Fluid Mechanics

- Fluid Mechanics: the study of forces that develop when an object moves through a fluid medium.
- Two fluids of interest
  - Water
  - Air

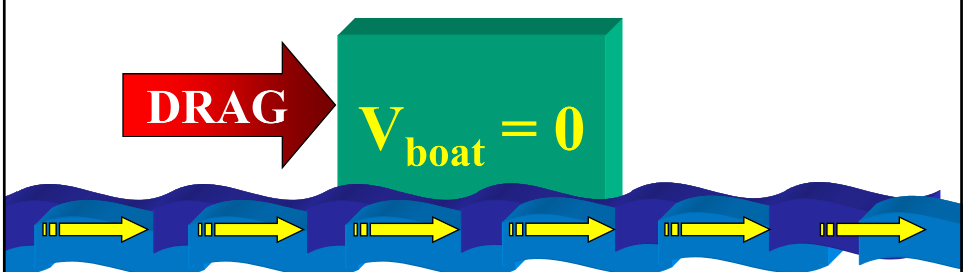
Fluid forces

- In some cases, fluid forces have little effect on an object's motion (e.g., shotput)
- In other cases, fluid forces are significant
  - badminton, baseball, swimming, cycling, etc.
- Three major fluid forces of interest:
  - Buoyancy
  - Drag
  - Lift

Drag and Lift

- The drag force acts in a direction that is **opposite** of the relative flow velocity.
  - Affected by **cross-section area** (form drag)
  - Affected by surface **smoothness** (surface drag)
- The lift force acts in a direction that is **perpendicular** to the relative flow.
  - The lift force is not necessarily vertical.

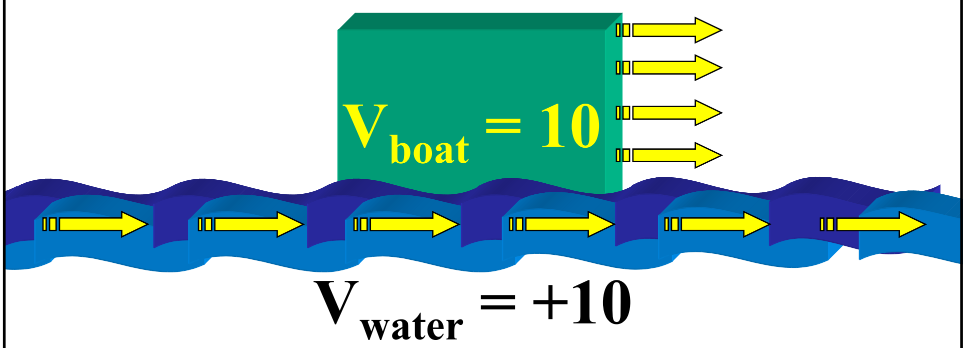
Relative Velocity: I



$$V_{water} = +10$$

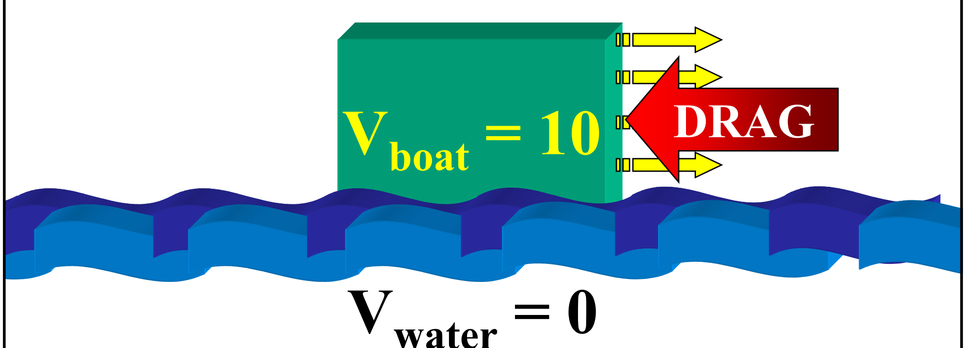
$$V_{boat} - V_{water} = 0 - 10 = -10$$

Relative Velocity: II



$$V_{boat} - V_{water} = 10 - 10 = 0$$

Relative Velocity: III



$$V_{boat} - V_{water} = 10 - 0 = 10$$

Drag

- Resistive force acting on a body moving through a fluid (air or water). Two types:
  - Surface drag: depends mainly on smoothness of surface of the object moving through the fluid.
    - shaving the body in swimming; wearing racing suits in skiing and speedskating.
  - Form drag: depends mainly on the cross-sectional area of the body presented to the fluid
    - bicyclist in upright v. crouched position
    - swimmer: related to buoyancy and how high the body sits in the water.
  - When would you want to *increase* drag?

