Version CD/6

EGT1

ENGINEERING TRIPOS PART IB

Wednesday 14 June 2023 09.00 to 11.40

09.00 to 10.40 Foreign Language Option

Or Civil Engineering Option

09.00 to 09.40 Foreign Language Option

And Civil Engineering Option

Paper 8

SELECTED TOPICS

*Answer **all** questions from section A. In addition:*
*If you are taking the Civil Engineering option **AND** the Foreign Language option, no further questions should be answered.*
*If you are taking **EITHER** the Civil Engineering option **OR** the Foreign language option, answer **two** questions from one of the Sections C-H.*
*If you are taking **NEITHER** the Civil Engineering option nor the Foreign language option, answer **four** questions from two of the Sections C-H. Not more than two questions from each Section may be answered.*
All questions in Sections C–H carry the same number of marks.
*The **approximate** number of marks allocated to each part of a question is indicated in the right margin.*
*Write your candidate number **not** your name on the cover sheet.*

Section A: *The Engineer in Business* ………………….. ……………………………………….A.1
Section B: *Civil and Structural Engineering has been assessed as coursework*
Section C: *Mechanics, Materials and Design* C.1
Section D: *Aerothermal Engineering* D.1
Section E: *Electrical Engineering* E.1
Section F: *Information Engineering* F.1
Section G: *Bioengineering*.. G.1
Section H: *Manufacturing and Management*... H.1

STATIONERY REQUIREMENTS

Single-sided script paper.

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM

CUED approved calculator allowed

Engineering Data Book

10 minutes reading time is allowed for the paper at the start of the exam.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

You may not remove any stationary from the Examination room.

Version MP/2

SECTION A: ***The Engineer in Business***

Answer ***all*** *questions from this section, on the special answer sheet.*

1 Which of the following statements is most consistent with behavioural theories of the firm?

(a) As the tenure of the CEO of a car company extends they are more likely to prioritise growth over profitability;

(b) Clothing factories operate to reduce individual workers bargaining power in order to increase profitability;

(c) Supermarkets run advertising campaigns to keep their advertising department happy;

(d) Coal fired power plants are often co-located next to coal mines;

(e) None of the above. [2.5]

2 There are eleven similarly sized fertilizer companies in a market. If one fertilizer company rises its prices by 10% and all the others almost immediately do the same, this is most likely to be an example of:

(a) Collusive pricing;

(b) Competitive pricing;

(c) Price discrimination;

(d) Predatory pricing;

(e) None of the above. [2.5]

3 Looking across all firms, which of the following situations is least favourable for firm growth?

(a) GDP rises by 3%, technological opportunity increases by 2%, managerial experience increases by 2%;

(b) GDP rises by 3%, technological opportunity increases by 3%, managerial experience increases by 2%;

(c) GDP falls by 3%, technological opportunity increases by 2%, managerial experience increases by 1%;

(d) GDP falls by 2%, technological opportunity increases by 2%, managerial experience increases by 1%;

(e) None of the above. [2.5]

4 Octopus Energy is a retailer of electricity and gas in the UK. It recently acquired a heat pump manufacturing business. Which statement best describes this strategy?

(a) Growth by backward vertical integration;

(b) Growth by forward vertical integration;

(c) Growth by merger;

(d) Growth by diversification;

(e) None of the above. [2.5]

5 Every year, Google implements over 500 improvements to its search algorithms to improve the customers' search experience and provide the most relevant and best quality content. Which marketing philosophy does this example best describe?

(a) Product-oriented;

(b) Selling-oriented;

(c) Promotion-oriented;

(d) Customer-oriented;

(e) None of the above. [2.5]

6 Airbnb's campaign "Don't Go There, Live There" compares the standardized tourist experience with the experience people get when travelling with Airbnb. Which element of the positioning strategy this campaign focuses on?

(a) Frame of reference;

(b) Points of parity;

(c) Points of difference;

(d) Category membership;

(e) None of the above. [2.5]

 (TURN OVER

7 Uber offers different options for customers with different needs, including UberX for affordable everyday trips, Uber Exec for premium rides and Uber Green for sustainable trips. Which of the following strategies best describes this?

(a) Branding;

(b) Market segmentation;

(c) Positioning;

(d) Targeting;

(e) None of the above. [2.5]

8 When meta launched a partnership with the US National Basketball Association to show live games through its metaverse service, this was an example of managers following

(a) Porter's ideas about reinforcing activity systems through tradeoffs;

(b) McGrath's ideas about organisational agility;

(c) Adner's ideas about ecosystem keystones;

(d) b and c;

(e) a, b, and c. [2.5]

9 When managers use the tool of five forces analysis, their implicit assumption is

(a) They can identify relevant sets of competitors.

(b) They can identify new ways to negotiate with employees.

(c) They can identify core competences.

(d) They can identify opportunities to grow.

(e) They can block new entrants. [2.5]

10 Which of the following is a product of VRIO analysis?

(a) A list of core competences;

(b) An analysis of the activity system;

(c) Recommendations for innovation rhythm and tempo;

(d) A dyadic- or pattern-based view of the business ecosystem;

(e) All of the above. [2.5]

END OF SECTION

SECTION C: *Mechanics, Materials and Design*

Answer not more than ***two*** *questions from this section.*

1 (a) Figure C.1 gives part of the time-varying stress history suffered by a critical part of the steel tower of a wind turbine.

