4.3 – Fundamentals of Biomechanics

4.3.1 - Define the terms: force, speed, velocity, displacement, acceleration, momentum and impulse

TERM	DEFINITION	EQUATION
Force	The mechanical interaction that goes on between 2 objects	MASS X ACCELERATION
Speed	The rate at which someone or something is able to move or operate at	DISTANCE --------------- TIME
Velocity	The speed of something in a given direction	DISPLACEMENT CHANGE ----------------------------------- TIME
Displacement	How far an object has moved horizontally, vertically or laterally	
Acceleration	The increase in rate of speed	CHANGE IN VELOCITY ------------------------------- TIME
Momentum	The quantity of motion of a moving body, measured as a product of its mass and velocity	MASS OF OBJECT X VELOCITY
Impulse	A motivating force	FORCE X TIME
Vectors	A measurement that have both size and direction	
Scalars	A measurement that only has size	

4.3.2 - Analyse velocity-time, distance-time and force-time graphs of sporting actions

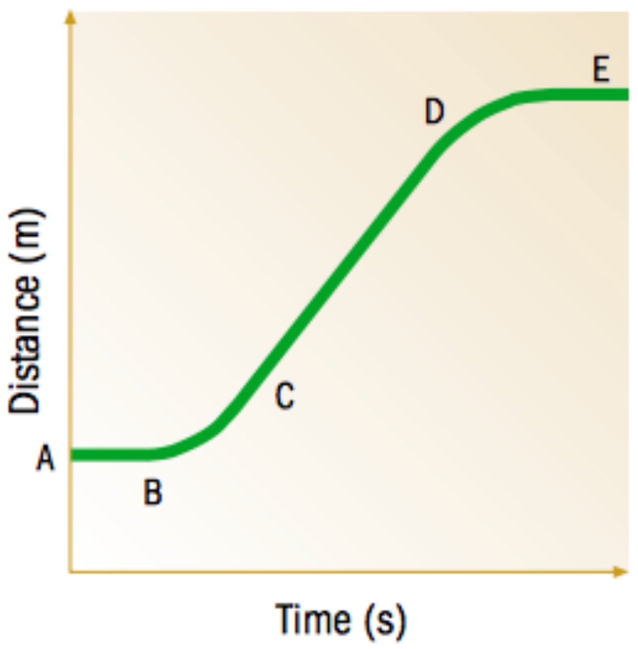
- The measurements of speed and velocity are used to describe the rate at which a body moves from one position to the next or how fast it is moving

TERM	EXPLANATION	VECTOR OR SCALAR	EQUATION	SYMBOLIC EQUATION	MEASUREMENTS
Speed	The rate of change of distance	Scalar	Speed = Distance / Time	S = D / T	S = (m/s) D = (m) T = (s)
Velocity	The speed of a body in a given direction and is the rate of change of displacement	Vector	Velocity = Displacement / Time	V = D / T	V = (m/s) D = (m) T = (s)
Force	The cause of an object with mass to change its velocity	Vector	Force = Mass X Gravity	F = M X G	F = (N) M = (kg) (g) G = (N kg)
Acceleration	The rate at which a body changes its velocity	Scalar	Acceleration = Change in Velocity / Time	$A = V_1 - V_2$ / T V_1 = Final Velocity V_2 = Initial Velocity	A = (m/s^2) V_1 - V_2 = (m/s) T = (s)
Displacement	The shortest distance between the initial point and the final point	Vector	Displacement = ½ (Initial Velocity + Final Velocity) X Time	S = ½ (U + V) T	S = (m) U + V = (m/s) T = (s)
Momentum	The product of mass and velocity: 'Quantity of Motion'	Vector	Momentum = Mass X Velocity	P = M X V	P = (m/s^2) M = (kg) (g) V = (m/s)

