ENG78

UNIVERSITY OF GREATER MANCHESTER

SCHOOL OF ENGINEERING

BEng(Hons) MECHANICAL ENGINEERING

SEMESTER TWO EXAMINATION 2024/25

ADVANCED THEMOFLUID & CONTROL SYSTEMS

MODULE NO: AME5013

Date: Wednesday 14th May 2025 **Time: 10:00 – 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.

QUESTION 1

a) Imagine you are driving a car equipped with adaptive cruise control. This system automatically adjusts the vehicle's speed to maintain a safe distance from the car ahead. It uses sensors to measure the distance and adjusts the throttle or applies the brakes as needed.

I. State three advantages and two disadvantages of closed-loop control systems, using the adaptive cruise control as a reference.

[5 Marks]

b) Imagine you turn on the air conditioning (AC) in a room on a hot day. The AC system aims to bring the room temperature down to the set value (e.g., 22°C). Initially, the temperature decreases rapidly but fluctuates before settling at the desired level. Discuss the difference between the transient and steady state responses of the system responses.

[4 Marks]

c) Define the following as it applies to control system architecture.

I. Proper system
II. Transient response
III. Transfer function

[6 Marks]

d) The impulse response of a 1st order system is given below as

$$\mathbf{c(t) = 2\,e^{-0.1t},\ t \geq 0}$$

Find

I. Time constant, τ
II. D.C Gain, K
III. Transfer function, G(s)

[10 Marks]

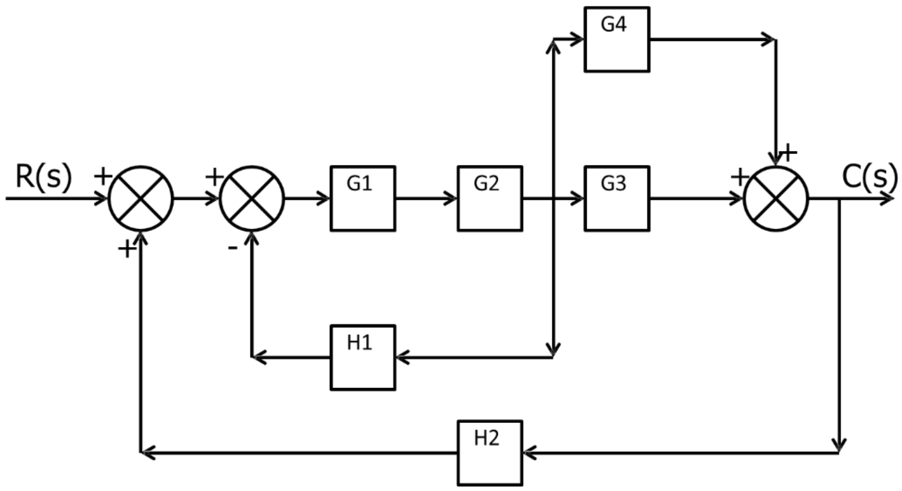
Total 25 marks

QUESTION 2

a) Imagine you are using a thermostat-controlled heating system in your home. The system aims to maintain a constant room temperature by automatically turning the heater on or off based on the current temperature. Describe the fundamental components of a closed loop control system and explain the role of each component in maintaining the desired room temperature.

[7 marks]

b) Simplify the block diagram below and write out the effective transfer function.



[10 Marks]

c) The speed control system of a car has the following transfer function below.

$$T(s) = \frac{2s + 5}{s^2 + 4s + 5 + K_c}$$

- What is the order of this system?
- Hence, find the values of controller gain Kc that make the feedback control system of the following transfer function stable.

[8 Marks]

Total 25 marks

QUESTION 3

a) Discuss the difference between open-loop and closed-loop control systems in terms of stability and explain how feedback in a closed-loop system affects its stability?

[6 Marks]

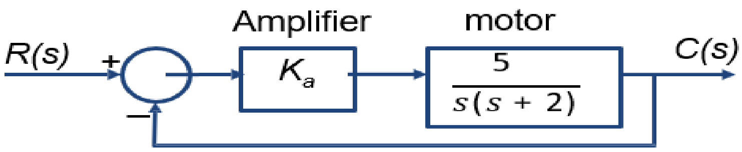
b) State Consider a closed-loop control system with a transfer function G(s) given by:

$$G(s) = \frac{3}{8s + 12}$$

I. Determine the steady-state error when the system is subjected to a unit step input (r(t)=1).

[9 Marks]

c) Servomotor is used to control the position of plotter pen as in the following figure, where damping ratio, ζ= 0.8. Determine



