BME2102:
Introduction to Biomechanics

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Schedule

			15331	15332	15333	15334	15335	15336	15337
			C01	**T01**	**L01**	**L02**	**L03**	**L04**	**L05**
			17:00 - 18:50	10:00 - 11:50	09:00 - 11:50	09:00 - 11:50	14:00-16:50	09:00 - 11:50	09:00 - 11:50
			YEUNG	YEUNG	YEUNG	YEUNG	YEUNG	YEUNG	YEUNG
			LT-18	LT-18	Y1501	Y1501	Y1501	Y1501	Y1501
Week	Date	Instructor	DONG Lixin	DONG Lixin					
1	3/9	F	Lect 1						
2	10/9	F	Lect 2						
3	16/9	R							
	17/9	F	Lect 3						
4	23/9	R							
	24/9	F	Lect 4						
5	28/9	T			Lab				
	29/9	W					Lab		
	30/9	R						Lab	
	1/10	F	National Day						
6	5/10	T				Lab			
	7/10	R							Lab
	8/10	F	Lect 5	Tutorial 1					
7	15/10	F	In-class Test						
8	19/10	T			Lab				
	20/10	W					Lab		
	21/10	R						Lab	
	22/10	F	Lect 6						
9	26/10	T				Lab			
	28/10	R							Lab
	29/10	F	Lect 7						
10	4/11	R							
	5/11	F	Lect 8						
11	9/11	T			Lab				
	10/11	W					Lab		
	11/11	R						Lab	
	12/11	F	Lect 9						
12	16/11	T				Lab			
	18/11	R							Lab
	19/11	T	Lect 10	Tutorial 2					
13	26/11	F	Lect 11						

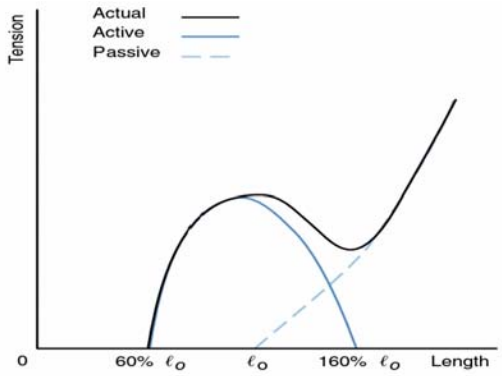
Labs

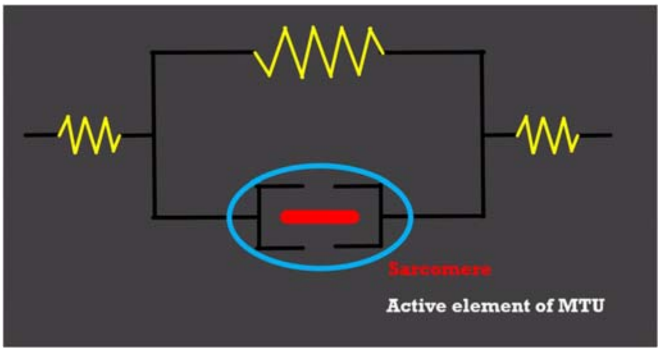
- Safety issues
  - Wear long pants please. No shorts, no skirts.—A make-up opportunity may be provided if you could not attend the lab due to this by so far but will NOT be possible for future cases.
- Being absent
  - With reasonable excuses: arrange to other sessions
  - Without reasonable excuses: no makeup
- For questions about the lab and your report grades, please contact your TA.
  - **YU Zejie**: zejieyu2-c@my.cityu.edu.hk
  - **LIAO Junchen**: junchliao2-c@my.cityu.edu.hk
  - **CAO Hui**: huicao8-c@my.cityu.edu.hk
  - **WANG Shuideng**: sdwang8-c@my.cityu.edu.hk
- Marking schemes
  - posted before the end of the first deadline of all Labs and reminded during Lecture 5.
  - not for telling you what should be included in the reports--the components have been listed in the Lab instructions
  - just for telling you the marks for each part of your report.

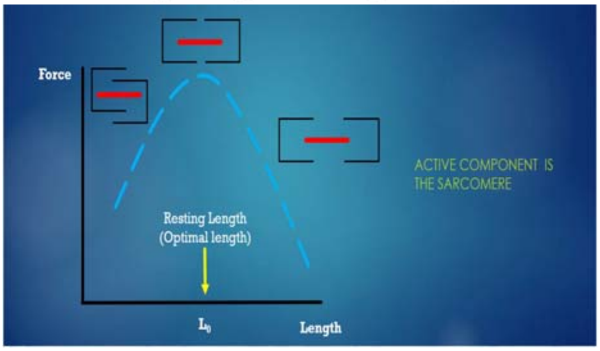
Information

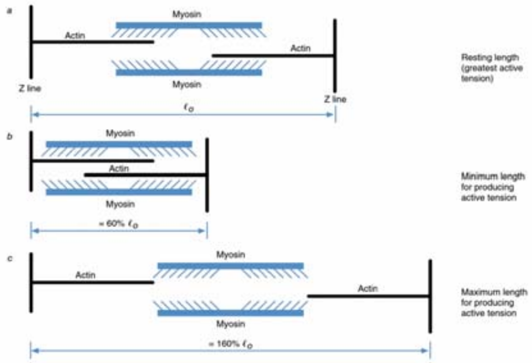
- Lab Reports (20% to the final grade)
  - Everyone should write a report (Not a team report. Teammates can only share the original data—not the processed ones or any other parts.)
  - For face-to-face sessions: one week after your session
  - Deadlines setup with the submission folders in the Canvas for the reports do not mean your individual deadline but the deadline for the Lab held latest. Very important!!!
  - Late submissions: 1 Day -10%, 2 Days -25%, 3 Days -45%, 5 Days -75 %, 1 Week or longer -100%
- HW4: due today
- HW5: posted, due **Nov. 5**
- In-class Test
  - Grading
  - Solutions will be available after grading.

Review









Review

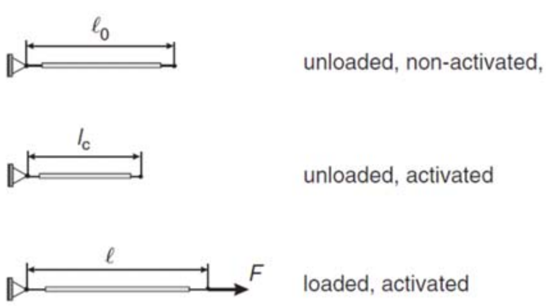


Figure 4.6

Different reference and current lengths of a muscle.

- l_0: the length of the muscle in the non-activated state
- l_c: the length of the muscle in the activated or contracted but unloaded state.
- l: the length of the muscle in the activated and loaded state.

