[ESS11]

UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BENG (HONS) MECHANICAL ENGINEERING

SEMESTER ONE EXAMINATION 2019/2020

ADVANCED THERMOFLUIDS AND CONTROL SYSTEMS

MODULE NO: AME6015

Date: Thursday 16th January 2020 **Time: 10:00am – 12:00pm**

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.

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

Candidates Require:

Thermodynamics properties of fluids (provided)

Formula sheet (provided)
Density of water = 1000kg/m^3

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Q1

a) Steam at 7 bar, dryness fraction 0.9 expands reversibly at constant pressure until the temperature is 200 ˚c. Calculate the work input and heat supplied per unit mass of steam during the process.

(15 Marks)

b) Steam at 0.05 bar, 100 ˚c is to be condensed completely by a reversible constant pressure process .Calculate the heat rejected per kilogramme of steam and the change of specific entropy.

(10 Marks)
Total 25 Marks

Q2

a) Derive the Darcy Weisbach Equation $h_f = \frac{f\,LV^2}{2gD}$ for the loss of Head due to friction in a

Pipeline using the Energy equation $\frac{P_1}{\rho g} + Z_1 + \frac{V1^2}{2g} = \frac{P_2}{\rho g} + Z_2 + \frac{V_2^2}{2g} + HL$

Where HL= the friction head loss h_f.

(17 Marks)

b) Oil with specific gravity of 0.85 with kinematic viscosity of 6x10^{-4} m^2/s flows in a 15cm pipe at a rate of 0.020 m^3/s. What is the head loss per 100 m length of pipe?

(8 Marks)
Total 25 Marks

Q3

a) A Prototype gate valve, which will control the flow I a pipe system conveying paraffin, is to be studied in a model. The pressure drop ΔP is expected to depend upon the gate opening h, the overall depth d, the velocity V, density ρ and viscosity μ.Perform dimensional analysis to obtain the relevant non-dimensional groups.

(15 Marks)

b) A Carnot engine is used in a nuclear power plant. It receives 1500 Mw of power as a heat transfer from a source at 327 o c and rejects thermal waste to a nearby river at 27 ˚c. The River temperature rises by 3˚c because of this power rejection by the plant, calculate:

i) The mass flow rate of the river
ii) The efficiency of the power plant

Take the value of specific heat capacity C_p=4.177kJ/kg K

Take $\dot{Q}=\dot{m}(h_2-h_1)$ and $(h_2-h_1) = C_p(T_2-T_1)$ **(10 Marks)**

Total 25 Marks

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Q4 A simplified position control system for an industrial robotic arm is shown in Figure Q4. The system is under a unit step input.

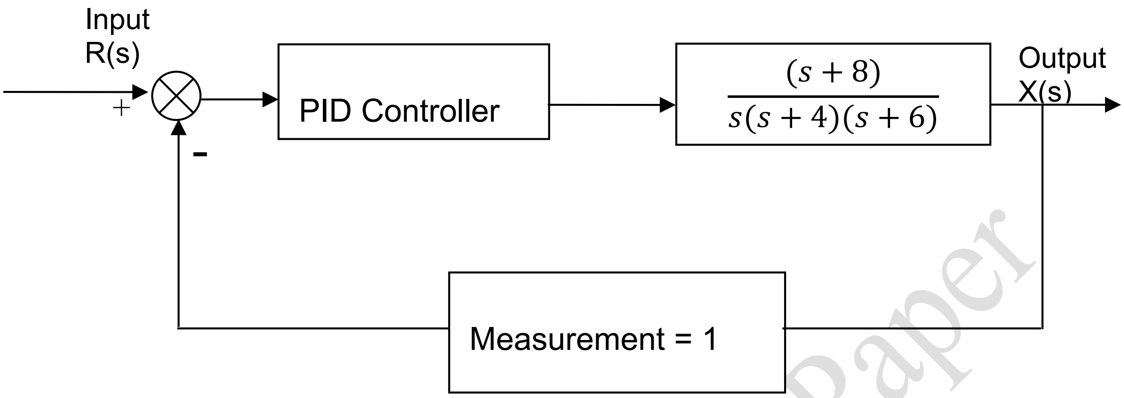

Figure Q4 A simplified position control system

The design criteria for this system are:

Settling time < 2 sec
Overshoot < 5%
Steady state error = 0.1 (for a unit parabolic input = $1/s^3$)

a) Design a PID controller to determine the parameters K_p, K_i, and K_d and clearly identify the design procedure.

