BULE HORA UNI

CHAPTER ONE

BASIC PRINCIPLES OF FLOW

Hwre-3172

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1.0. Introduction

- Kinematics of fluid deals with the geometry of motion(space – time relation ships) of fluids only without regards to the forces causing the motion.

- They are generally deals with
  - Velocity & acceleration of fluid, and
  - The description and visualization of motion.

- The concept of a free body diagram, as used in static of rigid bodies in a fluid static is usually inadequate for the analysis of moving fluids.

- Instead we frequently find the concepts of system & control volume to be useful in the analysis of fluid mechanics.

Introduction(con't)

- **A fluid system** refers to a specific mass of fluid within the boundaries defined by a closed surface.

- The shape of the system, & so the boundaries, may change with time, as when liquid flows through it.

- As a fluid moves& deforms, so the system containing it moves & deforms.

- A system approach is also known as

Introduction(con't)

- ***A control volume*** refers to a fixed region in space, which doesn't move or change shape.

- It is usually chosen as a region that fluid flows in to & out of it.

- The control volume approach is also called the Eulerian approach.

- Eulerian method is mostly used because it is more useful in the analysis of the majority of engineering problems.

Introduction(con't)

Describing the pattern of flow:

- Although fluid motion is complicated, there are various concepts that can be used to help in the visualization & analysis of flow fields.

- This pattern of flow may be described by mean of
  - Streamlines.
  - Stream tubes.
  - Path lines and
  - Streak lines.

Introduction(con't)

Types of flow:

A. Classification according to type of fluid :

(I) Ideal fluid flow.

(II) Real fluid flow:

(III) Compressible fluid flow.

(IV) Incompressible fluid flow.

B. *Classification according to variation of velocity, displacement and etc*

(V) Steady flow and unsteady flow.

(VI) Uniform flow and non-uniform flow.

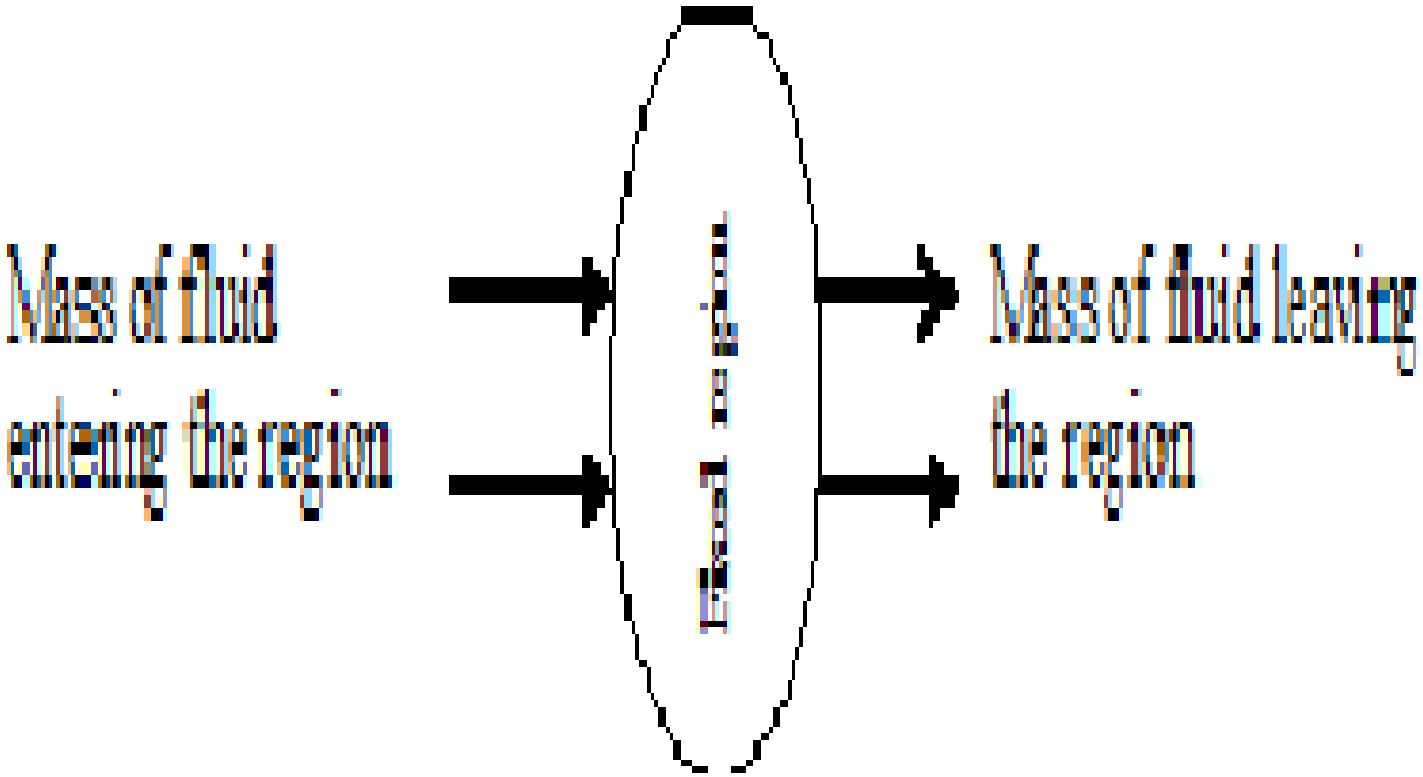
(VII) Laminar flow and Turbulent flow.

- The continuity equation is a mathematical statement of the principle of conservation of mass.

