ENG76

UNIVERSITY OF GREATER MANCHESTER

SCHOOL OF ENGINEERING

MSC MECHANICAL ENGINEERING / ELECTRICAL AND ELECTRONIC ENGINEERING / BIOMEDICAL ENGINEERING / ROBOTICS

SEMESTER TWO EXAMINATION 2024-25

ADVANCED ENGINEERING MODELLING AND ANALYSIS

MODULE NO: MSE7012/MSE7002

Date: Friday 16th May 2025 **Time: 14:00 – 17:00**

INSTRUCTIONS TO CANDIDATES:

There are FIVE 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

You are tasked with selecting a material for the wing of a medical delivery drone, say Zipline P2 drone **(see Figure Q1)**, which must support structural loads while integrating electronic and biomedical systems. The drone, used for emergency medical supply transport, experiences aerodynamic forces modelled as a uniformly distributed load (UDL). The wing is simplified as a cantilever beam with fixed length L and fixed-width b, while thickness h may vary.

The material must be lightweight, strong, and compatible with embedded sensors, actuators, and medical safety requirements.

Address the following:

a) **i.** Clearly state and justify the function and objectives of the wing material in the context of drone application.

[3 Marks]

ii. Identify and discuss the constraints relevant to this material selection problem.

[4 Marks]

iii. List the free variables associated with this problem, and briefly explain their significance.

[3 Marks]

iv. Derive the material performance index for this application based on the stated function, objectives, and constraints.

[5 Marks]

b) Using the derived material performance index, critically discuss ways the performance of the drone wing could be improved by modifying or optimising specific material properties.

[5 Marks]

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QUESTION 1 CONTINUES HERE

c) Based on your derived material performance index, select the most suitable material from the provided list in **Table Q1**. Justify your choice clearly, highlighting key properties relevant to the drone's operational requirements.

[5 Marks]

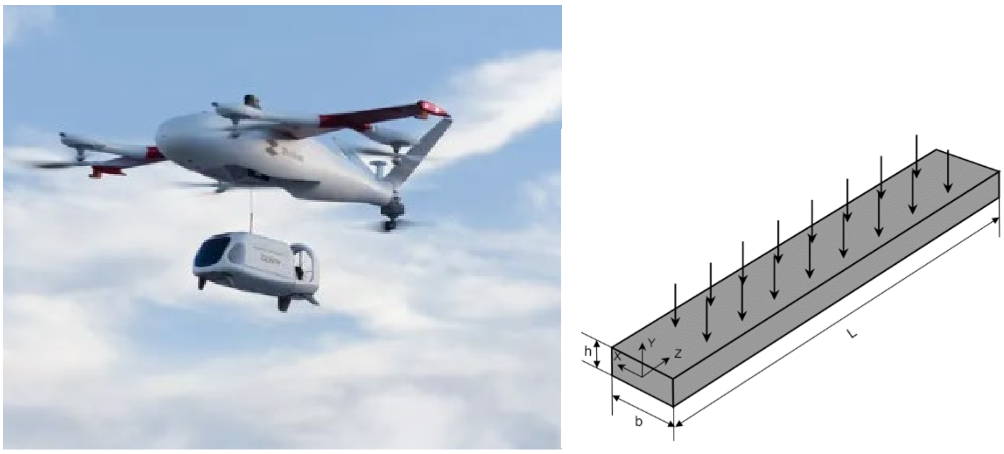

Figure Q1: (Left) Zipline P2 drone and (Right) Wing simplified as a rectangular beam.

Table Q1: Properties of materials for the aircraft wing model.

Material	Density (kg/m^3)	Young's modulus (GPa)	Strength (MPa)	Cost per kg (£)
Aluminium	2800	69	90	0.55
Wood	1600	10	50	0.05
Steel alloy	8550	190	450	2.0
Carbon Fibre Composite	1650	130	3550	20
Glass Fibre Composite	2540	72	3320	2.1

[Total: 25 Marks]

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QUESTION 2

Efficient thermal management is critical for maintaining optimal performance in high-powered electronic devices such as microprocessors. Consider an aluminium heat sink equipped with cylindrical fins **(see Figure Q2)** designed to dissipate heat from a microchip.

