



# SSC-JE

STAFF SELECTION COMMISSION

## MECHANICAL ENGINEERING

### STUDY MATERIAL

## HYDRAULIC MACHINES

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## CHAPTER-1

### IMPACT OF JET

→ A jet of liquid emerging from a nozzle has velocity and it possesses a certain amount of kinetic energy.

→ When this jet strikes an obstruction placed in its path, it will exert force on the obstruction. This impressed force is called impact of jet.

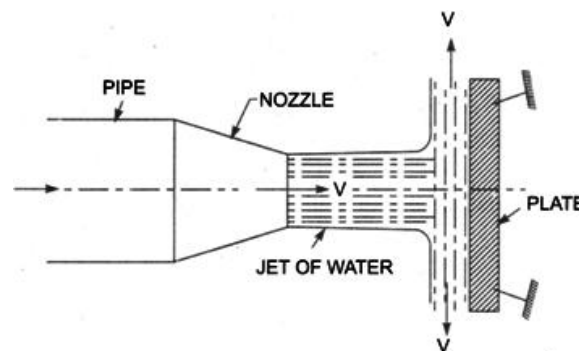
→ Hence impact of jet is means the force exerted by the jet on a plate which may be moving or stationary.

→ It states that net force acting on a fluid mass is equal to the change in momentum/second

in that direction *i.e.*,  $F = \frac{d}{dt}(M)$

#### 1. Force exerted by fluid jet on stationary flat plate:

##### (1) Flat place normal to the jet:



**Figure:** Force exerted by jet on vertical plate.

$F_x$  = Exerted by the jet on the plate in the direction of jet.

$F_x$  = Rate of change of momentum in the direction of force

$$F_x = \frac{\text{Initial momentum} - \text{Final momentum}}{\text{Time}}$$

$$= \frac{\text{Mass}}{\text{Time}} [\text{Initial velocity} - \text{Final velocity}]$$

$$= \rho a V [V - 0]$$

$$\boxed{F_x = \rho a V^2}$$

**Note:** When the force exerted on the jet is to be determined then final minus initial velocity is taken.

→ When the force exerted by the jet on the plate is to be obtained, then initial velocity minus final velocity is taken.

Where, a = cross-sectional area of jet

V = velocity of jet before striking.

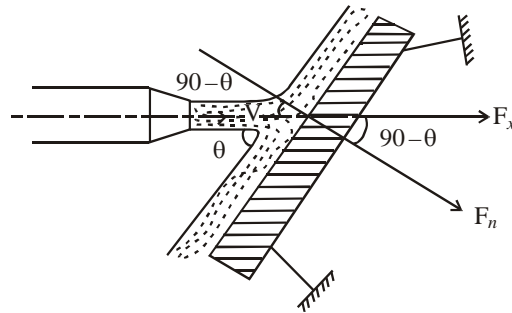
**(2) Flat plate inclined to the jet:**

Fig. Jet Striking Stationary inclined plate

- Component of force ( $F_x$ ) in the direction of flow.

$$F_x = \rho A V^2 \sin^2 \theta$$

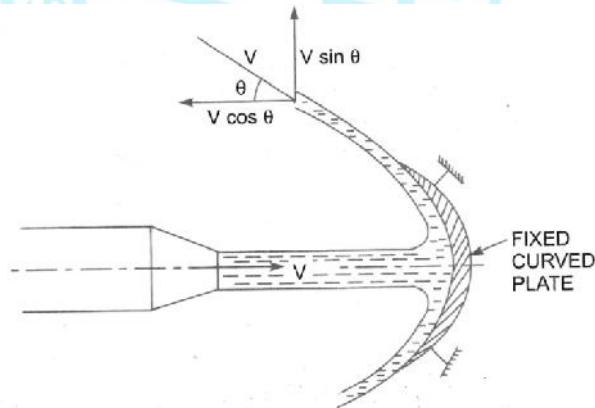
- Component of force ( $F_y$ ) in perpendicular to flow:

$$F_y = \rho A V^2 \sin \theta \cdot \cos \theta$$

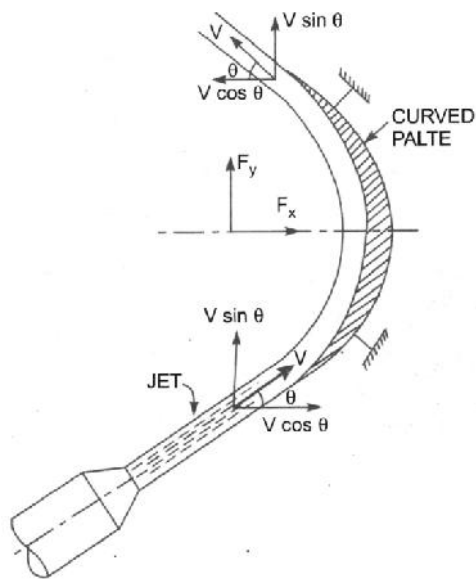
$V$  = velocity of jet before striking

$A$  = Area of jet

$$\text{Resultant force, } F = \sqrt{F_x^2 + F_y^2} = \rho A V^2 \sin \theta \text{ (Normal to plate)}$$

**2. Force exerted by fluid jet on stationary curved plate :****(1) Jet strikes the curved plate at centre:****Figure:** Jet striking a fixed curved plate at centre.

- $F_x = \rho A V^2 (1 + \cos \theta)$  angle of deflection =  $(180^\circ - \theta)$
- $F_y = -\rho A V^2 \sin \theta$

**(2) Jet strikes the plate at one end tangentially and the plate is symmetrical.****Figure:** Jet Striking curved fixed plate at one end.

- $F_x = 2\rho AV^2 \cos \theta$   
 $F_y = 0$

**3. Jet Strikes the curved plate at one end tangentially when the plate is unsymmetrical:**

Let  $\theta$  – is angle made by tangent at inlet tip with  $x$ -axis.

$\phi$  – is angle made by tangent at outlet tip with  $x$ -axis.

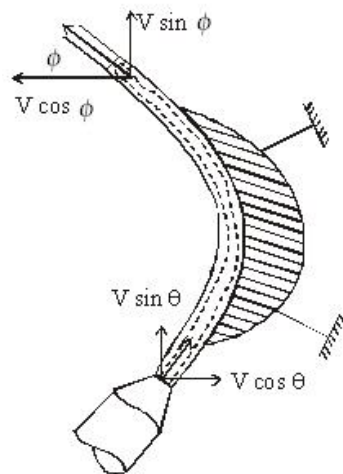


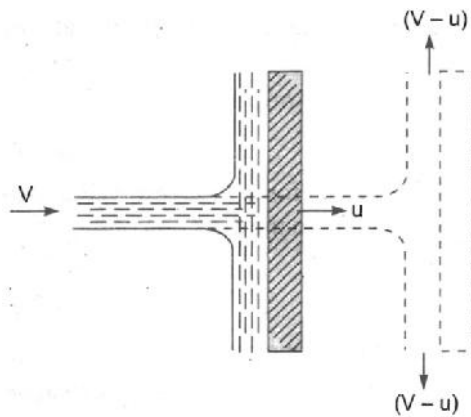
Plate is unsymmetrical to the  $x$ -axis