(i) Discuss what factors are likely to have influenced the stress history. [4]

(ii) Identify from the data in Fig. C.1 a suitable set of half-cycles of stress for use in a fatigue analysis. [5]

(iii) Outline how you would use data of the type given in Fig. C.1 to design the tower. Discuss what other factors you would consider in designing the tower? [4]

(b) (i) Explain why gears are often found in commercial wind turbines and why epicylic gears are commonly used. [3]

(ii) Discuss possible failure mechanisms for gearboxes in commercial wind turbines, including sketches of failure mechanisms and ways to design against failure. [4]

(iii) Sketch the layout of an epicyclic gear. Derive an expression, in terms of sun and ring tooth numbers N_S and N_R, respectively, for the ratio of sun to carrier speeds for the case where the ring is fixed. [5]

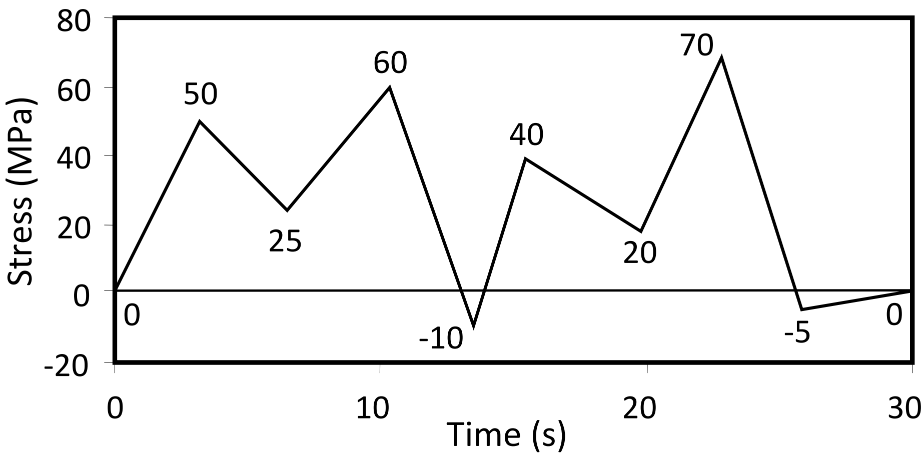

Fig. C.1

2 (a) The wind turbine shown in Fig. C.2 has swept area A. The free-stream air speed is V_0 and the density of air is ρ. The centreline of the turbine is marked A-B-C-D in the figure. The air speed at D is $u_1 = (1 - 2a)V_0$ where a is the axial induction factor.

(i) Sketch a graph showing the variation of air pressure along the line A-D. Indicate on your diagram the pressure drop Δp across the plane of the rotor. [4]

(ii) Use Bernouilli's equation along A-B-C-D to find an expression for Δp in terms of V_0, u_1 and ρ. [4]

(iii) Use your result from (ii) to find the thrust on the turbine when it is operating at the Betz limit. [4]

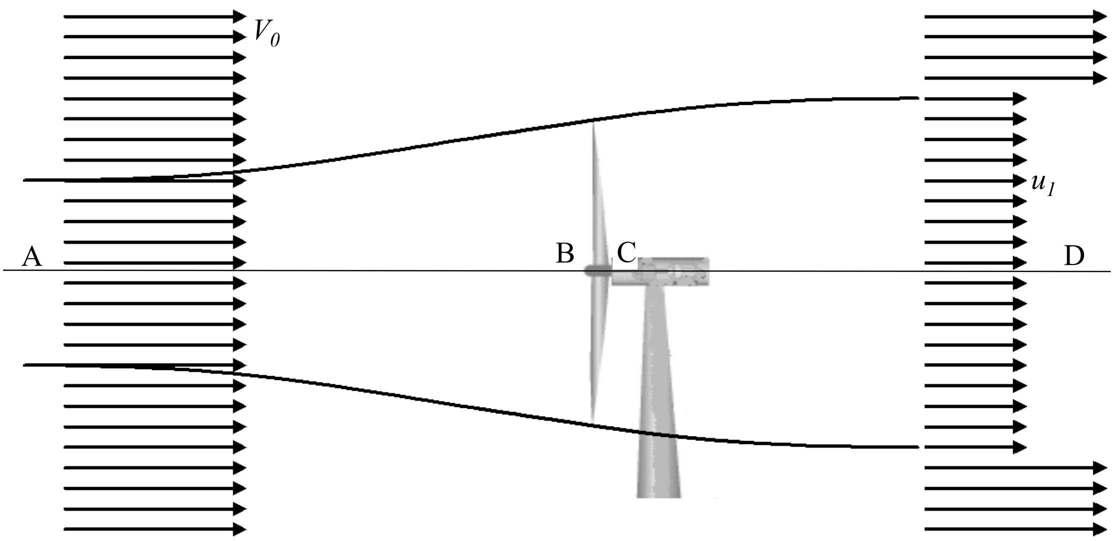

Fig. C.2

(b) A farm intends to supplement its solar power, especially in winter, by installing a 15 m diameter wind turbine. The turbine is coupled through a gearbox to a 3-phase, 12-pole, star-connected induction generator without rotor slip rings. The generator stator windings are connected directly to the 415 V, 50 Hz mains grid. The angles of the turbine blades self-adjust to maintain an approximately constant power coefficient $C_p = 0.35$, up to a wind-speed of 12 m s^{-1}. The distribution of average daily wind speeds for the farm over the winter period of 90 days is given in the table below.

Wind speed range (m s^{-1})	0–2	2–4	4–6	6–8	8–10	10–12
Number of days	14	35	22	13	5	1

Table C.1

(i) How many kW hr in total would the wind turbine be expected to produce over the winter period? [4]

(ii) Calculate the average wind speed over the entire winter period. What gearbox ratio would be required for the turbine to operate with a tip speed ratio of 8 at this average wind speed? What power is generated under these conditions? [4]

(iii) The induction generator has the following equivalent circuit parameters: $R_1 = 0.5\ \Omega$; $R_2' = 0.4\ \Omega$; $X_1 = X_2' = 2.5\ \Omega$, and X_m and R_0 may be ignored. Find the generator torque, slip, phase current and power factor under the conditions in part (ii). [5]

The following may be quoted without proof:

$$P = \tfrac{1}{2} C_p \rho A v^3,\ \lambda = \frac{\omega R}{v},\ T = \frac{3V^2 s}{\omega_s R_2'} \text{ and take } \rho = 1.23 \text{ kg m}^{-3}$$

3 Consider a three-bladed horizontal-axis wind turbine with blade radius $R = 30$ m operating at a rotational speed of 20 rpm. The aerodynamic loads are as follows: the tangential force intensity $F_T = 150\,\mathrm{N\,m^{-1}}$ is constant along the blade, and the normal force intensity F_N varies linearly from zero at the hub (taken as $r = 0$) to $F_{N\,\max} = 1500\,\mathrm{N\,m^{-1}}$ at the blade tip ($r = R$).

