FLUID MACHINERY

19/11/2016

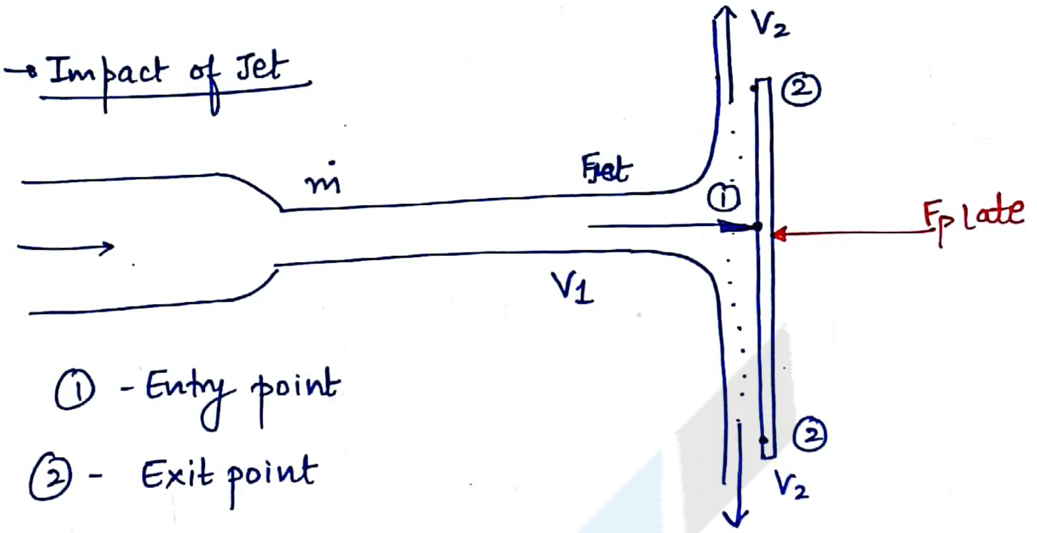
Fluid Machinery

D.S. Kumar only
↑
Book.

→ Turbine → hydraulic energy → Mech. energy

→ pump → Mech. energy → Hydraulic energy

→ Impact of Jet



① - Entry point

② - Exit point

Fplate = Net change in linear momentum of water

Fplate = Momentum of water @ Exit - Momentum of water @ Entry

→ $F_{plate} = \dot{m}\vec{V_2} - \dot{m}\vec{V_1}$

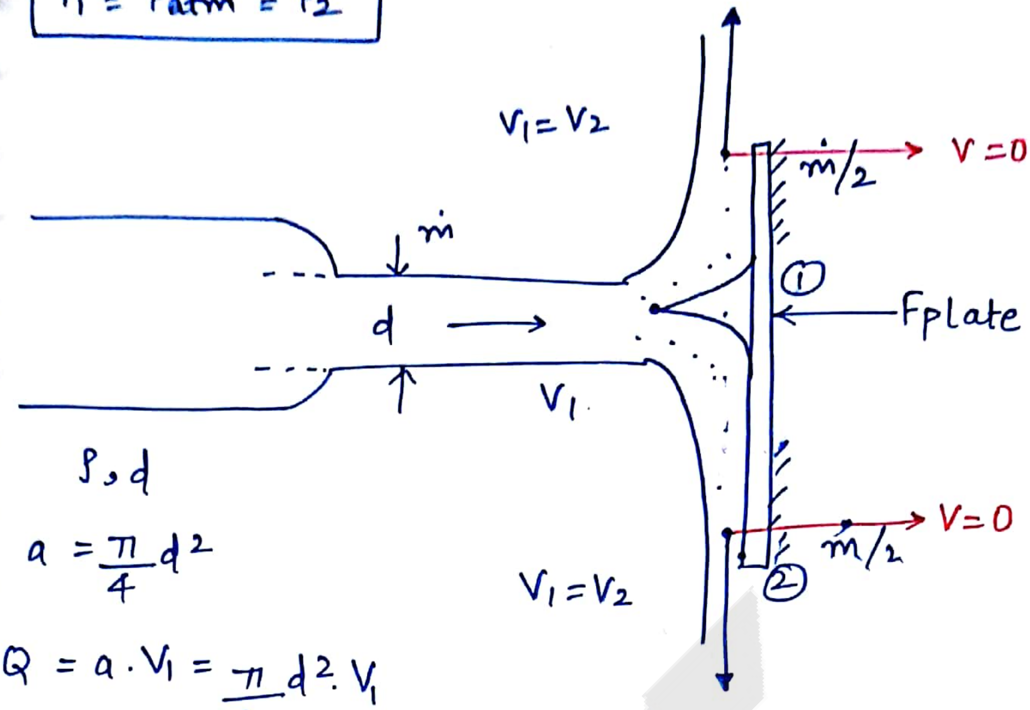
$F_{jet} = -F_{plate}$

→ $F_{jet} = \dot{m}\vec{V_1} - \dot{m}\vec{V_2}$

→ $\dot{m}$ = mass flow rate of water which strikes the body

Case ① jet strikes stationary vertical plate in normal direction.

$$\boxed{P_1 = P_{atm} = P_2}$$



ρ, d

$a = \frac{\pi}{4} d^2$

$Q = a \cdot V_1 = \frac{\pi}{4} d^2 \cdot V_1$

$\rightarrow \dot{m} = \rho a V_1$

$\rightarrow F_x = F_N = \dot{m} V_1 - \left[\frac{\dot{m}}{2} \times 0 + \frac{\dot{m}}{2} \times 0 \right]$

$= \dot{m} V_1$

$F_x = F_N = \rho a V_1^2 (N)$

$\rightarrow F_y = F_T = \dot{m} \times 0 - \left[\frac{\dot{m}}{2} \times V_2 + \frac{\dot{m}}{2} (-V_2) \right]$

$\underline{F_y = F_T = 0}$

<u>Note</u> → when jet strikes flat plate, then it will apply the force only normal dirn. to plate.

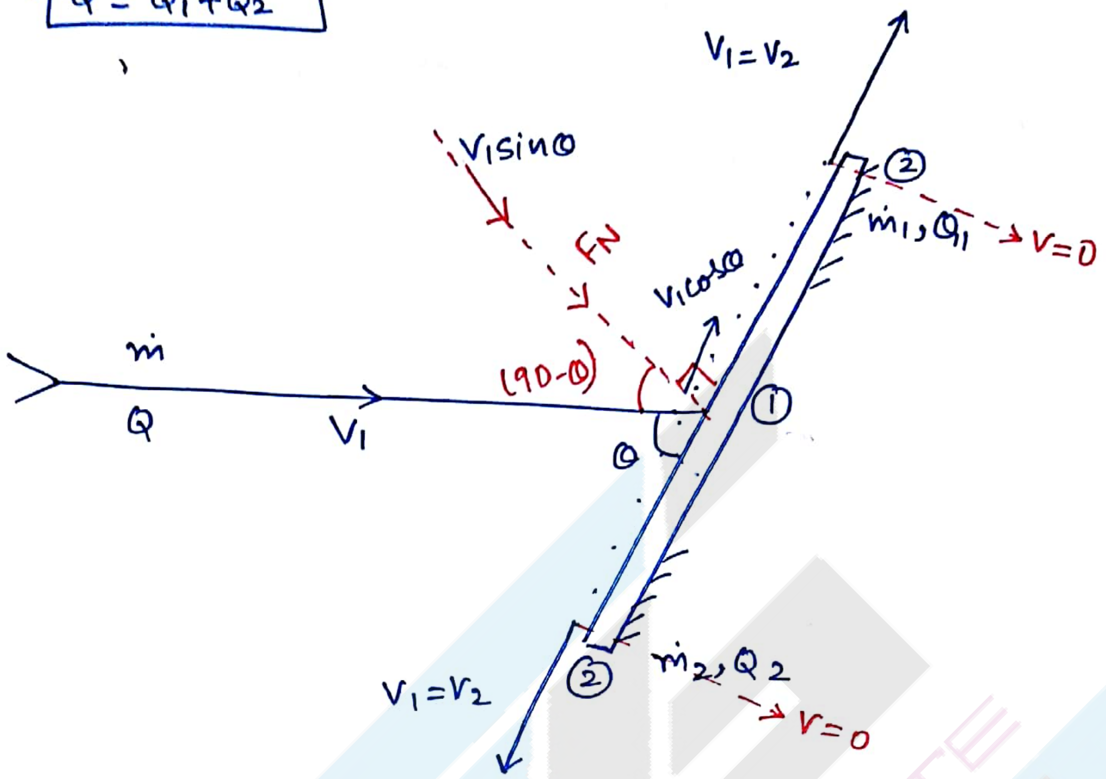
C-II → Jet strikes Stationary inclined plate

assuming Smooth surface.