- Now, in contrast with a simple elastic spring, the contracted length l_c serves as the reference length, such that the force in the muscle may be expressed as:

$$F = c\left(\frac{\ell}{\ell_c} - 1\right) \qquad \lambda_c = \frac{\ell_c}{\ell_0} \qquad \lambda = \frac{\ell}{\ell_0}$$

activation or contraction stretch

Review

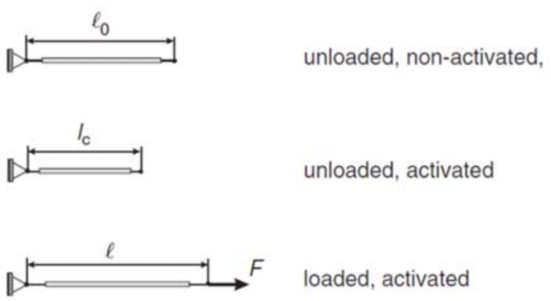


Figure 4.6

Different reference and current lengths of a muscle.

- l_0: the length of the muscle in the non-activated state
- l_c: the length of the muscle in the activated or contracted but unloaded state.
- l: the length of the muscle in the activated and loaded state.
- Now, in contrast with a simple elastic spring, the contracted length l_c serves as the reference length, such that the force in the muscle may be expressed as:

$$F = c\left(\frac{\lambda}{\lambda_c} - 1\right) \quad \text{with} \quad \lambda = \frac{\ell}{\ell_0}$$

Review

$$\ell_0 = |\vec{x}_{0,B} - \vec{x}_{0,A}| \qquad \lambda = \frac{\ell}{\ell_0} \qquad \ell = |\vec{x}_B - \vec{x}_A|$$

$$\vec{a}_0 = \frac{\vec{x}_{0,B} - \vec{x}_{0,A}}{|\vec{x}_{0,B} - \vec{x}_{0,A}|} \qquad \vec{a} = \frac{\vec{x}_B - \vec{x}_A}{|\vec{x}_B - \vec{x}_A|}$$

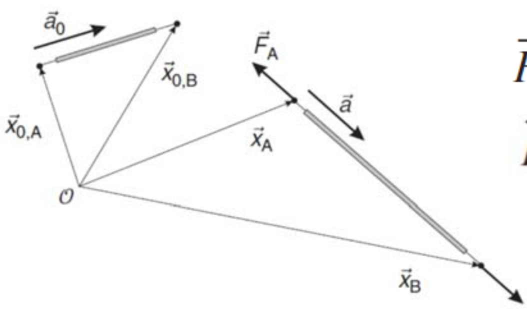


Figure 4.7

Spring in three-dimensional space.

$$\vec{F}_B = -\vec{F}_A$$

$$\vec{F}_B = F\vec{a}$$

$$F = c(\lambda - 1)$$

$$\vec{F}_B = c(\lambda - 1)\vec{a}$$

$$\vec{F}_A = -c(\lambda - 1)\vec{a}$$

V. Fluid Mechanics

Objectives

- Define fluid
- Define pressure
- Define relative and absolute motion
- Define buoyancy and buoyant force
- Explain how a fluid exerts forces on an object moving through it
- Identify the components of fluid forces
- Define drag force
- Distinguish between surface drag and form drag
- Define lift force
- Explain Bernoulli's principle
- Explain the Magnus effect
- Identify the various factors that determine the effect fluid forces have on an object

Fluids

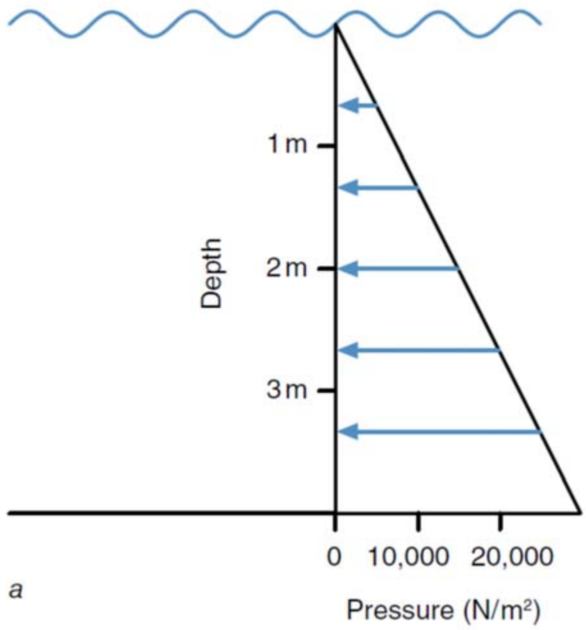
- Air & Water
- A substance that can easily flow or change its shape without separating.
- Substances that flow or continuously deform when acted upon by shear forces.

Measuring Fluids

- Pressure: Force/area (N/m^2)
- Specific Weight (γ) (gamma): Weight/volume (N/m^3)
- Density (ρ) (rho): Mass/volume (kg/m^3)
- Viscosity: internal friction, resistance to flow

Buoyant Force: Force Due to Immersion

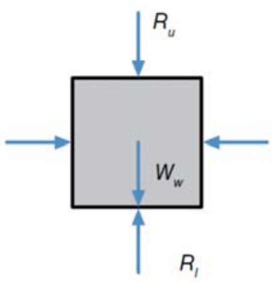
- The **pressure** the water exerts is due to the weight (force) of the water above you.
- But the water pressure doesn't just act downward on you; the water below you pushes upward on you, and the water to either side pushes laterally on you.
- Water pressure acts in all directions with the same magnitude, as long as you stay at the same level.



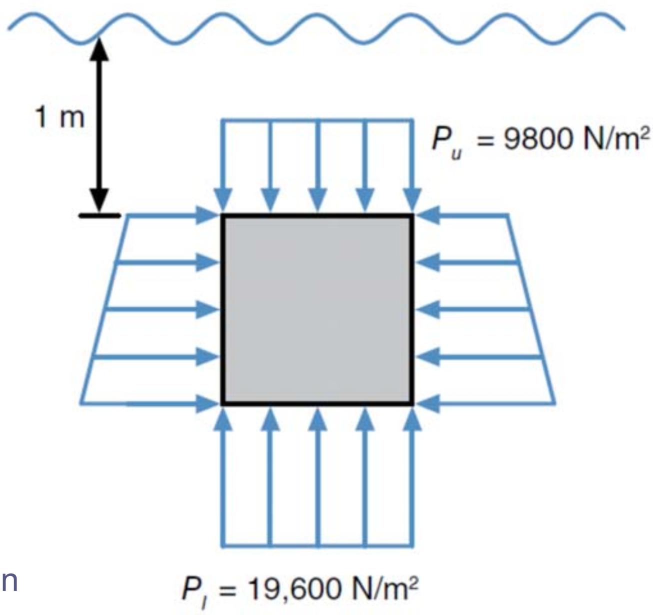
Graphical representations of the relationship between water pressure and depth

Buoyant Force: Force Due to Immersion

- One cubic meter (m^3) of water weighs about 9800 N, so at a depth of 1 m the water pressure is 9800 N/m^2. At a depth of 2 m, the 2 m^3 of water above a 1 m square weighs 19,600 N, so the pressure is 19,600 N/m^2