(a) Calculate the mechanical power generated by the turbine. [3]

(b) Consider the performance of the blade due to the aerodynamic flapwise bending loads. The structural properties of the blade are determined by a spar made of composite material with an elastic modulus $E = 70$ GPa and a failure strength $\sigma_f = 300$ MPa. The spar's depth d (associated with flapwise bending) varies linearly with distance x from the tip of the blade, i.e. $d = d_0\, x/R$, where d_0 is the depth at the hub end of the blade. The breadth of the spar varies such that the second moment of area I of the spar similarly varies linearly from zero at the blade tip to a maximum value of I_0 at the hub, i.e. $I = I_0\, x/R$.

(i) Show that the variation along the blade of the flapwise bending moment M in the blade is given by

$$M = R^2 F_{N\,\max}\left(\frac{1}{2}\left(\frac{x}{R}\right)^2 - \frac{1}{6}\left(\frac{x}{R}\right)^3\right)$$

[5]

(ii) For the case where $d_0 = 0.3$ m, determine the minimum value for I_0 which ensures that the flapwise bending loads do not cause the elastic deflection of the blade tip to exceed 0.5 m or the stress in the spar material to exceed its failure strength. [13]

(c) Discuss other factors which would need to be considered in designing the spar. [4]

END OF SECTION

SECTION D: Aerothermal Engineering

Answer not more than ***two*** *questions from this section.*

1 (a) Explain why, since the design of the first jet engines, turbine entry temperature has continually increased. Describe two ways in which engineers have enabled this to happen. [4]

(b) An aircraft cruises at a flight Mach number of 0.86 at an altitude where the ambient conditions are $T = 216.7$ K and $p = 19.4$ kPa. The thrust for the aircraft is provided by turbojet engines. The isentropic efficiency of the compressor is 0.89 and its pressure ratio is 25. Calculate the combustor inlet temperature. [3]

(c) The turbine entry temperature is 1600 K and the turbine isentropic efficiency is 0.91.

(i) Calculate the propulsive efficiency of the engine. [5]

(ii) Calculate the thermal efficiency of the engine. [2]

(d) In the inlet of the engine the flow decelerates reversibly and adiabatically so that the Mach number is 0.4 just upstream of the compressor (the flow remains purely axial). The mid-height radius of the first compressor blade is $r_{\text{mid}} = 0.42$ m and the mass flowrate is $\dot{m} = 35$ kg s^{-1}. Calculate the height of the first compressor blade. [5]

(e) The designer chooses a stage loading coefficient of $\psi = 0.35$ for the compressor and $\psi = 1.5$ for the turbine. Using sketches of the blades, explain why the stage loading coefficient of the turbine can be so much greater than that of the compressor. [6]

Assume that the working fluid is air throughout with $\gamma = 1.4$ and $R = 287$ J kg^{-1} K^{-1}.

2 (a) Explain, with physical reasoning, why the non-dimensional gross thrust $\tilde{F}_G$ takes the following form,

$$\tilde{F}_G = \frac{F_G + p_a A_N}{A_N p_{02}} \quad ,$$

where p_a is the ambient pressure, A_N is the area of the propelling nozzle and p_{02} is the stagnation pressure at engine inlet. [5]

(b) A twin-engined aircraft takes off from a runway at the standard sea level conditions given in the Databook. The aircraft mass is 350 tonnes. At take-off the aircraft speed is 90 m s^{-1}, the lift-to-drag ratio $L/D = 10$ and the climb rate is such that $\sin\theta = 0.03$. The mass flowrate through each engine is $\dot{m} = 120$ kg s^{-1}. Determine the net thrust and the gross thrust from each engine. [3]

(c) The same aircraft as that in part (b) now operates at a high altitude airport where the atmospheric pressure is 61.4 kPa and the ambient temperature is the same as the standard sea level value. The aircraft takes off with the same lift coefficient as at sea level conditions. The propelling nozzle area $A_N = 1.3$ m^2.

(i) Discuss two challenges of operating aircraft from high altitude airports. [4]

(ii) Calculate the speed of the aircraft at take-off. [2]

(iii) If the engines operate at the same non-dimensional condition as at sea level, calculate the total net thrust available to the aircraft. Comment on the result. [7]

(d) The same aircraft now operates at a third airport. This airport is at sea level (standard sea level ambient pressure) but the ambient temperature is 30 K higher than standard sea level conditions. Discuss ways in which the aircraft operator and engine manufacturer could mitigate the problems caused by taking off from this airport. [4]

Assume that the working fluid is air throughout with $\gamma = 1.4$ and $R = 287$ J kg^{-1} K^{-1}.

 (TURN OVER

3 (a) Explain why the altitude at which a long-haul aircraft cruises increases during the flight. [3]

(b) The total mass of an aircraft at the start of cruise is 260 tonnes. The flight Mach number is 0.85, the lift coefficient $C_L = 0.5$ and the wing area is 450 m^2. Find the altitude at the start of cruise. [4]

(c) The duration of cruise is 6 hours. During this time, the lift-to-drag ratio, thrust-specific fuel consumption and ambient temperature are all held constant with the following values: $L/D = 20$, sfc $= 0.015$ kg s^{-1} kN^{-1}, $T = 216.7$ K. Stating any assumptions made, find:

(i) the mass of fuel burned during cruise; [5]

(ii) the altitude of the aircraft at the end of cruise; [2]

(iii) the distance travelled by the aircraft during cruise. [2]

(d) By changing the engine design, the propulsive efficiency of the engines is increased by a factor of 1.1 but the thermal efficiency remains unchanged. Calculate the reduction in fuel burned if the aircraft cruises for the same distance as in part (c). [4]

(e) State a way in which the increase in propulsive efficiency in part (d) could have been achieved. Describe two challenges associated with changing the engine in this way. [5]

Assume that the working fluid is air throughout with $\gamma = 1.4$ and $R = 287$ J kg^{-1} K^{-1}.

