ENGINEERING TRIPOS PART IB

Paper 8 – Selected Topics

Introductory Business Economics 2004
Cribs

Question 1

a. [50%]

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

Assumptions of monopoly:
One firm
Entry assumed to be difficult due to nature of economies of scale or other barriers to entry
Can still be perfect information on consumer side.
Cost functions can exhibit economies of scale.

Outcome of monopoly:

P=MC but P>AC usually

Helpful to illustrate above with two diagrams.

b. [25%] Looking at total surplus this is lower under monopoly than under perfect competition. Producer surplus is higher, consumer surplus lower under monopoly. Deadweight losses of monopoly is the lost surplus. There may be distributional issues associated with the mix of surplus, usually we assume the loss of consumer surplus is more serious than an equivalent loss of producer surplus. Prices lower under perfect competition, if min AC is the same in both cases.

c. [25%] Monopoly is advantageous if it results from a desire to prevent wasteful duplication of fixed costs, eg. in natural monopolies where two or more firms is associated with lower social surplus than one. Monopolies may also be good at promoting productivity growth if they are better at R+D due to economies of scale in R+D or there are failures in the capital market which monopoly profits can overcome. The pursuit of monopoly may play an important incentive role in the economy and hence monopoly may be seen as the outcome of a healthy competitive process especially when monopoly results from patent or copyright creation.

Macro question:

Y=income
C=consumption
I=investment
r=interest rate
t= tax rate
W=wealth

2. a.
i. [20%] $I=f(r)$, $f'(r)<0$. Increase in interest rates would be expected to increase the savings rate in the economy and reduce the demand for investment. This implies that the multiplier falls due to the change in the savings rate and the autonomous injections into the economy fall due to the fall in investment. As national income is equal to the multiplier times the autonomous expenditure this implies national income will fall 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 fall. If investment falls then in equilibrium savings will fall, as savings must equal investment. Additional effect via exchange rate: exchange rate will rise due to inflow of hot money raising price of exports, reducing price of imports, this will further dampen aggregate demand and consumption via reduced autonomous expenditure. E.g. Savings rate in early 1990s in UK.

ii. [15%] $C=A+cY(1-t)$. Decrease in income tax will increase after tax income and increase the multiplier (as tax rate has similar dampening on multiplier to savings rate). This will increase national income and hence consumption. Savings will not change unless increase in consumption expenditure increases investment expenditure by firms. In equilibrium savings and investment should be equal. E.g. Lawson boom of late 1980s fuelled by cuts in basic income tax.

iii. [15%] $C=A+cY+dW$. House prices increasing will increase household wealth. This will reduce savings out of income and increase marginal propensity to consume. This will then have the effect of increasing the multiplier and total consumption. Total savings will stay the same but the marginal propensity to save will be lower. e.g. late 1980s housing boom in UK.

b.
i. [20%]$I=f(r)$, $f'(r)<0$. Increase in interest rate will reduce the amount of autonomous investment in the macro economy. This is because the declining marginal efficiency of capital means that there are less profitable investment opportunities at higher interest rates. E.g. reverse of US since 2001.

ii. [20%] $I=f(r)+g(E(Y))$, $g'(Y)>0$. Increase in expected national income would be expected to raise investment as this would increase the expected utilisation of existing capital equipment and increase the profitability of new investment at given interest rates e.g. Japan in the 1950s and 1960s. Better candidates may discuss the accelerator model.

iii. [10%] This depends. Rapid technological change increases the danger of facing competition from those with new technology. This means there would be additional investment in new capital equipment by those placed to benefit from it. There would be reduced investment in obsolete and possibly expensive capital equipment. So the mix of investments would change but the overall effect on total investment is uncertain. Eg. recent technology boom in the US increases demand for computers and reduces demand for heavy machinery.

Crib for Question 3

(a) Masonry buildings are particularly susceptible to *differential* settlement and cracking is associated with *tensile strain*. Buildings subjected to *hogging* deformation are more susceptible than those subject to *sagging*, because the tensile strains tend to be induced in the top of the building whereas in the sagging zone they are in the foundations. A settlement trough induced at or near the ground surface by a tunnel being constructed is *Gaussian* in shape: this means that the building directly above the tunnel centreline can be only in a sagging mode, whereas to one side it is more likely to be in a hogging mode. [4]

(b) *Compensation grouting* involves injection of grout into the ground between the tunnel and the building foundation in a *controlled* manner. The grout is injected from *tube-à-manchettes* (TAM's) which are installed in the ground *before tunnelling*, usually from an adjacent shaft. *Instrumentation* is installed on the building (levelling and/or electrolevels) and in the ground (extensometers) to monitor settlement and ground movements, and the grout is injected *in response to the measurements*. The principal aim is to reduce the potential *differential* settlement of the building, thereby limiting damage. [3]

(c) (i) *Segmental linings*. These are commonly used for lining circular tunnels, constructed with tunnelling machines. The segments are usually made out of *pre-cast concrete*, but sometimes from *SGI (Spheroidal Graphite Iron)*. Advantages: made in factory under carefully controlled conditions, relatively easy to handle, erected within tunnelling machine, *robust*, very rare for collapse to occur. Disadvantages: usually only OK for circular tunnels, therefore *lack of flexibility on shape*, difficult to vary thickness
(ii) *Sprayed concrete linings*. Sometimes known as *NATM (New Austrian Tunnelling Method)*. Concrete sprayed onto excavated soil surface, accelerators added, *hardens rapidly*, usually with *light reinforcement mesh or with steel fibres added.* Advantages: very *versatile*, can easily change thickness, *excavated shape*. Disadvantages: needs careful quality control, *susceptible to poor workmanship*, collapse of tunnels has occurred (eg Heathrow, 1994). [5]

(d) A tunnel's stability in clay is determined by its *stability ratio*, N, defined as

$$N = (\sigma_v - \sigma_t)/s_u$$

where σ_v = total vertical pressure at tunnel axis level
σ_v = tunnel support pressure (if any, = 0 if open face)
s_u = undrained strength of the clay at tunnel axis level

If the value of N is *less than about 5* the tunnel face will be stable.

In London, s_u is typically around *200 kPa* at usual tunnelling depths (say 20m), so that *N is around 2* for an open face tunnel (assuming unit weight of 20 kN/m^3). In Singapore marine clay, s_u is typically around *50 kPa* at usual tunnelling depths (say 20m) so that *N is around 8.* [4]

(e)Low permeability soils are *clays*, high permeability soils are *sands and gravels*, with silts in between. If tunnelling in clays, the permeability is low enough for there to be *no time for drainage* (unless tunnelling is halted) and therefore the *undrained strength* (see answer to (d)) is often high enough to ensure temporary stability of the tunnel face. The fact that the tunnel is below the water table in such cases is irrelevant. However, if tunnelling in sands and gravels below the water table, the *water will flow into the face*, causing collapse and de-stabilising the tunnel.

Potential problems in tunnelling below the water table in sands and gravels can be overcome by (a) lowering the water table by *pumping from wells* installed for the purpose (b) *injecting grout* into the ground in advance of tunnelling – usually chemical grouts – to reduce the permeability (c) using *compressed air* in the tunnel – all of (a), (b) and (c) enable open face tunnelling to proceed – or (d) *closed face* tunnelling machines, either *slurry* machines or *earth pressure balance* machines. [4]

4 (a) <u>Fill and sand</u> $\phi' = 35°$

$$K_a = \frac{1 - \sin\phi'}{1 + \sin\phi'} \quad \therefore \; K_a = \frac{1 - \sin 35°}{1 + \sin 35°} = 0.27$$

$$K_p = 1/K_a = 3.69$$

<u>Stiff clay, undrained</u> (short term, temprary)

passive pressure $\sigma_h = \sigma_v + 2 s_u$ where s_u = undrained shear strength = 100 kPa (note: often referred to as c_u)

active pressure $\sigma_h = \sigma_v - 2 s_u$

where σ_v = total vertical stress

<u>Stiff clay, drained</u> (long term conditions)

$$\phi' = 25°$$

$$K_p = \frac{1 + \sin 25°}{1 - \sin 25°} = 2.45$$

<u>Anchor Wall</u>

Ignore any influence of 40 kPa surcharge

- Active pressures: (Above water table ∴ zero pore pressures)

At top $\sigma_v = \sigma_v' = \sigma_h' = 0$

At bottom $\sigma_v = \sigma_v' = 4 \times 18 = 72$ kPa

$\sigma_h = \sigma_h' = K_a \sigma_v' = 0.27 \times 72 =$ <u>19.4 kPa</u>

- Passive pressures:

At top $\sigma_v = \sigma_v' = \sigma_h' = 0$

At bottom $\sigma_v = \sigma_v' = 4 \times 18 = 72$ kPa

$\sigma_h = \sigma_h' = K_p \sigma_v' = 3.69 \times 72 =$ <u>266 kPa</u>

Main Wall

- Active pressures

At top in fill: $\sigma_v = \sigma_v' = 40$ kPa (surcharge)

$\therefore \sigma_h = \sigma_h' = 0.27 \times 40 = \underline{10.8 \text{ kPa}}$

At 4m in fill/sand: $\sigma_v = \sigma_v' = 40 + 4 \times 18 = 112$ kPa

$\therefore \sigma_h = \sigma_h' = 0.27 \times 112 = \underline{30.2 \text{ kPa}}$

At 10m, in sand: $\sigma_v = 40 + 10 \times 18 = 220$ kPa

Pore pressure $u = 6 \times 10 = 60$ kPa

$\therefore \sigma_v' = 220 - 60 = 160$ kPa

$\therefore \sigma_h' = 0.27 \times 160 = 43.2$ kPa

$\sigma_h = \sigma_h' + u = 43.2 + 60 = \underline{103 \text{ kPa}}$

At 10m in clay: $\sigma_v = 220$ kPa

$\sigma_h = \sigma_v - 2 s_u$ (undrained, temporary)

$\therefore \sigma_h = 220 - 2 \times 100 = \underline{20 \text{ kPa}}$. ($s_u = 100$ kPa)

At 14m in clay: $\sigma_v = 220 + 4 \times 20 = 300$ kPa

$\therefore \sigma_h = 300 - 2 \times 100 = \underline{100 \text{ kPa}}$

- Passive pressures

At top: $\sigma_v = 0$

$\sigma_h = \sigma_v + 2 s_u$ (undrained, temporary)

$\therefore \sigma_h = 0 + 2 \times 100 = \underline{200 \text{ kPa}}$

At bottom: $\sigma_v = 4 \times 20 = 80$ kPa

$\therefore \sigma_h = 80 + 2 \times 100 = \underline{280 \text{ kPa}}$

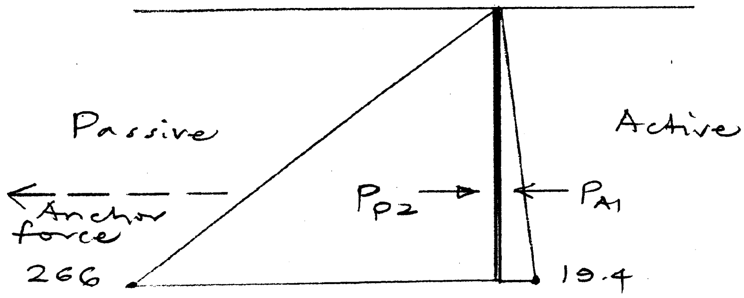
Pressure distribution sketched on next page

[8]