$$\boxed{P_1 = P_{atm} = P_2}$$

→ $\dot{m} = \dot{m}_1 + \dot{m}_2$

→ $\boxed{Q = Q_1 + Q_2}$



→ $\dot{m} = \rho a V_1$

→ $F_N = \dot{m} V_1 \sin\theta - [\dot{m}_1 \times 0 + \dot{m}_2 \times 0]$

$F_N = \dot{m} V_1 \sin\theta$

$F_N = \rho a V_1^2 \sin\theta$

→ $F_x = F_N \sin\theta = \rho a V_1^2 \sin^2\theta$

→ $F_y = F_N \cos\theta = \rho a V_1^2 \sin\theta \cos\theta$

→ $F_T = 0$

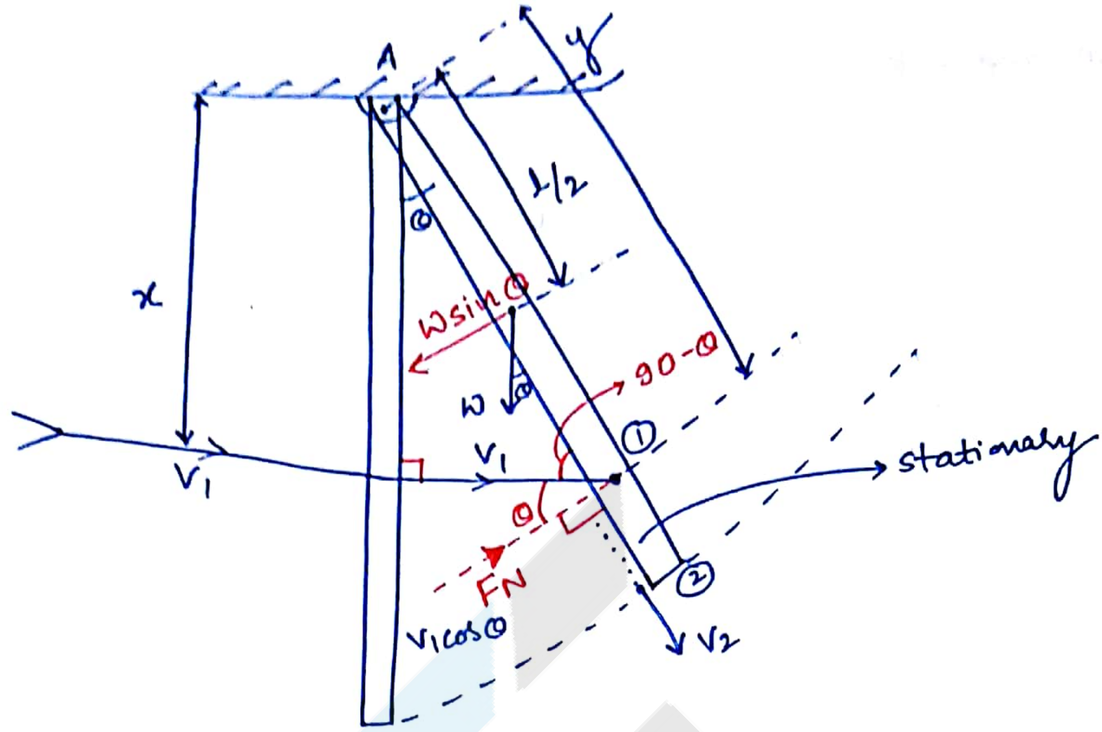
$\dot{m} V_1 \cos\theta - [\dot{m}_1 \times V_2 + \dot{m}_2 \times (-V_2)] = 0$

$\rho V_1 [Q \cos\theta - Q_1 + Q_2] = 0$

$Q \cos\theta - Q_1 + Q_2 = 0$

$Q = Q_1 + Q_2$

Case III → Jet strikes vertical hanging plate



l = Length of plate

ω = wt. of plate $= Mg$

at Eqm. Condn

$\Sigma M_A = 0$

$F_N \times y = \omega \sin\theta \times l/2$

→ $\dot{m} = \rho a V_1$

→ $F_N = \dot{m} V_1 \cos\theta - \dot{m} \times 0$

$F_N = \dot{m} V_1 \cos\theta = \rho a V_1^2 \cos\theta$

$\cos\theta = x/y$

$y = \dfrac{x}{\cos\theta}$

$\rho a V_1^2 \cancel{\cos\theta} \times \dfrac{x}{\cancel{\cos\theta}} = \omega \sin\theta \times l/2$

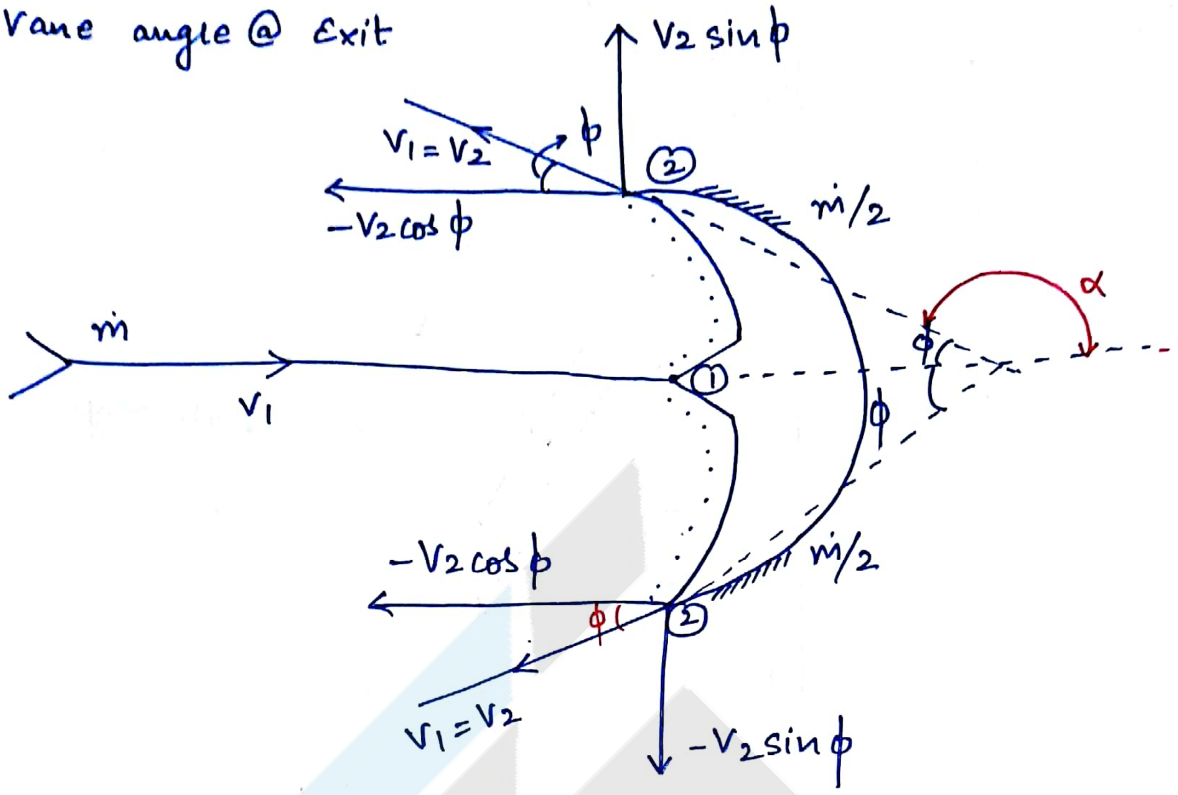
$$\boxed{\sin\theta = \frac{2\rho a V_1^2 x}{\omega l}}$$

$$\boxed{\theta = \sin^{-1}\left[\frac{2\rho a V_1^2 x}{\omega l}\right]}$$

Case IV → Jet strikes at the centre of stationary curve plate / vane / blade

Symmetrical vane

ϕ = Vane angle @ Exit



→ $\dot{m} = \rho a V_1$

→ $F_x = \dot{m}V_1 - \left[\frac{\dot{m}}{2} \times (-V_2\cos\phi) + \frac{\dot{m}}{2} \times (-V_2\cos\phi)\right]$

$F_x = \dot{m}V_1 + \dot{m}V_2\cos\phi$

$F_x = \dot{m}V_1(1+\cos\phi) = \rho a V_1^2(1+\cos\phi)$

→ $F_y = \dot{m} \times 0 - \left[\frac{\dot{m}}{2} \times V_2\sin\phi + \frac{\dot{m}}{2} \times (-V_2\sin\phi)\right]$