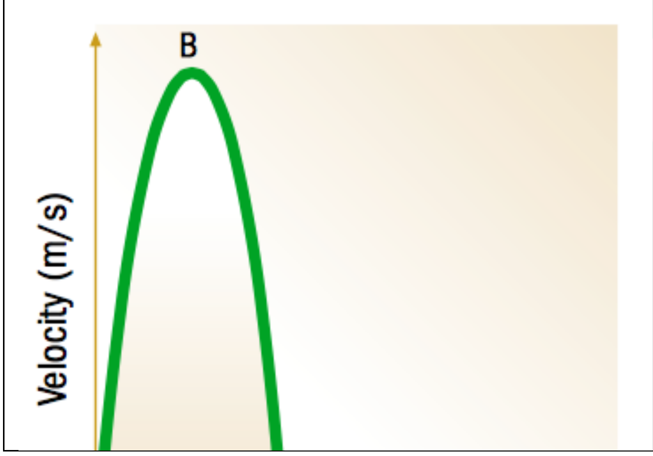
TERM	DEFINITION
Scalar	Quantities that are fully described by a magnitude (or numerical value) alone
Vector	Quantities that are fully described by both a magnitude and direction

DISTANCE - TIME GRAPH

GRAPH	LINE TYPE	MOTION ANALYSIS	LETTER

	Horizontal	No Motion	A - B
	Positive Curve	Acceleration	B - C
	Negative Curve	Deceleration	D - E

<u>VELOCITY - TIME GRAPH</u>

<u>GRAPH</u>	<u>LINE TYPE</u>	<u>MOTION ANALYSIS</u>	<u>LETTER</u>
	Horizontal	Constant	C - D
	Positive Curve	Acceleration	A - B

	Negative Curve	Deceleration	B - C

4.3.3 - Define the term center of mass

CENTER OF MASS & CENTER OF GRAVITY

- COM: The mathematical point around which the mass of a body or object is distributed
- COG: The mathematical point of the body or object at which the force of gravity can be considered to be acting

4.3.4 - Explain that a change in body position during sporting activities can change the position of the centre of mass

- These 2 terms (COM & COG) are often interchangeable, and for bodies or objects, where the force of gravity does not vary
- The 2 centers are in the same place, bodies and sporting elements

    - **HAMILL & KNUTZEN (2009)**
        - The center of gravity refers to the effect of gravity and so its only in the vertical direction and has no horizontal or lateral component

- COM:
    - Depends on the distribution of the material in a body or object
        - This will be affected by the density of the body or object and shape
            - In human body, the density will depend on the different tissues in the body (muscle, fat, skin and the air in the lungs)
            - The shape will depend on the position of the body segments and their different masses
                - Thus the center of mass will be in different place for individuals of different body types, ages and genders

REASONS FOR KNOWING THE POSITION OF COM

REASON	**EXPLANATION**	**EXAMPLE**
It determines the stability of static positions	If the vertical projection of a line downwards from the COM lies within the base of support The position of the body or object is stable and if disturbed by an external force, will return to its original position	• Between the feet when standing • This is the principle behind many balance activities
It is the axis for all free airborne rotations of the body or object		Somersaulting in diving
The COM acts as the reference point when considering whole body or object translation		• Long jump in athletics o The trajectory of the COM during ▪ Take off ▪ Flight Landing