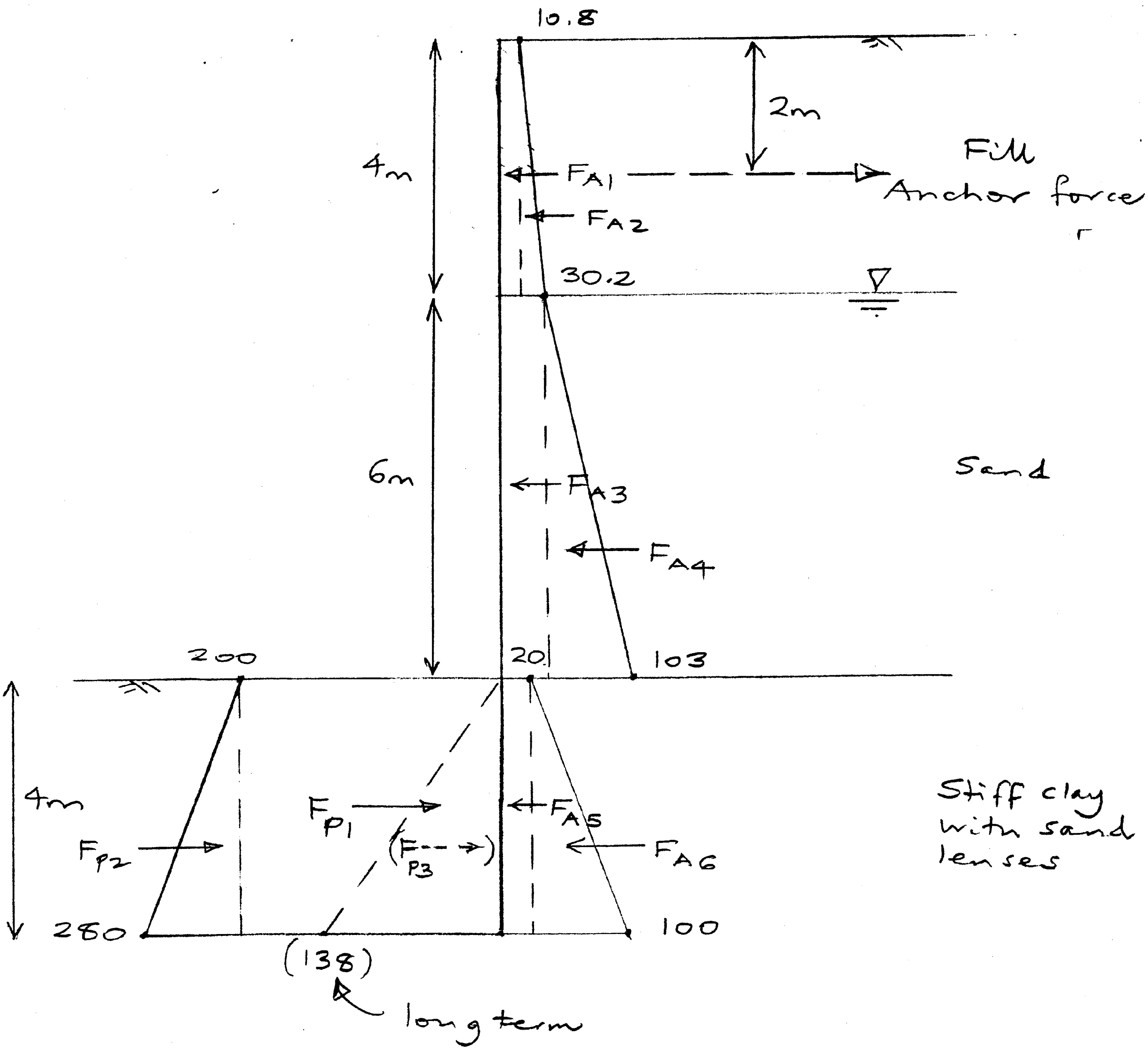
Anchor wall:

All pressures in kPa

Resultant forces for each stress block shown as P_{A1} etc



Main wall:



(b) Factor of Safety against translational failure of anchor wall = F_1

$$F_1 = \frac{\text{total passive forces}}{\text{total active forces}}$$

$$= \frac{P_{P2} + F_{P1} + F_{P2}}{F_{A1} + F_{A2} + F_{A3} + F_{A4} + F_{A5} + F_{A6} + P_{A1}}$$ (see p. 3)

$F_{A1} = 10.8 \times 4 = 43$ kN/m

$F_{A2} = \frac{1}{2}(30.2 - 10.8) \times 4 = 39$ kN/m

$F_{A3} = 30.2 \times 6 = 181$ kN/m

$F_{A4} = \frac{1}{2}(103 - 30.2) \times 6 = 218$ kN/m

$F_{A5} = 20 \times 4 = 80$ kN/m

$F_{A6} = \frac{1}{2}(100 - 20) \times 4 = 160$ kN/m

$P_{A1} = \frac{1}{2} \times 19.4 \times 4 = 39$ kN/m

∴ Total active forces = $43 + 39 + 181 + 218 + 80 + 160 + 39$

$= \underline{760 \text{ kN/m}}$

$F_{P1} = 200 \times 4 = 800$ kN/m

$F_{P2} = \frac{1}{2}(280 - 200) \times 4 = 160$ kN/m

$P_{P2} = \frac{1}{2} \times 266 \times 4 = 532$ kN/m

∴ Total passive forces = $800 + 160 + 532 = \underline{1492 \text{ kN/m}}$

∴ Factor of Safety $F_1 = \frac{1492}{760} = \underline{\underline{1.96}}$ [4]

(c)(i) Only change is passive pressure on main wall

At 4m, $\sigma_v = 4 \times 20 = 80$ kPa

$u = 4 \times 10 = 40$ kPa

∴ $\sigma_v' = 80 - 40 = 40$ kPa

∴ $\sigma_h' = K_p \sigma_v' = 2.45 \times 40 = 98$ kPa

∴ $\sigma_h = \sigma_h' + u = 98 + 40 = \underline{138 \text{ kPa}}$ (see p. 3 diagram)

$\therefore$ F_{p1} and F_{p2} replaced by F_{p3}

where $F_{p3} = \frac{1}{2} \times 138 \times 4 = 276$ kN/m

$\therefore$ revised total passive forces $= 1492 - (800 + 160) + 276$

$= \underline{808 \text{ kN/m}}$

$\therefore$ revised Factor of Safety $F_1 = \frac{808}{760} = \underline{\underline{1.06}}$ (Just safe) [3]

c(ii) Ignore all pressures on main wall in Fill

Calculate moments about anchor:

	Force (kN/m)	Lever arm (m)	Moment (kN-m/m)
Active:	$F_{A3} = 181$	5	905
	$F_{A4} = 218$	6	1308
	$F_{A5} = 80$	10	800
	$F_{A6} = 160$	10.67	1707
			4720
Passive	$F_{p3} = 276$	10.67	2945

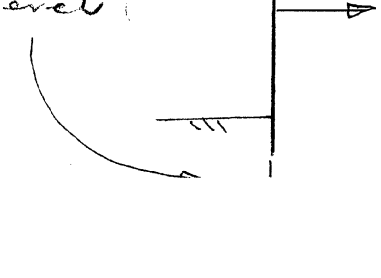
Factor of safety against rotational failure, F_2

$$F_2 = \frac{\text{total passive moment}}{\text{total active moment}} = \frac{2945}{4720} = \underline{\underline{0.62}}$$

[3]

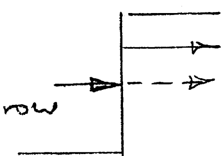
(d) Sand lenses lead to rapid drainage of clay in front of wall and considerable reduction in passive resistance available. Rotational failure of main wall will occur rather than translational failure ($F_2 < F_1$).

(a) increase penetration of wall below excavation level



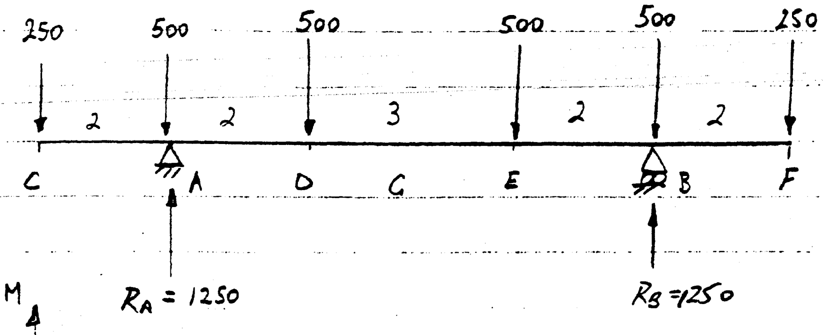
(b) provide a temporary prop

(c) provide additional anchor row

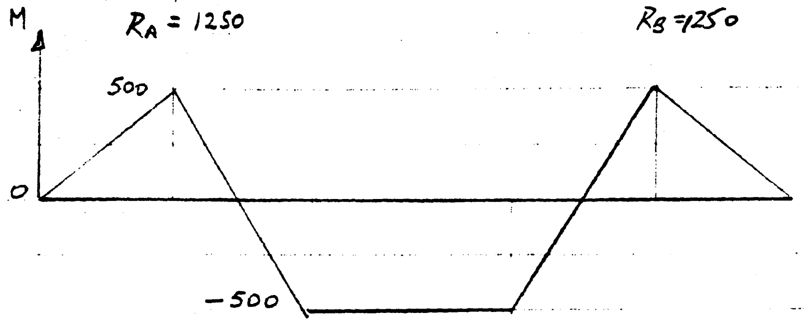


[2]

5 a) LOADING kN

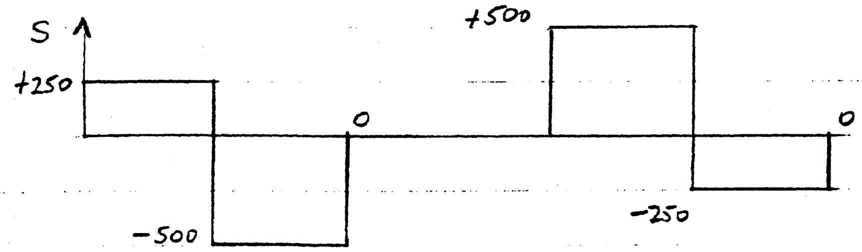


BMD kNm



At D $M_D = 250 \times 4 - 750 \times 2 = -500\,kNm$

SFD kN



b) **Beam Design**

Given $b = \frac{2}{3}d$ $\quad f_{cu} = 30\ N/mm^2$

$$\therefore bd^2 \geq \frac{M}{0.15 f_{cu}} \qquad d^3 \geq \frac{1.5M}{0.15 f_{cu}} \qquad d \geq \left(\frac{1.5M}{0.15 f_{cu}}\right)^{1/3}$$

$$d \geq \left(\frac{1.5 \times 500 \times 10^6}{0.15 \times 30}\right)^{1/3} = 551\ mm$$

Adopt $d = 600\ mm$ $\Rightarrow$ $b = \frac{2}{3}d = 400\ mm$

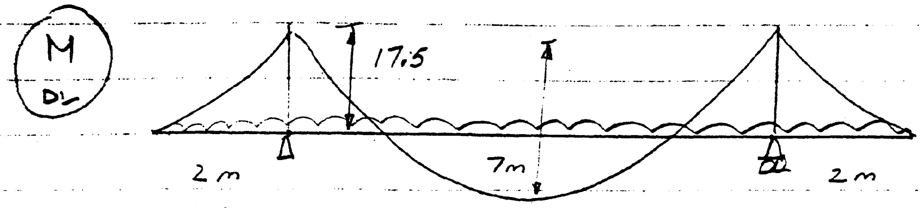
Assume 50mm cover $\Rightarrow$ $t = 650\ mm$

Check span depth ratio $\quad SDR = \frac{7000}{650} = 11$

c.f. IStructE Green book $\quad SDR = 12$ Simply supported $\quad$ OK.
(for beams) $\quad 15$ Continuous

c) Now include self-wt. Use $\gamma_f = 1.4$ for dead load.

$b = 400mm$ $t = 650mm$ $\gamma_{CONC} = 24\ kN/m^3$



Assume $\gamma_f = 1.4$ on dead load.

$$w_{DL} = \gamma_f \times b \times t \times \gamma_{conc.} = 1.4 \times 0.4 \times 0.65 \times 24 = 8.74\ kN/m.$$

$$\therefore M_{support} = \frac{wL^2}{2} = 8.74 \times \frac{4}{2} = 17.5\ kNm$$

$$M_{midspan}\quad \frac{wl^2}{8} = 17.5 \times \frac{49}{8} = 107.2\ kNm$$

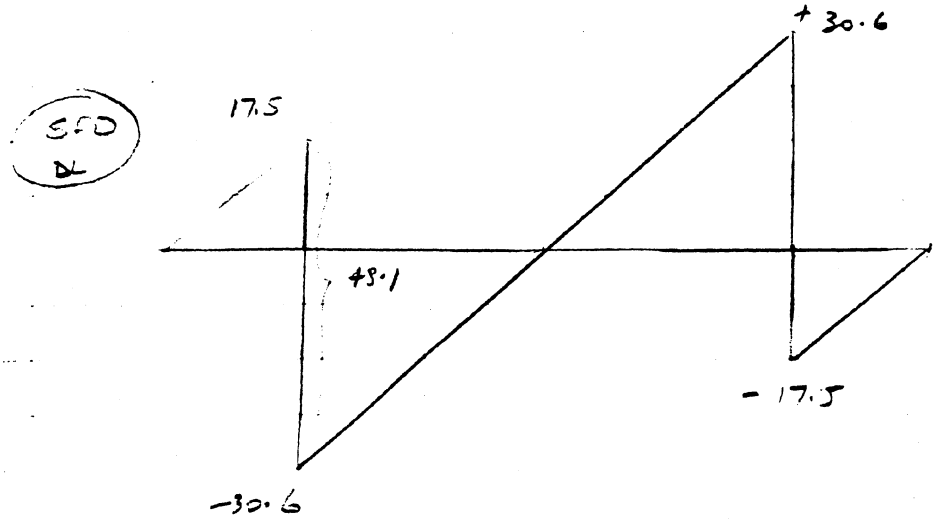
$$\therefore M_{midspan} = 107.2 - 17.5 = 89.7\ kNm.$$

$$\therefore M_{max_{DL}} = 89.7\ kNm \sim 90\ kNm \quad \text{at midspan}$$

Check depth of beam for $M_{max} = M_{LL} + M_{DL} = 590\ kNm$

$$\therefore d = \left(\frac{1.5 \times 590 \times 10^6}{0.15 \times 30}\right)^{1/3} = 581\ mm.$$

