UNIVERSITY OF BOLTON

SCHOOL OF ENGINEERING

BEng(Hons) MECHANICAL ENGINEERING

SEMESTER 1 EXAMINATION 2023-24

ADVANCED THERMOFLUIDS AND CONTROL

MODULE NUMBER: AME6015

Date: Friday 12th January 2024 **Time: 10:00 – 12:00**

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.

School of Engineering
BEng(Hons) Mechanical Engineering
Semester 1 Examination 2023_24
Advanced Thermo-fluids and Control
Module No. AME 6015

Question 1

A block diagram for a furnace temperature control system is shown in Figure Q1 below:

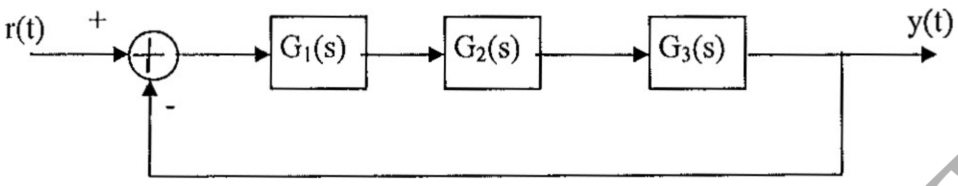


Figure Q1

Where,

$G_1(s) = 8$

$G_2(s) = \frac{2}{s+4}$

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

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]**

Total marks 25 marks

Please turn the page…

Question 2

A block diagram for a digital control system for a steam-turbine speed control is shown below in Figure Q2.

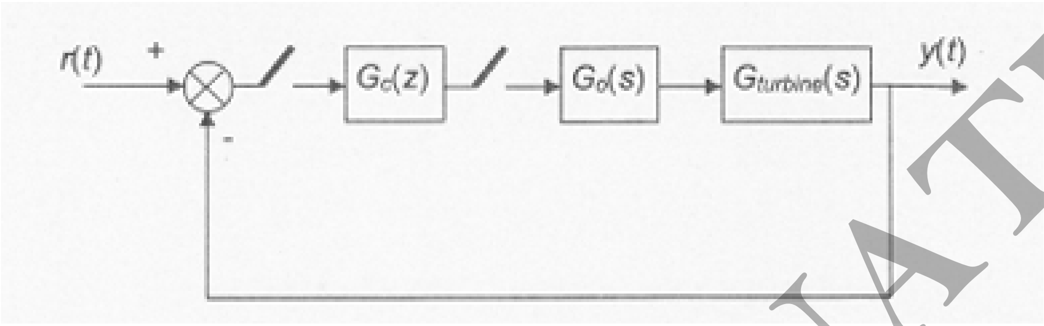


Figure Q2

Where,

The digital controller: G_C = **Kp**

The zero-order-hold: $G_O = \dfrac{1-e^{-sT}}{s}$

The dynamics of the steam-turbine: $G_{Turbine}(s) = \dfrac{0.5}{s+0.5}$

a) Determine the closed-loop z-transfer function for the system.

[12 marks]

b) if the gain of the digital controller Kp = 10, determine the range of the sampling time interval T that will make the closed-loop control system stable.

[6 marks]

c) If the sampling frequency f = 20kHz,determine the range of controller gain Kp that will make the closed-loop system stable.

[7 marks]

Total marks 25 marks

Please turn the page…

School of Engineering
BEng(Hons) Mechanical Engineering
Semester 1 Examination 2023_24
Advanced Thermo-fluids and Control
Module No. AME 6015

Question 3

A dynamic system is shown in the block diagram below, Figure Q3(a),

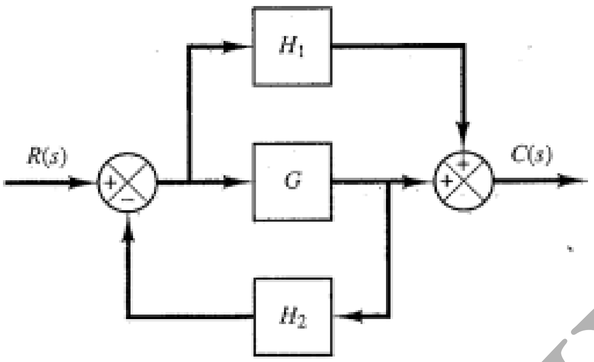


Figure Q3(a)

a) Show how the block diagram in figure Q3(a) could be reduced to describe the output over the input C/R. **[10 marks]**

b) From the Matlab graph shown in Q3(b), shown over the page, estimate the gain and phase margins **[6 marks]**

c) Sketch the magnitude and phase for the following functions.

