DRAFT EXAM PAPER CRIBS

EGT1
ENGINEERING TRIPOS PART IB 2022

Paper 8

THE ENGINEER IN BUSINESS CRIB

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

   (a) As the tenure of the CEO of a car company extends they are more likely to prioritise growth over profitability.
   (b) Clothing factories operate to reduce individual workers bargaining power in order to increase profitability.
   (c) Supermarkets run advertising campaigns to keep their advertising department happy.
   (d) Coal fired power plants are often co-located next to coal mines.
   (e) None of the above. [2.5]

Answer: c. (a) is a statement consistent with the Marris model of managerialism. (b) is a statement consistent with the Marxist theory of the firm. (c) is a statement of the behavioural theory due to Cyert and March. (d) is a statement consistent with the Capabilities approach to the firm (due to Chandler).

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

   (a) Collusive Pricing
   (b) Competitive Pricing
   (c) Price Discrimination
   (d) Predatory Pricing
   (e) None of the above. [2.5]

Answer: b. We are describing a competitive market. This is likely to be competitive pricing (b).

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

   (a) GDP rises by 3%, technological opportunity rises by 2%, managerial experience increases by 2%.
   (b) GDP rises by 3%, technological opportunity increases by 3%, managerial experience increases by 2%.
   (c) GDP falls by 3%, technological opportunity increases by 2%, managerial experience increases by 1%.
   (d) GDP falls by 2%, technological opportunity increases by 2%, managerial experience increases by 1%.
   (e) None of the above. [2.5]

Answer: c. GDP falls by more, lower technological opportunity and managerial experience rising less are all reasons for lower firm growth. (c)is worse for growth than other options in at least one dimension.

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

   (a) Growth by backward vertical integration.
   (b) Growth by forward vertical integration.
   (c) Growth by merger.
   (d) Growth by diversification.
   (e) None of the above. [2.5]

Answer: a. This an example of backward integration (retail to manufacturing).

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

   (a) Product-oriented.
   (b) Selling-oriented.
   (c) Promotion-oriented.
   (d) Customer-oriented.
   (e) None of the above. [2.5]

Answer: d. Google improves its product in order to improve its customer experience. This is an example of customer-oriented marketing philosophy.

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

   (a) Frame of reference.
   (b) Points of parity.
   (c) Points of difference.
   (d) Category membership.
   (e) None of the above. [2.5]

Answer: c. The campaign focuses on the points of differences between Airbnb and its competitors.

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

(a) Branding.
(b) Market segmentation.
(c) Positioning.
(d) Targeting.
(e) None of the above. [2.5]

Answer: b. Uber identifies different groups of customer needs. This is an example of market segmentation.

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

(a) Porter's ideas about reinforcing activity systems through tradeoffs.
(b) McGrath's ideas about organisational agility.
(c) Adner's ideas about ecosystem keystones.
(d) b and c.
(e) a, b, and c. [2.5]

Answer: d. (a) is not correct because there are no obvious tradeoffs involved.

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

(a) They can identify relevant sets of competitors.
(b) They can identify new ways to negotiate with employees.
(c) They can identify core competences.
(d) They can identify opportunities to grow.
(e) They can block new entrants. [2.5]

Answer: a. Five forces analysis can only be conducted when relevant competitor sets have been identified. The other answers either have no direct relation to five forces analysis or are potential products of such an analysis, not underlying assumptions.