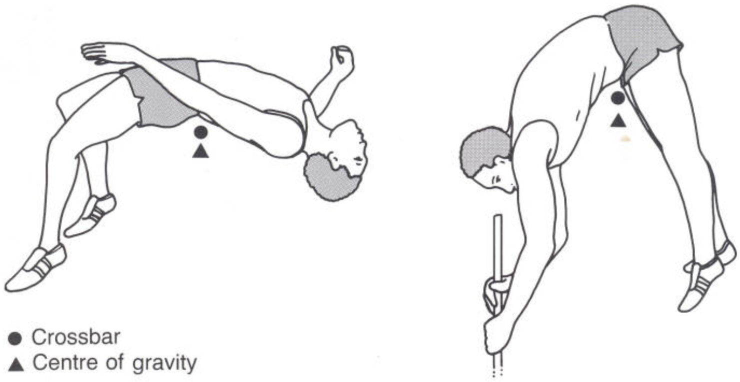
MEASURING COM

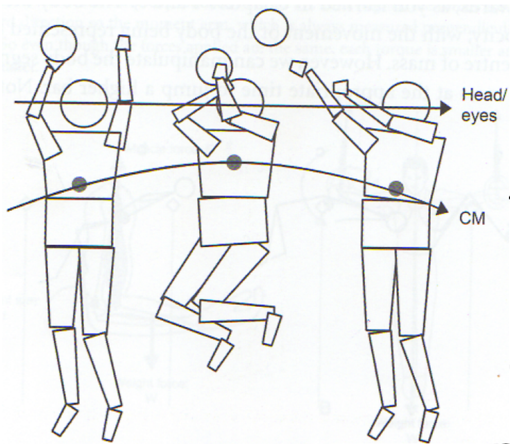
- Calculations from segmental positions and masses
- Reaction board
- Suspension of an object or model

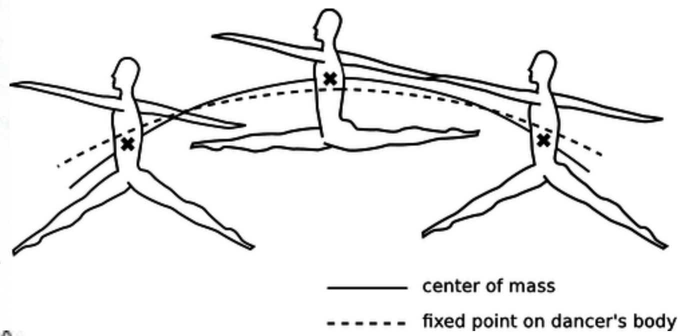
- Can only be measured to an accuracy of 1-2 kilometres from the human body

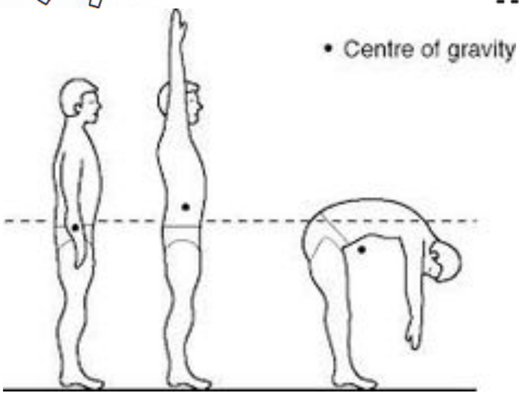
  - Due to errors introduced by:
    - Breathing
    - Blood circulation
    - Inaccuracies in segment densities and positions

