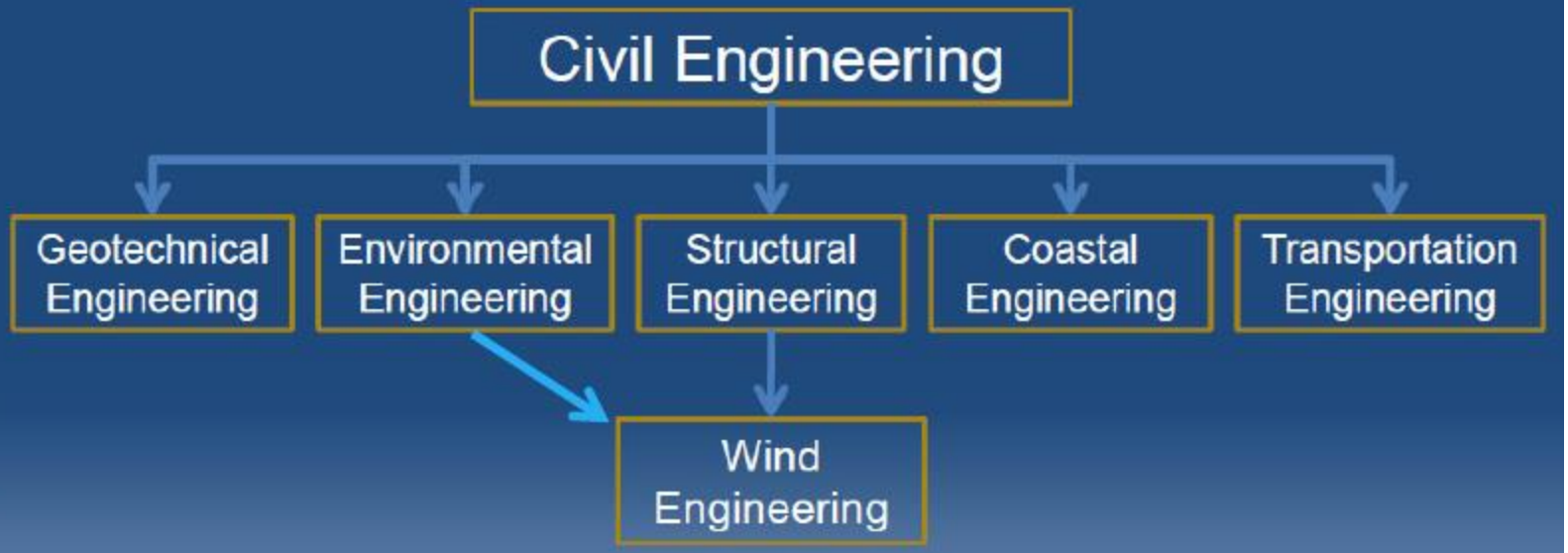
2018 Wall of Wind Challenge Informational Workshop

Presented By:
Dr. Amal Elawady
and
Erik Salna

February 23rd, 2018

Introduction

What is Wind Engineering?



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

FIU FLORIDA INTERNATIONAL UNIVERSITY

Wind can be a friend…

…or an enemy

FIU FLORIDA INTERNATIONAL UNIVERSITY

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

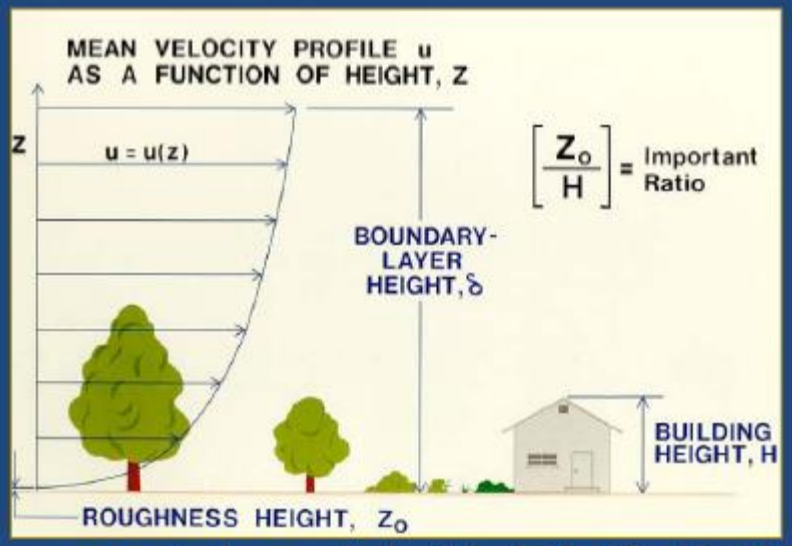
Aerodynamics is of central importance but most applications are non-aeronautical in nature