Find the following

I. Peak time, Tp

II. %OS,

III. Settling time, Ts

IV. Rise time, Tr

V. State the nature of the damping in this system.

[10 Marks]

Total 25 marks
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QUESTION 4

a) You are part of an aerospace engineering team designing a new commercial airliner. As you review the aircraft's instrumentation, you focus on the Pitot tube, which is used to determine airspeed by measuring pressures in the freestream airflow. Using Bernoulli's principle for subsonic flow, derive the formula for the aircraft's velocity (V) in terms of the total (stagnation) pressure (P_t), the static pressure (P_s), and the air density ρ. Include a simple, labelled schematic of the Pitot tube installation on an aircraft and briefly explain how Pitot tubes are employed in the aerospace industry for airspeed measurement, highlighting any practical considerations (such as probe heating and correct placement).

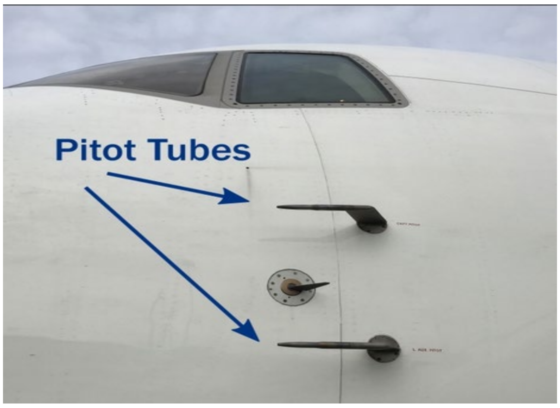

Figure 4 Pitot tube

[18 Marks]

b) You have been assigned to evaluate a new aircraft design using Computational Fluid Dynamics (CFD). In your answer, describe your overall approach from the moment you receive the design specifications to the point at which you interpret the final simulation data emphasising how you would accurately assess aerodynamic parameters such as lift, drag, velocity distributions, and pressure profiles under the aircraft's intended flight conditions.

[7 Marks]

Total 25 marks

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QUESTION 5

You are working as a mechanical engineer responsible for evaluating the performance of a water pipeline within an industrial plant. To measure the pressure difference between two key points, A and B, located along the pipeline, a U-tube manometer is installed as illustrated in the provided **Figure 5**. The pipeline conveys water with a density of 1000 kg/m^3, and the manometer utilises a liquid (Q) with a density of 13,600 kg/m^3. Point B is positioned 0.3 m vertically above point A. During an inspection, you observe that the vertical difference (h) in levels of the manometric fluid is 0.7 m.

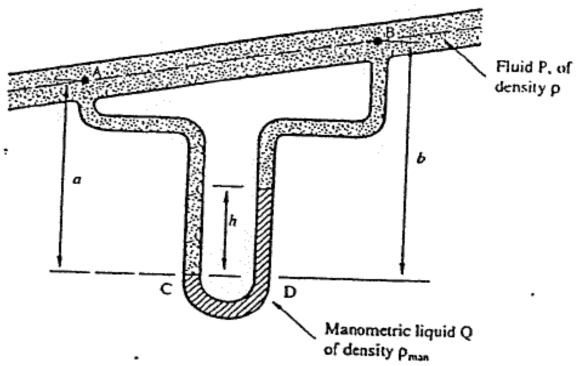

Figure 5 Manometer filled with Mercury

a) Using this diagram, derive an expression for the pressure difference ($P_A - P_B$) between two points.

[10 Marks]

b) Substitute the numerical values to determine ($P_A - P_B$) in Pascals.

[5 Marks]

c) Explain briefly how the differences in fluid column heights translate to the pressure difference between points A and B, noting any assumptions you make regarding fluid continuity and static equilibrium.

[10 Marks]

Total 25 marks
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QUESTION 6

a) Consider a water tank of considerable height h, completely filled with water. The tank is open to atmospheric pressure at the top, and there is a leakage hole at its base (at height h=0), which is also open to the atmosphere. Derive a mathematical relationship between the given parameters to determine the velocity of fluid flowing out of this leakage hole. Assume that fluid velocity at the outlet is the primary parameter of interest. Clearly state any assumptions and apply relevant principles of fluid mechanics in deriving your expression.

