PART IB PAPER 8 2005 DR M. KITSON

SECTION A *Business Economics*
Answer not more than one question from this section

1 (a) Describe the model of perfect competition. [6]

Assumptions of perfect competition:
Many firms
Identical cost functions, U shaped
Homogeneous products
Free entry and exit to market
Perfect information

Outcome of perfect competition:

P=min AC=MC

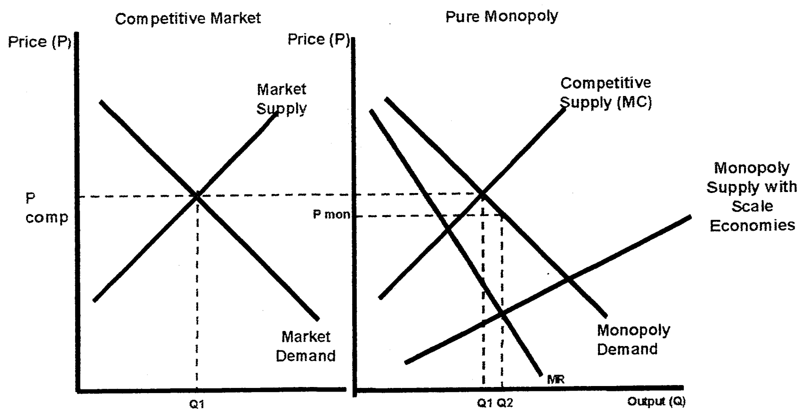
(b) Why is perfect competition so rare? [4]

Assumptions difficult to meet eg markets are normally characterised by heterogeneous products, barriers to entry and lack information. Better candidates may observe that ICT is moving some markets closer to perfect competition.

(c) Under what circumstances would you expect a monopoly to charge a lower price than if the industry was operating under perfect competition? [6]

Monopoly may charge a lower price if they can exploit economies of scale (see Fig 1 below). Monopolies may also be able to increase productivity if they are better at R+D or there are failures in the capital market which monopoly profits can overcome.

Fig1 Pure Monopoly and Economies of Scale



(d) What impact would a decrease in interest rates have on the level of investment in an economy? [4]

A decrease in interest rates would be expected to decrease the savings rate in the economy and increase the demand for investment. This implies that the multiplier increase due to the change in the savings rate and the autonomous injections into the economy increase due to the increase in investment. As national income is equal to the multiplier times the autonomous expenditure this implies national income will increase as a result of the increase in interest rates. As consumption is a function of the savings rate and the amount of income, consumption will increase. If investment increases then in equilibrium savings will increase, as savings must equal investment. Additional effect via exchange rate: exchange rate will fall due to outflow of hot money reducing the price of exports and increasing the price of imports: this will further increase aggregate demand.

2 (a) What is an oligopoly? [4]

A market dominated by a few large firms i.e. "Competition amongst the few"
High level of market concentration
Concentration ratio is the market share of the leading firms
Each firm produces branded / differentiated products
Entry barriers exist – long run supernormal profits
Mutual interdependence between competing firms
Intensive non-price competition is a common feature of oligopoly
Periodic aggressive price wars (fights for market share /dominance)
Strong tendency for many market structures to tend towards oligopoly in the long run

(b) Why might oligopolists wish to collude with each other? [4]

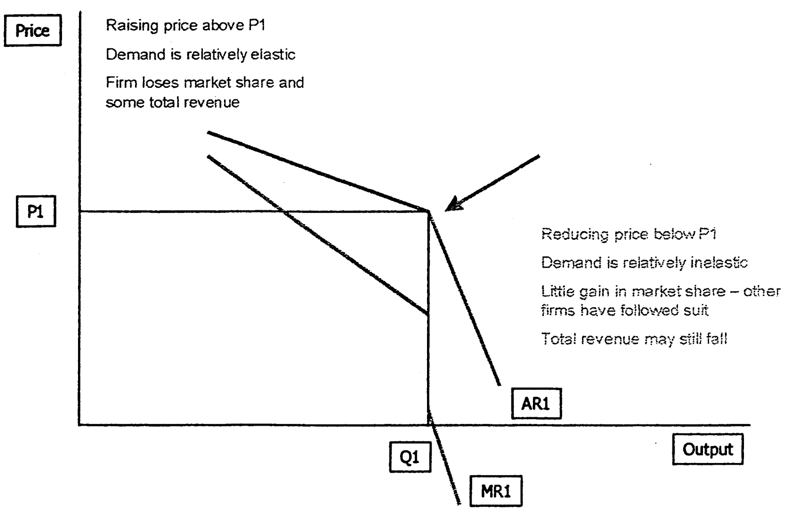
Collusion represents an attempt by firms to recognize their interdependence and act together rather than compete

Collusion – seen as a move towards joint-profit maximization
Requires control over the market supply of a commodity
Overt collusion: creation of a price fixing arrangement with a producer cartel responsible for allocating output / supply within the market
Tacit collusion: dominant firm 'price leadership' (one firm's price changes are matched by the other firms) or barometric-firm leadership (price leader the one judged to have best knowledge of prevailing market conditions)

(c) Explain the kinked demand curve theory. [6]

Rival firms are assumed to follow a price cut (making demand relatively inelastic) but firms are assumed not follow a price increase (making demand relatively elastic) (see below).

The Kinked Demand Curve



(d) Describe the likely effects on the UK economy if house prices were to *fall significantly* over the next two years. [6]

A fall in house prices will decrease household wealth. This will reduce consumption and through the multiplier will reduce national income. It will increase savings out of current income and decrease the marginal propensity to consume. It may result in a rise in indebtedness and lead to negative equity (ie where the current value of a house is less that outstanding debt on that property).

PART IB PAPER 8 SECTION B JUNE 2005
QUESTIONS 3-5 DR SPG MADABHUSHI
CIVIL AND STRUCTURAL ENGINEERING

Q.1

1

Sand $\phi' = 35°$

$K_a = \dfrac{1-\sin\phi'}{1+\sin\phi'} \Rightarrow K_a = \dfrac{1-\sin 35°}{1+\sin 35°} = 0.27$

$K_p = 1/K_a = 3.7$

Stiff clay

For undrained conditions, applicable only to temporary, short term situations:

- total active pressure $\sigma_h = \sigma_v - 2s_u$
  where s_u = undrained shear strength
  – sometimes also depicted as c_u
  and σ_v = total vertical stress

- total passive pressure $\sigma_h = \sigma_v + 2s_u$

(a) Active side of wall

Assume unit weight of water $\gamma_w = 10\ kN/m^3$

Water pressure at bottom of sand $= 10 \times 14$
$= 140\ kPa$

At bottom of sand, $\sigma_v = (10 \times 10) + (4 \times 20)\ kPa$
$= 180\ kPa$

Pore pressure $u = 140\ kPa$

$\therefore \sigma_v' = \sigma_v - u = 180 - 140 = 40\ kPa$

$\therefore \sigma_h' = K_a \sigma_v' = 0.27 \times 40 = 10.8\ kPa$

$\therefore \sigma_h = 140 + 10.8 = \underline{151\ kPa}$

At top of clay $\sigma_v = 180\ kPa$

$\therefore \sigma_h = \sigma_v - 2s_u = 180 - (2 \times 75) = \underline{30\ kPa}$

At bottom of wall $\sigma_v = 180 + 2 \times 20 = 220\ kPa$

$\therefore \sigma_h = \sigma_v - 2s_u = 220 - (2 \times 75) = \underline{70\ kPa}$

Passive side (dewatered side) of wall

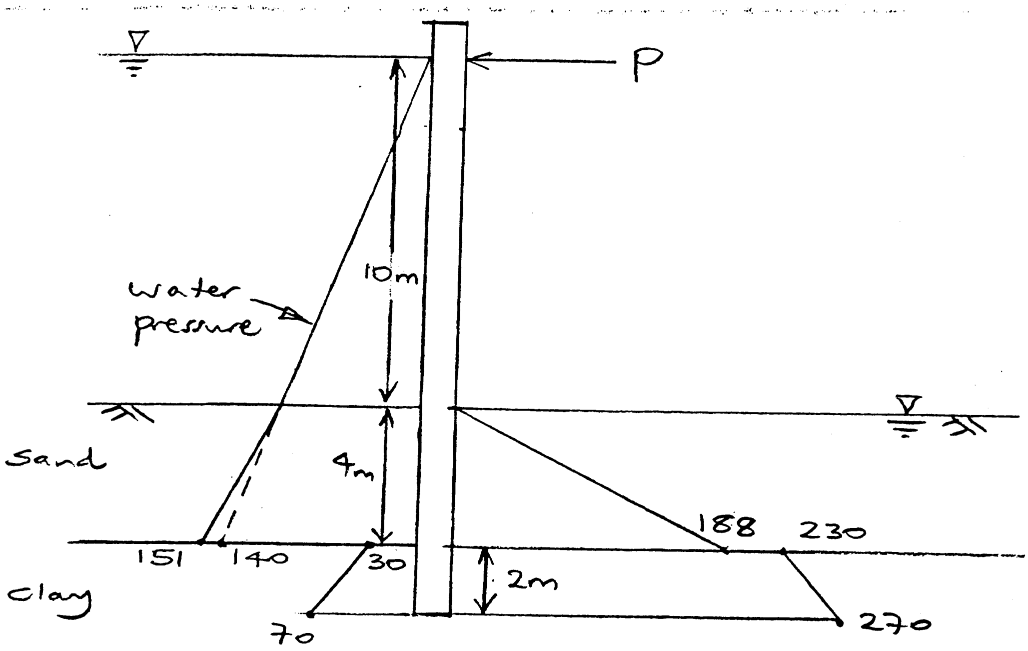
At bottom of sand, $\sigma_v = 4 \times 20 = 80$ kPa

$u = 4 \times 10 = 40$ kPa

$\therefore \sigma_v' = \sigma_v - u = 80 - 40 = 40$ kPa

$\therefore \sigma_h' = K_p \sigma_v' = 3.7 \times 40 = 148$ kPa

$\therefore \sigma_h = \sigma_h' + u = 148 + 40 = \underline{188 \text{ kPa}}$



At top of clay $\sigma_v = 4 \times 20 = 80$ kPa

$\therefore \sigma_h = \sigma_v + 2 s_u = 80 + (2 \times 75) = \underline{230 \text{ kPa}}$

At bottom of wall $\sigma_v = 80 + 2 \times 20 = 120$ kPa

$\therefore \sigma_h = \sigma_v + 2 s_u = 120 + (2 \times 75) = \underline{270 \text{ kPa}}$

Total 'active' force, P_A (including water pressure)

$= \left(\frac{1}{2} \times 140 \times 14\right) + \frac{1}{2}(151 - 140) \times 4 + (30 \times 2) + \frac{1}{2}(70 - 30) \times 2$ kN/m

$= 980 + 22 + 60 + 40$

$= \underline{1102 \text{ kN/m}}$

Total 'passive' force, P_P

$= \left(\frac{1}{2} \times 188 \times 4\right) + (230 \times 2) + \frac{1}{2}(270 - 230) \times 2$ kN/m

$= 376 + 460 + 40 = \underline{876 \text{ kN/m}}$

(3)

$\therefore$ Resolving horizontally, $P = P_A - P_P$

$\therefore P = 1102 - 876 = \underline{226 \text{ kN/m}}$

[8]

(b) Factor of safety against rotational failure

$$= \frac{\text{Total 'passive' moment}}{\text{Total 'active' moment}}$$ (taking moments about prop)

Total 'passive' moment

$= \left(\frac{1}{2} \times 188 \times 4\right) \times 12.7 + (230 \times 2) \times 15 + \frac{1}{2}(270 - 230) \times 2 \times 15.3$ kN-m/m

$= 4775 + 6900 + 612$

$= \underline{12,287}$ kN-m/m

Total 'active' moment (including water pressure):

$= \left(\frac{1}{2} \times 140 \times 14\right) \times 9.3 + \frac{1}{2}(151 - 140) \times 4 \times 12.7 + (30 \times 2) \times 15 + \frac{1}{2}(70 - 30) \times 2 \times 15$ kN-m/m

$= 9114 + 279 + 900 + 612$

$= \underline{10,905}$ kN-m/m

$\therefore$ Factor of safety $= \dfrac{12,287}{10,905} = \underline{\underline{1.13}}$

[4]

(This is very low. One way to increase the factor of safety is to place rockfill on river bed on dewatered side, prior to dewatering.)

