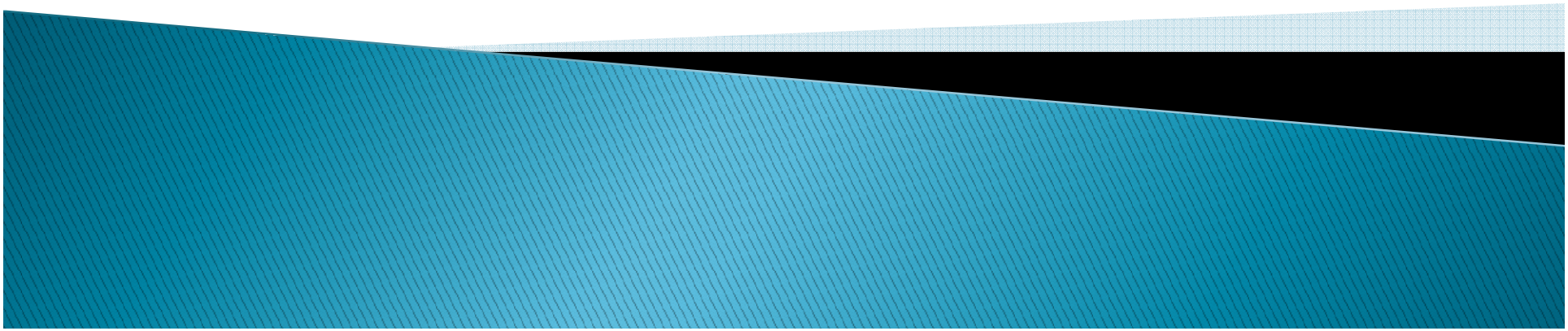
Human Movement in a Fluid Medium

Akhtar Rasul



The Nature of Fluids

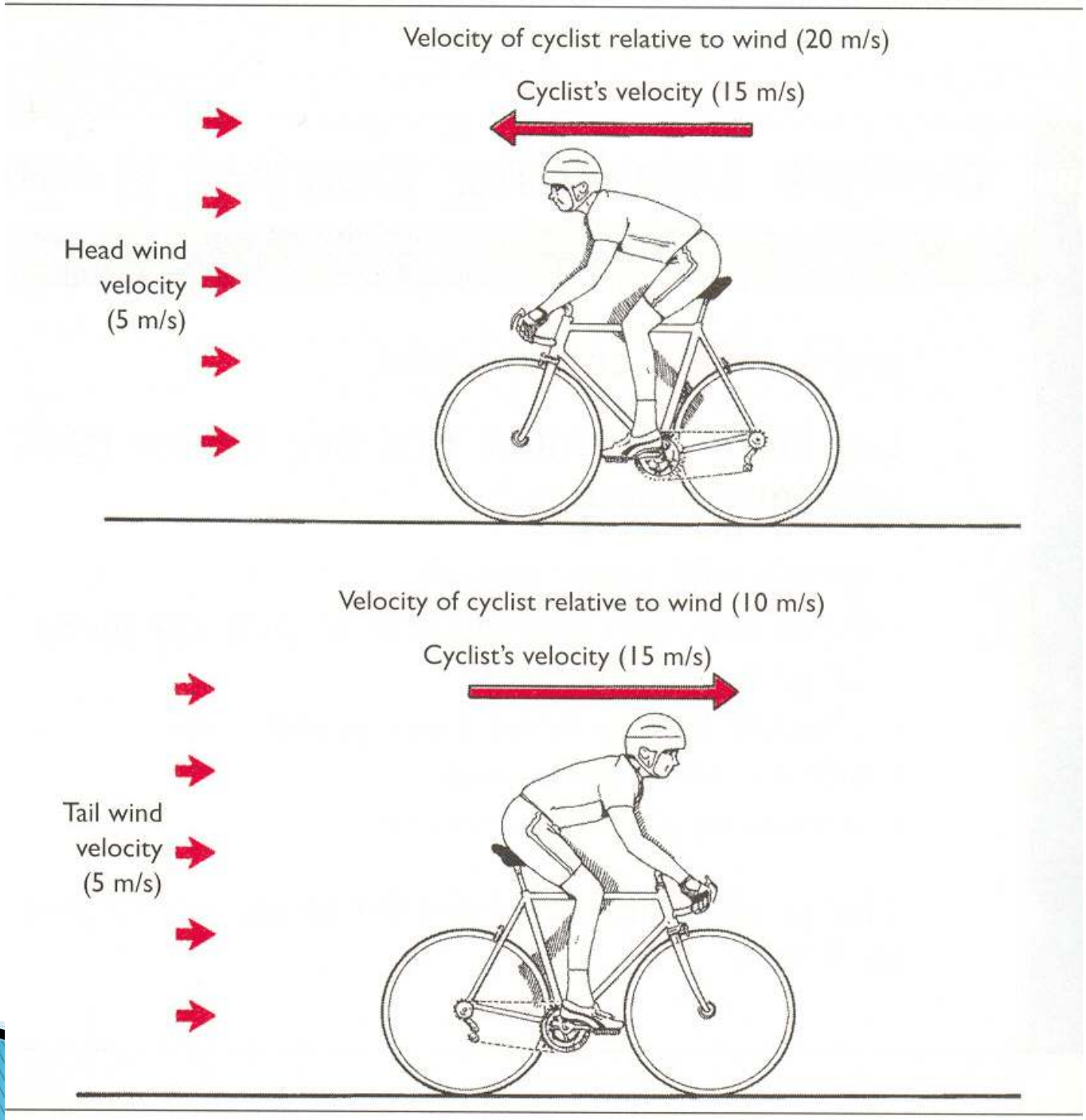
Fluid:

- Air and water are fluids that exert forces on the human body.
  - Although in general conversation the term fluid is often used interchangeably with the term liquid, from a mechanical perspective, a fluid is any substance that tends to flow or continuously deform when acted on by a shear force.
  - **Fluid**: substance that flows when subjected to a shear stress.

Relative Motion

Relative velocity:

- Velocity of a body with respect to a fluid is the vector subtraction of the velocity of the fluid from the velocity of the body.
  - Because a fluid is a medium capable of flow, the influence of the fluid on a body moving through it depends not only on the body's velocity but also on the velocity of the fluid.
  - Relative velocity: velocity of a body with respect to the velocity of something else, such as the surrounding fluid
  - When a body moves through a fluid, the relative velocity of the body with respect to the fluid influences the magnitude of the acting forces.


Velocity of cyclist relative to wind (20 m/s)
Cyclist's velocity (15 m/s)
Head wind velocity (5 m/s)
Velocity of cyclist relative to wind (10 m/s)
Cyclist's velocity (15 m/s)
Tail wind velocity (5 m/s)

Types of flow

- If the relative velocity of the object with respect to the water is low, there is little apparent disturbance of the immediately surrounding water e.g. human hand or a canoe paddle moves through the water
- If the relative velocity of motion through the water is sufficiently high, waves and eddies appear
  - When an object moves with sufficiently low velocity relative to a fluid medium, the flow of the adjacent fluid is termed laminar flow.
  - Laminar flow: flow characterized by smooth, parallel layers of fluid
  - When an object moves with sufficiently high velocity relative to a surrounding fluid, the layers of fluid near the surface of the object mix, and the flow is termed turbulent.
  - Turbulent flow: flow characterized by mixing of adjacent fluid layers

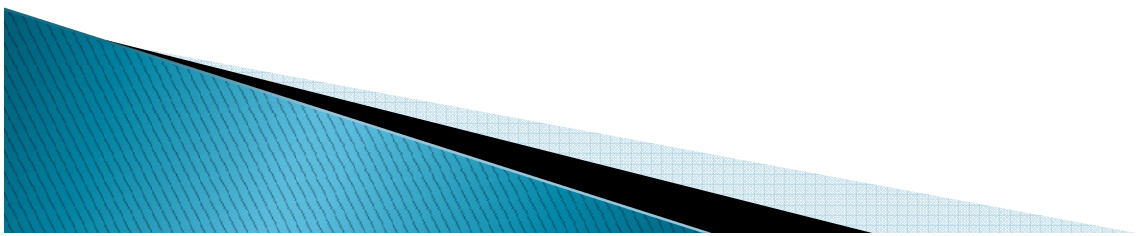
Laminar versus Turbulent Flow

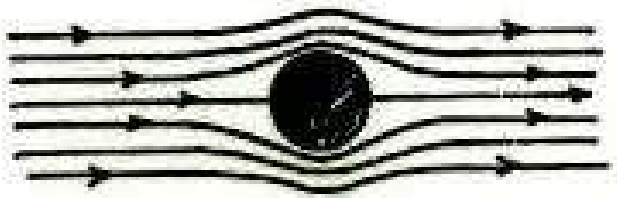
Laminar flow:

- Low velocity relative to fluid medium

Turbulent flow:

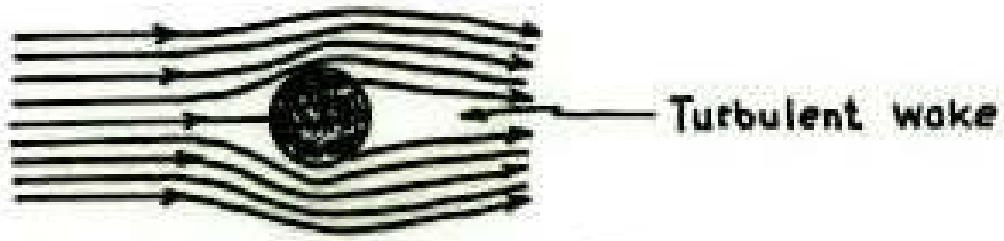
- High velocity relative to fluid medium