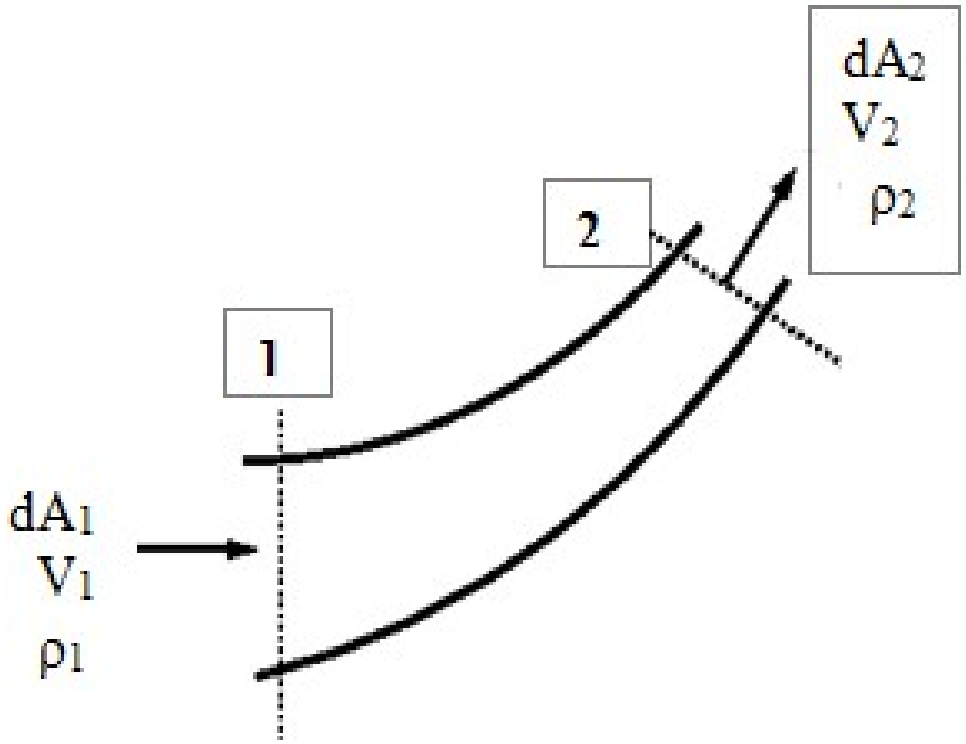
- Consider the following fixed region with flowing fluid.

- Fluid is neither created nor destroyed with in the region.

- It may be stored that the rate of increase of mass contained with in the region must be


Mass of fluid
entering the region
Mass of fluid leaving
the region

- Considers flow through a portion of a stream tube:



- Mass of fluid per unit time flowing past section-1

$= \rho_1 \, dA_1 \, V_1$ [kg/s]

Continuity Equation(con't)

- Mass of fluid flowing per unit of time past section 2

  $= \rho_2 \, dA_2 \, V_2$ [kg/s]

- For steady flow, by the principle of conservation of mass

  $\rho_1 \, dA_1 \, V_1 = \rho_2 \, d \, A_2 \, V_2$

- For the entire area of the stream tube

  $$\int_{A1} \rho_1 \, dA_1 V_1 = \int_{A2} \rho_2 \, dA_2 V_2 \qquad = \text{constant}$$

- If ρ_1 and ρ_2 are average densities at section (1) and (2), then

  $$\rho_1 \int_{A1} V_1 dA_1 = \rho_2 \int_{A2} V_2 dA_2 = \rho VA$$

  $= \text{constant}$

- $\rho_1 V_1 A_1 = \rho_2 V_2 A_2 = \rho VA = \text{constant}$

- This is equation of continuity applicable to steady, one-dimensional flow of compressible as well as incompressible ($\rho_1 = \rho_2$) flow.

- For incompressible flow, ρ = constant and doesn't vary form point to point, $\rho_1 = \rho_2$

- $A_1V_1 = A_2V_2 = Q$ = constant

- This is continuity equation for steady incompressible flow.

- Q is the discharge (or volumetric flow rate or flow) defined as

$$Q = AV \; [m^2 * m/s = m^3/s = \text{Volume/time}]$$

$$Q = A_1V_2 = A_2V_2$$

- Hence, the velocity of flow is inversely proportional to the area of flow section.

- This is useful for most engineering application.

1.3. Dynamic impact of fluid flow

- In dealing with dynamics of fluid flow, all forces that affect the phenomenon are considered.

- The dynamics of fluid motion deals with kinetics, which relates the kinematics with the forces responsible for causing the motion.

- This relation ship of fluid motion is established by the use of laws of nature.

1. The principle of conservation of mass (the continuity relation ship).
2. Newton's laws of motion.
3. The 1st and 2nd laws of thermodynamics.

- The dynamic behavior of fluid motion is governed by a set of equations, known as equations of motion.

- These equations are obtained by using the Newton's second law, which may be written as

$$F_x = m.a_x$$

- Where, F_x is the net force acting in the x-direction upon a fluid element of mass m

- A liquid in motion may possess three forms of energy.

1. Potential energy /elevation /positional energy/:

- This is because of its elevation above datum level.

- If a weight W of liquid is at a height of z above datum

Potential energy = Wz

Energy and head(con't)

2. Pressure energy:

- When a fluid flows in a continuous stream under pressure it can do work.

- If the area of cross – section of the stream of fluid is **a**, then force due to pressure p on cross- section is **Pa**.

- If a weight W of liquid passes the cross section, Volume passing in cross section = W/ρg.

- Distance moved by liquid $= \frac{W}{\rho g a}$

$$W = F^* S = Pa^* \frac{W}{\rho g a} = \frac{WP}{\rho g}$$

Energy and head(con't)

- Pressure energy per unit weight $\frac{P}{\rho g}$ = pressure head.

3. Kinetic energy:

- If a mass of fluid (m) moves at some velocity (v), then

Kinetic energy = ½ mv^2 = ½ W/g v^2.

- Kinetic energy pr unit weight = $\frac{v^2}{2g}$ = kinetic head.

- Total head = potential head + pressure head + velocity head

$$= Z + \frac{P}{\gamma} + \frac{v^2}{2g}$$

Energy and head(con't)

Bernoulli's theorem:

- It states that *the total energy of each particle of a body of fluid is the same provided that no energy enters or leaves the system at any point*.