FIU FLORIDA INTERNATIONAL UNIVERSITY

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" (≈ ⅔ 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:
$\bar{U}$ = 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)

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

FIU FLORIDA INTERNATIONAL UNIVERSITY

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

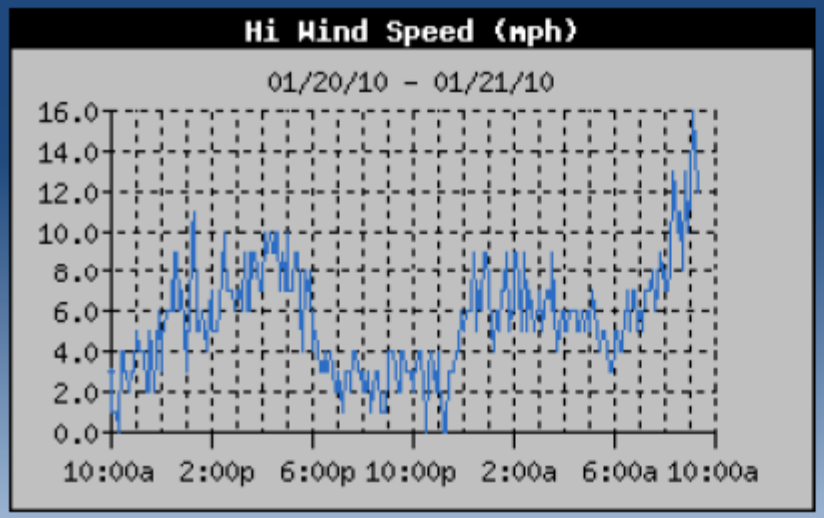


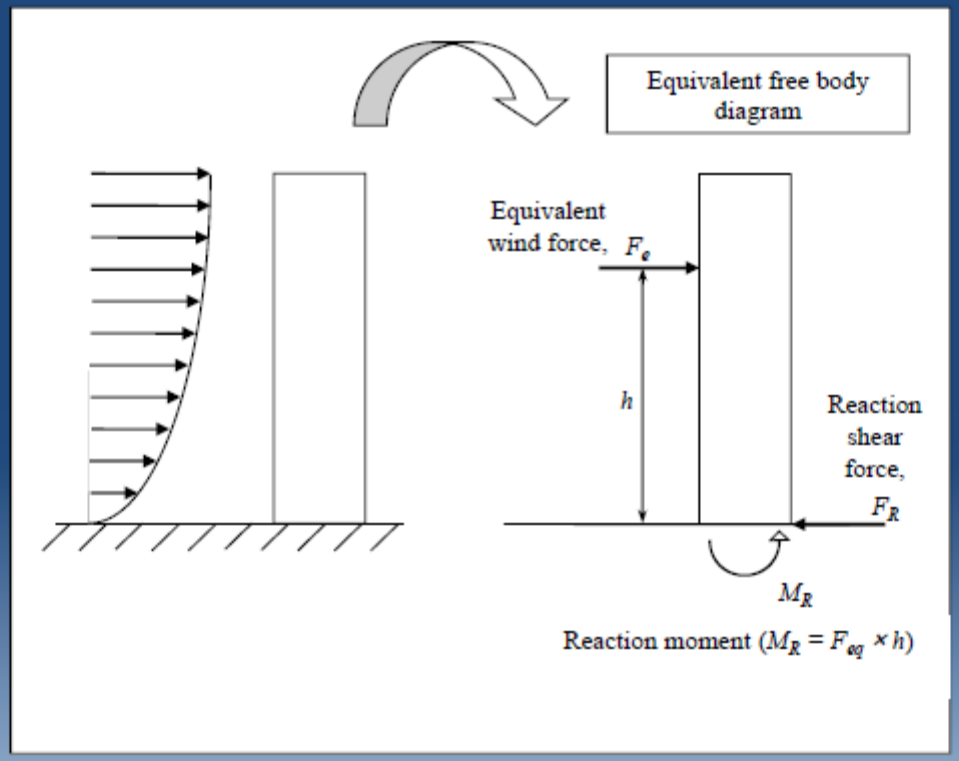
Image Source: (http://miamiweatheralert.com/history.htm)

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.

