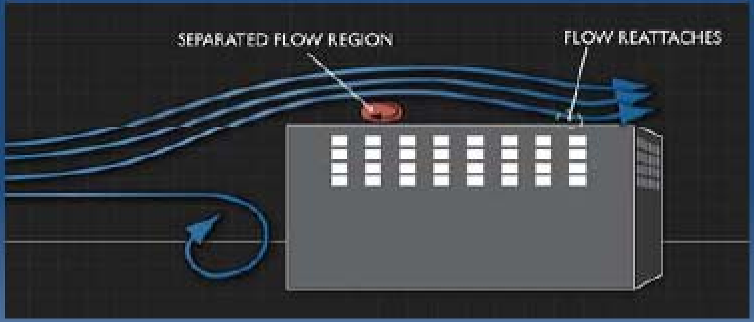
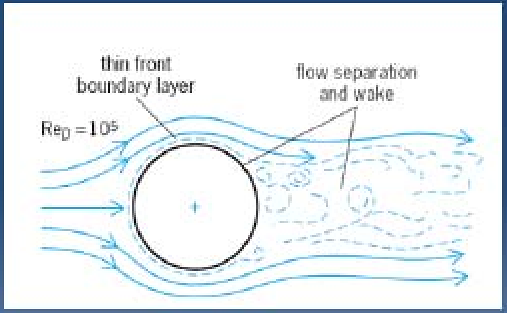
Basic Bluff Body Aerodynamics

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



(Image source:
http://www.cppwind.com/services/renewable_energy/solar/dc_paper/DCsolar_paper2.html)



(Image source:
http://accessscience.com/overflow.aspx?searchStr=Fluid+mechanics&stype=10&term=Fluid+mechanics&topic=PHYS:FLUID&p=2)

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Aerodynamics: Bernoulli's equation

- Pressure coefficient :

$$C_P = \frac{\Delta P}{\frac{1}{2}\rho V_o^{\,2}}$$

ΔP is the pressure induced by wind (above or below ambient atmospheric pressure); commonly ΔP is called P

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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)

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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)

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If there are fluctuating forces on buildings…

?

…how do we determine the wind loads?

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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

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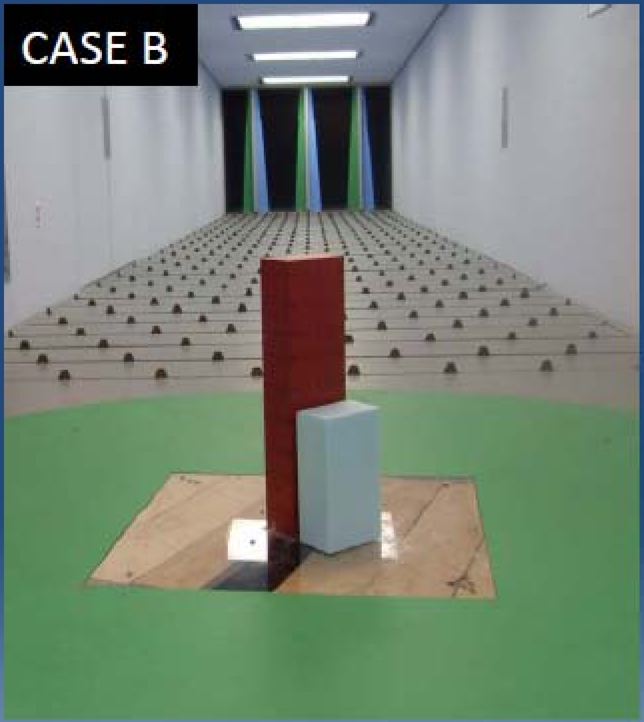
Example of small-scale BLWT models



RWDI wind tunnel models

(Dagnew and Bitsuamlak, 2010).