$F_y = 0$

α → angle of deflection ⇒ $\boxed{\delta = 180 - \phi}$

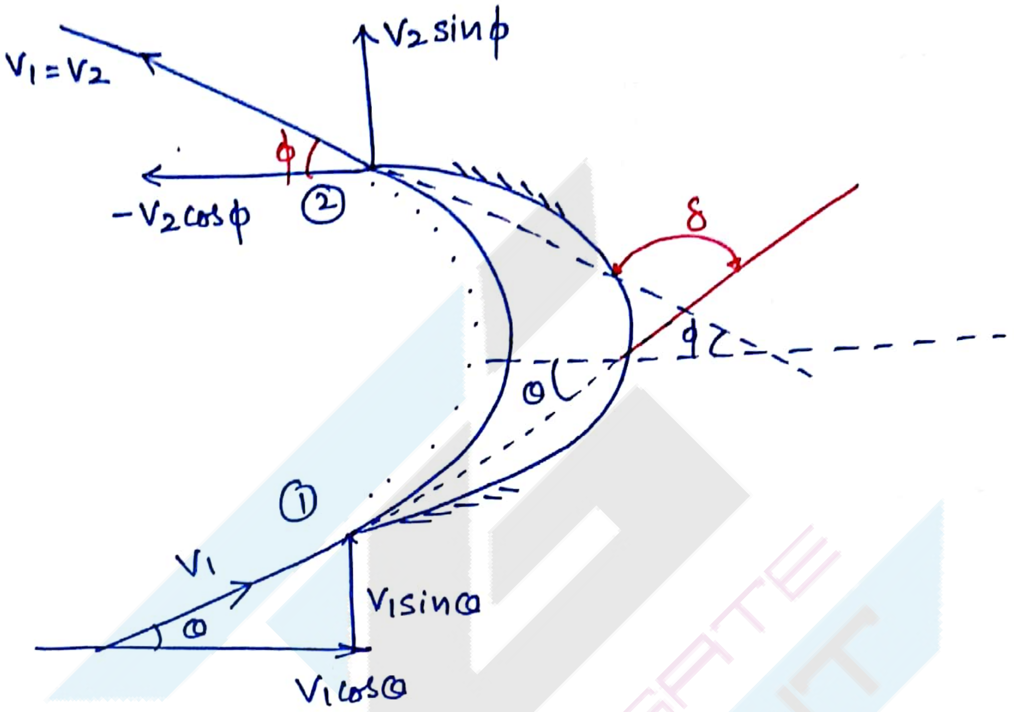
Case V → Jet strikes at the tip of stationary vane

Unsymmetrical Vane

θ = Vane angle @ Entry

ϕ = Vane angle @ Exit

δ = angle of Deflection = $\delta = 180 - (\theta + \phi)$



$\dot{m} = \rho a V_1$

→ $F_x = \dot{m} V_1 \cos\theta - \dot{m}(-V_2 \cos\phi)$

→ $F_x = \dot{m} V_1 (\cos\theta + \cos\phi)$

$F_x = \rho a V_1^2 (\cos\theta + \cos\phi)$

→ $F_y = \dot{m} V_1 \sin\theta - \dot{m} V_2 \sin\phi$

$F_y = \dot{m} V_1 (\sin\theta - \sin\phi)$

Symmetrical vane

$\theta = \phi$

$\delta = 180 - 2\theta$

$\delta = 180 - 2\phi$

WB ① $A = 0.0028 m^2$

$V_1 = 5 m/s$

$F = 70 N$

$F = \rho a V_1^2$ ✓

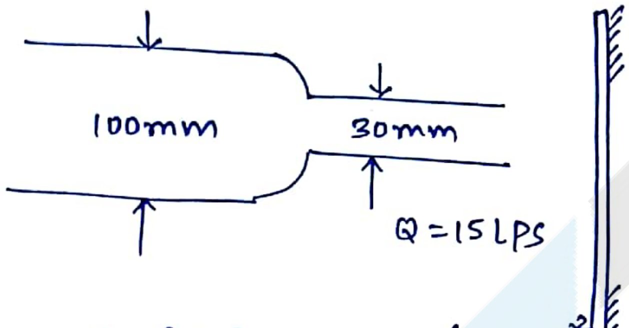
$Q = A_1 V_1$

$15 = \frac{\pi}{4}(.030$

(56) $d = 30 mm$

$Q = 15 \times 10^{-3} m^3/sec$

$d_1 = 100 mm$



$F = \rho a v^2 = 1000 \times \left(\frac{\pi}{4} \times 0.3^2\right) \times 21.2^2 = 318.3 N$

$a = \frac{\pi}{4} \times 0.03^2$

$Q = a \cdot V_1$

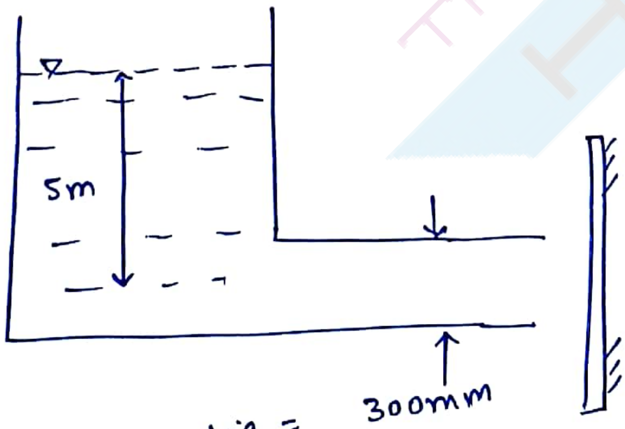
$0.015 = \frac{\pi}{4} \times 0.03^2 \times V_1$

$V_1 = 21.2 m/s$

$V = \sqrt{2gh}$ ~~44050~~

Gate-16 ME

(2)



Force = ?

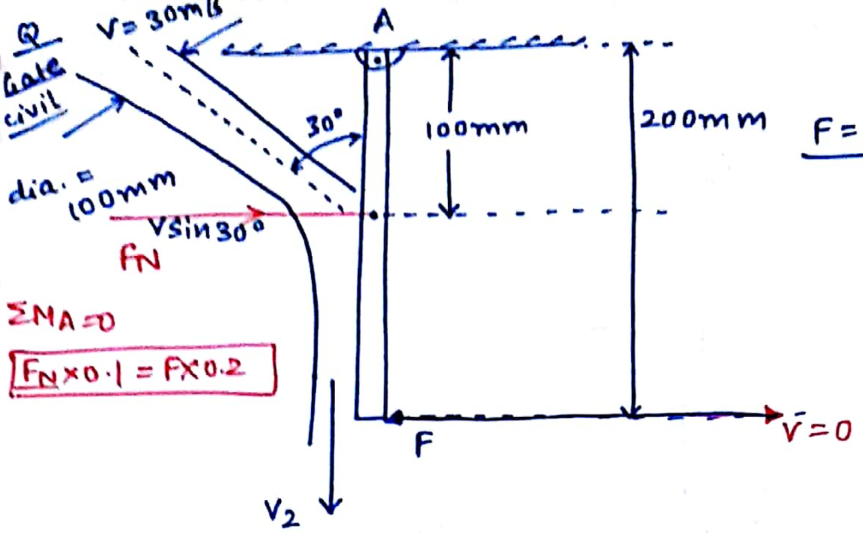
Sol $F = \rho a v^2$ ✓

$F = 1000 \times \frac{\pi}{4}(0.3^2) \times (\sqrt{2gH})^2$

$F = 6.927 KN$

$V = \sqrt{2gH} = 9.90 m/s$ ✓

Q Gate civil



F = ?

$\Sigma M_A = 0$

$\boxed{F_N \times 0.1 = F \times 0.2}$

Sol ~~$F_N = \rho a v_1^2 = 1000 \times \frac{\pi}{4} \times (0.1)^2 (30)^2 = 55.516\,kN$~~

~~F_N~~ $\dot{m} = \rho a v$

$\Rightarrow F_N = \dot{m} \times V\sin 30° - \dot{m} \times 0$

$F_N = \dot{m}\, v \sin 30° = \underline{\rho a v^2 \sin 30°}$

$1000 \times \left(\frac{\pi}{4} \times 0.1^2\right) \times 30^2 \times \sin 30° \times 0.1 = F \times 0.2$