What does drag look like?

$$F_D = C_D \rho A \frac{v^2}{2}$$

Lift

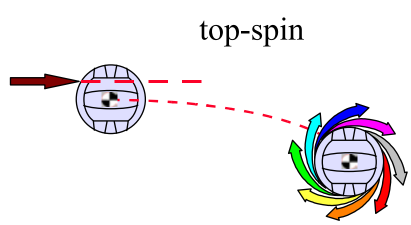
- Represents a net force that acts perpendicular to the direction of the relative motion of the fluid;
- Created by different pressures on opposite sides of an object due to fluid flow past the object
  - example: Airplane wing (hydrofoil)
- Bernoulli’s principle: velocity is inversely proportional to pressure.
  - Fast relative velocity ➡ lower pressure
  - Slow relative velocity ➡ higher pressure

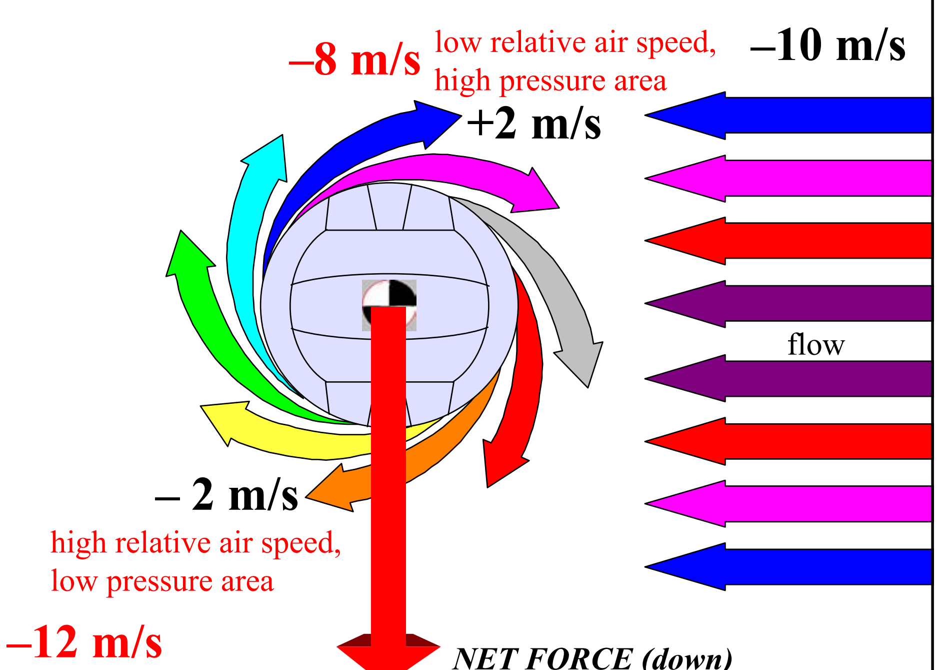
What does lift look like?