(c) Placing 1m of loose rockfill on the river bed on 'passive' side effectively adds a surcharge of $1 \times 20 = 20$ kPa

This increases the passive pressures acting on the wall:

At top of sand $\sigma_v = 20$ kPa

$u = 0$

$\therefore \sigma_v' = \sigma_v = 20$ kPa

$\therefore \sigma_h' = K_p \sigma_v' = 3.7 \times 20 = 74$ kPa

$\sigma_h = \sigma_h' = \underline{74 \text{ kPa}}$

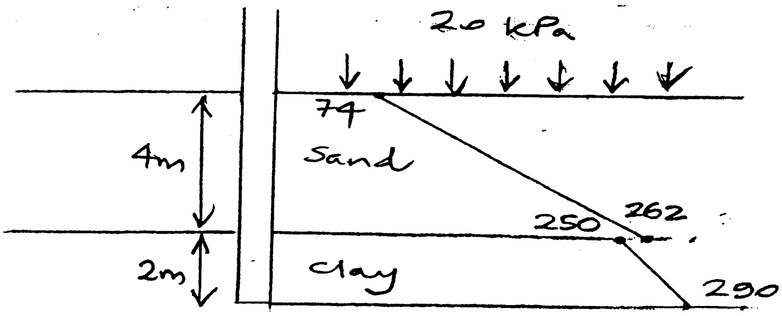
At bottom of sand $\sigma_v = 20 + (4 \times 20) = 100$ kPa

$u = 4 \times 10 = 40$ kPa

$\therefore \sigma_v' = 100 - 40 = 60$ kPa

$\therefore \sigma_h' = K_p \sigma_v' = 3.7 \times 60 = 222$ kPa

$\sigma_h = \sigma_h' + u = 222 + 40 = \underline{262 \text{ kPa}}$



Increased pressure distribution on 'passive' side

At top of clay $\sigma_v = 20 + (4 \times 20) = 100$ kPa

$\therefore \sigma_h = \sigma_v + 2S_u = 100 + (2 \times 75) = \underline{250 \text{ kPa}}$

At bottom of clay, $\sigma_v = 100 + (2 \times 20) = 140$ kPa

$\therefore \sigma_h = 180 + 2S_u = 140 + (2 \times 75) = \underline{290 \text{ kPa}}$

$\therefore$ Total passive force, P_p increased to:

$\frac{1}{2}(74 + 262) \times 4 + \frac{1}{2}(250 + 290) \times 2$ kN/m

$= 672 + 540 = \underline{1212 \text{ kN}}$

Passive force P_p increased to 1212 kN

$\therefore$ Prop force $P = P_A - P_p = 1102 - 1212$

$= -110$ kN/m

This means that the prop force P required for equilibrium becomes negative, i.e. a ~~tension. In practical terms, it~~ means that the temporary prop may not (in theory) be needed in the immediate short-term.

[6]

(d) However, in practice, it is dangerous to rely on undrained conditions operating for any significant period — it may be OK. for the short term, perhaps long enough to construct the tunnel structure, but considerable caution needed.

As drainage takes place in the clay (and this would be accelerated by any sand lenses in the clay), the active pressure would increase and the passive pressure would decrease.

[2]

Crib for Question 2

(a) In rock, the principal problem will be the excavatability of the rock – wear on the tunnel machinery, slow progress. In the clays tunnel stability will depend on the stability ratio, $N = (\sigma_v - \sigma_t)/c_u$ where σ_v is the total vertical stress at tunnel axis level and σ_t is the temporary support pressure (if any), and c_u is the undrained shear strength of the clay. For tunnels at 20m depth in the stiff clays, N for open face tunnelling will be in the range 1.6 –2.7 (assuming unit weight of 20 kN/m^2), which means that *open face mode* will be safe. For tunnels in the soft clays, N will be in the range 10-20 which means the tunnels can only be constructed in *closed face mode*, ie with face support. To control the water in the sands the tunnels must be constructed either in open face mode using compressed air, or in ground that has been treated by dewatering or grouting, or in closed face mode using slurry or earth pressure balance machines. [6]

(b) Segmental linings are in segments, usually made of precast concrete or spheroidal graphite iron, and are used in tunnelling machines (circular tunnel section). Bolted segments could be used in all of the anticipated ground conditions, but no lining may be necessary for the rock if it is strong enough; expanded segments can only be used in the stiff clays. Sprayed concrete linings could only be used in the rock and the stiff clays, because the excavated unlined tunnel has to be temporarily stable to enable the sprayed concrete to be applied. [3]

(c) Ground movements caused by bored tunnelling invariably result in a settlement trough. Masonry buildings are most susceptible to damage (cracking) because of tensile strains induced. This is associated with curvature induced in the building, caused by differential settlement; total settlement, if it is uniform, is not a particular problem. Hogging mode is usually more damaging than sagging mode. [3]

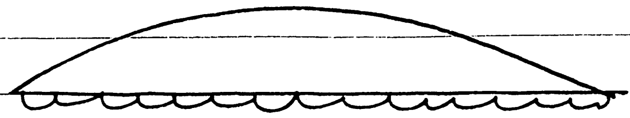
(d) Reinforced concrete boxes are constructed first and then jacked from a pit on one side of the railway to the other (as in Boston, USA). Ground freezing can be used to stabilize the soft clay and sands above and in the tunnel faces. Ground movements need to be carefully monitored to avoid excessive heave or settlement to the railway tracks. [3]

(e) Instrumentation and monitoring provide forewarning of unexpected events, a means of facilitating adjustment of construction procedures in a safe and systematic manner (the Observational Method), a means of controlling the quality of the work, records of movements of ground and buildings for repair purposes, and an important source of data for future projects. Typical examples of instrumentation are settlement monitoring stations, subsurface rod extensometers to measure vertical movements, subsurface inclinometers to measure horizontal movements, piezometers to measure pore pressures, and pressure cells to measure total stress changes. [5]

Q 3.(a)

Case 1

S.S.

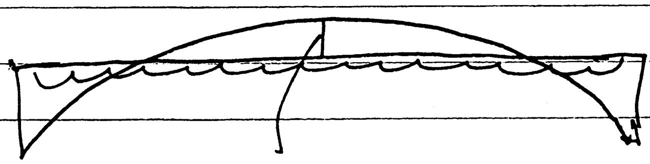


150 kN/m²

$$\frac{\overline{wL^2}}{8} = \frac{150 \cdot 15^2}{8}$$

$= 4220$ kNm/m

Case 2



$$\overline{wL^2}/12 = 2813 \text{ kNm/m}$$

$= 4220 - 2813$

$= 1407$ kNm/m

(b)

∴ At C need to design for singly reinforced $= 4220$ kNm/m.

Maximum moment for singly reinforced

$$= 0.15 f_{cu} b d^2 = 4220 \text{ kNm}$$

$b = 1000$ mm $\quad f_{cu} = 30$

$$\therefore d^2 \geq \frac{4220 \cdot 10^6}{30 \cdot 0.15 \cdot 1000}$$

$$\Rightarrow d \geq 970 \text{ mm}$$

(c) Overall depth = 1600 mm

Cover = 40 mm
rebar assume 40 mm

$\therefore$ Effective depth = 1540 mm.

$\therefore$ Guess $\frac{x}{d} = 0.5$ $\therefore$ lever arm $= \frac{3}{4}\, 1540$

$= 1155$ mm.

$$\therefore 0.87.\overset{=460}{f_y}.\ A_s\overset{1155}{h} = 4220.10^6$$

$$\Rightarrow A_s = \frac{4220.10^6}{0.87.460.1155} = 9130\ \text{mm}^2/\text{m}$$

Steel force = $0.87.\ f_y.\ 9130 = 3654$ KN/m

$\therefore$ Concrete stress $= 0.4.\ 30 = 12$ MPa.

$\therefore$ Depth of neutral axis = d_n

$$d_n \cdot \cancel{1000}.12 = 3654.\cancel{10^3}$$
$$\Rightarrow d_n = 305 \text{ mm}$$

$\therefore$ Corrected lever arm $= 1540 - 305/2$
$= 1388$ mm.

$$\therefore A_s \text{ required} = \frac{4220.10^6}{0.87.460.1388} = 7600\ \text{mm}^2/\text{m}$$

(Could iterate again but not worth it)

At (c) use 2/3 of this ($5067\ mm^2/m$)

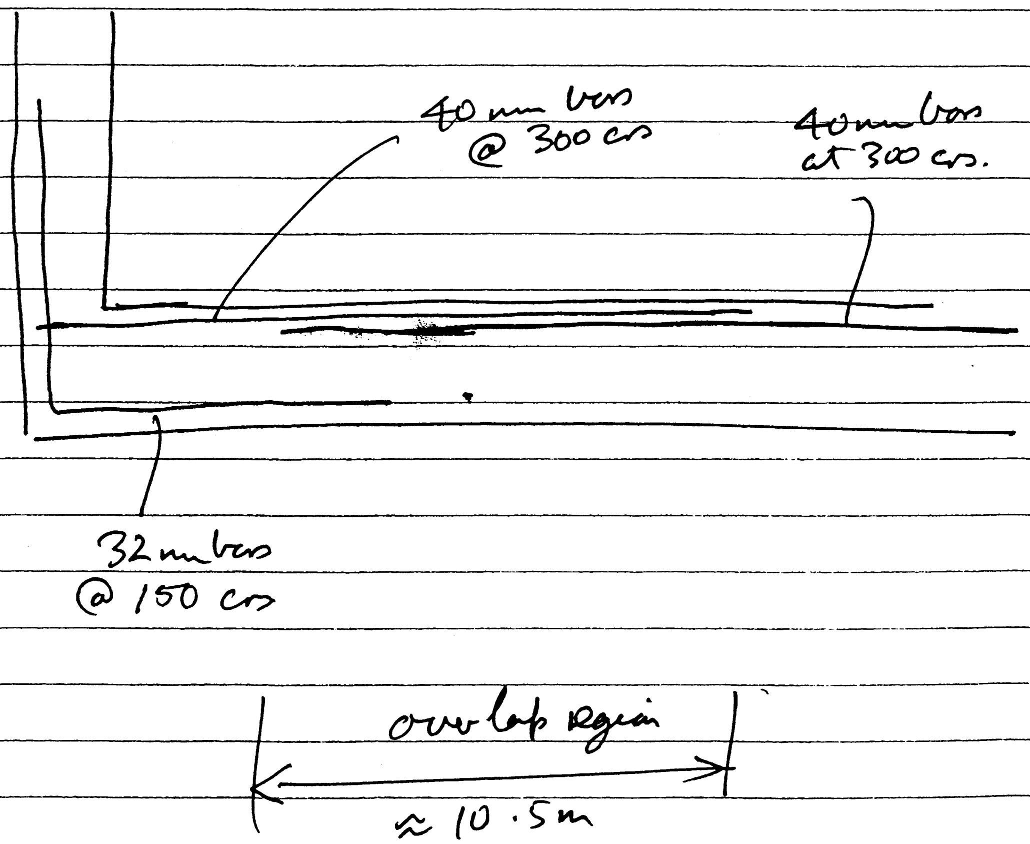
40 mm bars $\quad$ area $= \frac{\pi d^2}{4} = 1256\ mm^2$

$\therefore$ Need $\frac{7600}{1256} = 6$ bars/m

$=$ 40 mm bars @ 150 crs. at C

At A & B could use 32mm bars
(area = 64% of 40 mm bars) at same centres.

(d)



(e) Structures in ground need to have very little cracking. Minimum thickness only ensures strength so make thicker to reduce cracking & deflections.

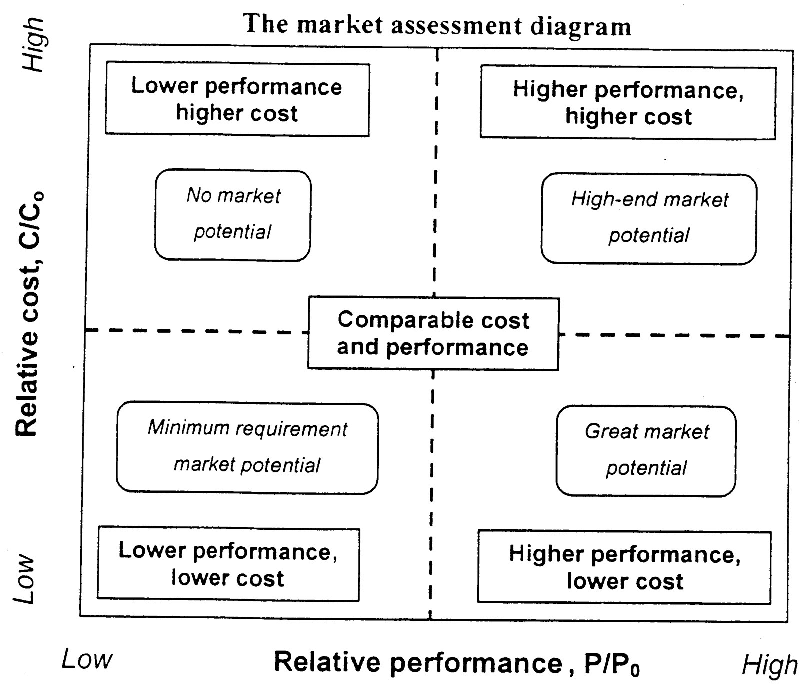
PART IB PAPER 8 SECTION C 2005
QUESTIONS 6 - 8 DR VS DESHPANDE
MECHANICS, MATERIALS AND DESIGN

Question 6:

(a) The primary considerations are:

1. Is the new material technically viable: What are its properties? What applications might a material with these properties fill?
2. What is the cost-price-value balance: What will the consumer pay for a product with the performance that the new material allows? Is the value to the consumer greater than the cost?
3. What are the characteristics of the market at which this product is targeted: Is the market big enough, and growing fast enough, to justify investment?
4. If the answers to all of the above are positive, who will get the profit: That depends on the degree to which the material and manufacturing technologies are protected by patents, or able to be kept secret, and by specialised procedures not easily reproduced by competitors.

