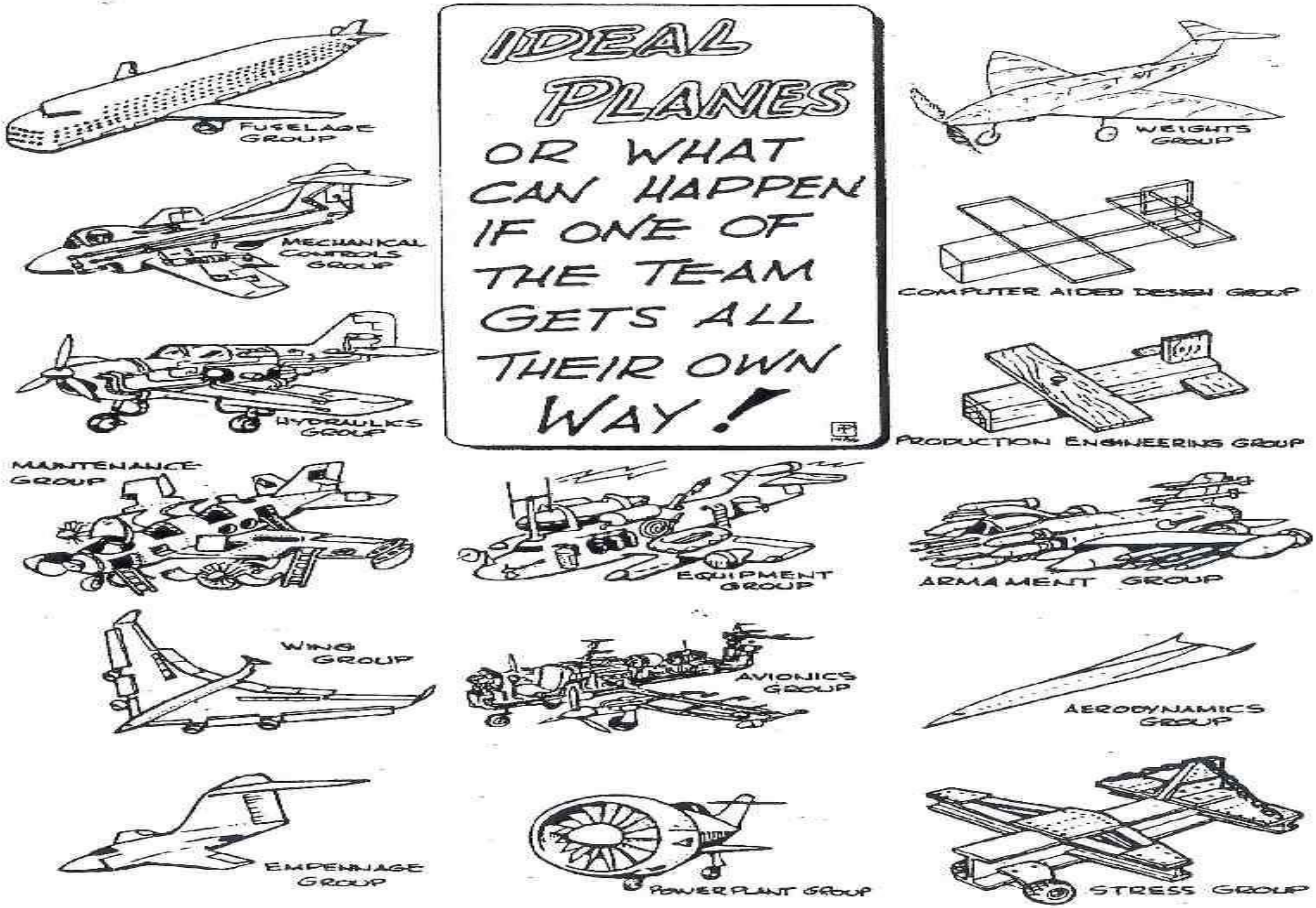
Basics of Aerodynamics

Principles of flight

Foreword

- ''How do I yearn to throw myself into endless space and float above the clear blue abyss''
- This was the dream of man since the beginning of time
- Early tower jumpers trusted their lives on home made 'wings' based on the assumptions that the source of the bird's lift was it's wing and the flapping motion, The source of it's propulsive power
- While factually correct, These deductions did not go far enough
- The tower jumpers did not come close to the understanding the amount of lift required to support a human body and they failed to grasp the difference between birds and humans
- Until the end of the 18th century, Little or no progress was made in the art of flight
- The Aeroplane or Airplane in American English was on the drawing boards was first practically idealised by the Renaissance genius Leonardo Da Vinci. I had all practical surfaces like the movable control surfaces and wings. The only thing that it lacked was propulsion. Da Vinci, In his design depended on muscle propulsion
- More than 200 years after Da Vinci's death, The progress was stalled until 1700 when man began to experiment with lighter than air craft such as balloons lifted by the virtue of heated air or hydrogen, But fixed wing bird of flight still remained a dream
- The first documented repetitive heavier than air flights were made by Otto Lillenthal of Germany
- The Wrights made the first documented powered heavier than air flights
- In the principles of flight lesson, You will learn about the physics that makes flight possible and the various phenomena that is associated with flight. You will also learn why airplanes come in different shapes and sizes. Also remember that every shape in an aeroplane has got something to do with aerodynamic efficiency and is never included for reasons of style and that it is a masterpiece of compromise as attested in the picture that follows