The base of the aluminium heat sink is maintained at a uniform temperature of 250°C. The temperature at the fin base (z = 0 mm) is held at 50°C, while the temperature at the fin tip (z = 10 mm) is 30°C. Assume the fin is cylindrical with a uniform cross-section. The thermal conductivity of aluminium is 160 W/(m·K).

Perform the following analyses:

(a) **i.** starting from fundamental principles of conduction heat transfer, derive the differential equation governing the temperature distribution along the cylindrical fin length. Clearly state and justify all assumptions made in the derivation.

[5 Marks]

ii. Solve the differential equation analytically to obtain an expression for the temperature distribution, T(z), along the fin length (0 ≤ z ≤ 10 mm).

[5 Marks]

iii. Using your derived expression, calculate the temperatures at positions z = 2 mm, 4 mm, 6 mm, and 8 mm along the fin. Provide detailed calculations and discuss how temperature variation along the fin influences heat dissipation effectiveness.

[5 Marks]

(b) Plot the analytical temperature distribution T(z) across the entire fin length (0 ≤ z ≤ 10 mm). Clearly annotate your graph to illustrate key temperature values and trends. Critically analyse the shape of your temperature distribution curve and discuss its physical significance in the context of fin efficiency and effectiveness.

[5 Marks]

(c) Using your derived analytical expression, calculate the heat flux (Q_z) at z = 0 mm (base of the fin) and discuss its physical meaning. Provide detailed calculations and interpret the relevance of this value in terms of thermal management performance for high-performance electronic devices.

[5 Marks]

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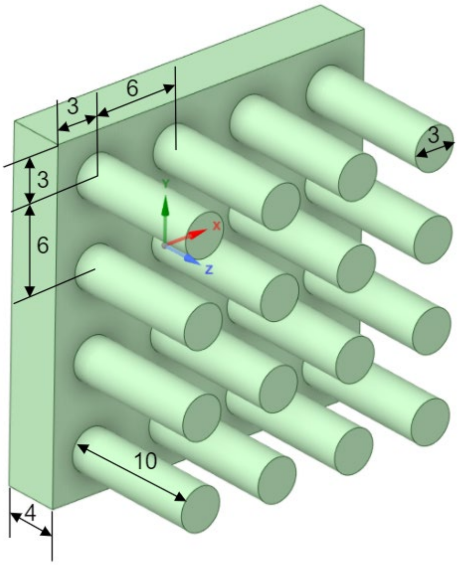

Figure Q2: Cylindrical fin schematic showing relevant temperature boundary conditions (z-axis aligned along fin length).

[Total: 25 Marks]

QUESTION 3

You are appointed to select the material for overhead electric transmission cables. The area of circular cross-section of the cable is A, and it should be installed on support towers separated by a length of L as shown in **Figure Q3**. The material needs to be selected such that the cable is light and experiences minimum deflection (**light and stiff**) against wind loads. The wind load can be approximated as a uniformly distributed load on the cable.

Address the following tasks:

a) **i.** Clearly define the primary function and objectives of the cable material in the given context.

[3 Marks]

ii. Identify and discuss the relevant constraints for this material selection scenario.

[4 Marks]

iii. List and briefly discuss the free variables involved in this selection problem.

[3 Marks]

iv. Derive the material performance index based on the identified function, objectives, and constraints.

[5 Marks]

b) Critically discuss how the cable's performance could be improved by adjusting specific material properties identified in your derived performance index.

[5 Marks]

c) Using your derived material performance index, select the optimal material from the options provided in **Table Q3**. Clearly justify your choice based on key properties essential for the transmission cable's operational requirements.

[5 Marks]

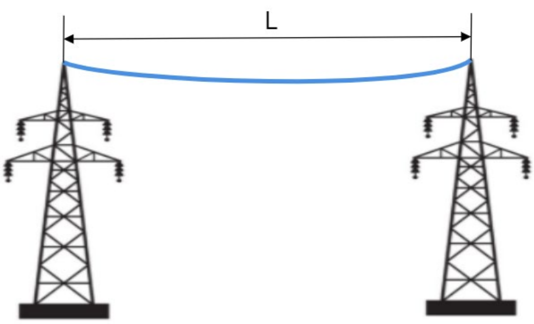

Figure Q3: Electric cable supported by two towers.