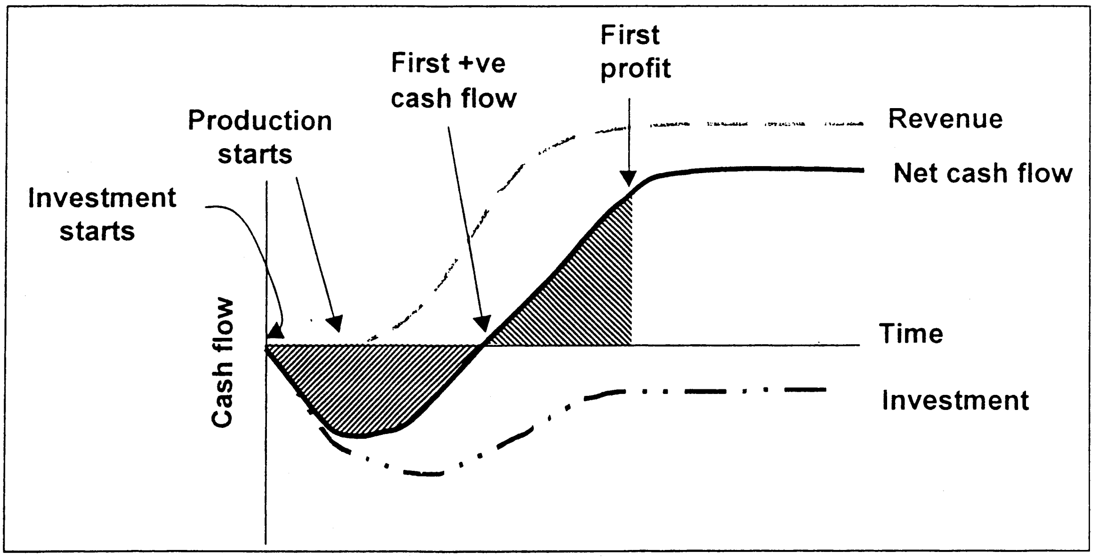
(b)



The market assessment diagram plots the performance of competing products against their price, both normalised by those of the current market leader. The quadrant in which the product made from the new material lies identifies the market opportunities.

(c) Metal foams compete with crushable tubular structures for application as energy absorption application in automobiles. Metal foam are isotropic and versatile in that that they can be produced in a variety of shapes to fit in almost any location in the automobile. On the other hand, crushable tubular structures are good energy absorbers in one direction only and cannot be used locations such as side doors etc. Thus metal foams have a higher performance than these tubular structures in some applications where the impact direction is unknown. However, they are more expensive that tubular structures. Thus metal foams may have application at the "high-end" of the market.

(d) In the schematic below, the dash-dot line shows the rate of investment (£/year) as a function of time. The dashed line shows the revenue rate (£/year) generated by sales of the product. The full line labeled "Net cash flow" shows the difference. Initial investment is required before production can start, leading to a negative cash flow. As production starts and grows, income is generated, ultimately leading to a positive cash flow. The product first generates a profit when the area under the curve on the positive side first exceeds that on the negative side. Thereafter there is a positive cash flow and an annual profit until, through obsolescence, the sales of the product decline and the revenue rate falls below the operating expenses.



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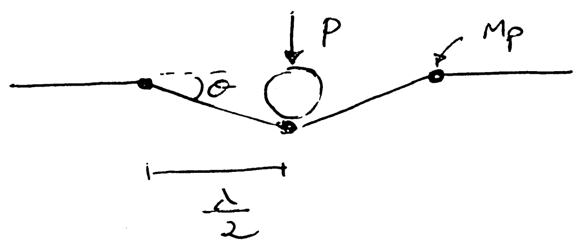
a)



$$P \frac{\lambda}{2} \theta = 4 M_p \theta + (\sigma_p \lambda)\left(\frac{\lambda}{4} \theta\right)$$

$$P = \frac{2\sigma_Y h^2}{\lambda} + \frac{\sigma_p \lambda}{2}$$

b)

$$\frac{dP}{d\lambda} = -\frac{2\sigma_Y h^2}{\lambda^2} + \frac{\sigma_p}{2} = 0$$

$$\lambda^2 = 4h^2 \sqrt{\frac{\sigma_Y}{\sigma_p}}$$

$$\lambda = 2h \sqrt{\frac{\sigma_Y}{\sigma_p}}$$

$$P_I = h\sqrt{\sigma_Y \sigma_p} + h\sqrt{\sigma_Y \sigma_p}$$

$$= 2h \sqrt{\sigma_Y \sigma_p}$$

(c) For uniform compression $P_U = \sigma_p L$

Equating $P_U = P_I$

$$\sigma_p L = 2h \sqrt{\sigma_Y \sigma_p}$$

$$\frac{L}{h} = 2\sqrt{\frac{\sigma_Y}{\sigma_p}}$$

(d) A low strength foam spreads the load over a wider area ($\lambda = 2h\sqrt{\frac{\sigma_y}{\sigma_p}}$, ie lower σ_p ⇒ higher λ). This results in

(i) a greater fraction of the energy absorber is used in the process

(ii) lower strains in the face sheet for the same level of indentation ~~thus~~ reducing the possibility of face sheet tearing.

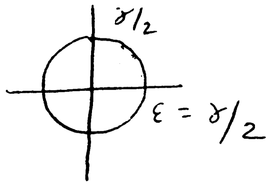
8.

(a) Relative density is defined as the ratio of the density of the cellular material to the density of the solid from which it is made

$$\bar{\rho} = \frac{2tl + \sqrt{2}\,tl}{l^2} = (2+\sqrt{2})\frac{t}{l}$$

(b)

(i)



$$\varepsilon = \frac{\gamma}{2}$$

(ii) assume unit depth into the paper

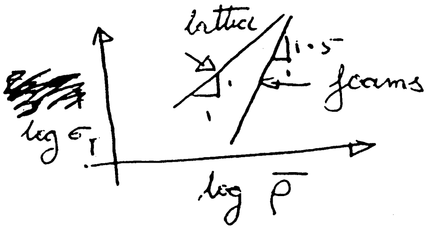
$$\text{Internal work} = \sqrt{2}\,t\,l\,\frac{\gamma}{2}\,\sigma_T$$

Equating internal & external work

$$\tau_Y\, l^2 \gamma = \frac{\sigma_T\, t l}{\sqrt{2}}\,\gamma$$

$$\frac{\tau_Y}{\sigma_T} = \frac{1}{\sqrt{2}}\frac{\bar{\rho}}{(2+\sqrt{2})}$$

(c) The stiffness & strength of foam scales as $\bar{\rho}^3$ & $\bar{\rho}^{1.5}$, respectively. as they deform by bending of the cell walls. On the other hand, lattice materials deform by stretching of the cell walls with their stiffness & strength thus scaling with $\bar{\rho}$.
Thus the stiffness & strength of foams is more sensitive to $\bar{\rho}$.



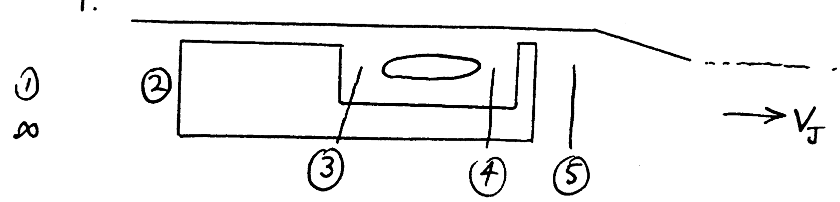
Engineering Tripos Part IB 2005 SECTION D

Paper 8 Selected Topics Aerothermal Engineering

QUESTIONS 9–11

DR TP HYNES

9.



(a) $p_{02} = 76.5\ kPa$

$T_{02} = 304.6\ K$

$$\eta_c = \frac{T_{03}^{\,IS} - T_{02}}{T_{03} - T_{02}} = \frac{\left(\frac{p_{03}}{p_{02}}\right)^{\frac{\gamma-1}{\gamma}} - 1}{\frac{T_{03}}{T_{02}} - 1}$$

$$\therefore \frac{T_{03}}{T_{02}} = 1 + \frac{1}{.85}\left[10^{\frac{\gamma-1}{\gamma}} - 1\right] = 2.095$$

$$\Rightarrow \underline{T_{03} = 638\ K}$$

(b) $\frac{\Delta h_0}{U^2} \leq 0.4$ per stage, n stages $\Rightarrow \frac{n\Delta h_0}{U^2} = \frac{h_{03} - h_{02}}{U^2} \leq 0.4n$

(For equality) $0.4n = 1005 \times \frac{638.1 - 304.6}{280^2}$

$= 4.27$

$\Rightarrow n = 10.7$

$\therefore$ $\underline{n = 11 \text{ stages minimum}}$

(c) Compressor work = Turbine Work $\Rightarrow T_{04} - T_{05} = T_{03} - T_{02}$

$\Rightarrow T_{05} = 1300 - (638.1 - 304.6)$ $\underline{= 966.5\ K}$

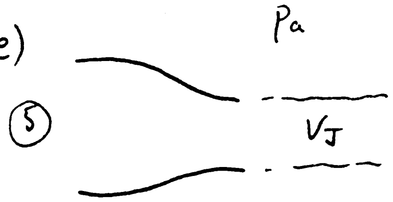
& $\eta_T = \frac{T_{04} - T_{05}}{T_{04} - T_{05}^{\,IS}} = \frac{1 - \frac{T_{05}}{T_{04}}}{1 - \left(\frac{p_{05}}{p_{04}}\right)^{\frac{\gamma-1}{\gamma}}}$

$$\therefore \frac{p_{04}}{p_{05}} = \left[1 - \frac{1}{\eta_T}\left(1 - \frac{T_{05}}{T_{04}}\right)\right]^{-\frac{\gamma}{\gamma-1}} = 3.236$$

$$\Rightarrow p_{05} = \frac{10 \times 76.5 \times 10^3}{3.236} = \underline{236.4\ kPa}$$

9 (d) $\dfrac{n\,\Delta h_o}{U^2} = \dfrac{1005(1300-966.5)}{300^2} < 2n \quad \Rightarrow \quad \underline{n = 2}$

(e)



Assuming flow isentropic in nozzle

$$\Rightarrow \quad p_{oJ} = p_{oS}\left(\frac{T_{oJ}}{T_{oS}}\right)^{\frac{\gamma}{\gamma-1}} = p_{oS}$$

S.F.E.E. for nozzle

$$\underbrace{\dot{Q} - \dot{W}_x}_{0} = \dot{m}\left(c_p T_{oJ} - c_p T_{oS}\right) \quad \therefore \quad T_{oJ} = T_{oS}$$

Also static pressure in jet p_J = atmospheric

i.e. $p_J = 26.5$ kPa

$$\therefore \quad T_J = T_{oJ}\left(\frac{p_J}{p_{oJ}}\right)^{\frac{\gamma-1}{\gamma}} = T_{oS}\left(\frac{p_a}{p_{oS}}\right)^{\frac{\gamma-1}{\gamma}}$$

$$= 966.5\left(\frac{26.5}{236.4}\right)^{\frac{\gamma-1}{\gamma}} = 517.2\,K$$

Finally $c_p T_{oJ} = c_p T_J + \dfrac{V_J^2}{2} \quad \Rightarrow \quad V_J = \sqrt{2 \times 1005 \times (966.5 - 517.2)}$

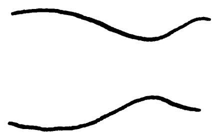
$$\underline{= 950.3 \ \text{m/s}}$$

Speed of sound in jet $= \sqrt{\gamma R T_J} = 456$ m/s

$\therefore$ V_J is <u>supersonic</u>

For isentropic flow through nozzle need

<u>convergent-divergent nozzle</u>



(f) $\eta_p = \dfrac{2 \times 400}{950.3 + 400} = \underline{59.2\%}$

& $F_{Net} = \dot{m}(V_J - V)$ (no $A_N \Delta p$ term since con-di nozzle)

$12 \times 10^3 = \dot{m}(950.3 - 400) \quad \Rightarrow \quad \dot{m} = 21.8$ kg/s

Supersonic aircraft $\left(a = \sqrt{1.4 \times 287 \times 225} = 300 \text{ m/s}\right)$

Turbofan (at least a high bypass ratio turbofan) would be much too big (high drag) and insufficient fan pressure ratio for this application. Turbojet is feasible/appropriate.

Examiner's Note:

Attempted by 60 candidates, mean mark 13.8/20

Well answered in general.

Common errors: —(i) confusing static and stagnation quantities

(ii) Incorrect treatment of nozzle.

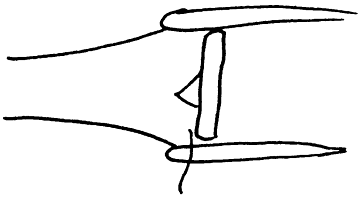
N.B. (a) Flow at exit to nozzle is not at the same temperature as the local atmosphere but at the same pressure.

(b) No work is extracted by nozzle.

(iii) High bypass ratio turbofan more suitable than turbojet. This aircraft is supersonic, so need high V_J (high stagnation pressure) and engine of small cross section. Large nacelles are ruinous for drag at supersonic speeds.