$\therefore d = 600mm$ OK for DL+LL.



d) Assume section is singly reinforced.

$$M = 0.87 f_y A_s d(1 - \tfrac{x}{2}) \quad \text{where } f_y = 460\ N/mm^2$$
$$d = 600mm.$$

$$\therefore A_s = \frac{M}{0.87 f_y d(1 - \frac{x}{2})} \quad \& \quad x = 2.175 \frac{f_y}{f_{cu}} \cdot \frac{A_s}{bd}.$$

Guess $x = 0.5 \rightarrow A_s = \dfrac{590 \times 10^6}{0.87 \times 460 \times 600(1 - 0.25)} = 3276 mm^2$

$$\Rightarrow x = 2.175 \times \frac{460}{30} \times \frac{3276}{400 \times 600} = 0.455$$

$$A_s = 3276 \times \frac{0.75}{0.773} = 3181\ mm^2$$

$$\Rightarrow x = 0.455 \times \frac{3181}{3276} = 0.442$$

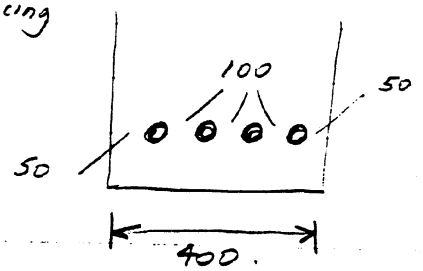
$$A_s = 3181 \times \frac{0.773}{0.779} = 3157 mm^2$$

$$\Rightarrow x = 0.442 \times \frac{3157}{3181} = \underline{0.44} \quad OK.$$

Require $A_s = 3157 mm^2$

Options 4 No. 32 @ $804 mm^2 \equiv 3216 mm^2$ *
3 No. 40 @ $1256 mm^2 \equiv 3768 mm^2$

Adopt 4 No. 32 bars. @ 100 spacing



Anchorage length Adopt $l_b = 40\phi$

$$\therefore l_b = 40 \times 32 = 1280 \sim \underline{1300mm}$$

Assume bars run full length top & bottom. Not worth curtailing due to short length that would be saved c.f. additional cutting, fixing costs.

e) Shear $\quad V_{cap} = (v_c + v_s)\,bd.$

$$v_c = 0.68\left(\frac{100 A_s}{bd}\right)^{0.33}\left(\frac{400}{d}\right)^{0.25} \quad N/mm^2$$

$$= 0.68\left(\frac{100 \times 3216}{400 \times 600}\right)^{0.33}\left(\frac{400}{600}\right)^{0.25} = 0.68 \text{ MPa}.$$

$$V = V_{DL} + V_{LL} = 30.6 + 500 = 531 \text{ kN}$$

Applied $\tau = \frac{531 \times 10^3}{400 \times 600} = 2.2 \; N/mm^2 > V_{cap.} = v_c + v_s.$

$\Rightarrow$ Shear links needed or slab thickness increased.

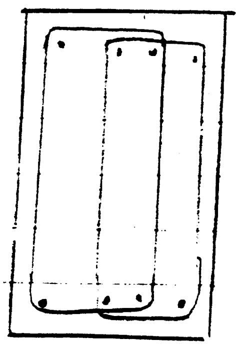
Require $v_s = 2.2 - 0.68 = 1.52 \; N/mm^2.$

$$v_s = 0.87 f_y \frac{A_{sq}}{bs} \quad \Rightarrow S = \frac{0.87 \times 460 \times A_{sq}}{400 \times 1.52} = 0.66 A_{sq}$$

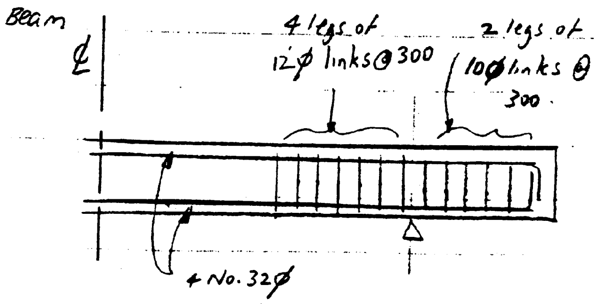
Bar size	A_{sq} (4 bars)	Spacing s (mm)	
8	200		
10	312	206	~ 200mm.
12	452	298	~ 300mm *
16	804	530	~ 500mm

NB $\quad S \leq \frac{3}{4}d = 0.75 \times 600 = 450mm.$

Adopt 4 legs of 12ϕ bar @ 300 spacing.



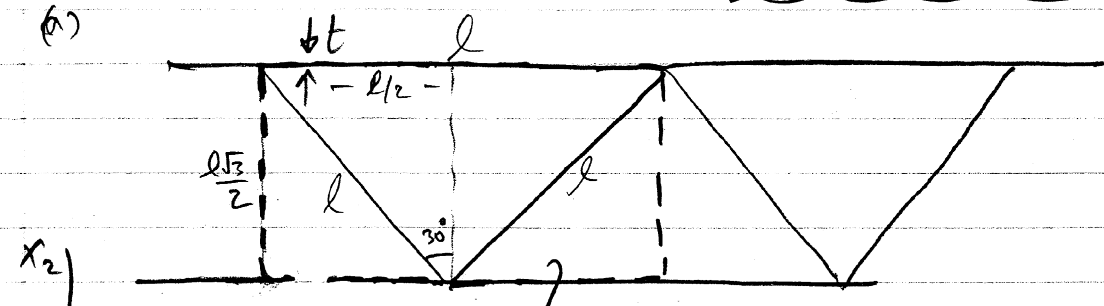
Wrap links around long. main bars as shown.
Need some top steel to support links.



Q6. **Crib for Section C, Paper 8, Part IB**

2003 – 2004

(a)



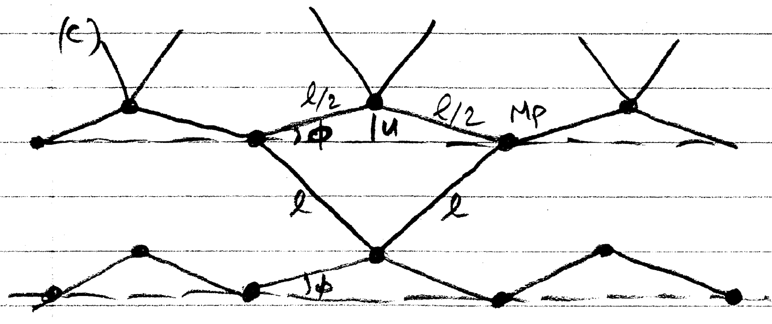
unit cell, area $A = \frac{\sqrt{3}\, l^2}{2}$

$$\bar{\rho} = \frac{tl + (tl/2)}{\frac{l\sqrt{3}}{2}\cdot\frac{l}{2}} = \frac{t}{l}\,\frac{\frac{3}{2}}{\frac{\sqrt{3}}{4}} = \frac{t}{l}\,2\sqrt{3}$$

So, $\boxed{\bar{\rho} = 2\sqrt{3}\,\frac{t}{l}}$ [4]

(b) The inclined struts carry no load.
Hence, $\sigma_{1Y} = \frac{\bar{\rho}}{3}\,\sigma_Y$ [4]

(c)



$M_p = \frac{1}{4}\sigma_Y b t^2$

b = thickness into page

Strain $\varepsilon_{22} = \frac{u}{l\sqrt{3}/2}$ $\quad u = \frac{\phi l}{2}$

$\sigma_{22}\,\varepsilon_{22}\,.\,A b = 2M_p\phi + 2M_p\phi$
(A: area of unit cell)

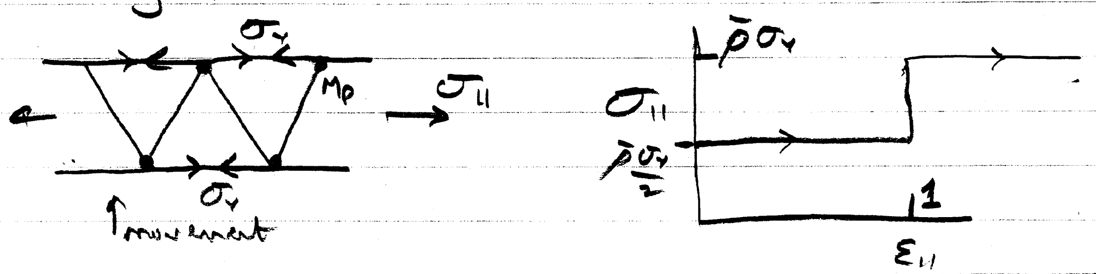
$\Rightarrow \sigma_{22}\,\frac{u}{l}\,\frac{2}{\sqrt{3}}\,\frac{\sqrt{3}}{2}\,l^2 b = \sigma_Y b t^2\,\frac{2u}{l}$

Q6. (c) cont'd.

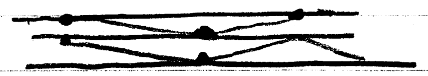
$$\Rightarrow \quad \sigma_{22} = 2\left(\frac{t}{l}\right)^2 \sigma_Y = 2\,\frac{\bar{\rho}^2}{4.3}\,\sigma_Y = \frac{1}{6}\bar{\rho}^2\sigma_Y$$

So,
$$\boxed{\sigma_{22} = \frac{\bar{\rho}^2}{6}\,\sigma_Y}$$
[8]

(d) Loading in x_1 direction:



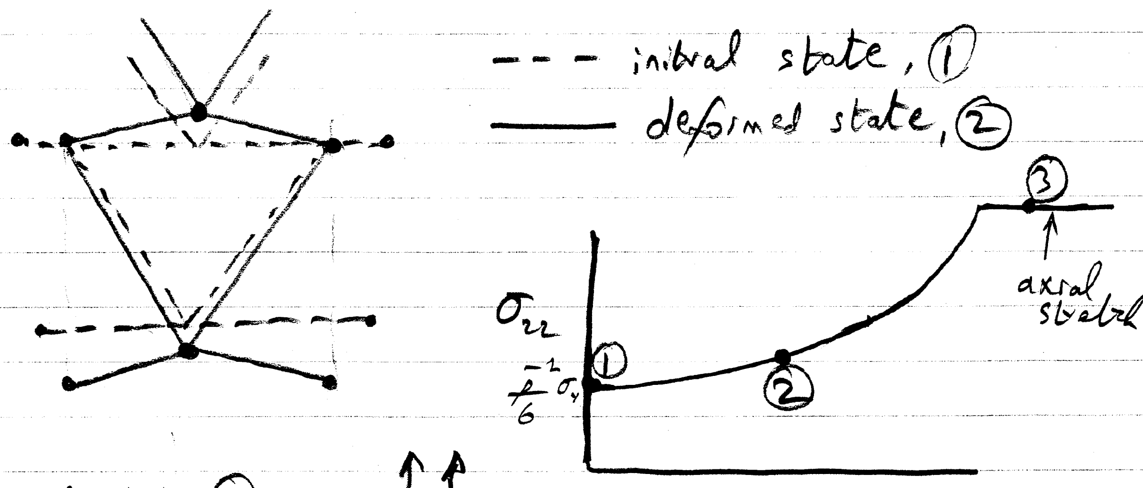
At large strains, the inclined members rotate and align along the x_1 direction, and begin to stretch axially.



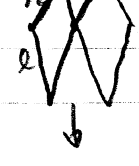
Lock-up at a nominal strain

$$\varepsilon_{11} = \frac{l - l/2}{l/2} = 1$$

Loading along the x_2 direction:



Final state ③ is



[4]

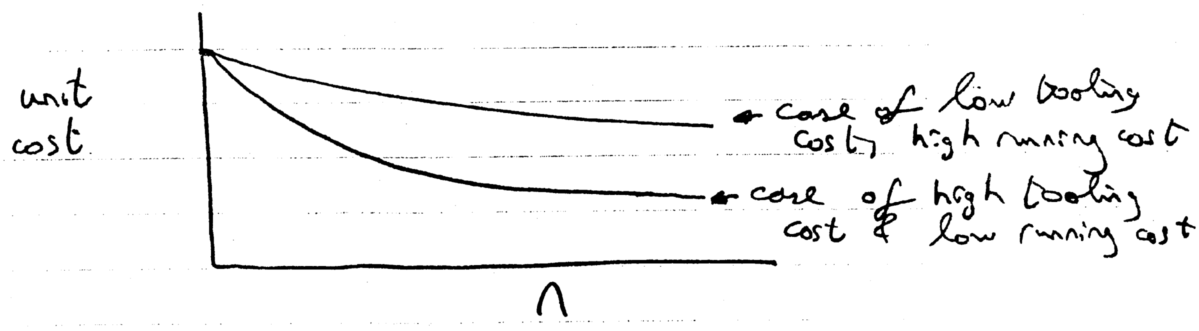
7 (a) Cost = manufacturing cost to the supplier.
This includes contribution from raw material cost, tooling cost, capital cost and running costs such as labour and energy.
Consider the cost of a single part.