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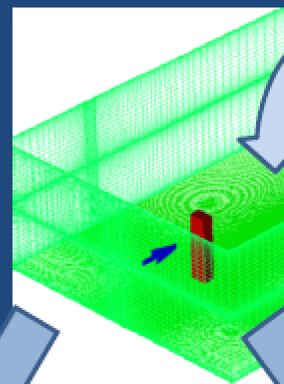
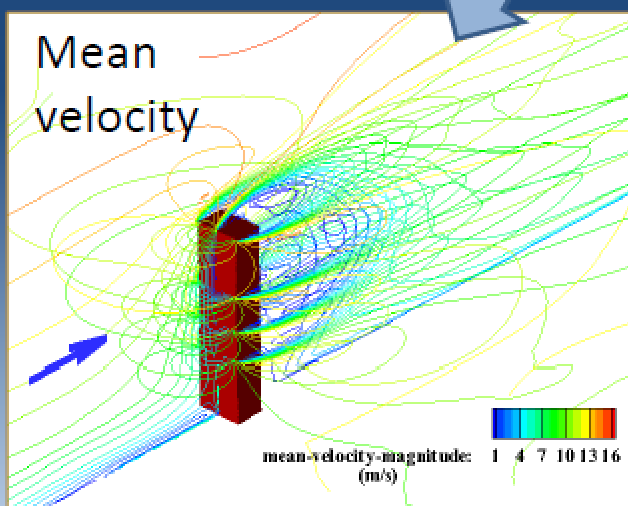
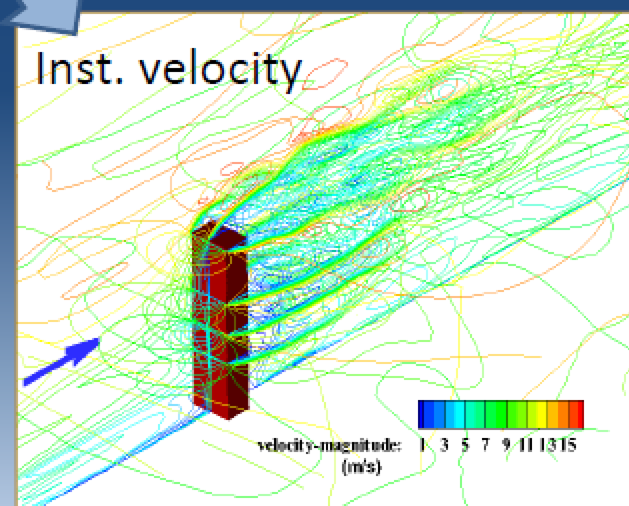
Computation Fluid Dynamics (CFD) Modeling

(Dagnew and Bitsuamlak, 2010).

CASE A







Large and Full Scale Testing

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Now we have the wind loads on the building...

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...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).

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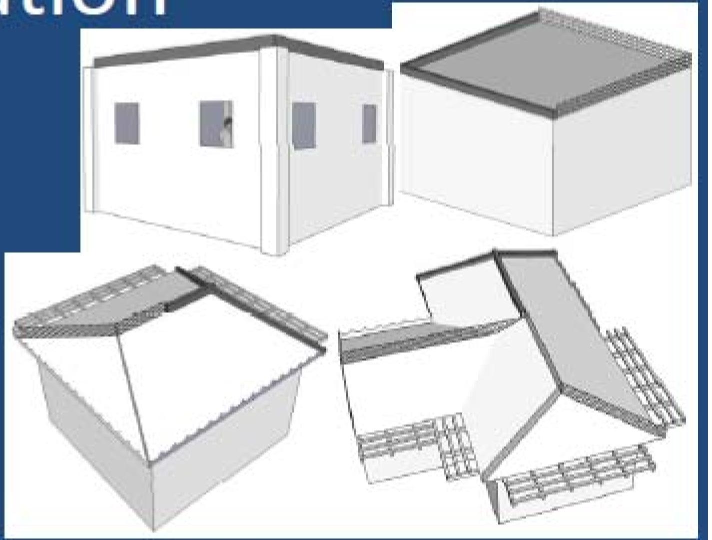
Aerodynamic/shape mitigation, optimization

- Low-rise roofs/wall corners
- High-rise buildings
- Energy infrastructure

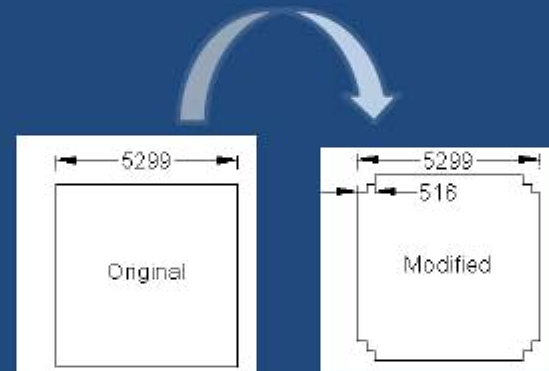
(wind farm optimization, wind load mitigation on solar panels etc.)



Real-world Tall Building Mitigation Example

Taipei 101

- Located in Taipei, Taiwan
- 101 floors
- World's tallest building from 2004 – 2010.