<u>VISUAL COM & COG</u>



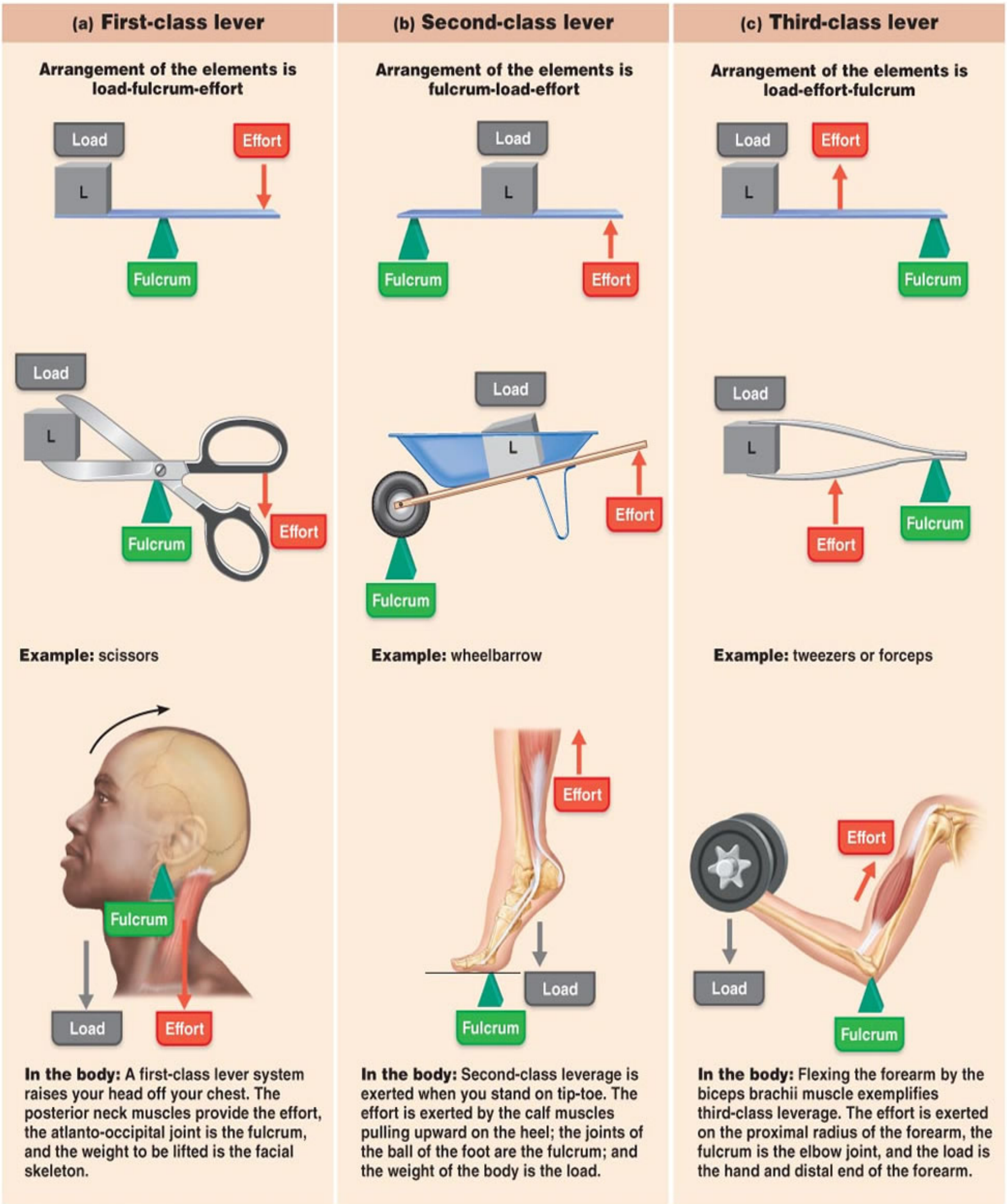






4.3.5 - Distinguish between first, second and third class levers

- Levers consist of a rigid rod, a fulcrum (axis), a resistance force and an effort force
- The distance at which the resistance acts from the fulcrum is the resistance arm
- The distance at which the effort acts from the fulcrum is the effort arm
- A lever has a mechanical advantage:
- This is how much effort force is multiplied by to overcome the resistance force and can be calculated as the effort arm divided by the resistance arms
- Levers can be classified into 3 types of depending on the positions of the effort and resistance force relative to the fulcrum



4.3.6 - Label anatomical representations of levers

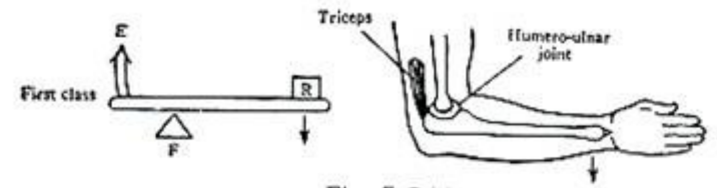


Fig. 7.7 (a)
First Class ; E ; F ; R ; Triceps ; Humero-ulnar joint.