Contribution from materials = $\frac{m C_m}{1-f}$

where m = mass of part
C_m = cost / unit mass
f = scrap fraction

Tooling cost = $\frac{\text{Total tooling cost } C_t}{\text{number of parts } n}$

Running cost = $\frac{\text{Factory running cost / hour}}{\text{production rate / hour}}$



'Price' is the sum of money that the product is sold for.

'Value' is the worth the customer puts on the product. It is closely related to the performance.

7 (a) contd.

The successful product has the property:

Cost << Price << Value.

If Price > Value then the 'product is not worth ~~the~~ price'

If price << value, then the 'product is 'good value for money'.

[6]

7 (b) Lattice materials have a much higher nodal connectivity than foams, and so deforming by stretching of the struts rather than by bending. For example, the octet truss has a FCC microstructure with a nodal connectivity of 12.

Lattice materials: $\frac{E}{E_s}$, $\frac{\sigma_Y}{\sigma_{YS}}$, energy absorption $\propto \bar{\rho}$ ← relative density

Foams, $\frac{\sigma_Y}{\sigma_{YS}} \propto \bar{\rho}^{3/2}$ $\frac{E}{E_s} \propto \bar{\rho}^2$

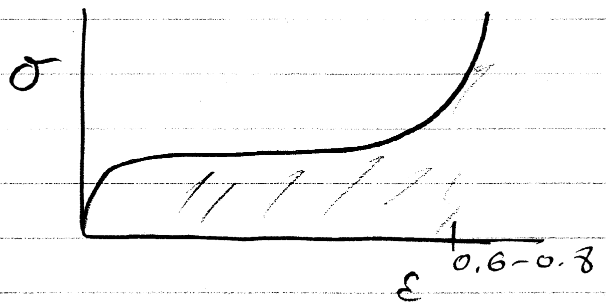
Typically $\bar{\rho} \sim 10\%$,
so $\sigma_Y(\text{foam}) \sim \frac{1}{3}\sigma_Y(\text{'lattice material'})$

[4]

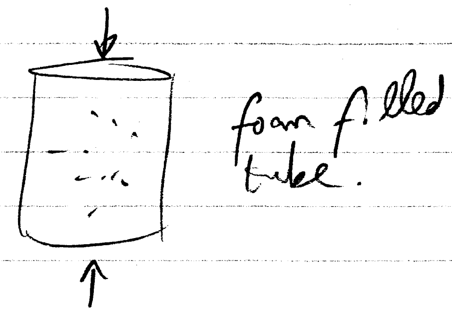
Q7. (b) contd.

Lattice materials are stretching-dominated structures while metal foams are bending-dominated. Foams, made by the melt route, have a low connectivity of 3-4. [4]

(c)



They can be compressed to large compressive strains in all directions.



The foam reduces the buckling wavelength & gives a synergistic strengthening & energy absorbing effect.

[4]

(d) Add TiH_2 particles or bubble N_2 gas into the melt, eg. cymat foam.

[6]

7(d) contd.

Melt processing routes of open celled foams is by either investment casting or by the infiltration of a porous aggregate of salt. A discussion of either method is acceptable.

Investment casting using a polymer template.

Cheap open-cell polymer foams with low relative densities (5-20%), and a wide range of cell sizes with great uniformity are available from numerous sources. They can be used as templates to create investment-casting moulds, into which a variety of metals and their alloys can be cast.

The polymer foam is coated with a ceramic slurry, which is then dried and embedded in casting sand (for mechanical support). The mould is baked to harden the casting material and to evaporate off the polymer template, leaving behind a negative image of the foam. The mould is subsequently filled with a metal alloy (eg . heat treatable Al alloys, steels, nickel, copper); if the alloy is difficult to cast, due to a substantial difference in solidus and liquidus temperatures (recall phase equilibrium diagram notes), an injection pressure is used to aid mould filling. Directional solidification occurs.

The California Company ERG, and the Kings Lynn company Porvair (see their advanced materials division, at www.porvair.com) make foams this way.

In a variant on the process, periodic lattice materials can be injection moulded and then used as the template for investment casting.

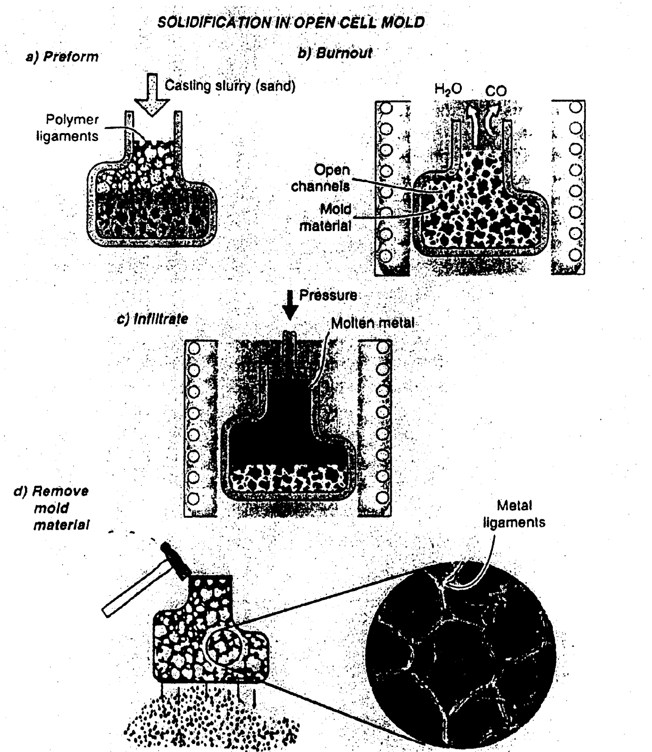


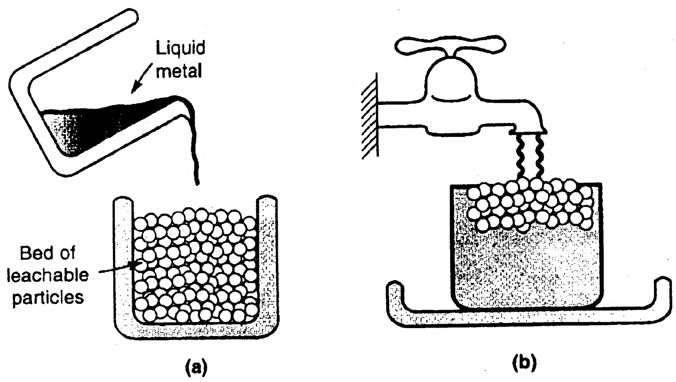
Figure 2.5 *Investment casting method used to manufacture open cell foams (DUOCEL process)*

Investment casting of open-cell foam using a polymer foam preform

7(d)

Infiltration of a porous aggregate of salt

Salt crystals are sintered together by wetting the surfaces of the grains with water. The salt bed has a relative density of 50%-70%, and can be considered to provide a ceramic mould for casting Al alloys with relative density 30%-50%. After casting, the salt is removed by leaching with water. A factory has been established in Nanjing, China and awaits orders!

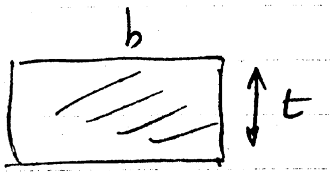


Casting into a sintered compact of salt, followed by removal of the salt mould by leaching.

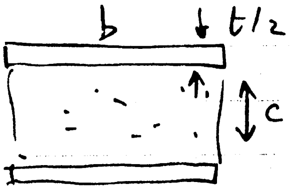
[6]

8

(a) Sandwiches give higher bending stiffness and strength than monolithic construction, for the same weight.



$$I_m = \frac{1}{12} b t^3$$



$$I_s \sim \frac{b c^2 t}{4}$$

$$I_s = I_m \cdot 3\left(\frac{c}{t}\right)^2$$

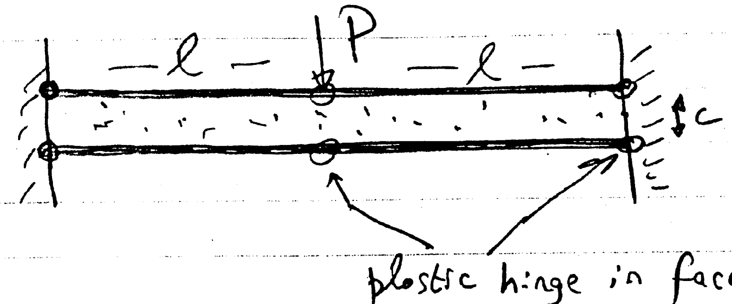
Now $c \gg t \Rightarrow I_s \gg I_m$.

Similarly for plastic moment, except now consider first moment of area Z.

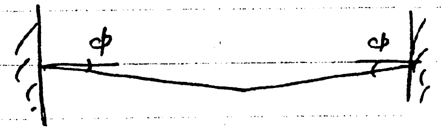
Consequently, sandwiches have a higher vibrational frequency (panel vibration) than the monolithic beam.

[5]

8 (b) (i)



work calculation. Rotated beam by ϕ about each support.



$$P l \phi = 4 M_p \phi + 2.(M_p 2\phi)$$

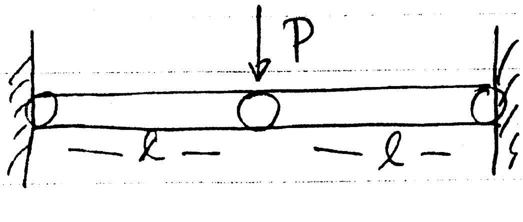
$$+ \tau_c \phi . c 2 l b$$

where $M_p = \frac{1}{4} b t^2 \sigma_Y$ for each face

Hence $$P = \frac{2bt^2 \sigma_Y}{l} + 2 bc \tau_c$$

[5]

(b)(ii)



Now let M_p be the plastic moment of the sandwich beam.

$$M_p = \sigma_Y b t (c + \frac{t}{2}) \approx \sigma_Y btc$$

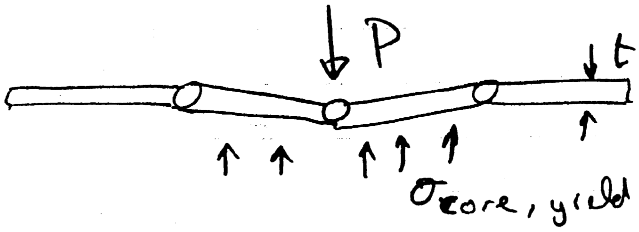
(b) (ii) contd.

Work calc^n. gives,

$$P l \phi = 4 M_p \phi \Rightarrow P = 4 \sigma_Y \frac{btc}{l}$$

[5]

(b) (iii) Indentation under the loading point and at the supports may occur.



Delamination of the core from the faces may occur under the shear stresses.

Wrinkling on the compressive face can occur for thin faces.

Failure can also occur by fatigue and creep of the faces and core.

[5]

N A Fleck,
June 2004

Q.9

(a) $\omega T = \text{Power} = \dot{m}\,\Delta h_0 = \dot{m}\,C_p\,\Delta T_0$

For compressor,

$$\Delta T_0 = \frac{T_{01}}{\eta}\left(PR^{1/3.5} - 1\right)$$

$$= \frac{300}{0.9}\left(27^{1/3.5} - 1\right)$$

$$= 521.4 \text{ K}$$

$\therefore$

$$\text{Torque} = \frac{\dot{m}\,C_p\,\Delta T_0}{\omega}$$

$$= \frac{50 \times 1005 \times 521.4}{6500 \times 2\pi/60}$$

$$= \underline{\underline{38.5 \text{ kNm}}}$$

(b) $\dot{W}_T = \dot{W}_C$

$$\Delta h_{0,max}^{STAGE} = 2 \times U^2 = 2 \times \left(\frac{6500 \times 2\pi}{60} \times 0.5\right)^2$$

$$= 2 \times 340.3^2 = 231.7 \text{ kJ/kg}$$

$\therefore$ Number of stages $> \dfrac{1.005 \times 521.4}{231.7} = 2.26$

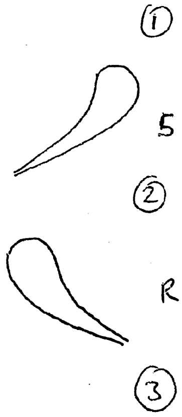
<u>Minimum number of stages is 3.</u>

$\underline{V_x = 0.55 \times 340.3 = 187.2 \text{ ms}^{-1}}$

<u>Actual Stage Loading</u> $= \dfrac{2.26}{3.00} \times 2 = \underline{1.51}$

(c) $\Delta h_o^{STAGE} = 1.005 \times 521.4 / 3$

$= 174.7 \ kJ/kg$.