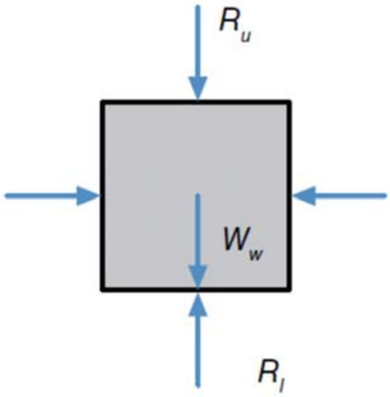


a free-body diagram of the forces acting on the cube of water



a 1.0 m^3 cube of water in 1.0 m below the water

Buoyant Force: Force Due to Immersion



a free-body diagram of the forces acting on the cube of water

$$\sum F = R_l + (-R_u) + (-W_w) = 0$$

$$\sum F = 19{,}600\text{ N} - 9800\text{ N} - 9800\text{ N} = 0$$

Specific Gravity and Density

- **Specific gravity** is the ratio of the weight of an object to the weight of an equal volume of water. Something with a specific gravity of 1.0 or less will float.
  - $\gamma = W / V$
    - W = gravity and V =volume
- Another measure that can be used to determine if a material will float is density. **Density** is the ratio of mass to volume.
  - The density of water is about 1000 kg/m^3. The density of air is only about 1.2 kg/m^3.

$$\rho = \frac{m}{V}$$

where

ρ = density,

m = mass, and

V = volume.

Fluid Forces

- When submerged into a fluid an object or body will experience two types of fluid forces
  - The Buoyant Force
    - Results from immersion in fluid
  - A Dynamic Force
    - Results from the object's or body's relative motion in the fluid
    - Broken into Lift & Drag

Buoyancy of the Human Body

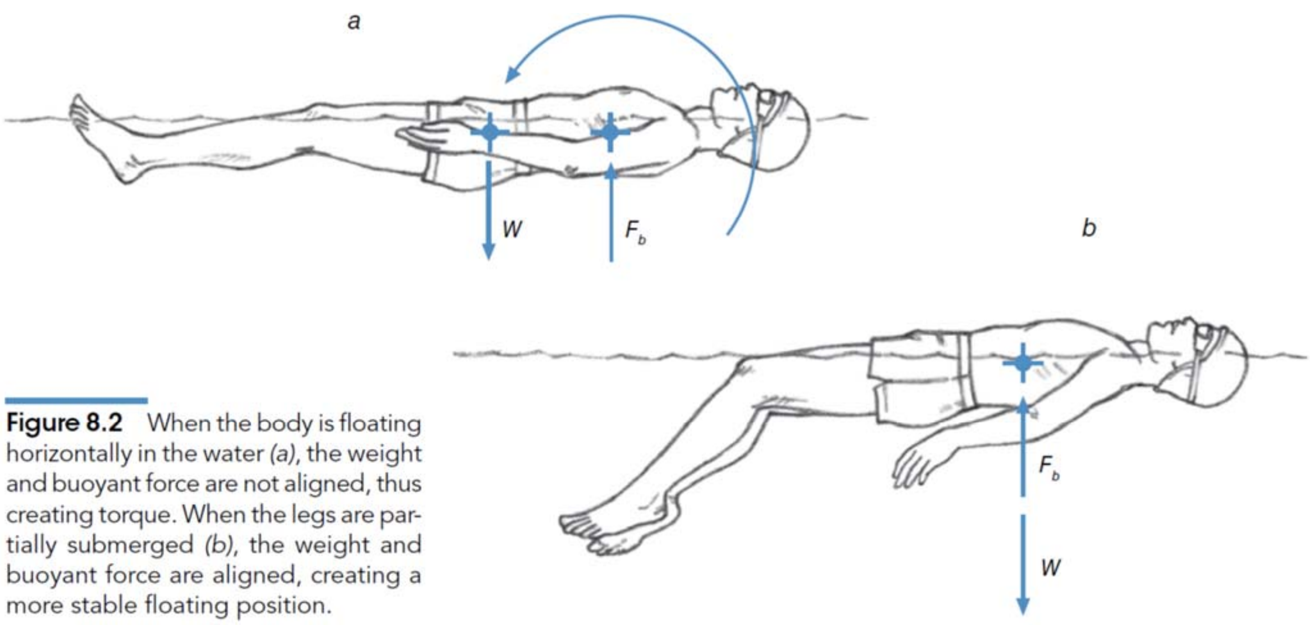


Figure 8.2 When the body is floating horizontally in the water *(a)*, the weight and buoyant force are not aligned, thus creating torque. When the legs are partially submerged *(b)*, the weight and buoyant force are aligned, creating a more stable floating position.

The Buoyant Force

- The Buoyant Force (F_B) is a reaction force from a fluid
  - Acts vertically in the positive direction through an object's Center of Volume (opposing Force of Gravity (W))
  - It is equal to the weight of the volume of displaced fluid by the object or body
  - If $F_B = W$ then the object will be in equilibrium
  - If $F_B < W$ then the object will sink
  - If $F_B > W$ then the object will float

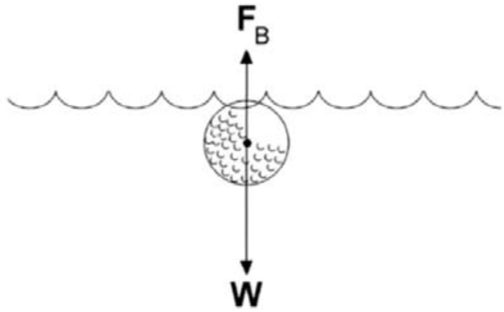


Figure 8.1. The resultant vector of gravity (**W**) and buoyancy (**F**$_B$) will determine if an inanimate object floats. This golf ball will sink to the bottom of the water hazard.

The Buoyant Force

- $F_B = V_d\ \gamma$
  - V_d = Volume displacement (m^3)
  - γ = Specific Weight of Fluid (N/m^3)

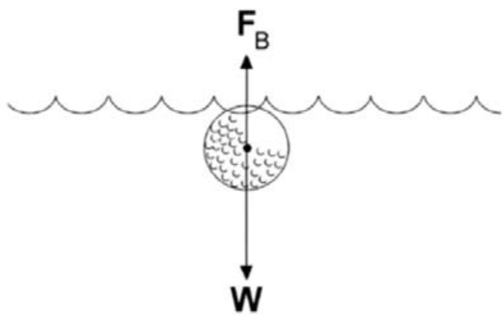


Figure 8.1. The resultant vector of gravity (**W**) and buoyancy (**F**$_B$) will determine if an inanimate object floats. This golf ball will sink to the bottom of the water hazard.

Dynamic Fluid Force: Force Due to Relative Motion

$$F \propto \rho A v^2$$

where

$\propto$ = is proportional to,

F = dynamic fluid force,

ρ = fluid density,

A = surface area of the object, and

v = relative velocity of the object with respect to the fluid.