$$F_x = \rho a V^2 [\cos \theta + \cos \phi]$$

$$F_y = \rho a V^2 [\sin \theta - \sin \phi]$$

#### 4. Force exerted by a jet on moving plate:

##### (1) Vertical flat plate moving in the direction of jet:



**Figure:** Jet striking a flat vertical moving plate

- $F_x = \rho A(v - u)^2$

A : Area of jet

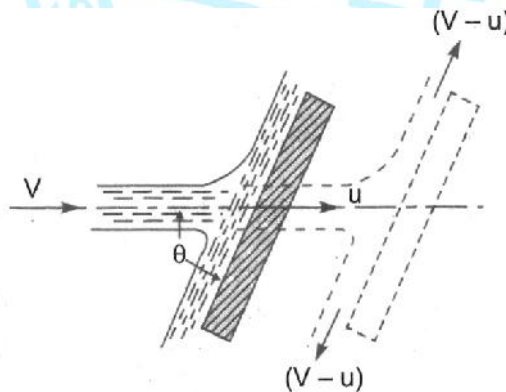
V : absolute velocity of jet

u : velocity of flat plate

- work done per second by the jet on the plate,

$$W = \rho A(v - u)^2 u \quad \text{Nm/s}$$

##### (2) Inclined flat plate moving in the direction of jet :



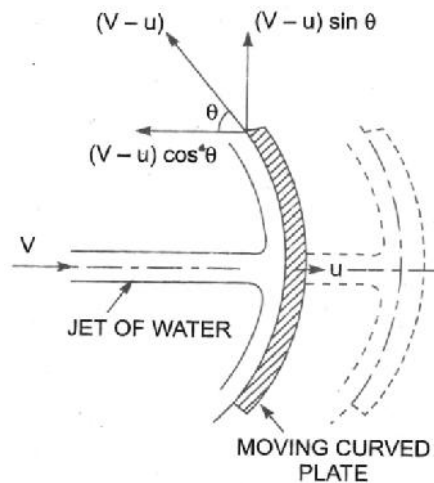
**Figure:** Jet striking and inclined moving plate.

- $F_x = \rho A(v - u)^2 \sin^2 \theta$

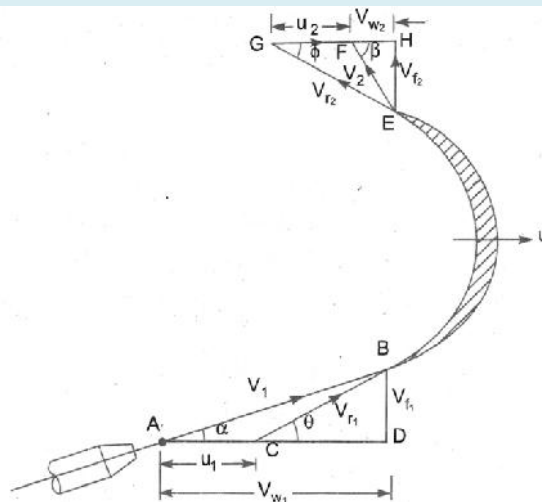
$$F_y = \rho A(v - u)^2 \sin \theta \cdot \cos \theta$$

- Work done per second by the jet on the plate

$$W = \rho A(v - u)^2 \cdot u \sin^2 \theta \text{ N.m/s}$$

**(3) Curved plate moving in the direction of jet and jet strikes at the centre of the plate :****Figure: . Jet striking a curved moving plate**

- $F_x = \rho A(v - u)^2 [1 + \cos \theta]$
- Work done per second by the jet on the plate:  
 $W = \rho A(v - u)^2 u [1 + \cos \theta]$

**5. Force exerted by a jet striking on an unsymmetrical moving curved vane tangentially at one end:****Figure: . Jet striking a moving curved vane at one of the tips.****(i) Velocity triangle at inlet :**

$u_1$  = velocity of plate at inlet

$v_{w_1}$  = velocity of white at inlet

$v_{f_1}$  = velocity of flow at inlet

$v_{r_1}$  = relative velocity of jet and plate at inlet

$v_1$  = velocity of jet at inlet

$\alpha$  = Guide blade angle or angle between the direction of jet and direction of motion of plate.

$\theta$  = vane angle at inlet or angle between the relative velocity ( $v_{r_1}$ ) with direction of motion of plate at inlet.

**(ii) Velocity triangle at outlet:**

$u_2, v_{w_2}, v_{f_2}, v_{r_2}, v_2$  Are the corresponding values at outlet.

$\beta$  = angle made by velocity ( $v_2$ ) with the direction of motion of vane at outlet

$\phi$  = vane angle at outlet.

- If the vane is smooth.

$$\boxed{u_1 = u_2 = u} = \text{velocity of vane in the direction of motion.}$$

$$\boxed{v_{r_1} = v_{r_2}}$$

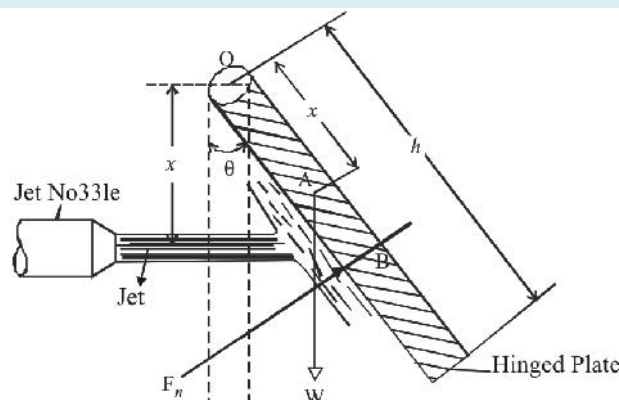
- If vane is symmetrical,  $\theta = \phi$
- Work done per second per unit weight of fluid striking per second.

