ENGINEERING TRIPOS PART IB

Friday 8 June 2001 2 to 4

Paper 8

SELECTED TOPICS

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

Do not answer questions from more than **two** *sections. In the case of candidates offering a foreign language answer questions from* **one** *section 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.

page

SECTION A (Civil and Structural Engineering) 2
SECTION B (Mechanical Engineering, Manufacture and Management) 8
SECTION C (Aerothermal Engineering)..11
SECTION D (Electrical Engineering)...15
SECTION E (Information Engineering) 18

(TURN OVER

SECTION A (Civil and Structural Engineering)
Do not answer more than **two** *questions from this section*

1 To support a temporary excavation 9 m below ground level a smooth vertical sheet pile wall is driven into the ground, as shown in Fig. 1a. The ground profile is a dense sand down to a depth of 9 m, underlain by a soft clay of low permeability. The ground water table is 1 m below ground level. The critical state angle of friction of the sand is 35°, and the unit weights above and below the water table are 17 kN/m^3 and 20 kN/m^3 respectively. The unit weight of the soft clay is 17.5 kN/m^3 and the undrained shear strength is 15 kN/m^2. A surcharge of 20 kN/m^2 acts on the ground surface behind the wall.

(a) Assuming that the wall transfers to the right sufficiently for active pressures to be generated, calculate the total horizontal pressures acting on the back of the wall immediately after excavation. Sketch the pressure distribution. [10]

(b) To maintain the temporary stability of the wall, ground treatment by cement mixing is undertaken in the top 3 m of clay in front of the wall before the excavation commences as shown in Fig 1b. The result of the ground treatment is effectively a low permeability strong clay. The treated zone has a unit weight of 22 kN/m^3 and the designer specifies that its undrained shear strength must be increased to at least S kN/m^2 . Soon after excavation commences, a prop is installed at a depth of 1 m below ground level. Calculate the value of S required to just prevent rotational failure of the wall about the prop when the excavation is completed. Ignore the small contribution of the pressure acting above the prop. [10]

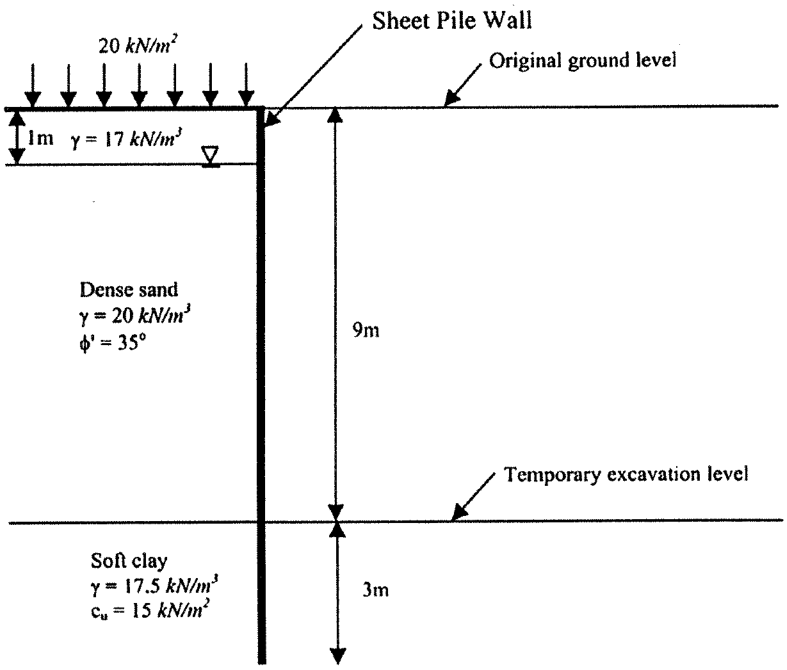

Sheet Pile Wall
20 kN/m²
Original ground level
1m γ = 17 kN/m³
Dense sand
γ = 20 kN/m³
φ' = 35°
9m
Temporary excavation level
Soft clay
γ = 17.5 kN/m³
c_u = 15 kN/m²
3m