EULER WORK EQ$^{N.}$

$\Delta h_o = U \Delta V_\theta$

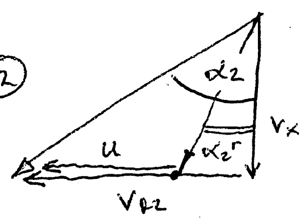
$\therefore \Delta V_\theta = 174.7 \times 10^3 / 340.3 = 513.3 \ ms^{-1}$.

EXIT from ROTOR is axial $\therefore V_{\theta 2} = \Delta V_\theta = 513.3 \ ms^{-1}$

$\therefore \alpha_2 = \tan^{-1}\left(\frac{V_{\theta 2}}{V_x}\right) = \tan^{-1}\left(\frac{513.3}{187.2}\right)$

$\alpha_2 = 70^\circ$.

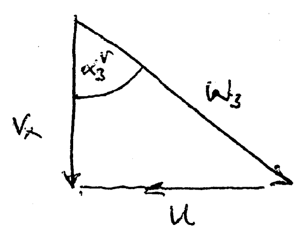
②



$W_{\theta 2} = V_{\theta 2} - U$
$= 513.3 - 340.3 = 173$

$\therefore \alpha_2^r = \tan^{-1}\left(\frac{173}{187.2}\right) = 42.7^\circ$.

③

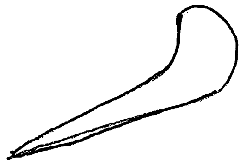


$\tan \alpha_3^r = \frac{-U}{V_x} = \frac{-340.3}{187.2}$

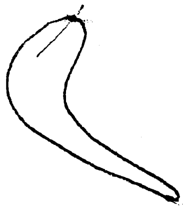
$\therefore \alpha_3^r = -61.2^\circ$.

(c) CONT.

STATOR



ROTOR

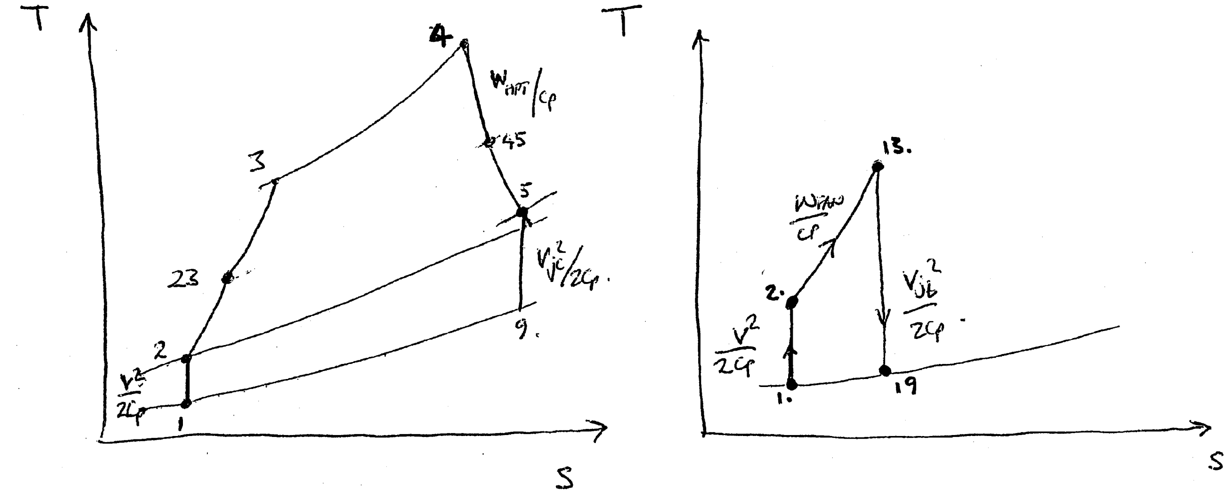


(d) Stage loading increases to 2.26 (from 1.51) This would probably reduce turbine efficiency by a few percent; and hence thrust would be reduced. There would be a weight saving which might compensate.

Examiner's note: Parts (a) and (b) were generally answered well, and there were several perfect or near-perfect attempts at determining the velocity triangles. (The examiners had initially thought this to be a straightforward question, but it was answered by less than one third of the students doing this section.)

Q.10

(a)



(b)

$$\Delta T_0^{HPT} = \Delta T_0^{HPC} = T_{03} - T_{023} = 449.7$$

$$\therefore \quad T_{045} = T_{04} - \Delta T_0^{HPT} = 1400 - 449.7 = 950.3\text{ K.}$$

$$\Delta T_{0,is}^{HPT} = \frac{\Delta T_0^{HPT}}{\eta} = 499.7 \Rightarrow T_{045}^{is} = 900.3\text{ K.}$$

$$\therefore \quad P_{045} = P_{04}\left(\frac{T_{045}^{is}}{T_{04}}\right)^{3.5} = 3.07\text{ bar.}$$

(c)

$$\Delta T_0^{LPT} = W_{LPT}/1005 = 355.22\text{ K} \Rightarrow T_{05} = 595.1$$

$$T_{05}^{is} = 555.31 \Rightarrow P_{05} = 0.4685\text{ bar.}$$

$$\therefore \quad T_9 = T_{05}\left(\frac{P_9}{P_{05}}\right)^{1/3.5} = 517.35.$$

$$V_{jc} = \sqrt{2c_p(T_{05} - T_9)} = 395.3\text{ ms}^{-1}$$

Location:	2	23	3	4	45	5	9	13
Pressure (bar):	0.450	0.720	14.40	14.40	3.07	0.4685	0.267	
Temperature (K):	257.8	299.0	748.7	1400	950.3	595.1		

(d) $$\Delta T_0^{FAN} = \frac{1/2\,(V_{jb}^2 - V^2)}{\eta\, c_p}$$

$$= \frac{1/2\,(395.3^2 - 250^2)}{\eta\, 1005} = 51.84\ K.$$

$$\Delta T_0^{LPT} = \Delta T_0^{LPC} + \beta\,\Delta T_0^{FAN}$$

(i) $\therefore$ $$\beta = [355.2 - (299 - 257.8)]/51.84 = \underline{\underline{6.06}}.$$

Net thrust, $$\frac{F_N}{\dot{m}_c} = (1+\beta)(V_{jc} - V)$$

$$= 7.06 \times (395.3 - 250)$$

(ii) $$= \underline{1025\ N/kg s^{-1}}$$

$$\eta_p \simeq \frac{V(V_j - V)}{1/2\,(V_j^2 - V^2)} = \frac{2V}{V_j + V} = \frac{2 \times 250}{250 + 395.3}$$

(iii) $$\underline{\underline{\eta_p = 77.5\%}}$$

Examiner's note: This was the most popular question. Most students more or less correctly drew the *T-s* diagrams. The majority of marks were lost in the calculation of the jet velocity and bypass ratio. In some cases it was incorrectly assumed that the pressure and temperature rise across the fan were the same for the core and bypass flows.

Q 11 (a)

$C_L \sim 1.5$ (margin for stall at ~2.0)

$\rho \sim 1.225$ (sea level – why not!)

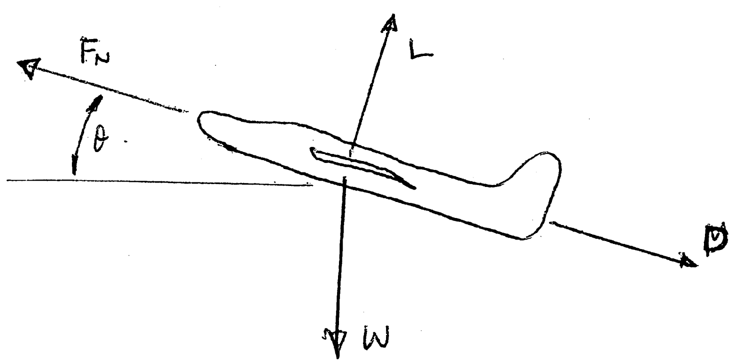
$v = 90\ ms^{-1}$ (~200 mph, limited by length of runway, tyre overheat etc.)

$$L = Mg = C_L \times \tfrac{1}{2}\rho v^2 A.$$

$$\therefore A = 500\times10^3 \times 9.81 \,/\, (0.5\times 1.225\times 90^2\times 1.5)$$

$$A \approx 660\ m^2$$

(b)



$$L = W\cos\theta \simeq W$$

$$F_N = D + W\sin\theta.$$

(c) $V = 0.85 \times \sqrt{1.4\times 287\times 226.7} = 256.3\ ms^{-1}$

$\therefore \sin\theta = 1.5/256.3 \simeq 5.85\times10^{-3}$

$F_N = D + W\sin\theta = W\left(\frac{D}{L} + \sin\theta\right)$

$= \times 10^3 \times 9.81 \times \left(\frac{1}{20} + 5.85\times10^{-3}\right)$

$F_N = 263\ kN.$

(d) $\dfrac{\dot{m}\sqrt{T_0}}{A_0} = \text{const.}$

$$\therefore \quad \dot{m}_{TO} = \frac{1.063}{0.46} \times \sqrt{\frac{259.5}{292.2}} \times 450 \simeq 980 \text{ kg/s}.$$

<u>Top of Climb:</u>

$$F_g = F_N + \dot{m}_a V = \frac{263\times10^3}{4} + 450 \times 256.3 = 181.1 \text{ kN per engine}.$$

Now "dimensionless" group is $\dfrac{F_g + A_N P_A}{A_N P_0}$

<u>Take off:</u>

$$F_g + A_N P_A = \frac{1.063}{0.46} \times \left(181.1\times10^3 + 2.5\times0.287\times10^5\right)$$

$$= 584.3 \text{ kN}.$$

$$\therefore \quad F_N = 584.3\times10^3 - 2.5\times1.013\times10^5 - 980\times90$$

($A_N P_A$; estimated, or consistent with table; RAM DRAG)

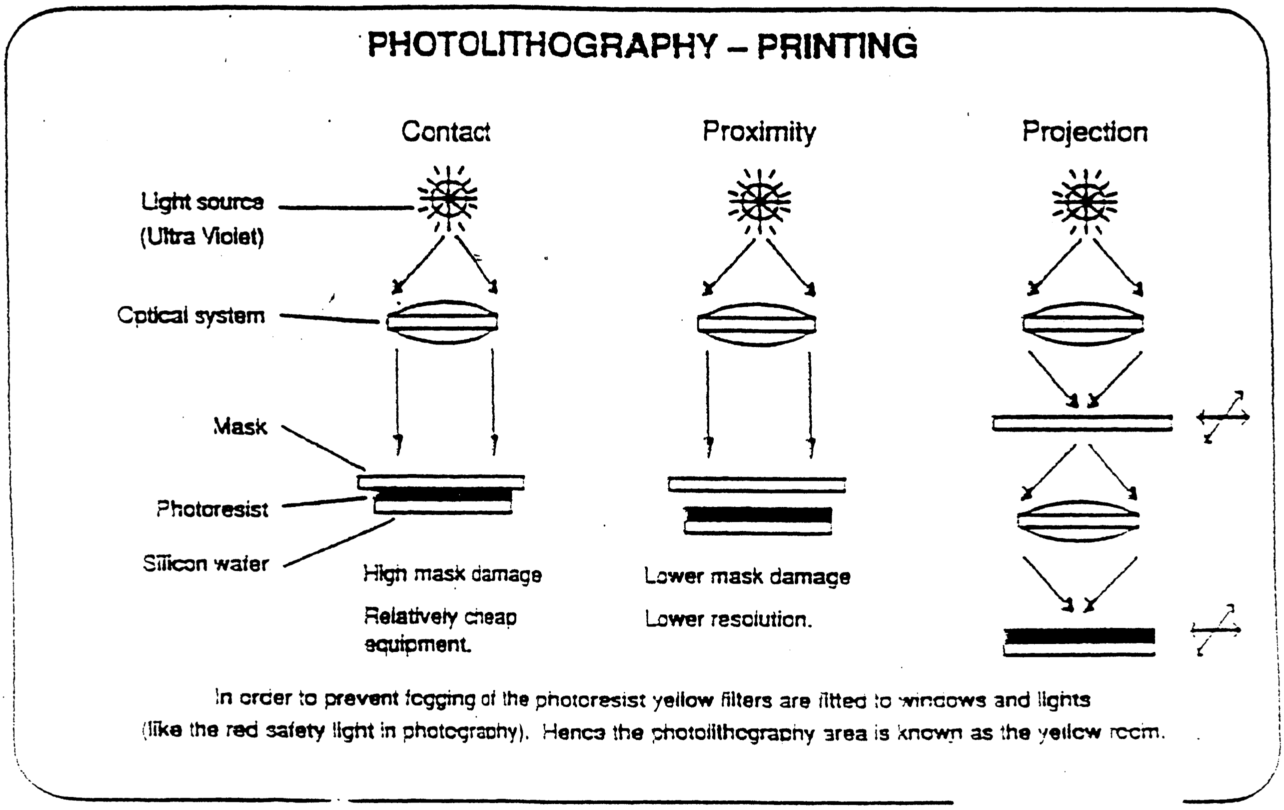
$$= \underline{243 \text{ kN per engine}}.$$

(TOTAL NET THRUST = 971 kN).

