ENGINEERING TRIPOS PART IB

Friday 9 June 2000 2 to 4

Paper 8

SELECTED TOPICS

Answer not more than **four** *questions.*

Answer questions from **two** *sections only.*

Do not answer more than **two** *questions from any section.*

All questions carry the same number of marks.

The **approximate** *number of marks allocated to each part of the question is indicated in the right margin.*

Answers to questions in each section should be tied together and handed in separately.

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SECTION A (Civil and Structural Engineering)

Do not answer more than **two** *questions from this section*

1 A watertight concrete tunnel structure of total weight 800 kN per metre length of tunnel is founded at a depth of 3 m below the level of the river bed in a tidal estuary. Granular fill is placed on one side of the structure, as shown in Fig. 1. A temporary surcharge of 50 kN/m^2 may be placed on the fill. The horizontal equilibrium of the structure is maintained by the passive resistance of the silty sand in the river bed and by friction on the base. By assuming that the base of the structure is rough and that the walls are smooth, calculate the overall factor of safety against sliding for the following conditions:

(a) Water level below the base of the structure and there is no surcharge. [8]

(b) The same conditions as in (a), but with the surcharge applied. [4]

(c) Water level at the top of the structure on both sides and with the surcharge applied. [8]

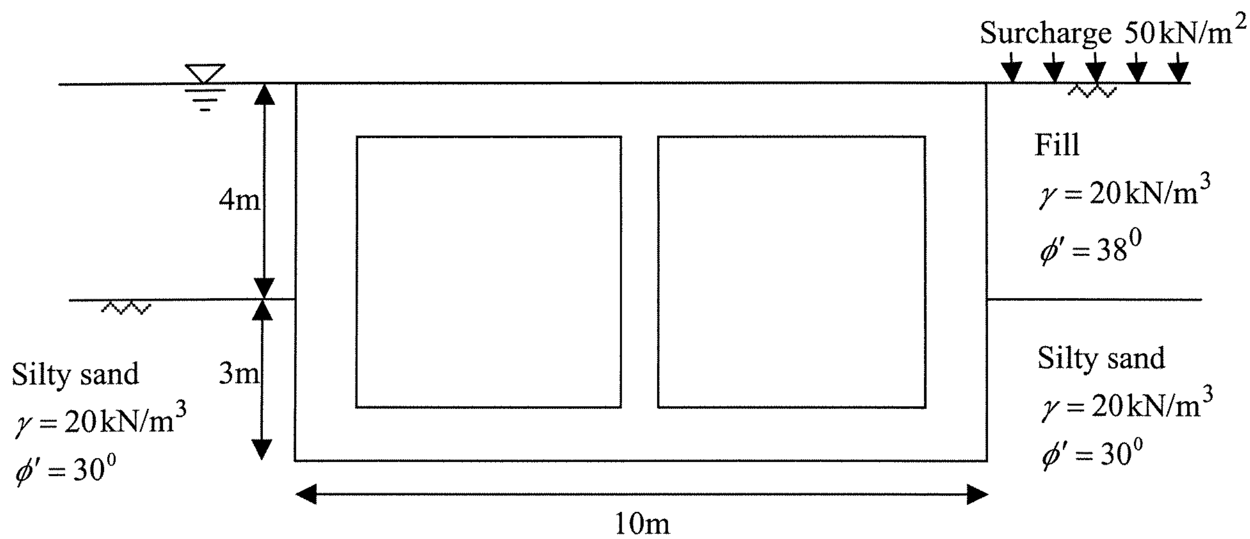

Fig. 1

2 Bored tunnels are to be constructed at depths of about 20 m for a new metro beneath a city through the following ground conditions:

(i) strong clay (undrained shear strength = 200 kN/m^2),
(ii) very soft clay (undrained shear strength = 20 kN/m^2) and
(iii) sands and gravels below the water table, which is near the ground surface.

