For comments, corrections, etc…Please contact Ahnaf Abbas: ahnaf@mathyards.com

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DEFINITIONS AND UNITS

	Symbol/Equation:	Units
Mass	m	kg
Acceleration	a	m/s^2
Velocity	v or c	m/s
Temperature	T	K (Kelvin) (0^0 C = 273 K)
Volume	V	m^3
Density	$\rho = m/V$	kg/m^3
Specific heat at constant volume	c_v	kJ/kgK
Specific heat at constant pressure	c_p	kJ/kgK
Specific volume	$v = V/m$	m^3/kg
Force = Mass x Acceleration	F = ma	$kg.m/s^2$ (1 $kg.m/s^2$ = 1N)
Pressure = Force / area	$P = F / A$	Pa (N/m^2) (1bar=10^5 Pa)
Pressure due to liquid column	$P = \rho gz$	N/m^2
Potential Energy	PE = mgz	J/kg or Nm
Kinetic Energy	KE = $\frac{1}{2}mc^2$	J/kg or Nm
Internal Energy	$U = mc_v$	J/kg or Nm
Work = Force x Distance	W = Fs	Nm or J (Joule)
Heat	$Q = mc\Delta T$	J or kcal (kilocalorie)

- *Heat transfer into the system* = +***q***
- *Heat transfer out of the system* = - ***q***
- *Increase in internal energy of the gas* = +***Δu***
- *Decrease in internal energy of the gas* = - ***Δu***
- *External work done by the gas* = + ***w***
- *External work done on the gas* = - ***w***

Power	P = W/t	Watts

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PROPERTIES OF SOLIDS AND FLUIDS

***Viscosity* -** Viscosity is the property that determines the fluids ability to flow.

Density – the measure of how heavy a substance is.

Specific gravity – the heaviness of a substance compared to that of water. It is expressed without units.

Specific volume – the volume occupied by 1kg of substance

Specific heat capacity – the amount of heat required to raise the temperature of 1kg of substance by 1K

Specific heat at constant volume - The heat energy required to raise the temperature of 1 kg of a gas by 1 K when the process takes place at constant volume.

Specific heat at constant pressure - The heat energy required to raise the temp of 1 kg of a gas by 1 K when the process takes place at constant pressure.

Enthalpy – The combination of the changes in internal energy and pressure and volume (U +Pv)

Entropy – The amount of heat transferred reversibly during a non-flow process

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FLUID MECHANICS

Pressure

$\mathbf{P = \frac{F}{A}}$

Hydrostatic Pressure

P= ρgz or ρgh

Gauge pressure

$P_g = P_{absolute} - P_{atm}$

Hydrostatic Force and centre of pressure

$\mathbf{F = \rho g \bar{x} A}$ $\qquad$ $\mathbf{x_c - \bar{x} = \frac{I_G}{A\bar{x}}}$

Second moments of area

$I_G = \frac{bd^3}{12}$ (rectangle) $\qquad$ $I_G = \frac{\pi r^4}{4}$ (circle)

Continuity equation

$\mathbf{\dot{m} = \rho_1 A_1 v_1 = \rho_2 A_2 v_2}$ $\qquad$ $\mathbf{\dot{m} = \rho_1 A_1 c_1 = \rho_2 A_2 c_2}$

$\mathbf{\dot{V} = Q = A_1 v_1 = A_2 v_2}$ $\qquad$ $\mathbf{\dot{V} = Q = A_1 c_1 = A_2 c_2}$

Steady flow energy equation:

$q - w = \Delta e_k + \Delta e_p + \Delta(pv) + \Delta u.$

$q + (\tfrac{1}{2}c_1^2 + gz_1 + p_1v_1 + u_1) = w + (\tfrac{1}{2}c_2^2 + gz_2 + p_2v_2 + u_2)$

Bernoulli's equation: $\frac{p_1}{\rho} + \frac{c_1^2}{2} + z_1 g = \frac{p_2}{\rho} + \frac{c_2^2}{2} + z_2 g$ ***or*** $\mathbf{\frac{p_1}{\rho g} + \frac{c_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{c_2^2}{2g} + z_2}$

Momentum (one dimensional flow): $\mathbf{F = \rho Q(v_2 - v_1) = \dot{m}(v_2 - v_1)}$

Momentum (two dimensional flow): $\mathbf{F = \sqrt{F_x^2 - F_y^2}}$ ***&*** $\mathbf{\tan\alpha = \frac{F_y}{F_x}}$

Force on a pipe bend:

$F_x = P_1A_1 - P_2A_2\cos\theta + \rho Q(v_1 - v_2\cos\theta)$
$F_y = P_2A_2 \sin\theta + \rho Q v_2 \sin\theta$

Force exerted by a jet:

$F = \rho A v^2$ or $F = \rho A v^2 \sin\theta$ (for a fixed surface)
$F = \rho A (v - u)^2 \sin\theta$ (for a moving surface)

Forces on a curved vane:

$F_x = \rho A v^2 (\cos\theta - 1)$ (Fixed surface)
$F_y = \rho A v^2 \sin\theta$
$F_x = \rho A (v - u)^2 (\cos\theta - 1)$ (surface moving away)
$F_y = \rho A (v - u)^2 \sin\theta$

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THERMODYNAMICS

Perfect gases:

Boyle's Law:

PV = constant $P_1 V_1 = P_2 V_2$

Charles' Law:

$\frac{V}{T} =$ constant $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

Combined law: $\frac{PV}{T} =$ constant $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$.