END OF SECTION

SECTION E: *Electrical Engineering*

Answer not more than ***two*** *questions from this section*

1 (a) Describe the structure of the following types of MOSFETs: planar gate, FinFET and Gate-All-Around (GAA). Draw a diagram of each to illustrate your answer. [8]

(b) With reference to your answer to part (a), explain why FinFETs are commonly used in preference to planar gate MOSFETs in current microprocessors and why GAA MOSFETs are predicted to replace FinFETs in the future. [5]

(c) What are the additional challenges of fabricating GAA MOSFETs compared with FinFETs? [4]

(d) A depletion-mode GAA MOSFET is to be made with a crystalline silicon channel with a cross-sectional radius of 10 nm and a physical channel length of 30 nm. The silicon is doped with a donor impurity concentration of 10^{17} cm^{-3} and it has a relative permittivity of 11.7. Derive an expression for the potential on the curved surface of the silicon channel with respect to the centre if the silicon is fully depleted by the application of a gate voltage. Calculate this potential, stating any assumptions that you make, and comment on your answer. [8]

2 (a) Explain what is meant by *effective mass* in the context of carriers in semiconducting materials. Why this is important for the performance of transistors? [4]

(b) Figure E1 shows the *E-k* diagram for three different semiconducting materials called simply A, B and C. Which semiconductor will have the greatest effective mass for electrons in the conduction band and which will have the smallest effective mass for electrons in the conduction band? Justify your answers. [4]

(c) A particular semiconductor has an electron mobility of 1000 $cm^2\ V^{-1}\ s^{-1}$ and an electron effective mass in the conduction band that is $0.3m_e$ where m_e is the mass of an electron. The semiconductor has been doped with a donor impurity concentration of $10^{16}\ cm^{-3}$ and it has been patterned to make a small cube of semiconducting material with sides that are 200 nm long and contacts have been added to two opposing faces of the cube.

(i) Estimate the average time between collisions that a single conduction band electron will have with the semiconductor lattice. [4]

(ii) If a voltage of 10 mV is applied between the contacts on the opposing faces, what is the average time it would take a single conduction band electron to cross from one contact to the other? [4]

(iii) Estimate the current flow between the contacts under the application of this 10 mV bias. [4]

(iv) Explain why increasing the voltage applied between the contacts to 100 mV might not result in a ten times increase in current flow compared with your answer to part (iii). What is the significance of this for the design of a MOSFET? [5]

NOTE: For a semiconductor

$$\mu = \frac{q\tau}{m^*}$$

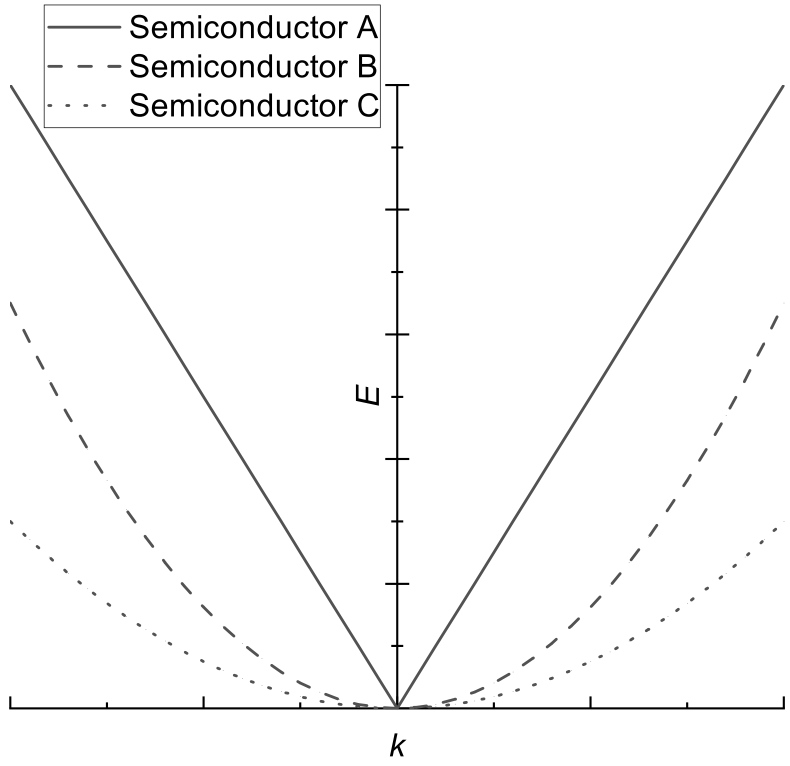

Fig. E1

3 Figure E2 (which is not drawn to scale) shows a cantilever made from a 500 nm thick layer of silicon nitride that has been deposited onto a crystalline silicon substrate. The cantilever, which is 100 µm long and 80 µm wide, is to be used as a resonant structure in a MEMS device.