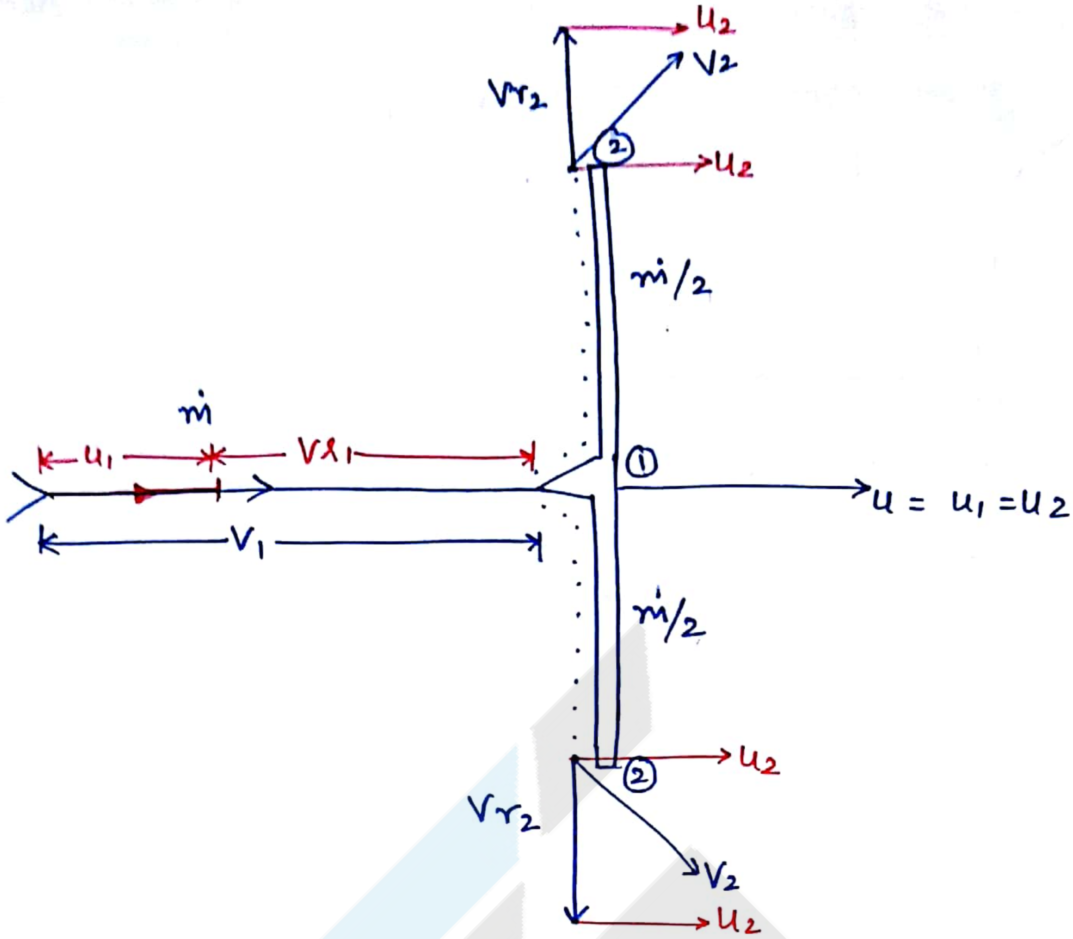
$\boxed{F = 1767\,N}$

Case VI Jet strikes moving flat plate →

$\boxed{P_1 = P_{atm} = P_2}$ $V_2 <<< V_1$

$Z_1 \approx Z_2$

V_1	u_1	V_{r_1}
10	0	10 ✓
10	6	4 m/s
10	20	(−) ✗



$u_1, u_2 \rightarrow$ velocity of plate/ vane @ entry & exit

$V_{r_1}, V_{r_2} \rightarrow$ Relative velocity of water wrt plate/vane @ entry & exit

$\rightarrow \dot{m} = \rho a V_{r_1} = \rho a (V_1 - u_1)$

$\rightarrow F_x = F_N = \dot{m} \times V_1 - \left[\frac{\dot{m}}{2} \times u_2 + \frac{\dot{m}}{2} \times u_2\right]$

$F_x = F_N = \dot{m} \times V_1 - \dot{m} u_1 = \dot{m}(V_1 - u_1)$

$\underline{F_x = F_N = \rho a (V_1 - u_1)^2}$

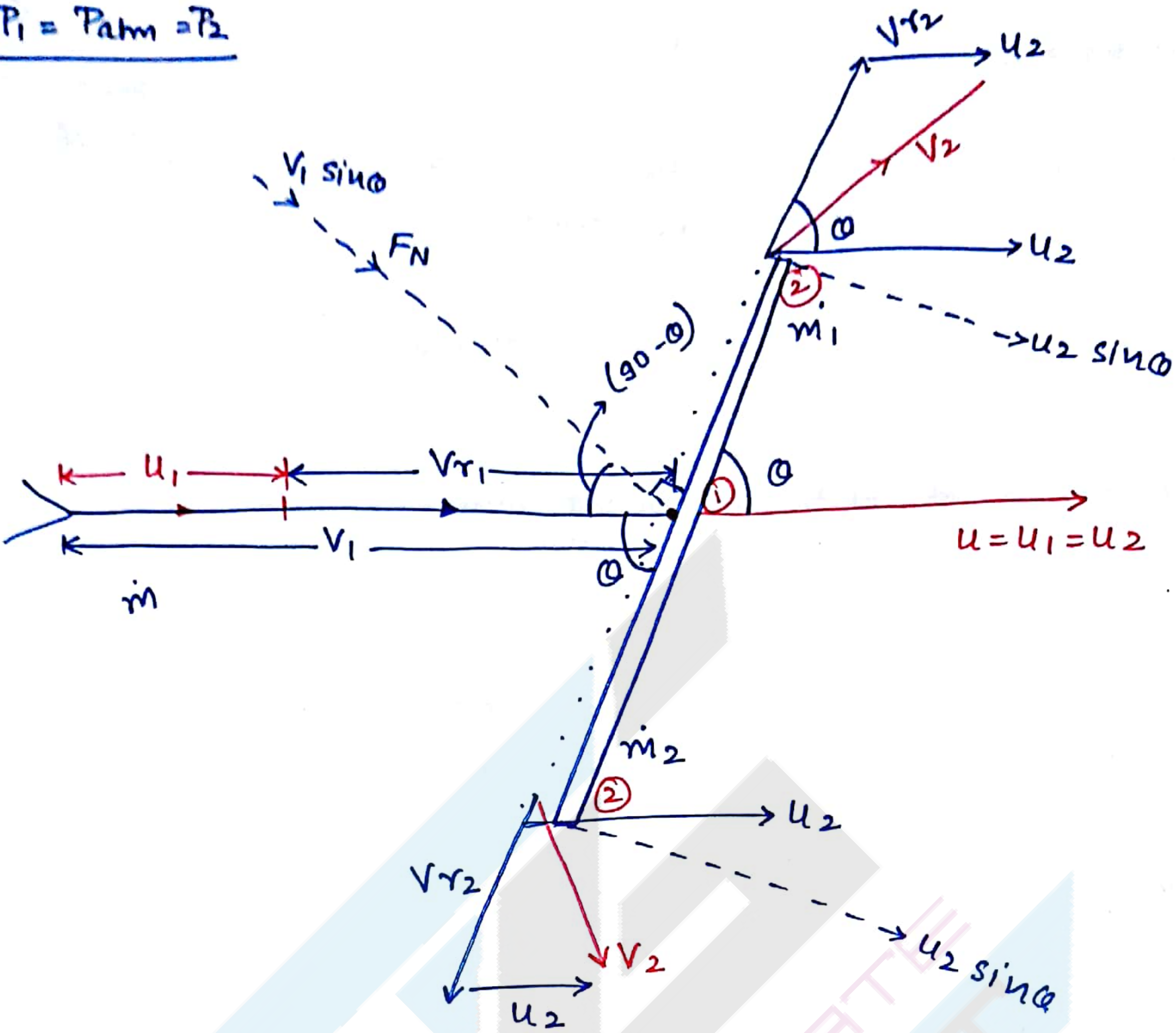
$\rightarrow F_y = F_T = \dot{m} \times 0 - \left[\frac{\dot{m}}{2} \times V_{r_2} + \frac{\dot{m}}{2}(-V_{r_2})\right]$

$F_y = F_T = 0$

$\rightarrow WD = F_x \times u = \rho a (V_1 - u_1)^2 u$ watt

Case VII → Jet strikes moving inclined plate :→

$P_1 = P_{atm} = P_2$



$\dot{m} = \dot{m}_1 + \dot{m}_2$

$\rightarrow \dot{m} = \rho a V_{r_1} = \rho a (V_1 - u_1)$

$F_N = \dot{m} V_1 \sin\theta - [\dot{m}_1 u_2 \sin\theta + \dot{m}_2 \times u_2 \sin\theta]$

$F_N = \dot{m} V_1 \sin\theta - \dot{m} u_2 \sin\theta$

$F_N = \dot{m} (V_1 - u_1) \sin\theta$

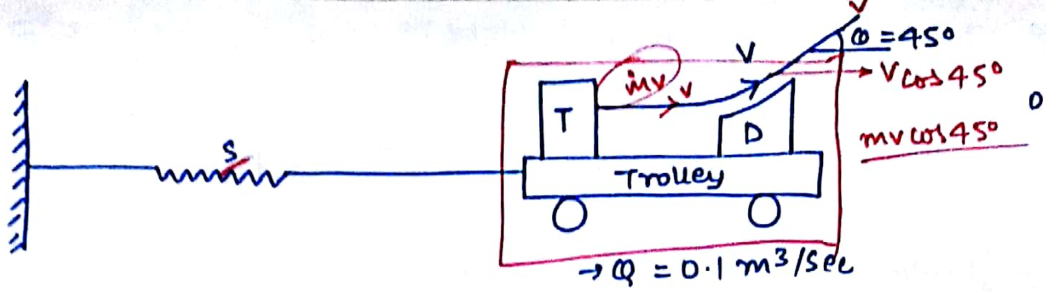
$F_N = \rho a (V_1 - u_1)^2 \sin\theta$

$F_x = F_N \sin\theta = \rho a (V_1 - u_1)^2 \sin^2\theta$

$F_y = F_N \cos\theta = \rho a (V_1 - u_1)^2 \sin\theta \cos\theta$

$WD = F_x \times u = \rho a (V_1 - u_1)^2 \sin^2\theta \cdot u$ watt

Q



$\rightarrow V = 4m/S$

$Q = A_1V_1$

$0.1 = 4 \times A_1$

$0.025 = A_1$

$0.025 \times 4 = A_2V_2$

$0.025 \times V_2 = 0.1$

$F_S = mV\cos 45°$

$= 1000 \times 0.1 \times 4 \times \cos 45° = 400 \times \frac{1}{\sqrt{2}} = 200\sqrt{2}$