Fig 1a

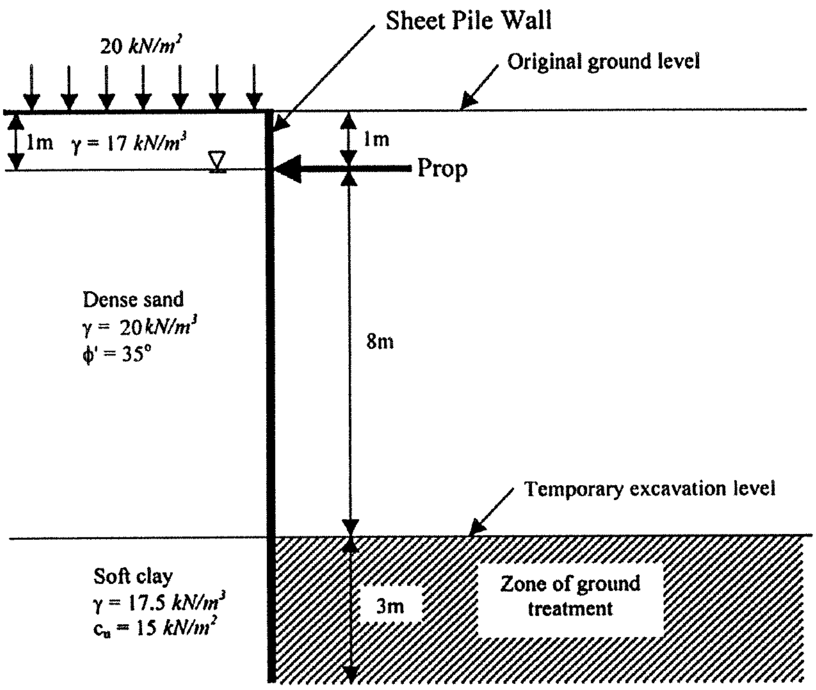

Sheet Pile Wall
20 kN/m²
Original ground level
1m γ = 17 kN/m³
1m
Prop
Dense sand
γ = 20kN/m³
φ' = 35°
8m
Temporary excavation level
Soft clay
γ = 17.5 kN/m³
c_u = 15 kN/m²
3m
Zone of ground treatment

Fig. 1b

2 You are undertaking a feasibility study for a new metro to be constructed beneath a major city. One of the lines is to run beneath a busy street, with buildings on both sides, as depicted in Fig. 2. The ground conditions are 4 m of coarse sand overlying 10 m of stiff clay, which is underlain by a coarse dense gravel. The water table is 3 m below ground level. The stiff clay has an undrained shear strength of approximately 100 kN/m^2.

Two buildings of concern to the client are depicted in Fig. 2. One building (A) is a modern multi-storey structure founded on piles bearing on the gravel. The other building (B) is of great historic value, built in the 18th century, of masonry construction and is on shallow foundations.

Advise the client on the relative merits of a reinforced concrete cut-and-cover twin tunnel box, as shown in Fig. 2, compared with two 5 m diameter bored tunnels which are shown dotted in Fig. 2. You need not discuss the relative costs. Your advice should address the following:

(a) Possible methods of wall construction for the cut-and-cover option, and likely sequence of construction of the box, including consideration of propping arrangements (calculations are not required). The walls, base and roof of the box are 1 m thick. Illustrate your proposed construction sequence with simple sketches. [8]

(b) Appropriate methods of tunnelling for the bored tunnel option, with consideration of the stability of the tunnel face and how the tunnels might be lined; [3]

(c) How the water-bearing sand and gravel strata would affect construction of either option, and what would have to be done to prevent any problems. [3]

(d) How the ground movements associated with each option might affect the two buildings. Suggest two techniques that could be adopted to prevent possible damage. [3]

(e) The instrumentation that should be specified to control the construction of either option. [3]