(a) Describe the types of tunnel construction techniques that would be appropriate to ensure stability for each of the above ground conditions. What other design considerations are important? [8]

(b) Outline a typical instrumentation system that you would design to monitor the tunnel construction, giving reasons for your choice. How might this be used to implement the Observational Method? [6]

(c) How might settlement that is associated with the construction of the tunnels affect buildings? Outline how a compensation grouting scheme could be designed to protect a building at risk, illustrating your answer with sketches. [6]

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3 An excavation for a new underground station is being built using diaphragm walls that are 20 m deep. The critical design case for the walls is a temporary condition where the base slab has been placed and a closely spaced row of props has been inserted at a depth of 9 m. This situation is illustrated in Fig. 2. For this case, the loading can be regarded as a triangular distribution of forces, which includes the hydrostatic and the soil loads.

(a) Determine the bending moment and shear force diagrams for the wall. [5]

(b) The wall is built from concrete with a cube strength of 40 N/mm^2. Determine the thickness of the wall that is required if it is to be singly reinforced using high yield steel of yield strength 460 N/mm^2. Also calculate the amount of reinforcement that is required at the propping position and where the bending moment is a maximum between the prop and the base. [7]

(c) Discuss qualitatively whether there would be any economic advantage in making the wall doubly-reinforced. [4]

(d) The props are eventually to be replaced by a cast slab. The reinforcement of the slab is to be joined to the main wall reinforcement by means of screw-in couplers at the face. Suggest a layout of the reinforcement in the wall at this position that satisfies the requirements found in (b) above and that will facilitate this later work. [4]

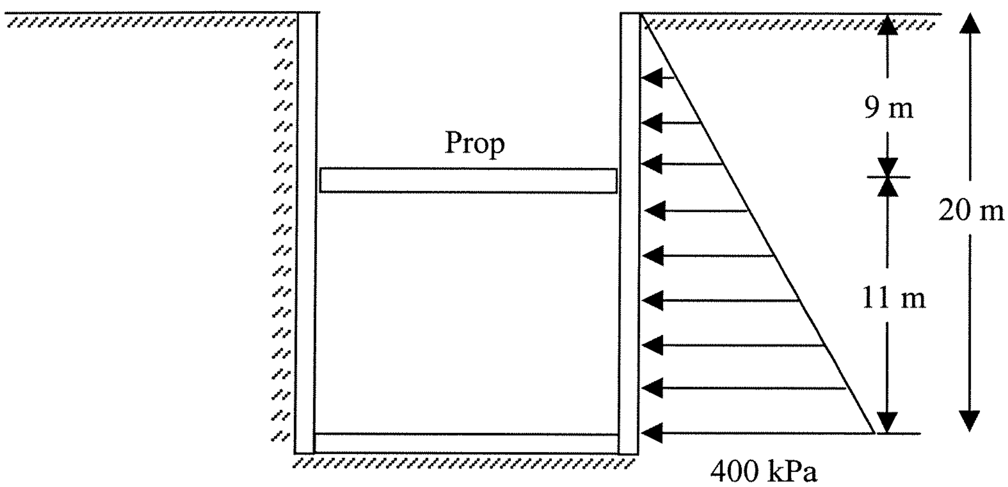

Fig. 2

SECTION B (Mechanical Engineering, Manufacture and Management)
Do not answer more than **two** *questions from this section.*

4 You are the head of manufacturing at a leading ski company. You have been informed by the head of research and development that the skis to be manufactured for the 2001/02 ski season will include an external damping device. This device consists of piezoelectric crystals attached to three shunt circuits and includes an LED to indicate that the device is working. The shape of the entire device can be considered to be a thin rectangular plate. It is to be mounted on the forebody of the ski just ahead of the front binding as shown in Fig. 3. It is now June 2000 and you must deliver demonstration skis by March 2001 targeted at the 2001/02 ski season. If this deadline is missed the ski cannot be launched until the following season (2002/03).