(a): LAMINAR (TYPE I) FLOW

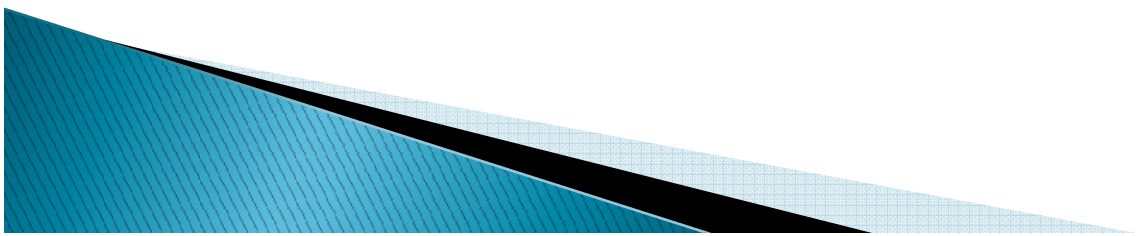
(b): PARTIALLY TURBULENT (TYPE II) FLOW



(c): FULLY TURBULENT (TYPE III) FLOW

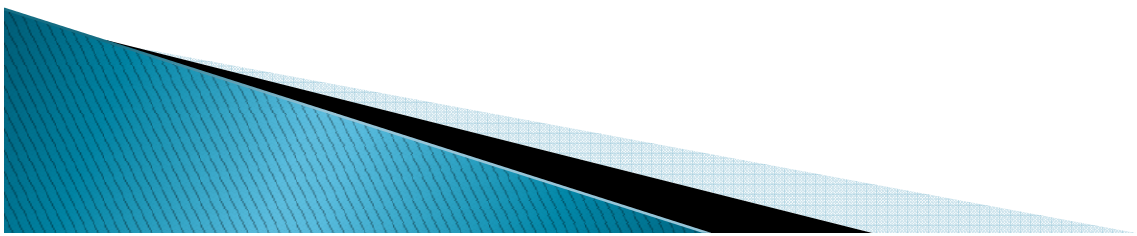
Fluid Properties

- Other factors that influence the magnitude of the forces a fluid generates are the fluid's density, specific weight, and viscosity.
- The denser and heavier the fluid medium surrounding a body, the greater the magnitude of the forces the fluid exerts on the body.
- The property of fluid viscosity involves the internal resistance to a fluid to flow, Increased fluid viscosity results in increased forces exerted on bodies exposed to the fluid.



Fluid Properties

- Density (ρ) = mass / volume
- Specific weight (γ) = ratio of weight to volume
- Viscosity = internal resistance to flow
  - Atmospheric pressure and temperature influence a fluid's density, specific weight, and viscosity



Buoyancy

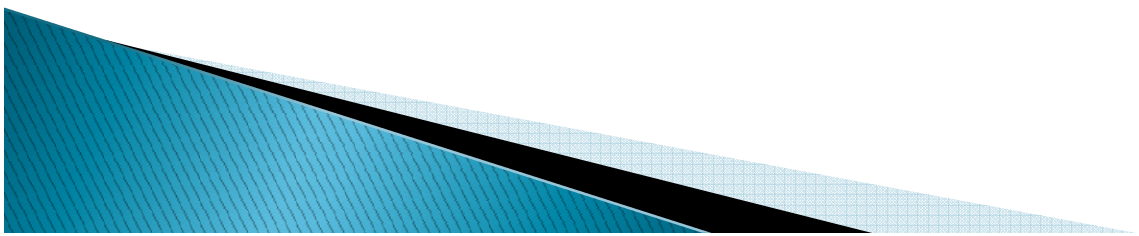
- Buoyancy is a fluid force that always acts vertically upward.
- Archimedes' principle:
- Weight of the fluid is calculated by multiplying the specific weight of the fluid by the volume of the portion of the body that is surrounded by the fluid.
- Buoyancy (F_b) is calculated as the product of the displaced volume (V_d) and the fluid's specific weight (γ).
- The more dense the surrounding fluid, the greater the magnitude of the buoyant force.
- Center of volume: point around which a body's volume is equally distributed and at which the buoyant force acts.

Buoyancy

Archimedes' principle: the magnitude of the buoyant force acting on a given body is equal to the weight of the fluid displaced by the body.

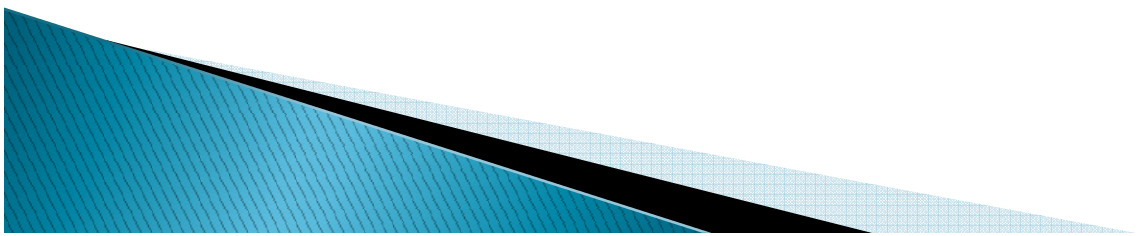
- $F_b = V_d \gamma$

Center of Volume: point around which a body's volume is equally distributed and at which the buoyant force acts.



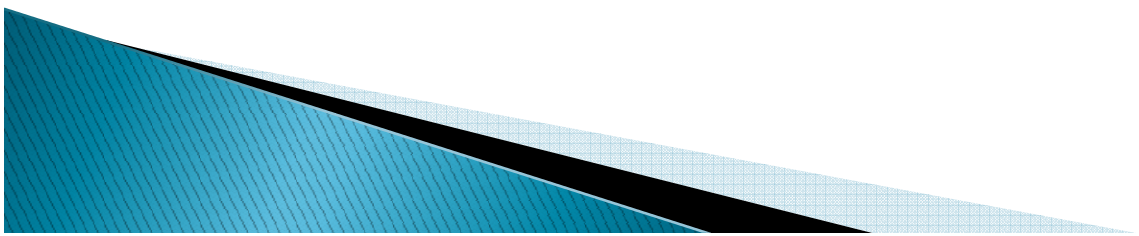
Flotation of the Human Body

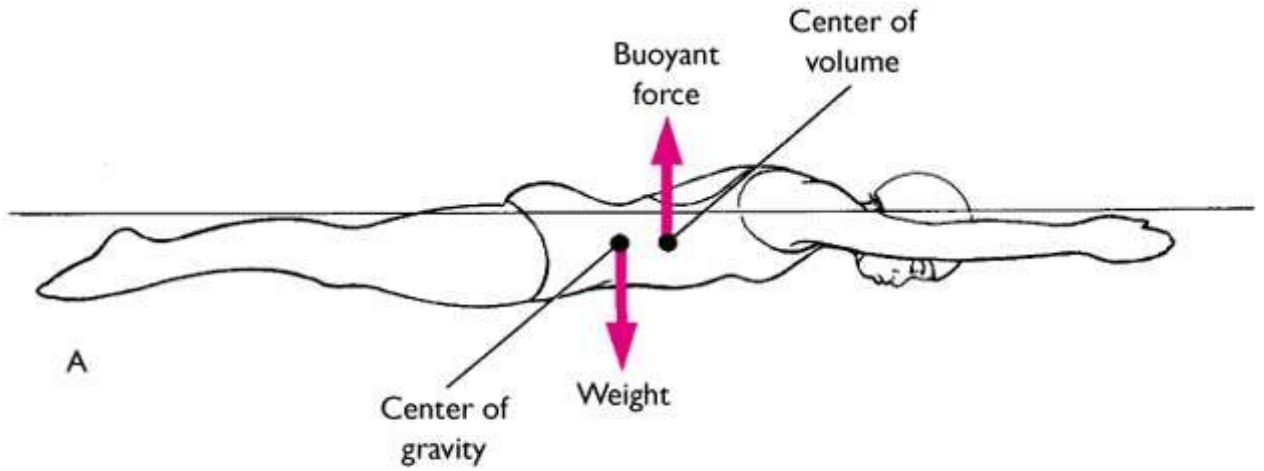
- Some individuals cannot float in a motionless position, and other float with little effort.
- Floatability is a function of body density
- For flotation, buoyant force must be greater than or equal to body weight
- Orientation of the human body
- Torque on the floating human body

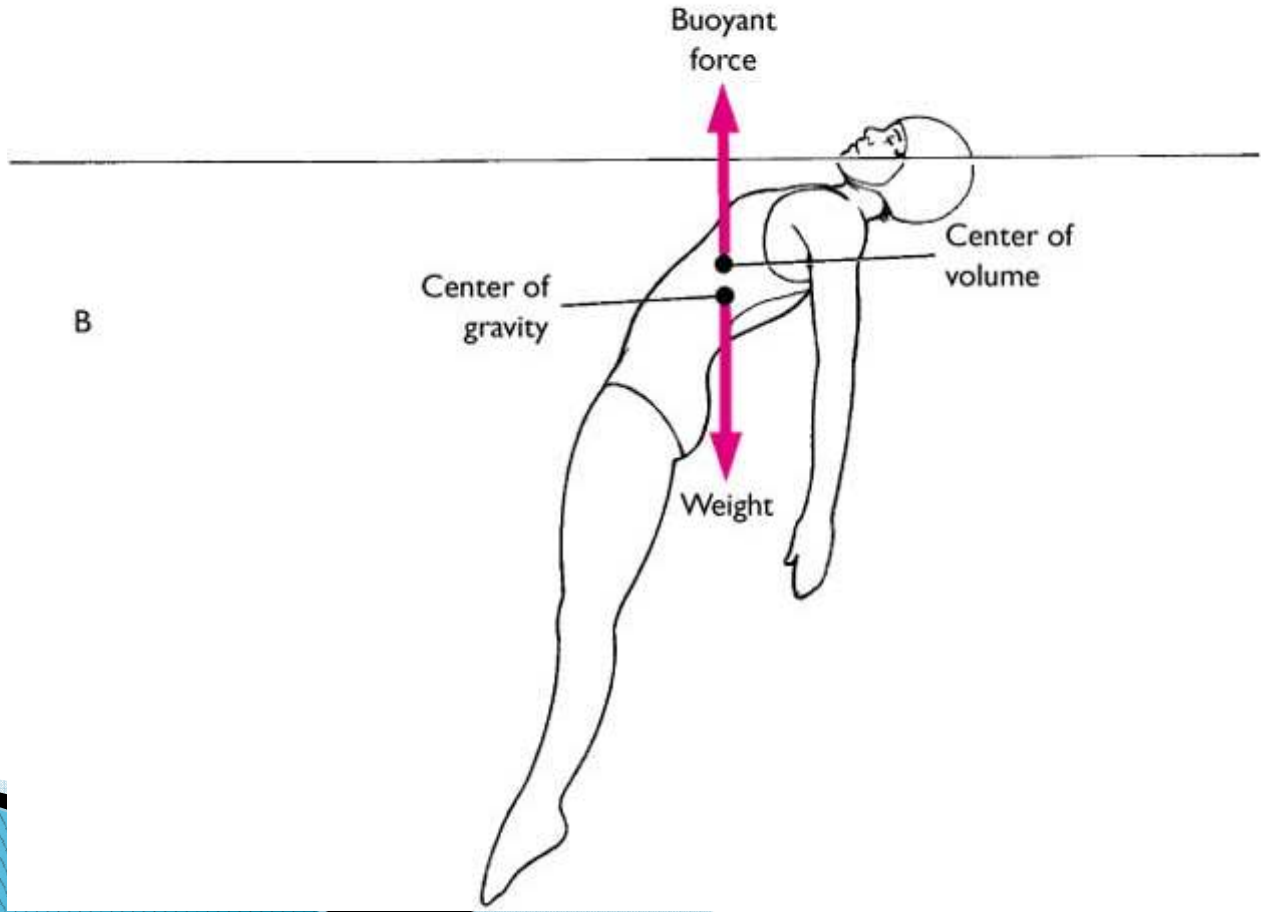


Flotation

- Depends on body's buoyancy and its weight
- Weight = buoyant; body floats in a motionless state
- Weight > buoyant; body sinks, moving downward in the direction of the net force
- Most object float statically in a partially submerged position