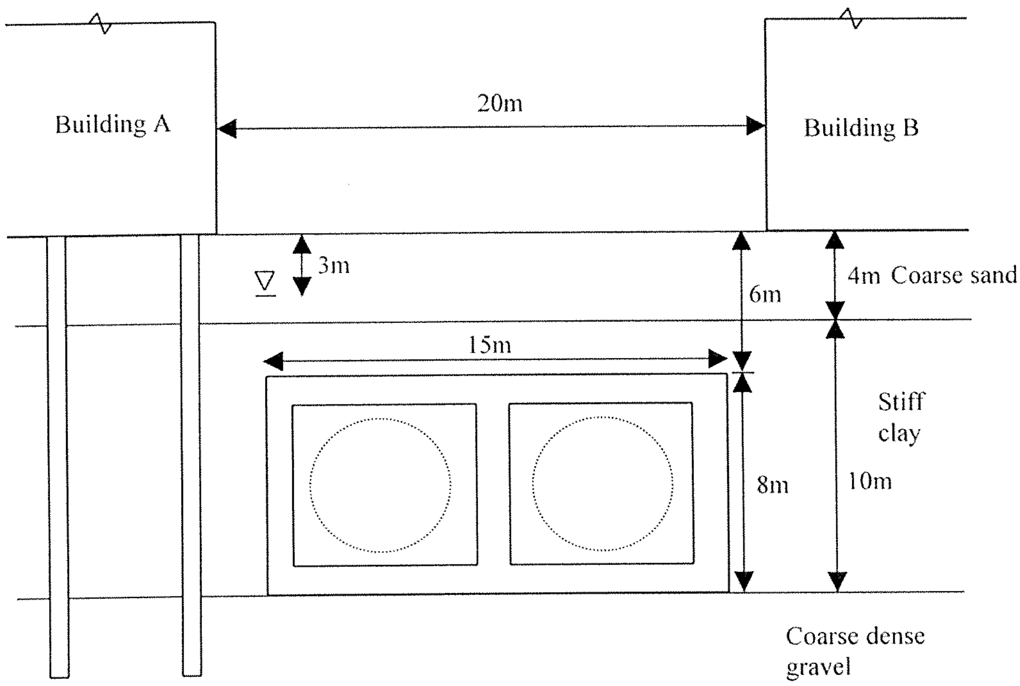


Fig. 2

(TURN OVER

3 Fig. 3 shows a tunnel structure to be constructed using reinforced concrete with a cube strength of f_{cu} = 40 MN/m^2. The roof slab acts as a prop to the retaining walls either side. The walls can be assumed to be pinned both to the roof slab and at the base. The vertical load from the roof slab coming onto the retaining walls may be neglected.

The lateral loading on the walls has the profile shown in Fig. 3. This profile includes both soil and hydrostatic loading plus an allowance for live load. Partial factors on loading are already included in the derivation of this profile.

By considering a metre long section of tunnel:

(a) Find the magnitude of the horizontal reactions exerted by the wall on the roof slab at A and by the hinge on the base of the wall at B. [4]

(b) Sketch the bending moment and shear force diagrams for the wall, showing the magnitude and location of the maximum values on each plot. [5]

(c) Assuming the wall to have constant thickness t over its entire height, estimate the thickness of wall required if it is to be singly reinforced with high yield steel of f_y = 460 MN/m^2. Determine the amount of flexural reinforcement required at the location of maximum bending moment and suggest an appropriate combination of bar size and spacing to use in the design. [6]

(d) Discuss the factors you would consider when deciding whether or not to curtail the main flexural steel bars. [3]

(e) What, if any, secondary reinforcement would be necessary for this wall? [2]

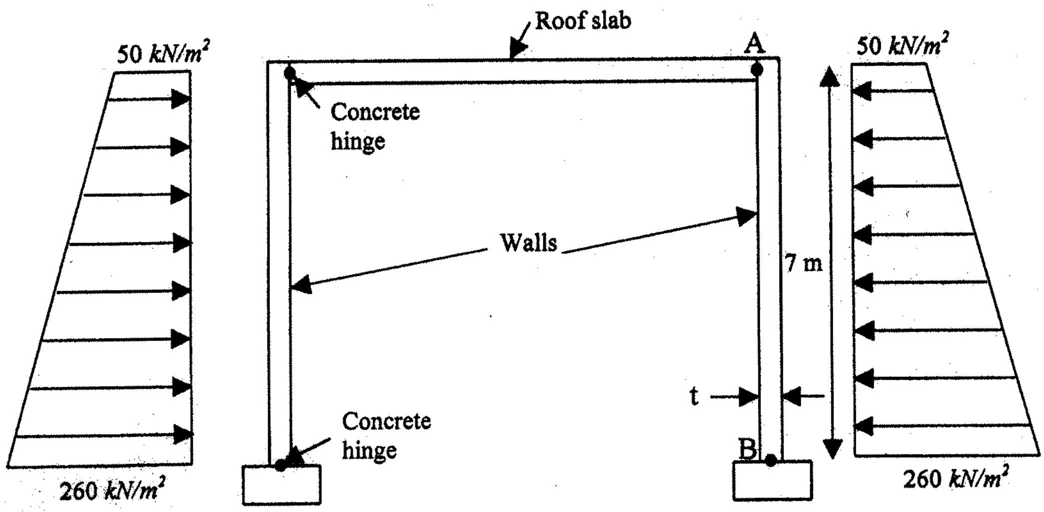


Fig. 3

(TURN OVER

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

4 A popular downhill ski can be approximately modelled as a uniform beam of overall length 1.95 m, having a cross-section as shown in Fig. 4. The outer structure is made of CFRP, and the core is made of spruce.