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

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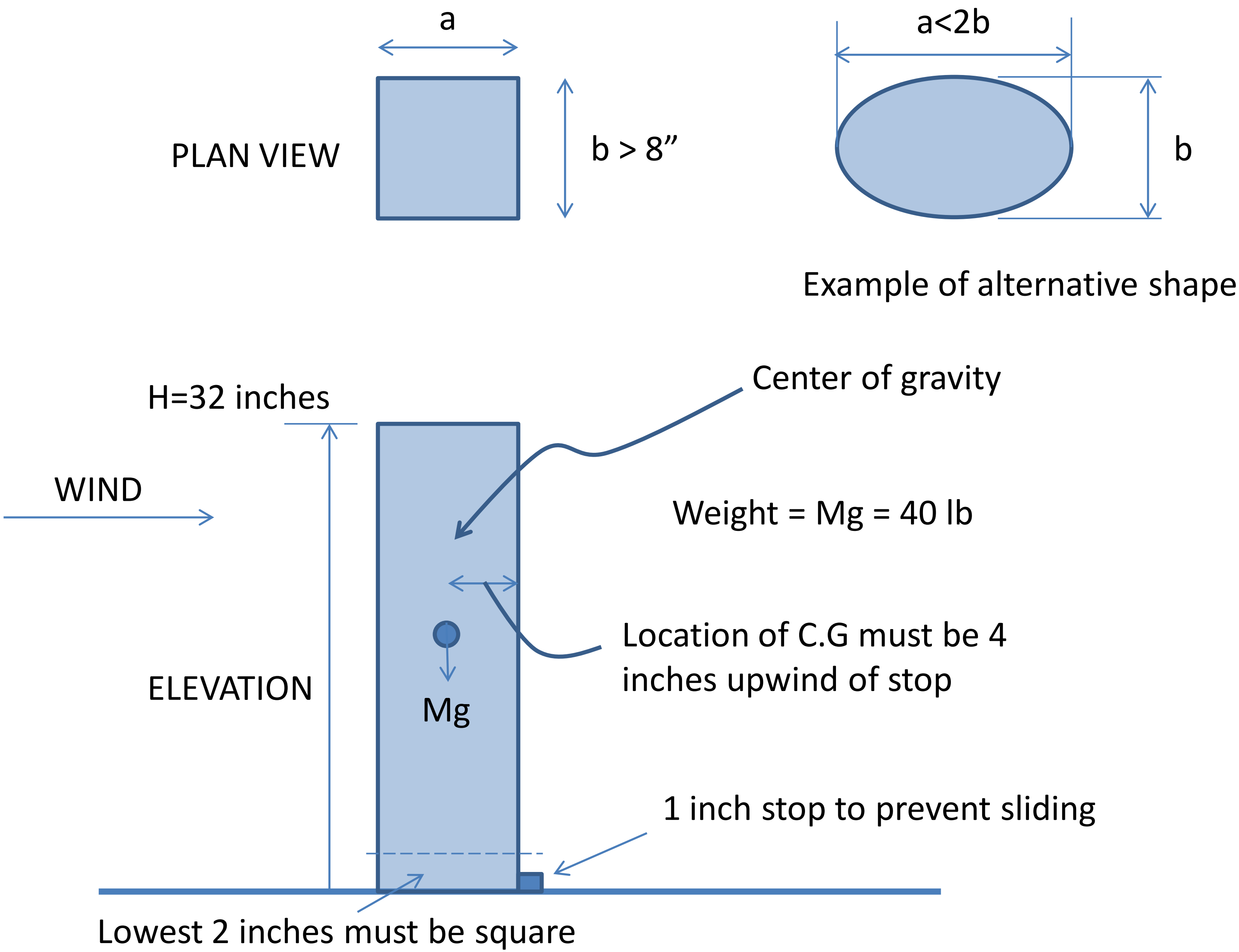
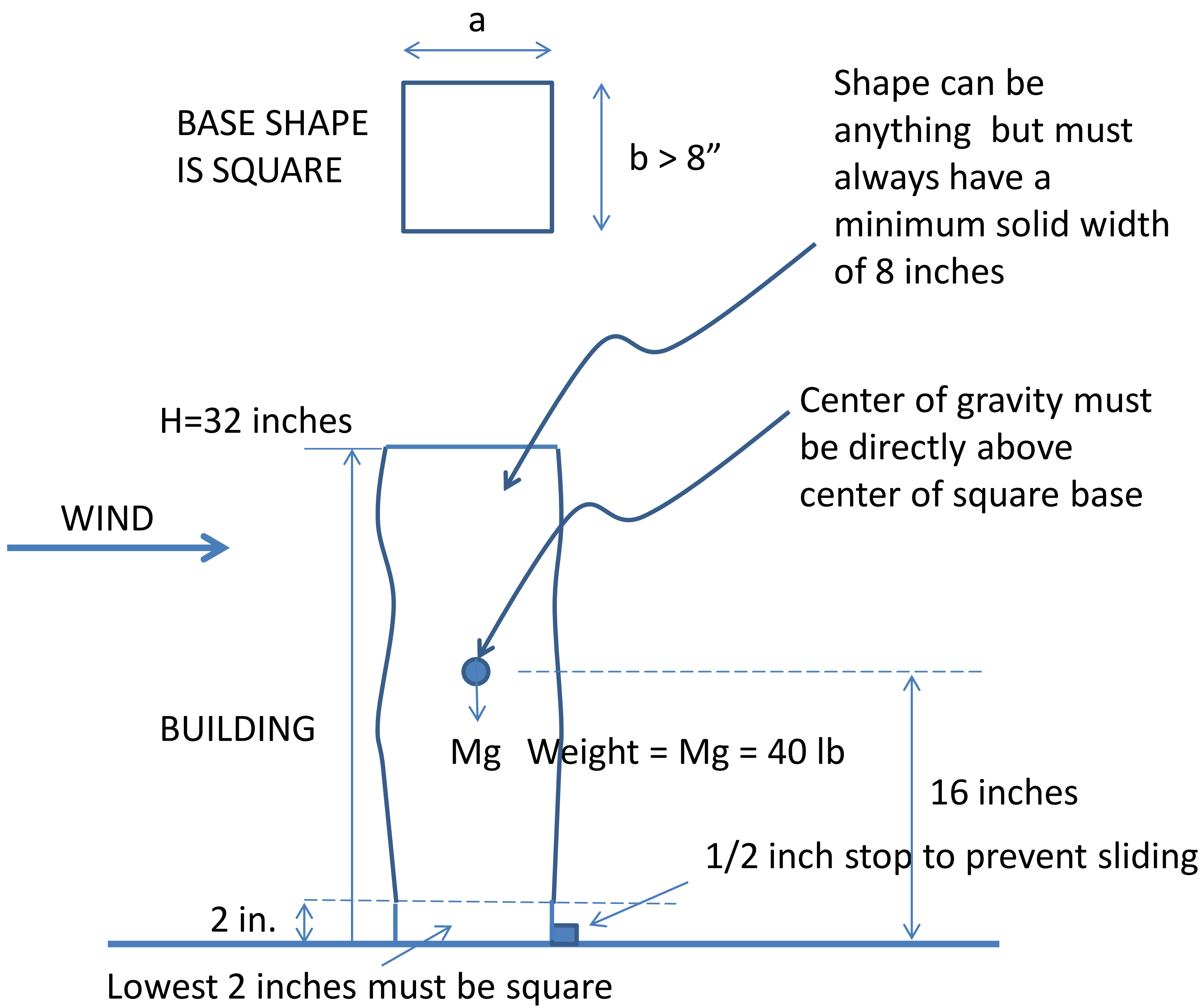