Figure 5 Leakage in water tank

[17 Marks]

b) You are part of a design team evaluating the aerodynamic performance of a new aircraft wing. In this context, explain how variations in the angle of attack influence both the lift coefficient and drag coefficient, and discuss why this relationship is critical for determining the wing's overall aerodynamic efficiency and operational flight envelope.

[8 Marks]

Total 25 marks

END OF QUESTIONS

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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

$e_{ss} = \lim_{s\to 0}[s(1-G_O(s))\theta_i(s)]$ (for an open-loop system)

$e_{ss} = \lim_{s\to 0}[s\dfrac{1}{1+G_o(s)}\theta_i(s)]$ (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)

$e_{ss} = \lim_{s\to 0}[-s\cdot\dfrac{G_2(s)}{1+G_2(s)G_1(s)}\cdot\theta_d]$ (if the system subjects to a disturbance input)

$$\frac{bo}{(s^2+a1s+ao)}$$

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

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

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

$\theta_O=G_{ss}(1-e^{-t/\tau})$ (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)

Second-order systems

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

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

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

The transient response has four distinct part identifiable

(a) Rise time, $T_r = \frac{\pi-\theta}{\omega_n\sqrt{1-\varsigma^2}}$

(b) Peak time, $T_p = \frac{\pi}{\omega_n\sqrt{1-\varsigma^2}}$

(c) Percentage maximum overshoot, %MP = $e^{-(\varsigma\pi/\sqrt{1-\varsigma^2})}$ x 100%

(d) Settling time (2% error), $T_s = \frac{4}{\varsigma\omega_n}$

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- Output of the first order system with a unit impulse input is

$$c(t) = K(\frac{1}{\tau})e^{-(t/\tau)}$$

$$c(t) = K(1 - e^{-t/\tau}), t \geq 0$$

- Output of the first order system with a unit ramp input is

$$c(t) = K[1 - e^{-(t/\tau)}]$$

$$G(s) = \frac{C(s)}{R(s)} = \boxed{\frac{K}{\tau s + 1}}$$

Steady state

$$e_{ss} = \lim_{t\to\infty} e(t) = \lim_{s\to 0} sE(s)$$

$$E(s) = \frac{1}{1 + G(s)} R(s)$$

$$E(s) = R(s) - C(s)$$

$$e_{ss} = \lim_{s\to 0} \frac{sR(s)}{1 + G(s)}$$

According the value of ζ, a second-order system can be set into one of the four categories:
Overdamped - when the system has two real distinct poles ($\zeta > 1$).
Underdamped - when the system has two complex conjugate poles ($0 < \zeta < 1$).
Undamped - when the system has two imaginary poles ($\zeta = 0$).
Critically damped - when the system has two real but equal poles ($\zeta = 1$).

Laplace of higher derivatives

$$\mathrm{L}\{f'(t)\} = sF(s) - f(0)$$

$$\mathrm{L}\{f''(t)\} = s^2F(s) - sf(0) - f'(0)$$

$$\mathrm{L}\{f'''(t)\} = s^3F(s) - s^2f(0) - sf'(0) - f''(0)$$

Therefore in general:

$$\mathrm{L}\{f^n(t)\} = s^n\mathrm{L}\{f(t)\} - s^{n-1}f(0) - s^{n-2}f'(0) - \ldots - f^{n-1}(0)$$

where $f(0)$ is value of $f(t)$ @ $t = 0$, $f'(0)$ is value of $f'(t)$ @ $t = 0$

T.F.= $\dfrac{C(s)}{R(s)} = \dfrac{G(s)}{1 + G(s).\mathrm{H}(s)}$

	$f(t)$	$\mathcal{L}(f)$		$f(t)$	$\mathcal{L}(f)$
1	1	$1/s$	7	$\cos \omega t$	$\frac{s}{s^2 + \omega^2}$
2	t	$1/s^2$	8	$\sin \omega t$	$\frac{\omega}{s^2 + \omega^2}$
3	t^2	$2!/s^3$	9	$\cosh at$	$\frac{s}{s^2 - a^2}$
4	t^n $(n = 0, 1, \cdots)$	$\frac{n!}{s^{n+1}}$	10	$\sinh at$	$\frac{a}{s^2 - a^2}$
5	t^a (a positive)	$\frac{\Gamma(a + 1)}{s^{a+1}}$	11	$e^{at} \cos \omega t$	$\frac{s - a}{(s - a)^2 + \omega^2}$
6	e^{at}	$\frac{1}{s - a}$	12	$e^{at} \sin \omega t$	$\frac{\omega}{(s - a)^2 + \omega^2}$

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