Sol

Case VIII → Jet strikes at the tip of moving vane

$P_1 = P_{atm} = P_2$

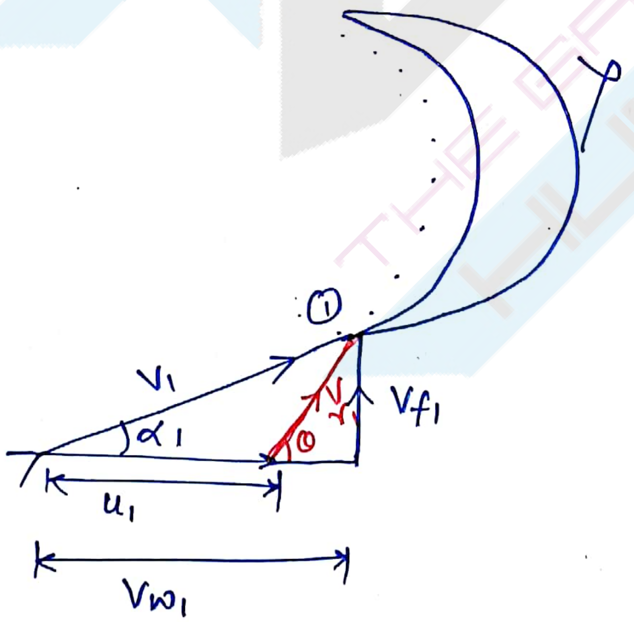
α = Nozzle angle

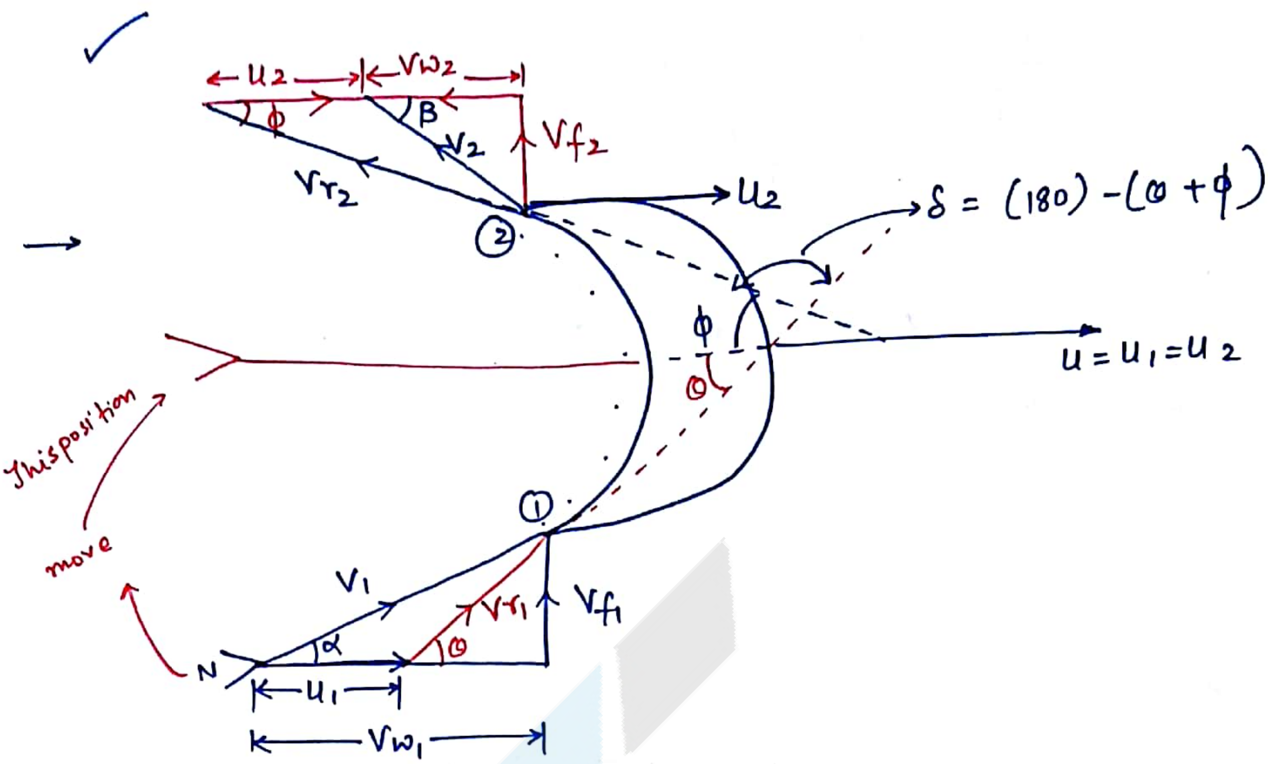
β = angle @ which water leaves the vane

$\theta \rightarrow$ Vane $\angle$ at entry

$\phi \rightarrow$ Vane $\angle$ at exit

$\delta \rightarrow$ angle of deflection





$Vw_1, Vw_2 \rightarrow$ whirl/swirl velocity of water @ entry & exit

$Vf_1, Vf_2 \rightarrow$ flow velocity of water @ entry & exit

$\rightarrow \dot{m} = \rho a V r_1 =$

$\rightarrow F_x = \dot{m} \times Vw_1 - \dot{m} \times (-Vw_2)$

$\rightarrow F_x = \dot{m}\,(Vw_1 + Vw_2)$

$\rightarrow F_y = \dot{m} Vf_1 - \dot{m} Vf_2$

$F_y = \dot{m}\,(Vf_1 - Vf_2)$

$WD = F_x \times u = \dot{m}\,(Vw_1 + Vw_2) \times u$ watt

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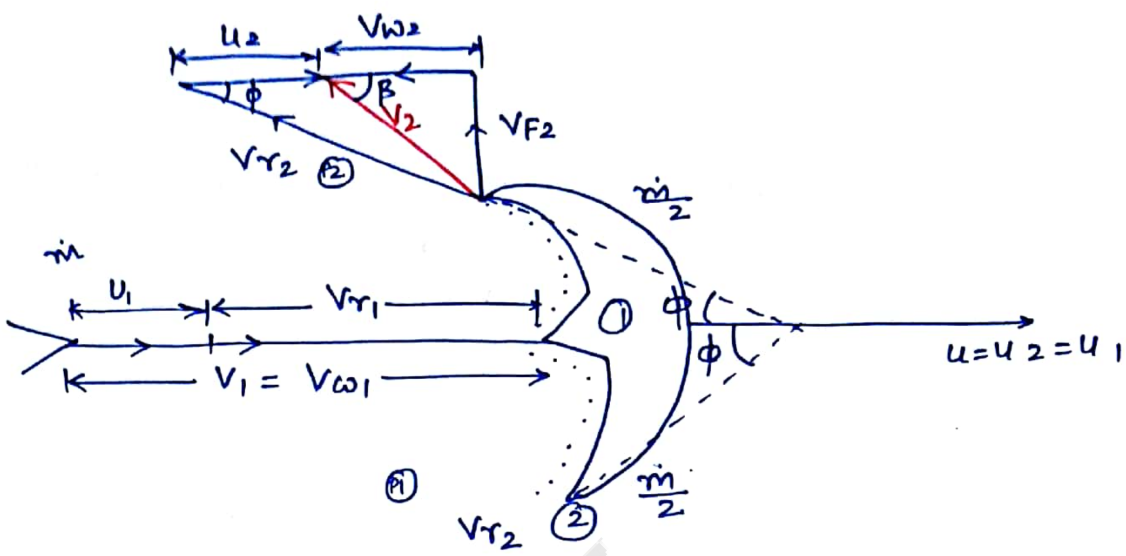
Case IX Jet strikes at the centre of moving vane :-

Symmetrical Vane



$\rightarrow \dot m = \rho a V_{r_1} = \rho a (V_1 - u_1)$

$\rightarrow F_x = \dot m \times V_{w_1} - \left[\frac{\dot m}{2} \times (-V_{w_2}) + \frac{\dot m}{2} \times (-V_{w_2})\right]$

$F_x = \dot m V_{w_1} + \dot m V_{w_2}$

$F_x = \dot m (V_{w_1} + V_{w_2})$

$\rightarrow F_y = \dot m \times 0 - \left[\frac{\dot m}{2} \times V_{f_2} + \frac{\dot m}{2} (-V_{f_2})\right]$

$F_y = 0$

$WD = F_x \times u = \dot m (V_{w_1} + V_{w_2}) \cdot u$

$\rightarrow \dfrac{W.D.}{\text{wt. of fluid which strikes the vane}} = \dfrac{WD}{\dot m g} = \dfrac{\cancel{\dot m}(V_{w_1} + V_{w_2})u}{(\cancel{\dot m} g = \cancel{\rho a V_{r_1}} \times g)}$ — $\rho a V_{r_1}$

$$\frac{WD}{\dot m g} = \frac{(V_{w_1} + V_{w_2})u}{g} \ \underline{(m)}$$

Note → The dirn. of V_{r_1} & V_{r_2} always will be tangential to vane for without shock entry and exit.