(a) Suggest a suitable process for depositing the silicon nitride layer and justify your answer. What are the main process parameters that will need to be controlled during deposition and why are they important? [8]

(b) Write a short process flow for patterning and etching the silicon nitride layer that would follow on from the deposition of part (a). [6]

(c) Suggest three methods for selectively etching the silicon from underneath the silicon nitride. Which of the three methods would you recommend using? Justify your choice. [5]

(d) A 20 nm layer of copper is deposited onto the structure shown in Fig E2. Draw a cross-sectional diagram of the Section X-X of the cantilever structure after this copper layer has been deposited for each of the following possible methods of deposition:

(i) atomic layer deposition,

(ii) thermal evaporation,

(iii) rf magnetron sputtering. [6]

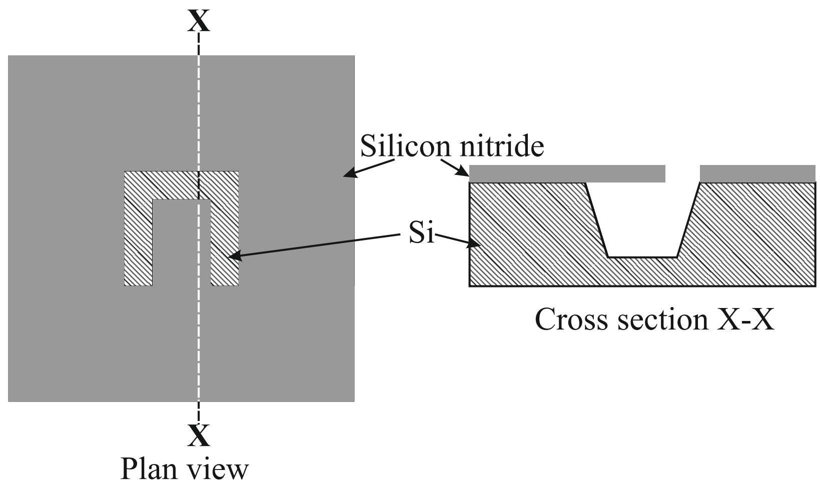

Fig. E2

END OF SECTION

SECTION F: ***Information Engineering***

Answer not more than **two** *questions from this section.*

1 (a) Consider the following models for classifying whether a 100×100 pixel RGB image contains a pedestrian or not: (i) Logistic Regression; (ii) a Multilayer Perceptron (MLP) with 2 hidden layers of n neurons; (iii) a Convolutional Neural Network (CNN) using 2 layers of 11×11 convolution with k channels, followed by an output layer. For **each** of these models:

(i) Write an expression for the output, y, as a function of the input, x, and the parameters. Use W, b, and σ to denote the weights, biases, and activation functions, respectively, and use subscripts to distinguish the parameters of different layers. Use $*$ to denote convolution. [6]

(ii) Compute the number of parameters the model has. [3]

(iii) List one advantage and one disadvantage of this model. [6]

(b) In a CNN, the **receptive field** of a neuron is the region of pixels in the input image that can influence that neuron's output/activation. Consider again the CNN from part (a), and assume no padding of the input image.

(i) How many pixels do the receptive fields of neurons in the first convolutional layer include? [1]

(ii) How many pixels do the receptive fields of neurons in the second convolutional layer include? [1]

(iii) Suppose we add a 2×2 (non-overlapping) average pooling layer in between the first and second convolutional layers. How many pixels would be in the receptive fields of neurons in the second convolutional layer in this model? [1]

(iv) What is one issue that could occur if the receptive field of neurons in the convolutional layers of a CNN are too small? [2]

(c) This question is about overfitting.

(i) Explain what overfitting is in one sentence. [1]

(ii) Explain how overfitting can be detected in one sentence. [1]

(iii) How can overfitting be avoided or mitigated? List 3 ways. [3]

2 (a) A 1280×720-pixel greyscale photograph, $I(x, y)$, has been taken from a camera mounted on a car driving down Trumpington Street in Cambridge. We wish to extract edges from the image.

(i) Which operation used in the process of edge detection is particularly sensitive to noise? Provide details of a 2D convolution operation that can be used to reduce noise in the image signal. [2]

(ii) How can the convolution operation described in your previous answer be implemented efficiently? Assuming that a 7×7 kernel is employed with "valid" convolutions (no zero padding is applied to image $I(x, y)$) what is the % reduction in the total number of multiplications required to remove noise using an efficient implementation rather than a naive implementation? Does this % reduction change if the image to be denoised was larger? If so, how? [6]

(b) (i) Describe how the *aperture problem* motivates the use of features beyond edges for finding correspondences. What kind of invariance can be established using edges that cannot be achieved using blobs? [2]

(ii) In order to identify the position and scale of blobs in the image, we wish to construct a discretised scale space, $S(x, y, \sigma_i)$ for various values of σ_i. By using the *reproducing property* of the Gaussian, or otherwise, derive an expression for the convolutions to be performed in order to compute $S(x, y, \sigma_{i+1})$ from $S(x, y, \sigma_i)$, noting that $\sigma_{i+1} = 2^{1/s}\sigma_i$ where s denotes the number of image scales per octave. Explain how this derivation contributes to the efficiency of identifying the locations and scales of blobs in images over a naive approach. [3]

(iii) Complementing your answer to (ii), describe three other computational mechanisms that enable the positions and scales of blobs in images to be identified efficiently. [4]

(c) (i) Describe five ways in which normalisation is used in the SIFT framework and explain the objective of each normalisation step with regard to the ultimate goal of finding correspondences. [4]

(ii) The car drives down Trumpington Street on a Sunday at noon and takes a photograph of a gate at a particular location. It drives the same route five minutes later, then once again 24 hours later at noon the following Monday. Each time it drives the route, it takes a photograph at the same location. Give three specific examples of nuisance factors that could arise when finding correspondences between the photographs taken 24 hours apart that differ from those arising in the photographs taken 5 minutes apart. Which limitations of SIFT descriptors, if any, are likely to be most affected by these nuisance factors? [4]

