MEC2015 : FLUID MECHANICS

Lecture – 1

Introduction

- Administration
- Thermodynamics / Solid Mechanics Review
- Basic Calculus Review

<u>MEC2015 Fluid Mechanics</u> - 3 Units - Required / Sophomore

- Pre-Requisite :
  MEC2018熱力學, PRI4051-01産業數學(PRI4025工學數學1, MEC2035機工解析)
  or Consent by Lecturer(先受科目認定試驗)

- Text : Fluid Mechanics 8th ed. -Frank M. White -McGraw Hill/ 飜譯本
  Lecture Note on E-Class

- Lecture given under assumption that students have actually read the material

- Students expected to study at least nine hours/wk on this subject

- Grading: DGU Guidelines

  HW**(15)** < 60% ; Quiz[Best12]**(10)** **<** 40% -1 Final Grade
  3 Exams **(75) Sat at 11AM** ; Absence on any exam Final grade of F
  Participation, Q&A**(~5)**
  Can be readjusted depending on in-class or on-line lecture

- Plagiarism : Getting outside help on Quiz/Exam, Etc.

  1st offense -1 Final Grade 2nd offense Final grade of F

Lecture Schedule (Tentative)

dongguk UNIVERSITY

Wk	Lecture	HW	Wk	Lecture	HW
1-9/1	Admin/Review Ch.1: 1,11 Ch.1: 2~4, 6, 7	1 2	9-10/27	Ch.3: 5 Ch.4: 1~2	8
2-9/8	Ch.1: 5, 8, 9 / Ch.4: 7 Ch.2: 1~4, 10	3	10-11/3	Ch.4: 3, 6, 10 Q&A	
3-9/15	Ch.2: 5 Ch.2: 6~7	4	11-11/10	Exam #2 (11/12) Ch.6: 1~3	9
4-9/22	Ch.2: 8~9 Ch.5: 1~3	5	12-11/17	Ch.6: 6, 7, 10 Ch.6: 8. 9, 11, 12	
5-9/29	Ch.5: 3~5 Q&A		13-11/24	Ch.11: 3~5 Ch.7: 1~5	10 11
6-10/6	Exam #1 (10/6) Ch.3: 1~3	6	14-12/1	Ch.7: 6 Ch.9: 1~4	12
7-10/13	Ch.3: 4 Ch.3: 4		15-12/8	Ch.9: 5, 6, 9 Q&A	
8-10/20	Ch.3: 6 / Ch.11: 1,2,6 Ch.3: 7, 5	7		Exam#3 (12/17)	

Course Objective & Learning Outcomes

Course Objective

1. Students should be able to utilize basic fluid mechanical principles to understand, formulate and solve fluids engineering problems.
2. Students should be able to discern fluids engineering part of a mechanical engineering problem and apply appropriate fluid mechanical principles and analytical methods to solve the problem.
3. Students should be able to utilize Moody diagram in solving piping problems and understand the basic working principles of fluid meters including manometers.

Learning Outcomes

[1] 수학, 과학, 공학 및 컴퓨터 지식을 기계공학문제 해결에 활용할 수 있는 능력

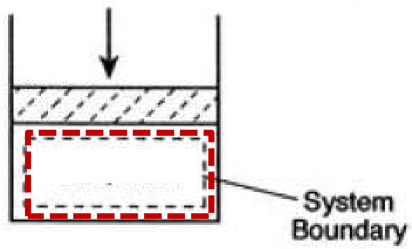
An ability to apply the knowledge of mathematics, basic science, engineering, and information technology to solve engineering problems

[3] 기계공학문제를 물리학적으로 단순화 시킨 후 수학적으로 공식화할 수 있는 능력

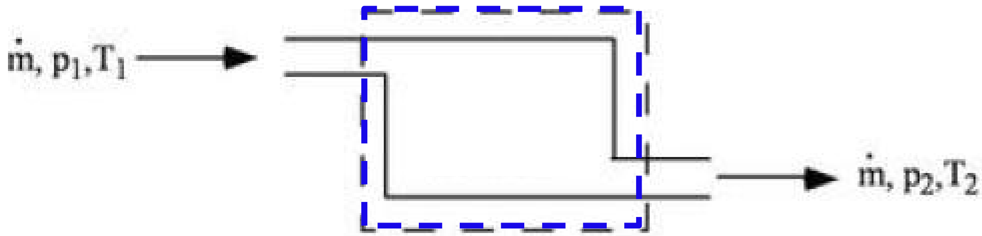
An ability to define and formulate the engineering problems

System(시스템) vs. **Control Volume(檢査體積)**

System(시스템)
- Identifiable mass
- Physical Laws apply



Control Volume(檢査體積)
- Space surrounding a region of interest
- Stationary/Moving, Constant/Varying



(Thermodynamic) **Property** ~ Uniquely defined state of a substance

- pressure, p
- temperature, T
- density, ρ
- internal energy, U u
- enthalpy, H h
- volume, V v