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

(a) A list of core competences.
(b) An analysis of the activity system.
(c) Recommendations for innovation rhythm and tempo.
(d) A dyadic- or pattern-based view of the business ecosystem.
(e) All of the above. [2.5]

Answer: a. The others are associated with positional, agility and ecosystem based analytical frames respectively

[End of Paper]

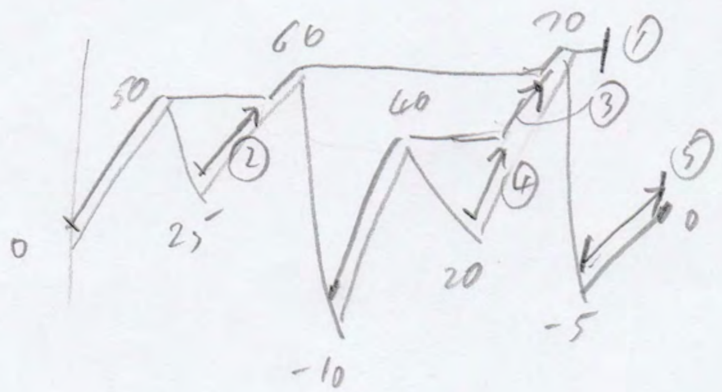
CRIB 1B P8 Section C. 2022/23 M SUTCLIFFE

1 (a)(i) Loading – cyclic loading from rotation of blades
– including wind shear and tower passing
– random wind loading

response – vibration of tower and blade

structural – stress depends on load and geometry
– so tower shape and wall thickness
– also stress-raisers, eg. joints

(a)(ii)



① 0→70, ② 25→50, ③ -10→60, ④ 20→60, ⑤ -5→0

(a)(iii) Obviously need longer record including better understanding of outliers

May need to model outliers (which will be critical) using typical wind spectrum and structural response

Use Goodman's rule and Miner's law to include mean stress

Could bin data into different mean stress and amplitude to simplify analysis

Need to include testing and codes.

Check on details of geometry and σ concentrations elsewhere

Corrosion may be an issue.

1 (b) (i) - need to get significant step up in speed from rotor speed (governed by aerodynamics) to generator speed (governed by power)

- Epicyclics are a light relatively, cheap, small form of gearbox. Light and small needed as on tower head.

(ii) Gear failure -

tooth bending

fatigue failure here

-

contact failure governed by loading and geometry

- lubrication / wear of gears

Bearing failure - large loads, difficult environment

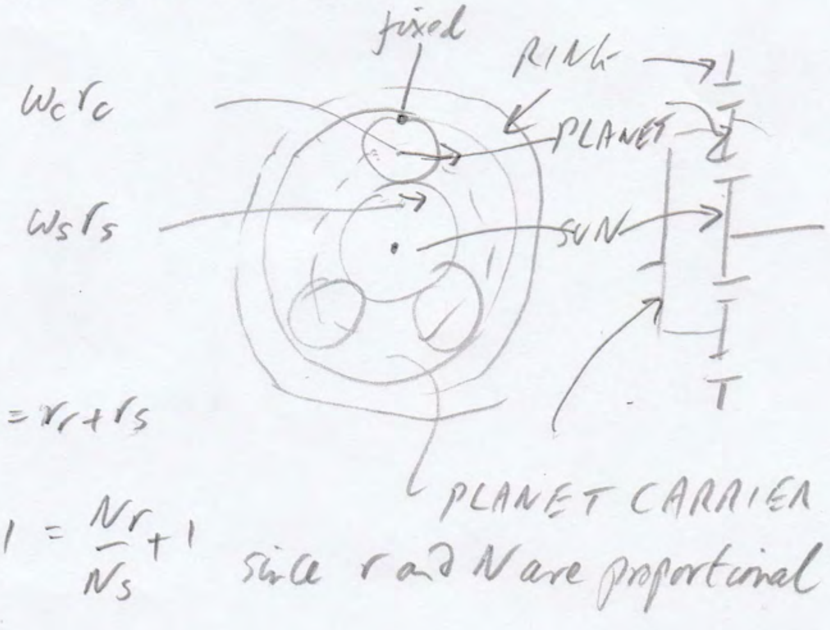
Fatigue of shaft, eg with vibration in drive chain

Can design for gear failure using simple models

Helical gears can reduce vibration

(iii)