(a) Draft a project plan showing the key activities required to deliver the new ski. Assume that the complete damping device is purchased from a supplier. [7]

(b) It is proposed that the new ski will be manufactured within the existing production facility. What is the impact of this decision on the current manufacturing process? [3]

(c) Define a possible manufacturing strategy for the new ski using the process described in part (b) and considering issues of capacity, processes, human resources, quality, control policies and suppliers. [7]

(d) Identify the major risks involved in the launch of the new ski. [3]

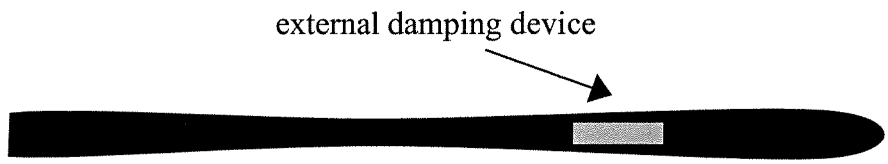

Fig. 3

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5 You are the chief engineer for a leading ski manufacturer. Due to the need for a competitive product, you want to decrease the mass and increase the flexibility of the current ski design while maintaining the current level of damping. A feasibility study is required to investigate the use of damping devices to reduce undesired vibrations in the new ski design.

(a) A wood ski with the same plan as in Fig. 4 has a total length of 2 m, a total uniformly distributed mass of 2.5 kg and a uniform bending stiffness of 600 Nm^2. The natural frequency of a cantilever beam of length l and mass m is given by

$$\omega_n = 3.52\sqrt{\frac{EI}{ml^3}}\,.$$

Determine the relationship between the actual length of the beam and the effective length needed to model it as a single degree of freedom system assuming that the effective mass is half the mass of the cantilever beam. Using this result, calculate the effective spring constant and natural frequency for both the forebody and afterbody of the ski assuming that the forebody is 1.5 times longer than the afterbody. [7]

(b) A new ski is being designed with the same plan as in Fig. 4 having a total length of 2 m, a total uniformly distributed mass of 2.5 kg and a lower uniform bending stiffness than the wood ski. Responses A, B, C, and D in Fig. 5 represent the forebody and afterbody displacement responses for both the wood and new skis. Given that the wood ski has a damping factor of 0.15 while the new ski has a damping factor of 0.1, match the responses to the correct material and segment of the two skis. [2]

(c) Identify the key design requirements for a damping device that will improve the dynamic performance of the new ski. Express these requirements in terms of the headings force, energy, material, signal, geometry, ergonomics, and maintenance. Propose one design concept for realising these requirements and briefly explain the physical principle(s) involved. Sketch your concept in both section and plan. [9]

(d) Sketch a possible sales vs. time profile for the new ski with damping device over the first two years of production giving rough numerical values for the axes. [2]