Characteristic Gas Equation: pV=mRT

Gas constant R $R = c_p - c_v$

Joules Law – internal energy change:

$\Delta U = m\, c_v\, \Delta T \quad = m\, c_v\, (T_2 - T_1)$

or $\Delta u = c_v \Delta T$

Enthalpy change

$\Delta H = m\, c_p\, \Delta T \quad = m\, c_p\, (T_2 - T_1)$

or $\Delta h = cp\ \Delta T$

The non-flow energy equation: $Q - W = \Delta U$ or $Q - W = (U_2 - U_1)$

Enthalpy: H= U + pV

Work Transfer:

Constant pressure process: $Q = mc_p\Delta T$

Work done (constant volume): W = 0

Work done (constant pressure): $W = p\Delta V$

General gas (polytropic) process (PV^n = constant): $W = \frac{P_1V_1 - P_2V_2}{n-1}$ or $\frac{\Delta(PV)}{1-n}$

Pressure ratio: $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$

Volume ratio: $\frac{T_2}{T_1} = \left(\frac{v_2}{v_1}\right)^{\frac{n-1}{n}}$

Hyperbolic or isothermal process ($PV^n = C$ where n = 1)

$W = P_1V_1 \ln\left(\frac{V_2}{V_1}\right)$ *or* $W = P_2V_2 \ln\left(\frac{V_2}{V_1}\right)$

Reversible adiabatic process (PV^γ = constant where $\gamma = c_p/c_v$)

Properties of wet steam:

Dryness fraction x

x = mass of saturated steam / mass of wet steam

Internal energy of wet steam

$u = u_f + x\,(u_g - u_f)$

The specific volume of wet steam

$v = x\, v_g$

The specific enthalpy of wet steam

$h = h_f + x\, h_{fg}$

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MECHANICAL PRINCIPLES FORMULA SHEET

Stress $\sigma = \dfrac{\text{force}}{\text{area}}$

Poisson's ratio $\mu = \dfrac{\text{lateral strain}}{\text{direct strain}}$

Modulus of elasticity $E = \dfrac{\text{stress}}{\text{strain}}$

Rigidity modulus $G = \dfrac{\text{shear stress}}{\text{shear strain}} = \dfrac{E}{2(1+\mu)}$

Bulk modulus $K = \dfrac{\text{volumetric stress}}{\text{volumetric strain}} = \dfrac{E}{3(1-2\mu)}$

Biaxial strains:

In direction of x, $\varepsilon_x = \dfrac{(\sigma_x - \mu\sigma_y)}{E}$

In direction of y, $\varepsilon_y = \dfrac{(\sigma_y - \mu\sigma_x)}{E}$

Areal strain $= \varepsilon_A = \dfrac{\Delta A}{A} = \varepsilon_x + \varepsilon_y$

Triaxial strains: ***Volumetric strain*** $= \dfrac{\Delta V}{V} = \dfrac{3\sigma}{E}(1-2\mu) = \varepsilon_x + \varepsilon_y + \varepsilon_z$

Thin wall cylinders: ***Hoop stress*** $\sigma_h = \dfrac{pd}{2t}$

Longitudinal strain $\sigma_L = \dfrac{pd}{4t}$

Thick wall cylinders ***Circumferential stress*** $\sigma_c = a + \dfrac{b}{r^2}$

Radial stress $\sigma_r = a - \dfrac{b}{r^2}$

Thick wall cylinders subject to internal pressure only:

Radial stress $\sigma_r = \dfrac{pr_1^2}{r_2^2 - r_1^2}[1 - r_2^2/r^2]$

Circumferential stress $\sigma_c = \dfrac{pr_1^2}{r_2^2 - r_1^2}[1 + r_2^2/r^2]$

Stress in thin spherical shells $\sigma = \dfrac{pd}{4t}$

Epicyclic gear train:

Operation	***Rotation*** Arm	A	S	P
1. Fix arm and rotate A by one rev.	0	1	$-t_A/t_s$	t_A/t_p
2. Rotate ALL by -1 revolution	-1	-1	-1	-1
3. Add 1 and 2	-1	0	$-1- t_A/t_s$	$-1+ t_A/t_p$