FIU FLORIDA INTERNATIONAL UNIVERSITY

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



FIU FLORIDA INTERNATIONAL UNIVERSITY

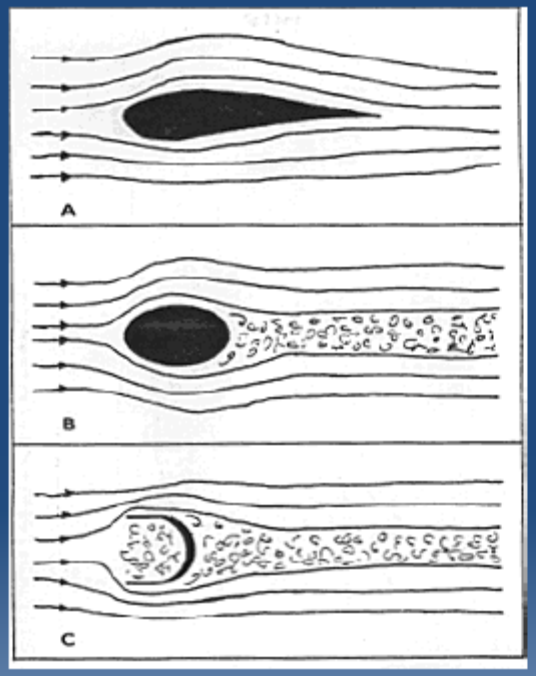
Wait a minute!

Wind loading is not that simple….

FIU FLORIDA INTERNATIONAL UNIVERSITY

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

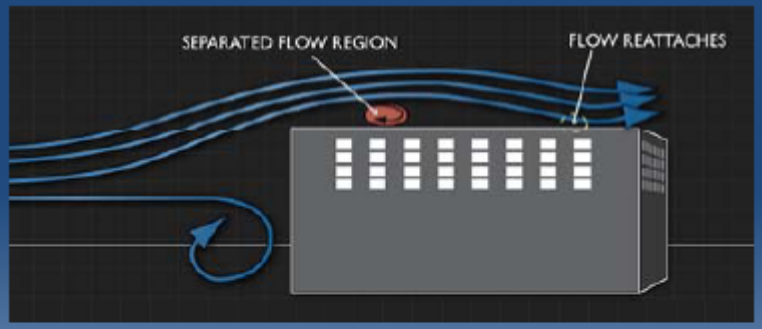
Bluff Bodies

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

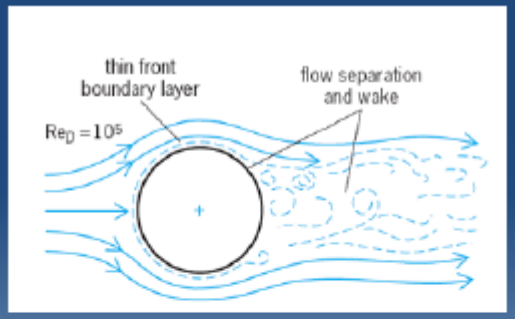
FIU FLORIDA INTERNATIONAL UNIVERSITY

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)

FIU FLORIDA INTERNATIONAL UNIVERSITY

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

FIU FLORIDA INTERNATIONAL UNIVERSITY

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)

FIU FLORIDA INTERNATIONAL UNIVERSITY

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)

FIU FLORIDA INTERNATIONAL UNIVERSITY

If there are fluctuating forces on buildings…

?

…how do we determine the wind loads?

FIU FLORIDA INTERNATIONAL UNIVERSITY

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

FIU FLORIDA INTERNATIONAL UNIVERSITY

Example of small-scale BLWT models

RWDI wind tunnel models

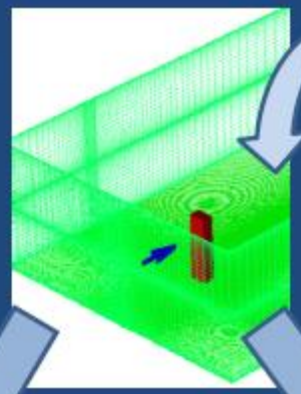
(Dagnew and Bitsuamlak, 2010).