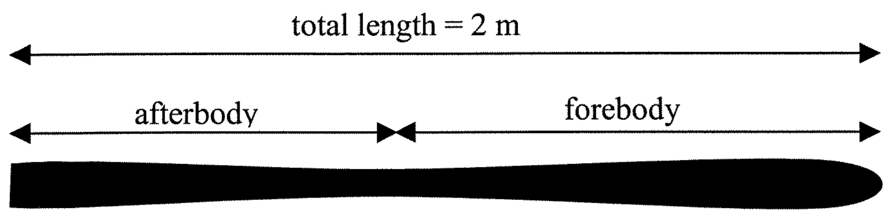

Fig. 4

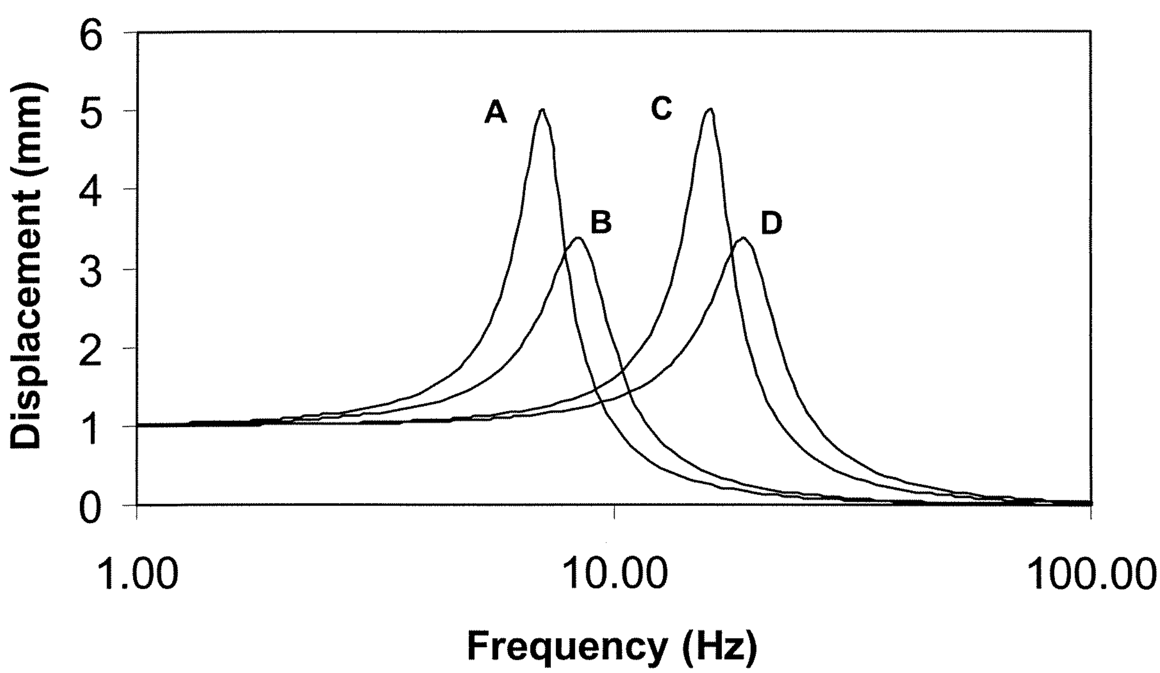

Fig. 5

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6 You have received support for further investigation into the use of damping devices for alpine skis. Testing is now required to determine the dynamic properties of skis with the new damping device. You intend to build a test facility using a shaker for vibration generation and accelerometers to measure the response of the ski. You are interested in measuring the response associated with the first resonant frequency. You have a shaker that generates a peak to peak force of 100 N, has a total stroke of ± 7 mm, a suspension spring constant of 12 N/mm and a moving mass of 0.2 kg.

The shaker provides a constant amplitude sinusoidal displacement that is applied at the centre of the ski. The system response associated with the first resonant frequency is assumed to be symmetrical about the centre of the ski. A model of the system as a single degree of freedom system is shown in Fig. 6. The system has an effective mass m_e of 1 kg, an effective spring constant k_e of 5685 N/m, and a damping constant λ of 15 Ns/m.

(a) Mounting the ski vertically above the shaker (Fig. 6) requires that the shaker supports the entire mass of the ski, which is 2 kg. For this arrangement, what is the operational stroke of the shaker? Using the full operational stroke, what is the displacement associated with the first resonant frequency? [6]

(b) Show that the shaker is unable to achieve its full operational stroke at the first resonant frequency of the ski. Calculate the maximum stroke length that can be used with this shaker to measure the displacement associated with the first resonant frequency. [6]

(c) Where on the ski should you place accelerometers to measure the response at the first resonant frequency and why? What are the potential sources of measurement error? [2]

(d) The signals from the accelerometers must be filtered due to excess noise. Draw a circuit for an appropriate band-pass filter with unity midband voltage gain and a midband frequency of 12.5 Hz. Indicate the values of all components on the circuit. [6]

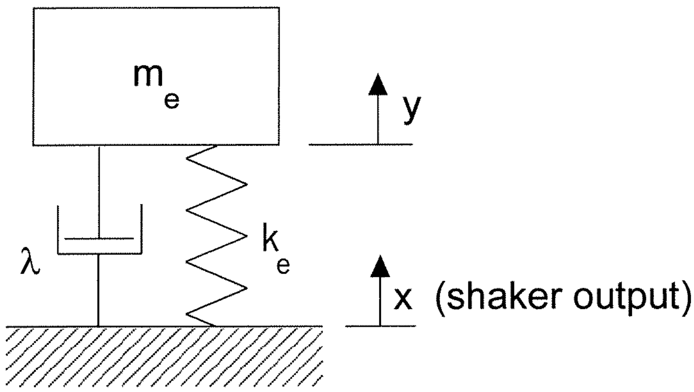

Fig. 6

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SECTION C (Aerothermal Engineering)

Do not answer more than **two** *questions from this section*

7 Figure 7 shows, schematically, the rotor blades at the mean-radius of a fan of a high bypass ratio civil aircraft engine. The directions of the *relative* velocities at inlet to and exit from the rotor are shown. The *absolute* velocity is axial at entry to the fan. The blade speed U is constant throughout the rotor.