(i) `$G1(s) = \frac{10}{0.2s+1}$ **[3 marks]**

(ii) $G2(s) = \frac{2500}{S^2 + 80S + 2500}$ **[3 marks]**

(iii) $G3(s) = \frac{8}{S}$ **[2 marks]**

d) Sketch the final result of G1(s)*G2(s)*G(s) and estimate the phase and gain margin. **[7 marks]**

QUESTION 3 CONTINUED OVER THE PAGE…

Please turn the page…

QUESTION 3 CONTINUED…

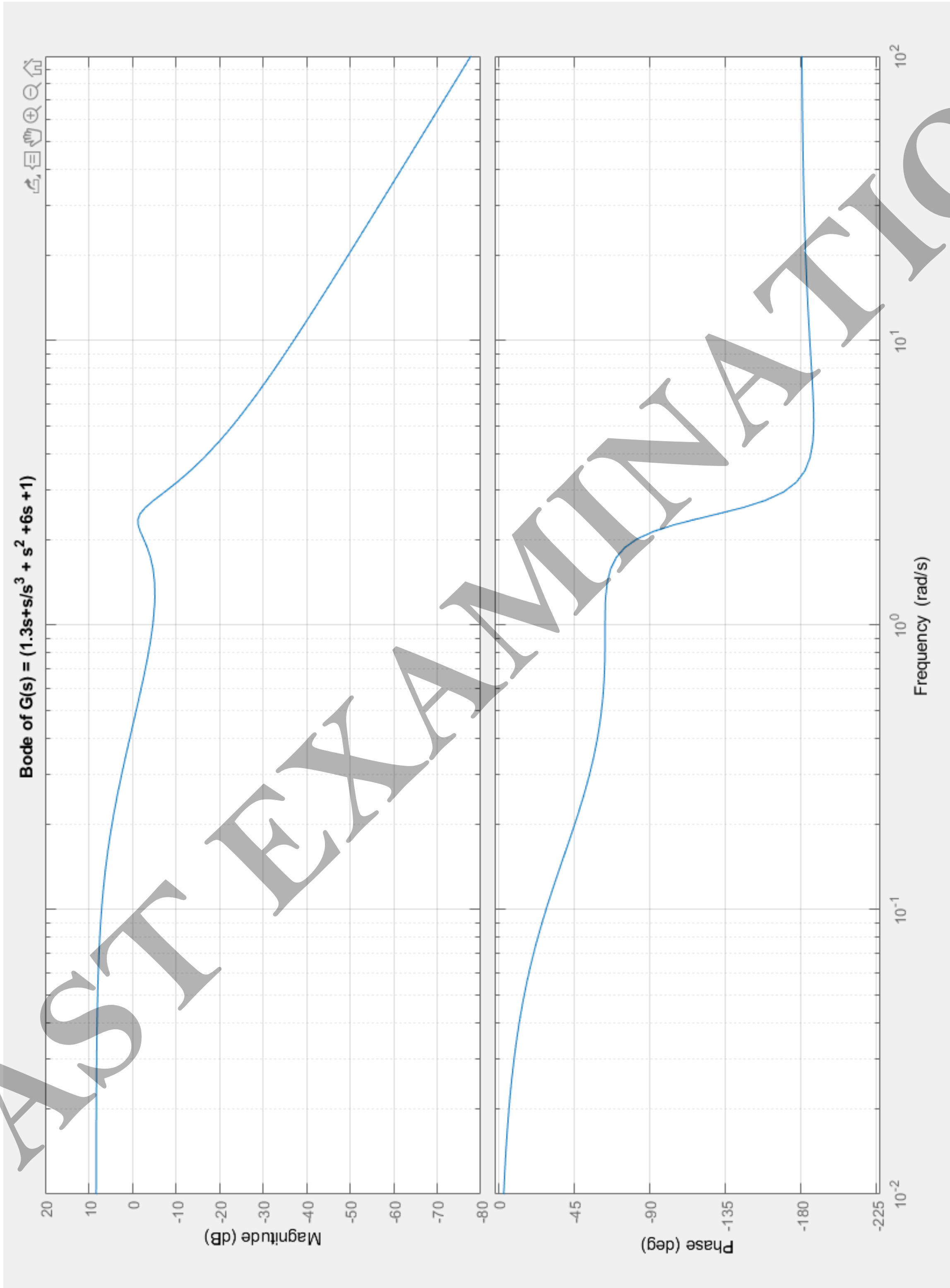


Figure 3(b)

Total marks 25 marks
Please turn the page…

Question 4

a) Describe the three key steps involved in a typical Computational Fluid Dynamics (CFD) simulation.

[4 Marks]

b) Determine the head loss resulting from a flow of 100 litres per second of glycerine at 20° C through a pipe with a length of 100 meters and a diameter of 20 centimetres. The Specific Gravity of Glycerine is 1.26 and Dynamic Viscosity = 0.886 Pa.s.

[6 Marks]

c) Derive the Darcy Weisbach Equation for the loss of Head due to friction in a Pipeline using the Bernoulli's Energy Equation.

[15 Marks]

Total Marks 25 Marks

Question 5

a) Draw a Temperature – Enthalpy diagram for a process of steam formation and label the following: sensible heat region, latent heat region, saturated temperature, saturated liquid, saturated dry vapour and wet steam region.

[6 Marks]

b) Calculate the Enthalpy of steam at the pressure of 10 bar. Take specific heat capacity c_p of superheated steam as 1.85kj/kgC.

i. When dryness fraction x=0.6
ii. When dry saturated
iii. When superheated at 200°C

[6 Marks]

c) A quantity of steam of a pressure of 20 bar and dryness fraction of 0.8 occupies a volume of $0.1551 m^3$. The gas expands according to polytropic process of $pv^{3.5}=c$ to a pressure of 6 bar. Determine:

i. The mass of steam present and Enthalpy when pressure is 20 bar.