(a) Explain briefly the different functions of the two materials used in the construction of the ski. [2]

(b) Using the material data given on page 17 of the Materials Data Book, estimate the total mass of the ski, and its bending stiffness EI. [7]

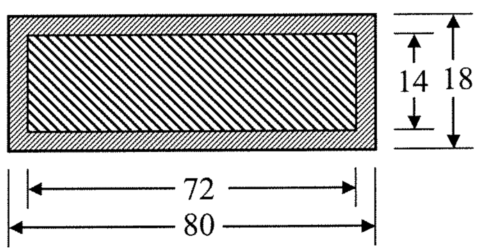
(c) In a static test, the ski is simply supported at two points 0.85 m fore and aft of the midpoint of the ski, and a mass of 45 kg is hung from the midpoint to simulate the mass of a skier. How far would you expect the midpoint of the ski to deflect under this loading? Is this amount affected by the camber or self-weight of the ski? [7]

(d) The manufacturers of the ski wish to lower its bending stiffness without changing its external dimensions, or increasing its overall mass. Discuss qualitatively how this might be done:

(i) without changing the materials from which the ski is made;

(ii) if alternative materials can be used for the core of the ski. What engineering properties would be required in the new core material?

[4]



All dimensions in mm

Fig. 4.

5 (a) Explain the concepts of an equivalent mass and equivalent spring stiffness in modelling the dynamic performance of a ski. [2]

(b) A ski of mass 2 kg and total length 1.9 m is clamped at its binding point, and its forebody stiffness (measured by applying a vertical force to the ski tip and measuring its deflection) is found to be 18 $\mathrm{Ncm^{-1}}$. If the forebody of the ski is 1.5 times as long as its afterbody, estimate its bending stiffness, *EI*. [4]

(c) The fundamental natural frequency of a uniform cantilever of length l and mass m is given by the formula

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

Find the fundamental natural frequency of the forebody of the ski, and find a suitable value for the equivalent spring stiffness if the equivalent mass of the forebody is to be taken as one half of its actual mass. [5]

(d) It is proposed to fit a tuned mass damper of mass 0.02 kg to the forebody of the ski. Draw a suitable model for the new system. Calculate the spring constant which the mass damper should have if the system is to have constant tuning. [4]

(e) Explain qualitatively the effect of damping on the performance of the system by drawing diagrams to show what would happen if the damping factor ζ were set to zero, to infinity, or to some intermediate value. Explain also the concept of 'optimal' tuning, stating why this can give a better result than constant tuning. [5]

(TURN OVER

6 As Technical Director of a medium-sized brewing company that does not at present market a 'widget' beer, you recently commissioned a team of designers to produce a design for a new widget which does not infringe any of the existing patents. The team has now reported back to you, stating that they believe they have found a possible design.

Write a proposal for the Board of your company, making the case for the future production of a version of the company's popular 'Old Sheep' bitter (currently selling 10 million cans per year) in widget form. To convince the Board to back the project, your proposal will need to cover, concisely, the following aspects of your case:

(a) A Project Plan, identifying the key stages in the future development and production of the new widget beer; [6]

(b) A Sales Forecast, showing your prediction of how sales of the new cans will develop over the next three years; [3]

(c) An extract from the Design Specification produced by your team of designers, showing not more than eight of the most important requirements for the widget, excluding production considerations; [5]

(d) A discussion of the Manufacturing Strategy for the new product, identifying up to six key issues that must be addressed before the product can be launched. [6]

SECTION C (Aerothermal Engineering)

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

7 (a) Explain why the turbofan engine is very common in high thrust civil applications. Why is a high bypass ratio desirable? Briefly explain what factors limit the bypass ratio. [5]

(b) A two-shaft turbofan engine is fitted to an aircraft. At cruise conditions, the stagnation temperature T_{02} and stagnation pressure P_{02} at inlet to the engine are 245 K and 31 kPa respectively. The fan has a stagnation pressure ratio of 1.65 and an isentropic efficiency of 0.88. Find the stagnation pressure and the stagnation temperature at exit from the fan. [3]