(a) At inlet to the fan, the *absolute* Mach number is 0.6 and the *absolute* stagnation temperature T_{01} is 260 K. Find the static temperature T_1 and the *absolute* velocity V_1 at inlet to the fan. [2]

(b) Sketch the velocity triangle at inlet to the rotor. Find the blade speed U and the *relative* velocity V_1^{rel} at inlet to the fan. [5]

(c) The *relative* velocity V_2^{rel} at the exit of the rotor is 280 m/s. Sketch the velocity triangle at exit from the rotor. Determine the *absolute* flow angle at rotor exit. [5]

(d) For the rotor, the shaft work input per unit mass flow w_{in} is given by Euler's Work Equation

$$w_{in} = U\left(V_{\theta 2} - V_{\theta 1}\right)$$

where $\left(V_{\theta 2} - V_{\theta 1}\right)$ represents the increase in tangential velocity across the rotor. Find the work done per unit mass flow and the increase in the *absolute* stagnation temperature for the rotor in Fig. 7 [3]

(e) The fan has an isentropic efficiency of 0.9. Determine the overall stagnation pressure ratio of the fan. [3]

(f) What is the purpose of the stator blades in the bypass duct? [2]

Assume that for air, $\gamma = 1.4$, $R = 287$ Jkg^{-1}K^{-1} and $c_p = 1010$ Jkg^{-1}K^{-1}.

