Typhoon Haiyan

1. Force of wind blowing against vertical structure

2. Destructive Pressure exerted on Buildings

3. Atmospheric Pressure variation driving the Typhoon’s winds

4. Energy of Typhoon

5. Height of Storm Surge
1. Force of wind blowing against vertical structure

Wind blowing against a wall or a tree evidently exerts a force.

How large a force?

Can we calculate it?

For $v = 80 \text{ m/s}$

The mean density of Air at sea level is $1.225 \text{ kg/m}^3$
I’m sure someone will point out that $F = \Delta p/\Delta t$

In my calculation I’m finding the momentum supplied by the air every second. So $\Delta t = 1$

Here is the same argument made in words, with a diagram.

- At 2 m/s an air molecule can travel 2 m before hitting the wall.
- All of the molecules between it and the wall also hit in the same time interval. Thus 2 m$^3$ of air hits each square meter of the wall every 2 sec
- At 3 m/s by the same logic, 3m$^3$ of air hits the wall per second.
- So…. At v m/s, v m$^3$ of air hits the wall per second!
2. Destructive Pressure exerted on Buildings

Many houses and buildings had their roofs torn off leaving the walls standing.

Evidently just the wind blowing over the top of a house in a built-up neighborhood can take it off. Even if the structure is otherwise sheltered from the wind.

Using Bernoulli’s principle we can estimate the pressure difference between the inside of a house, and the outside when a 90 m/s wind blows across the roof.

Will the roof be able to hang on?
Lind blowing over a roof

\[ P_{\text{out}} \begin{array}{c} \uparrow \\\\\\ \uparrow F \\ V_{w} = 90 \text{ m/s} \end{array} \]

Pressure = \( \frac{F}{A} \)

\[ \therefore F = P \times A \]

Force lifting roof

\[ F = \Delta PA \]

Force holding roof on

weight of roof = \( mg \)

Bernoulli's Principle

\[ P_{\text{out}} + \frac{1}{2} eV_{\text{out}}^2 + egh = P_{\text{in}} + \frac{1}{2} eV_{\text{in}}^2 + egh \]

\[ \Delta P = P_{\text{out}} - P_{\text{in}} = \frac{1}{2} eV_{\text{wind}}^2 \]

Pressure Difference \( \Delta P = 4961 \text{ Pa} \)

for this roof \( F = A \Delta P = 8 \times 5 \times \Delta P \)

\[ F = 40 \times 4961 \]

\[ F = 20,000 \text{ N} \]

HURRICANE STRAPS

Fix the roof to the walls and foundation, so the whole weight of the house can oppose the pressure force.
3. Atmospheric Pressure variation driving the Typhoon’s winds

Near the “eye” of the storm the winds blow fastest, circling a region of unusually low air pressure.

Outside the Typhoon, in the free atmosphere the air pressure remains normal.

Using Bernoulli’s Principle we can estimate the pressure drop driving the reported wind speeds of 40-90 m/s
Central pressure in a typhoon

\[ P_A = 101 \text{ kPa} \]

\[ V = 90 \text{ m/s} \]

\[ P_T + \frac{1}{2} eV^2 + egk = P_A + \frac{1}{2} eV_A^2 + egk \]

\[ P_T = P_A - \left( \frac{1}{2} eV_T^2 \right) \]

\[ = P_A - \left( \frac{1}{2} \times 1.225 \times 90^2 \right) \]

\[ P_T = P_A + \Delta P \]

\[ \Delta P = 4961 \text{ Pa} \]

\[ \therefore P_T = 101 \times 10^3 - 496 \times 10^3 \]

\[ = 96.38 \text{ kPa} \]

\[ \frac{\Delta P}{P} = \frac{4.96}{101} \approx 5\% \]

The National Weather Service with their equipment and supercomputers estimated

\[ P_T \approx 90 \text{ kPa} \]

\[ \frac{\Delta P}{P} \approx 9-10\% \]
4. Energy of Typhoon

Highest sustained winds 80 m/s
Say the average wind speed was 40 m/s
Radius of the inner most destructive part of the Typhoon ~ 300 km
We can model the typhoon as a rotating cylinder of air
Hence find the total kinetic energy

Destructive events are often compared in terms of equivalent explosive energy or “nuclear bomb” units. 1 ton of high explosive releases $4.2 \times 10^9$ Joules Nukes pack 100,000 to 1 million times this energy

What was the Equivalent Energy of Typhoon Haiyan?
You can think for yourself about the assumptions going into this model. How reasonable do you think they are? How reliable is the result?
5. Height of Storm Surge

- We already found that the atmospheric pressure inside a typhoon is lower than normal.

- With less pressure of air pushing down on the ocean, the surface will rise up.

- How high?
Storm Surge

\[ \Delta P = 10\% \text{ of } P_{\text{atmospheric}} \]

\[ P_{\text{atmospheric}} = 101 \text{ kPa} \quad (\text{US}) \]

\[ \Delta P \text{ calculated} \approx 5000 \text{ Pa} \\
25 \text{ kPa} \]

\[ P = \rho g h \]

\[ \Delta P = \rho g \Delta h \]

\[ \Delta h = \frac{\Delta P}{\rho g} \]

\[ = \frac{5000}{1000 \times 9.8} \]

\[ = \frac{5000}{9800} \approx 0.5 \text{ m} \approx 0.5 \text{ meters sea level rise.} \]

For \( \frac{\Delta P}{P} \approx 10\% \) we would get 1m of surge.
Fluids in Motion: Units of Chapter 10

• Flow Rate and the Equation of Continuity
• Bernoulli’s Equation
• Applications of Bernoulli’s Principle
• Airplanes, Baseballs
• Torricelli’s Theorem
• Viscosity
• Flow in Tubes: Poiseuille’s Equation, Blood Flow
• Surface Tension and Capillarity
• Pumps, and the Heart
10-10 Applications of Bernoulli’s Principle: from Torricelli to Airplanes, Baseballs, and TIA

Lift on an airplane wing can be ascribed to the different air speeds and pressures on the two surfaces of the wing.