ii. The volume, dryness fraction and Enthalpy when pressure is 6 bar.

[13 Marks]

Total marks 25 Marks

Please turn the page…

Question 6

a) The Enthalpy of 2kg of steam at the pressure of 50 bar is 3850kj. Determine the condition and dryness fraction of the steam.

[4 Marks]

b) A reversible engine operates between the temperatures of 2800˚C and 400°C. Draw a p-v diagram of Carnot cycle, illustrating all the processes, and determine and the efficiency of the engine.

[8 Marks]

c) A car engine burns 5kg of fuel (equivalent to addition of Q_H) at 1500K and rejects heat to the exhaust at an average temperature of 750K. If the fuel provides 40,000kj/kg of energy, what is the maximum amount of Work the engine can provide. Assume that the car engine operates according to Carnot cycle.

[13 Marks]

Total marks 25 Marks

END OF QUESTIONS

Formulae sheets follow over the page

Please turn the page…

Formula sheet

Blocks with feedback loop

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

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

Steady-State Errors

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

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

$$e_{ss} = \frac{1}{1+\lim_{z\to 1} G_0(z)} \quad \text{(if a digital system subjects to a unit step input)}$$

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

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

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

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

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

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

Please turn the page…

School of Engineering
BEng(Hons) Mechanical Engineering
Semester 1 Examination 2023_24
Advanced Thermo-fluids and Control
Module No. AME 6015