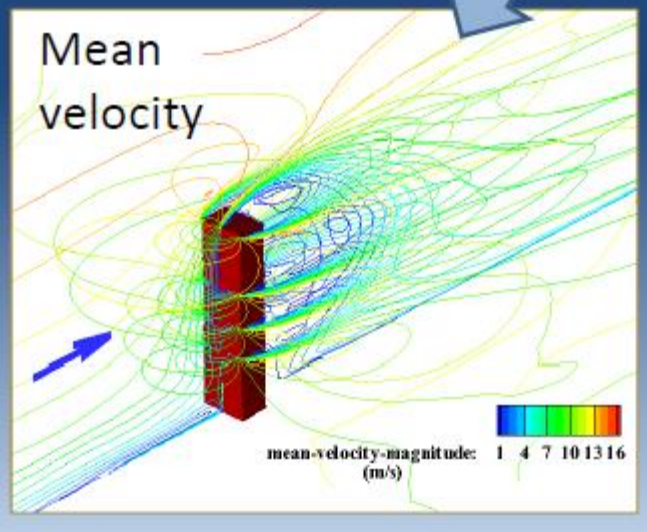
FIU FLORIDA INTERNATIONAL UNIVERSITY

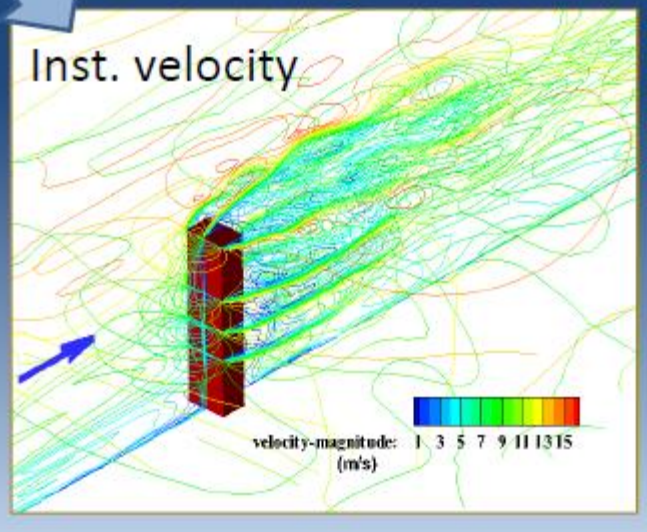
Computation Fluid Dynamics (CFD) Modeling

(Dagnew and Bitsuamlak, 2010).

CASE A







Large and Full Scale Testing

FIU FLORIDA INTERNATIONAL UNIVERSITY

Now we have the wind loads on the building…

?

…isn't that all we need to design the building?

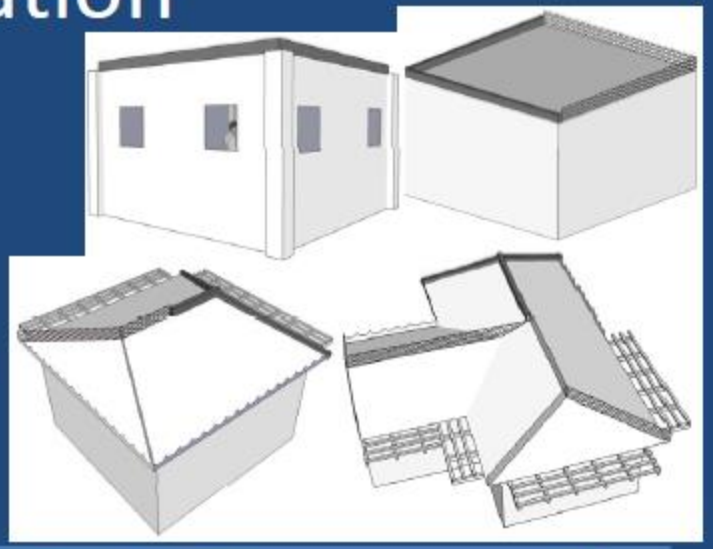
Yes, but we can still enhance the design to mitigate the wind loading (i.e. there can be economic gains by reducing the wind loads).