10.a) Lift = Weight & $C_L = \dfrac{L}{\frac{1}{2}\rho V^2 A} \Rightarrow A = \dfrac{L}{\frac{1}{2}\rho V^2 C_L} = \dfrac{100\times10^3\times 9.81}{\frac{1}{2}\times.365\times250^2\times.5}$

$\Rightarrow \underline{A_{wing} = 172\ m^2}$



2

$p_{02} = p_{0\infty}$, $T_{02} = T_{0\infty}$

$\Rightarrow T_{02} = T + \dfrac{V^2}{2c_p} = 217 + \dfrac{250^2}{2\times1005} = \underline{248\ K}$

$p_{02} = p_a\left(\dfrac{T_{02}}{T_a}\right)^{\frac{\gamma}{\gamma-1}} = 22.7\left(\dfrac{248}{217}\right)^{\frac{\gamma}{\gamma-1}}$

$= \underline{36.2\ kPa}$

b) $\text{Drag} = \dfrac{\text{Lift}}{L/D} = \dfrac{100\times10^3\times 981}{18} = 54.5\ kN$

$\therefore$ Each engine must produce $\underline{27.25\ kN}$ Net Thrust

$F_G = F_N + \dot{m}V = 27.25 + \dfrac{100\times250}{1000} = \underline{52.25\ kN}$ Gross Thrust

(per engine)

c) At 6 km

In level flight $L = W \Rightarrow V = \sqrt{\dfrac{W}{\frac{\rho}{2}C_L A}} = \sqrt{\dfrac{9.81\times10^5}{0.5\times.660\times0.5\times172}}$

$\Rightarrow \underline{V = 186\ m/s}$

d) $T_{02}\big|_{6km} = 249 + \dfrac{1}{2}\dfrac{186^2}{1005} = 266\ K$

$p_{02}\big|_{6km} = p_a\big|_{6km}\left(\dfrac{T_{02}\big|_{6k}}{T_a\big|_{6k}}\right)^{\frac{\gamma}{\gamma-1}} = 47.2\left(\dfrac{266}{249}\right)^{3.5} = 59.5\ kPa$

$\dfrac{\dot{m}\sqrt{c_pT_{02}}}{p_{02}A_N}$ is the same $\Rightarrow \dot{m}\big|_{6km} = \dot{m}\big|_{11km}\sqrt{\dfrac{T_{02}|_{11}}{T_{02}|_6}}\ \dfrac{p_{02}|_6}{p_{02}|_{11}}$

i.e. $\dot{m} = 100\sqrt{\dfrac{248}{266}}\ \dfrac{59.5}{36.2} = \underline{159\ kg/s}$

10 d) $\frac{F_G + p_a A_N}{p_{02} A_N}$ is the same $\Rightarrow$ $\frac{F_G^6 + p_a^6 A_N}{p_{02}^6 A_N} = \frac{F_G^{11} + p_a^{11} A_N}{p_0^{11} A_N}$

$\Rightarrow F_G^6 = \frac{52.25 \times 10^3 + 22.7 \times 10^3 \times 0.3}{36.2 \times 10^3 A_N} \; 59.5 \times 10^3 A_N - 47.2 \times 10^3 \times 0.3$

$= 82.9 \text{ kN}$

$F_N^6 = \underset{(F_G \; - \; \dot{m} V)}{82.9 \times 10^3 - 159 \times 186} = 53.3 \text{ kN}$

Now, the required thrust is 54.5 kN
[Drag = $\frac{\text{Weight}}{L/D}$ which has not changed]

∴ Not quite enough thrust available at same engine setting BUT cruise setting is not maximum available, so almost certainly can increase by the 2% required, by increasing speed (by increasing fuel-flow) of engine.

Examiner's Note:

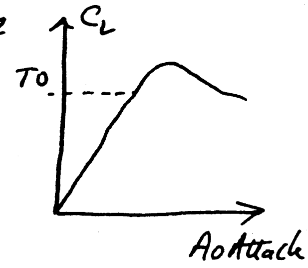
Attempted by 66 candidates, mean mark 14/20

In general, very well answered. Again most common error was mixing static and stagnation quantities or using sea-level p_a at 11 km !

11. (a) Take off requirements

Maximum speed $\simeq 90\ \mathrm{m\,s^{-1}}$ constrained by tyre life

Have C_L as large as possible (after allowing a margin to prevent stall) typically ~ 1.6

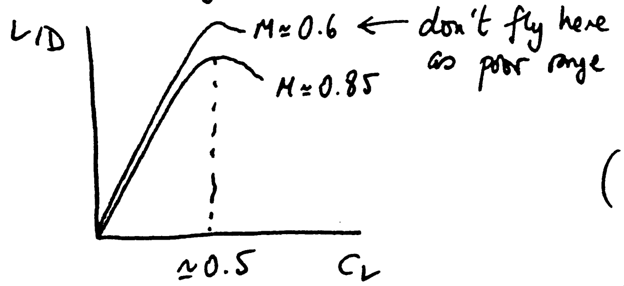


$$C_L = \frac{L}{\frac{1}{2}\rho A V^2}$$

Lift = weight at rotation, so area $= \frac{C_L \frac{1}{2}\rho V^2}{L}$

(b) Breguet range equation shows distance is a function of ML/D, so make this high for range

For cruise seek max L/D (typically at $C_L \sim 0.5$) for efficiency



M chosen for range

altitude chosen so that L/D max

(Weight = Lift $= \rho \frac{V^2}{2} A\, C_L$

ρ varies with altitude)

(c) $\eta_{thermal} = \frac{\text{K.E. to air}}{\text{heat to air}} = \frac{\frac{1}{2}\dot{m}_a (V_j^2 - V^2)}{\dot{m}_f\, LCV}$ lower calorific value of fuel

$\eta_{propulsive} = \frac{\text{power to aircraft}}{\text{K.E. to air}} = \frac{\text{Thrust} \times V}{\frac{1}{2}\dot{m}_a (V_j^2 - V^2)}$

(Thrust $= \dot{m}_a (V_j - V) \Rightarrow \eta_P = \frac{2V}{V_j + V}$)

$\eta_{ov} = \eta_{th} \cdot \eta_P$

High $\eta_P \Rightarrow$ low'ish V_j (provided thrust satisfied) & high $\dot{m}_a$

$\Rightarrow$ turbofan at high bypass ratio

limited by nacelle drag & engine weight

11(c) ctd

High η_{th} $\Rightarrow$ high pressure ratio cycle $\Rightarrow$ many compression stages (limited by max temp & weight)

(d) Turbines operate in a favourable pressure gradient

Compressors " " " an adverse " " , so that have thicker boundary layers and the chance of separation (stall $\rightarrow$ surge)

$\therefore$ Turbines can be much more aerodynamically aggressive and have a higher work coefficient (change in stag. enthalpy per stage)

(e) (i) Fan compresses all of the air through engine $\dot{m}_a$

Turbine expands only the air through the core $\dot{m}_c$

For high bypass ratio turbofans $\dot{m}_a >> \dot{m}_c$

(ii) Fan radius is much higher than turbine radius. They turn at same angular velocity $\therefore$ Blade speed higher in fan.

Both of these imply more turbine stages.

<u>Examiner's Note:</u>

This is a more or less verbatim copy of the best answer produced during the exam. It achieved full marks.

<u>Note</u> (i) the length — 1½ pages

(ii) short, sharp, statements = notes rather than an essay

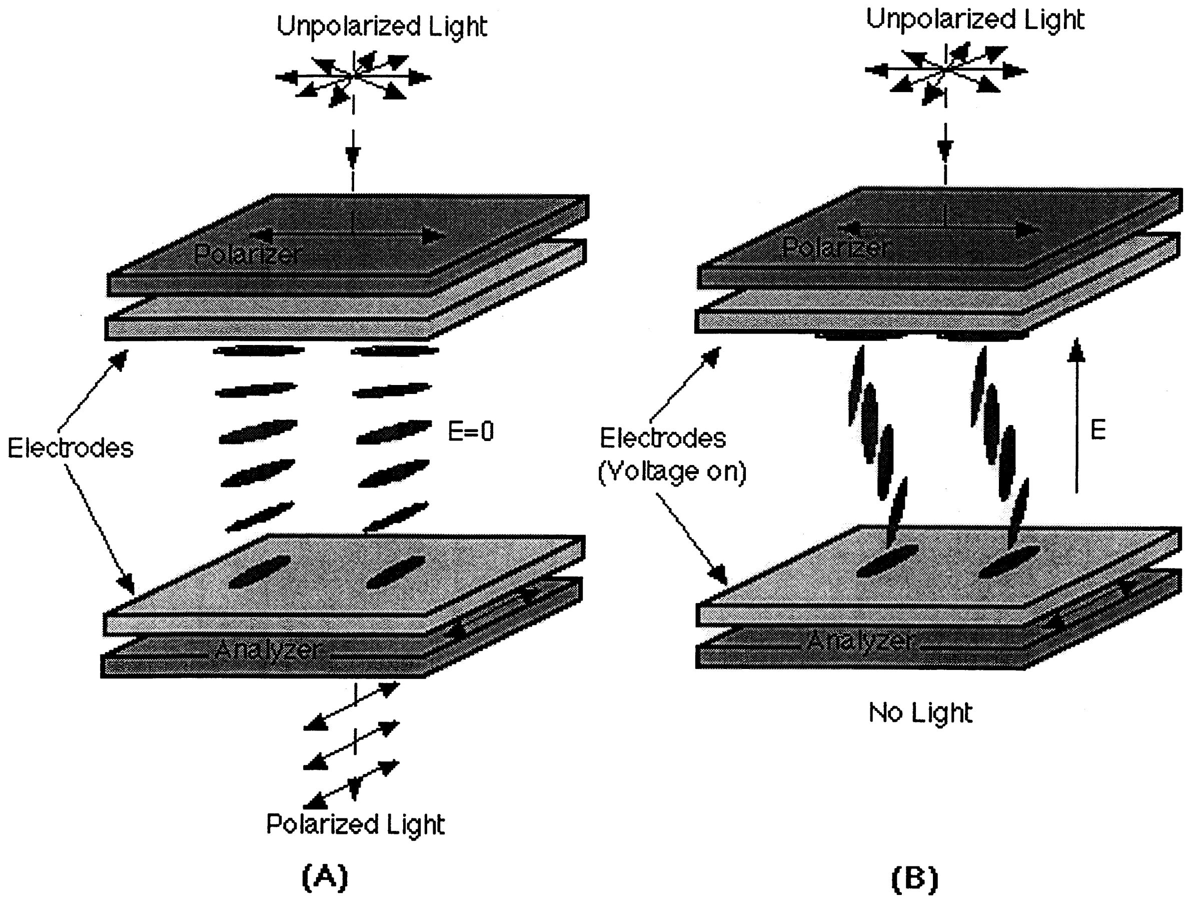
Attempted by 50 candidates, mean mark 10.5/20

The average was brought down by some half-hearted attempts. Some candidates wanted to write down all they could remember from their notes. As they strayed into areas they could only half remember, they were quite happy to contradict what they had just (correctly) written & lost the marks they had just gained.

PART IB, PAPER 8 SECTION E 2005
ELECTRICAL ENGINEERING PROFESSOR WI MILNE
QUESTIONS 12-14

12

Operation of display-- back light always on and the liquid crystal allows light to pass through or not dependent upon the applied field.



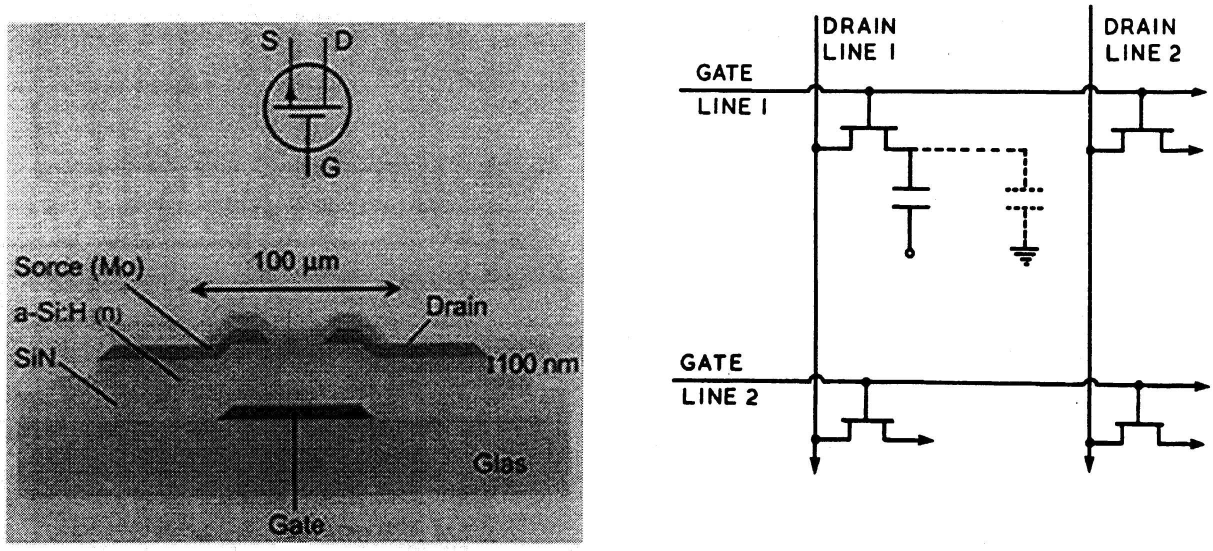
The electric field (applied between the transparent conducting ITO-coated glass plates) controls the polarization rotation. The electric field places a torque on the liquid crystal molecules trying to orient them parallel to the field, i.e. perpendicular to the cell walls. Although the molecules in the center will retain their parallel order, the majority of the molecules in the center will turn parallel to the light path. Thus a large part of the polarization-rotation vanishes and the cell goes to the opposite transmission state – i.e. black for a NW cell and clear for a NB cell.
This principle led to the production of the liquid crystal display (LCD) . This is known as a **passive display** as the action is rather like a light valve where by application of a field across the Liquid crystal layers, light from a **backlight** is allowed to pass through or is prevented from passing through the structure.