![Diagram showing air pressure difference on airplane wing](image-url)
Boeing 777

Lift Force

Weight

Air pressure on upper wing surface

Air pressure on lower wing surface

Mass = 220,000 kg
Wing Area = 427 m²
Speed = 905 km/h

Range = 17,370 km
Altitude = 12 km
5.6 million flights
By drawing a free body diagram and identifying the vertical forces (weight, and the force exerted by air pressure above & below the wing) we discover that a large air pressure difference is required to support the plane during level flight.

Notice the relationship between weight and wing area.

This Newtonian analysis leaves the question “what causes this pressure difference?” unanswered.

**Bernoulli’s principle** provides the solution. Faster moving air above the wing creates a region of lower pressure.

This difference in air pressure acts on the wing to create a net upward force, equal to the weight.

Finally we calculate how much faster the air above the wing must be moving.

In practice this is accomplished by making the upper surface of the wing curved, forcing the air to travel further, and hence faster.
Chimneys and Burrows

- Air flow across the top helps smoke go up a chimney.
- Many chimneys have caps like this to force the airflow to be horizontal over the opening.
- The fast moving air creates a low pressure region that draws smoke up and out.

Air flow over multiple openings can provide the needed circulation in underground burrows.
Venturi’s Effect. Wind velocity and pressure: A special case of the foregoing

A venturi meter can be used to measure fluid flow by measuring pressure differences.
A ball’s path will curve due to its spin, which results in the air speeds on the two sides of the ball not being equal.

Which way does this ball curve?
1. Towards A
2. Towards B
3. Up
4. Down
Viscosity

Real fluids have some internal friction, called viscosity.

Molasses is an example of a highly viscous fluid.

The viscosity can be measured; it is found from the relation

\[ F = \eta A \frac{v}{l} \]  

(10-8)

where \( \eta \) is the coefficient of viscosity.
Flow in Tubes; **Poiseuille’s Equation**, 

The rate of flow in a fluid in a round tube depends on the viscosity of the fluid, the pressure difference, and the dimensions of the tube.

\[ Q = \frac{\pi R^4 \Delta P}{8\eta L} \]

The volume flow rate is proportional to the pressure difference, inversely proportional to the length of the tube, and proportional to the fourth power of the radius of the tube.
Flow in Tubes; Poiseuille’s Equation, Blood Flow

This has consequences for blood flow – if the radius of the artery is half what it should be, the pressure has to increase by a factor of 16 to keep the same flow rate.

Usually the heart cannot work that hard, but blood pressure goes up as it tries.
Surface Tension and Capillarity

The surface of a liquid at rest is not perfectly flat; it curves either up or down at the walls of the container. This is the result of surface tension, which makes the surface behave somewhat elastically.
Surface Tension and Capillarity

Soap and detergents lower the surface tension of water. This allows the water to penetrate materials more easily.

Water molecules are more strongly attracted to glass than they are to each other; just the opposite is true for mercury.

Remember the word Surfactant?
• If the molecules of a liquid attract both each other, and the walls of the container (a consequence of electrostatics and polarity – see next semester) this attractive force pulls the surface of the fluid up the side of the container, until the weight of column of liquid exceeds the available force.

• If the tube is narrow, there is more surface area in contact, and hence the force per unit volume is greater.

• If the tube is wider, there is less surface area per unit volume, and the fluid does not rise as far.

• On the other hand if the fluid molecules are repelled by the wall of the container, then the force will push the fluid surface down!
Capillary Action and Biology

- Surface tension can draw liquid up a narrow tube.
- The thinner the tube, the higher the fluid will travel.
- There is a limit, and even tubes the diameter of a Xylem cell (around 500 µm) can lift water only a few cm.
- Plants and trees need to create a large negative pressure in their fluid carrying tubes (several atmospheres worth since roughly 1 ATM of pressure is needed per 10 meters of height.
- Evaporation of water molecules from pores in the leaves “drags” additional water molecules up the tube.
- Osmotic pressure from the roots can help or hinder depending on the circumstances.
Capillary Action and Uptake of Fluids by Porous Materials

• Porous materials such as paper, cloth, brick, wood etc. tend to soak up water
• These materials are filled with microscopic tubes (such as fibers or xylem tubes), cracks, and pores.
• Being so narrow these structures pull water and other fluids via capillary action.
• Capillary action can be used to sort dissolved molecules by mass or density, as in Chromatography.
10-14 Pumps, and the Heart

This is a simple *reciprocating* pump. If it is to be used as a *vacuum* pump, the vessel is connected to the *intake*; if it is to be used as a *pressure* pump, the vessel is connected to the *outlet*.

Think Bicycle pump!
Pumps!

(a) is a centrifugal pump; (b) a rotary oil-seal pump; (c) a diffusion pump
The heart of a human, or any other animal, also operates as a pump.
Summary

Main Concepts

• The Equation of Continuity
• Bernoulli’s Principle
• Torricelli’s Theorem
• Viscosity
• Pouiseuille’s Equation

Applications

Plumbing, Aircraft, Baseball, Blood flow, Weather