Dynamic Fluid Force: Force Due to Relative Motion

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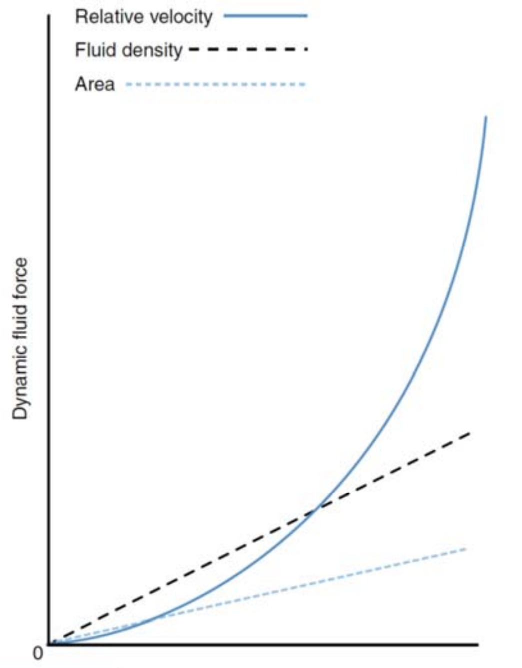


Figure 8.3 The relationship between dynamic fluid force and object area, fluid density, and relative velocity.

Relative Velocity

- In order to analyze the effects of a fluid on an object we must understand both the velocity of the object and the fluid – either can be in motion
- We use Relative Velocity to understand the relative velocity of the object compared to the fluid
  - $V_{Rel} = V_{Obj} - V_{Flu}$

Drag Force

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

where

F_D = drag force,

C_D = coefficient of drag,

ρ = fluid density,

A = reference area (usually the cross-sectional area of the object perpendicular to the relative velocity), and

v = relative velocity of the object with respect to the fluid.

Drag Force

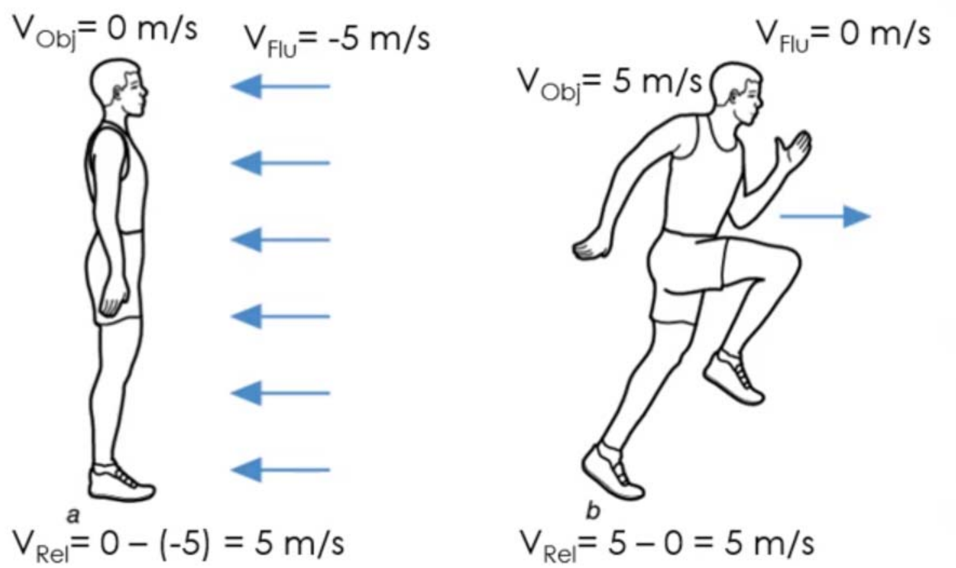


Figure 8.4 Relative velocity between a runner and the wind.

Drag Force

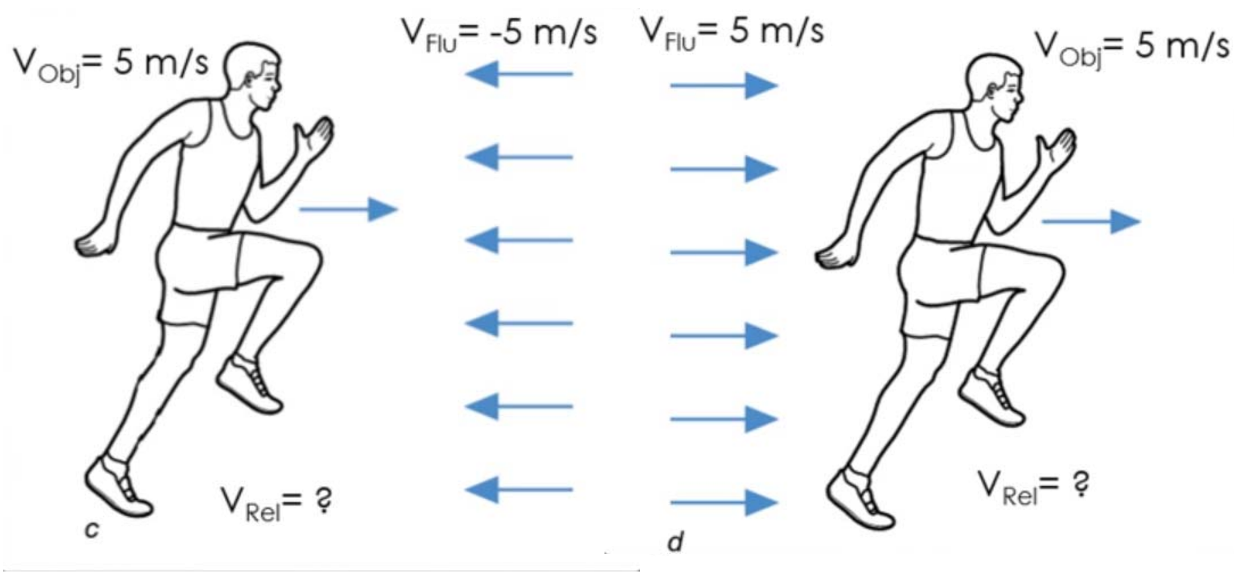


Figure 8.4 Relative velocity between a runner and the wind.

Resultant Dynamic Fluidic Force

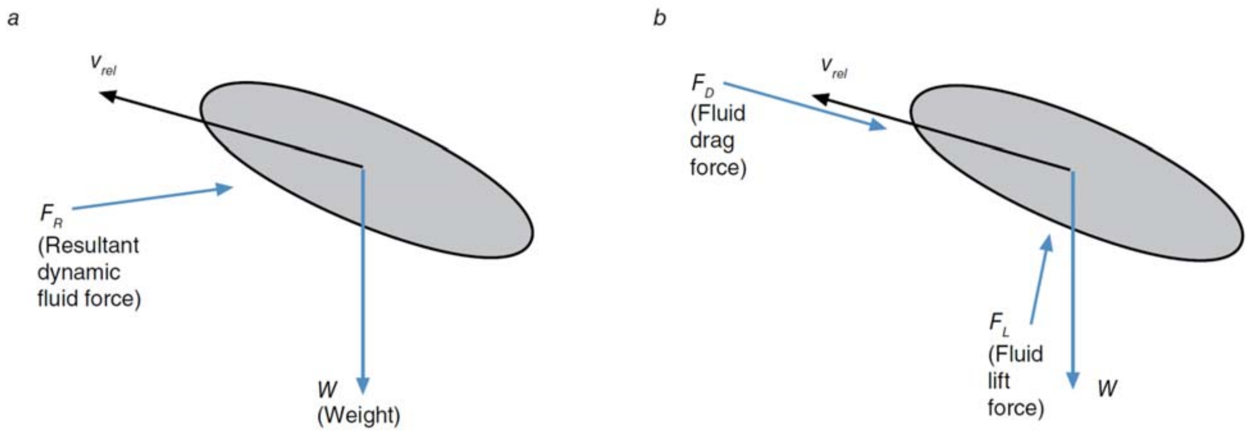


Figure 8.5 The resultant dynamic fluid force (F_R) acting on an object *(a)*; the drag (F_D) and lift (F_L) components of this force *(b)*.