The more sophisticated active matrix addressed system includes switching elements in each pixel- see below.

AMLCD
Here each display pixel is equipped with its own TFT switch. Thus the glass substrate contains a matrix of TFTs whose gates are connected to the row lines and source

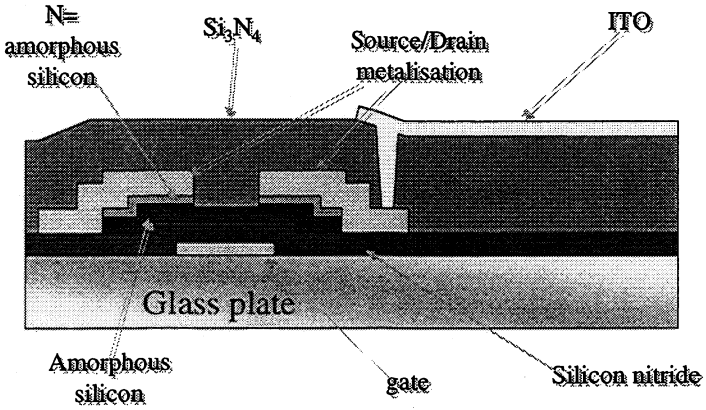
electrodes are connected to the column lines. The pixels are not constructed as the intersection of row and column lines (as in the case of passive matrix addressing), but rather by individual electrode regions connected to the drains of the TFTs. The counter electrode extends over the whole pixel area of the opposite glass substrate.

The addressing scheme is very straight-forward – see Fig. The TFTs simply act as switches. The rows are opened sequentially and when open, the voltage on the column is transferred to the liquid crystal cell. The charge needed to maintain the electric field can be stored in a capacitor located on every pixel.



Cross section of the (a-Si:H) TFT in the active matrix and schematic of TFT at each pixel

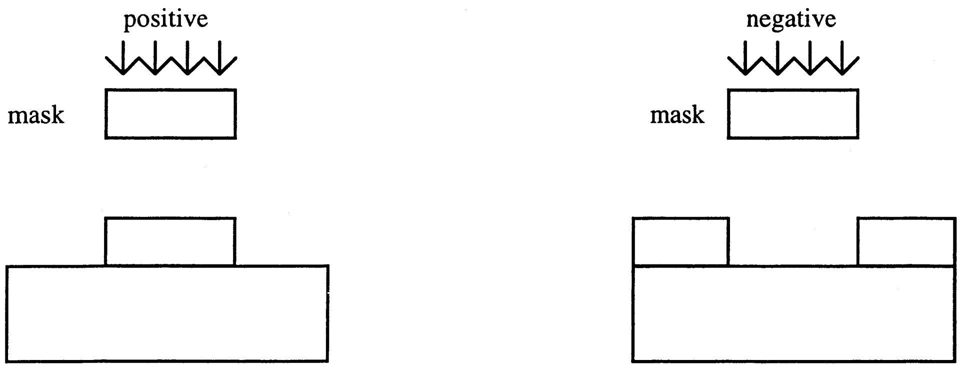
The amorphous silicon Thin Film Transistor is manufactured as shown in the next figure and is then incorporated into the Active Matrix Liquid Crystal Display .



- Schematic of Complete TFT Structure

[6 mark

(b) (i)



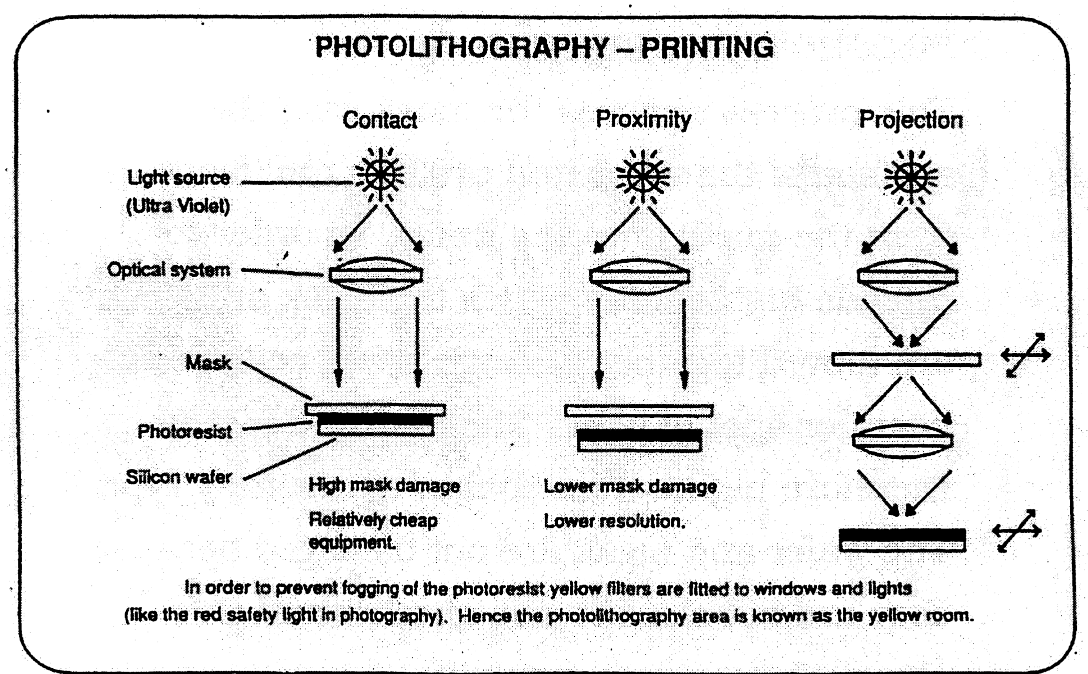
+ve resist the exposed regions become more soluble and thus are more easy to remove during development. Net result is that the patterns formed in the +ve resist are the same as those on the mask.

For –ve resist the exposed regions become less soluble and the patterns formed on the substrate are the reverse of the mask pattern.

Usually –ve resist will be chosen because lower exposures are required, so giving greater through-put.

[4 marks]

b (ii)



Proximity/Contact Printing is characterised by getting the mask as close as possible to the surface of the wafer to minimise errors due to dispersion of the light beam and vibration. In some cases the mask may actually touch the wafer (contact printing). Such machines are relatively cheap but both wafer and mask will suffer some mechanical damage during exposure.

Projection Printing
This process removes the mask from the surface of the wafer and projects the image from the mask onto the wafer. In order to provide high quality optics the mask and wafer are moved together through a well collimated beam or spot of light.
The machine cost is therefore higher than that of a proximity type. The wafer and mask are not damaged because they are not close to one another and this obviously improves mask life.

The optical elements in most modern projection printers are so perfect that their Imaging characteristics are dominated by diffraction effects rather than by lens aberration – diffraction limited systems. The resolution of a diffraction limited printer is roughly 0.5 (λ / NA) where NA is the numerical aperture of the projection optics and $\lambda (NA)^2$, i.e. a high resultion (large NA) is achieved at the expense of depth of focus.→ need to use step and repeat, projection system.

[4 marks]

(iii)

$$\text{resolution} \sim 0.5\left(\frac{\lambda}{NA}\right)$$

$$0.3\times10^{-6} \sim \frac{0.5\left(0.25\times10^{-6}\right)}{NA}$$

$$NA \sim \frac{0.5\times0.25}{0.3} = 0.42$$

$$\text{Depth of Field} \sim \frac{\lambda}{(NA)^2} \sim 1.4\mu m$$

Depth of field is a problem as wafer thickness variation will mean that you cannot use a full wafer exposure – need to use step and repeat – see below

[4 marks]

(iv)A power density of .06Wcm^{-2} is equal to 60mWcm^{-2}.
→ exposure time = $\frac{150}{60}$ = 2.5 seconds [2 marks]

Q13

a) book work- need to include figure of current saturation etc [3 marks]

b accumulation increases current from low value by increasing carrier conc. Depletion reduces and ultimately switches off the current and carrier density in channel from an existing value.

[2 marks]

c SiO2 is used as gate oxide, dielectric between metal lines, passivant, etch mask, diffusion mask. Gate oxide use is most important for this course.
Si uses MOSFET design with SiO2 as an excellent gate dielectric - good. Best, most commercially useful design - good. Si has reasonable band gap and moderate mobility and thus speed – not so good. GaAs does not have native oxide to use as gate dielectric - bad. Also cannot use SiO2 on GaAs – v bad. GaAs uses MESFET design. GaAs has higher mobility and thus higher speed - good. GaAs has higher cost of material - good.

[5 marks]

d) Gauss law $\varepsilon E = N.e.x$

integrate $-\varepsilon V = N.e.x^2/2$ or $V_g = Nex^2/(2\varepsilon)$

[4 marks]

e) $10^{19}\ \mathrm{cm}^{-3} = 10^{25}\ \mathrm{m}^{-3}$

$$V = (\varepsilon E^2/2eN) = ([2.10^7]^2\ 10^{-10}/2\ \ 1.6.\ 10^{-19}\ .\ 10^{25}) = 0.012\ \mathrm{V}$$

[6 marks]

14)
a doped semiconductor – ionised dopants supply all the carriers. Free carriers act like conduction electrons in a metal. Conductivity limited by scattering of carriers with vibrating atoms.

[3 marks]

b **mobility** = velocity / electric field.

Conductivity = mobility x charge x electron density [not in data book]

Effective mass is a parameter defined as force on electron for example due to an electric field divided by the resulting electron acceleration. It has dimensions of mass, but need not equal the free electron mass.

[3 marks]

c. constant field scaling. sizes shrink by factor k. transistors per chip k^2, lengths $1/k$, power per chip = 1.

[4 marks]

d. $v = \mu E$, $E = V/d$ $t = d/v$ so $t = d^2 /\mu V$

mobility = 3.3 m2/Vs.

$t = 10^{-7}\ 10^{-7} /(3.3\ 0.8) = 3.8\ 10^{-15}$ s

This is much faster than equivalent Si FET for which $t \sim 10^{-12}$ s.

[6 marks]

e From data book,

$V = Ned^2/2\varepsilon$. so $N = 2\varepsilon\ V/ e\ d^2$

$N = 2 \times 1.5.10^{-10} /2\ .\ 1.6.10^{-19}\ (10^{-7})^2 = 1.875 \times 10^{22}\ m^{-3}$

[4 marks]

PART IB, PAPER 8 SECTION F 2005
INFORMATION ENGINEERING
QUESTIONS 15-17
PROF A. HOPPER

Cribs

Question 1.

a)

•The service area is covered by approximately hexagonal cells to achieve tight packing (tessellation). In a practical system the actual cells will be designed to overlap to some extent and their actual shape will depend upon local topography

•A cellular system comprises a network of Base Stations (BSs), which communicate with mobile stations (MSs)

•An MS communicates with the BS serving the cell in which it currently resides

•When the MS moves from one cell to another, 'handoff' or 'handover' from the current BS to the BS serving the new cell occurs

•High capacity is achieved by:

–**Dynamic channel allocation** – i.e., channels are only allocated to users when they are required.

–**Frequency reuse** – A systematic way of using the same channels over and over again. This is necessary since only a finite number of channels are allocated to an operator. In this case the same channels are reused in cells separated by a specified minimum distance. This distance (known as the *reuse distance*) is governed by the maximum level of interference that can be tolerated from nearby cells (*cochannel* cells) without causing unacceptable quality of service.

b)

•To increase capacity, what options are available?

–Allocate more frequencies N – difficult owing to congested spectrum

–Go digital to reduce p

–Employ directional antennas (known as sectorisation) at the base stations to reduce interference and hence reduce the effective reuse pattern

–Reduce the size of cells (known as microcells) so that fewer users occupy each cell – can be expensive owing to the requirement for more base stations to be deployed

•Essentially the allocated spectrum is divided between clusters having p cells, e.g., 3, 4, and 7

•As p increases, so does the distance between cochannel cells:

–This improves the received SNR

–At the cost of reducing capacity, since the total number of channels N, must now be divided amongst a larger number of cells, p. That is a maximum of N/p channels (calls) can be allocated per cell. For reasonable user satisfaction, the probability of reaching this level of calls (blocking) should be quite low, say < 5%.

•The minimum value of p that can be used depends upon the minimum SNR that can be tolerated at a receiver.

•Old analogue systems (e.g., TACS) require a min of 18dB SNR, requiring the use of $p = 7$. Digital modulation schemes using ECC (as in GSM) can tolerate much lower SNR values and so can use smaller reuse patterns, e.g., $p = 3$ or 4.