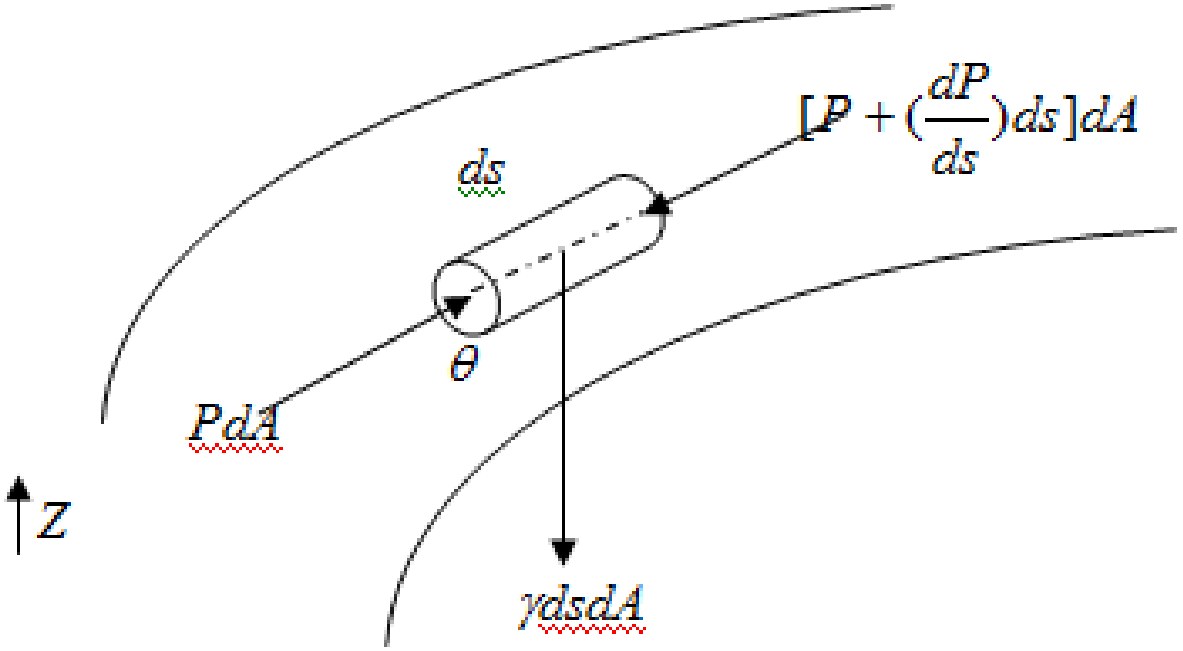
- The division of this energy between potential, pressure and kinetic energy may vary, but the total remains constant.

- In symbols

$$Z + \frac{P}{\gamma} + \frac{v^2}{2g} = constant$$

Bernoulli's Equation

- Consider a cylindrical element of stream tube having cross-sectional area $\mathbf{d_A}$, length **ds** and unit weight $\boldsymbol{\gamma}$ as shown in motion alon



Bernoulli's assumptions:

1. The flow is Steady and incompressible type of flow.
2. Frictionless and non viscous flow.
3. No shaft work - no pump or turbines on the streamline.
4. No transfer of heat - either added or removed.

- The normal forces on the side faces are in equilibrium and as the fluid is assumed non-viscous, there is no shear stress.
- The velocity varies along the streamline and there is acceleration

Bernoulli's Equation(con')

- It is necessary to take into account force due to acceleration when considering the longitudinal balance of force.

- In the ease of steady flow the velocity doesn't vary at a point so that local acceleration will be zero and for velocity variation with position convective acceleration will be different from zero .

- The forces tending to accelerate the fluid mass are pressure force on the two ends of the element

- $[\sum Fs = mq_s]$ in the arbitrary's' direction.

$P d_A - (P + \frac{dp}{ds} ds)\, dA - \rho g ds\, dA \cos\theta = m a_s$

$ds \cos\theta = dz$

$m = \rho v = \rho ds dA$ and $a_s = \frac{dv}{dt} + v\frac{dv}{ds}$ but $\frac{dv}{dt} = 0$ local acceleration for steady flow

Then substitute in to the above equation and we get

$-dP d_A - \rho g\, dA dz = \rho dA\, v dv$ or

$dP d_A + \rho g\, dA dz + \rho dA\, v dv = 0$, cancel dA both sides and divide both sides by ρg, we get

$$\frac{dp}{\gamma} + dz + \frac{V}{g} dv = 0$$

Bernoulli's Equation(con')

- For the case of an incompressible fluid γ may be treated as constant, the integration gives

$$\int \frac{dp}{\gamma} + \int dz + \int V\frac{dV}{g} = Constant$$

$$\frac{P}{\gamma} + Z + \frac{V^2}{2g} = Constant$$ (Bernoulli's Equation)

- The Bernoulli equation is the basis for the solution of a wide range of hydraulics problems.
- For two points along a streamline, the Bernoulli equation may be expressed in the form of

$$y_1 + \frac{P_1}{\gamma} + \frac{v_1^2}{2g} = y_2 + \frac{P_2}{\gamma} + \frac{v_2^2}{2g}$$ (for ideal fluid)

Bernoulli's Equation(con')

Bernoulli's Equation for real fluid:

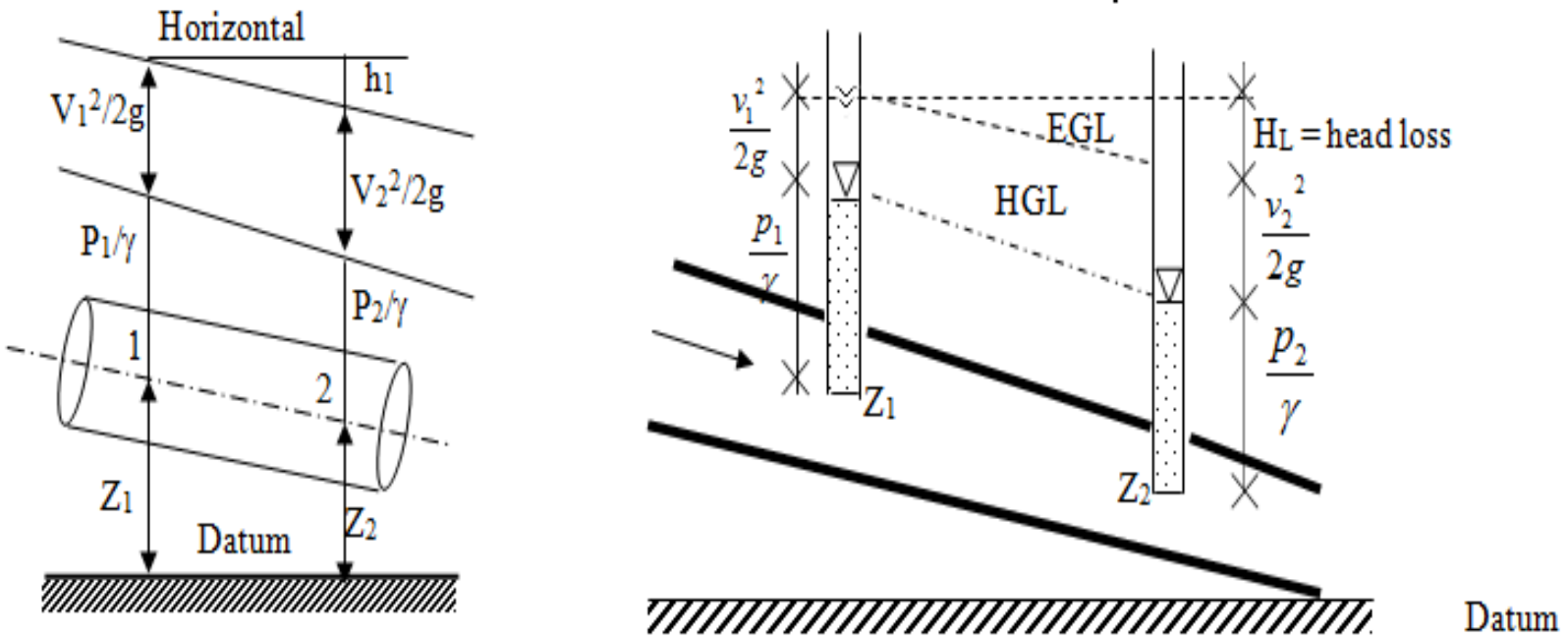


Fig. Energy and hydraulic grade lines

$$\frac{V_1^2}{2g} + \frac{P_1}{\gamma} + Z_1 = \frac{V_2^2}{2g} + \frac{p_2}{\gamma} + Z_2 + h_l$$