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Table Q3: Properties of materials for the electric cable.

Material	Density (kg/m3)	Conductivity (10E6) (Siemens/m)	Strength (MPa)	Young's modulus (GPa)
Silver	10600	62.1	140	90
Stainless steel	7800	1.32	505	180
Aluminium	2800	36.9	90	75
Copper	8800	58.6	210	130
Brass	8600	15.9	360	120
Bronze	8900	7.4	125	72

[Total: 25 Marks]

QUESTION 4

Consider a robotic gripper finger structurally modelled as a cantilever beam, fixed at one end, as illustrated in the schematic of a ROBOTIC parallel gripper provided **(see Figure Q4)**. The gripper finger is subjected to a uniformly distributed load (UDL) in the negative Y-direction while performing precise grasping tasks involving sensitive biomedical or electronic components. The mechanical properties of the gripper material include a Young's modulus of E = 4 MPa and Poisson's ratio v = 0.42, indicating compliance suitable for delicate handling operations. Accurate understanding of deformation under various load conditions **(provided in Table Q4)** is crucial for optimising gripping mechanisms, ensuring mechanical integrity, enhancing gripping effectiveness, and preventing damage to delicate objects.

Address the following tasks:

a) **i.** Clearly state and justify the assumptions involved when using analytical beam theory to model this scenario.

[3 Marks]

ii. Derive the analytical expression to compute the displacements at the free end of the cantilever beam under the given distributed loads.

[5 Marks]

iii. Using the derived analytical expression, calculate the displacement at the free end of the gripper finger for each UDL magnitude listed in **Table Q4**. Clearly demonstrate your calculations.

[7 Marks]

b) Calculate the percentage errors between your analytically computed displacement values and the experimentally measured values provided in **Table Q4**. Clearly present your calculations and discuss briefly.

[5 Marks]

c) Determine an approximate threshold value of UDL beyond which the displacement error computed using analytical expressions exceeds 10%. Discuss the significance of this threshold with respect to robotic gripping applications.

[5 Marks]

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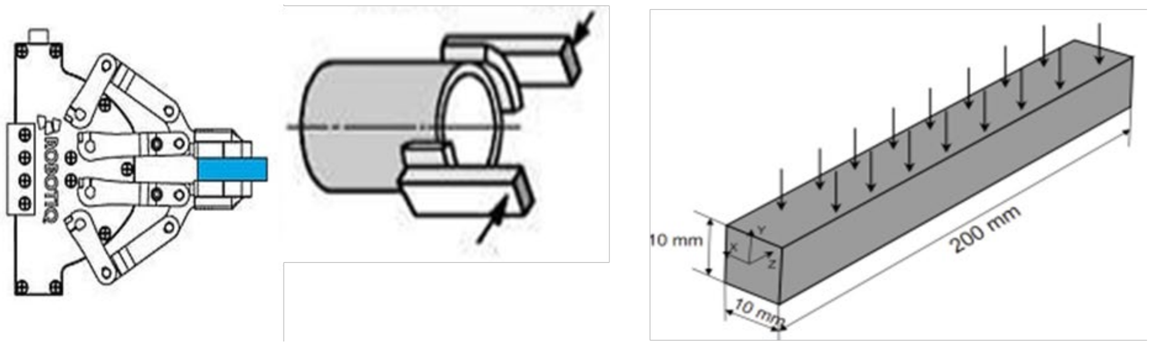

Figure Q4: ROBOTIC parallel gripper schematic and beam dimensions.

Table Q4: Displacement at varying UDL magnitudes.