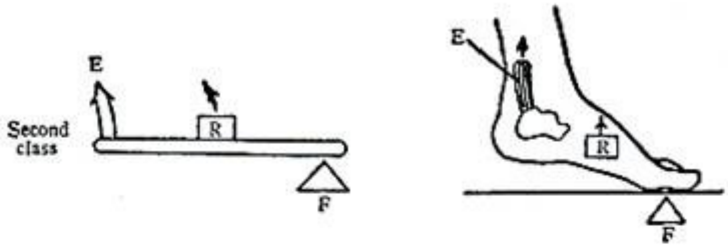


Fig. 7-7 (b)
Second Class ; F ; E ; R ; E ; R ; F .

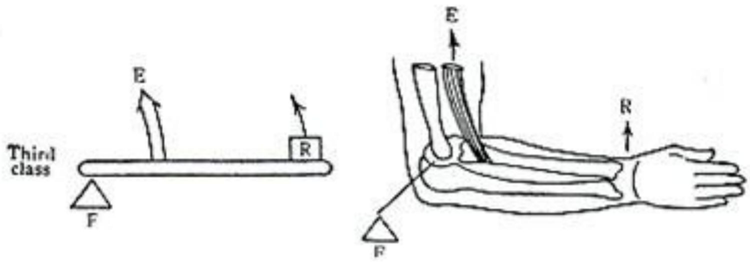


Fig. 7-7 (c)
Third Class ; F ; E ; R ; F ; E ; R .

4.3.7 - Define Newton's three laws of motion

	LAW	EXPLANATION
1	The Law of **Inertia**	• An object at rest will stay at rest o Unless an outside force is placed on it
2	The Law of **Acceleration**	• The relationship between an objects mass (m), its acceleration (a) and the applied force: o **F=ma**
3	The Law of **Counter Force**	• For every action there is an equal and opposite reaction

4.3.8 - Explain how Newton's three laws of motion apply to sporting activities

LAW	APPLICATION TO SPORT	EXAMPLE
The Law of **Inertia**	• A body at rest tends to remain at rest A body in motion continues in motion with consistent speed and in the same direction unless acted upon by an outside force	STATICS Athlete / Object is motionless • Olympic lifter • Diver before a dive • Gymnast after the landing DYNAMICS Athlete / Object is in motion • Cyclist coasting at a constant velocity Skier coasting at a constant velocity
The Law of **Acceleration**	• The velocity of a body is changed only when acted upon by an additional force The produced acceleration or deceleration is proportional to and in the same direction of the force	• If a baseball player hits a ball with double the force, the rate at which the ball will accelerate (speed up) will be doubled. Football players can slow down, stop, or reverse the direction of other players depending upon how much force they can generate and in which direction.

4.3.9 - State the relationship between angular momentum, moment of inertia and angular velocity

TERM	SYMBOL	DESCRIPTION
Angular Momentum	**L**	A vector quantity that represents the product of a body's moment of inertia
Moment of Inertia	**I**	A measure of an object's resistance to changes in its rotation velocity and angular velocity
Angular Velocity	**W**	A particular axis

EQUATION RELATING ANGULAR MOMENTUM, MOMENT OF INERTIA & ANGULAR VELOCITY

- ANGULAR MOMENTUM = MOMENT OF INERTIA X ANGULAR VELOCITY
  - L = I X W

4.3.10 - Explain the concept of angular momentum in relation to sporting activities

- Angular momentum is conserved when no outside torques act on an object
  - As the moment of inertia decreases, the angular rotation has to increase to keep the same angular momentum
    - This is most evident when a figure skaters spins

- When a figure skater starts a spin
  - Arms outstretched: **LARGE MOMENT OF INERTIA**
  - As the skater brings the arms in: **DECREASING THE MOMENT OF INERTIA**
  - The rotational speed increases