→ WD(KE)

$P_1 = P_2 = P_{atm}$

$V_2 \ll V_1$

→ smooth vane

$V_{r_2} = V_{r_1}$

→ Rough vane

$V_{r_2} < V_{r_1}$

$V_{r_2} = K V_{r_1}$

→ WD (Pr. E + KE)

$V_2 \ll V_1$

$P_2 \ll P_1$

→ smooth vane

$V_{r_2} \gg V_{r_1}$

→ Rough vane

$V_{r_2} > V_{r_1}$

$= V_{r_1}$

$< V_{r_1}$

$V_{r_1} \neq V_{r_2}$

K → coefficient of vane friction.

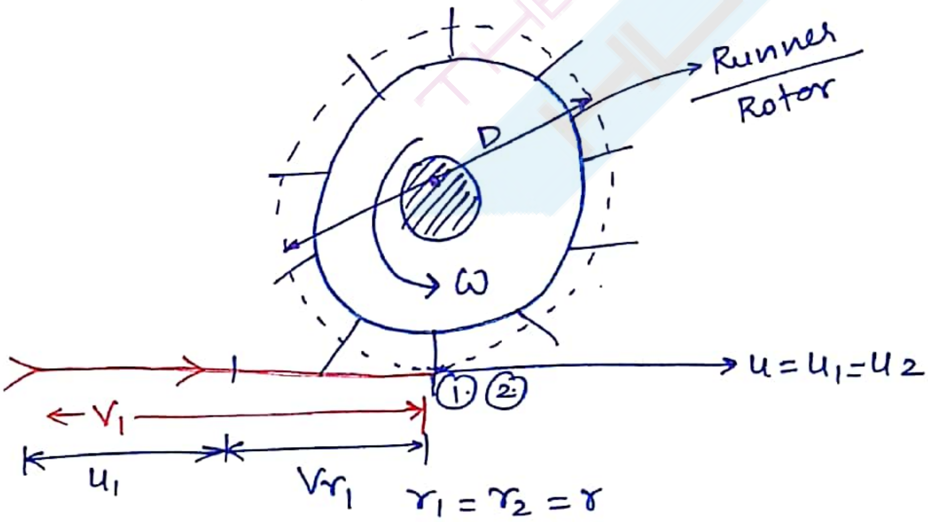
$$\eta = \frac{\dot{m} \cdot (V_{w_1} + V_{w_2}) \cdot u}{\frac{1}{2} \cdot \dot{m} V_1^2}$$

$\dot{m} = \rho a V_{r_1}$; $\dot{m} = \rho a V_1$

→ To increase the η of system

→ front view

TFR



$u_1 = u_2 = u = \omega r = \frac{\pi D N}{60}$

D = dia. of wheel

N = speed (rpm)

TFR

Tangential flow Runner

$\rightarrow \boxed{\dot{m} = \rho a V_1}$

$\rightarrow F_x = \dot{m} \times V_1 - \left[\frac{\dot{m}}{2} \times u_2 + \frac{\dot{m}}{2} \times u_2\right]$

$F_x = \dot{m} V_1 - \dot{m} u_2$

$F_x = \dot{m}(V_1 - u_1) = \rho a V_1 (V_1 - u_1)$

$\rightarrow F_y = 0$ (No axial force on Runner)

$\rightarrow$ WD $= F_x \times u = \rho a V_1 (V_1 - u_1) \cdot u$

$$\eta = \frac{\cancel{\rho a V_1} (V_1 - u_1) \cdot u}{\frac{1}{2} \cancel{\dot{m}} V_1^2}$$

$$\eta = \frac{2(V_1 - u_1) \cdot u}{V_1^2}$$

$\eta = fn(V_1, u)$

for a const. V_1

$$\frac{d\eta}{du} = 0$$

$$\frac{d}{du}\left(\frac{2(V_1 - u_1) \cdot u}{V_1^2}\right) = 0$$

$$\frac{2}{V_1^2} \frac{d(V_1 - u_1) \cdot u}{du} = 0$$

$$\frac{d}{du}\left((V_1 - u_1) \cdot u\right) = 0$$

$V_1 - 2u = 0$

$\boxed{u = \frac{V_1}{2}}$ ✓

$$\rightarrow \eta_{max} = \frac{\cancel{2}\left(V_1 - \frac{V_1}{2}\right) \cdot \frac{V_1}{\cancel{2}}}{V_1^2}$$

$\rightarrow \boxed{\eta_{max} = \frac{1}{2} = 50\%}$

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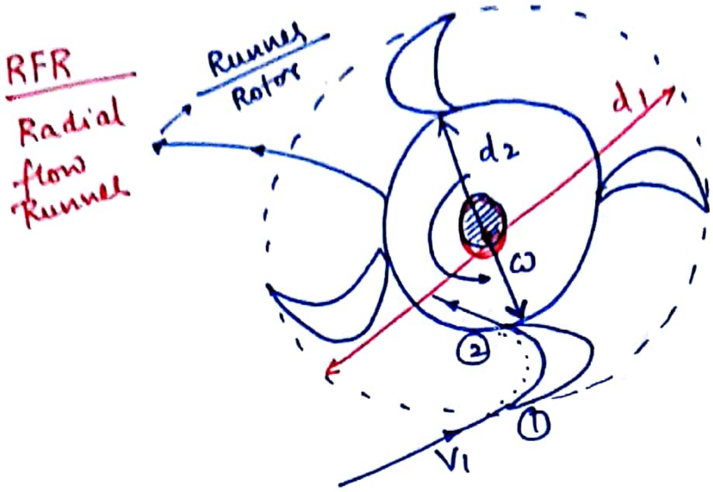
Inward Radial flow