3 Consider the graph shown in Fig. F.1, where the numbers represent the length associated with each edge.

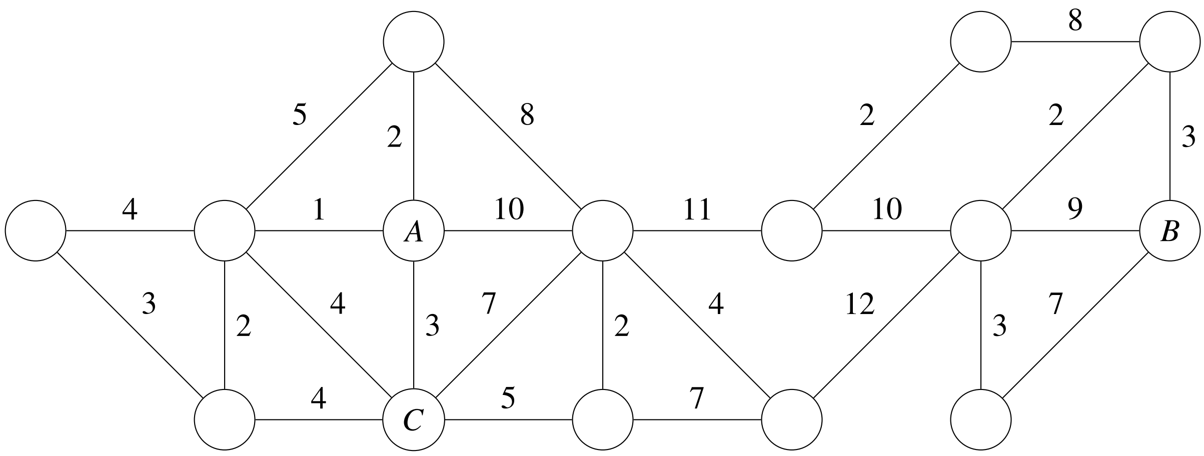

Fig. F.1

(a) Give 3 different methods of finding the shortest path from all nodes to node A. For each method, state how you would know that the paths found are indeed the shortest. [4]

(b) Find the shortest distance from all nodes to node A using a method of your choice, and verify that any condition for optimality from part (a) is satisfied. [9]

(c) If instead it was only necessary to find the shortest path between nodes A and B, and Dijkstra's algorithm is to be used, would it be more efficient to start by finding shortest paths to/from A or to/from B? [3]

(d) Explain why, for any node s, $\text{dist}(s, B) \geq \text{dist}(A, B) - \text{dist}(A, s)$. Using this as a heuristic, together with the distances you found in part (b), use the A* algorithm to find the shortest distance from node C to node B. [9]

END OF SECTION

SECTION G: *Bioengineering*

Answer not more than ***two*** *questions from this section.*

1 For the following question, assume tissue to be mostly water. You can assume the speed of sound in water is 1480 m/s and the refractive index of water is 1.33.

(a) Compare the round-trip travel time for a short acoustic pulse and a short optical pulse that reflect off a structure at a depth of 2 cm in the eye. Comment on what this means for the feasibility of detection with conventional detection electronics for each modality. [5]

(b) Compare and contrast time-domain (TD) and frequency-domain (FD) optical coherence tomography (OCT). [6]

(c) A laser beam in a TD-OCT system has a peak wavelength of 800 nm, and a Gaussian FWHM bandwidth of 50 nm. What is the coherence length of this beam? How does this relate to the spatial resolution of the system? [3]

(d) The reference-arm mirror of the TD-OCT system in (c) is translated at a speed of 5 m/s. Considering the bandwidth of the system, what would be the minimum required frequency response for the photodetector? [4]

(e) The scattering coefficient, μ_s, of the tissue being measured by TD-OCT is 10 cm^{-1}. What is an approximate limit for the depth of a section being imaged? [1]

(f) Comment on the wavelength chosen in the system in (c) referring to biological tissue optics. [3]

(g) What is an OCT scan used for and what conditions can it detect? [3]

2 (a) Describe the main properties of an “ON-center, OFF-surround line detector” type of V1 simple cell, including what is referred to as “linearity”. Explain how its receptive field structure is accounted for in Hubel and Wiesel’s feedforward model. [4]

(b) The Hermann grid illusion was taught to you in lectures in the form depicted in Fig. G.1A. At the intersections of the white lines, people typically perceive ghostly gray smudges, i.e. spots that appear darker than they actually are.

(i) With the help of appropriate schematics, summarise the theory as to how this phenomenon might arise based on the receptive field structure of retinal ganglion cells. [4]

(ii) Similar gray smudges are typically perceived at the intersections of the *black* lines in the variation shown in Fig. G.1B. Explain with reasons whether or not this is consistent with the theory of part (b)(i). [2]

(iii) It has also been shown that, when the original grid of Fig. G.1A is modified to have serrated (instead of straight) lines as shown in Fig. G.1C, the illusion is much weaker. Explain with reasons whether or not this is consistent with the theory of part (b)(i). [2]

(c) This question is about the principles of vision in the *Copilia*.

(i) What are the main components of its eye? [1]

(ii) Explain with reasons what is the effective dimensionality of the retina. [1]

(iii) What is the effective dimensionality of its vision, i.e. in how many dimensions can it detect objects visually (without changing its body’s position or orientation), and what mechanisms contribute to achieving this dimensionality? [1]

(d) This question is about efficient coding in the retina.

(i) Explain what the word “white” refers to in the context of efficient coding in the retina. [2]

(ii) What cells in the retina perform whitening? [1]

(iii) Define the set of assumptions that leads to the prediction of whitening. [7]