IDEAL PLANES
OR WHAT CAN HAPPEN IF ONE OF THE TEAM GETS ALL THEIR OWN WAY!
FUSELAGE GROUP
WEIGHTS GROUP
MECHANICAL CONTROLS GROUP
COMPUTER AIDED DESIGN GROUP
HYDRAULICS GROUP
PRODUCTION ENGINEERING GROUP
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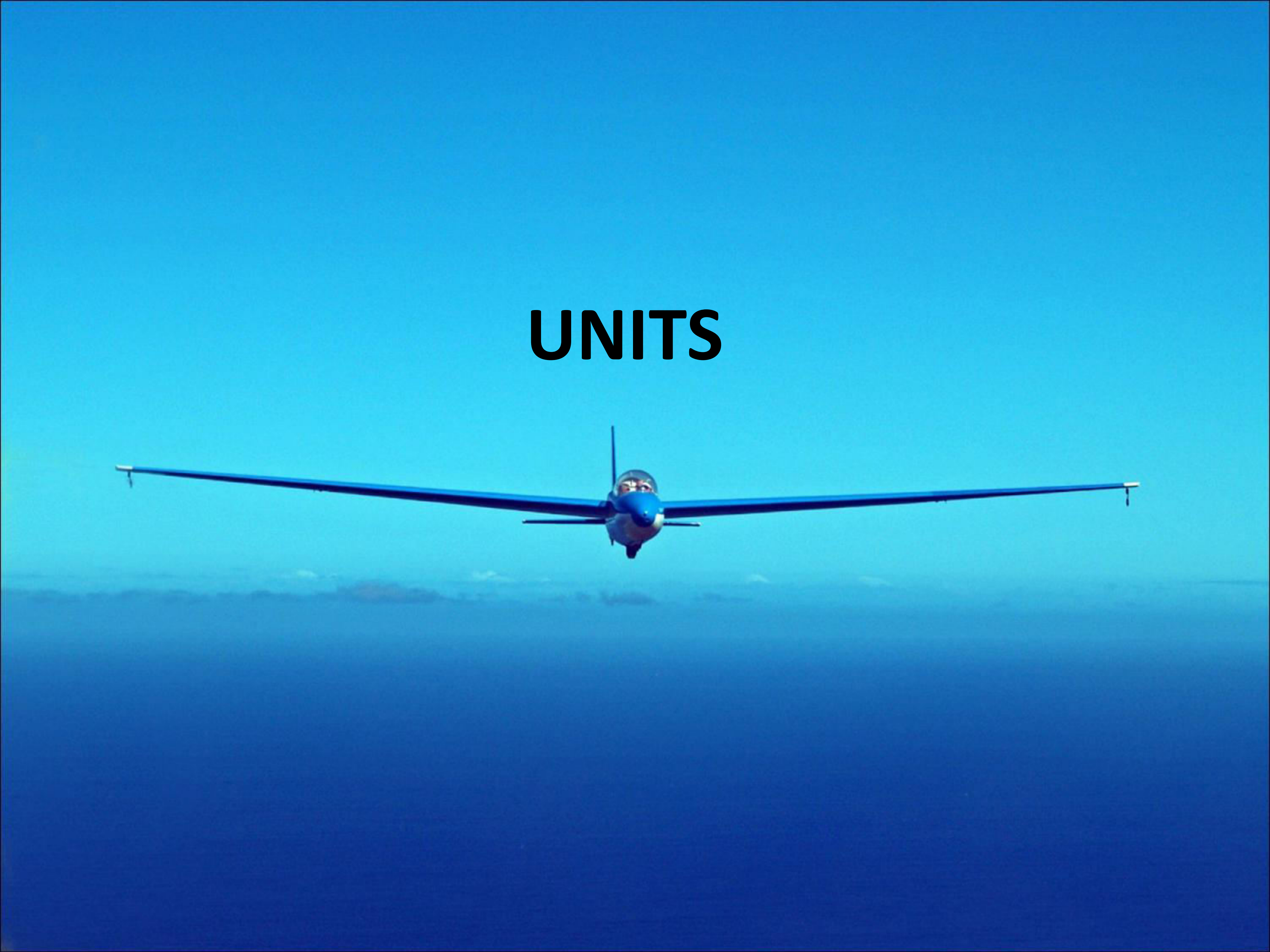

UNITS

Force

- An influence that causes a body to undergo a change either in its direction, State of movement or geometrical aspects i.e. deformation
- C.G.S. unit Dyne
- S.I. unit Newton
- Possesses both magnitude and direction so it is a vector quantity