(19 Marks)

b) Describe, helped by equations and sketches, how the error item is handled by proportional, integral and derivative controller. **(6 Marks)**

Total 25 Marks

Q5. A translational mechanical system is shown in Figure Q5.

a) Derive the differential equations describing the behaviour of the system.

(6 Marks)

b) Select the state variables and transfer the differential equations obtained from Q5(a) above to the relevant first-order differential equations.

(4 Marks)

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Q5 continued…

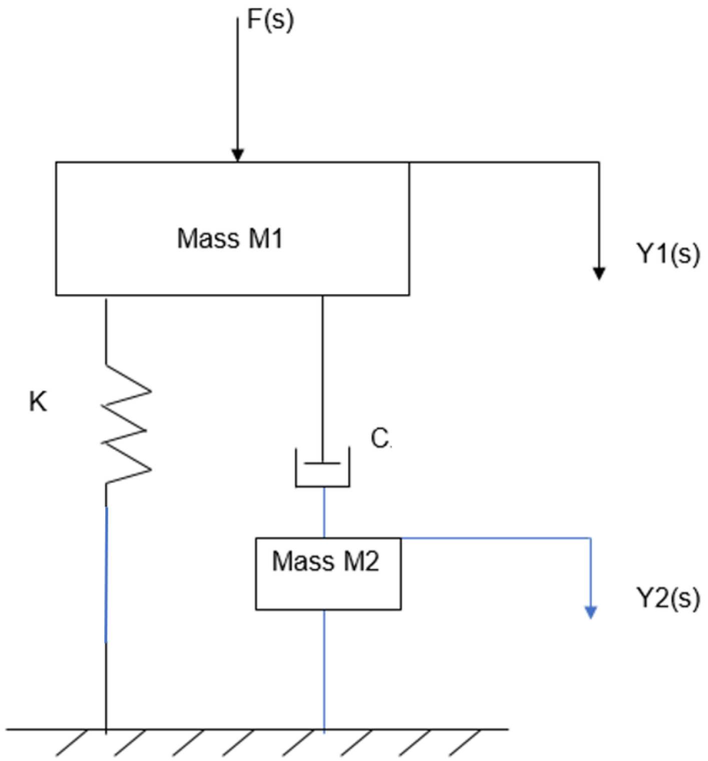

Figure Q5 A Translational Mechanical System

c) Determine the state space equations and system matrices A, B, C and D, where A, B, C, and D have their usual meaning.

(10 marks)

d) Analyse the following system's controllability and observability:

$A = \begin{bmatrix} 3 & -8 \\ 0 & 4 \end{bmatrix}$ $B = \begin{bmatrix} 6 \\ 2 \end{bmatrix}$ $C = \begin{bmatrix} 1 & -5 \end{bmatrix}$

(5 marks)

(Total 25 marks)

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Q6. An automation assembly model is shown in Figure Q6, in which the computer performs the function of controller to control the assembly process.

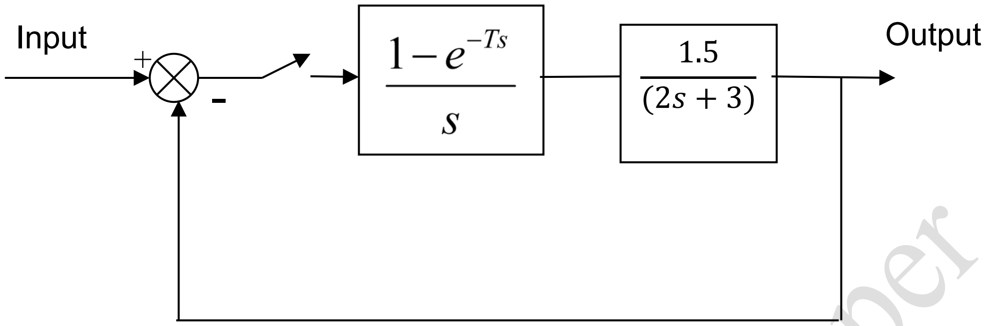

Figure Q6 An automation assembly control system

a) Find the sampled-data transfer function, Gsys(z) = $\frac{Output}{Input}$ for the digital assembly control system . The sampling time, T, is 0.15 seconds.