Buoyant force
Center of volume
A
Center of gravity
Weight


Buoyant force
Center of volume
Center of gravity
B
Weight

Drag

- **Drag**: is a force caused by the dynamic action of a fluid that acts in the direction of the free stream fluid flow
- Generally, a drag is a resistance force: a force that slows the motion of a body moving through a fluid.
- The drag force acting on a body in relative motion with respect to a fluid is defined by the following formula:
- In this formula, F_D is drag force, C_D is coefficient of drag, ρ is fluid density, A_p is the projected area of the body or the surface area of the body oriented perpendicular to the fluid flow, and v is the relative velocity of the body with respect to the fluid

Drag

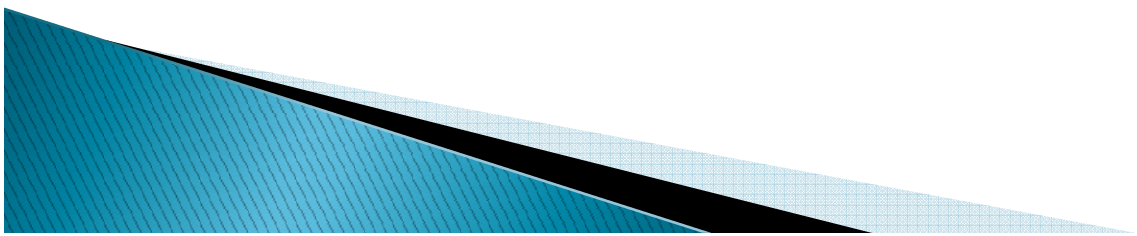
- $F_D = \frac{1}{2} C_D \rho A_p v^2$

Coefficient of drag:

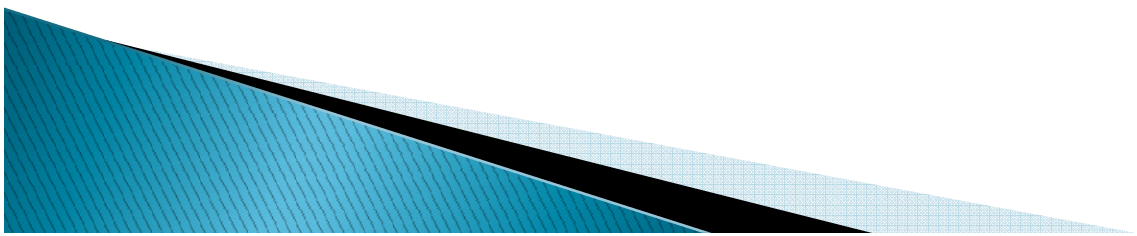
- Depends on shape & orientation of a body

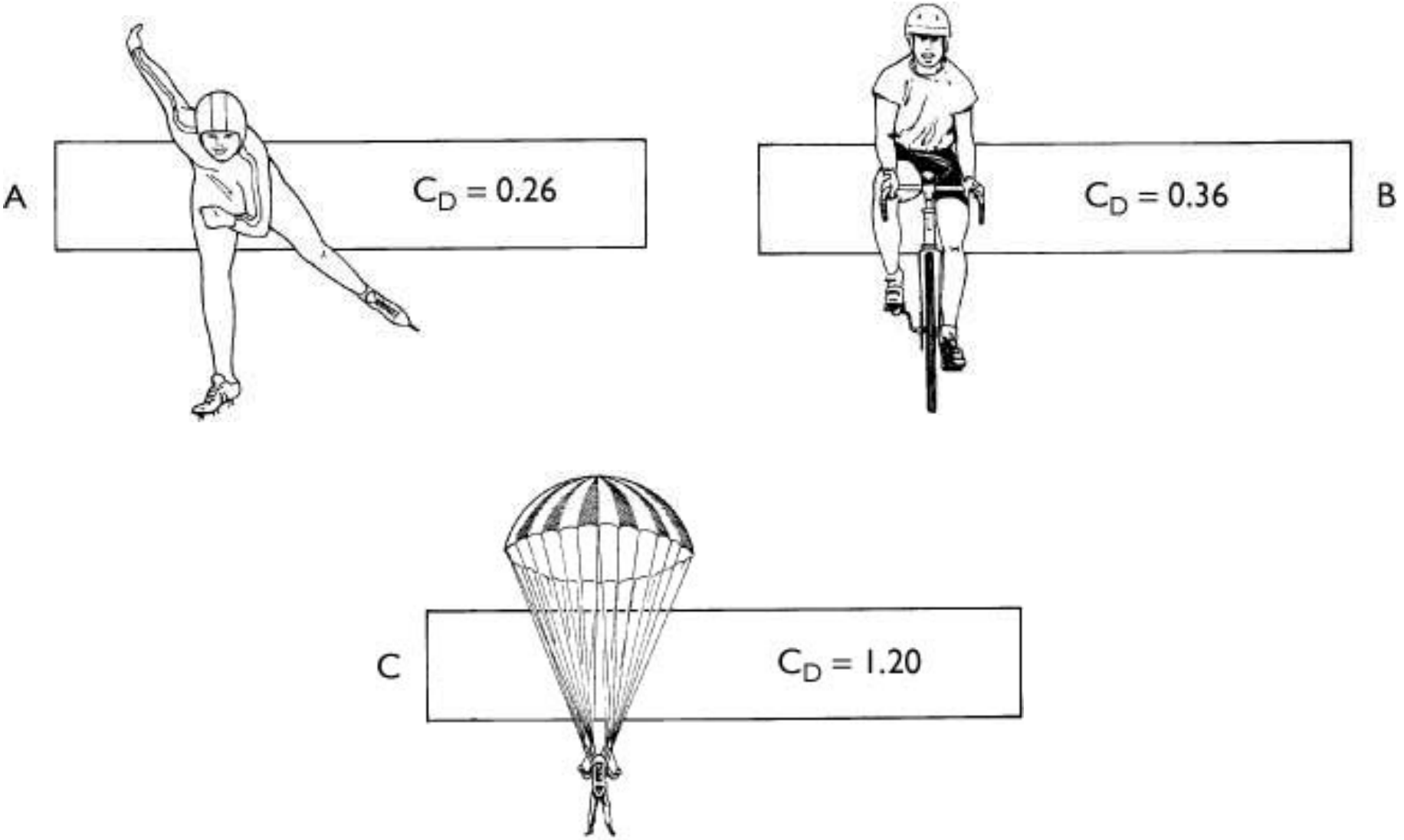
Components of total drag force:

- Skin friction
- Form drag
- Wave drag



- **Coefficient of drag**: unitless number that is an index of a body's ability to generate fluid resistance
- Its size depends on the shape and orientation of a body relative to the fluid flow, with long, streamlined bodies generally having lower coefficients of drag than blunt or irregularly shaped objects.




A
$C_D = 0.26$
$C_D = 0.36$
B
C
$C_D = 1.20$

Skin Friction

- Skin friction, surface drag, or viscous drag: Resistance derived from friction between adjacent layers of fluid near a body moving through the fluid
- Fluid particles slowed due to shear stress Boundary layer: layer of fluid immediately adjacent to the body
- Factors that affect skin friction drag
  - Velocity of fluid flow
  - surface area
  - roughness
  - viscosity

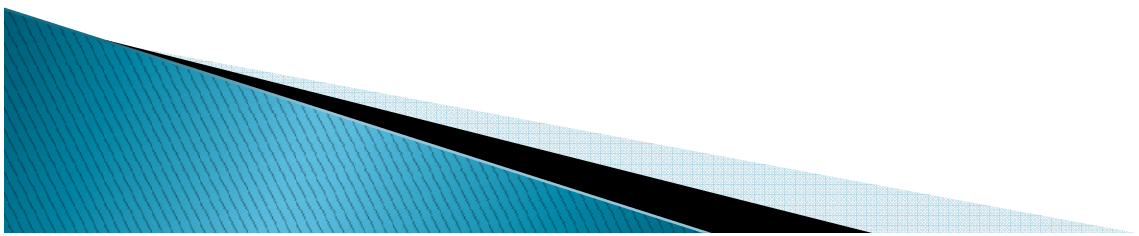
Wave Drag

Wave drag: Resistance created by the generation of waves at the interface between two different fluids, such as air and water

- Major effect on human swimmers in open
- Factors that affect wave drag
  - Greater up-and-down motion
  - Increased swimming speed
- Skilled swimmer produce smaller waves than less-skilled swimmers, presumably due to better technique (less up-and-down motion)