Mass

- Defined as the quantity of matter in a body. Denoted by symbol ‘m’
- C.G.S. Unit Gram (g)
- S.I. Unit Kilogram (Kg)
- It is a measure of how difficult it is to start or stop a body
- A body with a higher mass will have more resistance to acceleration
- This view breaks down at very high speeds for subatomic particles hence there is no universal definition for mass

Weight

- Weight of an object is the force on the object due to gravity
- It is denoted by ‘*W*’
- It is the product of mass times the local gravitational acceleration i.e. m X g
- Example 1 Kg of mass weighs 1 X 9.8 = 9.8 Newtons, Where acceleration due to gravity is 9.8 m/s^2
- S.I. unit of weight is Newton but in commercial use the word ‘weight’ means ‘to have a mass of’. Used in this sense, The S.I. term is Kilogram

Difference between mass and weight

- Mass is the quantity of matter contained in a body, while weight is the force by which the body is pulled to the earth's center
- Mass is an intrinsic property of a body, as it remains the same everywhere in the universe. Weight is variable due to change in the magnitude of the gravitational force applied by the earth
- Mass is denoted by "M" while Weight (W) = Mass (M) X Gravitational acceleration (g)
- Mass can never be zero, for then the body will have no existence. Weight can be zero if there is no gravitational force acting on the body, like that in the space
- Your weight can differ on parts of the Earth because acceleration due to gravity differs on different parts of the world for example it is 9.7803 m/s^2 at the Equator and 9.8322 m/s^2 at the North Pole. Your mass will stay the same despite the discrepancies in weight at different places on the Earth
- Mass is indestructible But weight can be increased when there is more gravitational impact and decreased when less gravitational impact
- Mass is measured by a common balance. Weight is measured by a spring balance.
- Mass is scalar and has no direction dependency. Weight is vector and is directed towards the center of the earth

Work

- Work is said to be done when a force moves an object in the direction in which it is acting
- The work done by a constant force of magnitude *F* on a point that moves a displacement *d* in the direction of the force is the product, W =F X d
- S.I. unit of work is Newton Meter or Joule (J)
- If a 1 moves through 5 meters, Work done is 5 Nm or 5 J
- Needless to say, no work will be done if you try to push the wall next to you with all your might as there is no displacement


If at all, Displacement occurs, The
don’t blame me or Physics

Power

- Power is the rate at which work is done or work divided by time (Seconds)
- S.I. unit is Joule per second or Watt (W)

Concepts

Momentum

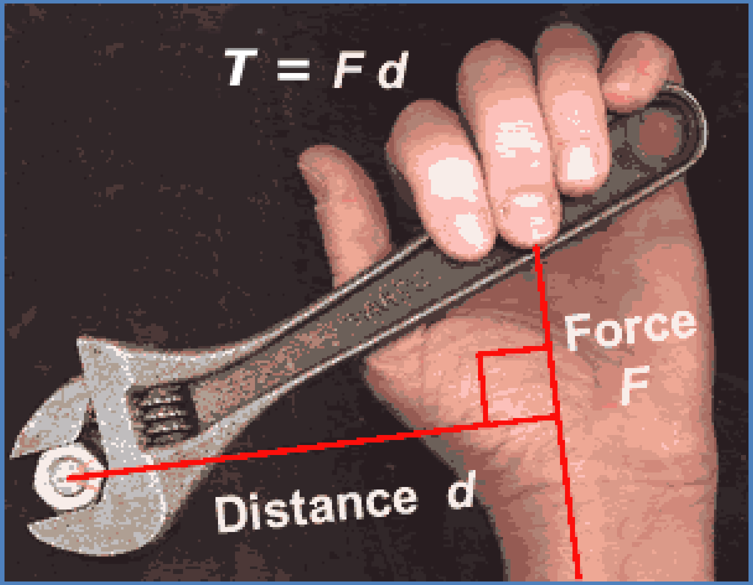
- Momentum is the product of mass and velocity and is a vector quantity
- Unit of momentum is nameless and is Kg.m/Sec
- Example : A small bird striking you while you while you are walking may cause very little discomfort, But the same bird can cause significant damage to a fast flying aircraft surface in the event of a bird strike. This is one of the reasons why many airspaces restrict aircraft speeds to less than 250 Knots below 10,000 feet

Inertia

- Inertia is the resistance of a physical object to a change in its state of motion and direction
- Example : Coffee falling from the cup when it is suddenly accelerated. The coffee resists any change to its current physical state and hence tends to fall backwards