, h_l =head loss

- It is often important to determine the force produced on a solid body by fluid flowing steadily over it.

- For example,
  - The force on a pipe bend caused by the fluid flowing through it.

  - The force exerted by jet of fluid striking against a solid surface.

- All these forces are ***hydrodynamic forces*** and they are associated with a change in the momentum of the fluid.

- The magnitude of such a force is determined by **Newton's second law** of motion, by modifying the law to suit particularly to the steady flow of a fluid called the steady flow momentum equation.

- Only the forces acting at the boundaries of this space concern us, and use of momentum equation doesn't require the knowledge of the flow pattern in detail.

- Moreover, the fluid may be compressible or incompressible and the flow with or without

- Consider a stream tube shown below with the following assumptions.

  - The c/s of stream tube is sufficiently small so that the velocity may be considered uniformly distributed.

  - The flow is steady i.e. the stream tube remains stationary with respect to the fixed coordinate axis.

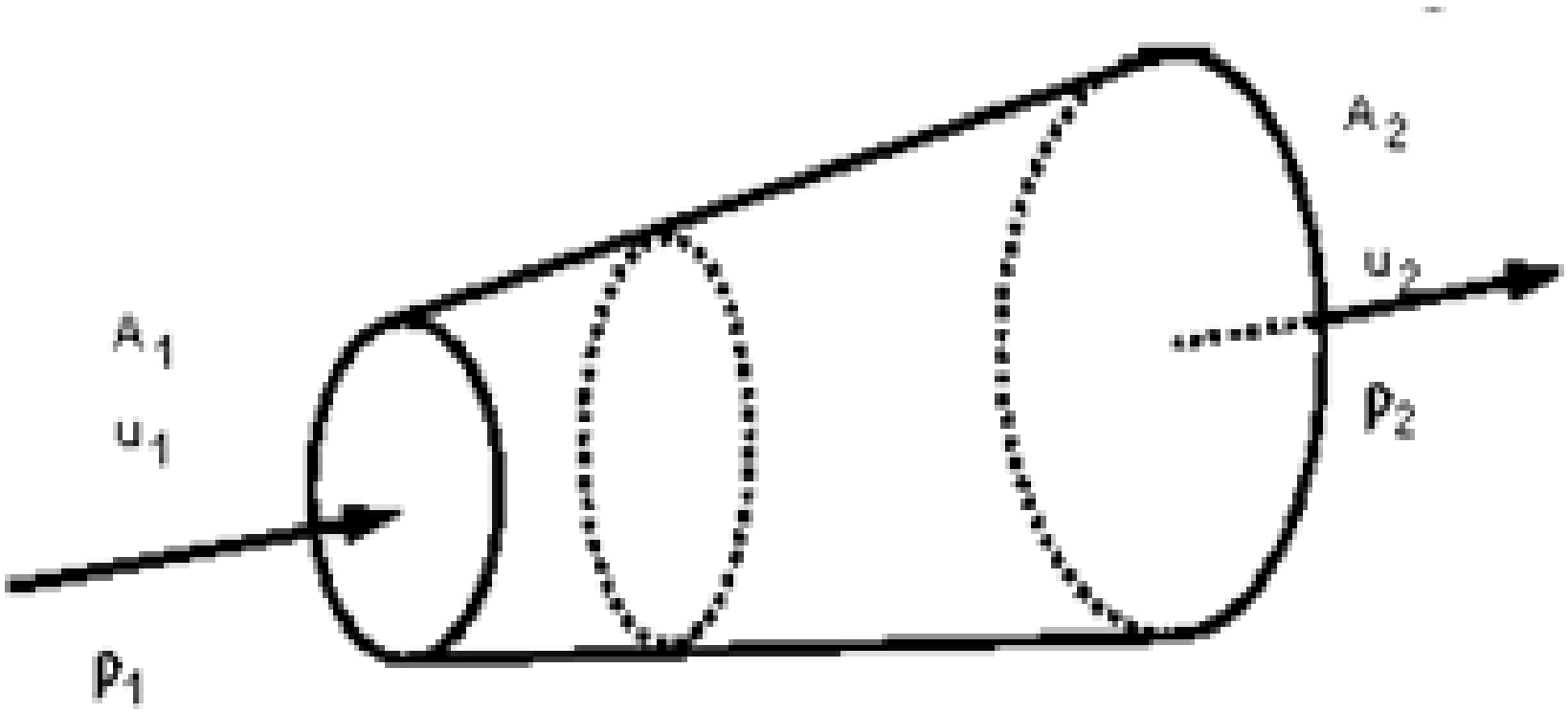


Fig. stream tube.

Impulse-momentum theorem(con't)

- Newton's second law

$$F = m\,a$$

$$F = m\,\frac{dv}{dt}$$

$$F\,dt = m\,dv$$

- Momentum principle expresses that the rate of change of momentum is equal to the net force acting on the fluid mass.

- Momentum of fluid entering section 1 –1 in a time Δt in the x –direction

$$= \rho\, dQ\, \Delta t\, V_1(x)$$

- Momentum leaving section 2- 2 in time Δt

$$= \rho\, dQ\, \Delta t\, V_2\,(x)$$

From momentum principle

$$dFx = \frac{P\, dQ\, \Delta t\, [v_2(x) - v_1(x)]}{\Delta t}$$

$$dFx = \rho dQ\, [V_2(x) - V_1(x)]$$

dFx = net force exerted on the fluid in the x –direction.