FIU FLORIDA INTERNATIONAL UNIVERSITY

Aerodynamic/shape mitigation, optimization

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

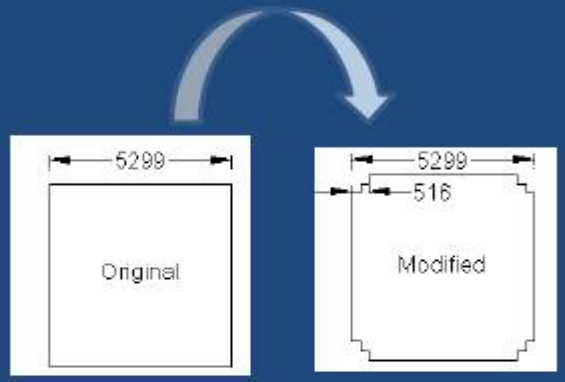
(wind farm optimization, wind load mitigation on solar panels etc.)



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)

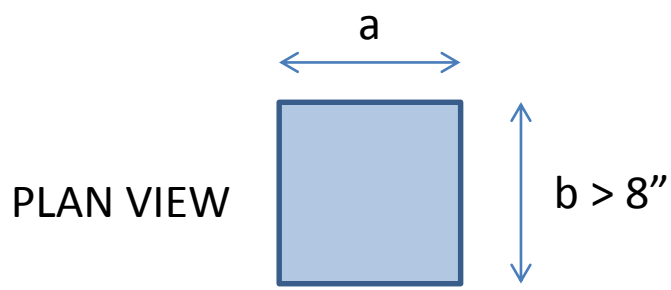
FIU FLORIDA INTERNATIONAL UNIVERSITY

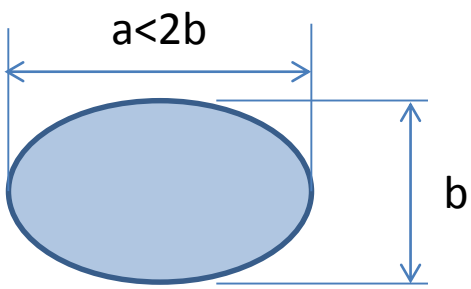
2018 Wall of Wind Challenge

- The objective for the 2018 Wall of Wind Mitigation Challenge is for students to improve a building's aerodynamic performance. Each team's task is to develop a mitigation solution that will improve aerodynamic performance through shape optimization by minimizing aerodynamic drag. By optimizing the overall shape of a building model, the mitigation solution will reduce the reaction forces and moments and reduce the wind-induced force on the building's models foundation.
- The goal is for a building model to remain upright to as high a wind speed as possible. Building models will be tested by the FIU Wall of Wind on the day of the live competition on May 23rd. The models will be tested for two wind directions at 90 degrees from each other to evaluate the effectiveness of the solution. The model will be prevented from sliding by a small ½ inch high stop at the back and side edges of the base.
- Each Team will be supplied with a gold colored wooden base (8x8x2 inches) for their building model.
- 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.
- Judges will also evaluate the building models on aerodynamic performance, aesthetics, practicality, marketability and feasibility, and how innovative.