(c) The ambient pressure is 20 kPa. Determine the exit velocity of the bypass nozzle. [2]

(d) After the core air-stream has passed through the fan, it enters the core compressor. The core compressor has a stagnation pressure ratio of 22. The stagnation temperature T_{03} at exit from the core compressor is 751 K. The high-pressure turbine has an isentropic efficiency of 0.90. 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 exit from the high-pressure turbine. [4]

(e) The bypass ratio is 8.5. The low-pressure turbine has an isentropic efficiency of 0.92. Determine the stagnation temperature T_{05} and the stagnation pressure P_{05} after the low pressure turbine. [4]

(f) Determine the velocity V_9 of the core jet. [2]

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, $\gamma = 1.4$, $R = 287\ \mathrm{Jkg^{-1}K^{-1}}$ and $c_p = 1010\ \mathrm{Jkg^{-1}K^{-1}}$.

(TURN OVER

8 Fig. 5 shows, schematically, the mean-radius of the single stage high-pressure turbine of a two-shaft turbofan engine. The velocity is axial at inlet to the stator. The direction of the *absolute* velocity at exit from the stator and the direction of the *relative* velocity at exit from the rotor are shown. The axial velocity V_x is constant throughout the stage. The blade speed U is constant across the rotor.

(a) Explain why the turbofan normally has more than one shaft. [2]

(b) Explain why the core compressor will have more stages than the high pressure turbine. [2]

(c) The ratio of the axial velocity V_x to the blade speed U is 0.36 in the high-pressure turbine. Determine the relative flow angle at inlet to the rotor and the absolute flow angle at exit from the rotor. Sketch the velocity triangles at inlet to and exit from the rotor. [5]

(d) For a turbine stage, the work output per unit mass flow w_x is given by Euler's Work Equation

$$w_x = U(V_{\theta 2} - V_{\theta 3})$$

where $(V_{\theta 2} - V_{\theta 3})$ represents the change in tangential velocity across the rotor blades. The axial velocity V_x is 210 ms^{-1}. Find the work done per unit mass flow by the high-pressure turbine. The stagnation temperature at inlet to the high-pressure turbine is 1850 K. Hence determine the stagnation temperature at exit from the stage. [4]

(e) Determine the stagnation pressure at the exit of the high-pressure turbine if its isentropic efficiency is 0.88 and the inlet stagnation pressure is 1 MPa. [3]

(f) Calculate the static temperature and the static pressure at the exit of the rotor. Hence determine the area of the annulus at the exit of the rotor if the core mass flow rate is 50 kgs^{-1}. [4]

Assume that the combustion products behave as a perfect gas with the same properties as air. Assume that for air, $\gamma = 1.4$, $R = 287 \text{ Jkg}^{-1}\text{K}^{-1}$ and $c_p = 1010 \text{ Jkg}^{-1}\text{K}^{-1}$.