Scalar (intensive, extensive)
세기性質 크기性質

Vector : Need more than 1 number

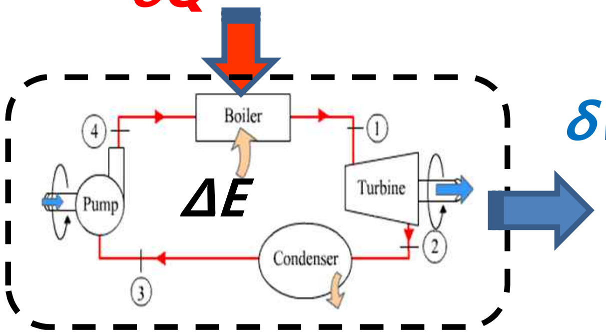
Displacement $\vec{x} = (x_1, x_2, x_3)$ Velocity $\vec{v} = (v_1, v_2, v_3)$ Force $\vec{F} = (F_1, F_2, F_3)$

Types of Energy

- Kinetic E. $\frac{1}{2}mv^2$ - Potential E. $m\,g\,\Delta z$ - Internal E. $U = m\,u$

Thermodynamics 1st Law

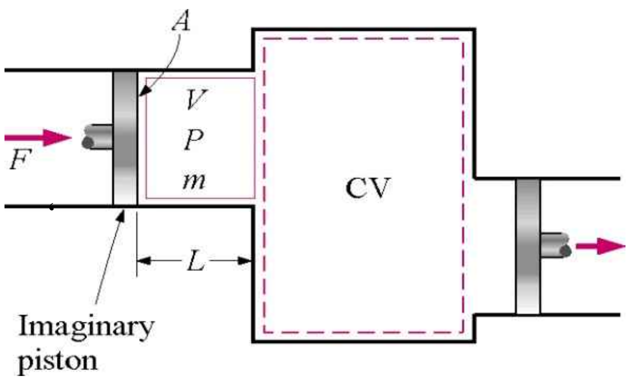
- Conservation of Energy applied to
  Heat & Thermodynamic Processes
- Relationship between
  Total Energy, Heat & Work of a System



$\Delta E = \delta Q - \delta W$

Enthalpy $h = u + pv \quad H = U + pV$

Work done by fluid as it enters the C.V. is ;



$$W_{flow} = FL = (pA)L = pV \quad \therefore w = W/m = pv$$

Flow Work(流動일)

Total Energy carried by a unit of mass as it crosses the Control Surface is

$$e = (u + pv) + \frac{v^2}{2} + g\,z = h + \frac{v^2}{2} + g\,z$$

Force, Torque

Force : **Any influence which tends to change the motion of an object**

$$\vec{F} = \frac{d(m\vec{V})}{dt} = m\vec{a} \quad [\ \mathrm{kg \times m/s^2 = N}\ ]$$

Vector quantity ~ Direction, Magnitude

$\vec{F}_1 = (0,-1)$

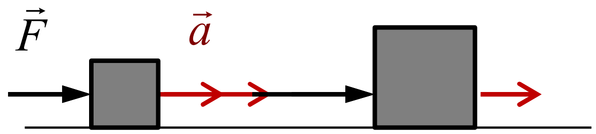
$\vec{F}_3 = (0,-1)$

$\vec{F}_2 = (0,-1)$

$\vec{F}_1 = \vec{F}_2 = \vec{F}_3$?

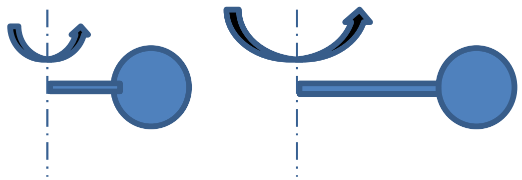
Inertia : resistance of any object to any change in its state of motion

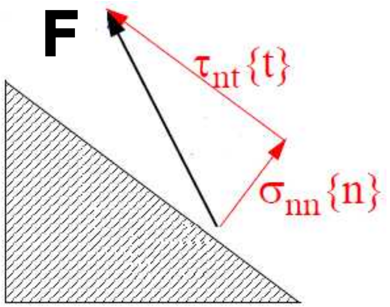
Linear	Mass	m	kg
Rotational	Moment of Inertia	$I = m \times r^2$	$\mathrm{kg \cdot m^2}$



Torque : Rotational motion of an object

$$\vec{r} \times \vec{F} = \vec{T} = \frac{d(I\vec{\omega})}{dt} = I\vec{\alpha} \quad [\ \mathrm{kg \cdot m^2/s^2 = N \cdot m}\ ]$$





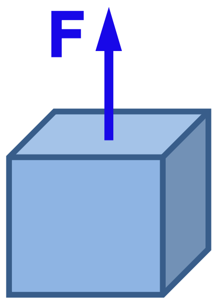
Normal(垂直) Stress/Strain vs. Shear(剪斷) Stress/Strain

Surface ⊥ Force — Surface // Force

Stress : Force / Area [N/m² = Pa]