(10 marks)

b) For a unit step input, find the steady-state error for the control system.

(3 marks)

c) Check the stability of the system. **(4 marks)**

d) If the controller has a 10 bit Analogue to Digital Converter with the signal range between -16 Volt to +16 Volt:

(i) What is the resolution of the AD converter? **(2 marks)**

(ii) What integer number represented a value of 7.5 Volts?

(2 marks)

(iii) What voltage does the integer 350 represent?

(2 marks)

(iv) What voltage does 1011001110 represent?

(2 marks)

Total 25 marks

END OF QUESTIONS

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PLEASE TURN THE PAGE FOR FORMULA SHEETS AND PROPERTY TABLES…

Formula sheet

Blocks with feedback loop

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

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

Steady-State Errors

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

$e_{ss} = \lim_{s\to 0}[s\dfrac{1}{1+\dfrac{G_0(s)}{1+G_0(s)[H(s)-1]}}\theta_i(s)]$ (if the feedback H(s) ≠ 1)

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

Laplace Transforms

A unit impulse function 1

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

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

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)

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

Second-order systems

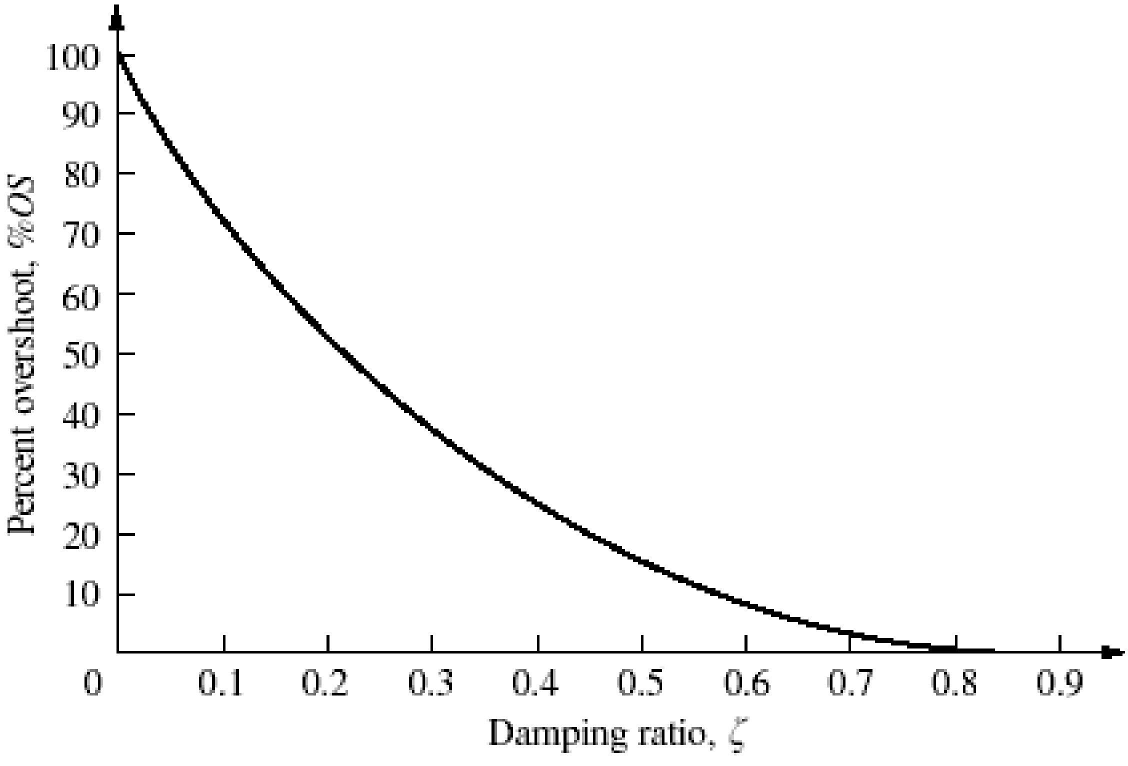
$$\frac{d^2\theta_o}{dt^2} + 2\zeta\omega_n \frac{d\theta_o}{dt} + \omega_n^2\theta_o = b_o\omega_n^2\theta_i$$