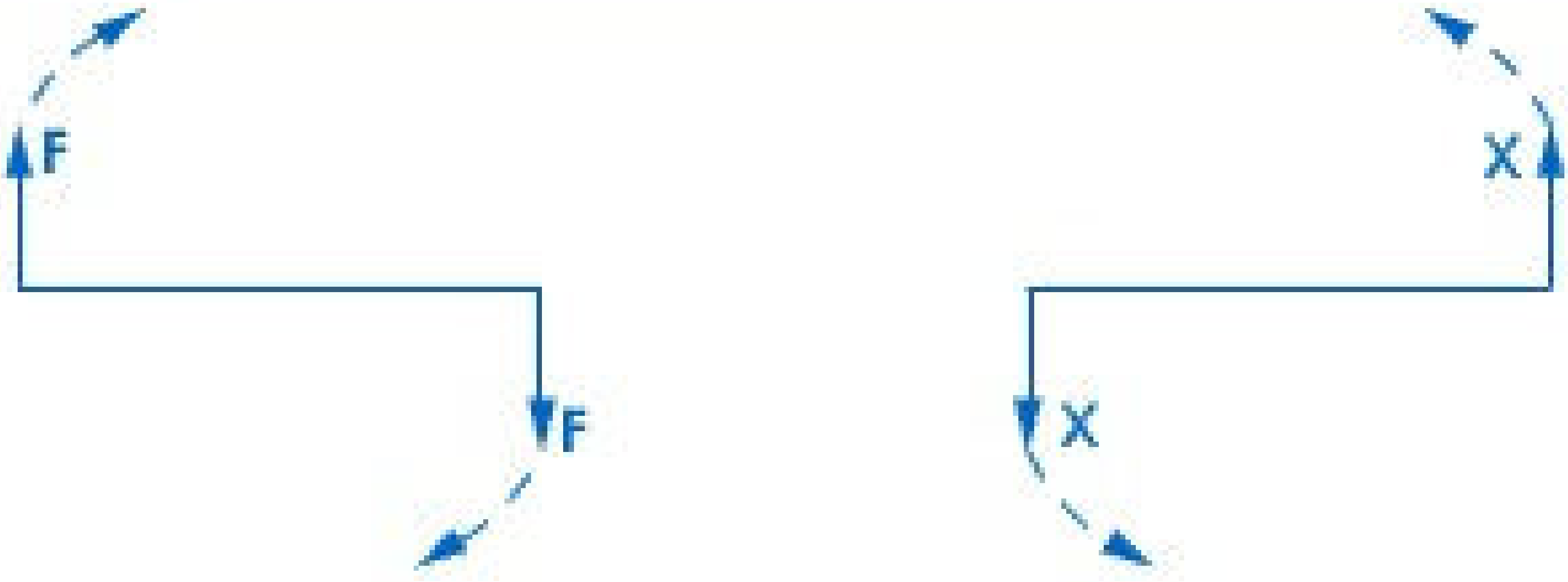
Moment of force/Torque

- The Moment of a force is a measure of its tendency to cause a body to rotate about a specific point or axis
- It is the product of the force and the distance between the point of rotation of the body and the line of force
- Unit is Newton.Meter
- Example : You can open your laptop by the top of your screen with a force. If you try to open it with the same force by the bottom of the screen, you cannot do so. This is because moment of the force or torque has been reduced as the distance from the pivot of the screen to the force applied that is your hand has reduced



Moment of a Couple

- Two equal and opposite forces acting on different point on a body constitute a couple
- Everyday examples : Turning of the key, Water tap, Bicycle pedal


F
F
X
X

Newton’s laws

- First law : Also called as the law of Inertia. States that every body remains in a state of rest or uniform motion in a straight line unless compelled to change that state by an external force. Example : A fast moving car brakes suddenly and the passengers lunge forward
- Second law : The acceleration of a body from a state of rest , Or uniform motion is directly proportional to the applied force and inversely proportional to it’s mass mathematically, F=ma where F is the net force applied, m is constant mass and a is the acceleration Example : Push a light box and a heavy box with the same force, The lighter box accelerates and moves faster
- Third law : Every action has an equal and opposite reaction. Example, The chair that you are sitting on is exerting back a same force on you, As your weight. If it exerted a lesser force, You would fall through the chair

Viscosity

- It is the measure of the internal friction of a fluid. It determines the ability of a fluid to flow
- Higher viscosity entails that the fluid will flow less readily and lesser viscosity entails that the fluid will flow more readily
- Changes in density
- Liquids become LESS viscous with increasing temperature and air becomes MORE viscous with increasing temperature
- Example : In winter, Oil becomes viscous and it needs heat in order to improve it’s fluidity

Density

- Density is mass per unit volume
- Denoted by the Greek letter ρ (Rho)
- Density of air varies inversely with temperature and directly with pressure
- When air is compressed, A greater mass of it can occupy a given volume and hence, It's mass per unit volume has increased and by definition, It's density has increased


The Gas Laws

Boyle’s law

- It is the relation between volume (V) and pressure (P) at constant temperature
- It state that volume of a fixed mass of gas is inversely proportional to the pressure, At constant temperature
- Mathematically, Boyle’s law can be written as PV = Constant
- An example of Boyle’s law in action is the deodorant spray
- **There are 2 substances inside the can, one being your product, Deodorant for example, the other being a gas that can be pressurized so much, that it retains a liquid state even when it is heated past its boiling point. This liquefied gas will be a substance that has a boiling point far below room temperature. The can is sealed, preventing this gas from boiling and turning into a gaseous state. That is, until you push down the nozzle. The moment the nozzle goes down, and the seal is released, there is now an escape route. The propellant instantly boils and expands into a gas and pushes down on the product trying to escape the high pressure, and expand it's *volume* the atmosphere where there is less *pressure*. This forces the product to shoot out from the nozzle, and you have a coat of paint.**