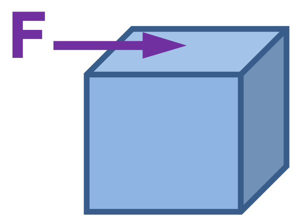
<u>**Normal**</u> Stress

$\sigma = F / A$



<u>**Shear**</u> Stress

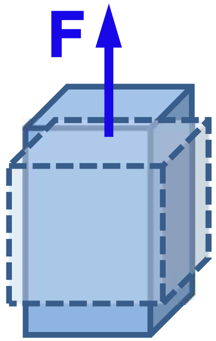
$\tau = F / A$



Strain : Deformation

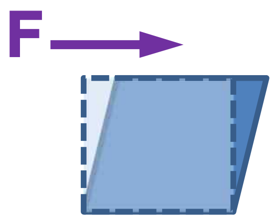
Normal Strain

$\varepsilon = \Delta L / L$



Shear Strain

$\gamma = \Delta\theta$



Stress ~ Strain

$\sigma = E\,\varepsilon$

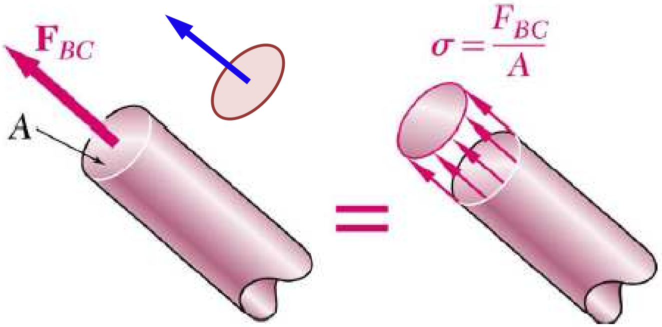
Young's Modulus

$\tau = G\,\gamma$

Shear Modulus

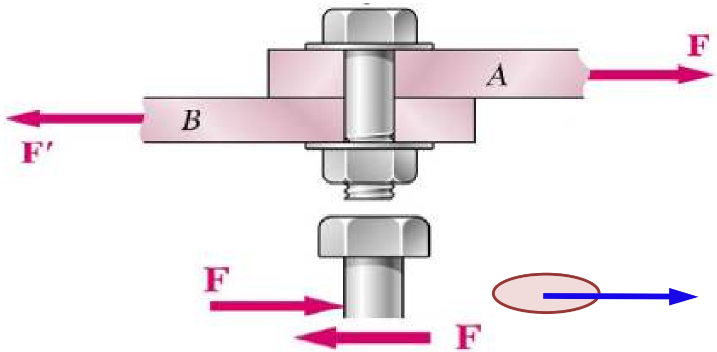
Stress : Force per Unit Area [N/m^2 = Pa]

[Normal Stress] σ

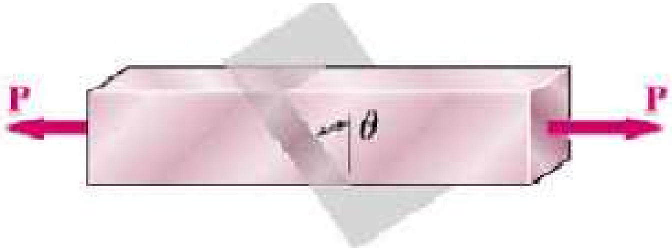


$$\sigma = \frac{F}{A} = \lim_{\Delta A \to 0} \frac{\Delta F}{\Delta A}$$

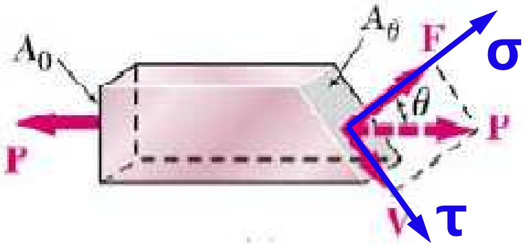
[Shear Stress] τ



$$\tau = \frac{F}{A} = \lim_{\Delta A \to 0} \frac{\Delta F}{\Delta A}$$



$\Rightarrow$



$$F = P\cos\theta$$

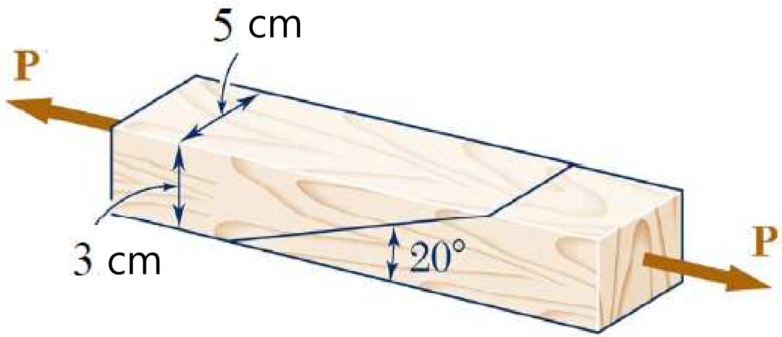
$$V = P\sin\theta$$

$$A_\theta = \frac{A_0}{\cos\theta}$$

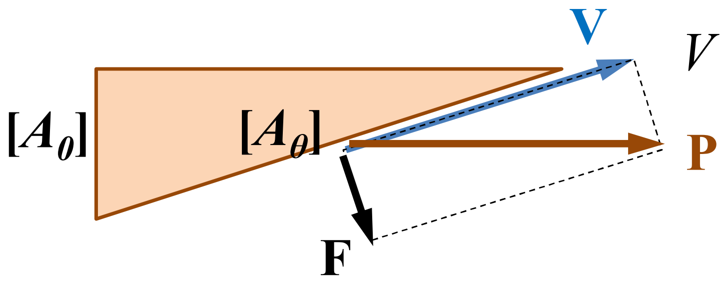
$$\sigma = \frac{F}{A_\theta} = \frac{P}{A_0}\cos^2\theta \qquad \tau = \frac{V}{A_\theta} = \frac{P}{A_0}\sin\theta\cos\theta$$