$$\boxed{W = \frac{1}{g} [v_{w_1} \pm v_{w_2}] \cdot u \text{ N.W / N}}$$

- Efficiency of jet ( $\eta$ ) :

$$\eta = \frac{\dots Av_{r_1}(v_{w_1} \pm v_{w_2})}{\frac{1}{2}(\dots Av_1)v_1^2} \quad [\text{Where } A = \text{area of jet}]$$

## 6. Forced Exerted by a Jet on a Hinged Plate:



For equilibrium of the plate

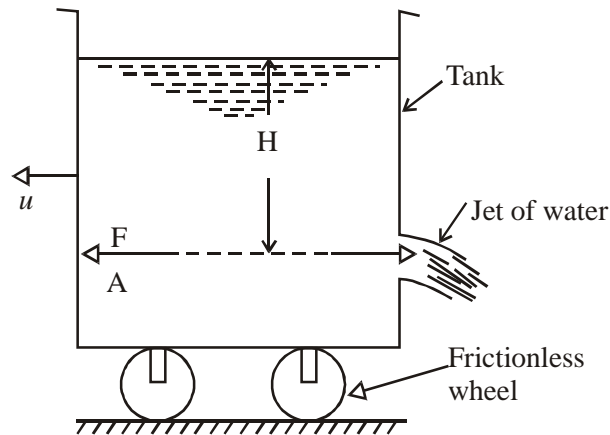
$$(\rho av^2) \times (x) = (W) \times (x \sin \theta)$$

$$\boxed{\sin \theta = \frac{\rho av^2}{W}}$$



### 7. Jet Propulsion:

Jet propulsion means the propulsion or movement of the bodies such as ships, Aircraft, rocket etc with the help of jet.



### 8. Jet propulsion of a Tank with an orifice:

Consider a large tank fitted with an orifice in one of its sides.

$H \rightarrow$  Constant head of water in Tank

$a \rightarrow$  Orifice Area

$v \rightarrow$  Velocity of the Jet of water

$C_v \rightarrow$  Coefficient of velocity of orifice.

$$v = C_v \sqrt{2gH}$$

Mass of water coming out = Density  $\times$  Volume =  $\dots aV$

**Case I.** When tank is stationary means  $u = 0$

Initial velocity of water in tank is zero and final velocity of jet  $v$ .

$$F = \dots aV[v - 0]$$

$$F = \rho av^2$$

Force acting on the water is  $F$ .

**Case II.** When;  $u \neq 0$   $F = \rho av_r[(v + u) - u]$   $v_r = (v + u)$

$v_r \rightarrow$  Relative velocity when jet is moving itself then velocity of jet cumulative with tank velocity *i.e.*

$$v_r = v + u$$

(i) **Efficiency of the propulsion:**

$$\eta = \frac{\text{Work done per second}}{\text{Kinetic energy of the issuing jet per second.}}$$

$$= \frac{\rho a(v+u) \times v \times u}{\frac{1}{2}[\rho a(u+v)] \times (u+v)^2} = \frac{2vu}{(u+v)^2}$$

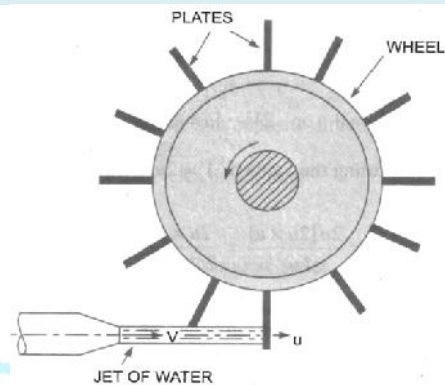
$$\eta = \frac{2vu}{(u+v)^2}$$

(ii) For Maximum Efficiency:  $\frac{d\eta}{du} = 0$

Then  $u = v$

$\eta = 50\%$

### 9. Force exerted by a jet of water on a series of a vane :



**Figure:** Jet striking a series of vanes.

- Work done by the jet on the series of plates per second  
 $W = \rho Av(v-u)u$
- Kinetic energy of jet per second :

