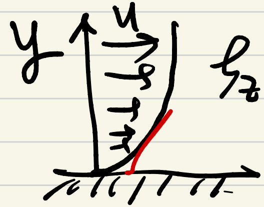
- vorticity vs vortex

수학적 정의

$\underline{\xi} = \nabla \times \underline{V}$

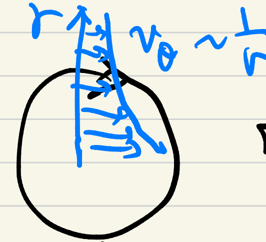


$\xi_z = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \neq 0$

0

no vortex

물리적 정의 ⓐ



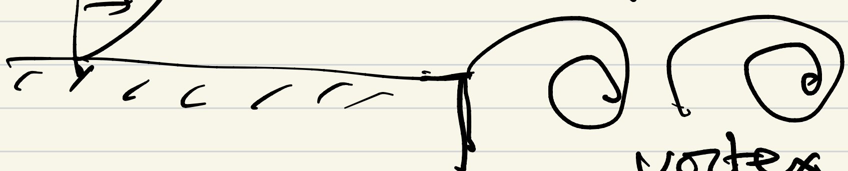
circular motion

vortex

$\nabla \times \underline{V} = 0$

zero vorticity

$\nabla \times \underline{V} \neq 0$



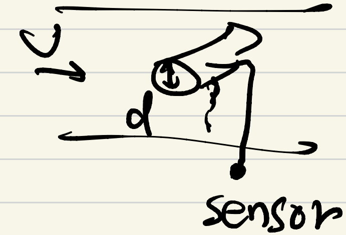
- frictionless irrotational flow → Bernoulli eq everywhere

$\underline{\xi} = \nabla \times \underline{V} = 0$ $\quad \underline{V} = \nabla \phi$ $\quad \phi$: velocity potential

$\phi = \text{const} \perp \psi = \text{const}$

Ch.5

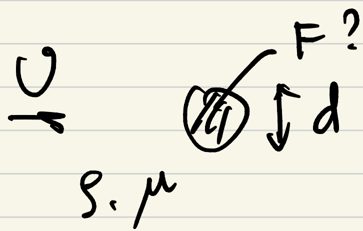
- Principle of dimensional homogeneity ($\hat{e}$)



$$A = B + C + E$$

$$W = mg \rightarrow W = \cancel{9.81}\, m$$

- Pi (π) theorem



$$F = F(U, d, \rho, \mu) \quad \ldots$$

L.T.M

$$\begin{array}{cccc} U & d & \rho & \\ LT & L & M L \end{array}$$

$$\pi_1 = F\, \underline{U^{\alpha} d^{\beta} \rho^{\gamma}} = [L^0 T^0 M^0]$$

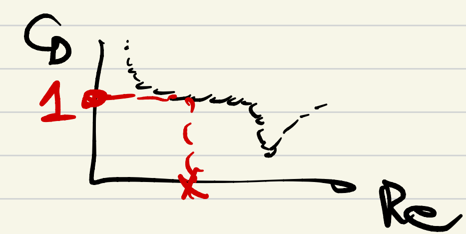
$$\pi_2 = \mu\, \underline{U^{\alpha'} d^{\beta'} \rho^{\gamma'}} = [L^0 T^0 M^0]$$

C_D — drag coeff.

$$C_D \equiv \frac{F}{\rho U^2 d^2} = g\left(\frac{\rho U d}{\mu}\right) = g(Re)$$

||

1



- Non-dimensionalization of governing eqs.

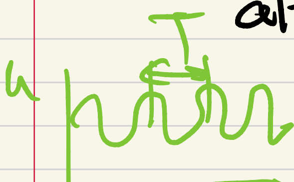
$\underline{v}^* = \frac{\underline{v}}{U}$, $x^* = \frac{x}{L}$ → $\underline{v} = \underline{v}^* U$, $x = x^* L$,

cont. eq → $\nabla^* \cdot \underline{v}^* = 0$

N-S. eq → $\frac{\partial \underline{v}^*}{\partial t^*} + (\underline{v}^* \cdot \nabla^*)\underline{v}^* = -\nabla^* p^* + \frac{1}{Re}\nabla^{*2}\underline{v}^*$

