210902

2021년 8월 24일 화요일 오후 1:18

Fluid Mechanics

송성진

SONG, SEUNG JIN

sjsong@snu.ac.kr.

880-1667

이상현]
임준영] Teaching Assistants.

course notes will be made available after each class.
(on ETL)

Text: Fluid Mechanics by Frank White
McGraw Hill
(HW probs from 8th Edition)
HW problems → posted on ETL.

Grading:

Midterm	#1	25%
"	#2	25%
Final Exam		35%
HW & others		15%

Weekly plan on p2 of syllabus.

Core courses → like learning a foreign language
learn new words & meaning

Why study fluid mechanics? → used in wide variety of areas
applications in science & engineering

fluids in various environments (applications) → pipelines
aircraft
machines

water
air

to study atmosphere

water
air

to study atmosphere
weather
planetary science (moon, mars, etc.)
chemical engineering (chemical plants)
electrical eng (computer cooling, power)
civil eng (river flows, pollution, ...)
mechanical } eng → airplane
aerospace } car, train,
naval } ships

biology → blood flow, air flow in lungs, etc.

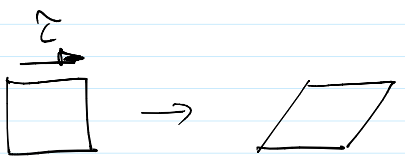
science vs. engineering

1. what?
2. why? → laws of nature

① what?
② why? → laws of nature
3. So what? → financial motivation via design manufacture of useful devices programs

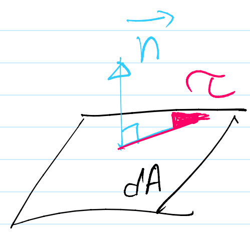
fluid → material that flows when subject to shear stress τ
"deforms"
shear: tangent to the surface
stress: force per unit area

e.g.



deformation

can be liquid or gas.



2 fluids most important to humans
water → body composition → liquid → incompressible → ρ = constant
air → to breathe → gas → compressible → ρ is variable
$\rho = \frac{P}{RT}$

ρ = mass per unit volume

momentum

mechanics } deals with forces → $\vec{F} = m\vec{a} = \frac{d(m\vec{v})}{dt}$
dynamics

mechanics } deals with **forces** → $\vec{F} = m\vec{a} = \frac{d(m\vec{v})}{dt}$

dynamics

mass, acceleration

$\frac{d}{dt}$ → rate of change versus time

kinematics → deals with **motions**

↳ $\vec{x}$, $\vec{v}$ ← velocity

displacement

Engineering Approach.

(Solve problems)

1. Make assumptions.
2. Simplify the problem
3. Obtain solution to the simplified problem
4. Check assumptions & solution.

Assume **fluid** to be a **continuum**.

e.g. water/air composed of individual molecules.
discrete

however, assume water/air to be a continuum

continuous material where properties change continuously.

$l \gg$ mean free path (λ)

length of interest

average distance travelled by molecules before collision with another molecule.

e.g. $l \sim 1$ meter for cars.

air

$l \sim$ meters.

air at sea level 290K has λ of 6.5×10^{-8} m

Dimensions vs. **Units**

Dimensions vs. Units

Dimensions		SI Unit	British Unit
Mass	M	kg	lbm
Length	L	m	ft
Time	T	sec	sec
Temperature	Θ	K.	R

Scalar vs. Vector

Scalar: temp, θ; mass, m → has only magnitude

Vector: velocity, $\vec{V}$ → magnitude & direction.

Lagrangian view vs. Eulerian view.

Approach used in this course → Eulerian view.

Lagrangian view → follows a particular particle of mass of interest (kth particle)

$X_k(t)$ displacement

$\boxed{\vec{V}_k(t)}$ velocity of kth particle at time t

$\vec{a}_k(t)$ acceleration

e.g. follows a police car

Eulerian view → focuses on particular location (space) $\vec{X}$ and time.

$\vec{X} = (x, y, z)$

$\vec{V}(\vec{x}, t)$ → velocity at location $\vec{X}$ at time t

e.g. velocity of cars at 서울대입구 사거리

Adopt Eulerian view in this course because we are not interested in particular fluid particles but we are interested in flows in space (buildings, cars, aircraft, ships, etc.)

Acceleration

210907

2021년 9월 2일 목요일 오전 10:46

Last lecture

Syllabus

Why study fluid mechanics

fluid → compressible vs. incompressible

mechanics, dynamics, kinematics

continuum assumption

dimensions & units

scalar vs. vector

Lagrangian vs. Eulerian views.