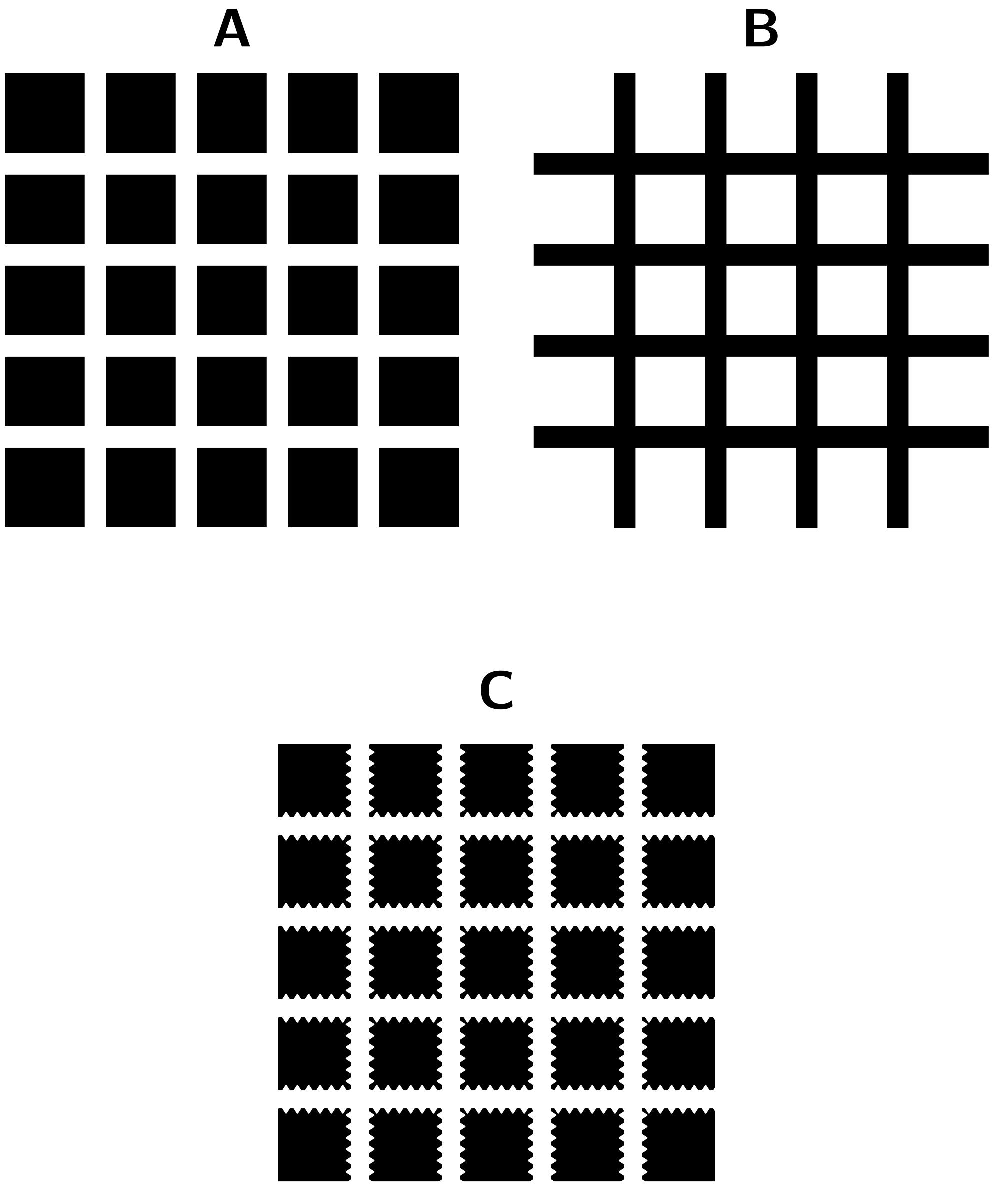

Fig. G.1

3 (a) What are the three layers of the wall of the eye? How does each layer contribute to the focusing ability of the eye? [4]

(b) Give an example of how aging can change the tissue properties of an eye component, and how this change can cause deteriorated physiological function of the eye. In addition, suggest a suitable strategy to augment or repair the deteriorated eye function, and discuss the strategy's operation principle. [5]

(c) What are the main functions of aqueous humour in the eye? Describe two major routes of aqueous humour drainage for the control of intraocular pressure, discussing their associated regulation mechanisms. [6]

(d) Discuss the material selection criteria for a daily disposal contact lens. Describe a possible manufacturing process for the mass production of daily disposal contact lenses. You may use a sketch to assist your answer. [4]

(e) Which of the following factor(s) are expected to lead to a measurable decrease in the magnitude of ocular rigidity? [3]

- photodamage of the retina
- decreased collagen density in the sclera
- thickening of the sclera
- thinning of the retina

(f) The mechanical response of a hydrated soft tissue block can be approximated by a spring and dashpot viscoelasticity model shown in Fig. G.2. When a constant stress is applied in uniaxial compression, out of options A to D shown in Fig. G.3, which is the expected profile of compressive strain response measured? [3]

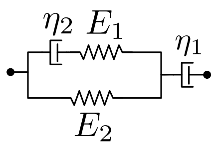

Fig. G.2

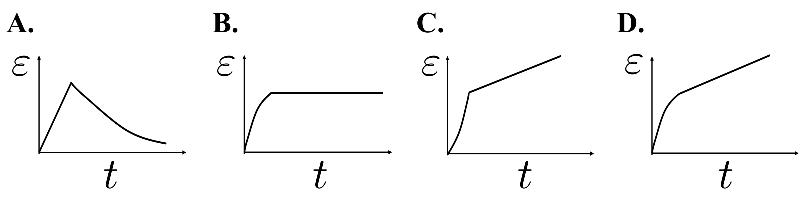

Fig. G.3

END OF SECTION

SECTION H: ***Manufacturing and Management***

Answer not more than ***two*** *questions from this section.*

1 (a) To deliver their technology to market, companies need to design their processes to manufacture and distribute their products. Explain the fundamental components of *operations design*, and the links between them. [15]

(b) Describe the main types of innovation. Give your own examples to support your answer. [4]

(c) How do *design rights* work for protecting inventions? [6]

2 (a) Young & Bright Ltd, an established company, has identified a market gap. They see an opportunity for designing a new on-line platform which helps students find social work internships. Discuss how you would advise them on what methods to use to understand what the users want. [12]

(b) How do *trademarks* work and help protect inventions? [5]

(c) Explain the role and impact of technology in operations design. [8]

3 (a) Explain what is meant by: *"Intellectual property rights put the owner in the driving seat"*. Give examples to support your answer. [4]

(b) (i) Explain the logic you would use to select funding sources to support a newly established start-up. [9]

(ii) What is crowdfunding? Explain its features and use in comparison to other sources of funding. [5]

(c) In a BBC interview, a senior consultant with 25 years of experience in supporting large firms in developing new products stated: *"Most innovations launched are not radical"*. Explain why that statement is correct. Give examples to support your answer. [7]

END OF PAPER

Engineering Tripos Part IB 2023
Paper 8 Selected Topics

SECTION C – Mechanics, Materials and Design

Answers

2. (b) (i) 1200 kN hr (ii) 4.18 m/s, 11.75, 2775 W, (iii) 53.0 Nm, -0.00645, 3.88 A, -175°, 0.996 lagging.