Considering planet velocities: $\omega_s r_s = 2\omega_c r_c$



Considering geometry

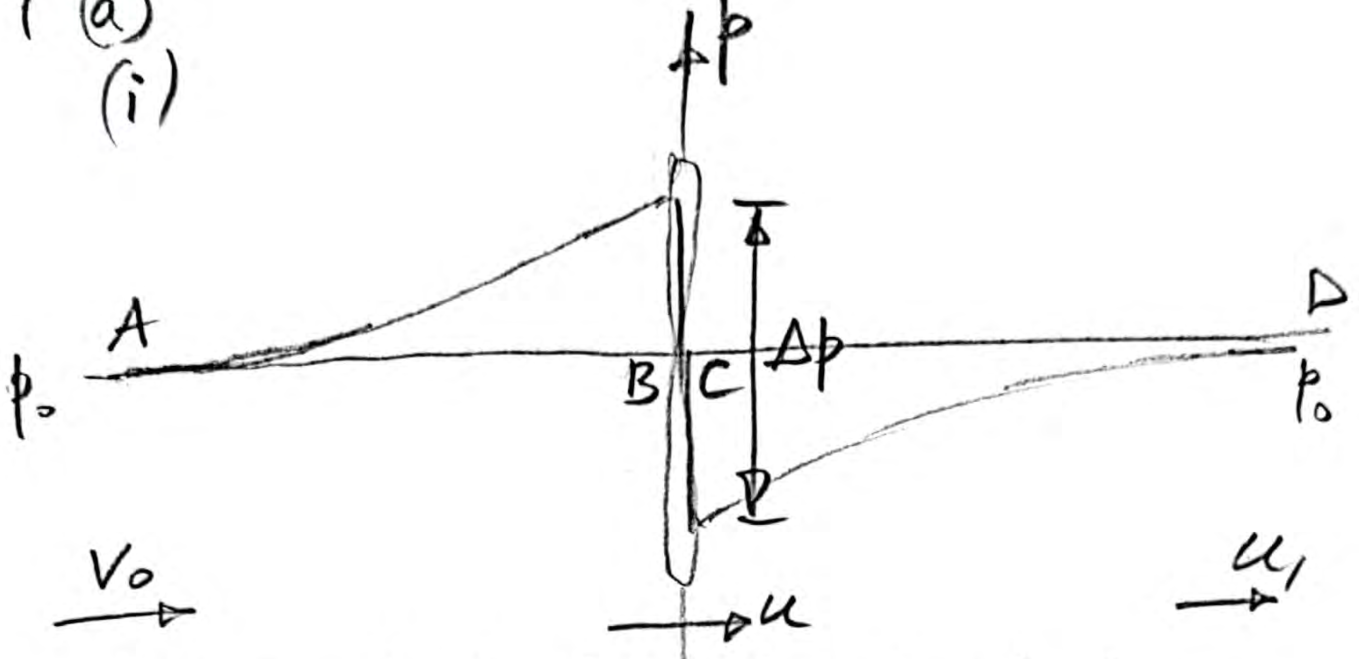
$r_c = (r_r + r_s)/2 \Rightarrow 2r_c = r_r + r_s$

$\frac{\omega_s}{\omega_c} = \frac{2r_c}{r_s} = \frac{r_r}{r_s} + 1 = \frac{N_r}{N_s} + 1$ since r and N are proportional

Q2a

1 (a)

(i)



pressure at A & D is atmospheric
(parallel streamlines)

(ii) Bernouilli A → B

$$p_0 + \frac{1}{2}\rho V_0^2 = p_B + \frac{1}{2}\rho u^2$$

Bernouilli D → C

$$p_0 + \frac{1}{2}\rho u_1^2 = p_C + \frac{1}{2}\rho u^2$$

$$\therefore p_B - p_C = \Delta p = \frac{1}{2}\rho (V_0^2 - u_1^2) \quad // \ \underline{\underline{\text{ans}}}$$