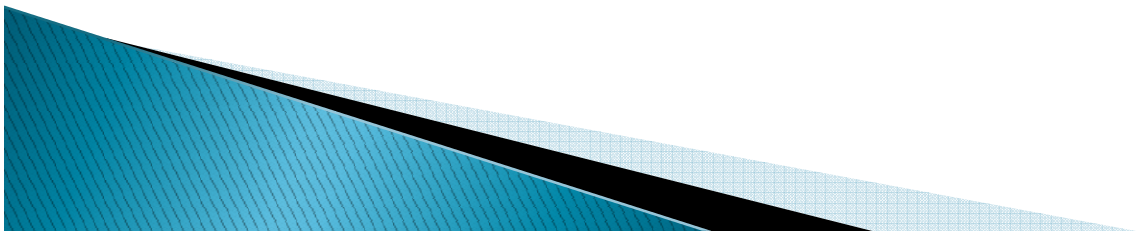
Form Drag

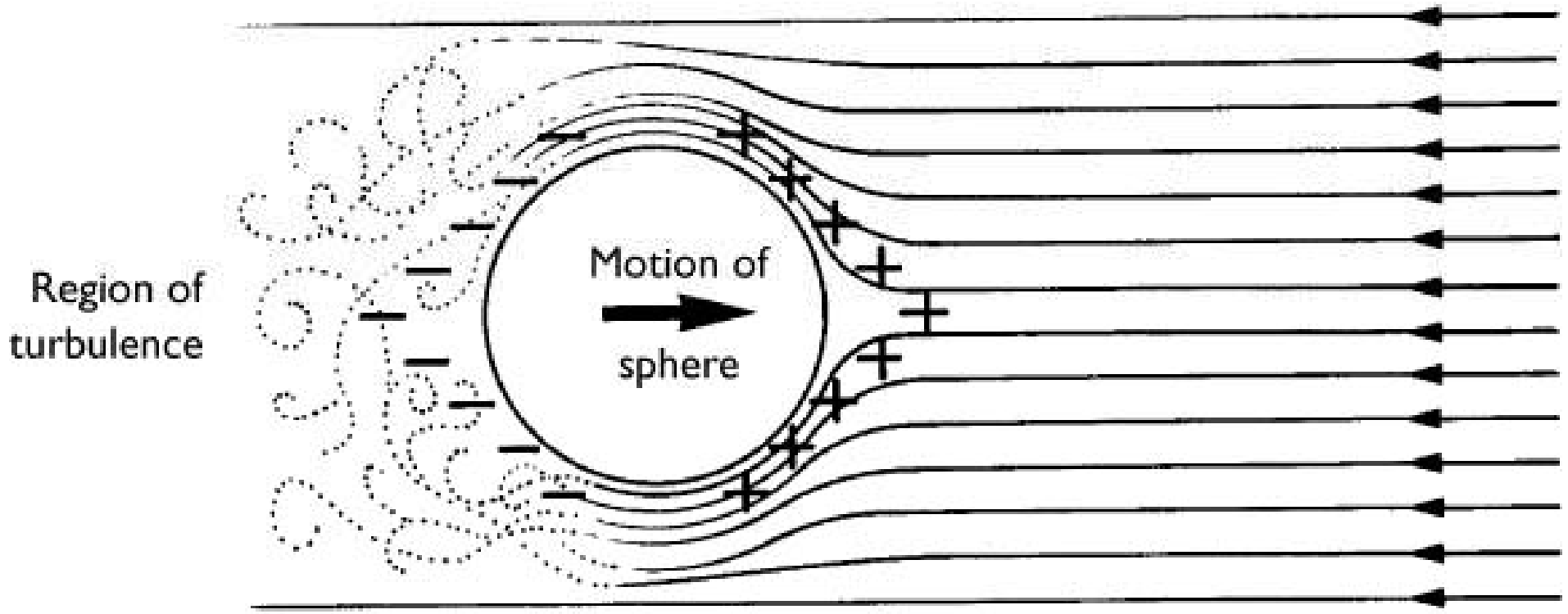
- Form drag or profile drag or pressure drag:
- Resistance created by a Pressure differential between the lead and rear sides of a body moving through a fluid
- Factors that affect form drag:
  - Relative velocity, pressure gradient, and surface area
- Streamlining helps to minimize form drag
- Cyclists drafting helps to minimize form drag