4.3.11 - Explain the factors that affect projectile motion at take-off or release

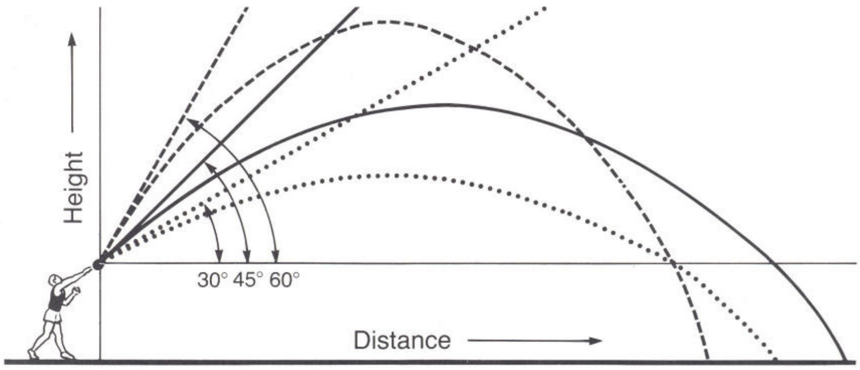
SPORTS INVOLVED IN THE PROJECTION OF AN OBJECT INTO THE AIR	**APPLYING TO THE HUMAN BODY**	**QUALITY OF PERFORMANCE**
• Shot Put • Football Tennis	• Gymnastics • Long Jump High Jump	Depends very largely on the performers ability to control the projectile

PROJECTILE MOTION		
DESCRIPTION	**EFFECT**	**USE OF INFORMATION**
• Any body that is given initial velocity (speed) and follows a path determined by the effect of gravity and air resistance The path followed by a projectile is called a trajectory	• The projectile is affected by horizontal and vertical motion Which are independent of each other	Information such as speed of release and angle of release to calculate how far the object with travel

3 FACTORS THAT AFFECT PROJECTILE MOTION

1) Angle of Release
2) Height of Release
3) Speed of Release

Such factors can be changed to influence distance



The parabolic flight path for various release angles

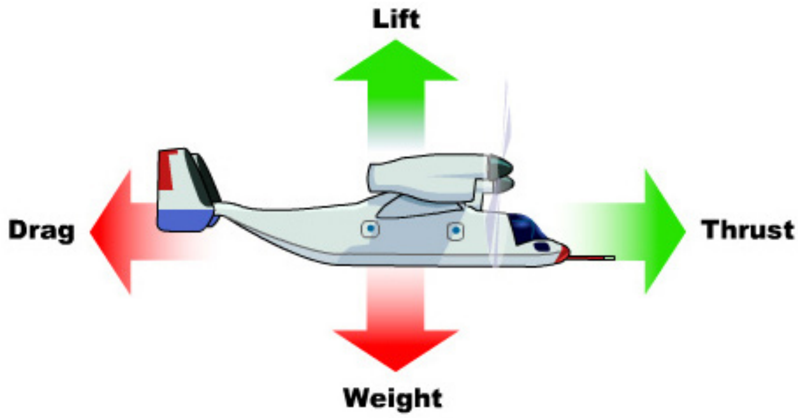
4.3.12 - Outline the Bernoulli principle with respect to projectile motion in sporting activities

FLUID DYNAMICS

- **DRAG FORCE**
  - Opposite to the objections motion
  - Increases as the object moves faster
    - As a body / object moves through a resisted medium
      - AIR: Projectile motion
      - WATER: Swimming

Small drag in streamlined position

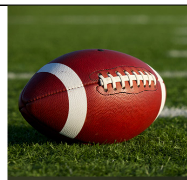
Large drag in unstreamlined position



- When the body / object moves through the fluid it experiences:
  - A force in the direction opposite to its motion
    - The force is known as: air / water resistance or drag

- The reason for the force opposing the direction is that the motion of the body / object is trying to:
  - Push apart molecules of the fluid
  - The forces between the molecules resist this
    - Thus applying a force to the body / object