$$F_L = C_L \rho A \frac{v^2}{2}$$

Examples

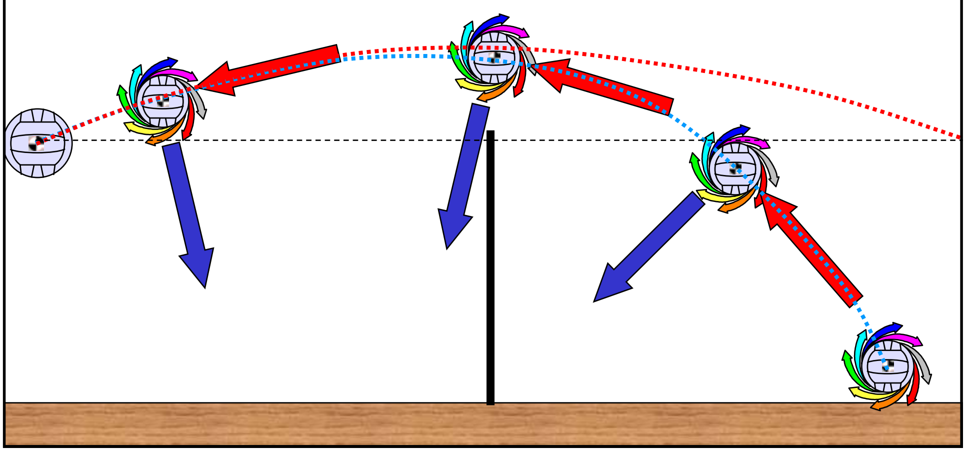
- Baseball: curveball, slider
- Golf: slice, hook
- Tennis: top-spin forehand
- Autoracing: downforce
- Soccer: “bender”
- Volleyball: top-spin jumpserve





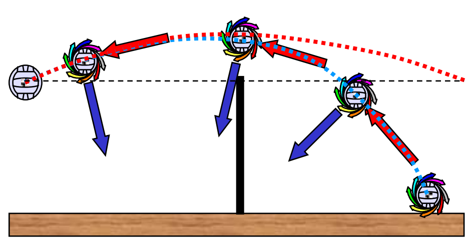
Volleyball: topspin serve

1) Spin *2) Drag Force* *3) Lift Force*



The Magnus Effect

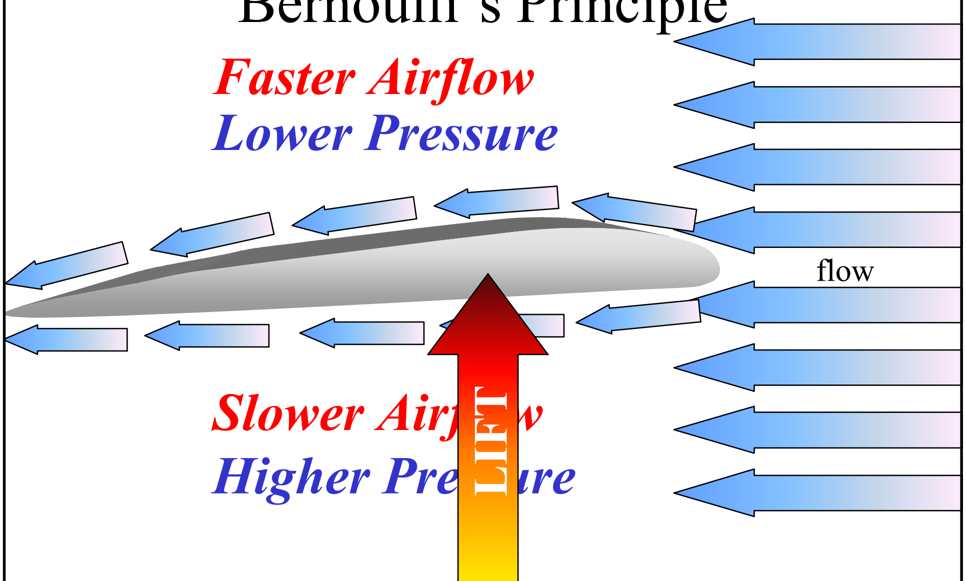
- The Magnus effect describes the curved path that is observed by spinning projectiles.
  - Explained by Bernoulli's principle and the pressure differences caused by relative differences in flow velocities.