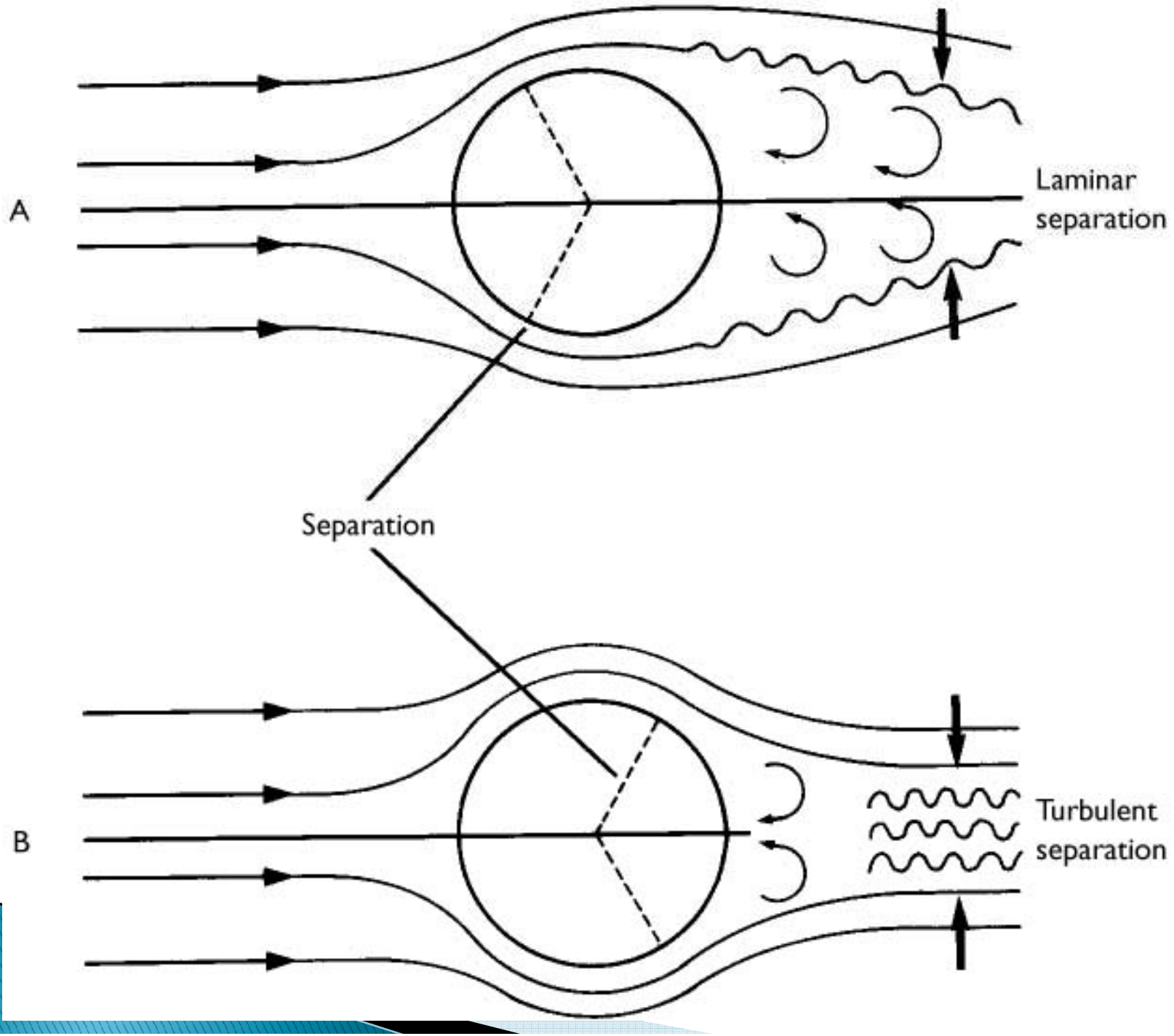


Bernoulli's principle

- Pressure in a fluid varies inversely with the velocity




Region of
turbulence
Motion of
sphere


A
Laminar
separation
Separation
B
Turbulent
separation

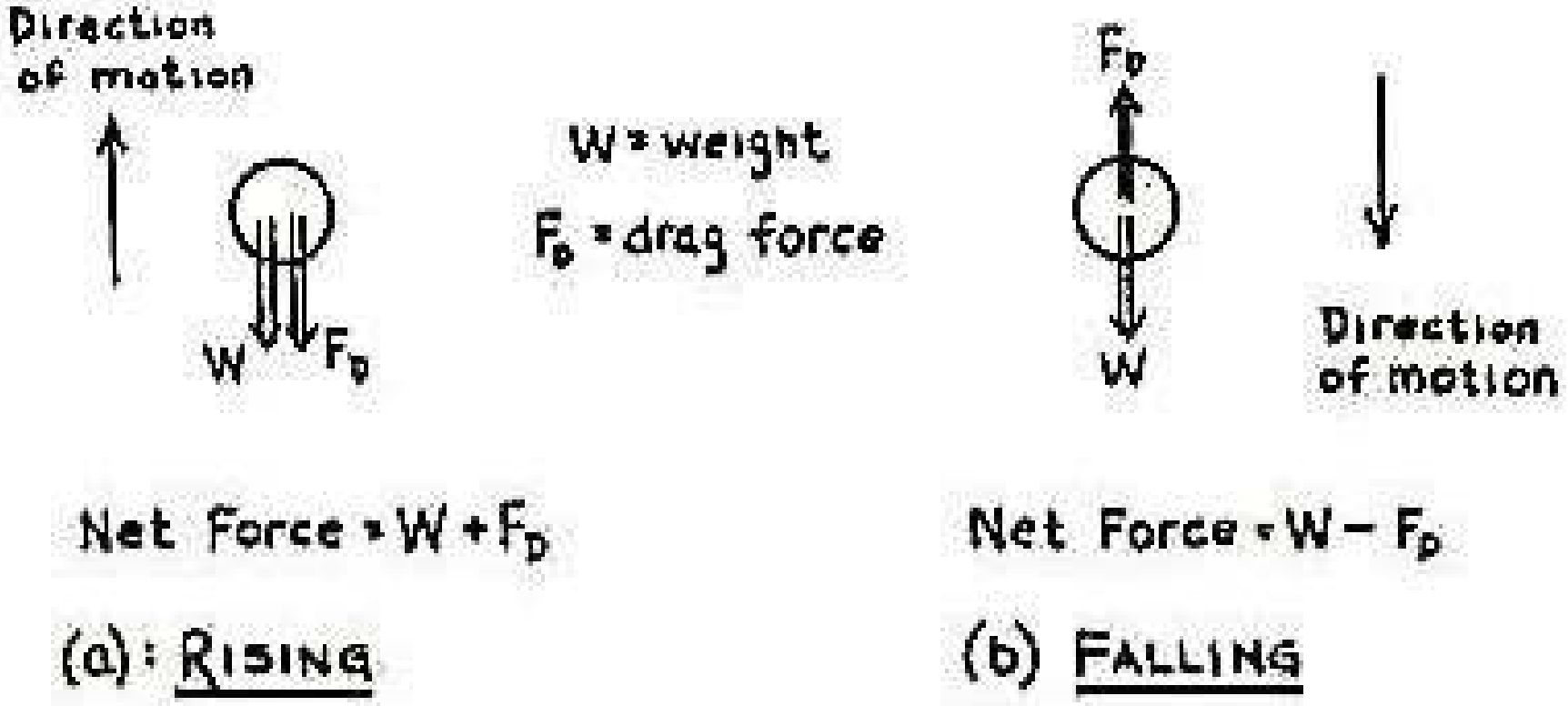


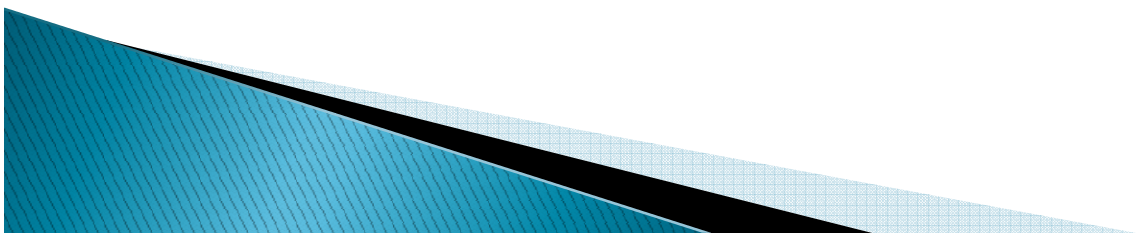
FIGURE 9.4 Forces on a ball moving vertically in air.

Lift Force

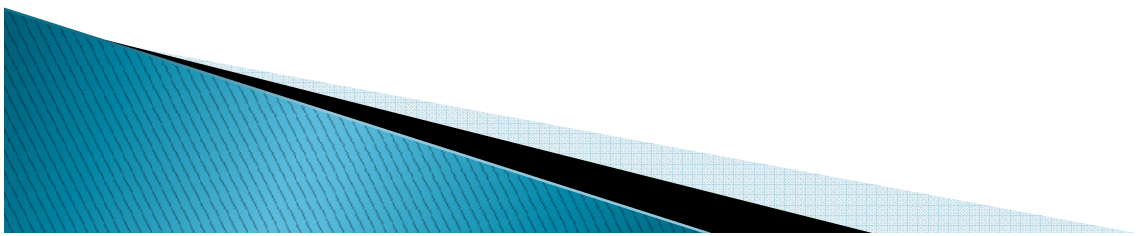
- Lift: force acting on a body in a fluid in a direction perpendicular to the fluid flow

Lift Force

- While drag forces act in the direction of the free stream fluid flow, another force, know as lift, is generated perpendicular to the fluid flow.
- Although the name lift suggests that this force is directed vertically upward, it may assume any direction, as determined by the direction of the fluid flow and the orientation of the body.



- Lift: force acting on a body in a fluid in a direction perpendicular to the fluid flow
- The factors affecting the magnitude of lift are basically the same factors that affect the magnitude of drag
- $F_L = \frac{1}{2} C_L \rho A_p v^2$
- In this equation, F_L represents lift force, C_L is the coefficient of lift, ρ is the fluid density, A_p is the surface area against which lift is generated, and v is the relative velocity of a body with respect to a fluid.



Foil Shape

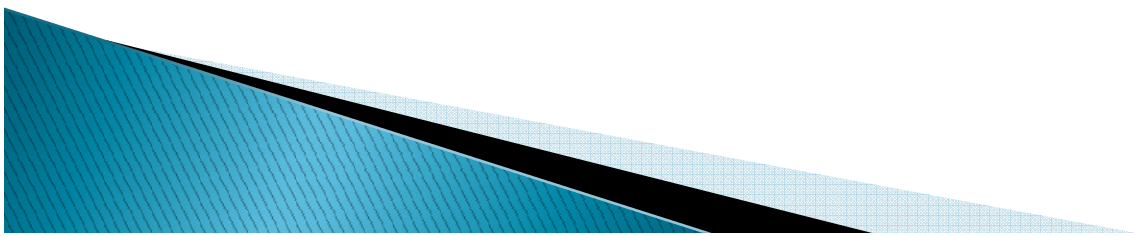
Foil: shape capable of generating lift in the presence of a fluid flow

Bernoulli principle: inverse relationship between relative velocity and relative pressure in a fluid flow

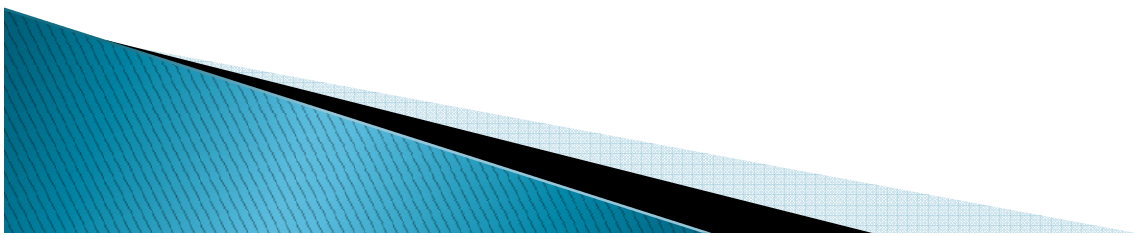
Factors that Affect:

- Velocity, pressure, and lift force

Coefficient of lift: unitless number that is an index of a body's ability to generate lift

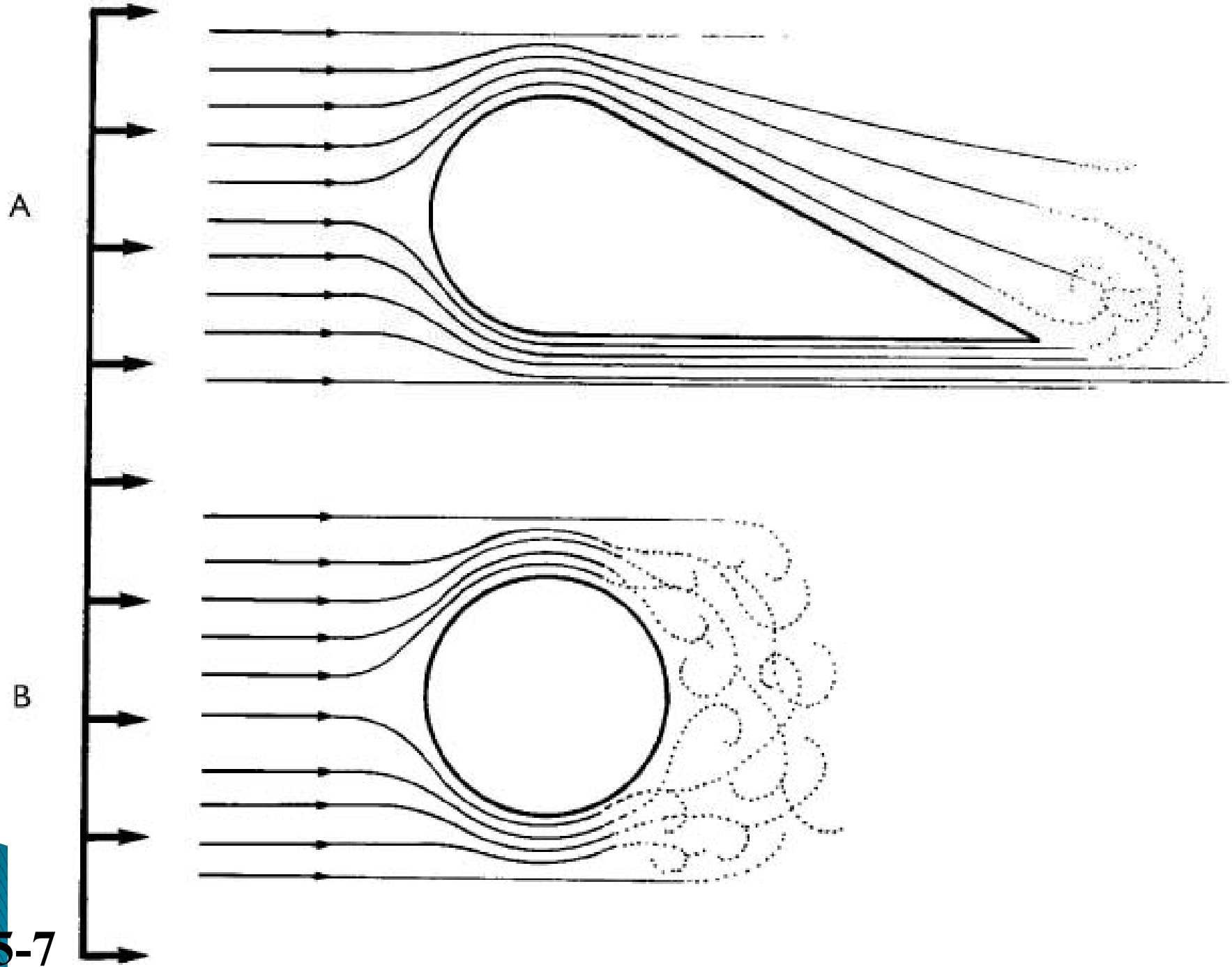


- One way is which lift force may be created is for the shape of the moving body to resemble that of a foil.
- Foil: shape capable of generating lift in the presence of a fluid flow
- When the fluid stream encounters a foil, the fluid separates, with some flowing over the curved surface and some flowing straight back along the flat surface on the opposite side.



- The fluid that flows over the curved surface is positively accelerated relative to the fluid flow, creating a region of relative high-velocity flow.
- The difference is the velocity of flow on the curved side of the foil and opposed to the flat side of the foil creates a pressure difference in the fluid, in accordance with a relationship derived by the Bernoulli.

