ENG27

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG(HONS) MECHANICAL ENGINEERING

SEMESTER 2 EXAM 2022-23

THERMOFLUIDS AND CONTROL SYSTEMS
MODULE NUMBER: AME5013

Date: Wednesday 10th May 2023 **Time: 2:00pm – 4:00pm**

INSTRUCTIONS TO CANDIDATES:

There are SIX questions.

Answer ANY FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

This examination paper carries a total of 100 marks.

Formulae sheet is attached at the end of the paper.

All working must be shown. A numerical solution to a question obtained by programming an electronic calculator will not be accepted.

Q1) a) What depth of oil which has a specific gravity of 0.8 will produce a pressure of 120 kPa? What would be the corresponding depth of water for the same amount of pressure?

[5 Marks]

b) A jet of water 10mm in diameter has a velocity of 18m/s. It strikes a plate moving in the same direction as the jet with a velocity of 3m/s. Determine the force exerted by the jet on the plate. What will be the force on the plate if the velocity of the plate is increased to 10m/s

[10 Marks]

c) In Figure Q1c fluid P is water and fluid Q is mercury. If the specific gravity of mercury is 13.6 times that of water and the atmospheric pressure is 101325 Pa, what is the absolute pressure at point A when h_1 = 15cm and h_2 = 30cm

[10 Marks]

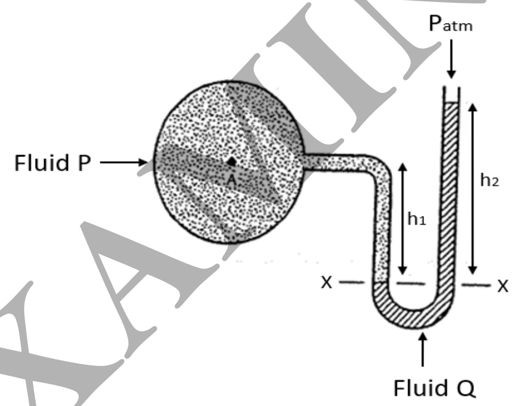

Figure Q1c: U-tube manometer opened to atmosphere

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Q2) a) Water (density = 1000 kg/m^3) flowing in a circular horizontal pipe has a diameter of 150mm and a velocity of 3 m/s. At the downstream section of the pipe, its diameter is reduced to 75mm as is shown in Figure Q2a. Determine the velocity at point 2 and the discharge rate in the pipe.

[5 Marks]

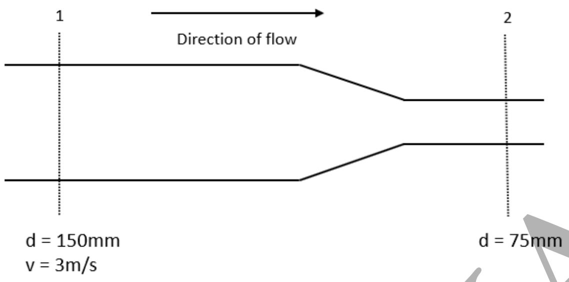

Figure Q2a: Circular pipe with a varying cross section area

b) A venturi meter with a throat diameter of 180mm is fitted into a horizontal pipeline of 360mm through which water flows. The pressure difference between the entry and throat is measured by a U-tube manometer. If the difference in level indicated by the manometer is 40cm, calculate the velocity at point 1 and at the throat of the venturi meter shown as point 2 in Figure Q2b.

[15 Marks]

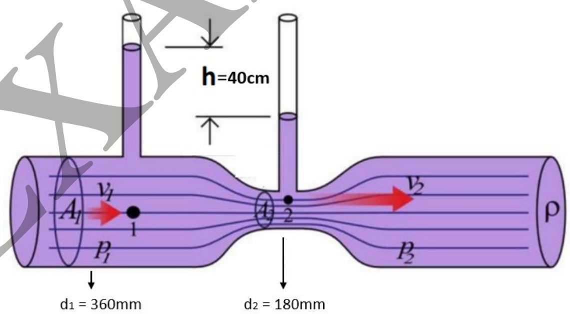

Figure Q2b: Venturi meter showing pressure difference between inlet and throat

c) Calculate the pressure at the throat of the venturi meter (point 2) if the pressure at point 1 is 50kPa.

[5 Marks]

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Q3) a) Define the following: Isobaric process, Isothermal process, Adiabatic process, Isochoric process and Bottom Dead Centre.