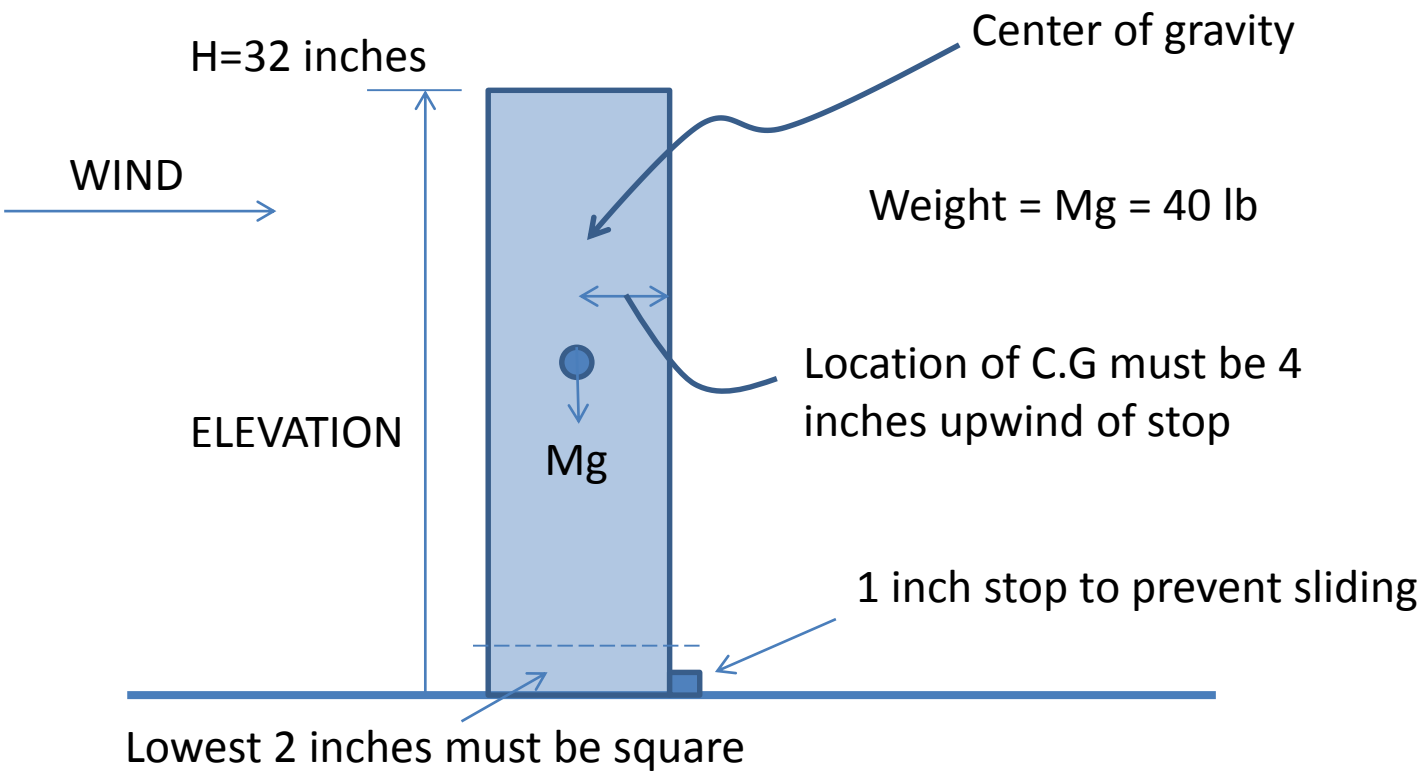
2018 Wall of Wind Challenge

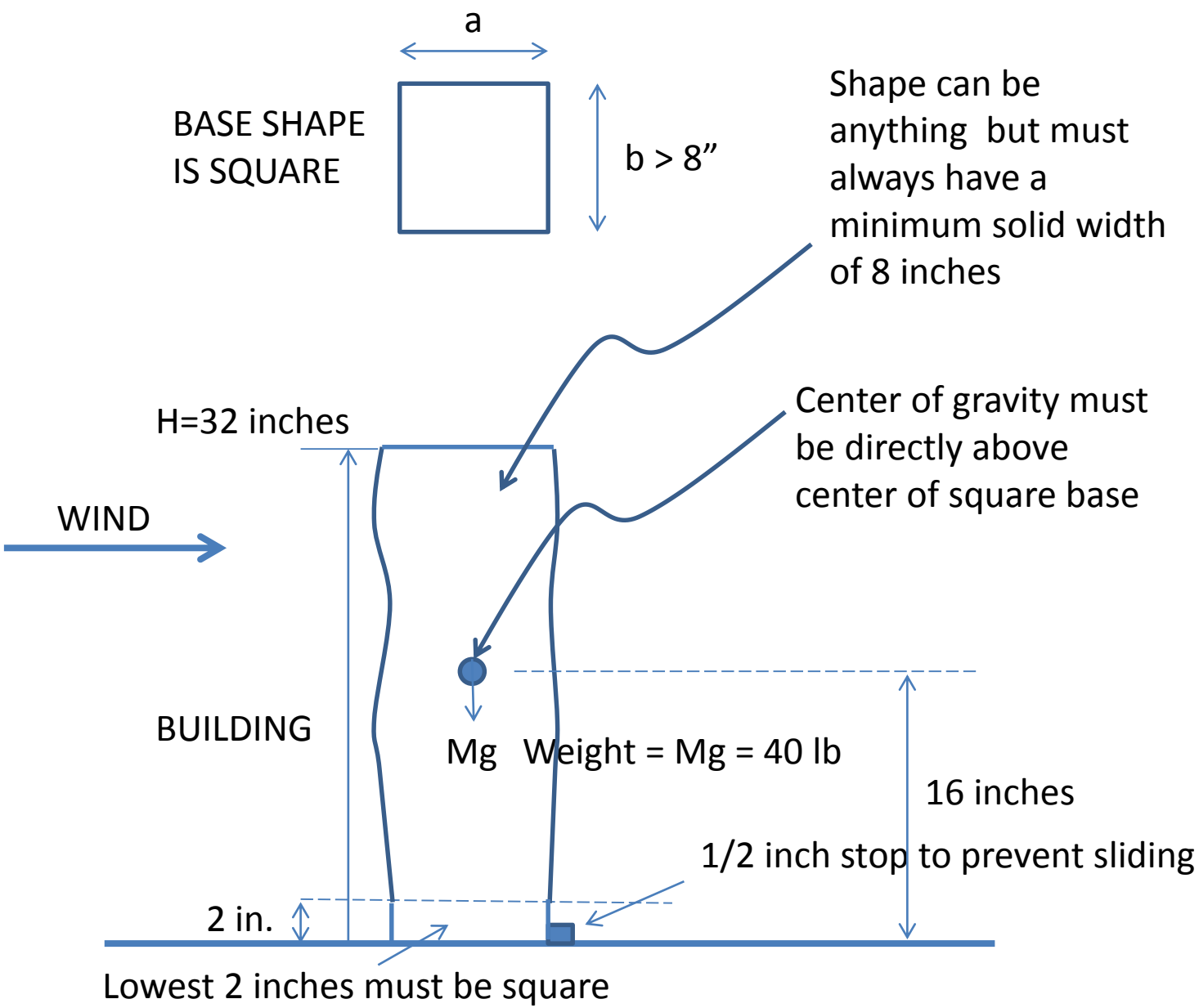
- The model building will be 32 inches high and its lowest 2 inches will be a gold wooden base, 8 inches square.
- Above the lowest 2 inches of the gold base, the building model must have a minimum solid width of 8 inches but can be wider.
- Any shape above the lowest two inches can be used as long as it is always has a solid width greater than 8 inches when viewed from any and all directions.
- The goal is to have a shape that has the least tendency to be blown over by the wind when tested for the two directions at 90 degrees to each other. The wind speed 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 the team's score.
- 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.