UDL (N/m)	Displacement (mm)
0.2	11.9
0.4	23.2
0.8	43.1
1.2	50.2
1.6	55

[Total: 25 Marks]

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QUESTION 5

You have been tasked with selecting an optimal material for a prosthetic leg, specifically an Osseo-integrated Prosthesis for the Rehabilitation of Amputees (OPRA) implant. Structurally, the implant can be modelled as a cylindrical tie subjected predominantly to axial loading during typical physiological activities such as walking, running, and other dynamic loading scenarios. **Figure Q5** illustrates the cylindrical tie subjected to axial loading via equal and opposite forces (F). The cylinder, characterized by fixed length (L) and free diameter (d), experiences axial extension due to these forces. The selected material must offer optimal strength-to-weight (**Light and Strong**) Recharacteristics suitable for human implantation and activity.

Address the following tasks:

a) **i.** Clearly define and justify the primary function and objectives of the OPRA implant material.

[3 Marks]

ii. Identify and discuss the constraints relevant to selecting materials for this prosthetic application.

[4 Marks]

iii. List and briefly discuss the free variables involved in this selection scenario.

[3 Marks]

iv. Derive the material performance index based on the defined function, objectives, and constraints.

[5 Marks]

b) Critically discuss how the performance of the OPRA implant could be improved by optimizing specific material properties identified from your derived material performance index.

[5 Marks]

c) Using the derived material performance index, select the most suitable material from the list provided in **Table Q5** . Clearly justify your choice based on key properties essential for the prosthetic implant's operational and physiological requirements.

[5 Marks]

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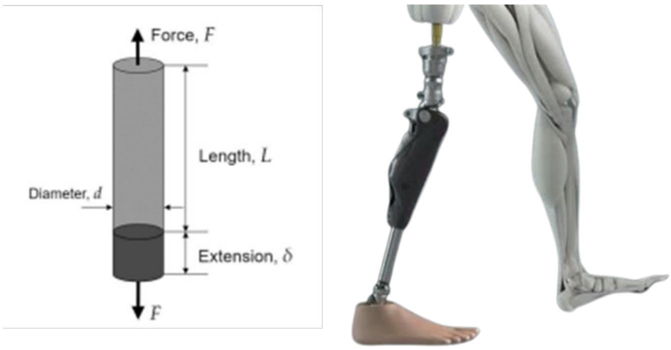

Figure Q5: Osseo-integrated Prostheses for the Rehabilitation of Amputees implant.

Table Q5: Properties of materials for the OPRA implant

Material	**Density (kg/m^3)**	**Young's modulus (GPa)**	**Strength (MPa)**
Titanium Grade 3	4321	121	237
Aluminium Alloy	2345	79	270
Steel alloy	8550	190	450
Carbon Fibre Composite	1650	130	3550
Glass Fibre Composite	2540	72	3320

[Total: 25 Marks]

<u>END OF QUESTIONS</u>

Formula Sheet Follows on Next Page

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FORMULAE SHEET

1. Heat transfer

Assumption is that the bar is oriented such that its axis is along the Z-axis. The heat is flowing from high temperature end to low temperature end.

The analytical solution for temperature distribution is given by,

$$T(z) = T_1 + \frac{T_2 - T_1}{L} * z \qquad {}^0C$$

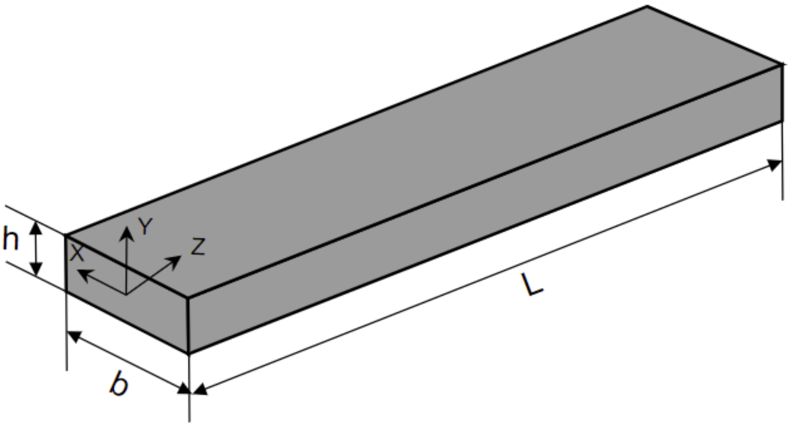
where, T_1 and T_2 are the temperatures at one end $(z = 0)$ and other end $(z = L)$ of the bar and $T_1 > T_2$.