[5 Marks]

b) A gas at initial state of 300K, 800kPa, and 0.3m^3 is expanded slowly in an isothermal process to a final pressure of 250kPa. Draw a p-v diagram for the process

[5 Marks]

c) A gas in a piston-cylinder assembly undergoes a polytropic process for which the relationship between pressure and volume is given by $pv^n = C$. The initial pressure is 3 bar, the initial volume is 0.1m^3 and final volume is 0.2m^3. Calculate the work done for the process if n=1.5

[15 Marks]

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Q4)

A block diagram for a furnace temperature control system is shown in Figure Q4 below:

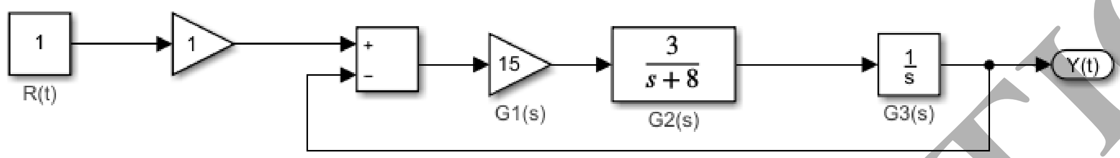

Figure Q4

Where,

$G_1(s) = 15$

$G_2(s) = \frac{3}{s+8}$

$G_3(s) = \frac{1}{s}$

a) Determine the system damping ratio, natural frequency, damped frequency, and steady state gain. **[7 marks]**

b) Determine the time domain response of the system, y(t), to a unit impulse input, r(t).

[6 marks]

c) For a unit step input, determine the system rise time, peak time, maximum percentage overshoot, and settling time for a 2% tolerance.

[6 marks]

d) If the input of $r(t) = 90, t \geq 0 \; and \; 0 , t \leq 0$

is applied, analyse the system steady state error.

[6 marks]

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Q5)

A block diagram for a control system for a steam-turbine speed control is shown below in Figure 5.

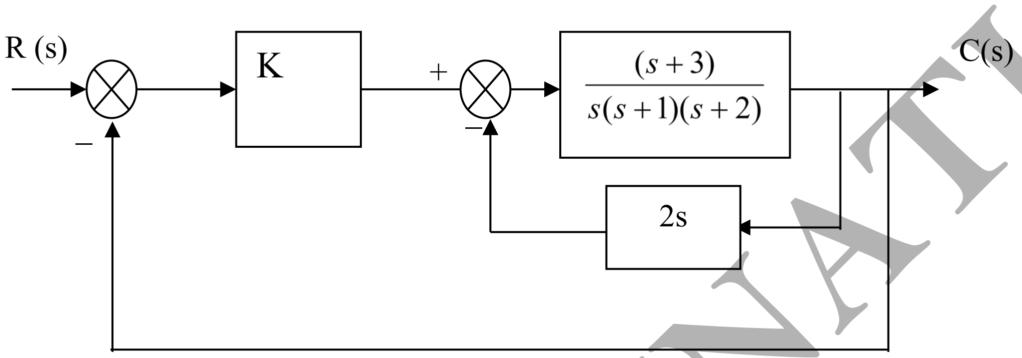

Figure 5

a) Derive the closed loop transfer function C(s)/R(s). **[10 marks]**
b) Sketch pole-zero diagram. **[6 marks]**
c) The order of the system. **[4 marks]**
d) Is the system stable. **[5 marks]**

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Q6)

a) A spring damper system has a transfer function of $G(s) = \frac{30}{10s+1}$. **[5 marks]**

If a unit step has been applied to the input, sketch a diagram to display the relationship between the input force and the output displacement.

b) Find the time constant and the steady state gain. **[5 marks]**

c) The relationship between the input signal to a radio telescope dish and the direction in which it points is a second-order system. Figure 6 shows the output of the system which subjects to a step input.