Shear Stress(剪斷應力)

Q : Two wooden members are joined by glue. If the maximum allowable shearing stress on the glued splice is 500 kPa, find the maximum load ***P***.



$$A_\theta = A_0 / \sin 20^\circ = (3\times 5)/\sin 20^\circ = 43.9(\text{cm}^2)$$



$$V = P\cos 20° = 0.94P$$

$$\tau = \frac{V}{A_\theta} = \frac{0.94P}{43.9} = 0.0214P \le \tau_{max} = 500(\text{kPa})$$

$$0.0214P \le \tau_{max} = 500(\text{kPa}) \qquad \therefore P \le 23{,}360(\text{kN})$$

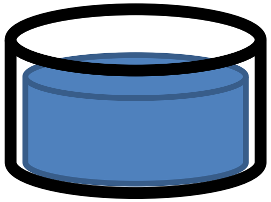
Free Body Diagrams(自由物體圖) are drawings used to show relative MAGNITUDE and DIRECTION of ALL FORCES acting upon an object of interest in a given situation.

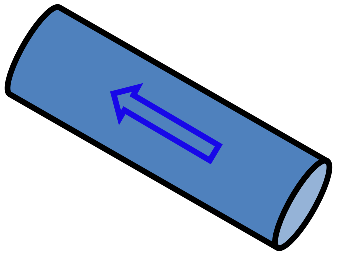
① Separate only the object that you are interested in.

② Find all forces acting on the object and draw appropriate force vectors.

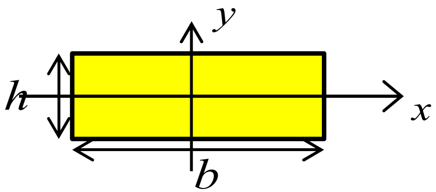
Forces important in Fluid Mechanics

$$\vec{F}_{\text{pressure}} + \vec{F}_{\text{viscosity}} + \vec{F}_{\text{gravity}} + \vec{F}_{\text{Drag/Lift}} + \vec{F}_{\text{Surface Tension}} + \cdots = \frac{d(m\vec{v})}{dt} = m\vec{a}$$



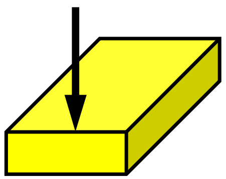


Moment of Inertia

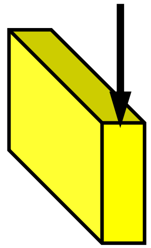


$$I_{xx} = \iint_A y^2 dA = \iint_A y^2 dx\,dy = \frac{b h^3}{12} \qquad I_{yy} = \iint_A x^2 dA = \iint_A x^2 dx\,dy = \frac{b^3 h}{12}$$

Deflection of Beam : $\delta_C = \dfrac{FL^3}{48EI}$



$$\delta_{C,xx} = \frac{FL^3}{48EI_{xx}} \qquad \delta_{C,yy} = \frac{FL^3}{48EI_{yy}}$$



(Physical) Dimensions, Units

Dimension M-L-T

1. from definition: Force= m a $= M L T^{-2}$

   $a=\Delta v/\Delta t=(\Delta x/\Delta t)/\Delta t=\Delta x/(\Delta t)^2 \sim LT^{-2}$

2. from units: Force ~ Newton ~ $\text{kg}\cdot\text{m/s}^2 \sim M L T^{-2}$

(SI) Unit   [M] kg [L] m [T] s [Θ] K

mass 1 liter of water = 1 kg = 1000 g = 2.205 lb_m

Dimensional Consistency $$\frac{p_1}{\rho}+\frac{V_1^2}{2}+gz_1=\frac{p_2}{\rho}+\frac{V_2^2}{2}+gz_2 \quad [\, L^2\, T^{-2}\,]$$

Dimensional Inconsistency : $$Q=\frac{2}{3}c_d\, b\sqrt{2g}\, h^{1.5} \qquad Q\ [\text{m}^3/\text{s}] \quad b, h\ [\text{m}] \quad c_d\ [\text{-}]$$

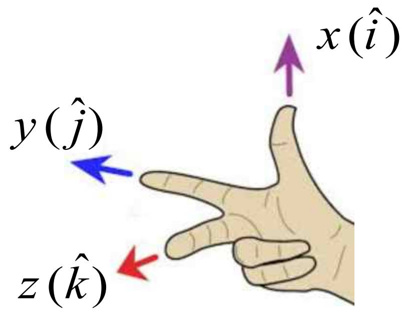
Inconsistency in Units : $$\text{EER} = \frac{\text{cooling rate}}{\text{electrical input}} = \frac{\text{btu/hr}}{\text{W}}$$

Vector Operation

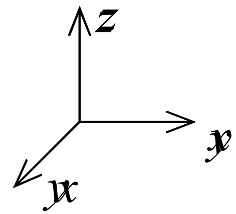
Vector : $\vec{f}(t) = f_x(t)\hat{i} + f_y(t)\hat{j} + f_z(t)\hat{k} = (f_x, f_y, f_z)$