The expression for heat flux is given by,

$$\text{Heat flux} = -k * \frac{dT}{dz}$$

$$\text{Heat flux} = -\text{heat transfer coefficient} * \frac{\text{temperature difference}}{\text{length of the bar}}$$

2. Section properties



Area, $A = bh$ and Area moment of inertia, $\mathrm{I} = \frac{b\,h^3}{12}$

Perpendicular distance from the top/bottom surface to the centroid, $\mathrm{y} = \frac{h}{2}$

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3. Equations for the simply supported beam

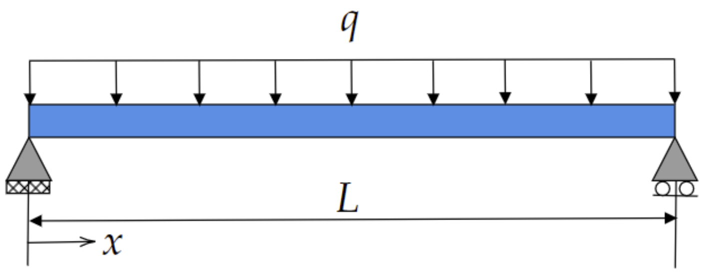

Figure: Simply-supported beam configuration.

Maximum displacement (at $x = L/2$), $\delta_{max} = \frac{5\,q\,L^4}{384\,E\,I}$

Maximum moment at $x = L/2$, $M_{max} = \frac{q\,L^2}{8}$

Maximum stress at $x = L/2$, $\sigma_{max} = \frac{M_{max} \cdot y}{I}$

4. Equations for the clamped-clamped beam

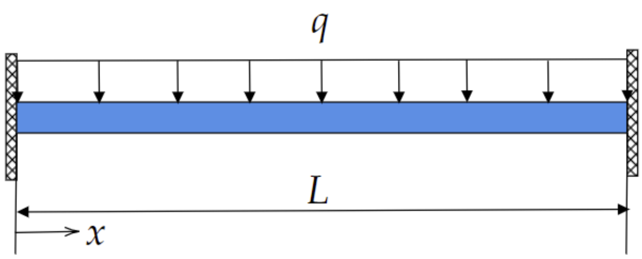

Figure: Clamped-clamped beam configuration.

Maximum displacement (at $x = L$), $\delta_{max} = \frac{q\,L^4}{384\,E\,I}$

Maximum moment at $x = 0$, $M_{max} = \frac{q\,L^2}{12}$

Maximum stress at $x = 0$, $\sigma_{max} = \frac{M_{max} \cdot y}{I}$

5. Equations for the cantilever beam

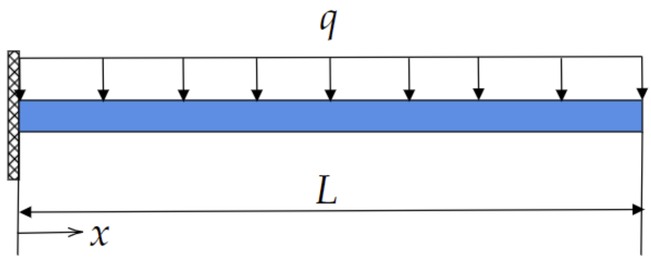

Figure: Cantilever beam configuration.

Maximum displacement (at $x = L$), $\delta_{max} = \frac{q\,L^4}{8\,E\,I}$

Maximum moment at $x = L$, $M_{max} = \frac{q\,L^2}{2}$

Maximum stress at $x = L$, $\sigma_{max} = \frac{M_{max} \cdot y}{I}$

6. Equations for the Neo-Hookean hyperelastic material model

From the Young's modulus, E, and Poisson's ratio, ν, the initial shear modulus (μ) and the incompressibility parameter (D_1) for the Neo-Hookean model are computed as:

Shear modulus, $\mu = G = \frac{E}{2(1+\nu)}$

Bulk modulus, $\kappa = \frac{E}{3(1-2\nu)}$

Incompressibility parameter, $D_1 = \frac{2}{\kappa}$

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