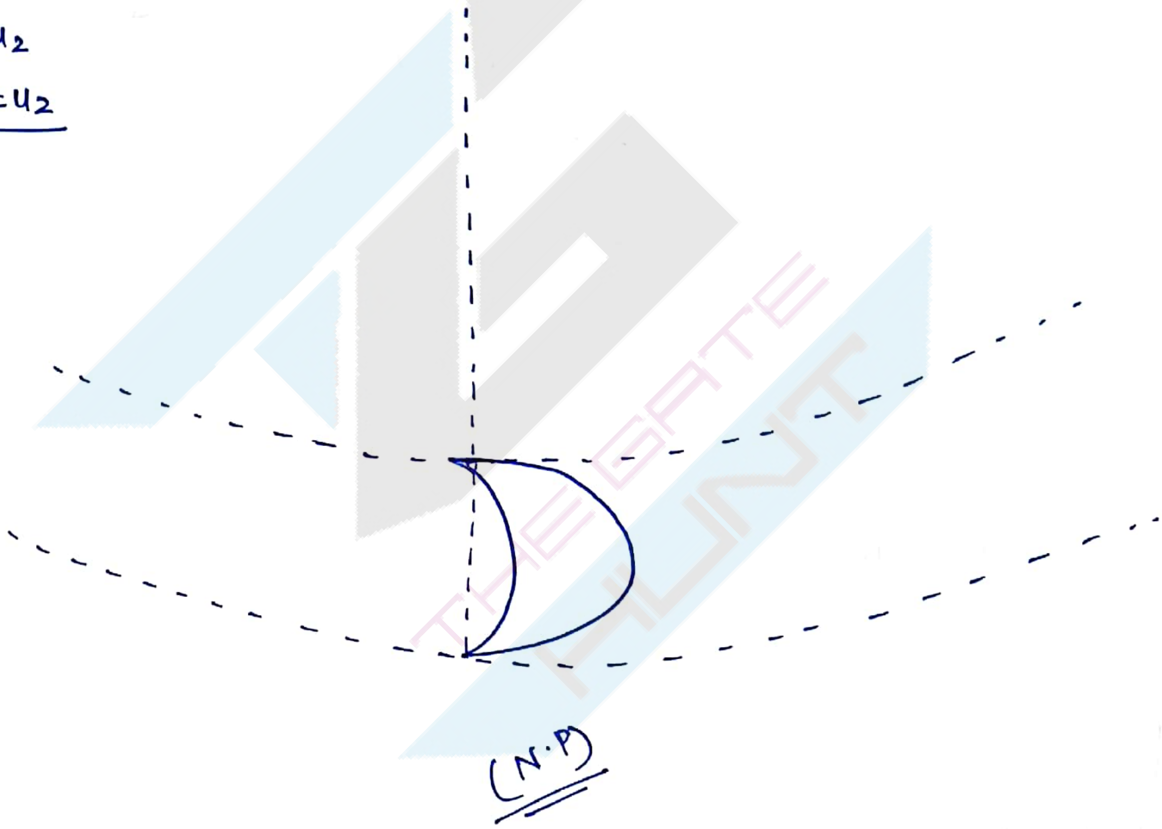
Top view



$d_1 > d_2$

$u_1 > u_2$

$u_1 \neq u_2$



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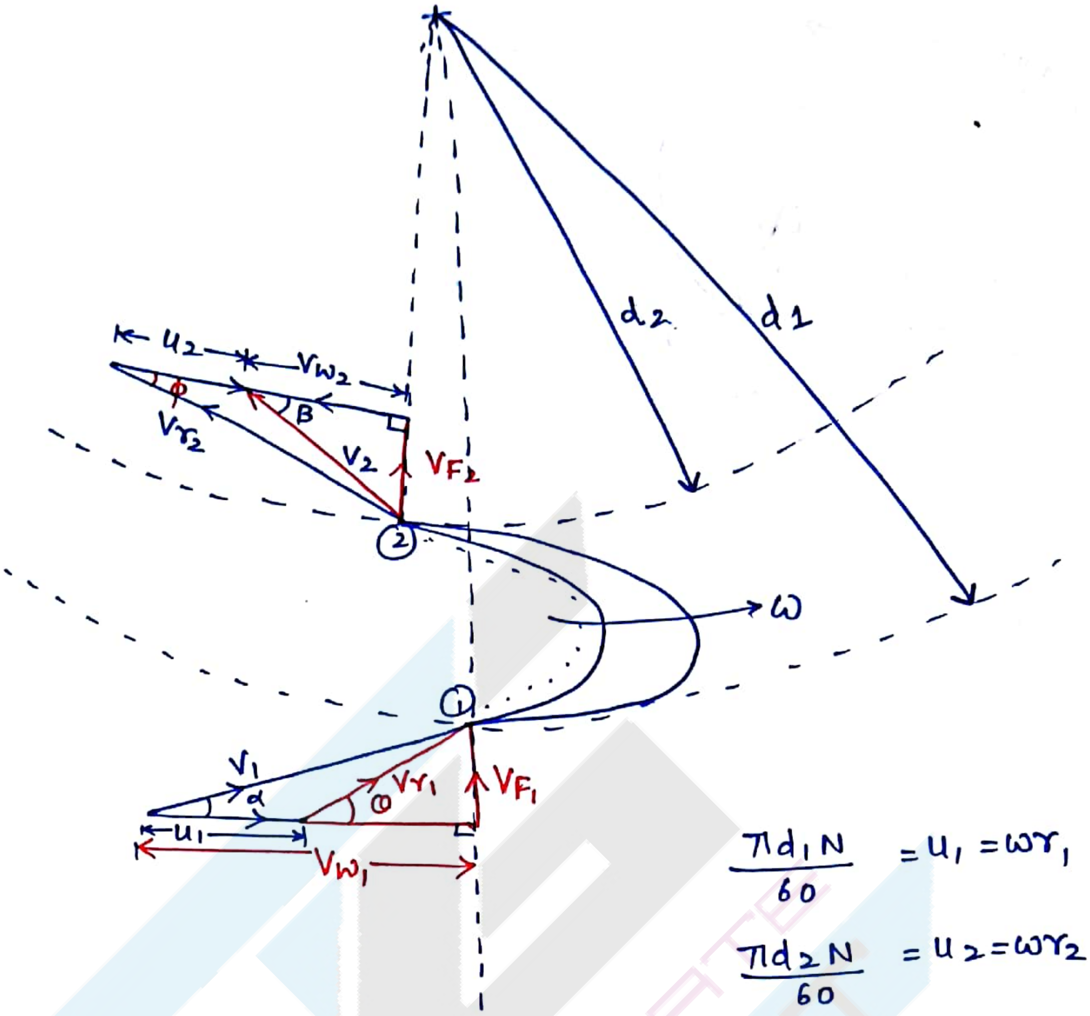

$$\frac{\pi d_1 N}{60} = u_1 = \omega r_1$$

$$\frac{\pi d_2 N}{60} = u_2 = \omega r_2$$

→ $\dot{m} = \rho a V_1 = \rho Q$

$WD = \underline{RP} = T \cdot \omega$

Torque = T = change in angular moment

→ angular moment = moment of linear momentum

→ linear momentum of water @ Entry in Tangential dirⁿ. $= \dot{m} V_{w_1}$

→ angular moment @ Entry $= \dot{m} V_{w_1} r_1$

→ linear —"— @ Exit —"— $= -\dot{m} V_{w_2}$

→ Angular —"— @ Exit $= -\dot{m} V_{w_2} r_2$

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$$T = \dot{m} V_{w_1} r - (-\dot{m} V_{w_2} r_2)$$

$$T = \dot{m} \,(V_{w_1} r_1 + V_{w_2} r_2). \quad N\text{-}m$$

$$RP = T \cdot \omega = \dot{m}\,(V_{w_1} r_1 + V_{w_2} r_2) \cdot \omega$$

$$\boxed{RP = \rho Q \,[V_{w_1} u_1 + V_{w_2} u_2]} \text{ watt}$$

$$F_y = \dot{m} V_{F_1} - \dot{m} V_{F_2}$$

$$F_y = \dot{m}\,(V_{F_1} - V_{F_2})$$

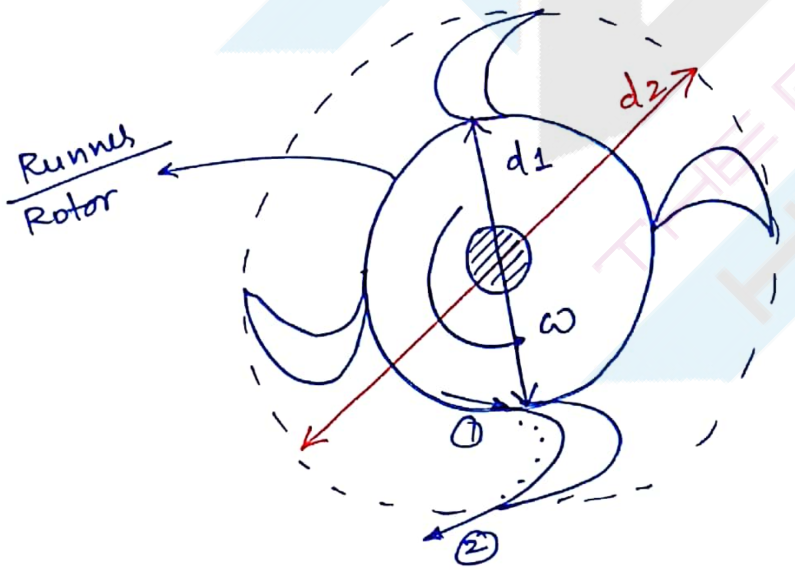
→ To get $F_y = 0$ (No Radial force on Runner)