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

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

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

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



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

Observability:

$$\mathcal{O} = \begin{bmatrix} C \\ CA \\ CA^2 \\ \vdots \\ CA^{n-1} \end{bmatrix}$$

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Table 4.1 Laplace transforms

Laplace transform	*Time function*	*Description of time function*
1		A unit impulse
$\frac{1}{s}$		A unit step function
$\frac{e^{-sT}}{s}$		A delayed unit step function
$\frac{1-e^{-sT}}{s}$		A rectangular pulse of duration T
$\frac{1}{s^2}$	t	A unit slope ramp function
$\frac{1}{s^3}$	$\frac{t^2}{2}$	
$\frac{1}{s+a}$	e^{-at}	Exponential decay
$\frac{1}{(s+a)^2}$	te^{-at}	
$\frac{2}{(s+a)^3}$	t^2e^{-at}	
$\frac{a}{s(s+a)}$	$1-e^{-at}$	Exponential growth
$\frac{a}{s^2(s+a)}$	$t-\frac{(1-e^{-at})}{a}$	
$\frac{a^2}{s(s+a)^2}$	$1-e^{-at}-ate^{-at}$	
$\frac{s}{(s+a)^2}$	$(1-at)e^{-at}$	
$\frac{1}{(s+a)(s+b)}$	$\frac{e^{-at}-e^{-bt}}{b-a}$	
$\frac{ab}{s(s+a)(s+b)}$	$1-\frac{b}{b-a}e^{-at}+\frac{a}{b-a}e^{-bt}$	
$\frac{1}{(s+a)(s+b)(s+c)}$	$\frac{e^{-at}}{(b-a)(c-a)}+\frac{e^{-bt}}{(c-a)(a-b)}+\frac{e^{-ct}}{(a-c)(b-c)}$	
$\frac{\omega}{s^2+\omega^2}$	$\sin\omega t$	Sine wave
$\frac{s}{s^2+\omega^2}$	$\cos\omega t$	Cosine wave
$\frac{\omega}{(s+a)^2+\omega^2}$	$e^{-at}\sin\omega t$	Damped sine wave
$\frac{s+a}{(s+a)^2+\omega^2}$	$e^{-at}\cos\omega t$	Damped cosine wave
$\frac{\omega^2}{s(s^2+\omega^2)}$	$1-\cos\omega t$	
$\frac{\omega^2}{s^2+2\zeta\omega s+\omega^2}$	$\frac{\omega}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t]$	
$\frac{\omega^2}{s(s^2+2\zeta\omega s+\omega^2)}$ with $\zeta<1$	$1-\frac{1}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t+\phi]$ with $\zeta=\cos\phi$	

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Table 15.1 *z*-transforms

Sampled f(t), sampling period T	$F(z)$
Unit impulse, $\delta(t)$	1
Unit impulse delayed by kT	z^{-k}
Unit step, $u(t)$	$\frac{z}{z-1}$
Unit step delayed by kT	$\frac{z}{z^k(z-1)}$
Unit ramp, t	$\frac{Tz}{(z-1)^2}$
t^2	$\frac{T^2 z(z+1)}{(z-1)^3}$
e^{-at}	$\frac{z}{z-e^{-aT}}$
$1-e^{-at}$	$\frac{z(1-e^{-aT})}{(z-1)(z-e^{-aT})}$
$t\,e^{-at}$	$\frac{Tz\,e^{-aT}}{(z-e^{-aT})^2}$
$e^{-at}-e^{-bt}$	$\frac{(e^{-aT}-e^{-bT})z}{(z-e^{-aT})(z-e^{-bT})}$
$\sin\omega t$	$\frac{z\sin\omega T}{z^2-2z\cos\omega T+1}$
$\cos\omega t$	$\frac{z(z-\cos\omega T)}{z^2-2z\cos\omega T+1}$
$e^{-at}\sin\omega t$	$\frac{z\,e^{-aT}\sin\omega T}{z^2-2z\,e^{-aT}\cos\omega T+e^{-2}}$
$e^{-at}\cos\omega t$	$\frac{z(z-e^{-aT}\cos\omega T)}{z^2-2z\,e^{-aT}\cos\omega T+e^{-2}}$

