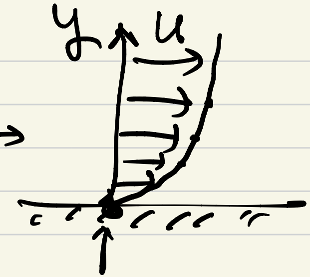
Review

- Viscosity

$$\underbrace{\tau}_{\text{shear stress}} = \overset{\text{property}}{\mu} \underbrace{\frac{\partial u}{\partial y}}_{\text{velocity grad.}} \rightarrow$$



$u=0$ no-slip condition

$$\underline{F} = m\,\underline{a}$$

(Newtonian fluid
Non-Newtonian)

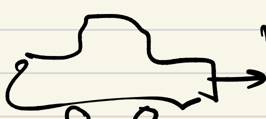
- Reynolds number

$$Re = \frac{\rho U L}{\mu} = \frac{UL}{\nu}$$

$\nu = \frac{\mu}{\rho}$: kinematic viscosity 동점성계수

m^2/s

1.5×10^{-5} air
10^{-6} water



$V = 105\,km/h$

$Re = ?$

$$Re = \frac{UL}{\nu} = \frac{150\times1000/3600 \times 4}{1.5\times10^{-5}}$$

$$= \frac{4}{1.5}\times\frac{1}{3600}\times10^{10} = \underline{10^7}$$

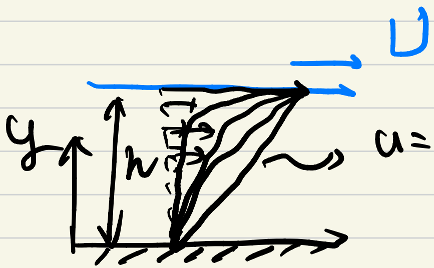
$$Re = \frac{\rho UL}{\mu} = \frac{\rho U^2}{\frac{\mu U}{L}} = \frac{\text{inertia}}{\text{shear stress}}$$

$$\tau = \mu \frac{\partial u}{\partial y} = \left[\mu \frac{U}{L}\right]$$

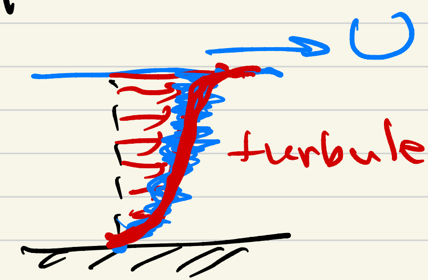
$Re \uparrow$ inertial effect $\uparrow$

$U^2 \rightarrow$ nonlinear $\uparrow \rightarrow$ turbulence

- Couette flow



$u = \frac{y}{h} \cdot U$ laminar flow (층류)

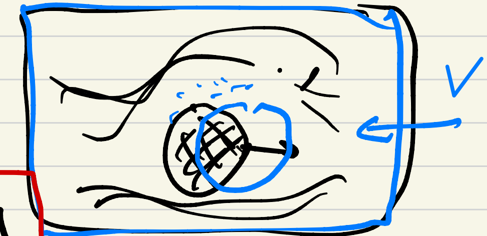


turbulent flow (난류)

- System vs. control volume

Reynolds transport theorem

$$\boxed{\frac{d}{dt}B_{sys} = \frac{d}{dt}\int_{C.V}\beta\rho\, d\forall + \int_{C.S}\rho\beta(\underline{V_r}\cdot\underline{n})\,dA}$$



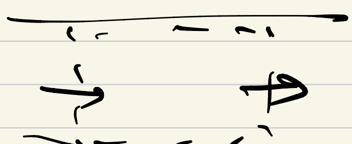
C.V

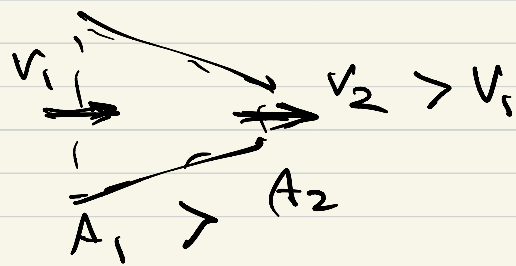
$$\beta = {dB}/{dm}, \quad \underline{V_r} = \underline{V} - \underline{V_c}$$