Charles' law

- It is the relation between volume (V) and temperature (T) at constant pressure (P)
- Charles' law states that volume of a given mass of gas is directly proportional to its absolute temperature, At constant pressure
- Mathematically, It can be written as V/T = Constant
- Example of Charles' law in action : A balloon fully inflated at home when taken outside in the hot sun will explode if kept long enough
- Take two good quality balloons and equally inflate them such that they have equal diameters. Place one in hot water and the other one in ice cold water. After 5 minutes, Remove them and check for the difference in diameters. The one kept in hot water will have a greater diameter than the one in cold water

Pressure law

- It is the relation between pressure and temperature at constant volume
- It states the pressure of a given mass of gas is directly proportional to it's temperature at constant volume
- Mathematically expressed as P/T = Constant
- Example of Pressure law in action : An aerosol can thrown into a fire may explode due to rise in pressure owing to heat

Combined gas law

- It is a combination of the Pressure law, Charles' law and Boyles law
- It states that the ratio between the pressure volume product and the temperature of a system remains constant

Static pressure

- The static pressure of the atmosphere at any given altitude is the pressure resulting from the mass of an imaginary column of air above that altitude or simpler still, Pressure exerted by still gas or liquid
- It is called static because it is the pressure exerted by static or stationary air
- It is the result of the weight of the atmosphere pressing down on the surface
- Static pressure will exert the same force on the object, In all the directions
- The unit for static pressure is N/m^2 and is denoted by p
- Static pressure decreases with increase of altitude
- Static pressure acts on objects within the atmosphere of the Earth at all times

Dynamic pressure

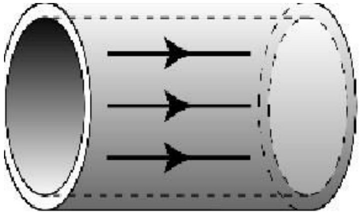
- Air has density (1.225 Kg/m^3 at m.s.l. in ISA)
- Any moving object possesses kinetic energy and will exert pressure on any object that stands in it's way
- Air in motion will also possess kinetic energy and will exert pressure on anything that comes it's way
- The Kinetic Energy possessed by one cubic meter of moving air is $(1/2)\rho V^2$. Where ρ is the density of the air in Kg/m^3 and V is the velocity of air in metres per second
- This pressure will be proportional to the velocity of the air. This pressure is called dynamic pressure owing to movement of air or relative movement
- It is denoted by q/Q
- It is important to note that dynamic pressure does not exist in isolation, But it exists together with static pressure
- The sum of static pressure and dynamic pressure is called stagnation pressure, Also called as total pressure or pitot pressure (True for compressible airflow)

Stagnation pressure

- The sum of static pressure and dynamic pressure is called stagnation pressure (True for compressible airflow)
- It is the static pressure at the stagnation point
- A stagnation point is where the velocity of the fluid is zero i.e. all the kinetic energy has been converted to pressure energy
- It is denoted by H
- Also called total pressure or static pressure

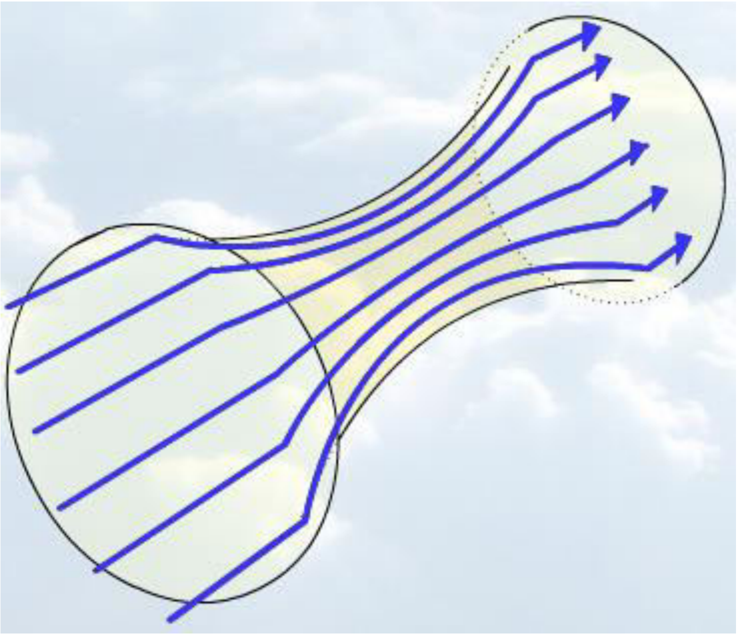
Equation of continuity

- The equation of continuity states that mass can neither be created nor destroyed. Air mass flow remains a constant, Dependent of velocity and density of the fluid and cross section area
- Consider the tube of uniform diameter pictured below, The mass flow through any point of the tube will be Avρ, Where A is the area of cross section of the rube, V is the velocity of the flow and ρ is the density of the fluid
- Applies to both compressible and incompressible fluids
- For Speeds below M0.4 density can be ignored and equation of continuity will be simply AV= constant