↳ particle, system ↳ space, control volume

Components of motion

Rigid body → 1. translation 2. rotation

Fluid → 1. translation 2. rotation + 3. deformation

Dynamics course covers rigid body dynamics using Lagrangian view

$X_k(t)$, $\vec{V}_k(t)$, $\vec{a}_k(t)$ e.g. following a police car

displacement of kth particle at time t

Fluid dynamics course covers fluid dynamics using Eulerian view

$\vec{V}(\vec{x}, t)$

e.g. focus on a location like a 서울대입구 사거리

Eulerian of view of velocity. $\vec{V}(\vec{x}, t)$

$$\vec{V}(x, y, z, t) = u\vec{i} + v\vec{j} + w\vec{k}$$

$\vec{i}, \vec{j}, \vec{k}$ are unit vectors in xyz directions

acceleration is change in velocity vs. time

Eulerian velocity field.

$$\underbrace{\vec{a}_k(t) = \frac{d\vec{V}_k(t)}{dt}}_{\text{Lagrangian view of acceleration of kth particle (following the kth particle)}} = \frac{\partial \vec{V}(\vec{x}, t)}{\partial t} + \frac{\partial \vec{V}(\vec{x}, t)}{\partial x}\underbrace{\frac{dx}{dt}}_{u} + \frac{\partial \vec{V}}{\partial y}\underbrace{\frac{dy}{dt}}_{v} + \frac{\partial \vec{V}}{\partial z}\underbrace{\frac{dz}{dt}}_{w}$$

if we follow the kth particle

'(following the kth particle)

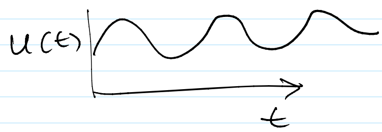
$$\underbrace{a_k(t) = \frac{d V_k(t)}{dt}}_{\vec{a}\text{ of kth particle}} = \frac{D\vec{V}}{Dt} = \underbrace{\frac{\partial \vec{V}}{\partial t}}_{\text{local acceleration}} + \underbrace{\left(u\frac{\partial \vec{V}}{\partial x} + v\frac{\partial \vec{V}}{\partial y} + w\frac{\partial \vec{V}}{\partial z}\right)}_{\text{convective acceleration}}$$

$$\boxed{\frac{DQ}{Dt} = \left(\frac{\partial Q}{\partial t} + \vec{V}\cdot\nabla Q\right)} \rightarrow \underbrace{\left.\begin{array}{l}\text{Substantial}\\ \text{Total}\\ \text{Material}\end{array}\right\}\text{ derivative}}_{\text{Rate of change in } Q \text{ following a particle}} \rightarrow \text{can be applied to scalar \& vector quantities}$$

Examining.

$$\frac{D\vec{V}}{Dt} = \underbrace{\frac{\partial \vec{V}}{\partial t}}_{\text{local } \vec{a}} + \underbrace{\left(u\frac{\partial \vec{V}}{\partial x} + v\frac{\partial \vec{V}}{\partial y} + w\frac{\partial \vec{V}}{\partial z}\right)}_{\text{convective } \vec{a}}.$$

e.g. $\underbrace{\vec{V}(\vec{x},t) = u(\vec{x},t)\vec{i}}_{1-D} = a \sin \omega t$ at a given $\vec{x}$



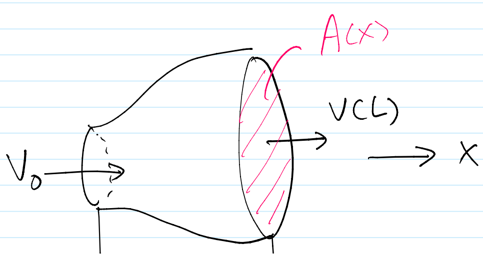
if $\frac{\partial \vec{V}}{\partial t} \neq 0 \rightarrow$ local acceleration at $\vec{x} \neq 0$

$\rightarrow$ unsteady flow

if $\frac{\partial \vec{V}}{\partial t} = 0$ then steady flow

Flow can be steady and yet still have convective acceleration.

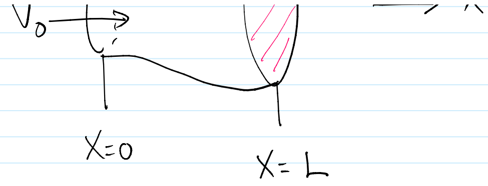
e.g. diffuser. $\left(\frac{dA}{dx} > 0\right)$



$\vec{V} = u(x) = V_0\left(1 - \frac{2x}{L}\right)$

$\frac{\partial u}{\partial x} = -\frac{2V_0}{L}$

convective acceleration.



$$\frac{\partial u}{\partial x} = -\frac{2V_0}{L}.$$

$$\frac{D\vec{V}}{Dt} = u\frac{\partial u}{\partial x} = V_0\left(1-\frac{2x}{L}\right)\left(-\frac{2V_0}{L}\right)$$

Flow decelerates in x as A(x) increases in x dir.