$\vec{g}(t) = g_x(t)\hat{i} + g_y(t)\hat{j} + g_z(t)\hat{k} = (g_x, g_y, g_z)$

Vector Identity : $\vec{f} = \vec{g}$ iff $f_x = g_x, f_y = g_y, f_z = g_z$



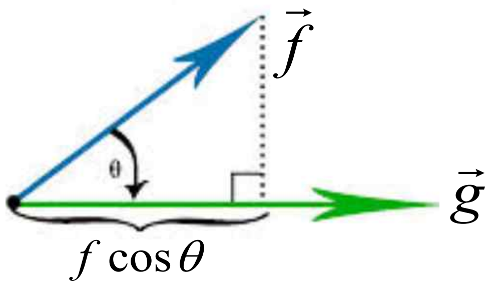
Right-hand Rule



Vector Multiplication :

Inner(Dot) product(内積)

$$\vec{f}\cdot\vec{g} = f_x g_x + f_y g_y + f_z g_z = \vec{g}\cdot\vec{f}$$

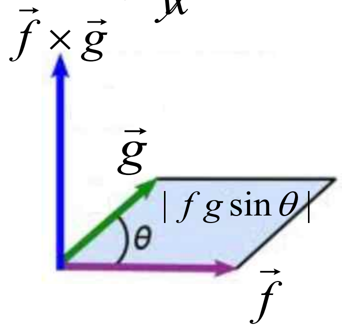


$$\vec{f}\cdot\vec{g} = f_x g_x + f_y g_y + f_z g_z = f\,g\cos\theta$$

$$W = \vec{F}\cdot\vec{l} = F\,l\cos\theta \;;\quad \theta = \pi/2 \rightarrow W = 0$$

Outer(Cross) product(外積)

$$\vec{f}\times\vec{g} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ f_x & f_y & f_z \\ g_x & g_y & g_z \end{vmatrix} = -\vec{g}\times\vec{f}$$

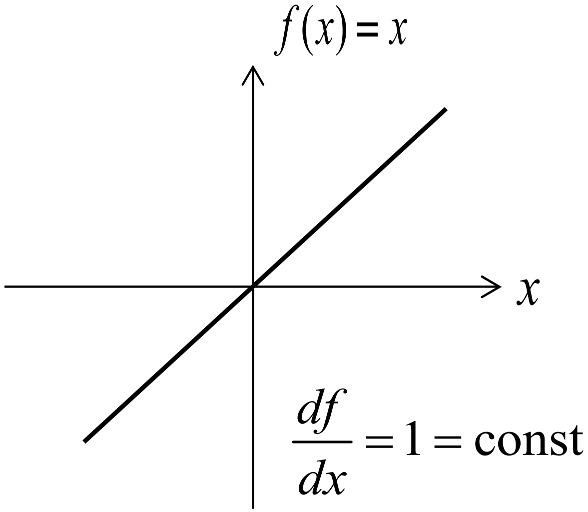


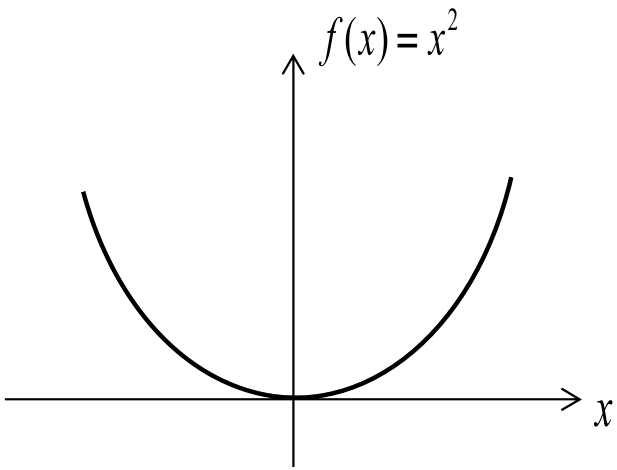
$$|\vec{f}\times\vec{g}| = f\,g\sin\theta$$