•Clearly this raises system capacity

c)
•Interleaving and Frequency Hopping combined with Error Correction Coding are the main techniques used to combat interference and fading channels.
•Two types of interleaving are employed:
–Bit interleaving: Essentially shuffles bits within one speech frame
–Block interleaving: Moves whole block of shuffled bits into different transmitted bursts, giving further protection against bursty errors resulting from signal fading. The aim of interleaving is to break-up bursts of errors due to signal fading causing them to appear as single errors at the input to the error correction decoder, thus improving its performance
•Frequency Hopping
–217 hops/s keeps max fade duration down to around 4.6 ms.
–When combined with half rate ECC (convolutional) and interleaving over 8 hops gives immunity to most types of fading
•When combined with FH, the interleaver is capable of breaking-up the bursts of errors even when the mobile is stationary
–Also randomises cochannel interference, thus minimising size of the reuse pattern (which would otherwise have to be designed for the worst case interferer), thereby raising system capacity

Question 2
a)
"Network-centric" or "server based" computer and communications
Concentrate applications and services on centralised managed facilities
Protocols to deliver only user-interface over networks to simple end-user equipment
Avoid user-data or un-recoverable state on the end-user equipment
Terminals simpler, complete system easier to manage

b)
Size – less hardware, smaller and more appealing footprint
Environment – no disk or fan, less heat and noise pollution
Longevity – simpler design will last longer, computing resources upgraded at centre
Stability – terminal is more stable, application set can be managed better centrally
Mobility – can move desktops around between terminals
Security – terminal is no longer a weak point, concentrate security efforts at centre
Cost – lower total cost of ownership

c)
X Window System
High level (applications are built in knowledge that graphics may be remote)

Xclient process runs on networked server machine
Xclient is application code (eg Xterm, Xclock) linked against X libraries

Xlibraries are programmatic interface to X protocol

X protocol is device independent operations eg create, move, delete window
Window is any element such as text, label, pixmap, hierarchically organised
X protocol provides network transparency (endianism, socket can be local/remote)

X server process runs on terminal equipment
X server decodes X protocol, builds data structures
Maps operations on to actual devices (screen, keyboard, mouse)
Accepts connections from multiple X clients

Plus: Open source
Plus: Still alive (Linux, KDE, GNOME, OpenOffice)
Minus: Unix centric
Minus: Bad at network interruption/terminal reboots – Xclients die
Minus: Terminal is stateful, Xclients rely on state built up in Xserver
Minus: No session mobility
Minus: No session sharing
Minus: Poor compression, bad over slow links

Microsoft Terminal Server
Middle level (applications don't know graphics are remote, but operating system does)

Standard Windows applications and operating system front end
Use standard Windows Messages (keys/mouse) and GDI (graphics display interface)

Terminal server provides virtual device interface for each user
Virtual keyboard, mouse and graphics driver backend
Virtual devices generate RDP (remote display protocol)

Win Terminal is RDP client
Terminal decodes RDP and maps on to actual keyboard, mouse and graphics drivers.
Terminals made by a number of manufacturers

Plus: Efficient (works at the OS driver level)
Plus: Good compression, reasonable over slow links
Plus: Supported by Microsoft
Plus: Session mobility
Minus: Microsoft centric, not good for mixed environments
Minus: Terminal Server license expensive
Minus: Proprietary protocol

VNC (Virtual Network Computing)
Low level (neither applications or operating systems know graphics are remoted)

VNC server is application level agent on server end
Snoops public OS interfaces, generates VNC protocol

VNC client is software running on terminal
Decodes VNC protocol and maps on to actual keyboard, mouse and graphics

Plus: Open source
Plus: Highly portable, and thus very interoperable
Plus: Session mobility

Plus: Session sharing
Plus: Good stability (doesn't replace OS or drivers)
Minus: Less efficient than RDP (have to work hard to get hints from OS)
Minus: Not multi-user on windows

SunRay
Solaris Servers run SunRay server software
SunRay server software comprises GNOME desktops and StarOffice applications
Generates low level VNC like protocol

Ship over proprietary sub/ip level private network

Proprietary terminal decodes protocol and maps onto keyboard, mouse, graphics

Minus: Completely closed world, private network island
Minus: Proprietary hardware terminal
Plus: SmartCard reader on terminal for session logon and security
Plus: Hot desking
Plus: Sharing

d)
Consider all costs of procuring, installing and maintaining a system, including personnel
Consider over a period of time, eg yearly average over five years

Direct costs (equipment) – terminals, servers, networking equipment
Direct costs (facilities) – power, heat, noise, air conditioning
Direct costs (software) – software procurement, license management
Direct costs (personnel) – system management, installation, upgrades, support
Indirect costs - self help and peer-peer help, inefficiency, frustration

Question 3
a)
i.
TESLA was designed to solve the problem of source authentication in the following context.
One source periodically broadcasts packets to many recipients.
Recipients will experience different delays and may occasionally even lose packets.
Recipients cannot afford to verify a public key signature on each packet.
The scheme should be efficient.

ii.
TESLA builds upon the earlier "Guy Fawkes" protocol but adds some improvements.

Each packet P_i is authenticated by a MAC. The sender divulges the MAC key only after the packet and its MAC have been received and can no longer be tampered with.

To prevent a man-in-the-middle opponent from
- forging a packet,
- then computing a valid MAC with an invented key,

- and then releasing the invented key,
the keys themselves must be validated. In TESLA, they are part of a Lamport hash chain. To validate a key k_j, the verifier only needs a previously-issued known-good key k_i from the same hash chain. Verification consists of hashing k_j for j-i times and checking whether the result is k_i.

Since the verification described in the above paragraph only requires "any previous key" as opposed to "the immediately previous key", the verification can still be carried out even after the recipient (= verifier) experienced packet loss.

The MAC key k_i that allows verification of packet P_i is only divulged after P_i has been sent. But *how long* after P_i was sent? If too soon, a man-in-the-middle attacker might receive k_i before a recipient receives P_i; if this possibility exists, the recipient should not trust P_i and source authentication will be impossible. If too late, the recipient experiences a long delay between receiving the packet and being able to verify it; in some time-sensitive cases (multimedia, stock tickers etc), the packet may become "stale" and therefore useless by the time its source has been validated. To fix this problem, in TESLA each packet is protected by several MACs. The keys to these MACs are released at different time intervals. Recipients who enjoy low network latency can use the early keys for verification and enjoy timely authentication; while recipients who suffer significant delays are still able to verify their packets with later keys.

iii.
The fields of packet P_i will be:

Payload M_i. Carries the information the sender wants to send.

Multiple MACs of this payload with different keys: MAC(K_i_1, M_i), MAC(K_i_2, M_i), ..., MAC(K_i_m, M_i). The first index says which packet this key protects. The second index says which Lamport chain this key belongs to.

Multiple revealed keys: K_j1_1, K_j2_2, ..., K_jm_m. Indices as above. The keys are relative to already-transmitted packets, so all the jx indices are < i.

b)
see pictures in handout

Question 4
a)
UWB or impulse radio is the use of extremely short duration pulses (sub-nanosecond) instead of continuous waves to transmit information.
The pulse directly generates a very wide instantaneous bandwidth signal according to the time scaling properties of the Fourier transform relationship between time and frequency.
Occupied Bandwidth >> Information Bandwidth.
It has a very low duty cycle 1/1000 or less.
UWB fractional bandwidth = (*fh* – *fl*) / fc > 25% or total BW > 1.5GHz.
It has low power consumption and a low probability of detection signature.

b)

The system consists of active tags which chirp out UWB pulses and receivers which are placed within a building.
Position is calculated from multiple sensor readings.
Multilateration is used to calculate the 3D position (ie time difference of arrival).
Four readings are required to calculate 3D position.
More readings provide better accuracy (outliers are thrown out).
Non-linear regression can be used to refine position.
Accuracy depends on the level of time synchronisation and the position of receivers.
Actual performance of systems ranges from 10cm to 100cm 95% of the time.

c)
Orientation can be obtained by having more than one tag attached to a rigid object
It may also be possible to obtain orientation by observing which sensors received the signals.
However this may be problematic because this technique requires the body to shadow the signal which happens with ultrasound but probably much less true with UWB.
Received signal strength might also be useful.

d)
In order to make the system scaleable the location system is made cellular.
An additional control radio is used to trigger individual tags.
If the UWB system combines communications with location a second radio system is not required.
When a tag moves from one cell to another a handover of the control link takes place to another base station.
The control frequencies can be reused in the normal way.
Additional sensors attached to the can be used to help determine which tag should be prioritised (eg trembler switch).
Higher level analysis (eg tag is moving) can also be used to schedule tag transmissions.
Applications should indicate their level of interest in particular objects.

PART IB PAPER 8 SECTION G 2005

BIOLOGICAL AND MEDICAL ENGINEERING DR R W PRAGER

QUESTIONS 18 — 20

18 *(a) Explain why it is desirable for a visual target (i) to be located on the fovea; (ii) to have an angular velocity that is very similar to that of the eye itself.*

(i) Because the fovea is specialised for high-acuity vision (closely packed receptors, optical hindrances such as nerve cells and blood vessels pushed out of the way, one-to-one connections with ganglion cells rather than convergence).

(ii) Because the visual acuity for a moving target is much lower than for a stationary one (a consequence of the sluggishness of the receptor response to changing light levels: a retinal slip velocity of 1 deg/sec generates neural blur equivalent to about 3 dioptres of myopia). [4]

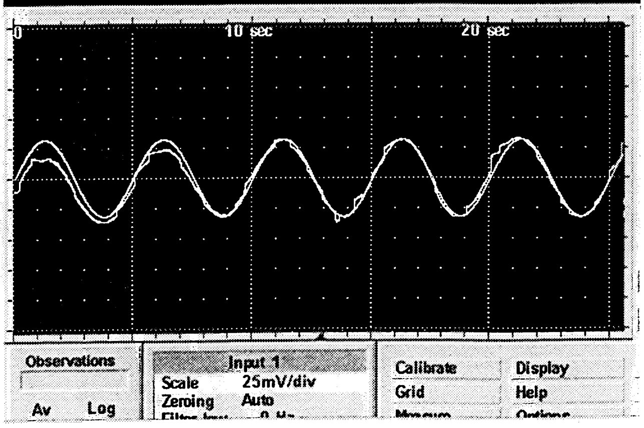
(b) What kinds of eye movement have evolved to solve these two problems?

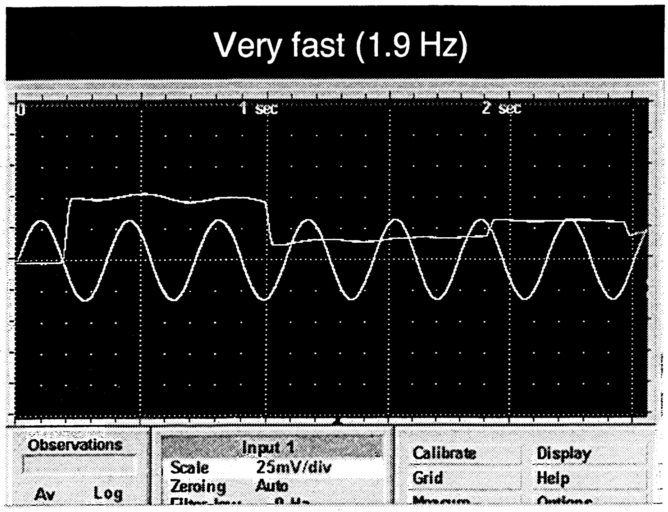
(i) Gaze-shifting movements. The predominant one is the saccade, a fast, ballistic movement for foveation: it has a velocity of many hundreds of deg/sec, and a duration of tens of milliseconds. In addition, vergence movements ensure that the image of a target is accurately foveated by both eyes, even when its distance changes.

(ii) Gaze-holding movements. These include two reflex movements (vestibulo-ocular reflex or VOR, and optokinetic response or OKR), and smooth pursuit. The VOR and OKR generate equal and opposite movements of the eye when the head moves, and are driven respectively by the semicircular canals (which monitor head angular velocity) and retinal slip velocity. Smooth pursuit is a higher-level response whose function is to maintain foveation of a small moving target, and reduce the retinal slip velocity of its image. [4]

(c) Sketch typical eye movements that might be observed when, after some practice, a subject tracks a stimulus moving sinusoidally with amplitude 5 deg in a horizontal line normal to the line of sight (i) at 0.2 Hz; (ii) at 1.9 Hz.

Slow pursuit (0.2 Hz)

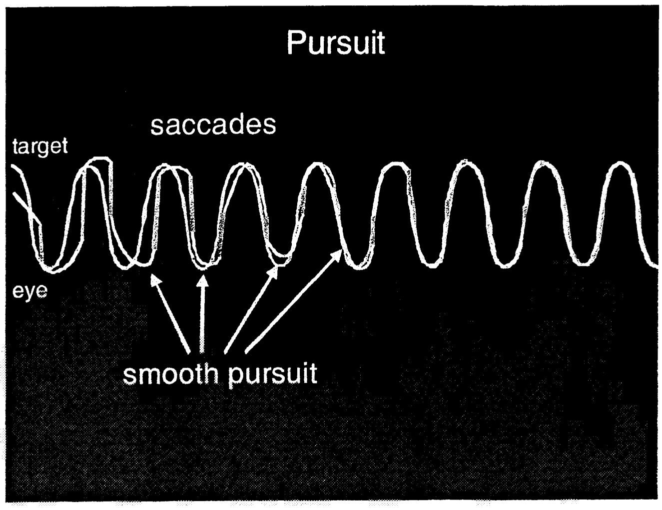




[4]

Low frequency tracking is typically accurate, with relatively few and small correction saccades; at higher frequencies the amplitude of the smooth pursuit component will typically diminish, with larger saccades that may or may not (see above) be well adapted to the target motion.