Examiner's note: Parts (a), (b) and (c) were on the whole answered well (although most students used C_L=0.5 at take-off). There were very few correct attempts at the dimensional analysis section. A significant number of students used the expression given for (choked) dimensionless mass flow to determine a value for the specific heat capacity (which in most cases was wrong because they'd used conditions at entry to the engine rather than the nozzle) rather than just matching the dimensionless group between cruise and ground conditions.

Sew E 16 6 04

12 (a)



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 I maging 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 numberical aperture of the projection optics and $\lambda/(NA)^2$. i.e. a high resolution (large NA) is achieved at the expense of depth of focus.

Current projection line systems are capable of 0.13 micron resolution, 0.1 micron registration and a throughput of approx. 20 off 200 mm diameter wafers per hour.

Far UV research systems are capable of <0.1 micron resolution.

Electron beam systems – they are currently able to operate at resolutions down to ≤ 0.1 micron resolution.

Eelctron beam systems – they are currently able to operate at resolutions down to $\leq 20\,\text{nm}$ but will only have a minimal throughput and therefore these would only be used for very specialist applications. For systems with resolutions of approx. 0.25 micron a throughput of approx. 0.5 wafer per hour would be possible. E-beam systems are generally used to produce the photomasks but can be used directly to write on wafers.

X-ray lithography systems have approx. 0.13 microns resolution and 0.13 microns registration but are still a long way from the production line – masks are a major problem at present.

(b) from Fig.

Class 10 clean room, therefore 10 particles per cubic foot larger than or equal to 0.5 micron in size. Therefore ~350 per cubic metre.

Air volume which flows over the wafer in 2 mins is

$$\frac{30m}{\min} \times \pi \left(\frac{.3m}{2} \right)^2 \times 2 \text{ min}$$

$$= 30 \times 3.14 \times \frac{(.3)^2}{4} \times 2 = 4.24m$$

therefore number of particles contained in air volume is

$$350 \times 4.24 = 1484$$

and with a 5% sticking coefficient means ~74 particles will land on the wafer!

(c) ignoring parasitic effects

$$\text{RC} = \left(\frac{\rho \ell}{\text{A}} \right) \times \left(\frac{\varepsilon_0 \varepsilon_r A}{spacing} \right)$$

Therefore RC =

$$\left(\frac{2.7\times10^{-6}\times2\times10^{-1}}{(.4)(.4)\times10^{-8}}\right)\left(\frac{8.85\times10^{-14}\times3.9\times0.4\times10^{-4}\times2\times10^{-1}}{.5\times10^{-4}}\right)$$

$$=\left(\frac{5.4\times10^{-7}}{.16\times10^{-8}}\right)\left(\frac{8.85\times3.9\times0.8\times10^{-19}}{.5\times10^{-4}}\right)$$

$$=\left(\frac{54}{.16}\right)\left(\frac{8.85\times3.9\times0.8\times10^{-15}}{.5}\right)$$

$$(18{,}638\times10^{-15})s$$

$$=1.864\times10^{-11}s$$

Cu-lower Resistivity

Polymide-lower k

13

(a) $\sigma = Ne\mu$

consider a tube of charge of cross sectional area 1 m^2. In 1 sec, a tube of length v will pass any point, v = velocity of electrons. It will have volume v, and so total charge passing = v.N.e.

conductivity = current per unit area/electric field.
Electron velocity v = field x mobility = E.μ

Therefore σ = vNe/E = Ne.Eμ/E = N.e.μ

(b)

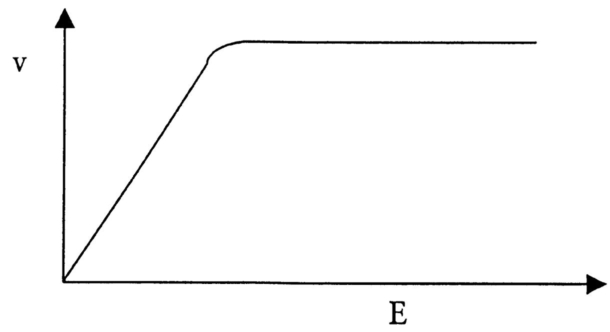
$$N = 4/(3.61\times10^{-10})^3 = 8.5\times10^{28}m^{-3}$$

$$\mu = \sigma/(Ne) = 6\times10^{7}/(8.5\times10^{28}\times1.6\times10^{-19}) = 4.4\times10^{-3}m^2/V.s$$

(c)

$$\sigma = 1.2\times10^{20}\times1.6\times10^{-19}\times4.4\times10^{-3} = 8.47\times10^{-2} = 0.0847\text{ohm}-1.\text{m}-1$$

(d)



Initially, the velocity increases linearly with field, with linear mobility, in Si=0.1 $m^2/V.s$. At a critical field, scattering mechanism changes at a critical field E*, and there is a maximum velocity, the scattering limited velocity, v_{sat}. There is no over-shoot for Si.

(e)

$$E^* = v_{sat}/\mu = 1.25\times10^5/0.25 = 5\times10^5\text{ V/m.}$$

$$V = E^*.L \qquad L = 2/5\times10^5 = 0.4\times10^{-5} = 4\times10^{-6}m$$

$$\text{Transit time} = L/v = 4\text{x}10^{-6}/1.25\times10^5 = 8\times10^{-6}\times4\times10^{-6} = 32\times10^{-12} = 32\text{ps.}$$

(f) yes. The critical field is not an upper limit. Just increase the field, make a shorter channel length or use a different material for active regions.

14.

Dopant creates mobile charge down to a fixed depth in a channel. The channel conducts well at 0 gate volts. The negative gate voltage is applied which depletes this charge down to its total depth, and the channel switches off.

Gauss law.

Box of area A and height h. Charge density = N.
Charge enclosed = N.e.A.h.
Field a bottom = 0.
By symmetry, no field out of sides.
Total electric displacement through top surface, $\varepsilon E.A = NeAh$

$E=Neh/\varepsilon$

Integrate w.r.t h
$V=0.5\ Neh^2/\varepsilon$

(c) $\sigma = Ne\mu$, so $N = 4/1.6\times10^{-19} = 2.5\times10^{19}\,m^{-3}$

(d) $v = \mu E, E = V/L,\ L = vt$
so
$L = \mu Et = \mu(V/L)t$, $\quad L^2 = \mu Vt = 1\times2\times2.10^{-12} = 4\times10^{-12} \quad L = 2\times10^{-6}\,m.$

(e) $V = 0.5\times2.5.10^{19}\times1.6\times10^{-19}\times\left(0.2\times10^{-6}\right)^2/10^{-10} = 8\times10^{-4}\,V$

(bit low because of low N value used)

(f) $E = Neh/\varepsilon = 2.5.10^{19}\times1.6.10^{-19}\times0.2.10^{-6}\times/10^{-10} = 8\times10^{3}\,V/m.$

Much small than breakdown field.

Crib question 16

a.

i. The owner may lose the PDA and someone may find it. The person finding the PDA may wish to access its content, but must not be allowed to do so.

ii. The typical PDA OS supports a single user and has some kind of login program that is invoked whenever the PDA is turned on or woken up from suspend mode. The PDA should suspend and lock itself after a few minutes of inactivity, otherwise it might be unlocked when lost and found.

The login program asks for a password and keeps the PDA locked until the correct password has been input. Multiple attempts are allowed; however, after a certain number of failed attempts, the login program may insert an extra delay or even a reboot after each failed attempt.

iii. The login program checks the validity of a typed password by hashing it and comparing the result with the value stored in the password file. The typed password is valid only if the two match. Since the hash is one-way, someone who manages to read the password file and learn the stored value cannot recover the original password from it, except perhaps via a dictionary search.

iv. A new password for the PDA can only be defined if one knows the previous password, or if none is currently set. A special "set password" program must be invoked. This will first check your knowledge of the old password (if any) and then allow you to set a new one. It will then store a hash of the new password in the password file.

b. (Open question: other answers may also be ok.)

i. The software you supply with the card includes a modified login program. With this new program one can either type the password as usual, or supply a fingerprint. The card outputs a digest of the fingerprint in the same way that the keyboard outputs a typed password. As happens with a normal password, the assessment of whether the supplied fingerprint digest is valid is done in the login program by comparing the data produced by the input peripheral (keyboard or reader) with the data stored in the password file. The owner may also disable the "typed password" facility, forcing authentication to happen via fingerprint only.

ii. There are no secrets in the card. The card just transforms a fingerprint into a bit string that encodes its salient features. This is then compared by the login program against the data in the password file.

Ideally, the verification data stored in the password file should be sufficient to check whether a fingerprint digest is valid but not to generate a valid fingerprint digest. Whether this is possible or not depends on how the fingerprint verification algorithm works. If this is possible, then the system stores no secrets anywhere. If it is not possible, then the password file is storing a valuable secret.

iii. A new fingerprint for the PDA can only be defined if one can produce the currently active fingerprint (or password), or if none is defined. A special "set fingerprint" program must be invoked. This will first check that you can produce the old fingerprint and then allow you to set a new one, presumably in the context of a transfer of ownership of the PDA.

iv. The fact that the verification is done in the login program, not in the card. So the card can't just say "yes", it has to say a fingerprint that matches the one stored in the password file.

v. The legitimate user can just borrow or buy another fingerprint reader card and use it like the first. Since no secrets are stored in it, the card just works as an input peripheral. (This assumes that the individual readers can be pre-calibrated so that their outputs are consistent.)

Crib question ~~2~~ 15

a.

i.

BUFFERING: A technique whereby the data transferred between device and computer is accumulated in an area of memory (called a buffer) before being transferred. The transfer doesn't happen as soon as a piece of data trickles in, but later, when the buffer becomes full or is explicitly flushed. Useful when the individual transfers are expensive for small payloads, and also to smooth out an irregular data rate from the writer. Example: writing a stream of bytes to disk.

SPOOLING: A technique in which the data produced by various writers is accepted by a central entity (the spooler) and serialized before being forwarded to an output device. The data from each writer is always sent out as one contiguous block, even if the writes all happen in parallel. Without spooling, the output from the various writers would be interleaved---and, if we take printing as an example, it is obvious why this would be undesirable.

CACHING: A technique whereby a dynamic subset of the data from a slow subsystem is held in a fast but small memory (the cache) in the hope that it will be referenced again soon. This speeds up repeated attempts to access the slow subsystem: accesses after the first are serviced from the cache and are therefore faster. Example: processor access to main memory.

DMA: (Direct Memory Access.) A technique of transferring data between memory and peripheral in which the processor gives instructions for the transfer of a whole block of data into or from a specified area of main memory, but is not thereafter involved in loading or storing the data from either the memory or the device until the transfer is over. Useful for large transfers in which using the processor would be too slow (firstly because each word would have to be first read, then written, using two bus transactions instead of one; and secondly because the processor would be spending its cycles on this as opposed to other tasks). Example: disk I/O.

ii. Yes. Spooling is an OS-level function that allows several applications to send data to a single device that cannot accept interleaved data streams. Buffering is a lower-level function, with no knowledge of applications or data streams. Spooling may use buffering.

b.

i.

BLOCKING I/O: A technique whereby the program that invokes the I/O operation is suspended until the operation completes. Use blocking I/O when programming simplicity is more important than maximum speed, for example in offering a scripting API to end users.

NON-BLOCKING I/O: A technique whereby the I/O system call returns immediately, transferring whatever data could be transferred at that time and perhaps deferring completion of the transfer until later. Use non-blocking I/O when you don't know whether there is any data to be transferred and the program can't freeze if there isn't, for example when reading data from the mouse.

ii. An asynchronous read is a special case of a non-blocking read. "Non-blocking" just means that the system call returns immediately. The "asynchronous read" returns immediately, but requests a read (of a certain number of bytes, or of as much as there is before the connection breaks) that will be completed some time in the future. The application will have to find out about completion by some other means. One can however imagine a non-blocking read that is not an asynchronous read: a call that just returns immediately with whatever data was already available (buffered up) at the time of the call, without scheduling any follow-up action for later.

c. A process wants to use a device, which may be busy processing previous commands and therefore may not be ready to accept new ones. With polling, the process checks the device repeatedly, waiting for it to become free, and then uses it. With interrupts, instead, it's the device itself that, once it is ready, causes a special piece of code (the interrupt handler) to be invoked.

Imagine a series of repeated I/O operations. If the peripheral is fast and its data rate steady (no fluctuations), then the busy-wait time of a polling CPU will be low. If we used interrupts in such a situation, then each I/O transaction would carry the high cost of an OS-level context switch. This would be much more expensive than straightforward polling.