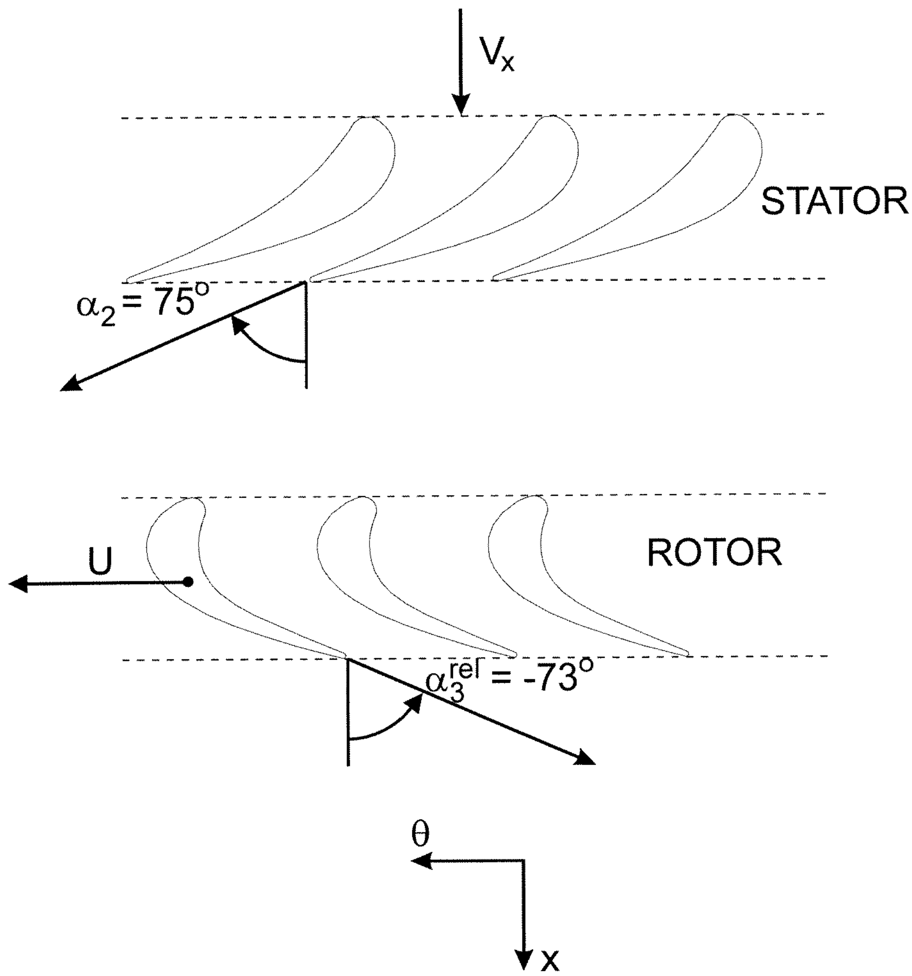


Fig. 5

(TURN OVER

9 (a) A simple turbojet cruises at Mach 0.85. The stagnation pressure and the stagnation temperature are 31 kPa and 248 K respectively at entry to the compressor. Determine the ambient pressure, the ambient temperature and the speed of the aircraft. [3]

(b) A stationary test is carried out on the ground. At the same compressor pressure ratio as at cruise, it is found that the mass flow rate of air through the engine is 10 kg/s and the turbine entry temperature is 1800 K when the ambient pressure is 101 kPa and the ambient temperature is 288 K. Show that the stagnation temperature T_{04} at turbine entry is 1550 K at cruise conditions in flight. Hence find the mass flow rate of air $\dot{m}$ at the same conditions. The propelling nozzle and the stator blades of the single stage turbine are choked. [4]

(c) The turbojet has a simple convergent propelling nozzle with a throat area of 0.016 m^2. The ratio of the inlet stagnation temperature T_{04} to exit stagnation temperature T_{05} of the turbine is 1.27. For the cruise condition, find the stagnation pressure P_{05} at inlet to the propelling nozzle given that it is choked. Hence determine the velocity and pressure at the exit face of the nozzle. [4]

(d) Why is the pressure at the exit face of the nozzle not equal to the ambient pressure? [2]

(e) Determine the gross thrust at cruise conditions. [3]

(f) Determine the gross thrust of the engine during the test on the ground. [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, $\gamma = 1.4$, $R = 287\ \text{Jkg}^{-1}\text{K}^{-1}$ and $c_p = 1010\ \text{Jkg}^{-1}\text{K}^{-1}$.

The non-dimensional mass flow rate of air through a choked nozzle of area A is given by

$$\frac{\dot{m}\sqrt{c_p T_0}}{A P_0} = 1.281$$

where T_0 is the stagnation temperature and P_0 is the stagnation pressure at entry to the nozzle.

SECTION D (Electrical Engineering)
Do not answer more than **two** *questions from this section.*

10 (a) Explain, with the aid of diagrams, what is meant by:

(i) Positive resist technology;
(ii) Negative resist technology. [3]

(b) Describe the lithographic process currently used in the manufacture of silicon transistors and discuss the possible future developments in optical lithography which may enable the printing of smaller features than are currently possible. Discuss the relative merits of X-ray lithography and e-beam lithography for next generation fast transistors. [8]

(c) Outline the benefits of step and repeat exposure with reduction optics in comparison to whole wafer exposure. [3]

(d) An e-beam lithography system can step $0.05\ \mu m$ at a rate of $40\ MHz$. Assuming the beam current density is sufficient to harden the resist, estimate the time, in hours, taken to write a pattern, which occupies 20% of the area of a $200\ mm$ diameter wafer. State all assumptions you have made and comment on the answer obtained. [6]

(TURN OVER

11 You desire to design a metal oxide semiconductor field effect transistor (MOSFET) with a transit time of 5 ps using a 1 μm thick layer of n-type semiconductor on an insulating substrate.