$V_{F_1} = V_{F_2}$

Outward Radial flow

Top view

RFR



$d_2 > d_1$

$u_2 > u_1$

$\boxed{u_1 \neq u_2}$

$$\frac{\pi d_1 N}{60} = u_1 = \omega r_1$$

$$\frac{\pi d_2 N}{60} = u_2 = \omega r_2$$

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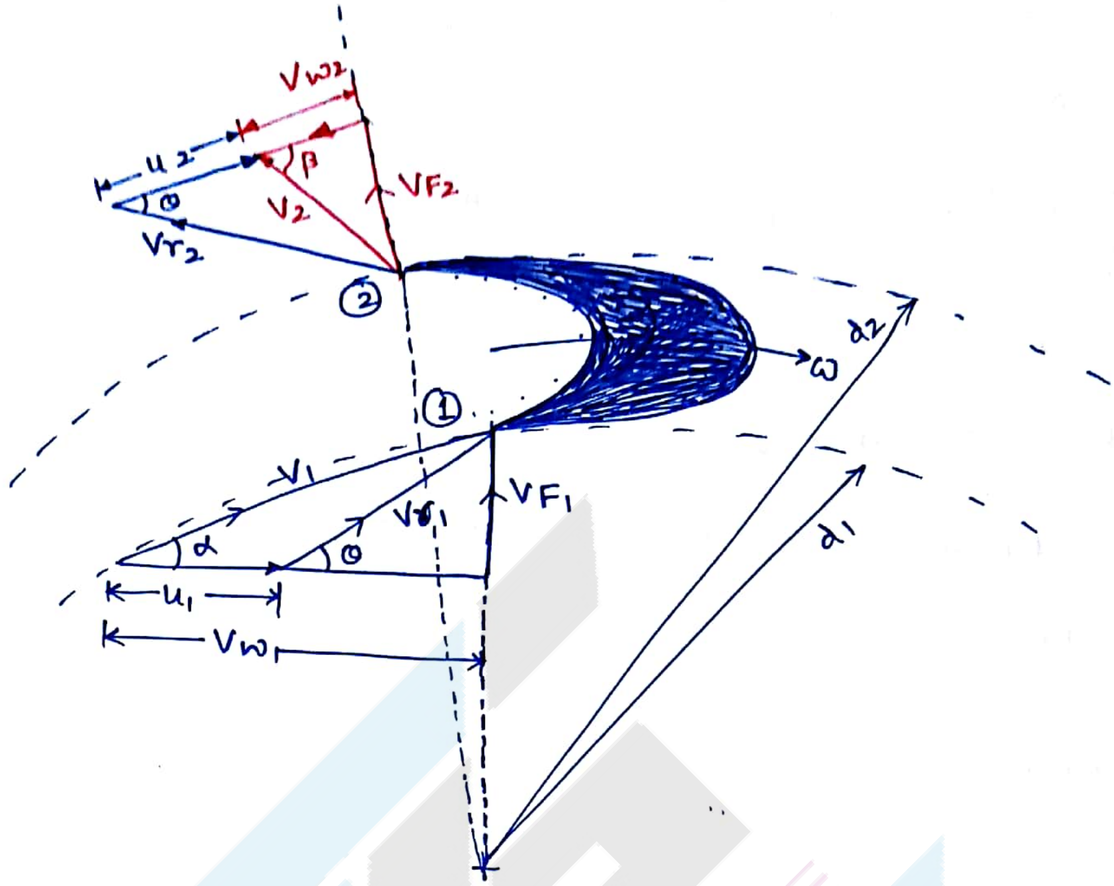


$$\boxed{RP = \rho Q\left(V_{w_1} * u_1 + V_{w_2} u_2\right)} \text{ (watt)}$$

RIP (Rest in Peace) ☺

$$\frac{RP}{\dot{m} g} = \frac{\left(V_{w_1} u_1 + V_{w_2} u_2\right)\dot{m}}{\dot{m} g} = H_e$$

metre

Euler's head for Turbine

MOHIT CHOUKSEY

Q64: Pg 59 A jet of water having a V 15 m/s strikes a curve frictionless vane is moving with a V 5 m/s, The vane is symm & deflec ∠ of jet is 120°. Find the angle of the jet at inlet so that there is no shock.

(267)

$V_1 = 15 m/s$

$V_{r_2} = V_{r_1}$

$u = 5 m/s$

$\delta = 120° = 180° - (\theta + \phi)$

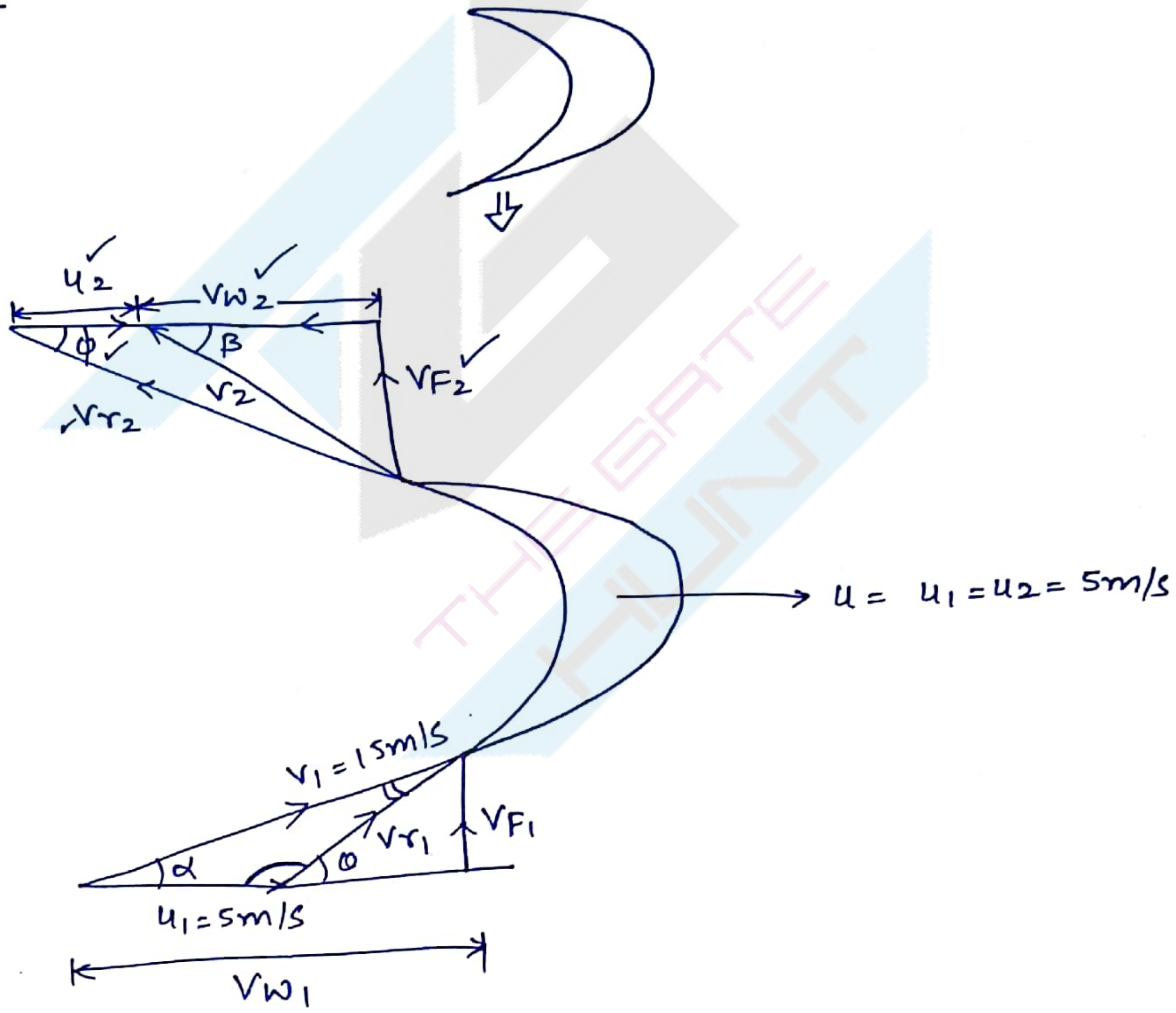
$\theta = \phi = 30°$ — no mention कहाँ jet hit करेगा blade को.

→ $\alpha = ?$ ✓

→ V_2

→ β

→ $\frac{WD}{mg}$



$180 - (\alpha + 180 - \theta)$

$= (\theta - \alpha)$

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$$\frac{V_{r_1}}{\sin\alpha} = \frac{V_1}{\sin(180-\theta)} = \frac{u_1}{\sin(\theta-\alpha)} \quad (\theta = 30^\circ)$$

$$\frac{V_{r_1}}{\sin\alpha} = \frac{15}{\sin 150^\circ} = \frac{5}{\sin(30-\alpha)}$$

$$\boxed{\alpha = 20.4^\circ}$$

$$\boxed{V_{r_1} = 10.46\,m/s = V_{r_2}}$$

$\rightarrow \sin\phi = \dfrac{V_{F_2}}{V_{r_2}}$

$\rightarrow V_{F_2} = 10.46 \times \sin 30^\circ$

$\rightarrow V_{F_2} = 5.23\,m/s$

$\rightarrow \cos\phi = \dfrac{u_2 + V_{w_2}}{V_{r_2}}$

$\cos 30^\circ = \dfrac{5 + V_{w_2}}{10.46}$

$$\boxed{V_{w_2} = 4.05\,m/s}$$

$V_2^2 = V_{w_2}^2 + V_{F_2}^2$

$$\boxed{V_2 = 6.62\,m/s}$$

$\rightarrow \tan\beta = \dfrac{V_{F_2}}{V_{w_2}} = \dfrac{5.23}{4.05}$

$$\boxed{\beta = 52.24^\circ}$$

$\rightarrow \dfrac{WD}{mg} = \dfrac{\cancel{m}(V_{w_1} + V_{w_2})\cdot u}{\cancel{m}g}$

$V_{w_1} = V_1\cos\alpha = 15\cos 20.4$

$V_{w_1} = 14.05\,m/s$

$\dfrac{WD}{mg} = \dfrac{(V_{w_1} + V_{w_2})u}{g}$

$= \dfrac{(14.05 + 4.05)5}{9.81}$

$\dfrac{WD}{mg} = 9.23\,m$.

$\boxed{4, 7, 58} \leftarrow$ HW

MOHIT CHOUKSEY