Crib question ~~3~~ 17

a.
Active Badge system is a good example
Badge transmits unique id
Diffuse infra-red is used as the medium (does not go through walls)
Room receiver(s) picks up transmission(s) and associates a receiver id to give a
Central server polls receivers
Depending on the speed of the network a time stamp can be added at the receiver or deeper within the network
Sequence numbers are used to detect duplicate receptions in rooms with multiple receivers
Location information is an attribute of a (software) object representing the physical entity being tagged

This attribute is in fact a pointer to a location service for the named object
Multiple location services can be used
At any time there is a mapping between an object, its name, and its location
A single global database of location information is not likely to work well because of the real time performance requirements on such systems (ie the location attribute is dynamic)
Caching location information close to where it is used is appropriate
Efficient searching of object space by location is required
The co-location function has to be implemented efficiently as it is used a lot
The whole distributed system has to deal with location information, naming, distribution models, and transaction management

b.
Marking time (sleep) mode is based on simple RC timeout, which is energy efficient
Pulse position modulation is used for transmission
Receiver is only switched on briefly after a transmission
A light-dependent resistor is used to reduce frequency of transmission in the dark
Pressing the badge button generates an immediate transmission hence system remains agile even if frequency of transmission is low
In principle other sensors (motion, radio-field) can be used to take badge out of sleep mode
For badges attached to equipment the frequency of transmission can be much lower

c.
Presentation of location of people and objects
Location sensitive communications
Location-oriented paging
Transportable desktops
Contextually-aware mobiles

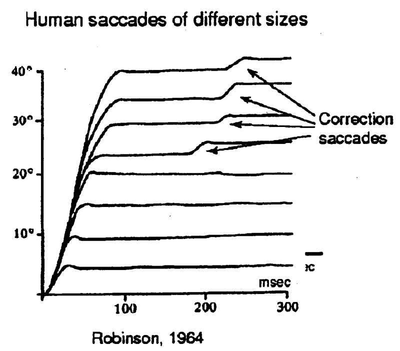
Engineering Tripos Part IB SECOND YEAR

Paper 8, Section G: Biological & Medical Engineering

Solutions to 2004 Tripos Questions

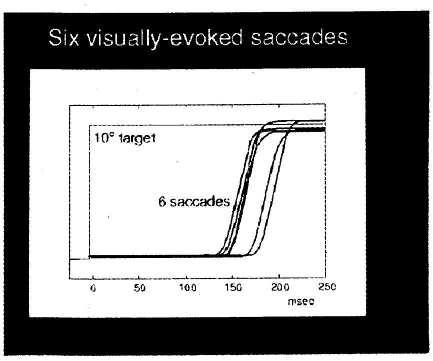
18. **Oculomotor control**

(a)



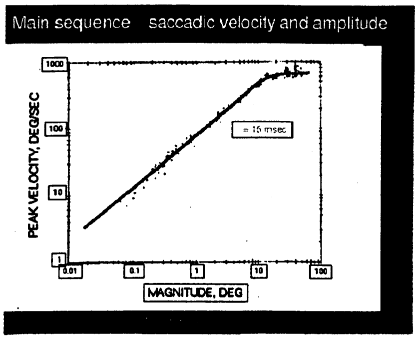
The crucial points are that the duration increases with amplitude, roughly $21 + 2.2A$ msec, where A is the amplitude in degrees, and that for larger saccades the velocity reaches an asymptotic value. [3]

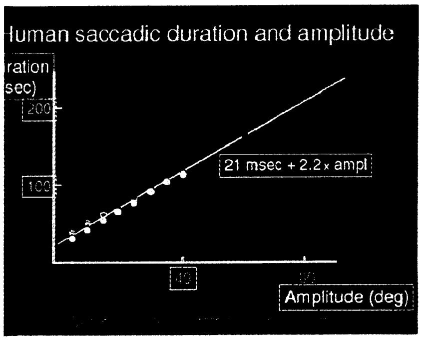
(b)



The trajectory of the eye would be expected to remain constant for a given amplitude; the main thing that varies is the latency or reaction time, but some saccades may also land inaccurately on the target, and be followed by a correction saccade. [3]

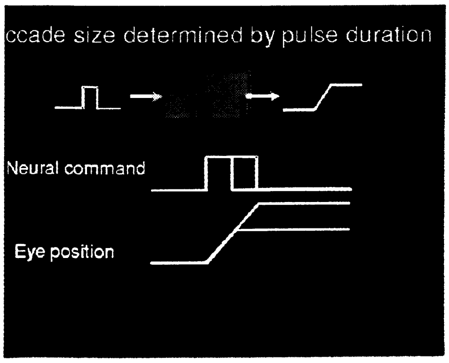
(c)





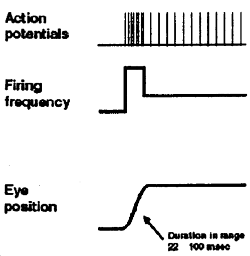
[4]

(d) They follow from the fact that the mechanical properties of the plant approximate at moderate ('physiological') frequencies to a linear first-order low-pass filter with a time constant of some 15 msec. In addition, saccades of different amplitudes are generated not by varying the size of the signal sent to the muscles (i.e. the frequency of the action potentials) but by varying the duration of a constant burst of activity. This generates the theoretical peak velocity/amplitude relationship shown above left.

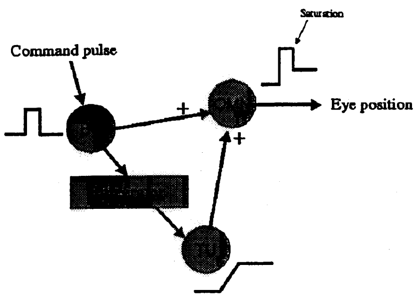


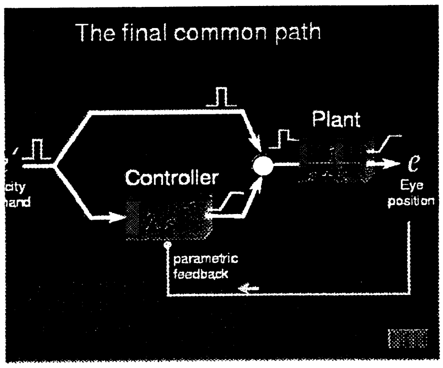
[4]

(e) The pattern of activity in the nerves innervating the ocular muscles to generate a saccade consists of a burst of high frequency action potentials (the pulse component that throws the eye as rapidly as possible to the new position), followed by relatively low frequency tonic firing (the step component that holds the eye in its new position).

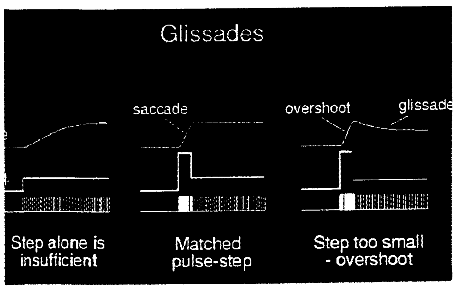


These two components appear to be generated by different groups of neurons in the brainstem (burst units BU and tonic units TU), whose outputs summate at the motor neurons themselves (OMN) to generate the pulse-step. The burst units drive the tonic units through a neural integrator.



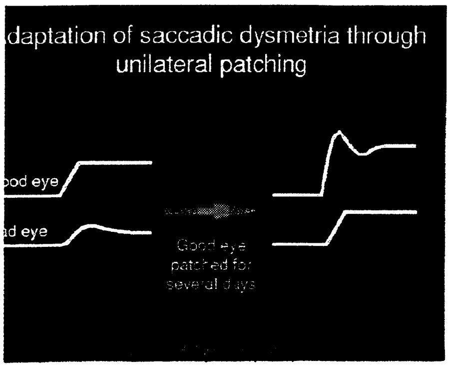


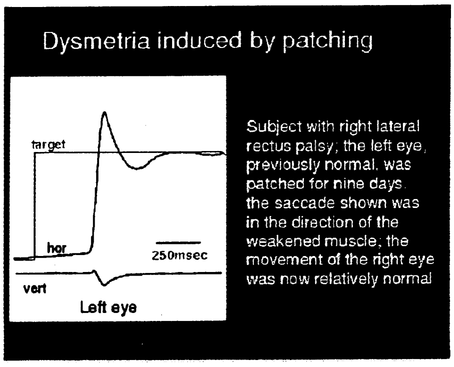
This neural circuit (known as the final common path) has the effect of nullifying the low-pass properties of the plant, so that the system as a whole acts as a pure integrator. For this to happen, the gain λ of the tonic integrator has to be continually matched to the characteristic frequency k of the plant. If this does not happen, glissades will be observed: the eye will either overshoot (if λ is too small) or undershoot (if it is too big), and settle only relatively slowly to the final position.



[3]

(f) In patients with weakness of the oculomotor muscles of one eye only, the system appears to be unable to match λ independently for each eye: in such cases the 'good' eye executes normal saccades, and the 'bad' eye's saccades show glissades and inadequate gain. But if the good eye is covered, after a matter of days the system adapts so that its saccades are relatively normal. Because this adaptation affects the good eye as well, its saccades show overshoot glissades and too large a gain.



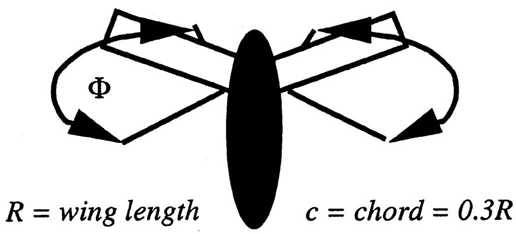


[3]

Assessors' remarks: This question tested the candidates' understanding of the oculomotor control system. It was an essay-style question, entirely book work. The better solutions were characterised by short, concise answers which addressed the specific points raised by the question. Poorer candidates reproduced large parts of the lecture notes in the hope of hitting the right answer by chance. There was significant variation in the candidates' ability to sketch curves illustrating the principal characteristics of saccades, with many candidates showing the shape only, with no indication of numerical scale.

19. **Mechanics of flight & swimming**

(a)



$$\phi = \bar{\phi} + \frac{1}{2}\Phi \cos(2\pi f t)$$

(i) The question says that the downwash is negligible compared with the flapping velocity, so use the small angle approximations from lecture 2 for the relative velocity and the vertical force:

$$U_r \approx \text{flapping velocity} ,$$
$$F'_{\text{vert}} \approx L' .$$

From first principles (or the lecture handout), derive the flapping velocity as

$$U(r,t) = r\frac{d\phi}{dt} = -r\pi\Phi f \sin(2\pi f t) \quad .$$

So the lift per unit span is

$$L' = \frac{1}{2}\rho c U_r^2 C_L \approx \frac{1}{2}\rho c r^2 \pi^2 \Phi^2 f^2 C_L \sin^2(2\pi f t) \quad ,$$

and the mean lift per unit span is

$$\bar{L}' = \frac{1}{4}\rho c r^2 \pi^2 \Phi^2 f^2 C_L \ .$$

Integrate the mean lift per unit span along one wing length and multiply by two for the other wing. Equate this to the weight since, according to the small angle approximation, the lift force is vertical.

$$\begin{aligned} mg &\approx \frac{1}{4}\rho\pi^2 \Phi^2 f^2 C_L \left[2\int_0^R c r^2\, dr\right] = \frac{1}{4}\rho\pi^2 \Phi^2 f^2 C_L \left[2\int_0^R (0.3R) r^2\, dr\right] \\ mg &\approx 0.05\rho\pi^2 \Phi^2 f^2 C_L R^4 \end{aligned}$$

[8]

(ii) Simply substitute to get

$$(75 \text{ kg})(9.81 \text{ m/s}^2) = 0.05(1.2 \text{ kg/m}^3)\pi^2(2 \text{ rad})^2 f^2(1.8)(2 \text{ m})^4 \Rightarrow f = 3.28 \text{ Hz}$$ [1]

(iii) From part (i), we have $m \propto \Phi^2 f^2 C_L R^4$. Over the six orders of magnitude for mass, Φ and C_L can vary only by relatively small amounts and therefore should be considered as constants. Hence the proportionality reduces to $m \propto f^2 R^4$. Given that $R \propto m^{1/3}$, we would expect frequency to vary as $f \propto m^{-1/6}$. [3]

(b) The potential function for an ideal vortex in polar coordinates is

$$\phi = \frac{\Gamma}{2\pi}\theta \qquad (1)$$

We find the velocity field for a single point vortex from the potential (equation 1) by differentiating ϕ. Recall $V_r = 0$ everywhere since $V_r = \partial\phi/\partial r$. For a vortex located at radius r_o from the origin, the tangential velocity is

$$V_\theta = \frac{1}{r - r_o}\frac{\partial\phi}{\partial\theta} = \frac{\Gamma}{2\pi(r - r_o)}$$

The velocity for the pair of point vortices located at $\pm r_o$ with circulation $\pm\Gamma$ respectively is thus

$$V_\theta = \frac{\Gamma}{2\pi}\left\{\frac{+1}{r - r_o} + \frac{-1}{r + r_o}\right\}$$

Placing the two vortices on the cartesian coordinate axes at $y = 0$ and $x = \pm r_o$, we can determine the velocity at the centre of the jet, $(x, y) = (0, 0)$, to be $V_r = 0$ and

$$V_\theta = \frac{-\Gamma}{\pi r_o} \approx -8.3 \text{ cm/s}.$$

In cartesian coordinates, this corresponds to $V_x = 0$ and $V_y = V_\theta$. [8]

Assessors' remarks: This was a quantitative question which required the candidates to analyse flapping flight and potential flow in fish wake vortices. The vast majority of candidates who attempted the question were clearly comfortable with this sort of analysis, with several scoring full marks. Many candidates got into a muddle with the dimensional analysis in (a)(iii), but this accounted for only a small proportion of the marks. The average mark would have been higher were it not for quite a few incomplete solutions, with candidates apparently running out of time.