(iii) Betz, $a = \frac{1}{3}$ $\therefore$ $u_1 = (1-2a)V_0 = \frac{V_0}{3}$

$$\therefore \quad \Delta p = \frac{1}{2}\rho V_0^2\left(1-\left(\frac{1}{3}\right)^2\right)$$

$$= \frac{1}{2}\rho V_0^2 \frac{8}{9}$$

$$\text{Thrust} = \Delta p A$$

$$= \frac{4}{9}\rho V_0^2 A$$

// ans

Q2(b)

15(a) $P = \frac{1}{2} C_p \rho A v^3$ $A = \frac{\pi D^2}{4} = 176.7\ m^2$ with $D = 15m$

C_p = 0.35, ρ = 1.23, A = 176.7

$\therefore P = 38 v^3$

total kWhr $= \Sigma$

$\therefore \frac{38 v^3 . days . 24}{1000}$

$= \Sigma 0.913 v^3 days$

v :	1	3	5	7	9	11	
days:	14	35	22	13	5	1	
kWhrs:	13 +	863 +	2511 +	4071 +	3328 +	1215 =	12001 kWhr

(b) $\bar{v} = \Sigma v \times days / 90 = 376/90 = 4.18\ ms^{-1}$

12-pole generator ⇒ 6 pole pairs ∴ sync. speed of generator $= 2\pi . 50/6 = 52.4$ rad/s

turbine $r = 7.5m$ with $\lambda = 8$ at 4.18 m/s wind speed ⇒ $\frac{4.18 \times 8}{7.5} = 4.46$ rad/s

∴ gearbox ratio $= 52.4 / 4.46 = 11.75 : 1$

$P = 38 . 4.18^3 = 2775\ W$

(c) $P = T_g \omega_g$ ∴ T_g, torque $= \frac{2775}{52.4} = 53.0\ Nm = \frac{3 V^2 s}{\omega_s R'_2}$

with $V = 415/\sqrt{3} = 239.6\ V$, $R'_2 = 0.4 \Omega$

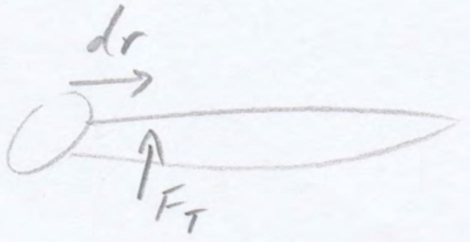
$\therefore -53 = \frac{3 . 239.6^2 . s}{52.4 . 0.4} \Rightarrow s = -0.00645$

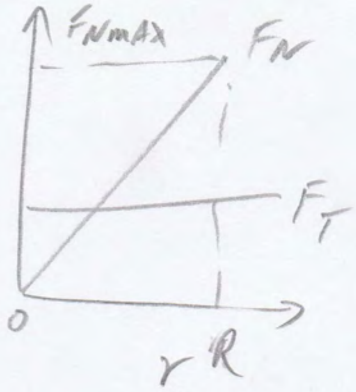
$$\bar{I} = \frac{V}{\left(R_1 + \frac{R'_2}{s}\right) + j(X_1 + X'_2)} = \frac{239.6}{\left(0.5 - \frac{0.4}{6.45 \times 10^{-3}}\right) + j5} = \frac{239.6}{-61.5 + j5}$$

$$\bar{I} = \frac{239.6}{61.7 \angle 175^\circ} = 3.88 \angle -175^\circ$$

Power factor, $\cos\phi$
$= \cos 175^\circ = 0.996$ lagging

3 (a) (i)





$$T = \int_0^R F_T \, r \, dr \times 3$$

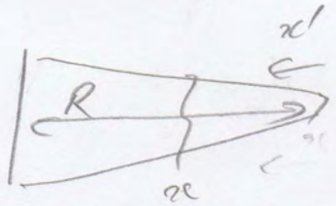
↑ # blades

Power = $T\omega$

$$= \frac{R^2}{2} F_T . 3 . \omega \qquad N m^{-1} . m^2 . s^{-1} = N m s^{-1}$$

$$= \frac{30^2}{2} . 150 . 3 . \frac{20 \times 2\pi}{60} = 0.42 \, MW$$

b(i)