The total force in the x –direction is given by

$$Fx = \int_A dFx = \int_A \rho dQ\, v_2(x) - \int_A \rho dQ\, v_1(x)$$

$$= \int_A \rho (v_2 dA_2) v_2(x) - \int_A \rho (v_1 dA_1) v_1(x)$$

- Assuming the fluid is incompressible

$$Fx = \rho V_2 A_2 (V_2 (x) - PV_1A_1 V_1 (x)$$

$$Fx = \rho Q [V_2(x) – V_1(x)]$$

- Similar equations for y and z directions may be written.

$$Fy = \rho Q [V_2(y) – V_1(y)]$$

$$Fz = \rho Q [V_2(z) – V_1(z)]$$

1) The force caused by a jet striking a surface

A. Impact on a flat surface

I) Stationary plate

A = area of jet

v_1 = velocity of jet

ρ = mass density

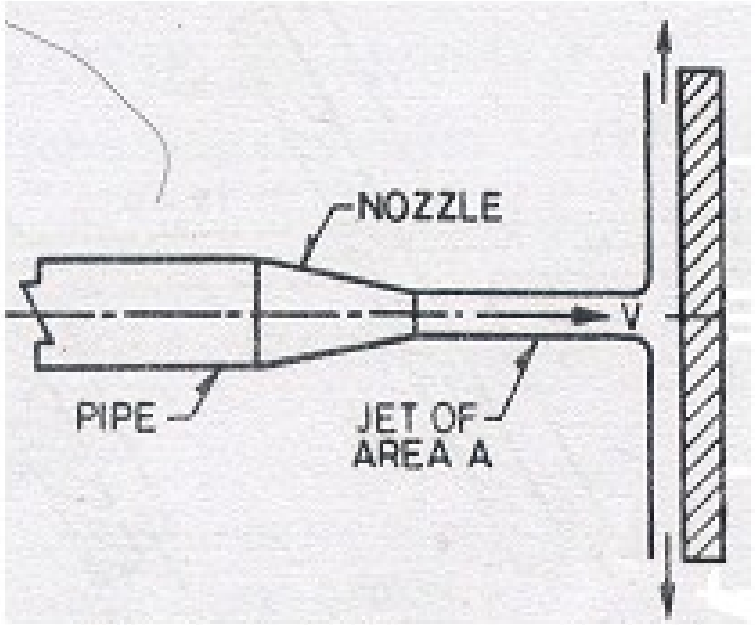


Fig. A jet hitting a vertical plate

- $Fx = \rho Q(v_2(x) - v_1(x))$

  $= \rho Q\,(0 - v_1)$ ⇒ momentum normal to the plate is destroyed.

$Fx = -\rho AV^2$ (force in the jet)

- Force exerted on plate = ρAV^2 (Equal and opposite to the force exerted on the jet = Fx).

II) Moving plate

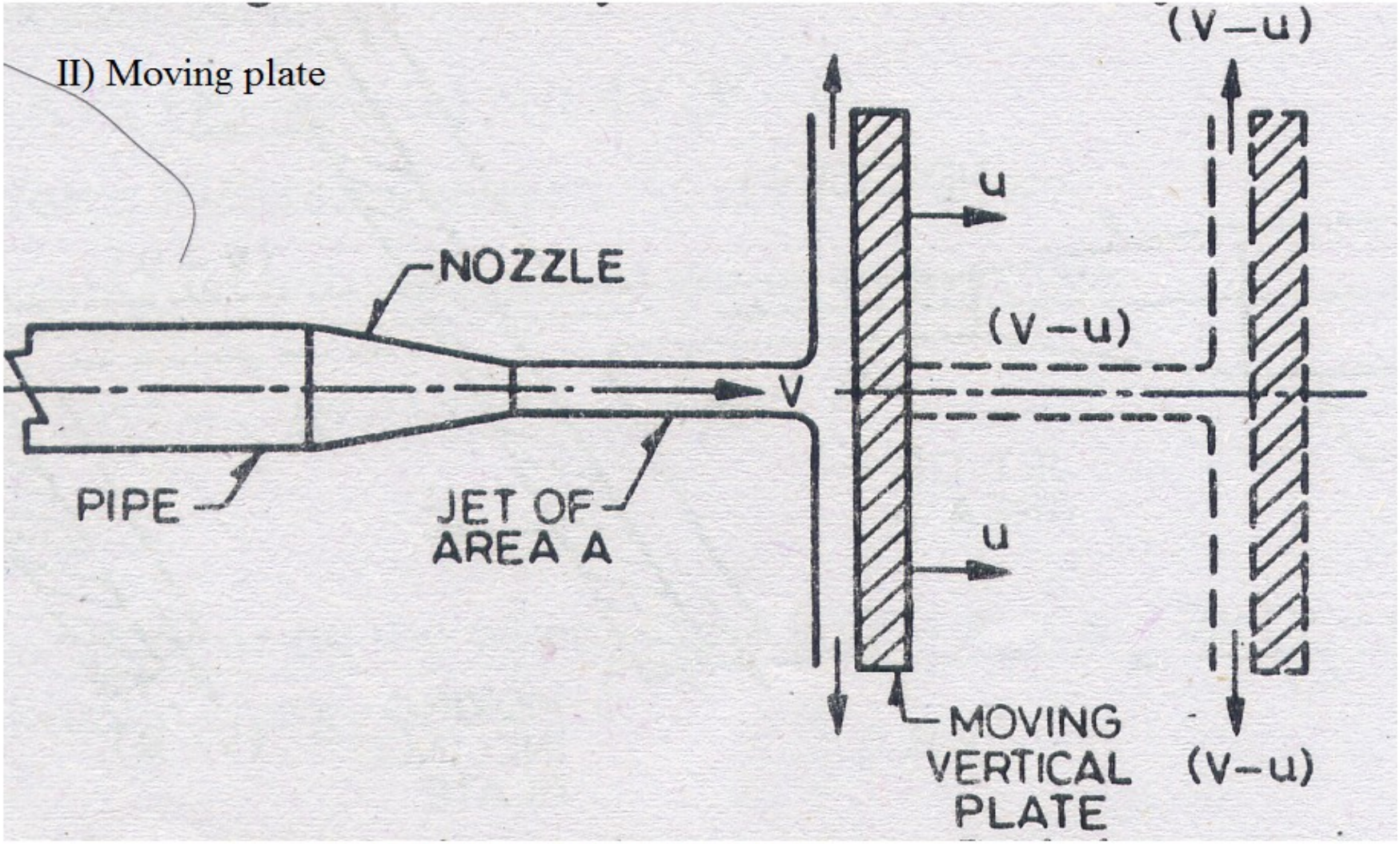


Fig. Ajet hitting a moving vertical plate

- Initial velocity of jet $v_{1x} = V_1 = V$

- Final velocity of jet = velocity of v_{2x} = U = velocity of plate.