Table 15.2 *z*-transforms

$f[k]$	$f[0], f[1], f[2], f[3], \ldots$	$F(z)$
$1u[k]$	$1, 1, 1, 1, \ldots$	$\frac{z}{z-1}$
a^k	$a^0, a^1, a^2, a^3, \ldots$	$\frac{z}{z-a}$
k	$0, 1, 2, 3, \ldots$	$\frac{z}{(z-1)^2}$
ka^k	$0, a^1, 2a^2, 3a^3, \ldots$	$\frac{az}{(z-a)^2}$
ka^{k-1}	$0, a^0, 2a^1, 3a^2, \ldots$	$\frac{z^2}{(z-a)^2}$
e^{-ak}	$e^0, e^{-a}, e^{-2a}, e^{-3a}, \ldots$	$\frac{z}{z-e^{-a}}$

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

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

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

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

$$\sum F = \frac{\Delta M}{\Delta t} = \Delta \dot{M}$$

$$F = \rho QV$$

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

$$dQ = du + dw$$

$$du = cu\, dT$$

$$dw = pdv$$

$$pv = mRT$$

$$h = h_f + xhf_g$$

$$s = s_f + xsf_g$$

$$v = x\, Vg$$

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

$$F = \frac{2\pi L\mu}{L_n\left(\frac{R_2}{R_3}\right)}$$

$$ds = \frac{dQ}{T}$$

$$S_2 - S_1 = C_{pL}\ \mathrm{L_n}\frac{T_2}{T_1}$$

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

$$S = C_{pL} \ \mathrm{L_n} \frac{T_f}{273} + \frac{hf_g}{T_f} + C_{pu} \ \mathrm{L_n} \frac{T}{T_f}$$

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

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

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

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

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

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

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

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

$$h_m = \frac{K\mathrm{v}^2}{2g}$$

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

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

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

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

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

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

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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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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	τ	M ^{0}L ^{0}T ^{0}
Momentum/Impulse	mv	MLT $^{-1}$		Elastic Modulus	E	ML $^{-1}$T $^{-2}$
Force	F	MLT $^{-2}$		Flexural Rigidity	EI	ML ^{3}T $^{-2}$
Energy - Work	W	ML ^{2}T $^{-2}$		Shear Modulus	G	ML $^{-1}$T $^{-2}$
Power	P	ML ^{2}T $^{-3}$		Torsional rigidity	GJ	ML ^{3}T $^{-2}$
Moment of Force	M	ML ^{2}T $^{-2}$		Stiffness	k	MT $^{-2}$
Angular momentum	-	ML ^{2}T $^{-1}$		Angular stiffness	T/η	ML ^{2}T $^{-2}$
Angle	η	M ^{0}L ^{0}T ^{0}		Flexibiity	1/k	M $^{-1}$T ^{2}
Angular Velocity	ω	T $^{-1}$		Vorticity	-	T $^{-1}$
Angular acceleration	α	T $^{-2}$		Circulation	-	L ^{2}T $^{-1}$
Area	A	L ^{2}		Viscosity	μ	ML $^{-1}$T $^{-1}$
Volume	V	L ^{3}		Kinematic Viscosity	τ	L ^{2}T $^{-1}$
First Moment of Area	Ar	L ^{3}		Diffusivity	-	L ^{2}T $^{-1}$
Second Moment of Area	I	L ^{4}		Friction coefficient	f /μ	M ^{0}L ^{0}T ^{0}
Density	ρ	ML $^{-3}$		Restitution coefficient		M ^{0}L ^{0}T ^{0}
Specific heat- Constant Pressure	C_p	L ^{2} T $^{-2}$ θ $^{-1}$		Specific heat- Constant volume	C_v	L ^{2} T $^{-2}$ θ $^{-1}$

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

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