- mass conservation : $B_{sys} = m$, $\beta = \frac{dB}{dm} = 1$

$$\Rightarrow \frac{dm}{dt} = \frac{d}{dt}\int_{C.V}\rho\, d\forall + \int_{CS}\rho(\underline{V_r}\cdot\underline{n})\,dA$$

$$\frac{dm}{dt} = 0$$

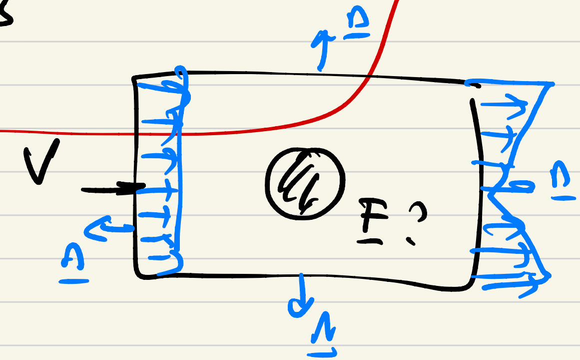




• mtm conservation $\qquad B_{sys} = m\underline{V}$, $\quad \beta = \frac{dB}{dm} = \underline{V}$

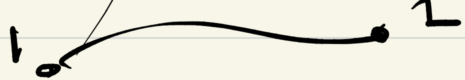
$$\rightarrow \frac{d}{dt}(m\underline{V}) = \frac{d}{dt}\int_{c.v} \rho \underline{V}\, d\forall + \int_{cs} \rho \underline{V}\,(\underline{V}_r \cdot \underline{n})\, dA$$

$$\frac{d}{dt}(m\underline{V}) = \Sigma \underline{F}$$



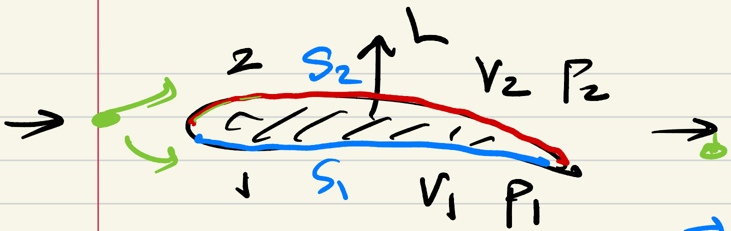
Bernoulli eq.

$$\int_1^2 \frac{\partial V}{\partial t}\, ds + \int_1^2 \frac{1}{\rho}\, dp + \frac{1}{2}(V_2^2 - V_1^2) + g(z_2 - z_1) = 0$$



unsteady frictionless flow
along a streamline

$$\frac{p_1}{\rho} + \frac{V_1^2}{2} + g z_1 = \frac{p_2}{\rho} + \frac{V_2^2}{2} + g z_2 = const$$



$S_2 > S_1 \rightarrow V_2 > V_1 \rightarrow P_2 < P_1 \rightarrow L\uparrow$

⇒ 응용유체역학

- Angular mtm cons.
- energy 〃

$\underline{V} = (u, v, w)$ three-dimensional

Ch. 4

$$\frac{\partial}{\partial t}(\rho \underline{V}) + \nabla\cdot(\rho \underline{V}\,\underline{V}) = \rho \underline{g} - \nabla p + \nabla\cdot(\mu \nabla \underline{V})$$

Navier-Stokes eq.

unsteady

nonlinear inertia term

press. term

linear viscous term

$$\frac{\partial}{\partial t}(\rho u) + \rho u\frac{\partial u}{\partial x} + \rho v\frac{\partial u}{\partial y} + \rho w\frac{\partial u}{\partial z} = \rho g_x - \frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

coupled

continuity eq. $\cancel{\frac{\partial \rho}{\partial t}} + \nabla \cdot (\rho \underline{V}) = 0$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

- stream function ψ

$$u = \frac{\partial \psi}{\partial y}, \quad v = -\frac{\partial \psi}{\partial x}$$

~~3D~~ $\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$

ψ = const : streamline

- vorticity (와도) vs. vortex (와류)

You are not supposed to understand turbulence because it is turbulence.