TYPES OF DRAG	**SUM UP**	**AFFECTED BY**	**EXAMPLE**
Surface Drag	Caused by the interaction between the surface of the body or object and the fluid molecules	• Velocity ○ A faster moving object has to push apart more molecules per second • Surface ○ A larger object will be contracting more fluid molecules • Nature ○ A smoother surface will push apart molecules more easily • Density Denser fluids have more molecules to push apart	

Form Drag	Caused by the shape of the body or object	• Frontal area of a body or object ○ Pushed more molecules • The shape of the body or object • Relative velocity Fluid of the body or object	  Streamline shape (rugby ball / American football) travelling end-on experiences less drag than a spherical ball as the fluid molecules are parted more easily by the pointed end of the rugby ball / American football
Wave Drag	Component of the drag moving at transonic and supersonic (speed close to sound) speeds due to the presence of shock waves	• The opposite force caused by the object making waves in the fluid Important in motion through water	 

- All of these factors combine into an equation for drag:
    - **F = ½C d A p v²**

SYMBOL	**MEANING**
C d	The drag coefficient, a variable affected mainly by the shape and surface roughness of the body or object
A	The frontal area of the body or object
p	Fluid density

- The drag force is negative because it resists the direction of motion of the body or object
- Drag force depends on the square of the velocity
- At low speeds there is little drag, at higher speeds there is higher drag
    - There is little effect of drag on running (although reducing it can help performance slightly)
    - There is a high effect of drag on cycling, therefore cyclists must try to reduce it by their body positions and clothing

- When fluid is moving (or a body or object is moving through it) the pressure it exerts reduces as its velocity increases
  - This is known as the **Bernoulli Principle**
    - And states that the pressure exerted by a fluid is inversely related to its velocity
      - When applied to a body or object, this means that faster fluid flow reduces the pressure on the body or object
        - If there is uneven speed flow on each side of the body or object, then there will be an uneven pressure on either side
- This means the body or object will move from high to low pressure, thus changing its motion

LIFT FORCE, MAGNUS FORCE & BOUNDARY LAYERS

LIFT FORCE

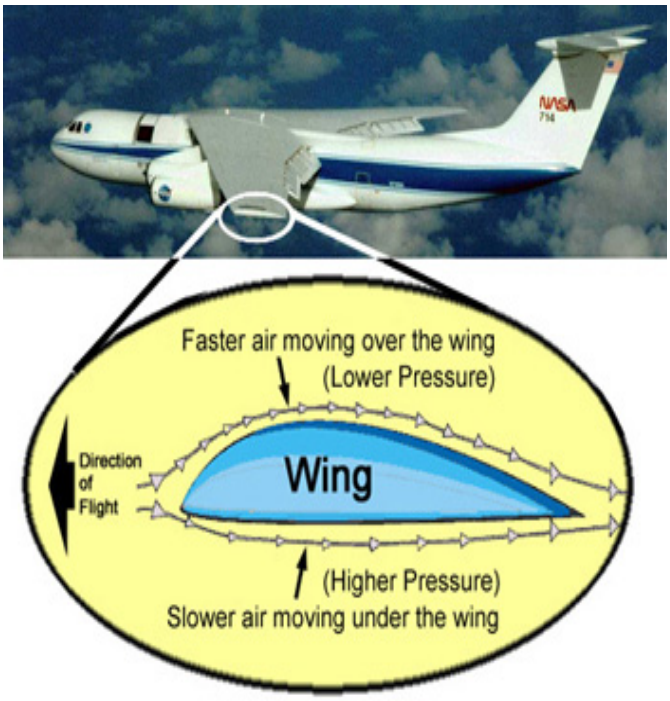
- This is a force acting at right angles to the direction of motion
- The aircraft wing is shaped differently on its top and bottom surfaces, thus leading to pressure differences above and below
- As the wing is shaped to speed up the flow over the top surface, the result is lower pressure above the wing and higher pressure below it, forcing the wing (and the airplane) upwards