Flow is steady (constant velocity at one location)

but flow velocity changes with location

Properties

→ describe state of a material in a quantifiable way

pressure p $\quad Pa = N/m^2$ → stress at a point in a static fluid ($\vec{V}=0$)

temperature T $\quad K$, $°C$ → measure of internal (thermal) energy of fluid

density ρ $\quad kg/m^3$ → mass/unit volume

specific weight $\gamma = \rho g$ $\quad N/m^3$ → weight/unit volume

specific gravity SG

$$SG_{gas} = \frac{\rho_{gas}}{\rho_{air}} \sim \frac{\rho_{gas}}{1\ kg/m^3}$$

$$SG_{liquid} = \frac{\rho_{liquid}}{\rho_{water}} \sim \frac{\rho_{liquid}}{1{,}000\ kg/m^3}$$

energy $\quad e = \underbrace{u}_{\text{internal}} + \underbrace{\tfrac{1}{2}V^2}_{\text{kinetic}} + \underbrace{gz}_{\text{potential}} + \cancel{\ldots}$

perfect gas law $\quad p = \rho RT$ where R = specific gas constant $= \frac{R_u}{MW}$

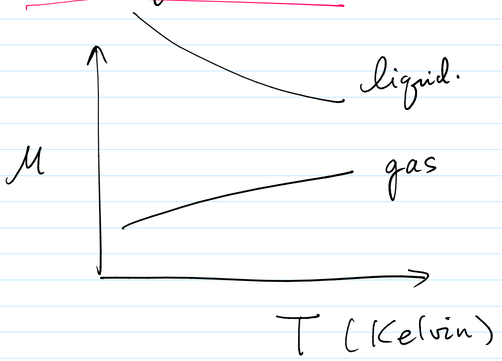
Specific heats $\quad c_v = \left(\frac{\partial u}{\partial T}\right)_\rho$

$$c_p = \left(\frac{\partial h}{\partial T}\right)_p$$

$k, \gamma = C_p / C_v$

$R = C_p - C_v$.

Viscosity. μ $\quad kg/(ms)$ → property to transport momentum from particle a to particle b via cohesive force and/or collisions
↓
friction.



in liquids, intermolecular forces dominant

gases → collision dominant

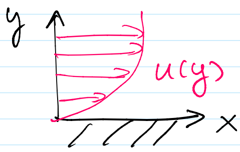
$\mu_{liquid} > \mu_{gas}$

$\mu_{liquid} \downarrow$ as $T \uparrow$

$\mu_{gas} \uparrow$ as $T \uparrow$

if $\mu = 0$, then invisid fluid

$\mu \neq 0$ $\quad$ viscous fluid (every fluid is viscous)



Newtonian fluid.

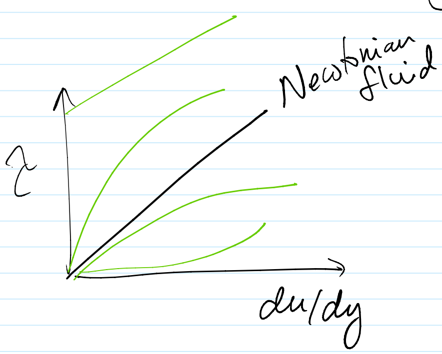
we only consider Newtonian fluid this semester.

$\tau = \mu \frac{du}{dy}$

shear stress. — viscosity — velocity gradient = strain rate of fluid element.

↳ = 0 if uniform flow (same velocity everywhere)

↳ ≠ 0 if non-uniform flow



— Non-Newtonian fluids

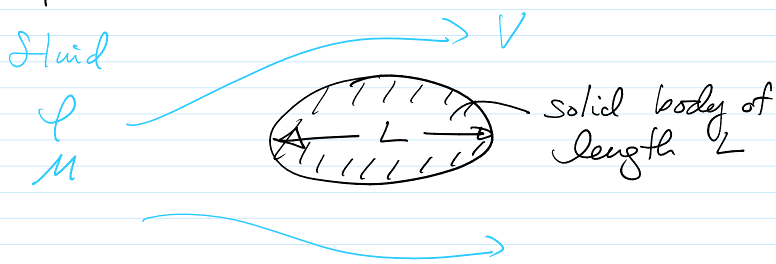
Newtonian fluids → water, air

Non-Newtonian fluids → blood, paint, etc.

Important Non-dimensional Parameter

Reynolds Number

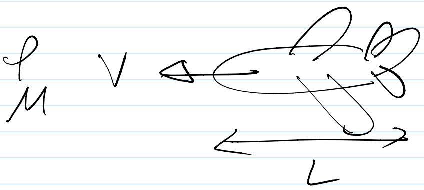
$$\boxed{Re \equiv \frac{\rho V L}{\mu}}$$



$$Re \sim \frac{\text{inertia}}{\text{viscous effects.}}$$

$Re \gg 1$ inertia dominant (viscosity negligible)

$Re \ll 1$ viscosity dominant (inertia negligible)

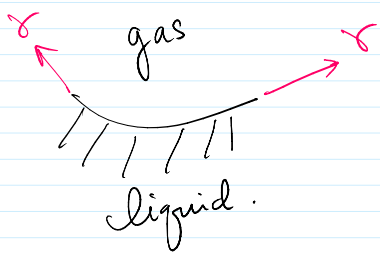


$Re \sim 10^6$ airplane.

◦ small bug moving slowly $\quad Re \lesssim 1$

Properties.

Surface tension γ (N/m)



property of liquids which tries to retain volume by intermolecular force near the free surface.

[contact angle
capillary rise/depression