- The velocity with which jet strikes the plate = V – U

  Mass of fluid striking plate/sec = $\rho A (V - U)$

  Force on plate = $\rho A (V - U) (V - U)$

  $= \rho A (V - U)^2$

III) Stationary inclined plate:

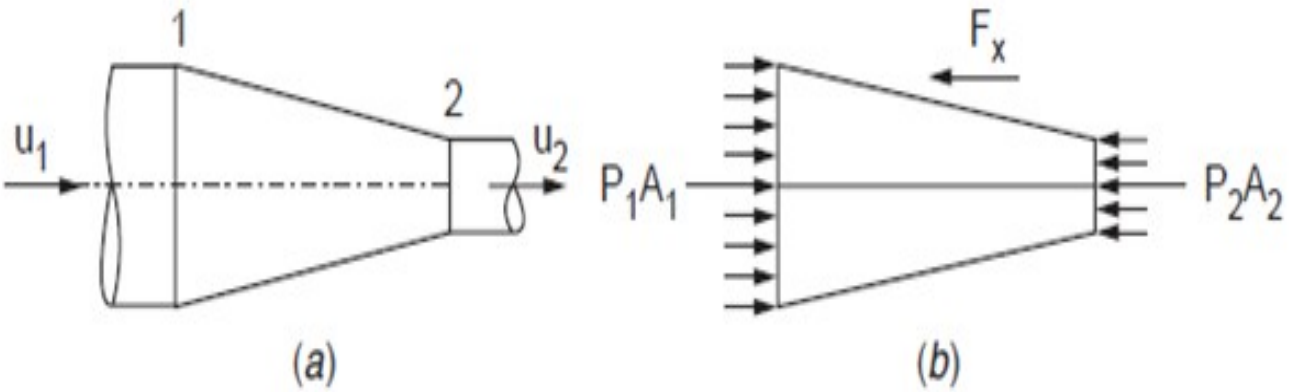
- Normal force on the plate = $\rho AV(V\sin\theta) = \rho AV^2 \sin\theta$

IV) Moving inclined plate:

- Normal force on the plate = $\rho A (V - U)^2 \sin\theta$

2) Forces Exerted on Pressure Conduits:

- Consider the reducer section shown in Figure.



- Assuming ideal fluid flow,

$$\Sigma Fx = P_1A_1 - P_2A_2 - F_x = \rho Q\,(u_2 - u_1)$$ Or the force on the fluid is given by

$$F_x = P_1A_1 - P_2A_2 - \rho Q\,(u_2 - u_1)$$

3) Force exerted on a reducing pipe bend:

- Consider the following condition when a pipe bend in a horizontal plane:

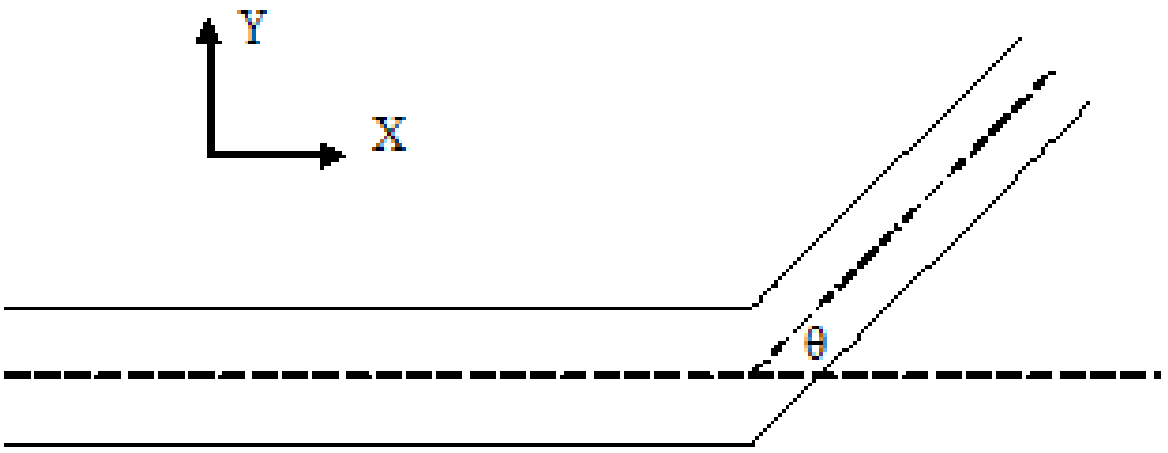


Fig. Force on a horizontal reducing bend

- Let F_x and F_y be the components of the force exerted on the fluid by the pipe bend.

- Then momentum equation in the x–direction can be written as:

$$P_1A_1 - P_2A_2\cos\theta - F_x = \rho Q(V_2\cos\theta - V_1)$$

$$Fx = P_1A_1 - P_2A_2\cos\theta + \rho Q (V_1 - V_2\cos\theta)$$

- Momentum equation in the y–direction can be written as:

$$F_y - P_2 A_2\sin\theta = \rho Q (V_2\sin\theta - V_1) \qquad (V_1 = 0)$$

$$F_y = P_2A_2\sin\theta + \rho Q(V_2\sin\theta)$$

4) Force Exerted on a Vane or Blade.

(A). Stationary vane or blade

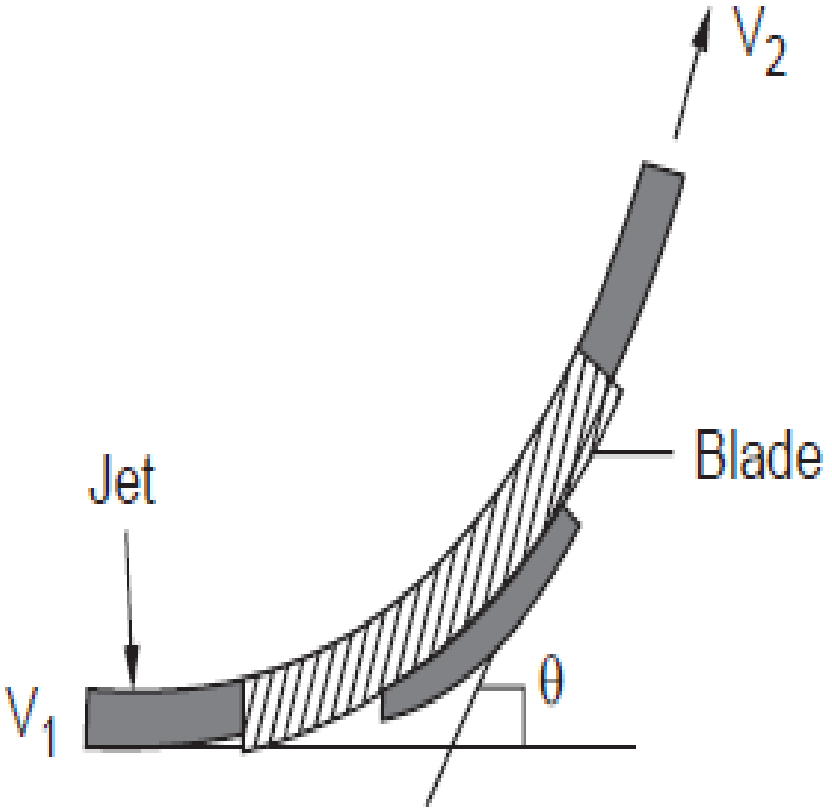
- In turbo machines fluid passes over blades and the blades are in motion.