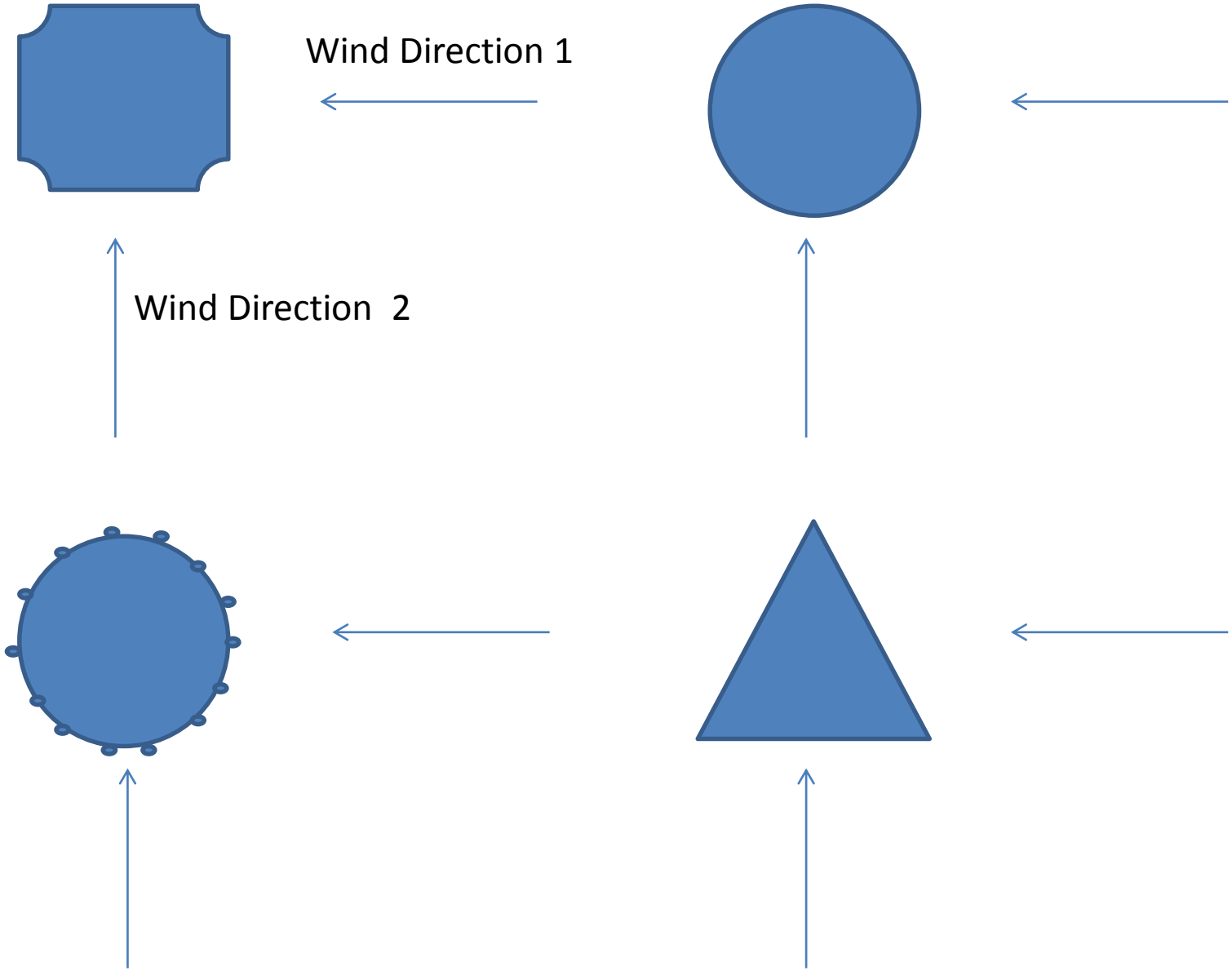


Example of alternative shape




a
BASE SHAPE
IS SQUARE
b > 8”
Shape can be anything but must always have a minimum solid width of 8 inches
Center of gravity must be directly above center of square base
H=32 inches
WIND
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



2018 Wall of Wind Challenge

- The technical details will be described in the 2018 Physical Guidelines document and will be available on the WOW Challenge web page.
- Each student team with be provided with $50 for buying materials and supplies. Students are permitted to spend more than the provided $50, but these additional costs shall be the responsibility of the student team..
- Each high school will be allowed to enter <u>one</u> team; it is up to each teacher from each school to determine how many students will participate as a Team for this competition; **<u>however, on the day of the *Challenge* competition, only 4 students from the Team will be allowed to compete</u>; <u>less than 4 can compete, but not more</u>;** all other teammates, teachers and family will be welcomed to attend the *Challenge* and watch the competition.
- Students will prepare three components for the competition: a physical test and an oral presentation on May 23rd, and a written technical paper ***due before the day of the competition.***
- The top 3 winning teams will be determined by a cumulative weighted score: physical (50%), oral (25%), paper (25%).

2018 Wall of Wind Challenge

- Oral presentations should effectively communicate some scientific process and analysis involved with the development of the hurricane wind mitigation solution for their building model; oral presentations should also consider the values and benefits of their mitigation solution, similar to a new business presentation to potential investors. . **The oral presentation details will be described in the 2018 Oral Guidelines document and found on the *WOW Challenge* web page.**
- Written technical papers should include any scientific or mathematical analysis involved with the development of their hurricane wind mitigation solution for their building model and describe how hurricane wind mitigation is being addressed with their solution. **The written technical paper details will be described in the 2018 Technical Paper Guidelines document and found on the *WOW Challenge* web page.**
- Bus transportation will be provided to teams as needed.

2018 Wall of Wind Challenge

Wednesday, May 23rd

8:00am - 9:00am:

High School Teams Arrive, Drop Off Building Models at the Wall of Wind and Check-in on 2nd floor, in Panther Pit.

9:00am – 9:30am: Opening Ceremony Remarks on 2nd floor, in Panther Pit

9:30am – 11:30am:

Judging for Physical Tests at Wall of Wind

10:00am – 12:00pm:

Judging for Oral Presentations in Room 2300

11:30am – 12:30pm: Lunch

12:45pm – 1:15pm: Awards Ceremony on 2nd floor in Panther Pit

1:15pm: WOW Challenge Ends

Thank you

Questions??

FIU FLORIDA INTERNATIONAL UNIVERSITY