Determine:

(i) the system's natural angular frequency (the undamped angular frequency) ω_n,
(ii) the damped angular frequency ω_d,
(iii) damping factor ζ,
(iv) the 100% rise time t_r,
(v) the percentage maximum overshoot,
(vi) the 2% settling time t_s,
(vii) and the peak time t_p of the output. **[15 marks]**

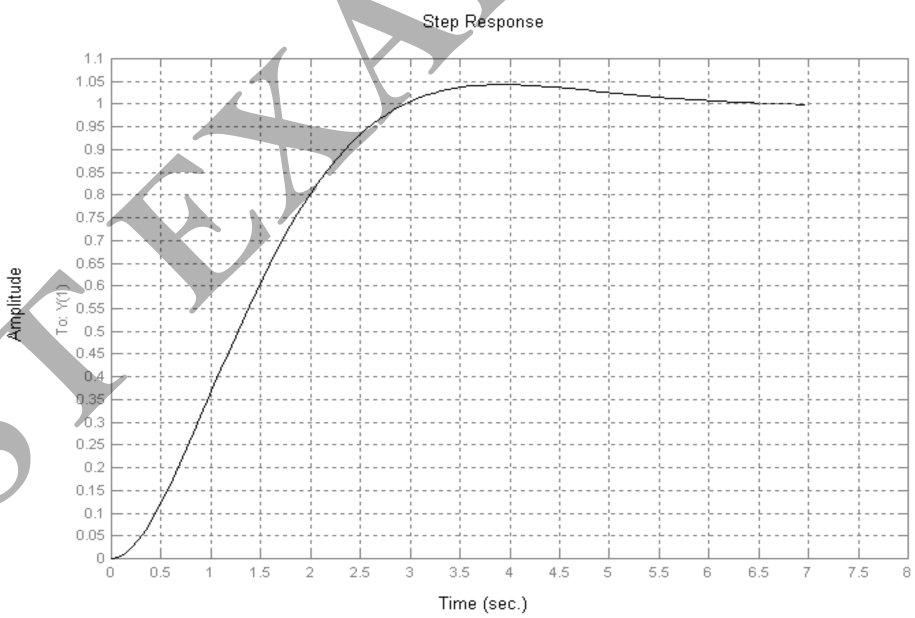

Figure 6

END OF QUESTIONS – PLEASE TURN PAGE FOR FORMULA SHEETS

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Formula sheet

Blocks with feedback loop

$G(s) = \frac{Go(s)}{1+Go(s)H(s)}$ (for a negative feedback)

$G(s) = \frac{Go(s)}{1-Go(s)H(s)}$ (for a positive feedback)

Steady-State Errors

$e_{ss} = \lim_{s\to 0}[s\frac{1}{1+G_o(s)}\theta_i(s)]$ (for the closed-loop system with a unity feedback)

$e_{ss} = \lim_{s\to 0}[s\frac{1}{1+\frac{G_o(s)}{1+G_o(s)[H(s)-1]}}\theta_i(s)]$ (if the feedback $H(s) \neq 1$)

$e_{ss} = \frac{1}{1+\lim_{z\to 1} G_o(z)}$ (if a digital system subjects to a unit step input)

Laplace Transforms

A unit impulse function 1

A unit step function $\frac{1}{s}$

A unit ramp function $\frac{1}{s^2}$

First order Systems

$G(s) = \frac{\theta_o}{\theta_i} = \frac{G_{ss}(s)}{\tau s+1}$

$\tau\left(\frac{d\theta_o}{dt}\right) + \theta_o = G_{ss}\theta_i$

$\theta_O = G_{ss}(1-e^{-t/\tau})$ (for a unit step input)

$\theta_O = AG_{ss}(1-e^{-t/\tau})$ (for a step input with size A)

$\theta_o(t) = G_{ss}(\frac{1}{\tau})e^{-(t/\tau)}$ (for an impulse input)