Second-order systems

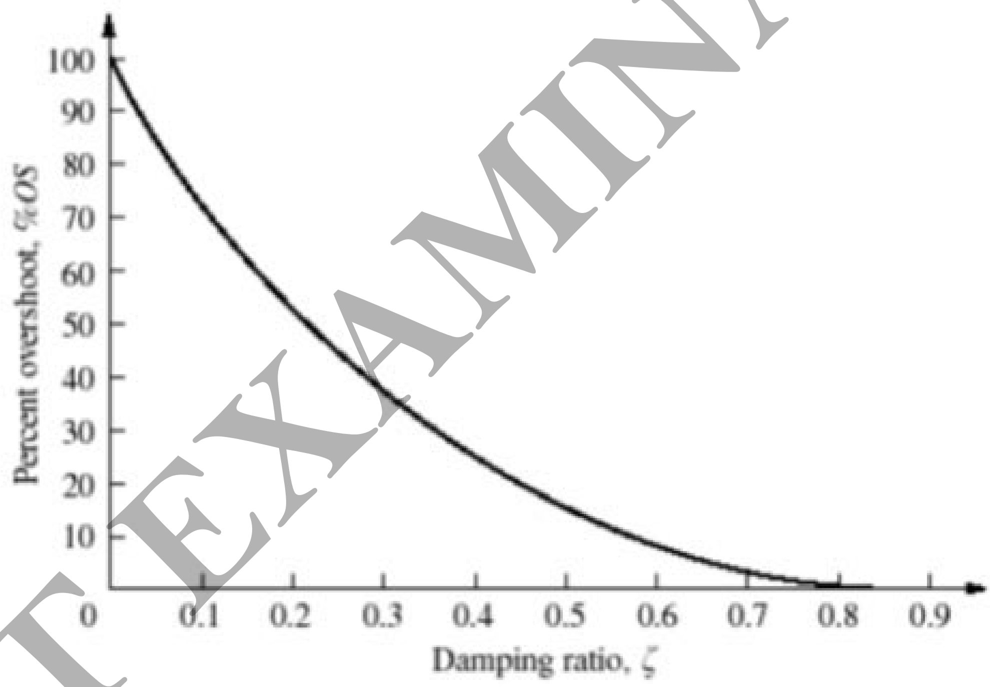
$$\frac{d^2\theta_o}{dt^2} + 2\zeta\omega_n\frac{d\theta_o}{dt} + \omega_n^2\theta_o = b_o\omega_n^2\theta_i$$

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

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

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

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



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

Observability:

Please turn the page…

School of Engineering
BEng(Hons) Mechanical Engineering
Semester 1 Examination 2023_24
Advanced Thermo-fluids and Control
Module No. AME 6015

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}	$\frac{z}{z-e^{-aT}}$
$\frac{1}{s(s+a)}$	$\frac{1}{a}\left(1-e^{-at}\right)$	$\frac{z\left(1-e^{-aT}\right)}{a(z-1)\left(z-e^{-aT}\right)}$
$\frac{b-a}{(s+a)(s+b)}$	$e^{-at}-e^{-bt}$	$\frac{z\left(e^{-aT}-e^{-bT}\right)}{a\left(z-e^{aT}\right)\left(z-e^{-bT}\right)}$
$\frac{b}{(s+a)^2+b^2}$	$e^{-at}\sin(bt)$	$\frac{ze^{-aT}\sin(bT)}{z^2-2ze^{-aT}\cos(bT)+e^{-2aT}}$
$\frac{s+a}{(s+a)^2+b^2}$	$e^{-at}\cos(bt)$	$\frac{z^2-ze^{-aT}\cos(bT)}{z^2-2ze^{-aT}\cos(bT)+e^{-2aT}}$

Please turn the page…

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	$Lf(t-a)$	$e^{-as}F(s)$

School of Engineering
BEng(Hons) Mechanical Engineering
Semester 1 Examination 2023_24
Advanced Thermo-fluids and Control
Module No. AME 6015

Thermofluids Formula Sheet

$$\lambda = \frac{64}{Re}$$

$$H_f = \frac{\lambda L v^2}{2gd}$$

$$Re = \frac{\rho v d}{\mu}$$

$$Q = VA$$

$$SPG = \frac{\rho_{fluid}}{\rho_{water}}$$

$$\rho_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = \rho_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 + h_f$$