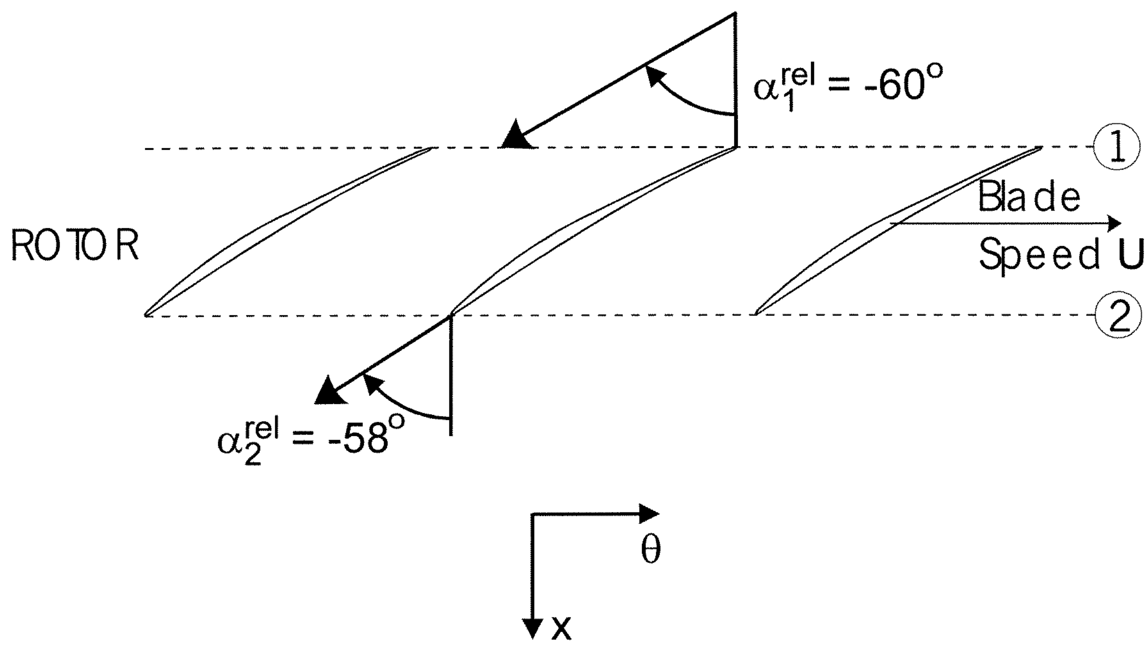

Fig. 7

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8 (a) A two-shaft turbofan engine is fitted to an aircraft which cruises at Mach 0.84 at an altitude where the ambient pressure is 29 kPa and the ambient temperature is 228 K. Show that the stagnation temperature T_{02} and stagnation pressure P_{02} at inlet to the engine are approximately 260 K and 46 kPa respectively. [3]

(b) After the core air-stream has passed through the fan, the stagnation temperature T_{024} is 289 K and the stagnation pressure P_{024} is 64 kPa. The core compressor has a stagnation pressure ratio of 25 and an isentropic efficiency of 0.9. Find the stagnation pressure P_{03} and the stagnation temperature T_{03} at exit from the core compressor. [4]

(c) The high-pressure turbine has an isentropic efficiency of 0.9. The stagnation temperature T_{04} at inlet to the high-pressure turbine is 1500 K. Determine the stagnation temperature T_{045} and the stagnation pressure P_{045} at entry to the low-pressure turbine. [5]

(d) The stagnation temperature T_{05} after the low pressure turbine is 610 K. After the fan, the stagnation temperature T_{013} is 301 K. Determine the bypass ratio. [4]

(e) The stagnation pressure P_{05} after the low pressure turbine is 43 kPa. Determine the velocity V_9 of the core jet. [4]

Neglect the mass flow rate of the fuel. Assume that the combustion products behave as a perfect gas with the same properties as air. Neglect any losses in the ductwork and the propelling nozzles. Assume that for air, γ = 1.4, R = 287 $\text{Jkg}^{-1}\text{K}^{-1}$ and $c_p = 1010\ \text{Jkg}^{-1}\text{K}^{-1}$.

9 (a) Explain the importance of the *propulsive efficiency* of an engine. Show that it can be estimated using the approximate expression

$$\eta_p = \frac{2V}{V + V_j}$$

where V is the flight speed and V_j is the jet velocity. [4]

(b) Explain what is understood by the *thermal efficiency* of an engine. What parameters most influence the thermal efficiency?

Explain what is understood by the *overall efficiency* of an engine. How is the overall efficiency related to the propulsive efficiency and the thermal efficiency?

Explain why most high thrust civil applications use bypass engines. Why is a military engine more likely to be a simple turbojet? [8]

(c) Sketch the general arrangement of a two-shaft turbofan engine, labelling each component. Sketch a temperature-entropy diagram for the core stream. Sketch a separate temperature-entropy diagram for the bypass stream. Indicate the changes in thermodynamic states on the temperature-entropy diagrams which correspond to the components labelled in your sketch of the engine. [8]

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SECTION D (Electrical Engineering)

Do not answer more than **two** *questions from this section.*

10 (a) Explain how the conduction occurs and how the gate voltage turns off the source-drain current in an n-type metal oxide semiconductor field effect transistor (MOSFET). [3]

(b) Derive the relationship between the gate voltage needed to turn off a MOSFET and the dopant density, stating the assumptions used. [5]

A MOSFET with a transit time of 10 ps is to be designed using a 0.25 μm thick layer of an n-type semiconductor of conductivity 80 $\Omega^{-1}m^{-1}$ on an insulating substrate. The supply voltage is to be 2.5 V. The semiconductor has a mobility of 0.01 $m^2V^{-1}s^{-1}$ and a dielectric constant of 10^{-10} Fm^{-1}. The electronic charge is given as 1.6 x 10^{-19} C.