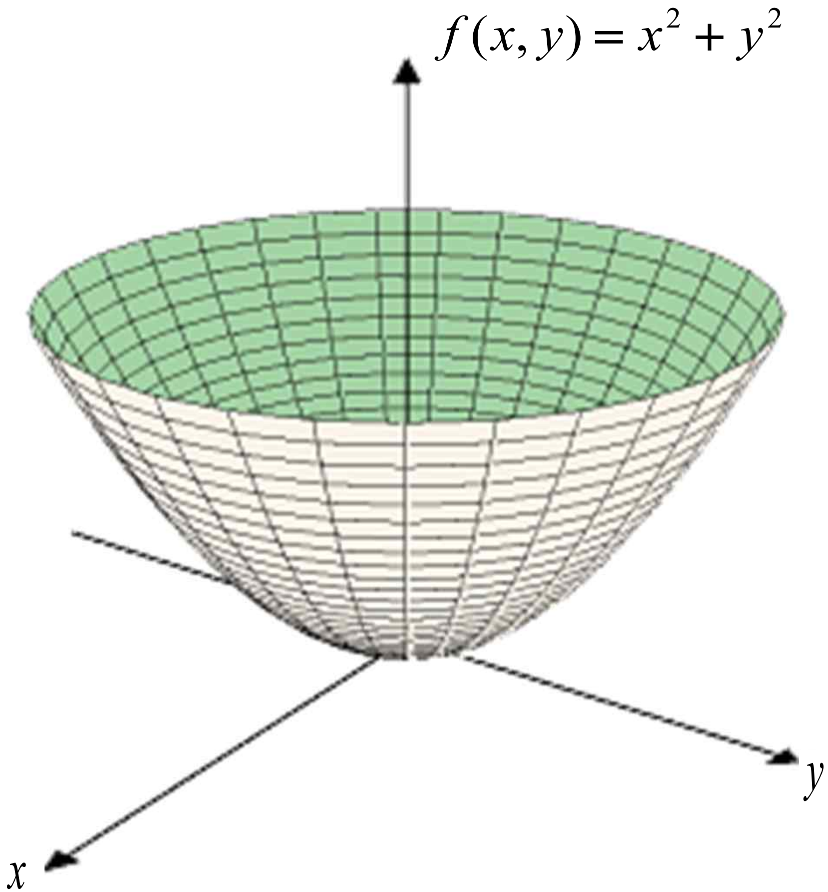
$$|\vec{T}| = |\vec{r}\times\vec{F}| = r\,F\sin\theta \;;\; \theta = 0 \rightarrow T = 0$$

Slope, Rate of Change, Gradient

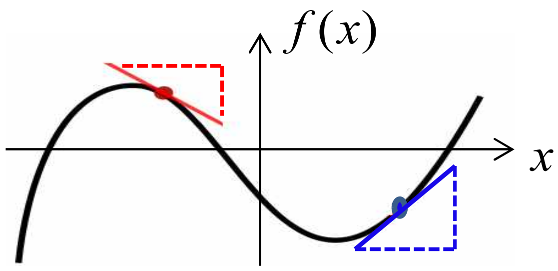
기울기(변화율)?





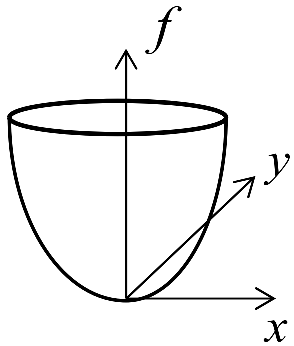


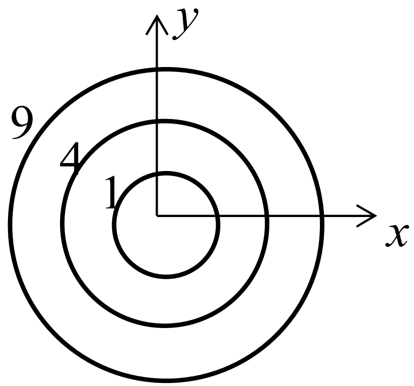
What is the change of $f(x)$?



$$df(x) = \frac{df}{dx}dx \quad \text{what is } dx\text{ ? } >0, <0\text{ ?}$$

What is the change of $f(x,y) = x^2 + y^2$?





$$\frac{\partial f}{\partial x}(y = const) \quad \frac{\partial f}{\partial y}(x = const)$$

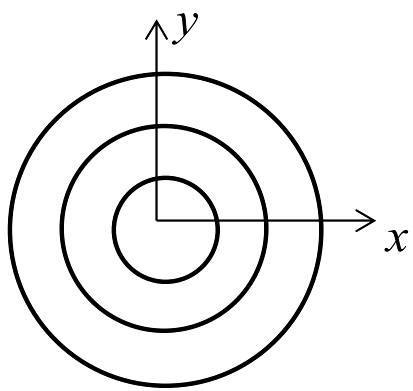
$$df(x,y) = \frac{\partial f}{\partial x}dx + \frac{\partial f}{\partial y}dy = \nabla f \cdot d\vec{X}$$

Directional Derivative

Gradient ▽ : $\nabla f(x,y) = \text{grad } f = \frac{\partial f}{\partial x}\hat{i} + \frac{\partial f}{\partial y}\hat{j} = (\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y})$

$$\nabla = \vec{\nabla} = \frac{\partial}{\partial x}\hat{i} + \frac{\partial}{\partial y}\hat{j} + \frac{\partial}{\partial z}\hat{k}$$

$$\nabla(x^2 + y^2) = \frac{\partial f}{\partial x}\hat{i} + \frac{\partial f}{\partial y}\hat{j} = 2x\hat{i} + 2y\hat{j}$$



- Points in the direction of greatest increase of function

- Magnitude is the greatest rate of increase of function

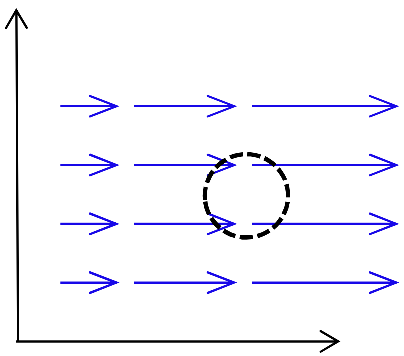
Gradient Operation ; Divergence, Curl

1. Divergence(發散)

$$\nabla\cdot\vec{V}=\left(\frac{\partial}{\partial x}\hat{i}+\frac{\partial}{\partial y}\hat{j}\right)\cdot(u\,\hat{i}+v\,\hat{j})=\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}$$