- **Bernoulli principle**: an expression of the inverse relationship between relative velocity and relative pressure in a fluid flow
- Factors that Affect;
- Different factors affect the magnitude of the lift force acting on a foil.
- The greater the velocity of the foil relative to the fluid, the greater the pressure differential and the lift force generated.
  - As both of these variables increase, lift increases.
- An additional factor of influence is the coefficient of lift, which indicates a body's ability to generate lift based on its shape.
- **Coefficient of lift**: unitless number that is an index of a body's ability to generate lift


A
B

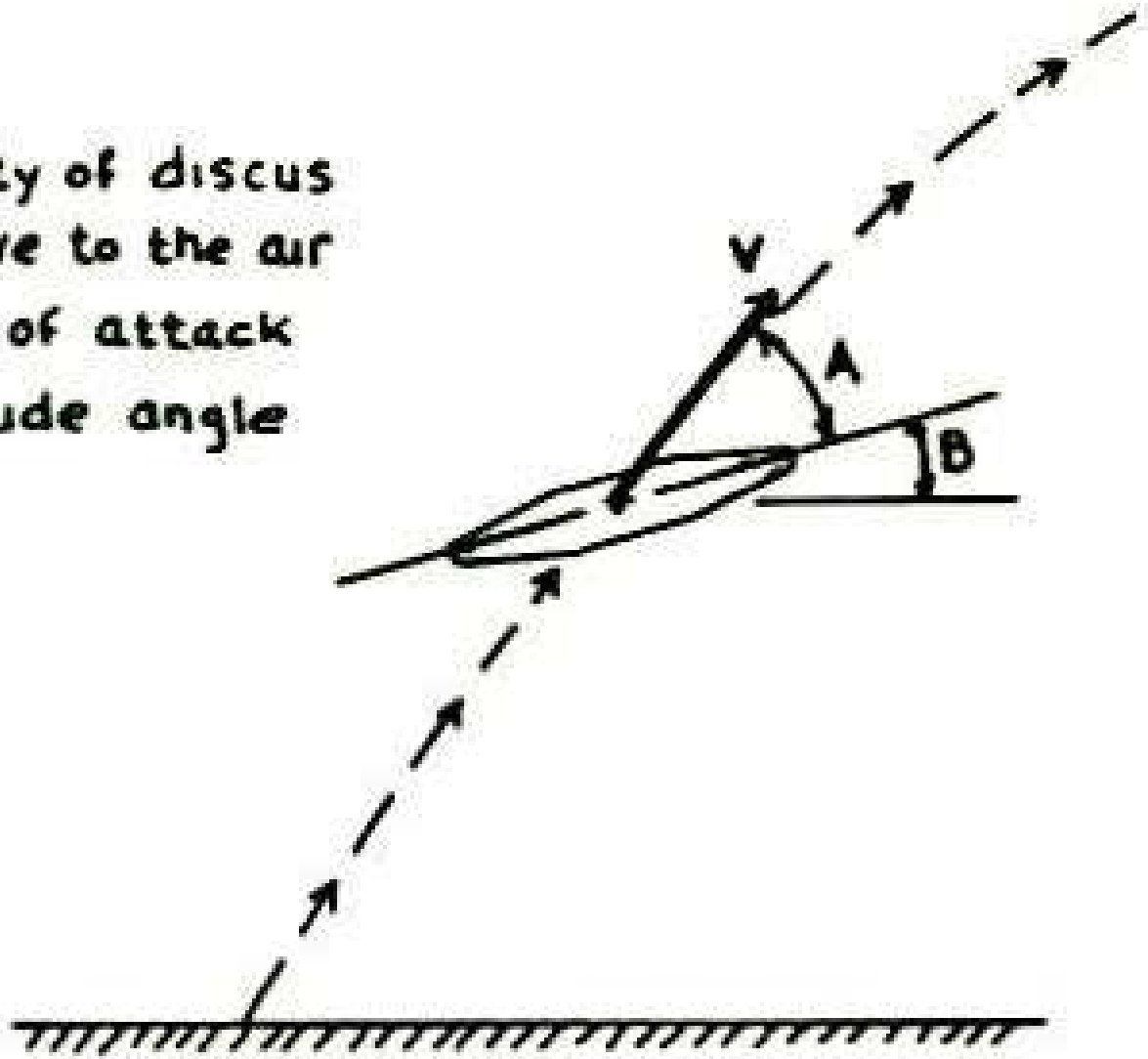
Foil Shape

- Semi-foil shape of projectiles such as the discus and javelin generate some lift force when oriented at appropriate angles with respect to the direction of the fluid flow.
- **Angle of Attack**: angle between the longitudinal axis of a body and the direction of the fluid flow
- **Lift/drag ratio**: the magnitude of the lift force divided by the magnitude of the total drag force acting on a body at a given time

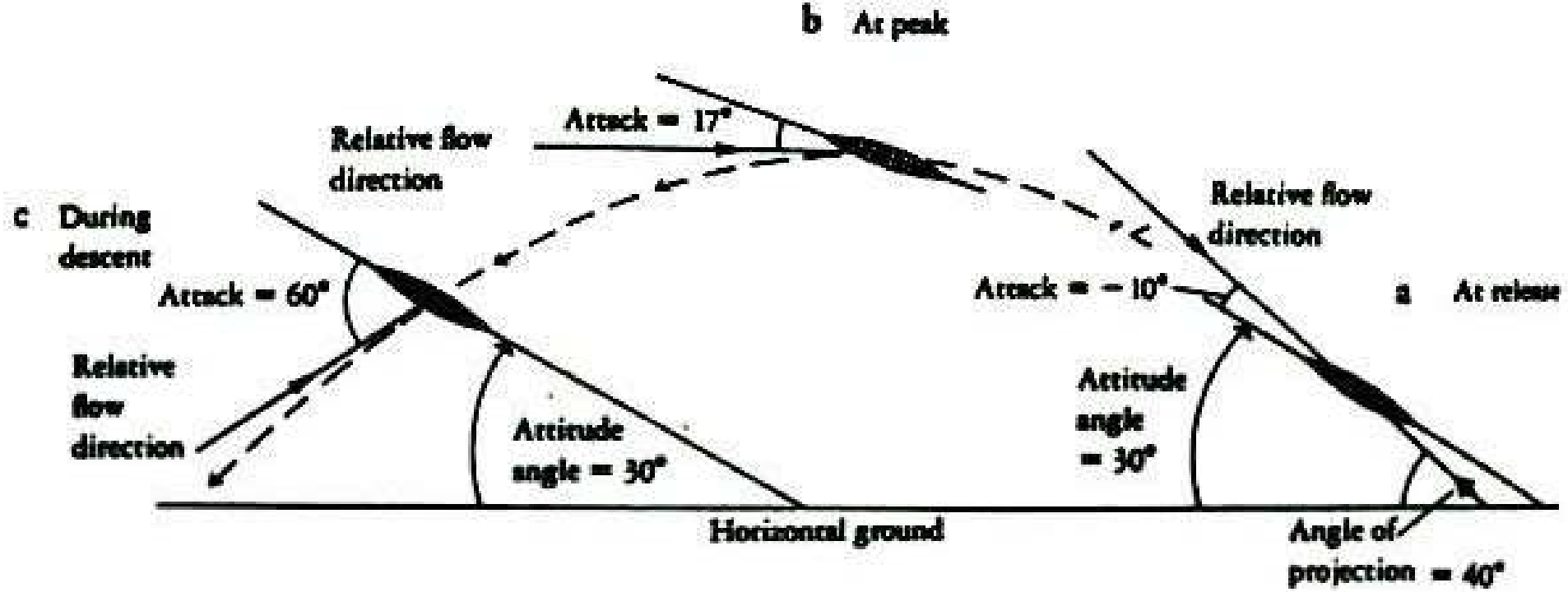
V = velocity of discus
relative to the air

A = angle of attack

B = attitude angle



(a)


b At peak
Attack = 17°
Relative flow direction
c During descent
Attack = 60°
Relative flow direction
Attitude angle = 30°
Horizontal ground
Relative flow direction
Attack = −10°
a At release
Attitude angle = 30°
Angle of projection = 40°