$$K_{-E} = \frac{1}{2} \dots Av^3$$

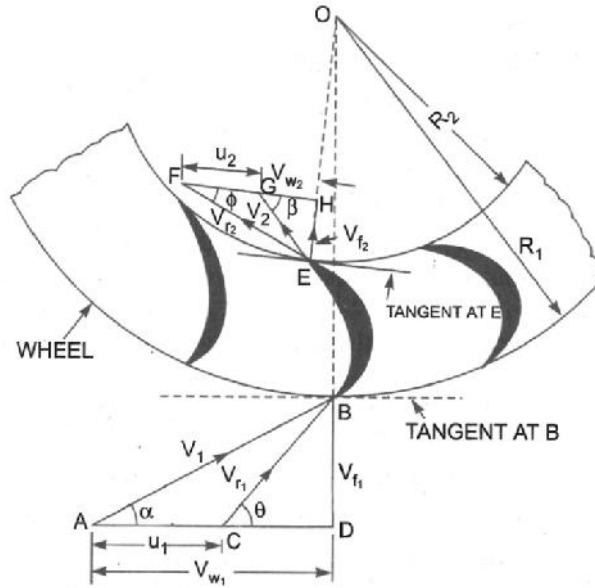
$$\text{Efficiency } (\eta): \eta = \frac{W}{K_{-E}}$$

$$\therefore \eta = \frac{2u[v-u]}{v^2}$$

For maximum efficiency,  $u = \frac{v}{2}$

Hence maximum efficiency  $\eta_{\max} = 50\%$

**10. Force exerted by a jet striking on a series of radial curved vanes:**



**Figure:** Series of radial curved vanes mounted on a wheel.

(i) Torque exerted by water on the wheel.

$$T = \rho A v_1 [v_{w1} R_1 + v_{w2} R_2]$$

(ii) Work done per second on wheel:

$$W = \rho A v_1 [v_{w1} u_1 + v_{w2} u_2] \dots \dots \dots \text{If } \beta \text{ is acute angle}$$

$$= \rho A v_1 [v_{w1} u_1 - v_{w2} u_2] \dots \dots \dots \text{If } \beta \text{ is obtuse angle}$$

$$= \rho A v_1 [v_{w1} u_1] \dots \dots \dots \text{if } \beta = 90^\circ$$

(iii) Efficiency, 
$$\eta = \frac{2[v_{w1} u_1 \pm v_{w2} u_2]}{v_1^2}$$

### Question and Solution

1. Calculate the force exerted by a jet of water of diameter 80mm on a stationary flat plate, when the jet strikes the plate normally with velocity 30 m/s

**Solution:** Given,

$$d = 80\text{mm} = 0.08\text{m}, \quad a = \frac{f}{4}(d)^2 = \frac{f}{4} \times (0.08)^2 = 5.0265\text{m}^2 \times 10^{-3}$$

$$V = 30\text{ m/s} \quad \dots = 1000\text{ Kg/m}^3$$

Hence, force =  $\rho av^2$

$$= 1000 \times 5.0265 \times 10^{-3} \times 30^2 = 4523.85\text{ N} \quad \text{Ans.}$$

2. A nozzle 50mm diameter delivers a stream of water at 20 m/s per perpendicular to a plate which moves away from the jet at 5 m/s. find

- (a) force on the plate  
 (b) work done, and  
 (c) efficiency of jet

**Solution:**

Given

$$d = 50\text{mm} = 0.05\text{ m}$$

$$\rho = 1000\text{ Kg/m}^3$$

$$\text{Area, } a = \frac{f}{4}(0.05)^2 = 1.963 \times 10^{-3}\text{ m}^2$$

Velocity of jet,  $V = 20\text{m/s}$

Velocity of plate =  $u = 5\text{ m/s}$

- (a) force in the plate,  $F_x = \dots a(V - u)^2$

$$= 100 \times 1.963 \times 10^{-3} \times (20 - 5)^2$$

$$= 441.675\text{ N}$$

- (b) work done per sec. by the jet,  $w = F_x u = 441.675 \times 5 = 2208.375\text{ N - m/s}$

- (c) Efficiency,  $y = \frac{\text{work done / s}}{\text{K.E. of jet / s}} = \frac{F_x u}{\frac{1}{2}(\dots av) \times V^2}$

$$= \frac{2208.375}{\frac{1}{2} \times 1000 \times 1.963 \times 10^{-3} \times 20^3}$$

$$= \frac{2208.375}{7852} = 0.28125 = 28.125\% \quad \text{Ans.}$$

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