- To start the analysis force on stationary vane is considered. In this case

  - Only the direction of the velocity is changed($V_1=V_2$).

  - Pressure forces are equal both at inlet and outlet.

  - The flow is assumed to occur in the horizontal plane.


V_2
Blade
Jet
V_1
θ

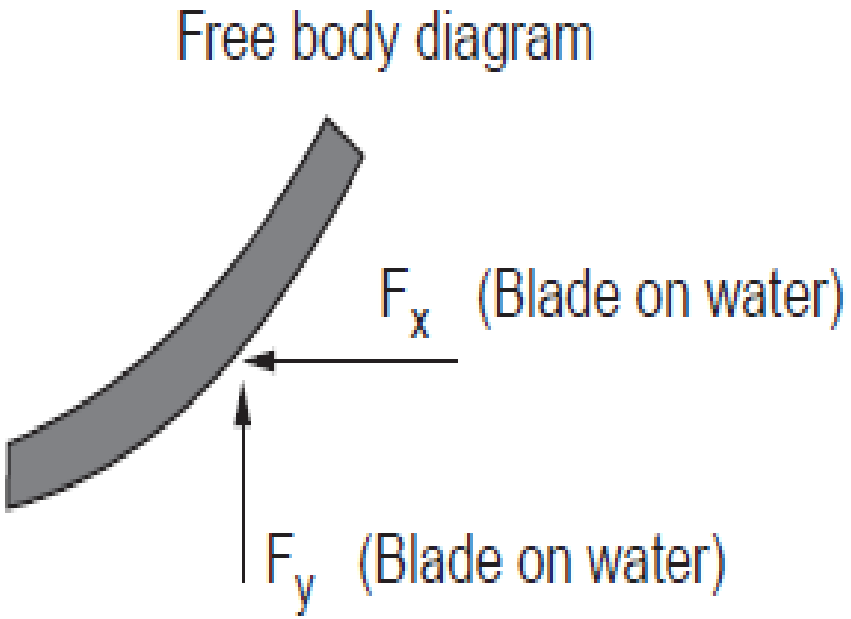

Free body diagram
F_x (Blade on water)
F_y (Blade on water)

Fig:1.3.2

- Force along x direction by the blade on fluid, with the assumed direction: Assuming $V_2 = V_1$ as no other energy transfer occurs,
  - $F_x = \rho Q (V_{2x} - V_1)$
  - $= \rho Q (V_2 \cos\theta - V1)$
  - $= \rho Q (V_1 \cos\theta - V_1)$

- $F_y = \rho Q (V_{2y} - V_{1y}) = \rho Q V_1 \sin\theta$

(B) Force on a Moving Vane or Blade.

- In order to determine the force on moving blades and the energy transfer between the blades and the fluid, the relative velocity between the fluid and the blade becomes an important factor.

- The blade may move in a direction at an angle to the velocity of the fluid.

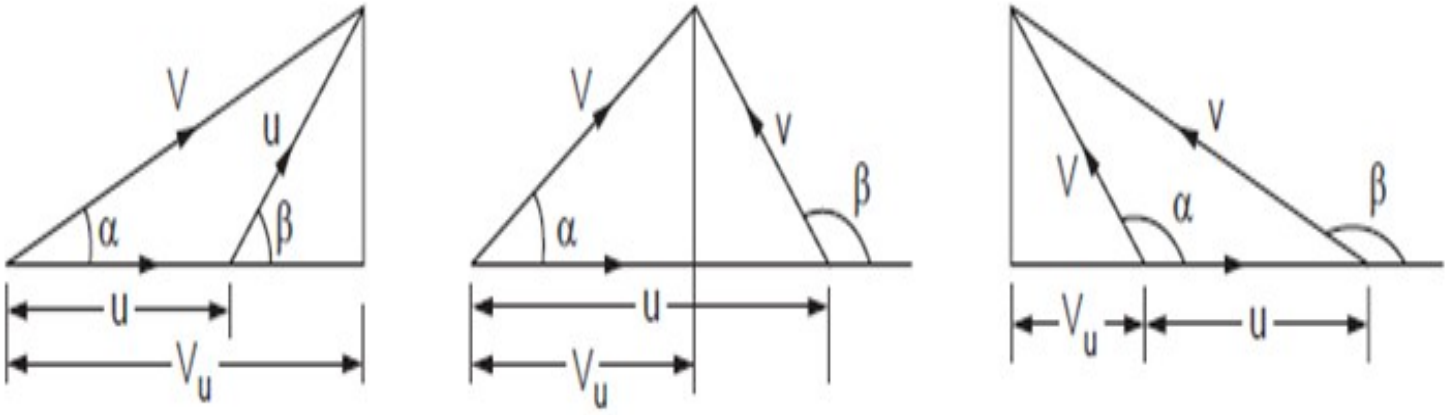
- The relative Velocity of a body is its velocity relative to a second body which may in turn be in motion relative to the earth.

- The absolute velocity V of the first body, is the vector sum of its velocity relative to the second body v, and the absolute velocity of the latter, u

- **Vectorially, $\mathbf{V = u \pm v}$**

- This is easily determined by vector diagram called as velocity triangle

- Some possible diagrams are shown in Figure below.



Sample Velocity diagrams

- Some of the general relations are,

$$V \sin\alpha = v \sin\beta \,, \quad V_u = V\cos\alpha = u + v\cos\beta$$

where, V_u is the component of the absolute velocity of the first body in the direction of the velocity u of the second body.

Differences between stationary vane and a moving vane:

- There are two main differences between the action of the fluid on a stationary vane and a moving vane in the direction of the fluid motion.

