L 15 Fluids [4]

- Fluid flow and Bernoulli’s principle
- Airplanes and curveballs
- Viscosity
- Surface tension

Basic principles of fluid dynamics

Volume flow rate: \( Q_v = v \times A \) (m³/s)

I. Continuity principle:

\[ v_1 A_1 = v_2 A_2 \]

II. Bernoulli’s principle:

- Fast flow → low pressure
- Slow flow → high pressure

Blowing air over the top of the tube lowers the air pressure on that side allowing the fluid to rise.

Bernoulli’s principle

Loosing your roof in a tornado

Wind tunnel visualization of air flow
Streamlines and fluid flow

- The black lines are the paths that the fluid takes as it flows.
- Wider spacing indicates low speed flow, narrow spacing indicates high speed flow.
- Color indicates pressure:
  - High pressure
  - Low pressure

Bernoulli’s Principle

- Fluid flow velocity = \( v \)
- Fluid pressure = \( P \)

\( \rightarrow \) where \( v \) is high, \( P \) is low
\( \rightarrow \) where \( v \) is low, \( P \) is high

Streamlines around a wing

From the perspective of the jet, the air is moving past it

- Induced drag
- Aerodynamic force
- Angle of attack
- Lift
- high speed \( \rightarrow \) low pressure
- low speed \( \rightarrow \) high pressure

Flow over an airplane wing

- Faster air, lower pressure
- Slower air, higher pressure
- Lift force

Control surfaces on a plane

- By extending the slats, the wing area can be increased to generate more lift at low speeds for takeoff and landing.

A baseball that is not spinning

- The ball is moving but from the ball’s perspective the air moves relative to the ball.
- The streamlines are bunched at the top and bottom indicating higher flow speed.
- The pressure forces are balanced.
A Spinning baseball

- The clockwise rotation of the ball causes the air to flow faster over the top.
- The streamlines are closer together on the top → high speed flow.
- By Bernoulli's principle, the air pressure is then lower on the top than on the bottom.
- The ball experiences a sidewise force.

Viscosity

- So far we have considered only “ideal” liquids → liquids that can flow without any resistance to the flow.
- “Real” liquids (like ketchup) have a property called viscosity which is a tendency for the liquid to resist flowing.

Viscosities of various substances

- Water has a viscosity of about 1 unit.
- Pancake syrup has a viscosity of 2500.
- Ketchup has a viscosity of 98,000.
- Lava: 100,000.
- Peanut butter has a viscosity of 250,000.
- Glass is a liquid with a very high viscosity of $10^{17}$ → it does flow, but very slowly!
- Viscosity depends on temperature → warm syrup flows faster than cold syrup.

Engine oil

- SAE – Society of American Engineers.
- The viscosity of oil tends to decrease as it heats up (oil breakdown).
- What does 10W-30 mean?

Viscosity index:

- Cold engine
- Hot engine

A higher viscosity index indicates the viscosity changes less with temperature than a lower viscosity index.

Seeing the effects of viscosity

- For example – pancake syrup flows more slowly than water – we say that pancake syrup is more “viscous” than water.
- Ketchup and molasses are also good examples.
- Viscosity is sometimes referred to as the “thickness” of a liquid.
- Viscosity is the most important property of motor oil.

Pancake syrup

Substances with higher viscosity take longer to flow down the ramp.

Viscosity is a measure of the resistance that one layer of liquid experiences when flowing over another layer.
Pitch drop experiment at the University of Queensland in Brisbane, Australia

- Pitch - used as a roofing material to prevent leaks
- Must be heated to be applied
- Viscosity ~ $10^{11}$ water
- Experiment began in 1927
- 8 drops have since fallen, one every decade or so

Flow through a pipe

Viscosity slows the flow of a fluid through a pipe

Poiseuille's Law

$$Q = \frac{k (P_2 - P_1) D^4}{L \eta}$$

- $\eta$ (eta) is the viscosity of the fluid, $k$ is a constant

- A 10% reduction in diameter reduces the flow by 34%
- If $D \rightarrow D/2$, the flow is reduced by 94%

Surface tension

An attractive force between molecules at the surface of a liquid.

The surface tension force allows light objects to be suspended on a water surface

This effect is NOT due to the buoyant force

Measuring viscosity

A pipe clogged with calcium deposits

Clogged arteries

If a segment of the soap film is punctured, surface tension pulls the strings apart