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Second-order systems

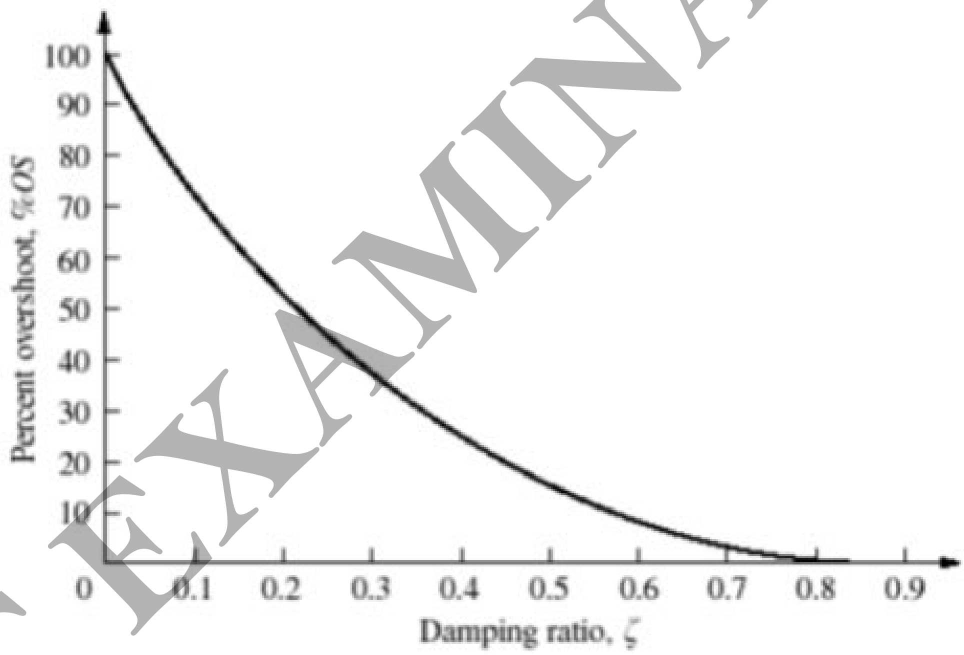
$$\frac{d^2\theta_o}{dt^2} + 2\zeta\omega_n\frac{d\theta_o}{dt} + \omega_n^2\theta_o = b_o\omega_n^2\theta_i$$

$$G(s) = \frac{\theta_o(s)}{\theta_i(s)} = \frac{b_o\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$\omega_d t_r = 1/2\pi$ $\omega_d t_p = \pi$

$$\text{P.O.} = \exp\left(\frac{-\zeta\pi}{\sqrt{(1-\zeta^2)}}\right)\times 100\%$$

$t_s = \frac{4}{\zeta\omega_n}$ $\omega_d = \omega_n\sqrt{(1-\zeta^2)}$



Controllability: R = [B AB A^2B.....$A^{(n-1)}$ B]

Observability:

Laplace transform and Z transform table

Laplace Domain	Time Domain	Z Domain
1	$\delta(t)$ unit impulse	1
$\frac{1}{s}$	$u(t)$ *unit step*	$\frac{z}{z-1}$
$\frac{1}{s^2}$	t	$\frac{Tz}{(z-1)^2}$
$\frac{1}{s+a}$	e^{-at}	$\frac{z}{z-e^{-aT}}$
$\frac{1}{s(s+a)}$	$\frac{1}{a}\left(1-e^{-at}\right)$	$\frac{z\left(1-e^{-aT}\right)}{a(z-1)\left(z-e^{-aT}\right)}$
$\frac{b-a}{(s+a)(s+b)}$	$e^{-at}-e^{-bt}$	$\frac{z\left(e^{-aT}-e^{-bT}\right)}{a\left(z-e^{aT}\right)\left(z-e^{-bT}\right)}$
$\frac{b}{(s+a)^2+b^2}$	$e^{-at}\sin(bt)$	$\frac{ze^{-aT}\sin(bT)}{z^2-2ze^{-aT}\cos(bT)+e^{-2aT}}$
$\frac{s+a}{(s+a)^2+b^2}$	$e^{-at}\cos(bt)$	$\frac{z^2-ze^{-aT}\cos(bT)}{z^2-2ze^{-aT}\cos(bT)+e^{-2aT}}$

Laplace Transforms of common functions

Functions		
Unit pulse (Dirac delta distribution)	$\delta(t)$	$F(s)=1$
Unit step function	$1(t)$	$F(s)=\frac{1}{s}$
Ramp function	$f(t)=at$	$F(s)=\frac{1}{s^2}$
Sine function	$f(t)=\sin at$	$F(s)=\frac{a}{s^2+a^2}$
Cosine function	$f(t)=\cos at$	$F(s)=\frac{s}{s^2+a^2}$
Exponential function	$f(t)=e^{at}$	$F(s)=\frac{1}{s-a}$
Operations		
Differentiation	$L(f'(t))$	$sF(s)-f(0)$
Integration	$L\left(\int f(t)dt\right)$	$\frac{1}{s}F(s)$
Time shift	$Lf(t-a)$	$e^{-as}F(s)$