Surface Drag

- Skin friction or viscous drag

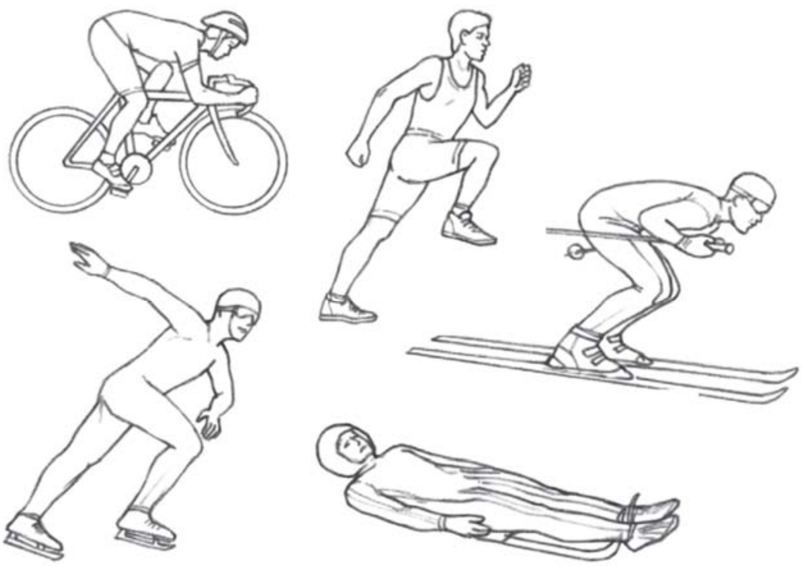


Figure 8.6 Athletes in certain sports wear skintight apparel to reduce surface drag.

Laminar Flow vs Turbulent Flow

- Laminar Flow
  - Fluid molecules stay close to the surface of the object and flow past in a smooth manner
- Turbulent Flow
  - Fluid molecules separate from the surface and beginning bouncing around in a chaotic fashion

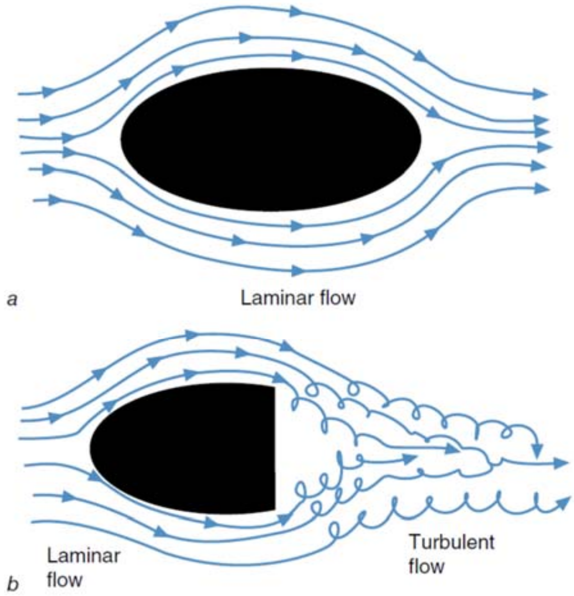


Figure 8.7 Examples of objects experiencing laminar flow *(a)* and laminar and turbulent flow *(b)*.

Form Drag

- Shape drag, profile drag, or pressure drag

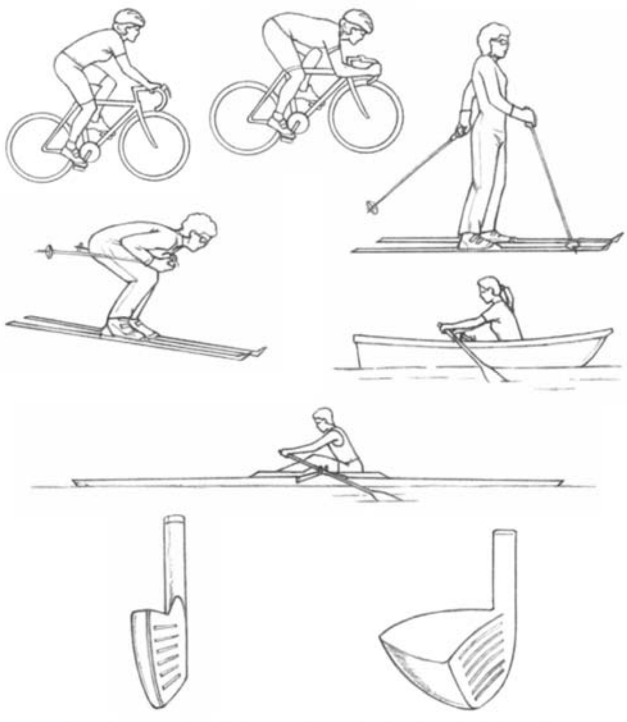


Figure 8.8 Examples of nonstreamlined and streamlined shapes that affect the magnitude of form drag.

Strategies for Reducing Drag Force

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

where

F_D = drag force,

C_D = coefficient of drag,

ρ = fluid density,

A = reference area (usually the cross-sectional area of the object perpendicular to the relative velocity), and

v = relative velocity of the object with respect to the fluid.

Strategies for Reducing Drag Force

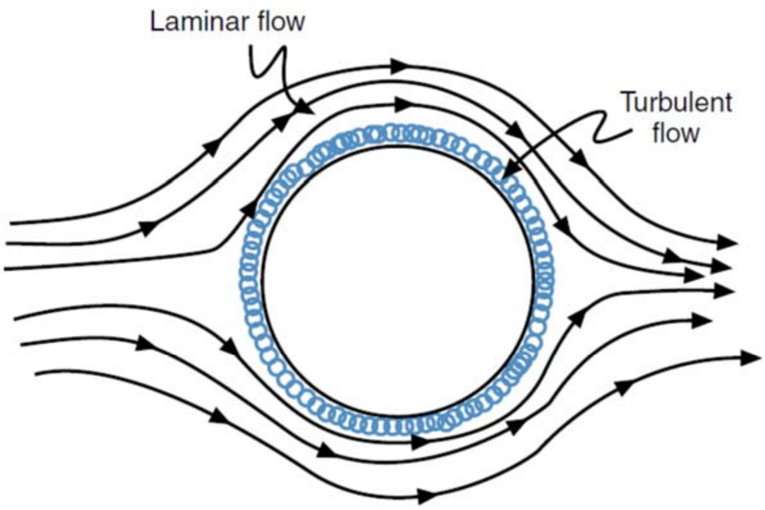


Figure 8.9 A rough surface might decrease form drag by creating a layer of turbulent flow completely surrounding the object on the leading and trailing edges. Outside of this turbulent layer is laminar flow.