20. **Structures at the molecular scale**

(a) In 'smooth swimming', the rotary motors drive the left-handed corkscrew flagellar filaments so that they push the cell forward through its aqueous environment; and the six-or-so filaments associate to form a single bundle. The bacterium travels in a straight line — so far as Brownian movement allows. Receptors in the cell wall detect individual molecules of nutrient.

There is a control system which measures the rate of encounter of such molecules with time; and if the rate is increasing the length of the smooth-swimming 'run' is extended.

A smooth-swimming run lasts for a second or so. It comes to an end when some or all of the flagellar motors go into 'reverse' — whereupon the corresponding flagella adopt a right-handed helical form at their proximal (ie. motor) ends. This produces chaotic motion; the bundle breaks up and the cell 'twiddles' or 'tumbles'. This phase of motion typically lasts 0.1 seconds or so. When the motors again revert to 'forward' motion, the cell moves off in a direction which depends on the random disposition of the individual flagella at the end of tumbling — so the next run of smooth swimming is in a *random* direction in 3D space. Again the run is lengthened/shortened if an increasing/decreasing temporal concentration of nutrients is detected.

In this way, the bacterium eventually finds its source of nutrients — having swum around ten times as far as it would need to if it were capable of continually steering itself towards the source of nutrition. [4]

(b) Identical building blocks that self-assemble in a spiral pattern can only build a *straight* rod if all blocks are in identical environments with respect to their neighbours: that is a straightforward matter of geometry. But bacterial flagellar filaments have a corkscrew shape, and are known (by chemistry) to be built from only *one* type of building block, namely the *flagellin* protein.

This paradox can be resolved by supposing that the protein can switch ('mechanically') between two slightly different conformations — neither of which by itself would have the right 3D geometry to build a tube, but which can together construct a tube: the blocks of conformation 'A', which are a little longer than the blocks of conformation 'B', lie on one side of the tube/rod, and so produce the required curvature.

The precise details of the bi-stable 'switch' between the two conformations have yet to be elucidated; but the general principle of the design is well understood. The arrangement is extremely subtle: a change of just one amino acid on the 450-long polypeptide chain of the flagellin protein can make the protein build a helical filament with different geometry. [4]

(c) A virus is a bundle of DNA or RNA contained in a 'capsule' of protein, which self-assembles from a 'coat protein' that is coded by the DNA. Some viruses attack bacteria: they are known as 'bacteriophages' ('fage' is Greek for eating, $\phi\alpha\gamma\epsilon$ is a well-known brand of Greek yoghurt). Some viruses of this kind have an apparatus for binding to the bacterial cell wall, and then injecting their cargo of DNA through it and into the cell. Once inside, it 'takes over' the cellular machinery, and uses the cell as a factory for making more copies of itself. Eventually the cell is full of the next generations of the virus; and it bursts, thereby releasing many viruses into the environment. [4]

(d) The increasing availability of the complete DNA sequences for many kinds of animals, flies, worms, bacteria, makes it possible for scientists to do computer searches for the similarities of particular genes from different species, and different kinds of species. For example, a protein called 'cytochrome C' is found in all species which use oxygen in their life-cycle. It turns out that there are small differences in the DNA sequence of this protein from species to species. Some of these involve different amino acids when the DNA is translated into protein; while others do not, because there is redundancy in the way in which the 64 different 3-letter words in the 4-letter DNA alphabet code for only 20 different amino acids. By comparing DNA sequences for such a protein from many different species, it is possible to map the data onto a 'tree' structure, in which changes occur by successive 'branches'. In this way, the stages in which different groups of species appeared can be determined. The results are much the same whatever particular gene is being studied. [4]

(e) **Either 'receptors'.** As mentioned in (a), the receptors for specific nutrient molecules are located in the cell wall. When such a molecule is detected, the receptor 'snaps shut' and a signal is sent to the interior of the cell, where it is processed to determine whether the rate of arrival of the particular molecule is increasing or decreasing with time. Receptors are examples of *trans-membrane proteins.* An individual bacterium will contain receptors which are specific to many differed molecular species (or 'ligands'). [4]

Or 're-engineering'. A receptor protein has an open 'mouth' which snaps shut when a particular molecule enters it and is recognised by it. Recognition is by amino acids on the polypeptide chain, which line the interior of the 'mouth'. These amino acids may be positively/negatively charged or hydrophobic — each of the 20 sorts of amino acids has its own characteristics.

Recognition occurs by a detailed matching of electric charge and shape. It has recently been shown by Hellinga and colleagues that existing receptors can be 'reengineered' to recognise molecules such as TNT, which are different from their natural ligands: it is a question of changing about a dozen amino acids in the 'mouth' region. A new design requires a massive computational effort, in order to minimise a total potential-energy function of more than 100 variables. By re-programming existing receptors to recognise TNT, these scientists are able to use bacteria to detect land-mines, or bombs that have been dumped in the ocean. [4]

Assessors' remarks: This question tested the candidates' understanding of structural and functional biological phenomena at the molecular scale, including the structure of bacterial flagellae, bacterial chemotaxis, the operation of a virus and the interpretation of DNA genomic sequences. It was an essay-style question, mostly book work but with some scope for extrapolation beyond the lecture notes. In general, the candidates showed a good understanding of this material. As with Question 18, the better candidates produced concise solutions, offering information only if strictly relevant to the question. Poorer solutions tended to be longer, with the candidates reproducing large parts of the lecture notes in the hope of hitting the right answer by chance.

14 6 04

Engineering Tripos Part IB 2004
Paper 8 section H: Manufacturing, Management and Design

Answers

Q.21

a) Appropriate examples are Nokia, IBM, Microsoft, Hewlett Packard, General Motors, Ford, Sony, with brief statements of why they meet the description

b)

Parameter	**Company A**	**Company B**
Processes	Informal, ad hoc, "whatever it takes", rapid, error prone	Formal processes, slow paced, eg design review, document control, QC,
Systems	Few	Many and settled systems, eg technical database/CAD, financial & materials control,
Activities	Heroic individual efforts, Chaotic, initiative-based	Organised teams, managed work, delegated authority
People	Many creator/innovator type personalities, few natural organisers; role flexibility	Managed balance between creator/innovator, and organiser types; fixed roles/job descriptions
Management style	Hands on, informal, untrained; bold decisions taken on incomplete information	Delegated, professional style; caution and risk assessment; staff development and empowerment
Communication and record keeping	High dependence on verbal communication and memory; "everyone knows everything"	Greater use of written communication; controlled dissemination: "need to know"
Market information	From intuition, insights and belief; reliance on feedback from a small number of potential customers	From experience and market research; statistically significant sampling of customer needs and price sensitivity
Competitors and IPR	Limited competitor awareness; inadequate IPR protection	Careful of competitors and IPR

c)

It is likely that there has been an element of luck about Company A's success, for example their faith in what the market needs rather than reliance on well-researched knowledge. They may not know all the reasons why they have been successful and so some of the success factors may be absent the second time around. For example, their success may depend in part on the short term absence of competition, and this may materialise strongly later if IPR or trade secrets have not been protected.

The informal, ad hoc processes which Company A has operated are inherently unscale-able. For example, their knowledge base and communication processes are in people's heads; information is not captured, recorded and shared in a systematic way. If this does not change then chaos will result from attempts to operate at higher scale and in any kind of repeatable way.

In addition, the realisation that more orderly and formal systems are required will often occur too late, when everyone is too busy dealing with the day to day crises (firefighting) to calmly establish operating systems and procedures which would have prevented the crises (fire prevention).

The creator/innovator personality types who typically make up most of the staff at innovative new start companies, such as Company A, do not typically appreciate fully the need for the Organiser personality types who are needed to set up and operate routines and systems necessary for orderly and high quality business processes. Thus, the initial imbalance of personality types can perpetuate itself as the founders of the business recruit clones of themselves rather than staff matched to the changing need.

However, Company A must have had some spark of inventiveness, brilliance or simple dynamism to have achieved what it has. Assuming it does survive the transformation to an organised and systematic way of operating, it faces another risk that it may lose its initial spark, innovative culture and agility, and become bureaucratic

[Mean mark 11.2/20. This question explored the differences in organisation and people-skills found in technology-based companies at different stages in their growth. Candidates were better at parts (a) and (b) than at (c) which required them to think about the challenges of producing a sustainable flow of innovation after a succesful initial concept.]

Q.22

(a)
Intellectual property (IP) allows people to own the results of their creativity and innovation in the same way as physical property.

Six types of IP recognised in the UK are: patents, copyright, trademarks, registered designs, unregistered design right, trade secrets or know-how (any five acceptable for the answer.

(b)
The company needs to consider protecting the design and functionality of the plug, the slogan and any other wording/design on the advertisement, and the trade name.

The manufacturing process is unlikely to be protectable, unless it includes some novel features. The design of the plug could in principle be protected by design right or as a registered design, but a competitor might find it easy to make small changes to the plug and avoid infringing this IP – it would be much better to identify what features of the design and functionality are novel and to seek to patent them. A search will be needed to establish the 'prior art' – i.e. what has been done before – and then to work out what features can be protected. The first step in obtaining a patent is to file a description with the Patent Office – this need not be a full application but it must include all features which will be included in the subsequent full application. It is essential that the invention is not made public before the application is filed – so that it is very urgent to do this before the exhibition, and to stress the need for confidentiality to all staff. It would also be useful to establish if any information about the design has leaked into the public domain – if it has, then the patent application may fail, or any patent granted be invalid. The company should take advice from a patent agent or lawyer immediately.

The slogan and advertisement will attract copyright, and under UK law this does not require registration – the act of publishing is enough to give copyright. The company needs to be sure that it is legally entitled to reproduce the photograph of the product – who owns the copyright? Even if the photograph was commissioned by the company, the owner of the copyright could be the photographer, or the company, or some other party. Advice from a lawyer might be helpful.

The name 'Safetiplug' is unlikely to be acceptable as a trade mark in the UK since it is (despite the mis-spelling) descriptive of the product. Trade marks are registered with the Patent Office. The company would be well advised to change the name if it wants to register it as a trade mark – which would have benefits in building brand identity and preventing competition.

The company should urgently seek expert advice from legal specialists to address these points.

[Mean mark 11.2/20. Part (a) was straightforward, while part (b) was more of a challenge since it involved application of the knowledge acquired in the course to a real-life problem. Most candidates suggested that patenting should be explored, but only about half spotted that the term 'Safetiplug' was descriptive of the product and would probably not be allowed as a trademark. There was some confusion over the difference between copyright and registration of a trademark.]

Q. 23

(a)

	Option A £ /k	Option B £/k
Sales	500	300
Direct costs		
Materials	-100	-50
Labour	-150	-50
Operating profit	250	200
Indirect costs		
Sales and marketing	-15	-15
Premises	-25	-25
General admin.	-25	-25
Profit before interest and tax	185	135
Tax	0	0
Interest on equipment	0	-10
Interest on working capital	-5	-5
Economic value added	**180**	**120**

(b)
Factors not included in the EVA which may need to be considered are:

- Layout and flow
  - which system will achieve better throughput (capacity) and utilization: which will be better balanced?
- Technology
  - how flexible is the CNC machine?
  - what is its setup time?
  - what are its maintenance costs?
  - is the quality of the product better for one option than the other?
- Job design
  - given the skills available in the local labour market, which option gives the better match?

- does option A require too much skill or does B lead to repetitive demotivating work?

- Network
  - how do the two options affect relationships with suppliers and customers?
  - is the lead time the same?
  - does the CNC machine require higher quality inputs?

- Future development
  - which option provides the better scope for expansion of the business?

(c)

On the basis of the EVA calculation, option A is clearly preferable. This could be reversed in the light of points considered in (b), but A would appear to be a safe option for this start-up company since:

- the sales figures are only estimates so the accounts are uncertain. There would be benefits in the flexibility and lower fixed costs provided by the manual system of option A; the CNC machine once bought is a fixed cost, while it is easier to change the number of workers. The machine will have a high set up cost and then be less flexible, whereas the manual process can be adapted more quickly

- the ability to test the market with a range of variants can be important early in the life of the company

[Mean mark 11.0/20. Part (a) was similar to an example covered in the lectures, and to an examples question, but a fair number of candidates made mistakes, commonly by including the capital cost of the machine in the EVA rather than the related interest charge. A range of factors was suggested in part (b), though very few candidates gave more than one or two.]