(a) Use Gauss' theorem to derive the formula for the gate voltage needed to turn off the MOSFET in the ideal case. [6]

(b) What is the maximum uniform donor concentration, in case (a) if the gate voltage is 0.5V? The permittivity of the semiconductor is $0.8\text{x}10^{-10}\ \text{Fm}^{-1}$. [3]

(c) Derive an expression for the maximum source-drain distance L to achieve the desired transit time, in terms of the mobility and drain voltage.

If the supply voltage is 2 V, what value of L would achieve the desired transit time if the semiconductor has a mobility of $0.4\ \text{m}^2\text{V}^{-1}\text{s}^{-1}$? [4]

(d) What is the resistance of the source-drain channel in case (c) if the width to length ratio (*W/L*) is set at 50? [3]

(e) What is the capacitance per unit area of the gate? [4]

The charge of the electron is 1.6×10^{-19} C.

12 (a) Sketch a velocity-field diagram for the electrons in Gallium Arsenide, GaAs. [2]

(b) Explain what is meant by the scattering-limited velocity v_s. Explain what causes this scattering limited velocity. [3]

(c) What is the energy U in electron-volts of the dominant phonon if v_s is equal to 10^5 ms^{-1} and the electron effective mass m^* is equal to 0.1 units ? [3]

(d) What is the scattering limited velocity of holes in case (c), if the hole effective mass m^* is equal to 0.3 ? [3]

(e) The mobility of electrons in GaAs is 0.1 $m^2V^{-1}s^{-1}$. GaAs with a donor density of $2x10^{21}$ m^{-3} is used to make a MESFET operating at a supply voltage of 1.5 V. At what value of source-drain length does the conduction become scattering limited? [3]

(f) To what transit time within the GaAs does this correspond ? [3]

(g) What is the saturated source-drain current density in this condition? [3]

The charge of electron $= 1.6\times10^{-19}$ C
The mass of electron $= 9.11\times10^{-31}$ kg

SECTION E (Information Engineering)
Do not answer more than **two** *questions from this section*

13 This question considers the management of hardware peripheral resources.

(a) Most processors provide a user mode and a supervisor (or kernel) mode.

(i) With respect to the operating system, what are the characteristics of each of these modes and what is the mechanism used to switch between them? [3]

(ii) Why is providing device management a useful component of an operating system? In particular, consider the case when there may be multiple competing processes requiring access to the same hardware resource. [4]

(b) A number of mechanisms can be used internally within a device driver to manage a hardware resource. These mechanisms include polling, interrupts or direct memory access (DMA).

Briefly discuss the features and the relative merits of each of these three mechanisms. [5]

For the following, classify (with reasons) whether polling, interrupts or DMA should be used to control that particular peripheral:

(i) Keyboard controller;
(ii) Sampling an A/D converter (e.g. to check battery voltage);
(iii) Disk controller;
(iv) RS232 serial interface.

[8]

14 (a) Consider a multi-user, multi-processing operating system, such as UNIX. Write brief notes on the support provided by the operating system for:

- (i) Process Management; [3]
- (ii) Memory Management; [3]
- (iii) Device Management. [2]

What are some of the hardware features required in the processor and support hardware in order to support these facilities? [3]

(b) For a mobile or wearable device, a UNIX-style operating system is not appropriate and one designed for embedded systems may be more suitable. Discuss some of the ways in which an embedded operating system would differ from that discussed in part (a). [4]

Choose a mobile or wearable device of which you have experience. Is an operating system appropriate for this class of device? Briefly justify your answer. [2]

(c) For battery powered devices, an additional responsibility of the operating system can be to provide power saving facilities. Discuss some of the methods that can be used by the operating system to conserve system power. You should consider both the CPU and any associated peripherals. [3]

(TURN OVER

15 You are required to design a low-cost low-power infra-red network suitable for room area communications between mobile (wearable) and fixed devices. The network should provide communications facilities and also location information. Make short notes on the following aspects of your design:

(i) Choice of transmission medium; [4]
(ii) Modulation scheme; [4]
(iii) Collision avoidance and resolution; [4]
(iv) Packet structure; [4]
(v) Speed of communications; [2]
(vi) Quality of location information. [2]

END OF PAPER