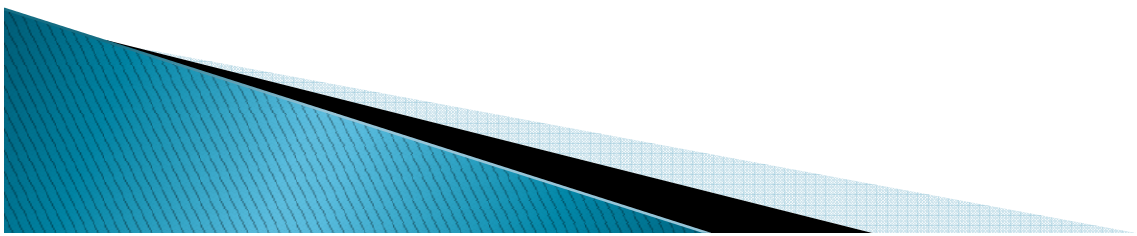
Magnus Effect

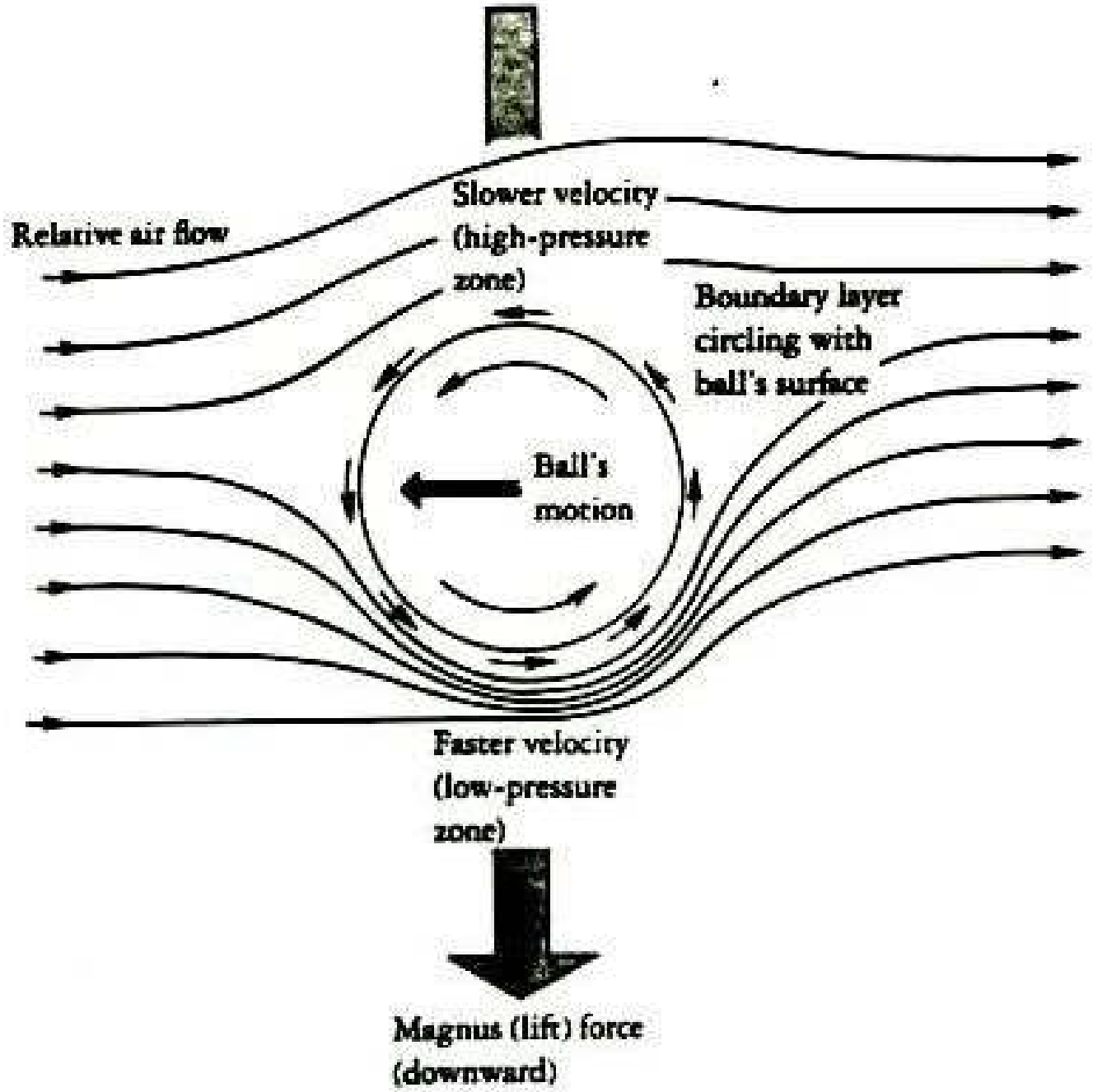
Magnus force: lift force created by spin

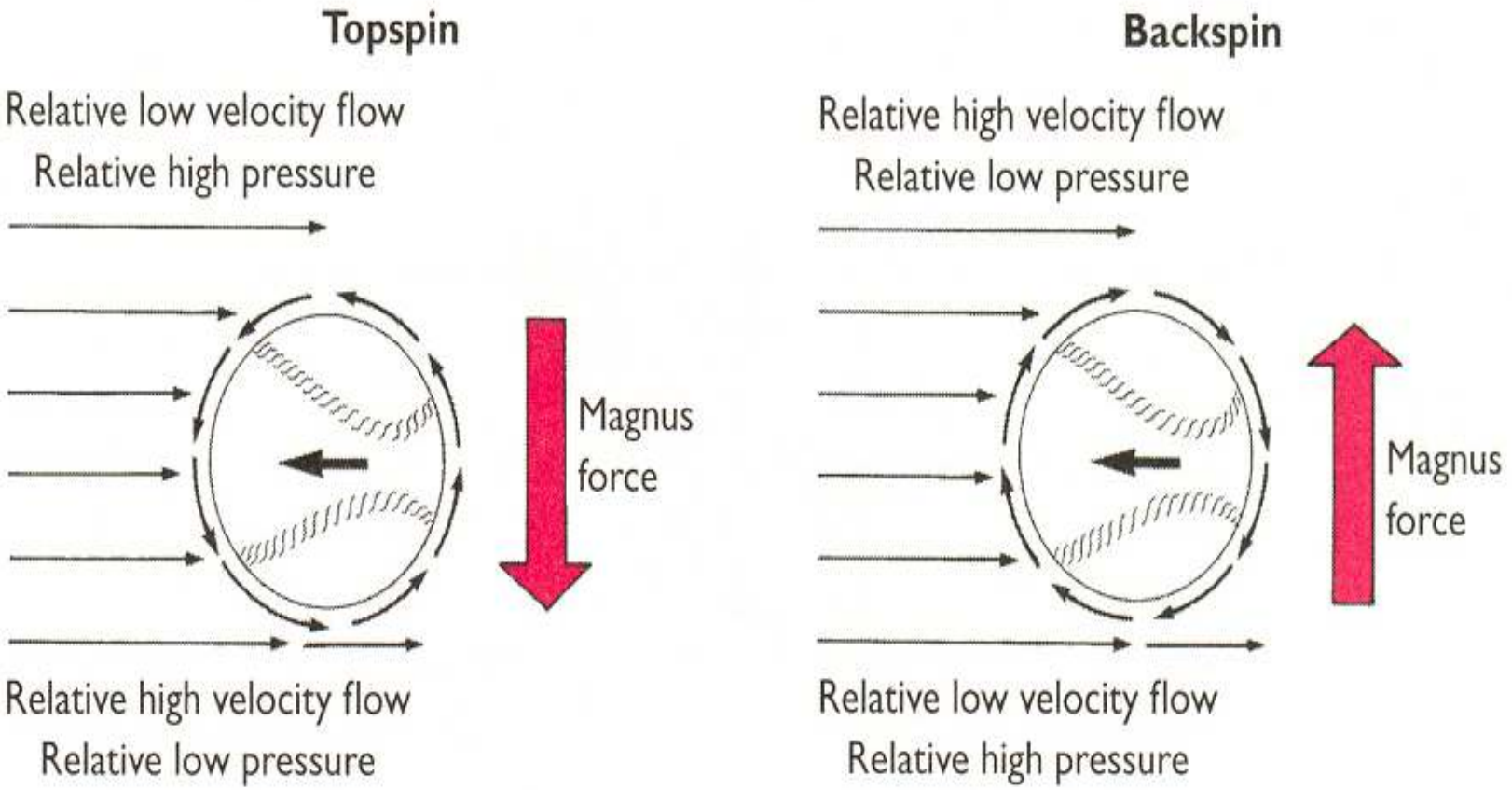
Magnus effect: deviation in the trajectory of a spinning object toward the direction of spin, resulting form the Magnus force

- Spinning objects also generate lift.
- When an object in a fluid medium spins, the boundary layer of fluid molecules adjacent to the object spins with it.
- When this happens, the fluid molecules on one side of the spinning body collide head-on with the molecules in the fluid free stream.
- This creates a region of relative low velocity and high pressure.
- On the opposite side of the spinning object, the boundary layer moves in the same direction as the fluid flow, thereby creating a zone of relative high velocity and low pressure.

- The pressure differential creates what is called the Magnus force, a lift force directed from the high-pressure region to the low-pressure region.
- **Magnus force**: lift force created by spin
- **Magnus effect**: deviation in the trajectory of a spinning object toward the direction of spin, resulting form the Magnus force

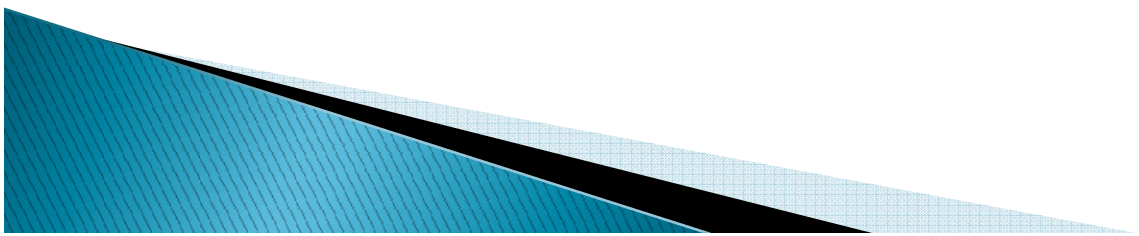


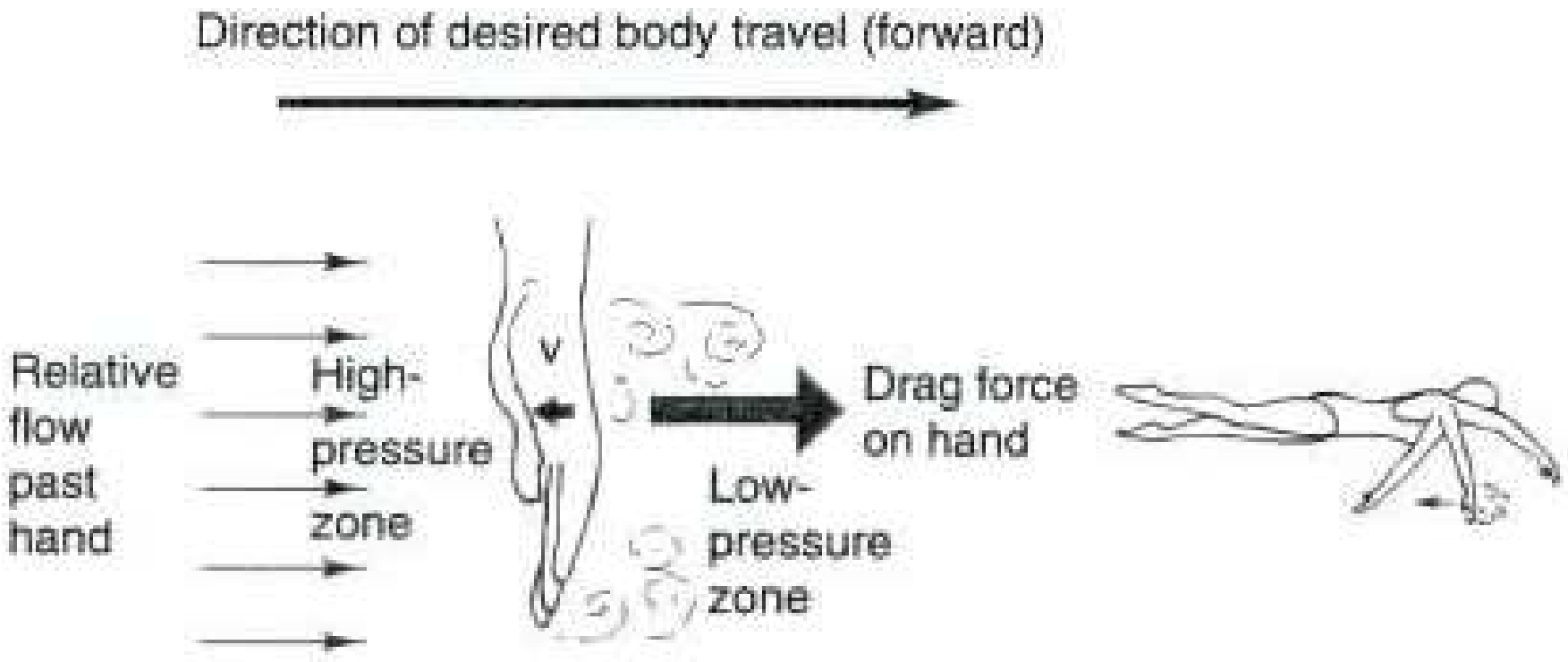

Relative air flow
Slower velocity
(high-pressure
zone)
Boundary layer
circling with
ball's surface
Ball's
motion
Faster velocity
(low-pressure
zone)
Magnus (lift) force
(downward)