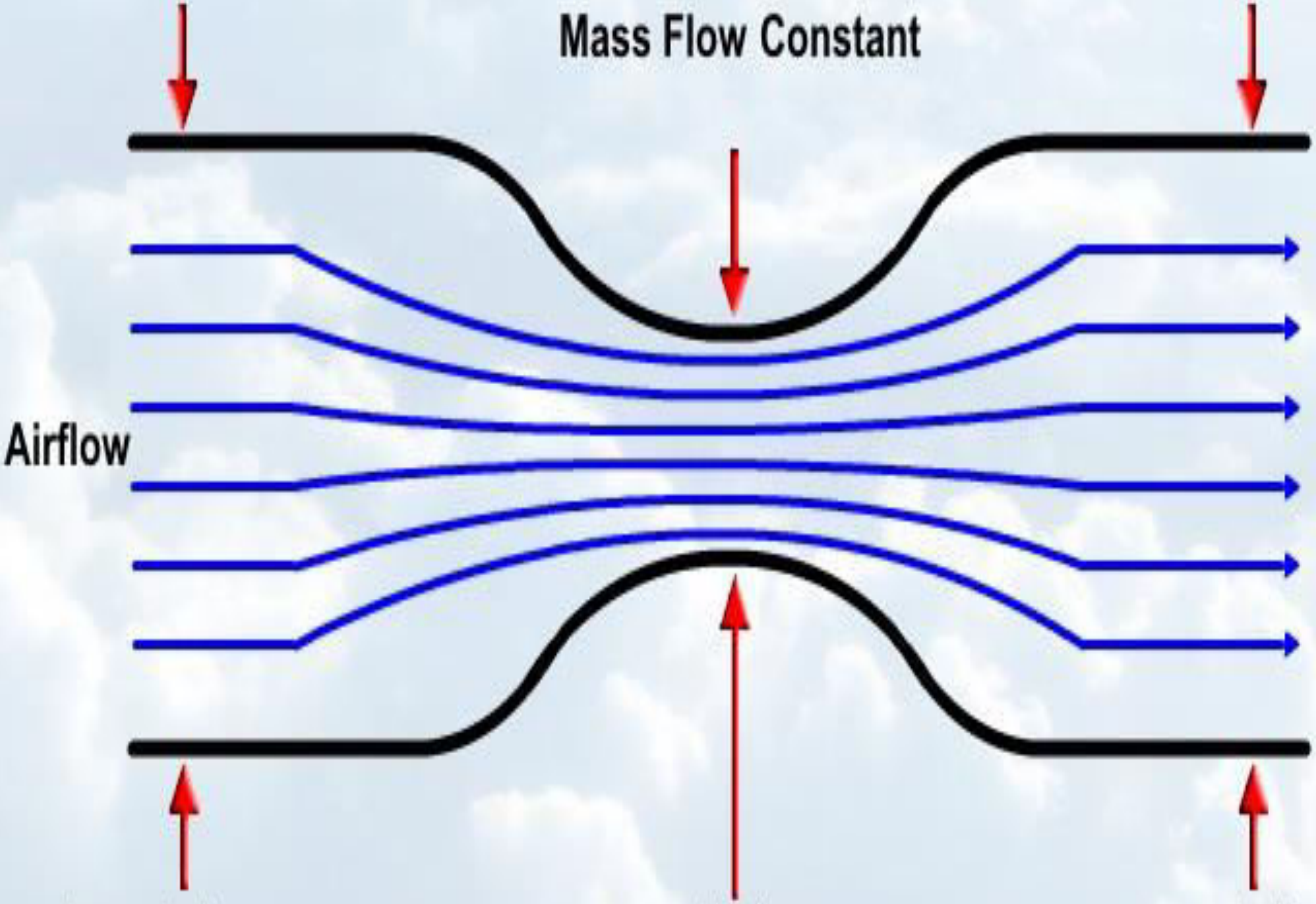


Equation of continuity

- Having considered air flow through a tube of uniform cross section, Let us now consider air flow through a venturi. A venturi is a tube with a constricted cross section area in the middle of the tube length
- The equation of continuity is AVρ = Constant
- Now, In a venturi, To follow the equation of continuity, If the area of cross section is reduced, It follows that Velocity has to increase
- Therefore, A decrease in area of cross section produces an increase in velocity and vice versa
- Changes of density at subsonic speeds can be disregarded as they very small can you can safely regard density remaining constant