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$$W = \frac{P_1 V_1 - P_2 V_2}{n - 1} \qquad W = P(v_2 - v_1)$$

$$W = PV \ln\left(\frac{V_2}{V_1}\right)$$

$$Q = C_d A \sqrt{2gh}$$

$$V_1 = C\sqrt{2g\, h_2\left(\frac{\rho g_m}{\rho g} - 1\right)}$$

$$\sum F = \frac{\Delta M}{\Delta t} = \Delta M^{\cdot}$$

$$F = \rho QV$$

$$Re = V L \rho/\mu$$

$$dQ = du + dw$$

$$du = cu\, dT$$

$$dw = pdv$$

$$pv = mRT$$

$$h = hf + xhf_g$$

$$s = sf + xsf_g$$

$$v = x\, Vg$$

$$\dot{Q} - \dot{w} = \sum \dot{m}h$$

$$F = \frac{2\pi L\mu}{L_n\left(\frac{R_2}{R_1}\right)}$$

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$$S_g = C_{pl}\ L_n \frac{T}{273} + \frac{h_{fg}}{T_f}$$

$$S = C_{pl}\ L_n \frac{T_f}{273} + \frac{hf_g}{T_f} + C_{pv}\ L_n \frac{T}{T_f}$$

$$S_2 - S_1 = MC_p\ L_n \frac{T_2}{T_1} - MRL_n \frac{P_2}{P_1}$$

$$F_D = \frac{1}{2} CD\ \rho u^2 s$$

$$F_L = \frac{1}{2} C_L \rho u^2 s$$

$$S_p = \frac{d}{ds}(P + \rho g Z)$$

$$Q = \frac{\pi D^4 \Delta p}{128 \mu L}$$

$$h_f = \frac{64}{R}\left(\frac{L}{D}\right)\left(\frac{v^2}{2g}\right)$$

$$h_f = \frac{4fLv^2}{d2g}$$

$$f = \frac{16}{Re}$$

$$h_m = \frac{Kv^2}{2g}$$

$$h_m = \frac{k(V_1 - V_2)^2}{2g}$$

$$\zeta = \left(1 - \frac{T_L}{T_H}\right)$$

$$S_{gen} = (S_2 - S_1)) + \frac{Q}{T}$$

$$W = (U_1 - U_2) - T_0(S_1 - S_2) - T_0 S_{gen}$$

$$W_u = W - P_0(V_2 - V_1)$$

$$W_{rev} = (U_1 - U_2) - T_0(S_1 - S_2) + P_0(V_1 - V_2)$$

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$$\Phi = (U - U_0) - T(S - S_0) + Po(V - V_o)$$