$Re = \frac{\rho U d}{\mu}$, St, Fr, We, Ma

alternating Karman vortex shedding at $Re \geq 47$



$d = 0.15\,m$

$\nu = 1.5 \times 10^{-5}\, m^2/s$

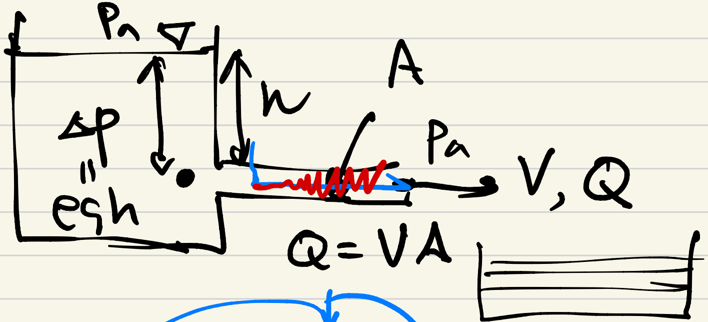
$Re = 47 = \frac{Ud}{\nu} \rightarrow U = 4.7\, mm/s$

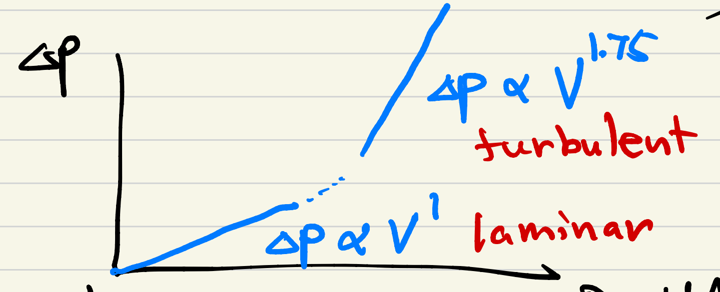
$St = \frac{fd}{U}$ strouhal number

Ch. 6 Viscous flow in ducts — internal flow

↕

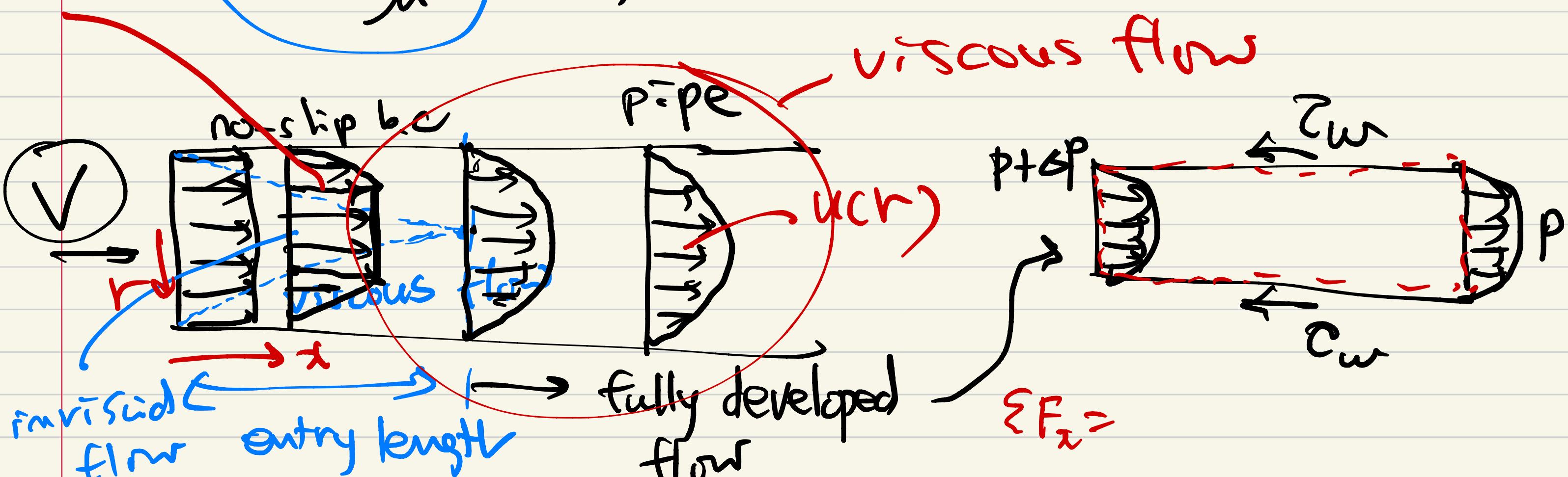
external flow (Ch. 7)



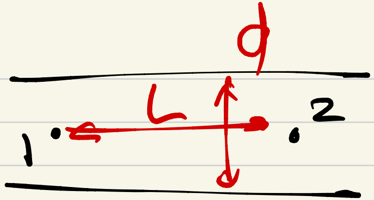


$Re = \frac{\rho V d}{\mu}$: Reynolds number

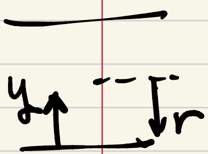
$u(r, x)$



head loss



$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + h_1 = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + h_2 + h_f$$