3. (b) (ii) 0.0043 m^4

SECTION D: Aerothermal Engineering

Answer not more than ***two*** *questions from this section.*

1 (a) Explain why, since the design of the first jet engines, turbine entry temperature has continually increased. Describe two ways in which engineers have enabled this to happen. [4]

(b) An aircraft cruises at a flight Mach number of 0.86 at an altitude where the ambient conditions are $T = 216.7$ K and $p = 19.4$ kPa. The thrust for the aircraft is provided by turbojet engines. The isentropic efficiency of the compressor is 0.89 and its pressure ratio is 25. Calculate the combustor inlet temperature. [3]

(c) The turbine entry temperature is 1600 K and the turbine isentropic efficiency is 0.91.

(i) Calculate the propulsive efficiency of the engine. [5]

(ii) Calculate the thermal efficiency of the engine. [2]

(d) In the inlet of the engine the flow decelerates reversibly and adiabatically so that the Mach number is 0.4 just upstream of the compressor (the flow remains purely axial). The mid-height radius of the first compressor blade is $r_{\text{mid}} = 0.42$ m and the mass flowrate is $\dot{m} = 35$ kg s^{-1}. Calculate the height of the first compressor blade. [5]

(e) The designer chooses a stage loading coefficient of $\psi = 0.35$ for the compressor and $\psi = 1.5$ for the turbine. Using sketches of the blades, explain why the stage loading coefficient of the turbine can be so much greater than that of the compressor. [6]

Assume that the working fluid is air throughout with $\gamma = 1.4$ and $R = 287$ J kg^{-1} K^{-1}.

2 (a) Explain, with physical reasoning, why the non-dimensional gross thrust $\tilde{F}_G$ takes the following form,

$$\tilde{F}_G = \frac{F_G + p_a A_N}{A_N p_{02}} \quad ,$$

where p_a is the ambient pressure, A_N is the area of the propelling nozzle and p_{02} is the stagnation pressure at engine inlet. [5]

(b) A twin-engined aircraft takes off from a runway at the standard sea level conditions given in the Databook. The aircraft mass is 350 tonnes. At take-off the aircraft speed is 90 m s^{-1}, the lift-to-drag ratio $L/D = 10$ and the climb rate is such that $\sin\theta = 0.03$. The mass flowrate through each engine is $\dot{m} = 120$ kg s^{-1}. Determine the net thrust and the gross thrust from each engine. [3]

(c) The same aircraft as that in part (b) now operates at a high altitude airport where the atmospheric pressure is 61.4 kPa and the ambient temperature is the same as the standard sea level value. The aircraft takes off with the same lift coefficient as at sea level conditions. The propelling nozzle area $A_N = 1.3$ m^2.

(i) Discuss two challenges of operating aircraft from high altitude airports. [4]

(ii) Calculate the speed of the aircraft at take-off. [2]

(iii) If the engines operate at the same non-dimensional condition as at sea level, calculate the total net thrust available to the aircraft. Comment on the result. [7]

(d) The same aircraft now operates at a third airport. This airport is at sea level (standard sea level ambient pressure) but the ambient temperature is 30 K higher than standard sea level conditions. Discuss ways in which the aircraft operator and engine manufacturer could mitigate the problems caused by taking off from this airport. [4]

Assume that the working fluid is air throughout with $\gamma = 1.4$ and $R = 287$ J kg^{-1} K^{-1}.

3 (a) Explain why the altitude at which a long-haul aircraft cruises increases during the flight. [3]

(b) The total mass of an aircraft at the start of cruise is 260 tonnes. The flight Mach number is 0.85, the lift coefficient $C_L = 0.5$ and the wing area is 450 m^2. Find the altitude at the start of cruise. [4]

(c) The duration of cruise is 6 hours. During this time, the lift-to-drag ratio, thrust-specific fuel consumption and ambient temperature are all held constant with the following values: $L/D = 20$, sfc $= 0.015$ kg s^{-1} kN^{-1}, $T = 216.7$ K. Stating any assumptions made, find:

(i) the mass of fuel burned during cruise; [5]

(ii) the altitude of the aircraft at the end of cruise; [2]

(iii) the distance travelled by the aircraft during cruise. [2]

(d) By changing the engine design, the propulsive efficiency of the engines is increased by a factor of 1.1 but the thermal efficiency remains unchanged. Calculate the reduction in fuel burned if the aircraft cruises for the same distance as in part (c). [4]

(e) State a way in which the increase in propulsive efficiency in part (d) could have been achieved. Describe two challenges associated with changing the engine in this way. [5]

Assume that the working fluid is air throughout with $\gamma = 1.4$ and $R = 287$ J kg^{-1} K^{-1}.

END OF SECTION

Numerical answers:

Q1

(b) 670.4 K

(c) (i) 0.375; (ii) 0.613

(d) 0.262 m

Q2

(b) 223 kN, 234 kN

(c) (ii) 115.6 m/s; (iii) 140.2 kN

Q3

(b) 11086 m

(c) (i) 38200 kg; (ii) 12100 m; (iii) 5418 km

(d) 3228 kg

ENGINEERING TRIPOS PART IB 2023

PAPER 8: SECTION E (ELECTRICAL ENGINEERING)

Numerical Answers

1	(d)	1.23 mV	
2	(c)	(i)	0.171 ps
		(ii)	40 ps
		(iii)	320 nA

Version ML/3 – CRIB

Numerical answers:

1.a Round trip times: 27 *mu*s for an acoustic pulse, 177 ps for an optical pulse.

1.c L_c = 5.632*mu*m.

1.d 25 MHz.

1.e 0.1 cm.