Strategies for Increasing Drag Force

Figure 8.10 The "gills" or scoops on the AQx water exercise shoes create a drag force as the foot is pulled through the water.

Lift Force

$$F_L = \frac{1}{2} C_L \rho A v^2$$

where

F_L = lift force,

C_L = coefficient of lift,

ρ = fluid density,

A = reference area (usually the cross-sectional area of the object perpendicular to the relative motion),

v = relative velocity of the object with respect to the fluid.

Lift Force

- Lift force is the dynamic fluid force component that acts perpendicular to the relative motion of the object with respect to the fluid.

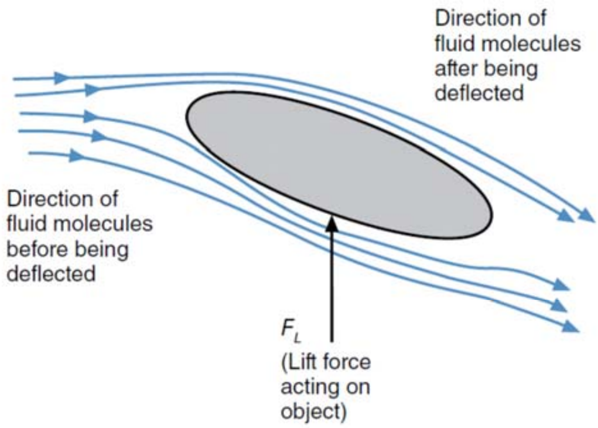


Figure 8.11 The fluid molecules passing by an object are deflected laterally. The change in direction is a lateral acceleration caused by the force exerted by the object. The reaction to this force is the lift force acting on the object.

Bernoulli's Principle

- Speed of movement dictates pressure systems

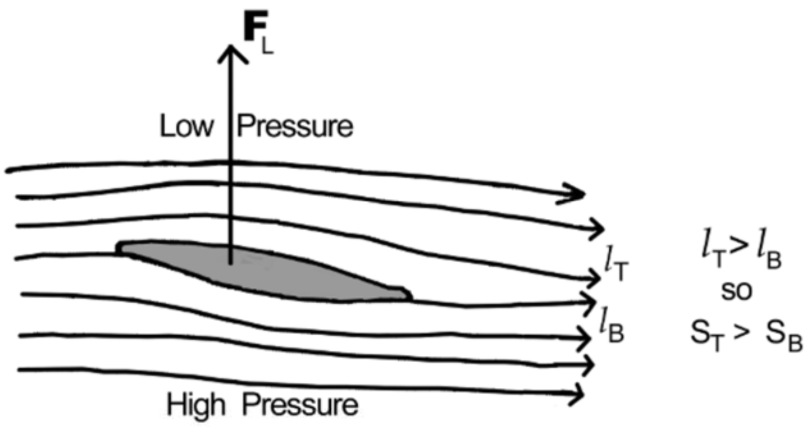


Figure 8.12. The lift force ($\mathbf{F}_L$) acting on a discus or airplane wing can be explained using Bernoulli's Principle. The greater distance (and faster speed of fluid flow) over the top of the wing (l_T) compared to the distance under the bottom (l_B) creates a pressure differential. The high pressure below and lower pressure above the wing lifts the airplane.

Understand Lift

- Fluid Molecules 'bounce' off of an object
- The change in direction of the fluid molecule results from a force applied to it by the object
- Newton's 3rd law tells us the molecule will create an equal and opposite force back on the object

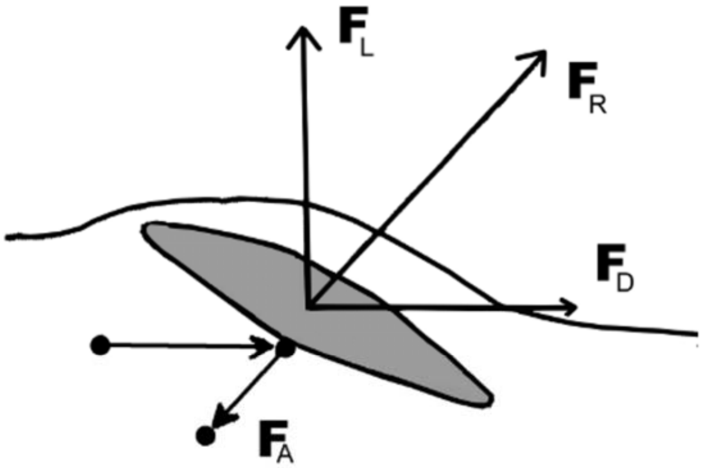


Figure 8.11. The kinetics of the lift and drag forces can be explained by Newton's laws and the interaction of the fluid and the object. The air molecules (·) deflecting off the bottom of the discus creates the lift (F_L) and drag (F_D) acting on the discus.

Bernoulli's Principle

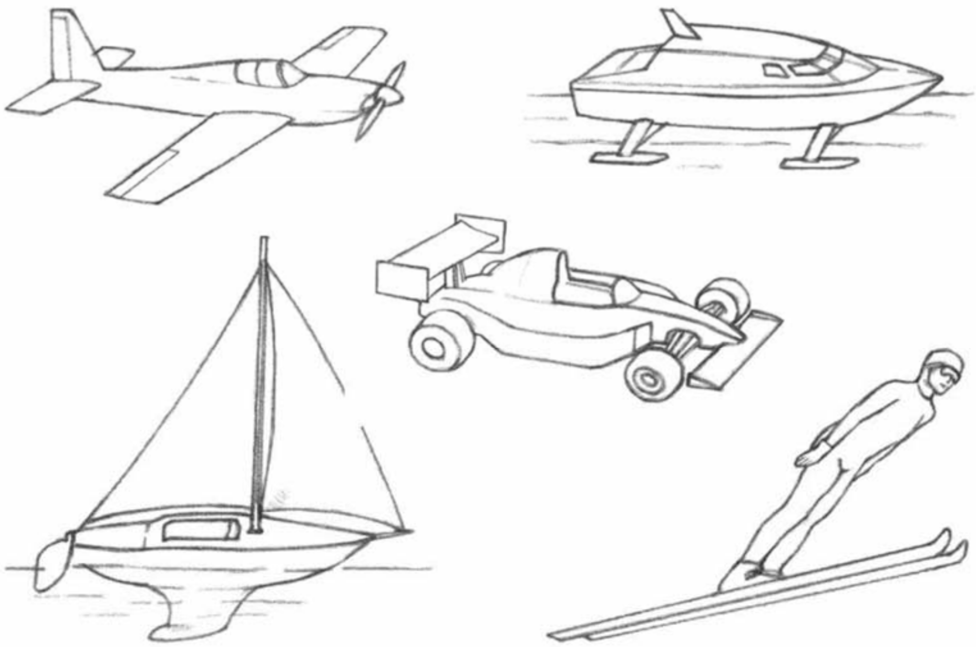


Figure 8.12 Examples of objects that create lift forces.