$$I = ToS_{gen}$$

$$V = r\omega$$

$$\lambda = \mu \frac{V}{t}$$

$$F = \frac{2\pi L \mu u}{L_n\left(\frac{R_2}{R_1}\right)}$$

$$T = \frac{\pi^2 \mu N}{60t}\left(R_1^4 - R_2^4\right)$$

$$p = \frac{\rho g Q H}{1000}$$

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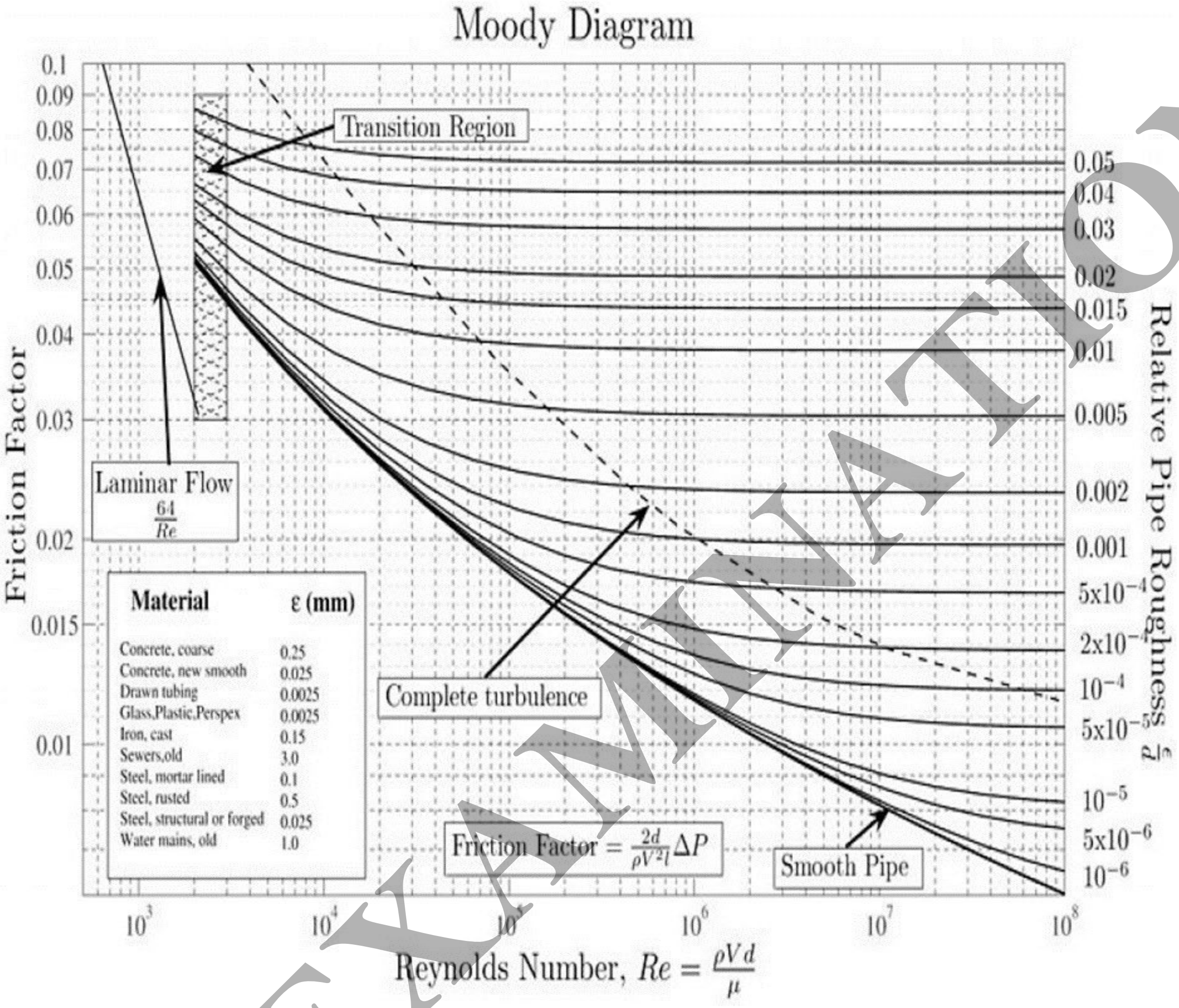

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DIMENSIONS FOR CERTAIN PHYSICAL QUANTITIES

Quantity	Symbol	Dimensions	Quantity	Symbol	Dimensions
Mass	m	M	Mass /Unit Area	m/A ^{2}	ML^{-2}
Length	l	L	Mass moment	ml	ML
Time	t	T	Moment of Inertia	I	ML^2
Temperature	T	θ	-	-	-
Velocity	u	LT^{-1}	Pressure /Stress	p /σ	$ML^{-1}T^{-2}$
Acceleration	a	LT^{-2}	Strain	ε	$M^0L^0T^0$
Momentum/Impulse	mv	MLT^{-1}	Elastic Modulus	E	$ML^{-1}T^{-2}$
Force	F	MLT^{-2}	Flexural Rigidity	EI	ML^3T^{-2}
Energy - Work	W	ML^2T^{-2}	Shear Modulus	G	$ML^{-1}T^{-2}$
Power	P	ML^2T^{-3}	Torsional rigidity	GJ	ML^3T^{-2}
Moment of Force	M	ML^2T^{-2}	Stiffness	k	MT^{-2}
Angular momentum	-	ML^2T^{-1}	Angular stiffness	T/η	ML^2T^{-2}
Angle	η	$M^0L^0T^0$	Flexibility	1/k	$M^{-1}T^2$
Angular Velocity	ω	T^{-1}	Vorticity	-	T^{-1}
Angular acceleration	α	T^{-2}	Circulation	-	L^2T^{-1}
Area	A	L^2	Viscosity	μ	$ML^{-1}T^{-1}$
Volume	V	L^3	Kinematic Viscosity	τ	L^2T^{-1}
First Moment of Area	Ar	L^3	Diffusivity	-	L^2T^{-1}
Second Moment of Area	I	L^4	Friction coefficient	f /μ	$M^0L^0T^0$
Density	ρ	ML^{-3}	Restitution coefficient		$M^0L^0T^0$
Specific heat- Constant Pressure	C_p	$L^2T^{-2}\theta^{-1}$	Specific heat- Constant volume	C_v	$L^2T^{-2}\theta^{-1}$

Note: a is identified as the local sonic velocity, with dimensions $L.T^{-1}$

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