a
PLAN VIEW
b > 8”
a<2b
b
Example of alternative shape
H=32 inches
Center of gravity
WIND
Weight = Mg = 40 lb
Location of C.G must be 4 inches upwind of stop
ELEVATION
Mg
1 inch stop to prevent sliding
Lowest 2 inches must be square

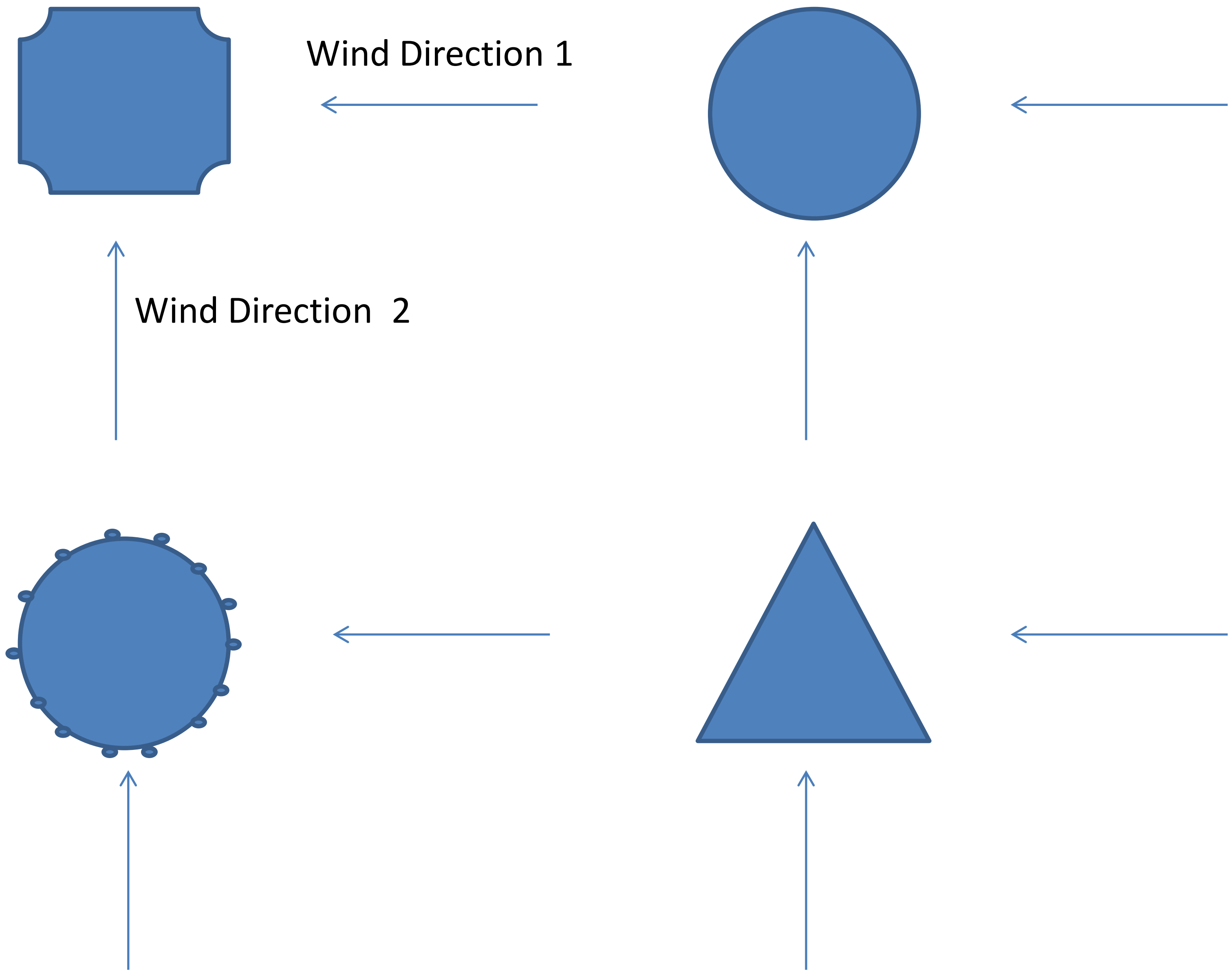
Description of the contest

1. In the experiment each team will build a model building and test it in the Wall of Wind. The model will be tested for two wind directions at 90 degrees from each other.
2. The aim is to build a model that will remain upright up to as high a wind speed as possible. The model will be prevented from sliding by a small ½ inch high stop that will be provided on the wind tunnel floor at the back and side edges of the base.
3. The model building will be 32 inches high and its lowest 2 inches must be 8 inches square.
4. Above the lowest 2 inches the building must have a minimum solid width of 8 inches but can be wider.
5. Any shape above the lowest two inches can be used as long as it is always has a solid width greater than 8 inches when viewed from any and all directions.
6. The aim is to have a shape that has least tendency to be blown over by the wind when tested for the two directions at 90 degrees to each other. In the test the wind speed in the WOW for each of the two directions will be gradually increased until the model blows over. The higher the wind speed at which this happens, the higher will that team's score be.
7. The weight of the model must no greater than 40 lb. The center of gravity must be directly above the center of the 8 inch square base (within 0.05 inches) and must be within 1 inch of the mid-height of the model building.
8. The score for each team for the blow over tests will be calculated as follows. Two blow over speeds will be recorded for each building, one for wind direction 1 and one for wind direction 2 at 90 degrees from the first direction. The score will be the lower of these two speeds plus 0.9 x the higher of the two speeds.
9. Wind speeds will be measured by FIU staff.



a
BASE SHAPE
IS SQUARE
b > 8”
Shape can be
anything but must
always have a
minimum solid width
of 8 inches
H=32 inches
WIND
Center of gravity must
be directly above
center of square base
BUILDING
Mg
Weight = Mg = 40 lb
16 inches
1/2 inch stop to prevent sliding
2 in.
Lowest 2 inches must be square

Examples of cross-section shapes



Thank you

Questions??

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