Bernoulli's Principle

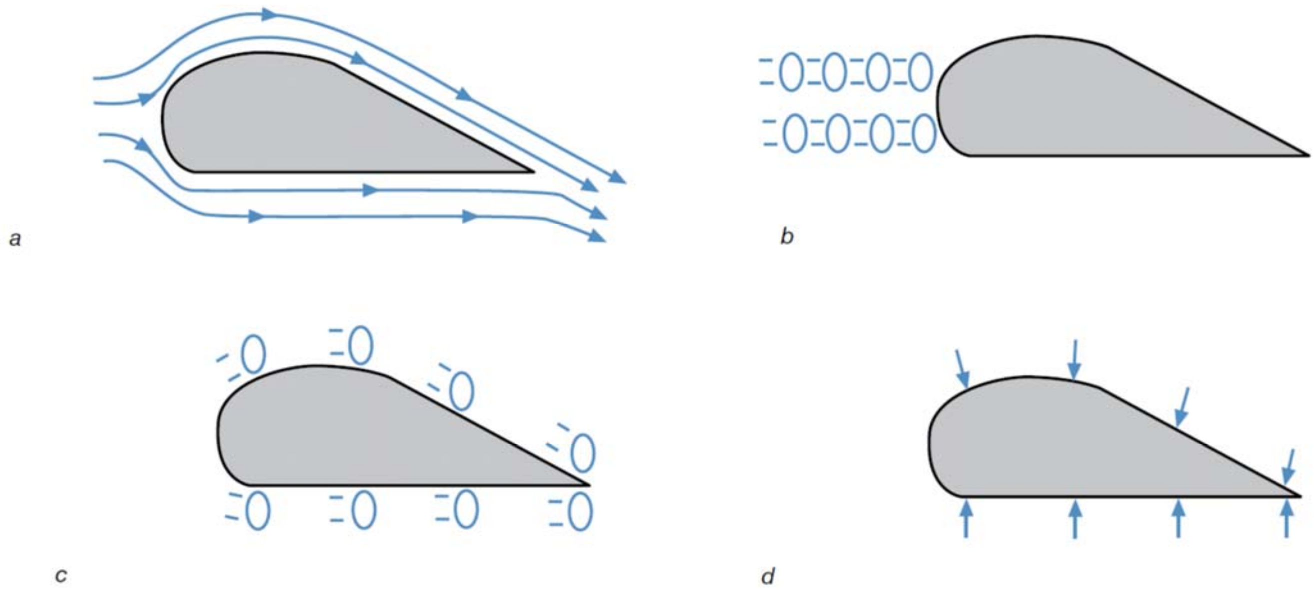
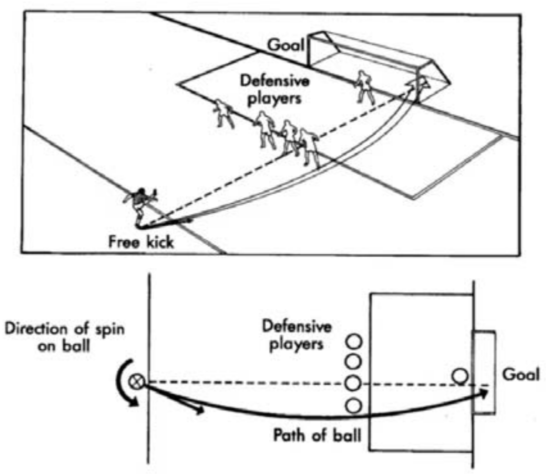


Figure 8.13 A possible explanation for Bernoulli's principle using an airfoil as an example.

Spin and the Magnus Effect

- A lift force caused by a spin is called a Magnus force.



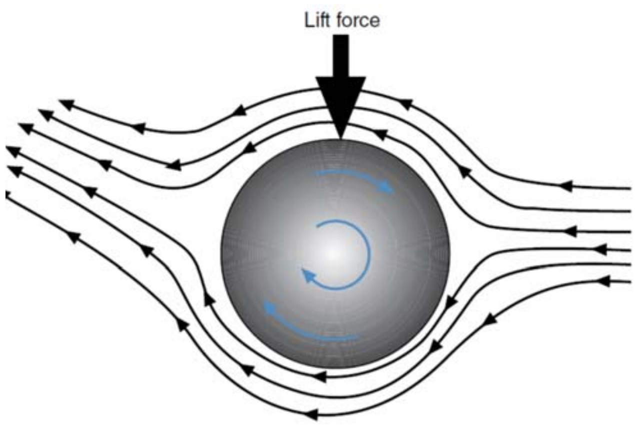


Figure 8.14 A ball with topspin has a lift force that acts downward on the ball.

Magnus Force

- Created on pressure systems developing on either side of a spinning object.
- One side will be spinning in the same direction as the relative velocity.
  - This creates a low pressure area
- The other side will be spinning in the opposite direction of relative velocity
  - This creates a high pressure area

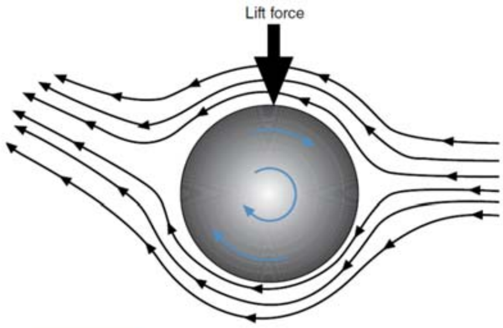
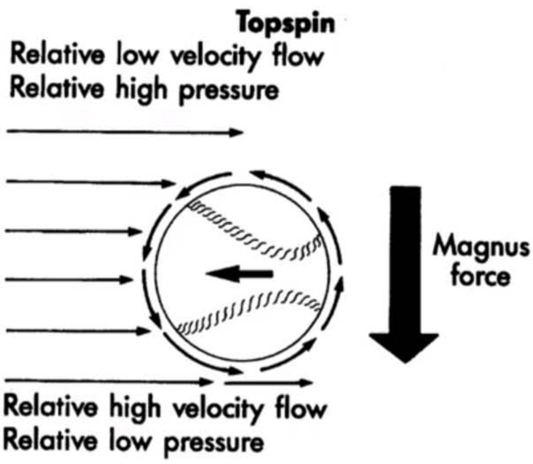
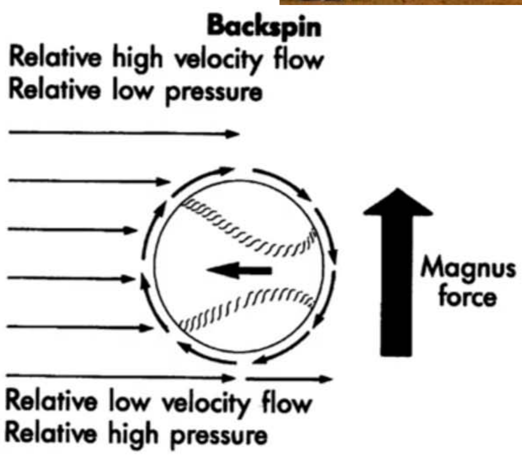


Figure 8.14 A ball with topspin has a lift force that acts downward on the ball.