A measure of the magnitude of a vector field's source(+) or sink(-).

$$\vec{V}=x\hat{i}+0\hat{j}$$



- There is more leaving than entering
- It is getting less dense
- There is a Source

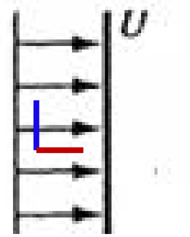
$$\nabla\cdot\vec{V}=\left(\frac{\partial}{\partial x}\hat{i}+\frac{\partial}{\partial y}\hat{j}\right)\cdot(x\hat{i}+0\hat{j})=1>0$$

2. Curl(回轉)

$$\nabla\times\vec{V}=\left(\frac{\partial}{\partial x}\hat{i}+\frac{\partial}{\partial y}\hat{j}+\frac{\partial}{\partial z}\hat{k}\right)\times(u\hat{i}+v\hat{j}+w\hat{k})=\begin{vmatrix}\hat{i} & \hat{j} & \hat{k}\\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z}\\ u & v & w\end{vmatrix}$$

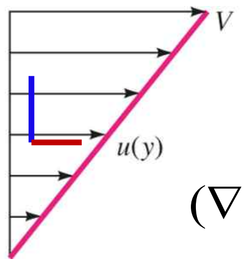
A measure of an infinitesimal rotation of a vector field. Irrotational if zero.

$$\vec{V}=(U,0)$$



$$(\nabla\times\vec{V})_z=\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}=0-0=0$$

$$\vec{V}=\left(\frac{U}{H}y,0\right)$$



$$(\nabla\times\vec{V})_z=\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}=0-\frac{U}{H}=-\frac{U}{H}<0$$

Linear Approximation & Taylor Series

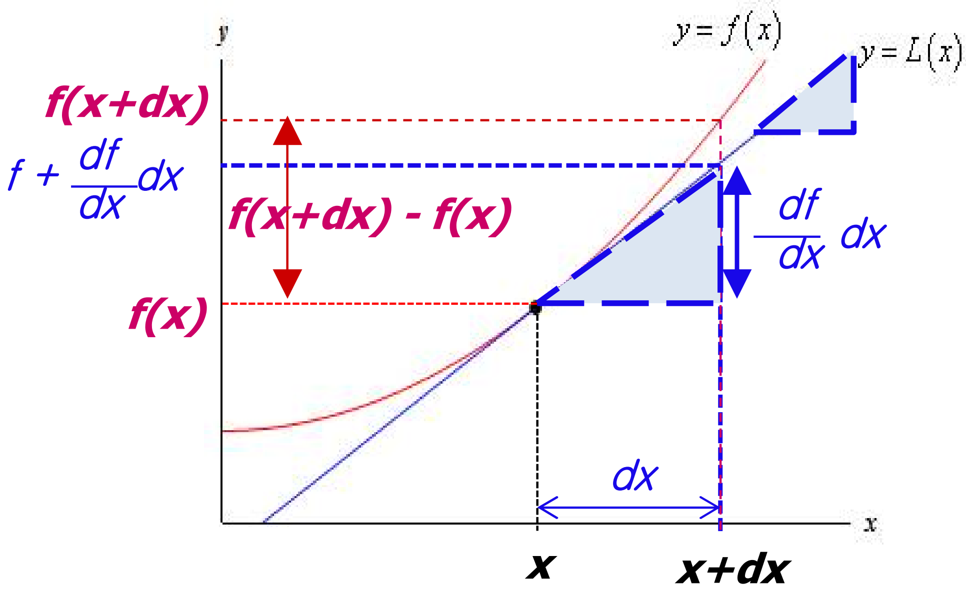
Make approximation of complex functions using tangent line at a point

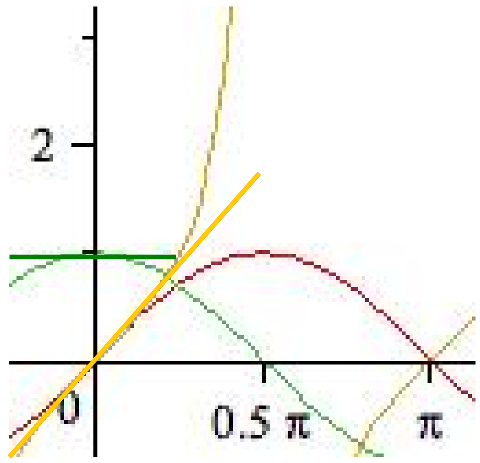
Taylor Series :

$$f(t)=f(a)+f'(a)(t-a)+\frac{f''(a)}{2!}(t-a)^2+\cdots+\frac{f^{(n)}(a)}{n!}(t-a)^n+\cdots$$

$$f(x+dx)=f(x)+f'(x)dx+\frac{f''(x)}{2!}(dx)^2+\cdots+\frac{f^{(n)}(x)}{n!}(dx)^n+\cdots$$

if $dx<<1;$





$\sin\theta \fallingdotseq \theta$

$\cos\theta \fallingdotseq 1$

$\tan\theta \fallingdotseq \theta$

Chain Rule : **Formula for computing the derivative of a composition of two or more functions or function of functions**