(d) In what way would these records differ if measured before rather than after a period of practice?



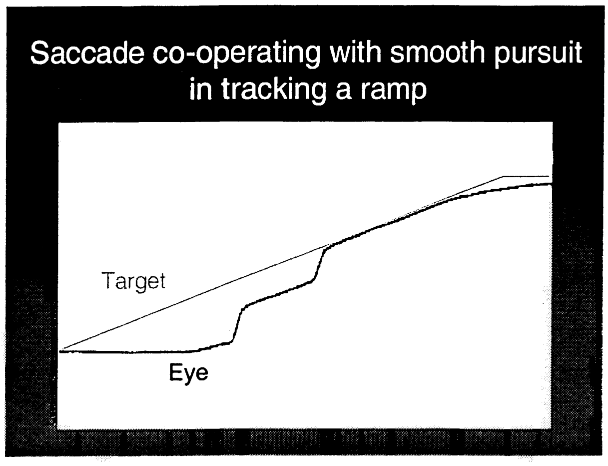
As shown above, at first smooth pursuit shows large phase lag and is poorly accommodated to the stimulus, with larger compensatory saccades; as time goes on the performance improves, with reduced phase lag and accurate tracking of the target with few correction saccades. [2]

(e) What experiments imply that that smooth pursuit is not primarily generated by a simple direct feedback system?

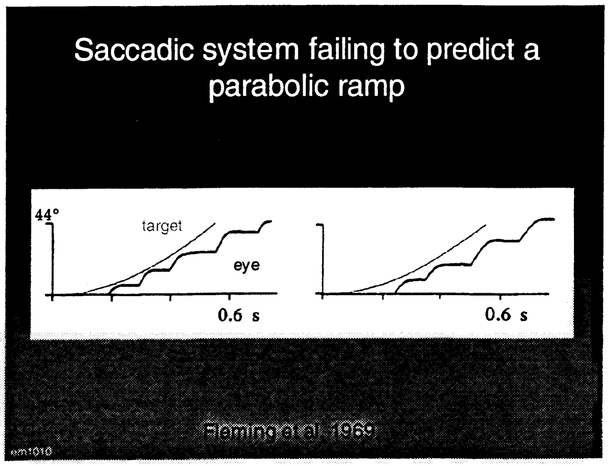
An error signal (retinal slip) is not a prerequisite: targets viewed intermittently (as in the cinema) or whose path is partially obscured (a pendulum swinging behind a small screen) still generate smooth pursuit, which persists for a short while after suddenly extinguishing visual input. Furthermore, smooth pursuit of deduced motion (as in the anorthoscope), or of audible targets in the dark, or of imaginary targets, is possible. [3]

(f) How can it be demonstrated that in the control of saccades the oculomotor system uses target velocity, but not acceleration, to determine the size of a future saccade?

In making a saccade to a target that suddenly moves off at constant velocity (a linear ramp stimulus), the smooth pursuit response is normally interrupted by one or more saccades that bring the eye roughly on to the target, thus allowing for the motion of the target during the system's response time. The amplitude of this saccade can be shown to be a linear function of the velocity of the target shortly after the start of the ramp.



If this experiment is repeated with a parabolic rather than a linear ramp, the saccades undershoot; their amplitude is still the same function of the target velocity one reaction time before the saccade, and does not take the acceleration into account.



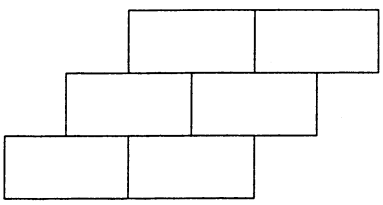
[3]

Assessor's comments. This question tested candidates understanding of the various techniques in the oculomotor system that are used for gaze shifting and gaze holding. Most candidates had a good understanding of saccades, probably as a result of the lab session. Smooth pursuit was found slightly more difficult to explain and only a small number of candidates mentioned the opto-kinetic response or the vestibulo-ocular reflex. The question generated a satisfactory spread of marks and was of about the right level of difficulty.

19.

(a) **Smooth swimming and tumbling.** Bacteria such as *Salmonella typhimurium* and E. Coli seek nutrients by executing a kind of random walk, consisting of "legs" of straight "smooth swimming"; at the end of which the cell "tumbles" and then goes on the nest leg in a random direction. If the cell is moving up a (temporal) gradient of nutrient (i.e. if the concentration of the nutrient is increasing with time) then the "leg" of smooth swimming is extended; but if the concentration is decreasing with time the leg is shortened. In this way the bacterium navigates towards a supply of food. In smooth swimming the 6 (or so) bacterial flagella rotate in the same sense and form a single bundle which pushes the cell forwards; but in the "tumbling" phase some flagella are rotating in reverse, and the bundle breaks up and the flagella just thrash around at random. [4]

(b) **Bi-stable building blocks.** The flagellar filament is a long, thin, helical structure, something like a corkscrew. It is built from a large number of identical "building-blocks" which may be thought of as being like pieces of stone cut so as to build, with a simple overlapping pattern, a circular cylindrical tower. But instead of the stones being cut to make discrete "rings" which stack onto each other, they are cut so as to build on a *spiral* pattern, with $5\frac{1}{2}$ blocks per turn. Now it would be tricky to make stone blocks like this, because they would have to be not only wedge shaped (as for the stones or "voussoirs" to build an ordinary arch), but also *twisted* a bit, to make a spiral path rather than a series of rings.



The actual building-blocks are identical protein molecules, which have "sticky patches" on their surface, and which "self-assemble" into this "tower" structure without the need for an external scaffold.

But there is a serious snag about the above description, for what we would build in this way is a *straight* tower. What we need to build is a tower that is *curved* so that, together with twist in the construction (which will normally be there; we would have to take special steps to design a tower with a non-twisted pattern of blocks) it will make the observed helical of corkscrew-like filament.

The trick which Nature uses is that, at one of the "sticky-patch" interfaces on the surface of the molecule, there are two slightly different ways in which the block can stick to its neighbour — i.e. there is a sort of "bi-stable switch" in the connection. Let us call these two slightly different connection schemes A and B respectively.

Now Nature has also arranged that, if all the bi-stable connections are in state A, the building-pattern described above will not actually fit together in 3 dimensions. And neither will it fit if all of the connections are in state B. However, the arrangement will build if, say 9 of the 11 connections in 2 turns of the pattern are of type A while the other 2 are of type B. In such a case there can be overall curvature of the "tower", because the type B connections can be a little bit longer than the type A ones.

By means of this very subtle arrangement, Nature has managed to build spiral flagellar filaments out of just one kind of building-block.

The protein in question — "flagellin" — has a very specific sequence of amino acids along its polypeptide chain. If one of these is changed, then the overall geometry of the building-block will be very slightly different; and so perhaps, the building process can only proceed if now 3/11 of the connections are of type B and 8/11 are of type A. Then the resulting corkscrew would have a different curvature and hence a different helical form.

In this way different mutants of the "wild-type" bacterium can build a *family* of discrete helical wave-forms. The complete family includes two special *straight* forms in which, by contrast with what is said above, the building pattern *can* proceed with "all A" or "all B" connections. As well as these 2 different straight forms there will be 10 intermediate distinct helical forms, with $1, 2, \ldots 10$ sets of connections in the B-form.

The "wild-type" has the "standard" helical corkscrew form, that is optimum for smooth swimming. Any mutation will make it less efficient at swimming; and such a mutant may not be able to survive in an evolutionary sense.

The bacterial flagellar protein "flagellin" has to have *exactly* the right amino acid sequence if the bacteria are to operate properly. That sequence was fixed about 10^8 years ago, long before the evolution of higher organisms. Nature had hit on a very subtle, optimum design which enabled bacteria to work very efficiently. [4]

(c) **Specialisation of cell function.** Each multi-cell organism starts life as a single cell which divides into 2 cells; then each daughter cell divides, into 2 cells, and so on. Each cell contains the DNA prescription for the whole organism, and each time a cell divides the DNA is duplicated. So at a certain point in the development of an organism, a decision has to be taken about whether a particular cell is to become a nerve cell, a liver cell or a muscle cell, etc. Somehow the genes which relate to nerve, liver or muscle function must be "switched on" preferentially. Although much of the detail of the mechanism of specialisation remains obscure, it is now known that there exists a range of "transcription factors", which are small proteins whose function is to locate particular genes in the DNA and having found them, to "switch them on." There must also be some sort of machinery to ensure that, say, liver-designated cells occur in a cluster which will eventually become the liver organ. It's a problem of *control.* [4]

(d) **Tracing evolutionary relationships.** Darwin's seminal idea of the evolution of living forms to produce, over sufficiently large times, different species, was conceived before the mechanism of inheritance through discrete "genes" was understood. He drew the first "evolutionary tree" whereby all living things could be traced back to some primordial organism. The earliest detailed evolutionary trees were established from the fossil record of organisms with bones; and later on general schemes which showed a tree branching into plants, fungi, flies, vertebrates, etc. could be drawn up.

A strong piece of evidence in support of the idea of the evolution of all living things from a primordial ancestor is that all living things — plants, fungi, flies, vertebrates ... — use exactly the same DNA molecule for prescribing proteins according to a universal code. So, now that it is possible to sequence DNA molecules quickly and cheaply, it is possible to compare DNA sequences of protein from different organisms, and to use computers to fit them into a "filogenetic tree." This can be done with haemoglobin molecules for different organisms, to construct an evolutionary tree for all animals which have blood. A much wider range of organisms can be studied *via* the the protein molecule "cytochrome c", which is present in *all* organisms which exchange oxygen with the atmosphere — i.e. practically all of earth's living organisms.

Do the evolutionary trees obtained by different methods, and by DNA sequences of different proteins agree well with each other? Yes (in a word). [4]

(e)(i) **Recognition by protein molecules of specific short sequences of DNA.** Each cell in any living organism contains the complete DNA sequence for the entire organism — which includes the DNA required to prescribe the construction of organs such as the eye, lung, pancreas, ... Each specialised cell must only "read" the small fraction of the total DNA sequence which is needed for its specialised functions. So there has to be machinery in the cell for locating particular genes along the DNA and then "switching then on." Special proteins are used for this purpose — proteins which can recognise short sequences of DNA with very high "specificity." They do this by having amino acids on their surface, arranged in a precise 3D geometrical way, which can make hydrogen-bonds with the exposed bases on one side of the DNA molecule. Such protein molecules can find a single "word" anywhere on the enormously long DNA molecule — like trying to find a single sentence in all of the books in a College Library. This can come about through the mechanism of "Brownian movement," which moves the protein molecules around incessantly: when an exact match is eventually found, the next stage of the process can occur.

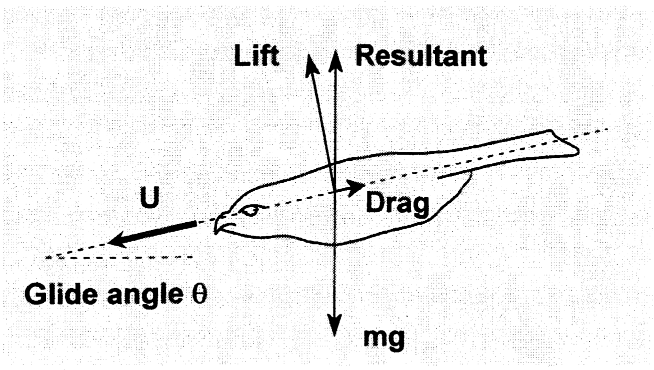
(e)(ii) **Recognition by protein molecules of specific chemical species.** Bacterial (and other) cells have "receptors" embedded in their outer walls. These are protein molecules which can recognise a particular small chemical molecule when it encounters one. When recognition takes place, the receptor send a signal to the interior of the cell to convey a message of the sort "keep the propulsive motors turning."

Receptor molecules have a sort of open "mouth" which is lined with particular amino acids. When a single specimen of the "right" small molecule enters the mouth — by Brownian movement — the hydrogen-bonds match up exactly and the mouth "snaps shut." That triggers the sending of the corresponding message; and then the specimen is released, leaving the receptor to recognise another molecule.

Recently, it has become possible to *alter* the sequence of amino acids within the "mouth" of a receptor, so as to make the receptor recognise an "un-natural" small chemical molecule, such as TNT. [4]

Assessor's comments. This question covered the structure of bacterial flagelli and the functioning of DNA and proteins at a very general level. Candidates generally found it difficult to explain the three-dimensional structure of the flagellum, but there were a small number of very good answers. There were a wide variety of answers to parts (c) and (d) so marks were awarded for sensible valid explanations from more than one perspective. In spite of being a descriptive question, it resulted in a good spread of marks as some weaker students tended to waffle off the point of the question and hence got a low score.