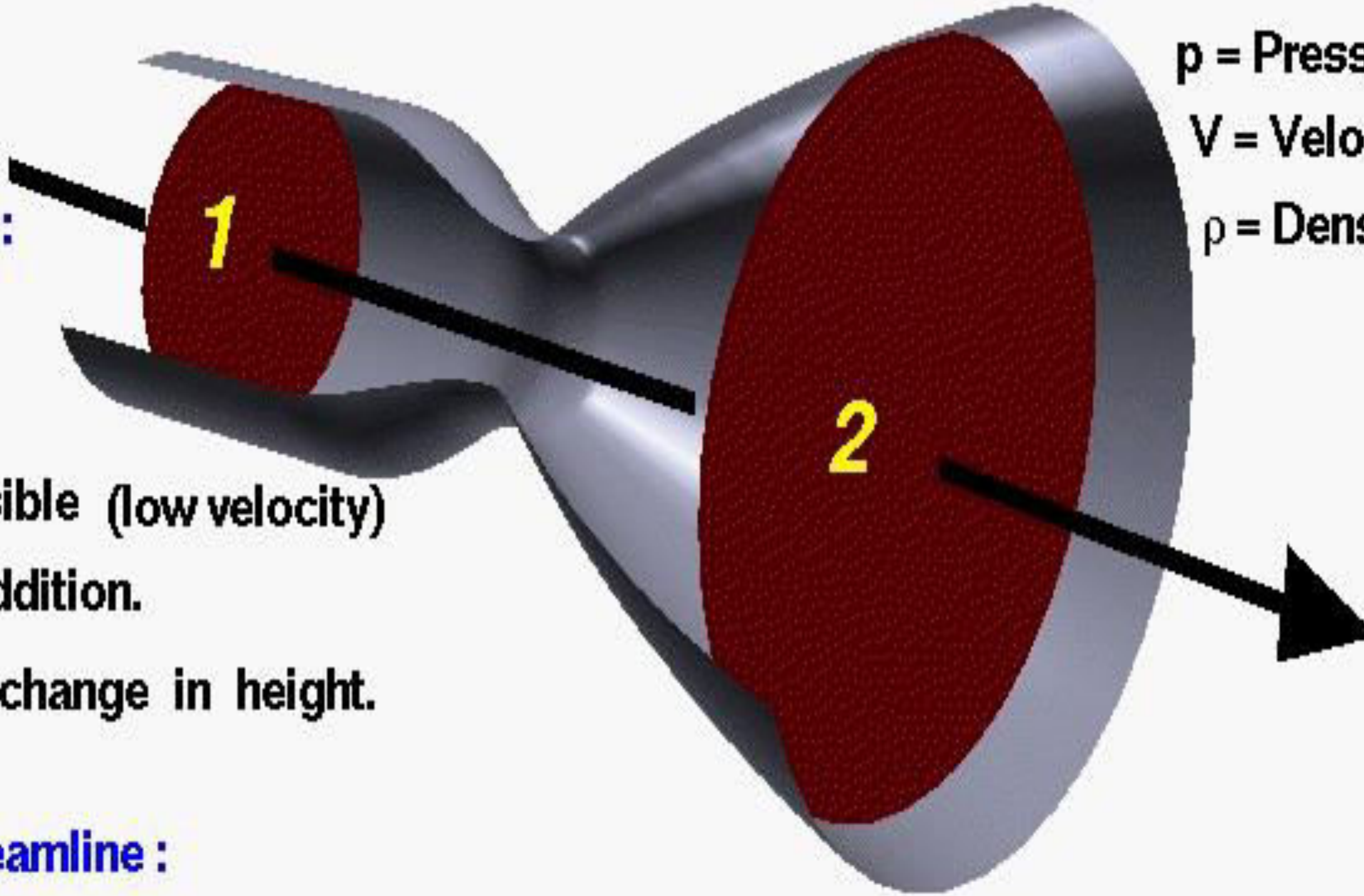
Mass Flow Constant



Area	1m²	½m²	1m²
Air Density	1 kg/m³	1 kg/m³	1 kg/m³
Velocity	52 m/s	104 m/s	52 m/s
Mass Flow	= 52 kg/s = Constant	= 52 kg/s = Constant	= 52 kg/s = Constant

Bernoulli's theorem

- The equation of continuity dealt with conserving mass flow, The Bernoulli's theorem deals with conserving energy, in a steady flow, the sum of all forms of mechanical energy in a fluid along a streamline is the same at all points on that streamline. This requires that the sum of kinetic energy and potential energy remain constant
- It states that: In a steady flow of an IDEAL/INVISCID (Incompressible and non viscous), The sum of kinetic energy and pressure energy per unit volume remains constant
- At low subsonic speeds less than M0.4, The flow can be considered to be an ideal gas
- This can be expressed mathematically as $p + \frac{1}{2}\rho V^2 = \text{constant}$ Where p is the static pressure and $\frac{1}{2}\rho V^2$ is the dynamic pressure



p = Pressure

V = Velocity

ρ = Density

Restrictions :

Inviscid

Steady

Incompressible (low velocity)

No heat addition.