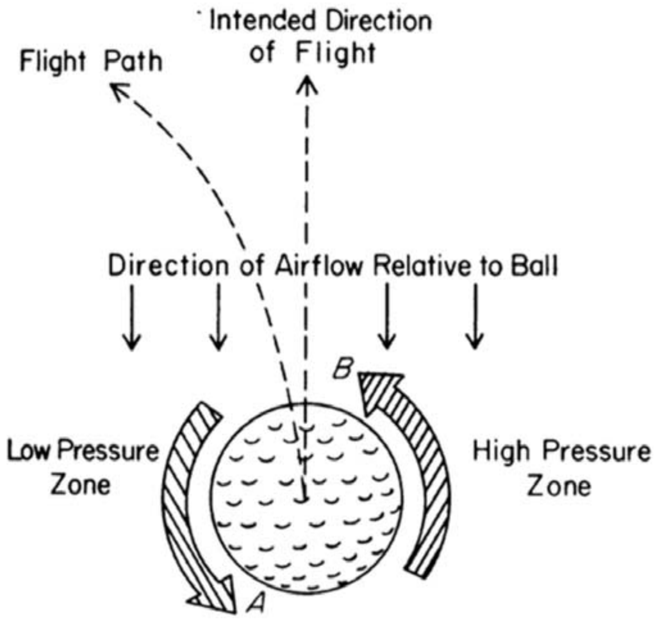
https://en.wikipedia.org/wiki/Magnus_effect

Magnus Force





Magnus Force



Effects of Dynamic Fluid Forces

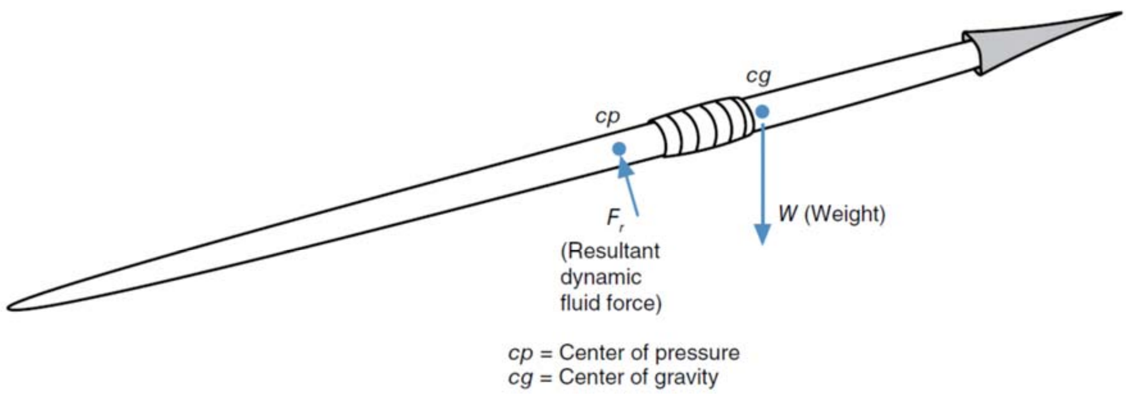


Figure 8.15 The forces acting on a javelin—its weight and the dynamic fluid force—act at different locations, thus creating a torque that causes the javelin to rotate so that the tip drops.

Effects of Dynamic Fluid Forces

- Two objects similar in size and shape will experience the same dynamic fluid forces, but the more massive object will experience less acceleration.

$$\sum F = ma$$

where

$\sum F$ = net force,

m = mass of the object, and

a = acceleration of the object.

$$F \propto \rho A v^2$$

$$a = \frac{\Sigma F}{m} \propto \frac{\rho A v^2}{m}$$

$$a \propto \frac{\rho A v^2}{m}$$

Effects of Dynamic Fluid Forces

- Two objects similar in size and shape will experience the same dynamic fluid forces, but the more massive object will experience less acceleration.
- The wind blowing in the face of a 50 kg distance runner will have a greater effect than the same wind blowing in the face of a 70 kg distance runner.
- It’s easier to throw a curveball with a Nerf ball than with a real baseball.

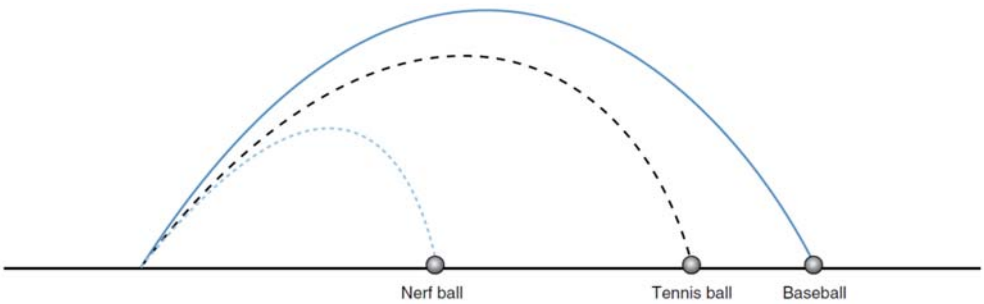
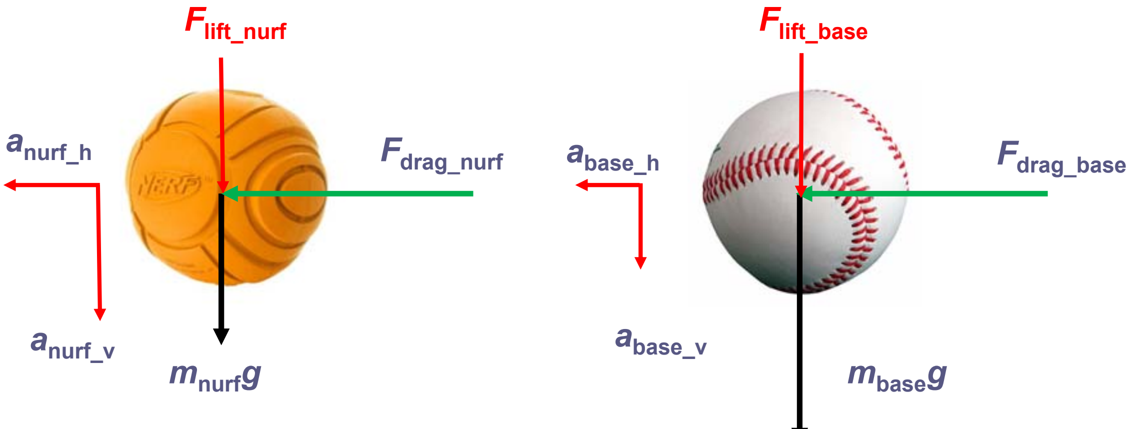


Figure 8.16 The trajectories of three balls with different masses, demonstrating that the effect of fluid forces is influenced by the mass of the object.

Effects of Dynamic Fluid Forces



$\Sigma F_{nurf\_v} = -F_{lift\_nurf} - m_{nurf}g = m_{nurf}a_{nurf\_v}$

$a_{nurf\_v} = -F_{lift\_nurf}/m_{nurf} - g$

$\Sigma F_{base\_v} = -F_{lift\_base} - m_{base}g = m_{base}a_{base\_v}$

$a_{base\_V} = -F_{lift\_base}/m_{base} - g$

$F_{lift\_nurf} = F_{lift\_base}$

$m_{nurf} < m_{base}$

So,

$a_{nurf\_V} > a_{base\_v}$