$$h = h_f + h_{fg}$$

$$h_{sup} = h_g + c_p(T_{sup} - T_s)$$

$$pv^n = c$$

$$mass = \frac{volume}{speafic\ volume}$$

$$v = xv_g$$

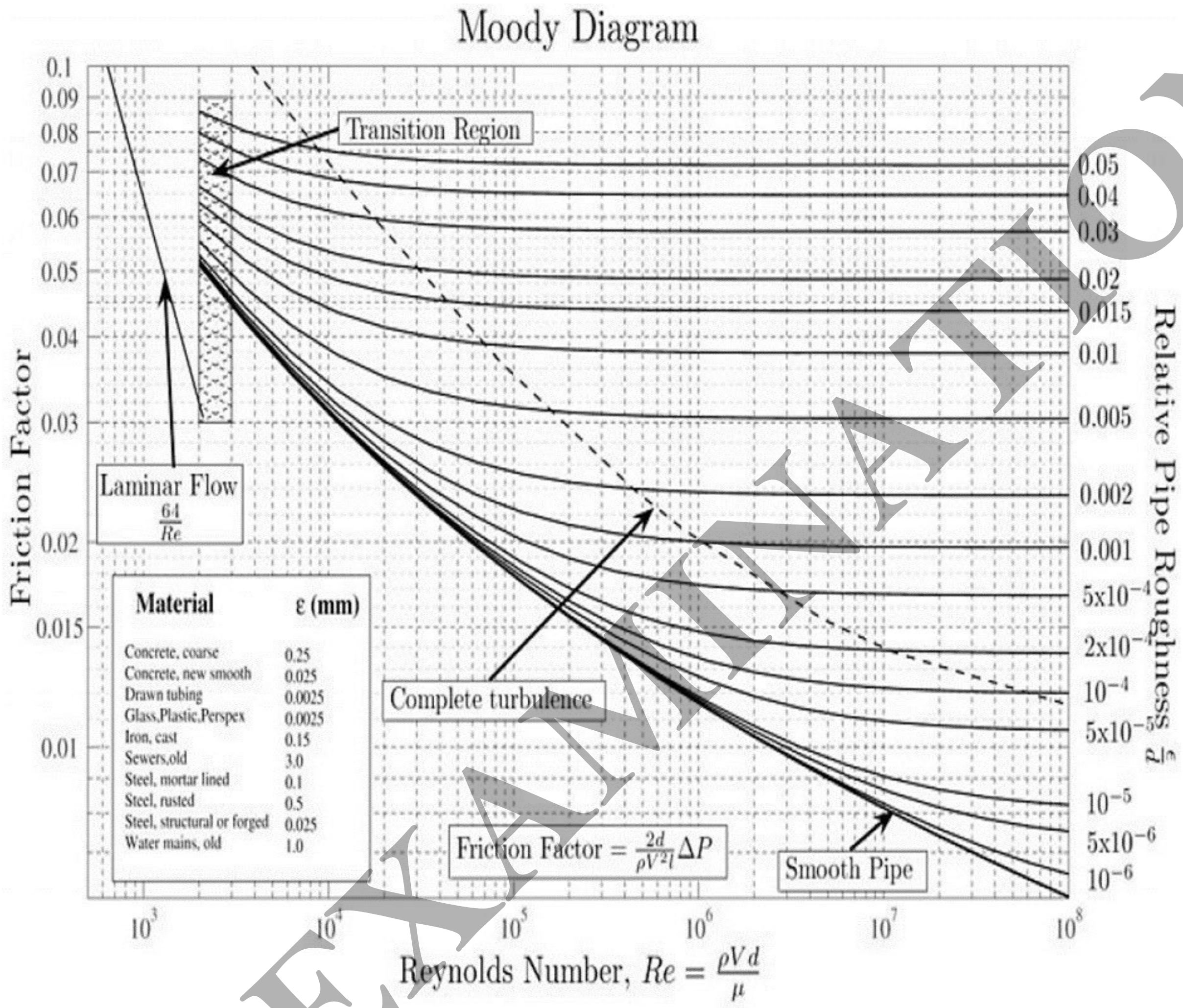
$$Specific\ Enthalpy = \frac{Actual\ Enthalpy}{mass}$$

$$Efficicncy = \frac{Output}{Input}$$

$$\eta_c = 1 - \frac{T_L}{T_H}$$

Please turn the page…

School of Engineering
BEng(Hons) Mechanical Engineering
Semester 1 Examination 2023_24
Advanced Thermo-fluids and Control
Module No. AME 6015



Please turn the page…

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	$M^0L^0T^0$
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	$M^0L^0T^0$	Flexibilty	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 $L.T^{-1}$

END OF PAPER