- The same effect happens to sails on boats, but as the sail is vertical, the force is directed sideways and forwards

- A javelin does not always fly best if it travels through its point - it usually goes further if it is angled slightly upwards relative to its motion

- If an object or body is experiencing a lift force it will rise or stay in the air longer if there was no lift force

If it is expecting negative lift, it will drop faster than with no force



MAGNUS FORCE

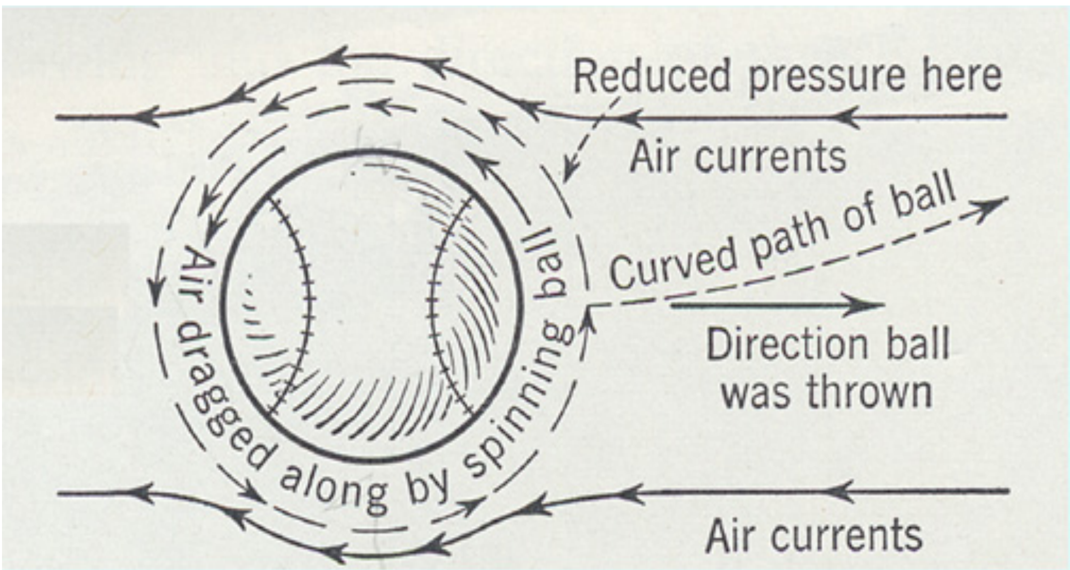
- When a body or object is rotating while moving through the air (spinning a ball) the air is dragged around by the rotation of the ball
- This causes an increased velocity on one side of the object and a decreased velocity on the other

- By Bernoulli's Principle, there are uneven pressures on the ball and the ball deviates from its motion

- If the axis of rotation (spin) is horizontal and at right angles to the direction of travel, this will cause backspin or a topspin and the ball will go up or down
- If the axis of rotation (spin) is vertical and at right angles to the direction of travel, this will create sidespin and the ball will deviate left or right

- Golf clubs are designed to create backspin of the golf ball during impact
- In the balls subsequent flight this backspin will keep the ball in the air longer and thus the range will be further
- Topspin is not required during golf, as this would bring the ball down quicker and thus decrease the distance travelled

- The angle faces of golf clubs and the surface grooves mean that the ball gains backspin when it contacts the ball and thus ensures longer flight



BOUNDARY LAYERS

1. The microscopic layers of fluid next to the body or object
2. Normally, these layers have all the molecules moving in the same direction and are called laminar boundary layers
3. If the body or object is moving very fast or if the surface is rough enough, the molecules of the boundary layers get mixed up

4. This causes less surface drag than would be expected so the body or object is not slowed down as much

5. This is way golf balls have dimples - they make boundary layers turbulent and thus the ball is not slowed up as much and this travels further