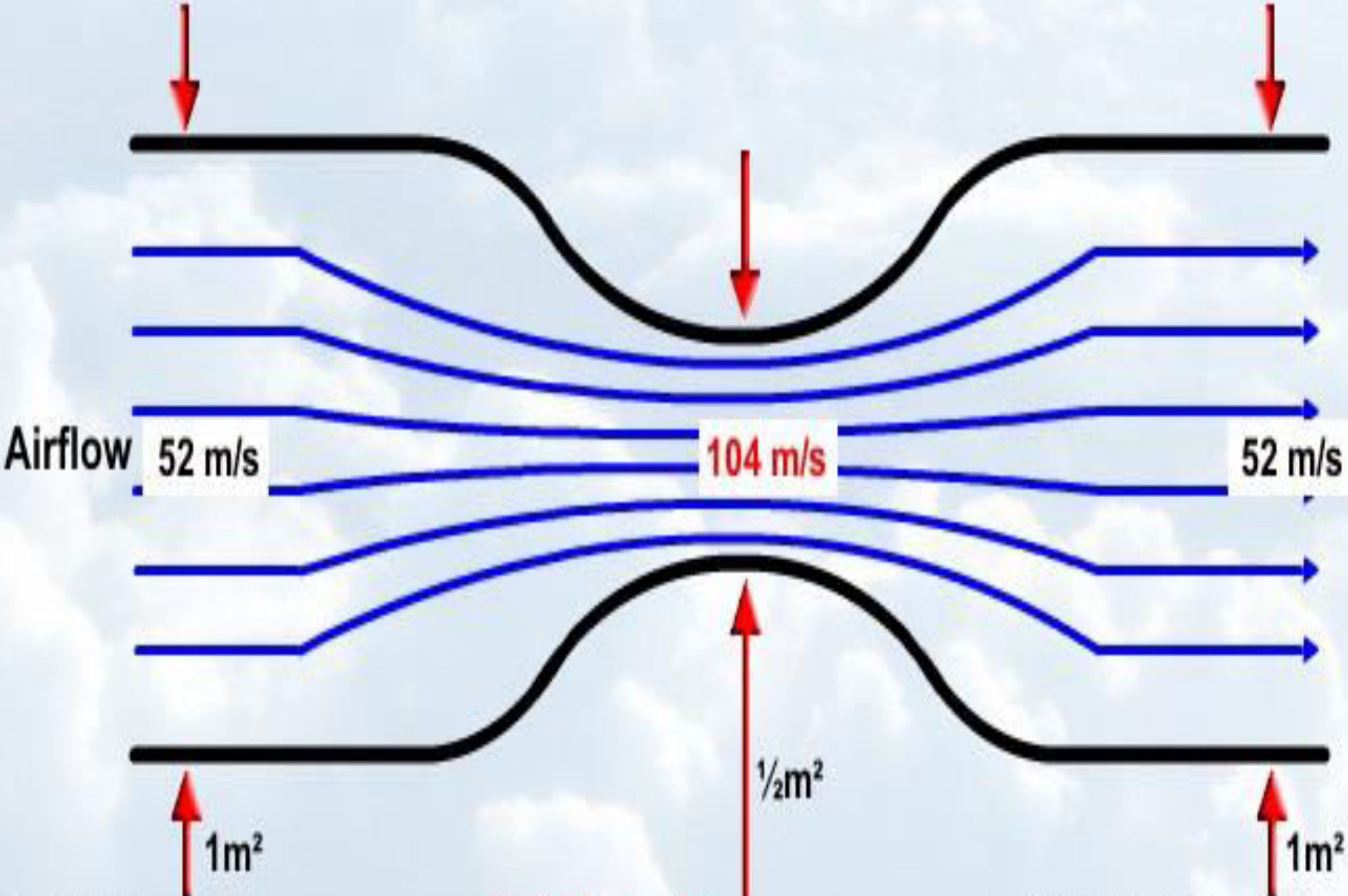
Negligible change in height.

Along a streamline :

static pressure + dynamic pressure = total pressure

$$p_s + \frac{\rho V^2}{2} = p_t$$

$$\left(p_s + \frac{\rho V^2}{2}\right)_1 = \left(p_s + \frac{\rho V^2}{2}\right)_2$$



Static Pressure:
101.3 KN/m² or 1013 hPa (mb)
Dynamic Pressure:
$\frac{1}{2} \rho \times V^2$ = 1.656 KN/m² or 16.56 hPa (mb)
Total Pressure:
103 KN/m² or 1030 hPa (mb)

Static Pressure:
96.4 KN/m² or 964 hPa (mb)
Dynamic Pressure:
$\frac{1}{2} \rho V^2$ = 6.62 KN/m² or 66.2 hPa (mb)
Total Pressure:
103 KN/m² or 1030 hPa (mb)

Static Pressure:
101.3 KN/m² or 1013 hPa (mb)
Dynamic Pressure:
$\frac{1}{2} \rho \times V^2$ = 1.656 KN/m² or 16.56 hPa (mb)
Total Pressure:
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