1. In the case of the moving vane it is necessary to consider both the absolute and relative velocities.

2. The amount of fluid that strikes a moving vane at any time interval is different from that which strikes the stationary vane.

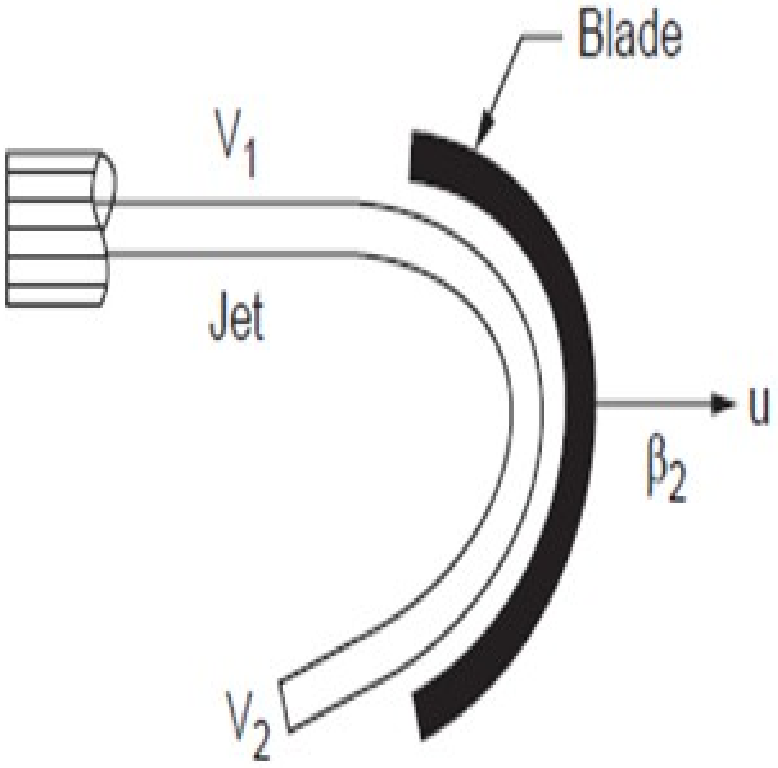
- If a jet of area A with a velocity V strikes, the vane moves away from the direction of the jet with a velocity u, then the mass of water striking the vane equals

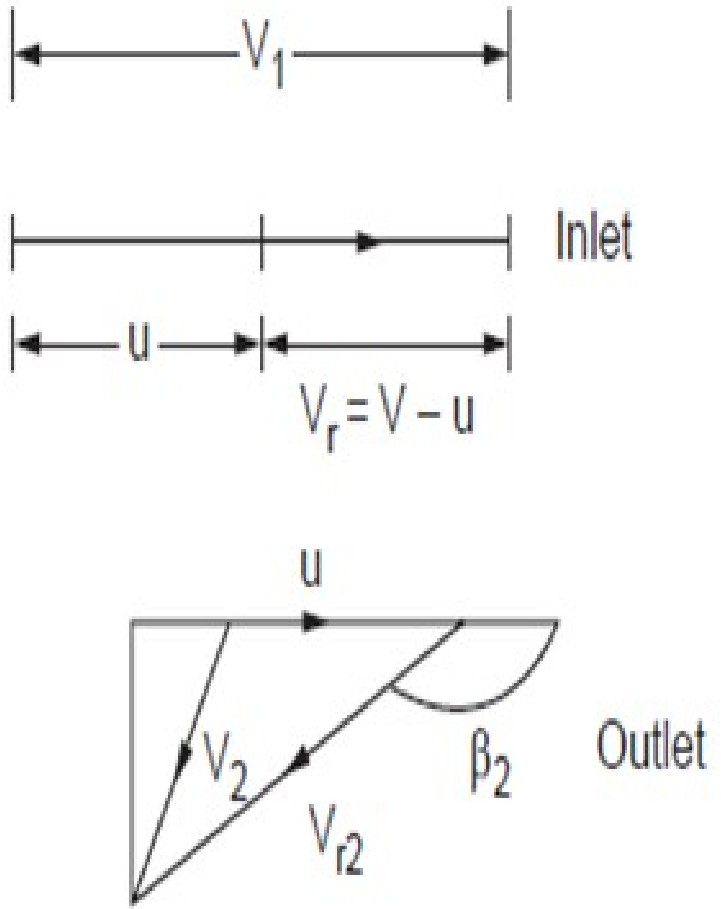
$\rho A(V - u)$ in kg/s.

Where (V – u) is the relative velocity between the jet and the vane.

- This can be realised the velocity of the vane is to be equal to that of the jet. In this case no water will strike the vane, obviously.

- Consider the flow as shown in figure below.


Blade
V_1
Jet
u
β_2
V_2


V_1
Inlet
u
$V_r = V - u$
u
V_2
β_2
Outlet
V_{r2}

- The velocity diagram with as inlet and outlet are shown in the figure above.
- Considering the force on the fluid in the direction of blade velocity (can be considered as x direction).

$$Fu = \rho A(V_1 - u)(V_{u2} \pm V_{u1})$$

$V_{u2} = (V_r \cos\beta_2 - u)$, denoting V_r as relative velocity

$$\therefore Fu = \rho A\,(V_1 - u)\,(V_r \cos\beta_2 - u \pm V_{u1})$$

- In the case shown, $V_{u1} = V$ itself.
- It is possible that $(V_{r2}\cos\beta_2 - u)$ or V_{u2} is negative depending upon the relative values of u and V_r i.e. $u > V_{r2}\cos\beta 2$.

- It is to be noted that the vane angle at the inlet should be in the direction of the relative velocity of the water when it touches the vane.

- Otherwise loss will occur due to the jet hitting the vane at an angle and then turning the follow on the vane surface.

- It was assumed that the relative velocity at inlet and at outlet is equal as no work was done by the vane on the fluid.

- In case of friction, $V_r = CV_{r1}$ = where C is a fraction.

- When the vane moves at a direction different from that of the jet velocity say at an angle α, then force on the fluid by the vane will be at an angle α.

- In such a case,

$$F_x = \rho A (V_1 \cos\alpha_{1i} - V_{r2} \cos\beta 2 - u) (V_1 \cos \alpha_1 - u)$$

$$= \rho A (V_1 \cos\alpha_1 - V_2 \cos\alpha_2)$$

- As it was already mentioned, a single moving vane is not of practical importance when a series of vanes fixed on the periphery of a well is struck by the jet.

- Work or energy transfer between the fluid and the water will be **F × u.**

End of chapter one

Thank u