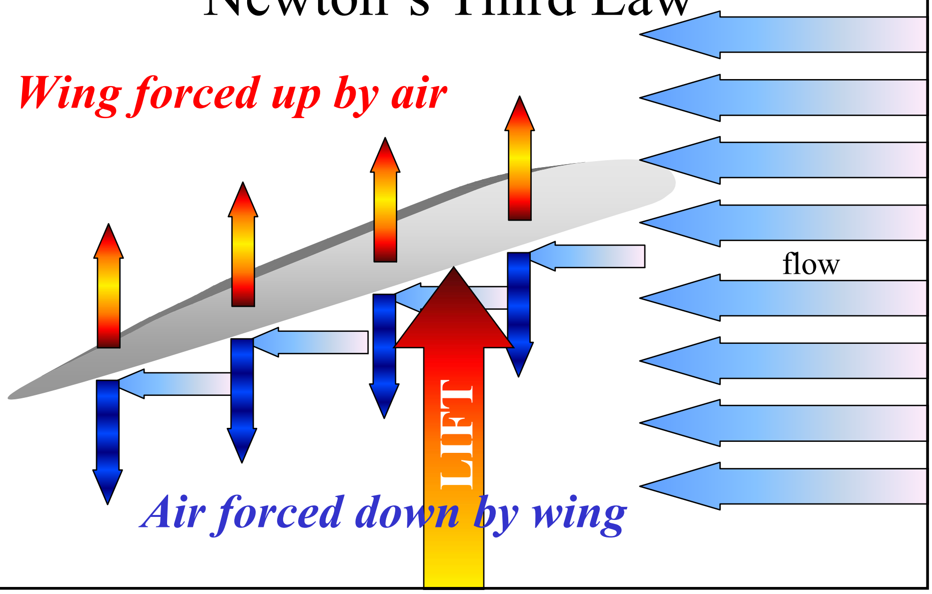
Explaining lift and drag

- The drag force acts in a direction that is opposite of the relative flow velocity (i.e., it opposes the relative flow)
  - Affected by surface area (form drag)
  - Affected by surface smoothness (surface drag)
- The lift force acts in a direction that is perpendicular to the relative flow.
  - The lift force is not necessarily vertical.

Bernoulli's Principle



Newton's Third Law



Buoyancy

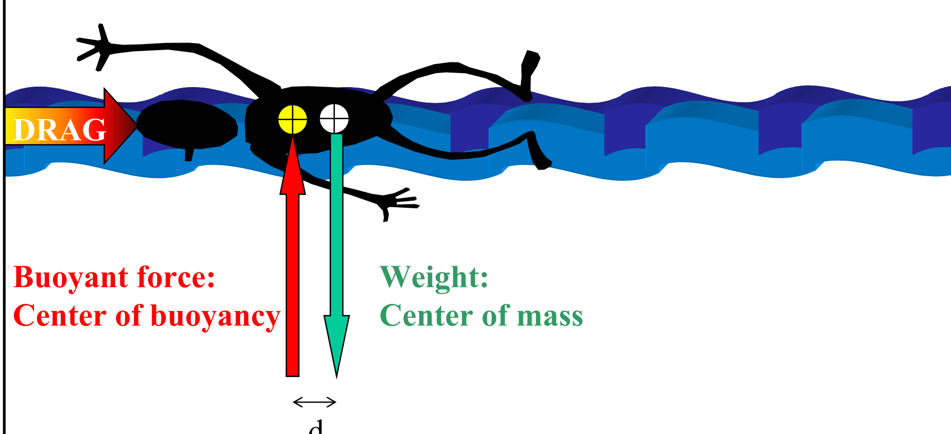
- Associated with how well a body floats or how hight it sits in the fluid.
- Archimede's principle: any body in a fluid medium will experience a buoyant force equal to the weight of the volume of fluid which is displaced.
  - Example: a boat on a lake. A portion of the boat is submerged and displaces a given volume of water. The weight of this displaced water equals the magnitude of the buoyant force acting on the boat.
  - The boat will float if its weight in air is less than or equal to the weight of an equal volume of water.
- Buoyancy is closely related to the concept of <u>density</u>.

Density = mass/volume

Example: Underwater weighing

- Body composition assessment using the underwater weighing technique is common application of Archimede's principle.
  - Human body is composed of varying amounts of muscle, bone, and fat.
  - Densities of:
    - Fat: 0.95 g/cm^3
    - Muscle: 1.05-1.10 g/cm^3
    - Bone: 1.4-1.9 g/cm^3
  - Underwater weighing provides a direct estimate of average body density. Prediction equations then allow for estimation of %fat and %lean body mass.

Center of buoyancy & swimming performance



Center of buoyancy

Increased tilt in water results in greater form drag! This decreases efficiency!

Research has shown that men have a greater ***d*** than women. This creates a greater “feet-sinking torque”.

It has been suggested that this is a bigger problem for men than for women - WHY?