1. If $y = f(u) \quad u = g(x) \quad ; \quad y = f\{g(x)\}$, then $\dfrac{df}{dx} = \dfrac{df}{du} \times \dfrac{du}{dx}$

(Ex.) $y = u^2 + 3, u = 2x + 1$

2. If $z = f(x, y) \quad x = g(t), y = h(t) \quad ; \quad z = f\{g(t), h(t)\}$, then $\dfrac{dz}{dt} = \dfrac{\partial z}{\partial x}\dfrac{dx}{dt} + \dfrac{\partial z}{\partial y}\dfrac{dy}{dt}$

(Ex.) $z = x^2 + 3y; x = 2t, y = e^{2t}$

or, $z = x^2 + 3y = 4t^2 + 3e^{2t}$

Single Variable :

$$\frac{df(x)}{dx} = x^2 + 1 \quad df = (x^2+1)\,dx \quad \int df = \int (x^2+1)\,dx \qquad \therefore\ f(x) = \frac{1}{3}x^3 + x$$

Multi-Variable :

$$\frac{\partial f}{\partial x} = x^2 - y^2 \qquad \frac{\partial f(x,y)}{\partial x}\Big|_{y=const} = x^2 - y^2$$

$$\int df = \int (x^2 - y^2)\,dx = \int x^2\,dx - y^2 \int dx = \frac{1}{3}x^3 + c_1 - y^2 x + c_2 = f$$

$$\int df = \int (x^2 - y^2)\,dx = \frac{1}{3}x^3 - xy^2 + c \quad = f(x,y)$$

$$\frac{\partial f}{\partial y} = -2xy + 1 \qquad \frac{\partial f}{\partial y} = \frac{\partial}{\partial y}\{\frac{1}{3}x^3 - xy^2 + g(y)\} = -2xy + g'(y)$$

$$\therefore\ -2xy + 1 = -2xy + g'(y) \qquad g'(y) = 1 \quad \therefore g(y) = y + c \qquad \rightarrow f(x,y) = \frac{1}{3}x^3 - xy^2 + y + c$$

Fluid (流體) Mechanics (力學)

Fluid mechanics is the study of fluids and their effect on boundaries in contact with them either in motion or at rest.

Based on the Principles of **Conservation of Mass & Energy,**
Newton's 2nd Law of Motion,
we want to know;

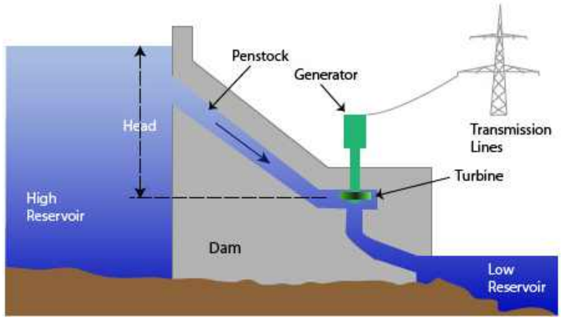
- Will the dam stand?

(Hydrostatic Pressure)

- What is the thrust?

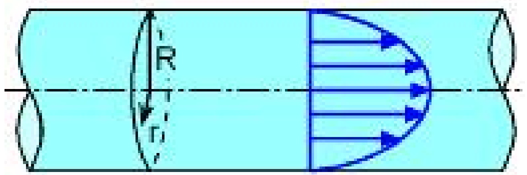
(Linear Momentum Equation)

- How much power is generated?



(Energy Equation)

- What is the max. velocity?

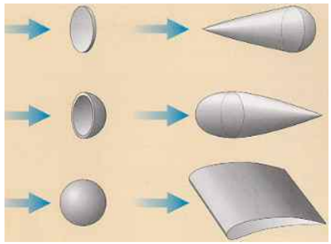


(Navier-Stokes Equation)

- How big a pump?

(Moody Chart)

- What is the drag force?



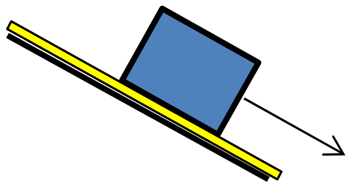
(Drag Coefficient)

What you should KNOW!

1. Course Requirements and Grading Policy
2. Basic Thermodynamic Concepts & Properties
3. Basic Solid Mechanic Concepts & F.B.D.
4. Dimensions, SI Units
5. Basic Vector Calculus and Multivariable Calculus

What you should BE ABLE TO DO!

1. Differentiate, transform between; Extensive, Intensive, Specific properties
2. Find the Dimension and Unit of in f $\Delta p = f \rho \frac{l}{d} \frac{v^2}{2}$
3. Draw F.B.D.'s of sliding block at positive, negative and zero accelerations
4. Find the Gradient of a Multivariable Function
5. Find a Multivariable Function from its partial derivatives



Announcement

Binder : Lecture Note(E-Class)
Quiz/HW Answer Sheet

Homework

HW #1 – Due 9/7 In Class

Next Lecture

Ch. 1: 2~4, 6, 7 Fluid Properties