20. (a) From the Lecture 1 Handout:



$$L = mg\cos\theta \approx mg$$

$$D = mg\sin\theta \approx mg\theta$$

$$L/D = \cot\theta$$

(i) Lift is expressed using the ubiquitous inertial force equation with planform area S and lift coefficient C_L:

$$L = \tfrac{1}{2}\rho S U^2 C_L = mg\cos\theta \approx mg$$

$$U \approx \sqrt{\frac{2mg}{\rho S C_L}}$$

[4]

(ii) For the albatross,

$$C_L \approx \frac{2mg}{\rho S U^2} = \frac{2(12\text{kg})(9.81\text{ms}^{-2})}{(1.2\,\text{kg}\,\text{m}^{-3})(3.5\,\text{m} * 0.24\,\text{m})(19\,\text{ms}^{-1})^2} = 0.65$$

$$D \approx mg\theta = (12\text{kg})(9.81\text{ms}^{-2})(2.5 * \tfrac{\pi}{180}) = 5.1\,\text{N}$$

[2]

(iii) The answer should be reasoned as follows:

- If wing loading and glide speed for the ultralight are similar to the albatross, then from 1(a) the lift coefficients must be similar.
- Therefore if the glide angle is worse for the ultralight, this must be due to a higher drag coefficient.
- Since the Re are similar, this is not explained by a scaling of viscous drag forces.
- So, either the body drag is higher for the ultralight, which is quite likely, or its wings have a lower L/D ratio than the albatross, which is also quite likely. [4]

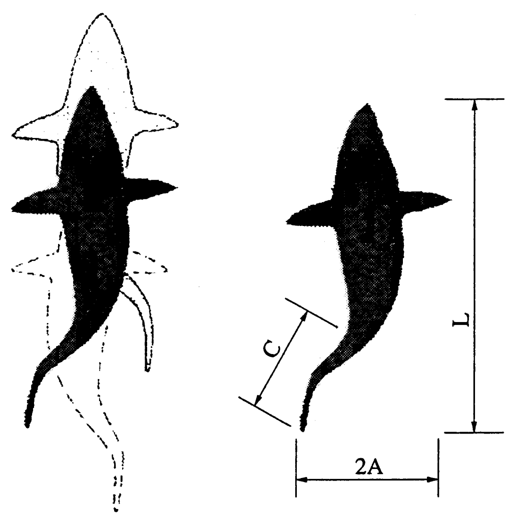
(b) (i) Bluefin tuna swims with an undulatory body motion, see figure (a) below. Its caudal (tail) fin oscillates side to side following the undulating body motion. This motion generates body bound vorticity that is shed from the tail in a reverse Karman vortex street to generate thrust. [2]

(ii) The definitions of the lengths are shown on figure (b) below.

1. Reynolds number = ratio of inertial forces to viscous forces = $\rho UL/\mu$
2. Strouhal Number = ratio of unsteady forces to inertial forces = $f2A/U$ where $2A$ is the peak-to-peak tail amplitude.
3. Length Ratio: $(2A)/C$. This length ratio is the ratio of the peak-to-peak tail fin amplitude for the main propulsive fin, $2A$ to the chord of the fin C.
4. Length Ratio: $2A/L$. L is the animal/vehicle length and $2A$ is the peak-to-peak tail fin amplitude.
5. Coefficient of Thrust: $C_t = \frac{\text{Force}}{\frac{1}{2}\rho U^2 \text{Area}}$. "Area" can be taken as the area of the tail fin. The "Force" is the propulsive force driving the fish forward. [4]

(iii) To achieve similar performance, we want C_t of the fish to match C_t of the robot. The Strouhal number gives the ratio of unsteady effect to steady effects in the fluid. Strouhal number and Amplitude to Chord ratio typically dictates the kind of vortex wake pattern that is formed by the body-tail or flipper propulsor, this pattern affects C_t, thus matching these parameters is important for obtaining the requisite thrust. Matching the two length ratios is important for geometric similarity.

The Reynolds number reflects the ratio of inertial forces to viscous forces. To ensure proper scaling we aim to scale with Reynolds number so: $Re_{\text{fish}} = Re_{\text{robot}}$. This will require us to scale length based on required speed or vice versa. If we cannot directly scale Reynolds number for some reason we want to ensure that our robot is operating in the same flow regime (laminar or turbulent) as the live fish. [4]



(a) Tunniform motion

(b) Fish dimensions

Assessors comments: This question was in two parts. The first part asked for a simple analysis of a bird in steady glide and the second covered the use of dimensional analysis in the design of underwater biomimetic vehicles. A surprisingly large number of candidates were unable to resolve forces in two orthogonal directions and ended up fudging the proof at the start. This question was less popular than the other two in this section and there were some very good and very poor answers. Candidates with a good understanding of the 1B fluids course were able to use this knowledge in sub-part (iii) of each part of the question.

IB Paper 8 Section H 2005

Question 21

(a) (i) The profit and loss account reports the income (or revenue) of the business and the costs it has incurred over some period. The difference between these two is termed the profit.

(ii) The balance sheet gives a snapshot of what is 'in the business' at some point in time. Any investment of money in the business leads to an increase in its liabilities, and the storage of the money is some form of asset.

After any transaction, the balance sheet must balance, and the retained profit reported in the balance sheet must be consistent with the profit reported in the profit and loss account.

(b)

	Day formed	1st financial year	2nd financial year
Profit and loss account			
Income		**0**	**0**
Direct costs: materials		1000	0
Gross profit		**-1000**	**0**
Indirect costs			
Lawyers fees		3000	
Marketing study			8000
Rent of premises		2000	2000
Operating profit		**-6000**	**-10000**
Interest		0	0
Net profit		**-6000**	**-10000**
Balance Sheet			
Fixed assets			
Equipment		8000	8000
Current Assets			
Cash	12000	1000	11000
Total assets	**12000**	**9000**	**19000**
Fixed liabilities			
Shareholders capital	15000	15000	15000
Loan			20000
Retained profit	-3000	-6000	-16000
Total liabilities	**12000**	**9000**	**19000**

(c) An investor would want to know everything possible about the likely future revenues and costs of the business, and its plans to manage them well. Essentially this is the information contained in a typical business plan:

- What is the market – who has the problem that the business is attempting to fix?

- What is the product or service offering – what solutions are to be used to address the problem?
- Management team – who is going to implement the plan and what is their track record?
- Business operations – how is the plan going to be executed?
- Financial projections – how and when will money be made and costs incurred?
- Marketing strategy – how will the business persuade people to buy the product/service?
- Resources – what is needed to allow the business to achieve the plan?
- Exit opportunities – how will investors get their returns?

With all such plans, the investor would want to know not just what is claimed in the plan, but would also want to see evidence that the claims are well founded.

Question 22

a) Design process: number of stages from idea, through spec, concept, embodiment, detail, implementation. Some sense of iteration. A good answer would distinguish between a descriptive and a prescriptive process

The design process addresses the set of technical activities. The New Product Development process places this design process within the wider business context, addressing project management issues, the business case, and project generation.

b) Value proposition – is a statement of the core benefits offered by the product. This is important as it focuses attention on delivering consumer benefits, as opposed to developing technology which has little market need.

Elevator Pitch: **For** the busy office worker **who** needs to boil water rapidly and efficiently, **the** easy-boil is a novel kettle **that** utilises new technology to boil water in under 10 seconds with less electricity **unlike** the traditional cordless kettle, our product is space saving, energy saving and money saving

c) Specification – would address the whole 'design mix' (core product, actual product, augmented product and meta-product) and contain the following 5 elements:

a) Overall system specification: sketch of the overall system layout and high level specification of the performance of the complete product: energy efficiency, boiling time, volume of water etc, aesthetics and ergonomics.

b) **Module specifications**: for each sub-system, providing detail for the design of this element. E.g. handle – size, shape, Power supply – voltage, size, shielding

c) **Interface specifications**: defining the interfaees between the modules in terms of energy, information and location/joining. E.g handle-jug interface, etc.

d) **Augmented product specification**: service, support, distribution, warranty issues. E.g. product life, recyclability, replacement of componenets etc.

e) **Meta-product specification**: relating to the business case, time constraints, cost constraints, production constraints, etc.

The specification provides the design team with targets to achieve and practical constraints which need to be addressed. A good spec quantifies or qualifies each element, providing boundaries against which the product can be evaluated.

d) 2 alternative product configurations (Four possible provided below):

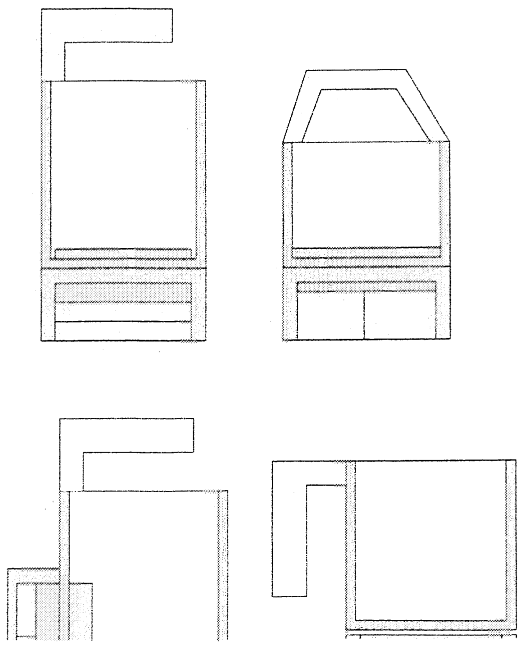
Idea 1: Handle on top, re-ordered components in the base. Achieves a greater area for the induction coil, but may not be so ergonomic

Idea 2: better proportion for the circuitry and power supply, with a full over the top handle – would be possible to make it look more like a traditional kettle.

Idea 3: Coil and technology to the side – would then push the kettle against the element – good on the kitchen surface, but would need to make sure the heating plate is covered with water. Not a good idea.

Idea 4: Place all the technology in the base, could then use just a simple glass jug to contain the water.

(Other ideas possible and would attract marks for sensible comments)



Question 23

(a) Four possible business models for making money from this idea:

Any combination drawn from:
In terms of products and services:
- *Sell a product*
- *Sell a service*
- *Sell a product plus services*
- *Sell a product plus consumables*

In terms of organising resources to exploit the idea:
- *Sell the idea to someone else*
- *License the idea to someone else*
- *Form a partnership with someone else*
- *Do it all yourself*

(b) One advantages and one disadvantage for each of the business models listed in your answer to part (a) for exploiting this invention: answer based on the following

	Advantage e.g.,	*Disadvantage e.g.,*
– Sell a product	*Increase revenue with higher volumes*	*Need to develop, make, distribute, support, etc.*
– Sell a service	*No manufacturing costs*	*Hard to scale up*
– Sell a product plus services	*Long-term revenues from sale of each product*	*Need infrastructure to provide services*
– Sell a product plus consumables	*Long-term revenues from sale of each product*	*Need infrastructure to provide support*
– Sell the idea to someone else	*A quick route to cash, no responsibility for building the business / achieving success, no further funding needed/capital investment.*	*Only get a small % of potential value, need to find someone to buy it.*
– License the idea to someone else	*Get the cash quite fast, little responsibility for building the business/achieving success, little further funding /capital investment needed.*	*Get relatively small % of value, need to find and manage licensees.*
– Form a partnership with someone else	*Use experience and resources of another business, increased speed to market, shared*	*Share the value with other people / organisations, need to work with (and 'get-on with') other people /*

	responsibility for building the business/achieving success, shared risk, reduced level of investment/capital	*organisations.*
– Do it all yourself	*You get 'all' the value generated, entrepreneur is in 'full' control of what happens.*	*You need to raise all the investment/capital, entrepreneur takes responsibility for all that goes wrong, you have to work within the limits of the resources you can access.*

(c) Briefly describe the options available to protect the intellectual property in your invention, and compare their merits for each of the business models listed in your answer to part (a).

Trade marks – could be used to protect name for marketing purposes but not the IP in the concept
Copyright – not applicable
Design right – could protect the shape of the light.
Patent – most useful if there is real novelty in the invention.
Trade secret – could possible keep invention inside 'black box' but depends on nature of technology. If novelty is in production process, this may be applicable. Otherwise it would probably be too easy to 'reverse engineer' and copy the idea.

	IP related issue
– Sell a product	*Design right, patent, and/or trademark.*
– Sell a service	*Cannot protect service other than through trade mark of brand.*
– Sell a product plus services	*Service hard to protect, so IP would have to rest with product (design right, patent, trade mark on name).*
– Sell a product plus consumables	*If selling consumables, want to ensure 'lock-in' so would need to have tight IP protection on consumable itself (e.g., patent or design right on power supply or bulb, etc.)*
– Sell the idea to someone else	*Need to have IP protected so that buyer knows what they are buying (and what they could just get for free)*
– License the idea to someone else	*Clear IP management very important to avoid 'leakage'. Need to balance costs of on-going patenting (and location of protection) with realistic assessment of licensing income.*
– Form a partnership with someone else	*As above, but working with others closely may result in unintended transfer of know-how.*
– Do it all yourself	*Easier to keep trade secrets when you own whole supply chain.*

(d) Describe the types and sources of funding that would be appropriate for each of the following stages of development of this invention::

(i) Initial idea and feasibility;

Types: equity, grants, consultancy

Sources: equity = family, friends, business angels; grants = government agencies (DTI), charities (NESTA); consultancy = potential customers or other players in the market

(ii) Initial commercialisation;

Types: Grants, debt, equity, revenue

Sources: Grants = government agencies (DTI), charities (NESTA); debt = banks; equity = business angels, venture capitalists; revenue = customers

(iii) Steady growth of sales.

Types: Debt, equity, revenue

Sources: Debt = banks, specialist finance houses; equity = venture capitalists, public markets (IPO); revenue = customers.