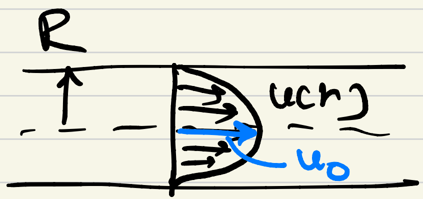


$$h_f = f \frac{L}{d} \frac{V^2}{2g}$$

f : Darcy friction factor

$$f \equiv \frac{8\tau_w}{\rho V^2}, \qquad V = \frac{1}{A}\int_0^R u(r)\, dA = \frac{1}{A}\int_0^R u(r)\, 2\pi r\, dr$$

bulk velocity



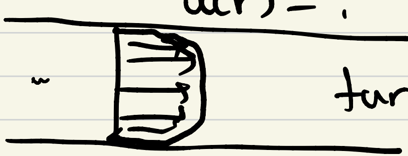
$$u = u_0\left(1 - \frac{r^2}{R^2}\right) \quad \text{laminar flow}$$

Poiseuille flow

$$Re = \frac{Vd}{\nu}$$

$$\tau_w = \mu \frac{\partial u}{\partial y}\Big|_w = -\mu \frac{\partial u}{\partial r}\Big|_{r=R}$$

$\bar{u}(r) = ?$



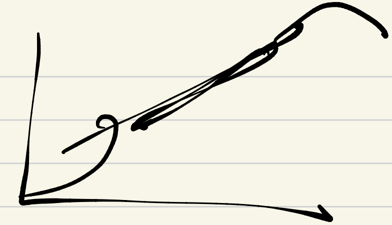
turbulent $\quad Re = \frac{Vd}{\nu} = 2500 \quad$ water $\nu = 10^{-6}\, m^2/s$, $d = 5\,cm$

$$2500 = \frac{Vd}{\nu} \rightarrow V = 0.05\, m/s$$

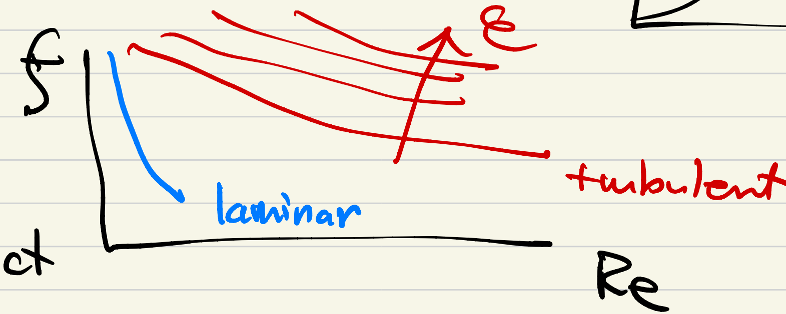
$u = \bar{u} + u'$

law of the wall

log law



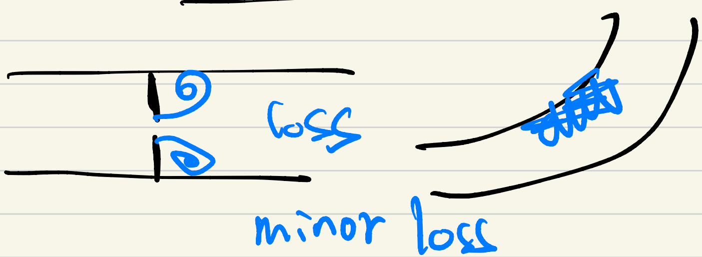
Moody chart



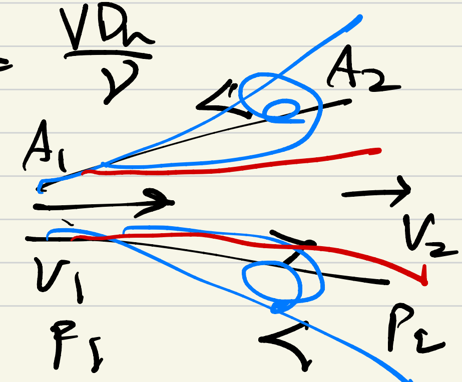
Non-circular duct

$$D_h = \frac{4A}{P}$$ hydraulic diameter

$$Re_{D_h} = \frac{V D_h}{\nu}$$

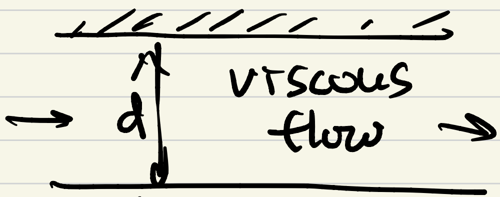


Diffuser



Ch. 7 Flow past immersed bodies

internal flow



$Re_d = \frac{Vd}{\nu}$

external flow

$\tau = \mu \frac{\partial u}{\partial y} = 0$