(c) What is the donor density? [3]

(d) What is the source-drain distance for the required transit time? [4]

(e) What gate-source voltage is required to turn the transistor off? [3]

(f) What is the gate field and how does it compare to the breakdown field of the semiconductor of 10^7 Vm^{-1}? [2]

11 (a) Silicon has a diamond cubic lattice with a lattice constant of 0.543 nm. What is the density of valence electrons in silicon? [4]

(b) If the band gap of silicon is 1.1 eV and the Fermi level lies in the middle of the band gap, what fraction of these electrons is excited into the conduction band at room temperature (20°C). [3]

(c) A typical dopant density is 10^{22} m^{-3}. At what temperature would the number of thermally excited electrons in intrinsic silicon equal this number. Hence explain why doping is a useful property. [3]

(d) Sketch the velocity-field diagram for silicon. Explain the meaning of *scatter-limited velocity.* [3]

(e) The mobility and scatter-limited velocity of silicon is $0.1\ m^2V^{-1}s^{-1}$ and $10^5\ ms^{-1}$. If silicon of donor density $2 \times 10^{21}\ m^{-3}$ is used to make a fast FET, operating on a supply voltage of 2 V, with a source-drain channel that has a width/length ratio of 50, at what source-drain length does the conduction become scatter limited and what transit time does this correspond to? [5]

(f) Can an FET design go faster than this? [2]

The Boltzmann constant $k = 1.38 \times 10^{-23}\ JK^{-1}$. The electronic charge is 1.6×10^{-19} C.

12 (a) Compare and contrast the use of Silicon, Gallium Arsenide and Germanium for use in the manufacture of integrated circuits. [4]

(b) Describe the "wet" and "dry" methods of growing high quality silicon dioxide (SiO_2), indicating the material properties of greatest importance when such layers are to be used as the gate insulator in high frequency Metal Oxide Semiconductor Transistors (MOSTs). Discuss the potential problems of continuing to use this material for such an application as device dimensions continue to shrink. [8]

(c) A single crystal wafer of silicon is 475 μm thick. As part of an integrated circuit fabrication process a 40 nm layer of Silicon Dioxide is required to be grown as the gate insulating layer. If a dry oxidation growth process is used, estimate the thickness of silicon left after the oxide is grown and also the total thickness of oxide plus silicon. [6]

(d) Describe two other uses for oxide films in integrated circuit manufacture.

[2]

SECTION E (Information Engineering)

Do not answer more than **two** *questions from this section*

13 Consider a multi-user, multi-processing operating system such as UNIX.

(a) What characteristics distinguish I/O-bound and compute-bound processes? [3]

(b) State for each of the following application processes whether it should be categorised as I/O-bound or compute-bound:

(i) a Web server,
(ii) an array multiplication program and
(iii) a file server. [3]

(c) How does an operating system determine if a program is I/O-bound or compute-bound? [4]

(d) Outline how and why processes are scheduled differently depending on whether they are I/O-bound or compute-bound. [6]

(e) How can allocating the wrong number of page frames to an ordinarily compute-bound process make it spend much of its time doing I/O? [4]

14 Consider a Web server process running on a UNIX operating system. The Web server receives requests for Web pages over the network in the form of URLs. It reads in the appropriate file from disk and transmits the file over the network to the requesting Web client.

(a) Each Web request is made over a TCP/IP socket connection. Outline the sequence of system calls to set up a connection that must be made by:

(i) the Web server and
(ii) the Web client.

Describe the function of each system call. [6]

(b) What is the UNIX disk block cache and under what circumstances does it improve the performance of the Web server? [4]

(c) On a uniprocessor machine, can more Web traffic be handled by running 5 Web server processes instead of 1? Would the situation be the same on a multi-processor machine? Justify your answers. [6]

(d) What system calls are provided by UNIX to enable processes to manage file system concurrency control? Would these be needed to provide concurrency control between 5 Web servers accessing the same Web page files? [4]

15 (a) What is meant by a "client-server" architecture? [4]

(b) Discuss the partition and operation of client functions and server functions in the following systems:

(i) a Personal Computer (PC), [4]
(ii) an X-terminal (X) and [4]
(iii) a Virtual Network Computer (VNC). [4]

(c) What makes a stateless thin client, such as VNC, attractive and what are the consequences of this type of design? [4]

END OF PAPER