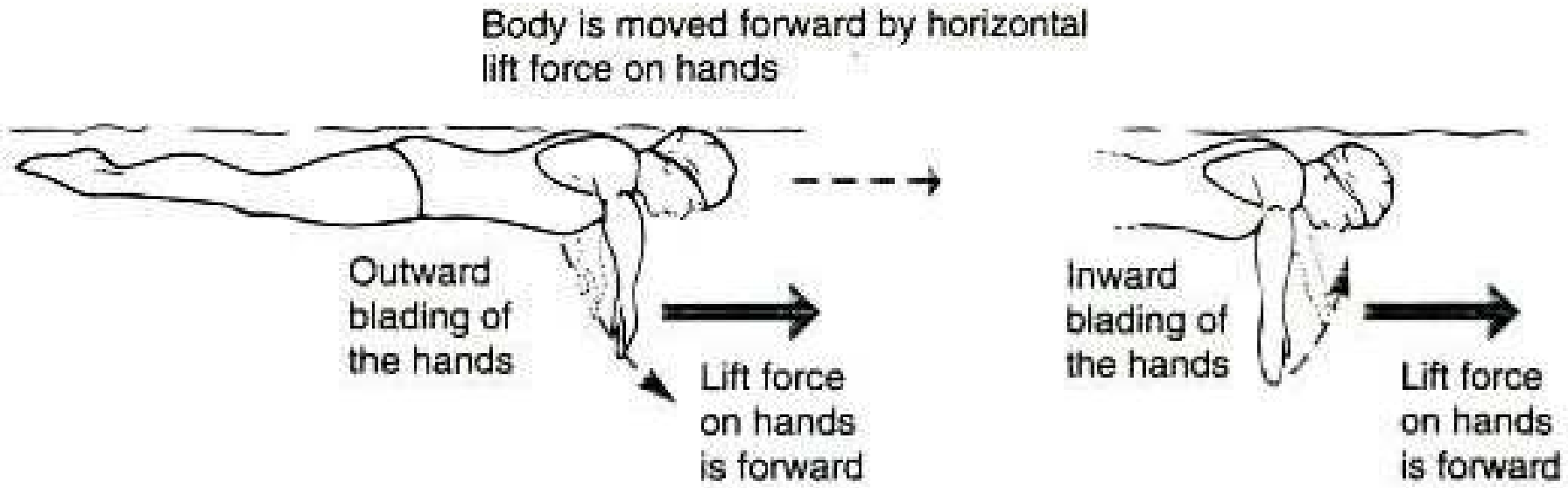

Topspin
Relative low velocity flow
Relative high pressure
Magnus force
Relative high velocity flow
Relative low pressure
Backspin
Relative high velocity flow
Relative low pressure
Magnus force
Relative low velocity flow
Relative high pressure

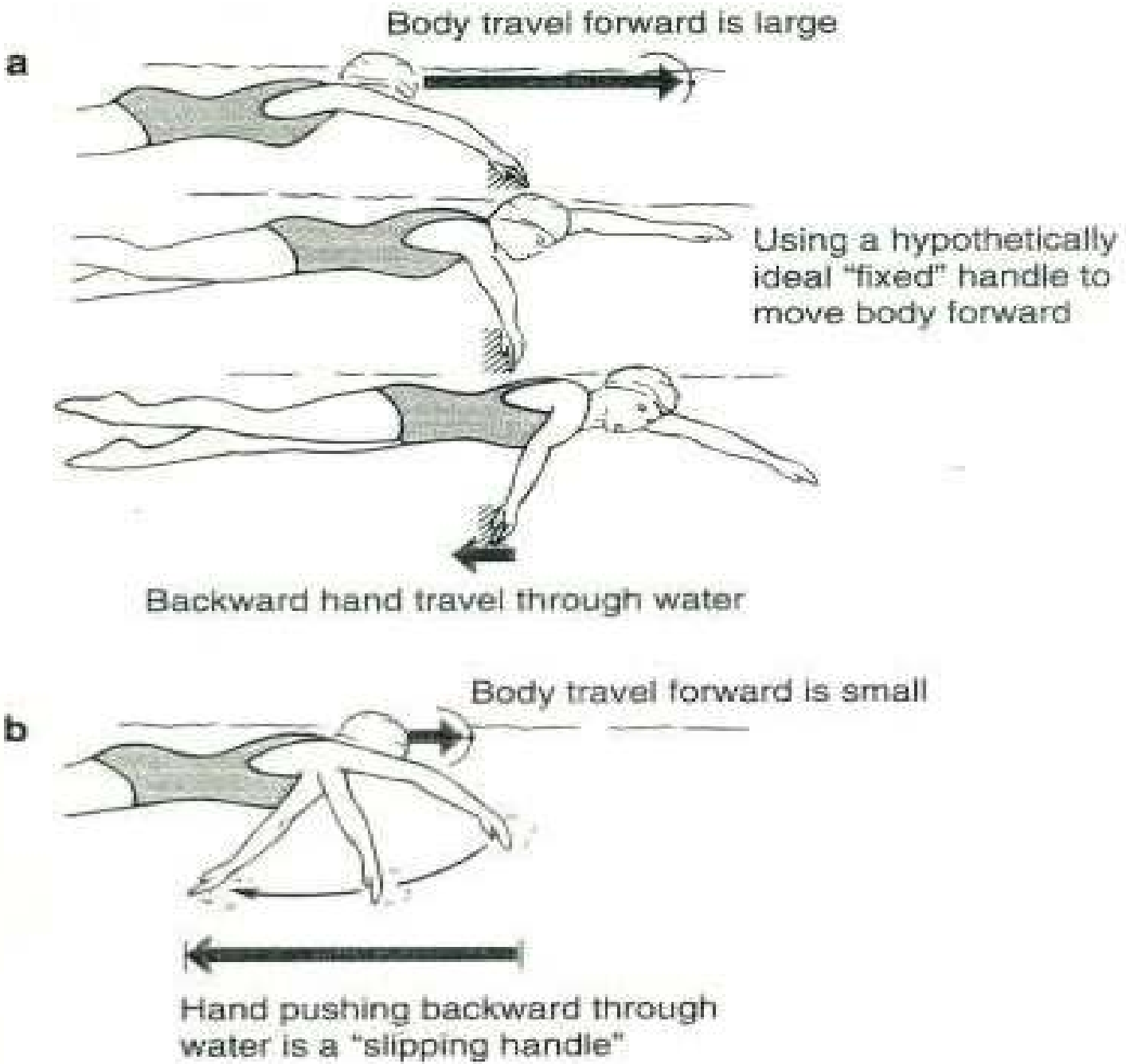
Propulsion in a Fluid Medium

- Resistive drag acts on a swimmer
- Propulsive drag: force acting in the direction of a body's motion
- Propulsive drag theory: attributes propulsion in swimming to propulsive drag on the swimmer
- Propulsive lift theory: theory attributing propulsion in swimming at least partially to lift acting on the swimmer




Direction of desired body travel (forward)
Relative flow past hand
High-pressure zone
v
Low-pressure zone
Drag force on hand


Body is moved forward by horizontal lift force on hands
Outward blading of the hands
Lift force on hands is forward
Inward blading of the hands
Lift force on hands is forward


a
Body travel forward is large
Using a hypothetically ideal "fixed" handle to move body forward
Backward hand travel through water
b
Body travel forward is small
Hand pushing backward through water is a "slipping handle"

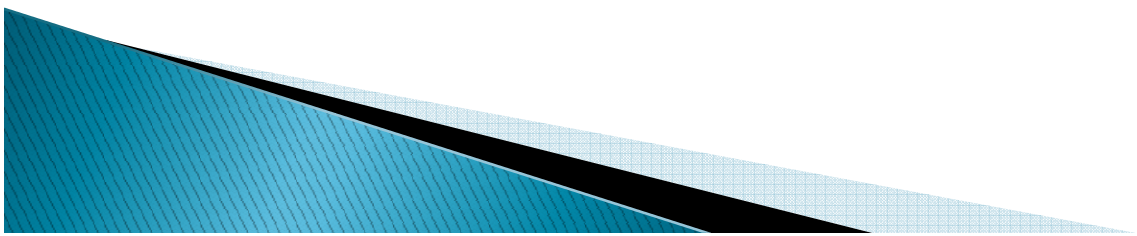
Propulsion in a Fluid Medium

Vortex Generation

- may play a role in swimming propulsion

Stroke Technique

- product of stroke length (SL) and stroke rate (SR).



- Vortex Generation
- Researchers have found a poor correlation between physiological and mechanical approaches to calculating propelling efficiency in swimming.
- This has led to the speculation that some unknown processes may play a role in swimming propulsion, with one possibility being the generation of vortices in the water by the swimmer.
- Stroke Technique
- Just as running is the product of stride length and stride rate, swimming speed is the product of stroke length (SL) and stroke rate (SR).
- Of the two, SL is more directly related to swimming speed among competitive freestyle swimmers.

The End