$$M(x) = \int_0^{x'=x} F_{Nmax}\left(1 - \frac{x'}{R}\right)(x - x')\,dx'$$

$F_N = F_{Nmax}\left(1 - \frac{x'}{R}\right)$

$$= \int_0^x F_{Nmax}\left(x - \frac{x'}{R}x - x' + \frac{x'^2}{R}\right) dx'$$

$$= R^2 F_{max}\left(\frac{x^2}{R^2} - \frac{x^3}{2R^3} - \frac{x^2}{2R^2} + \frac{x^3}{3R^3}\right)$$

(bii) see next pages

$$= R^2 F_{Nmax}\left(\frac{1}{2}\left(\frac{x}{L}\right)^2 - \frac{1}{6}\left(\frac{x}{L}\right)^3\right)$$

(c) Other loads - eg edgewise (may be carried by shell) and centripetal loads

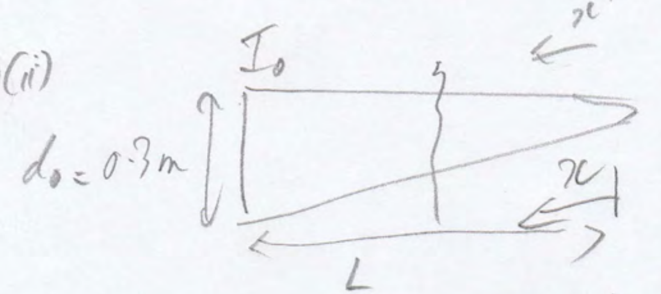
Geometry - how will the spar fit in the envelope
- is the specified taper best - optimise

Materials - maybe a mix of materials along the spar would help

Manufacture - get good quality at a low price
- facilities to make long sections

Testing - especially fatigue & joints, plus regulatory

3 (b)(ii)



~~$$x - \frac{x'}{L}x - x' + \frac{x'^2}{L}$$~~

~~$$M(x) = \int_0^{x'=x} F_{\text{max}}\left(1 - \frac{x'}{L}\right)(x - x')\,dx'$$~~

~~$$= L^2 F_{\text{max}}\left(\frac{x^2}{L^2} - \frac{x^3}{2L^3} - \frac{x^2}{2L^2} + \frac{x^3}{3L^3}\right)$$~~

~~$$L^2 F_{\text{max}}\left(\left(\frac{x}{L}\right)^2\frac{1}{2} - \left(\frac{x}{L}\right)^3\frac{1}{6}\right)$$~~

$$I = I_0\frac{x}{R} \qquad d = d_0\frac{x}{R}$$

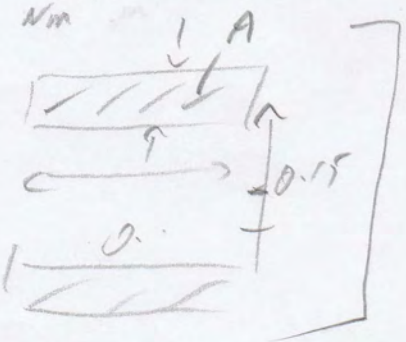
For failure: $\frac{\sigma}{y} = \frac{M}{I} \Rightarrow I_0 > \frac{Mr}{\sigma_y y_{\text{max}}}$ at root assumed critical

$$I_0 > \frac{0.45\times10^6 \times 0.15}{300\times10^6} = 2.25\times10^{-4}\,m^4 \quad \frac{Nm\,m}{Nm^{-2}}$$

[eg $A \times 0.15^2 \times 2 = 2.25\times10^{-4}\,m^4$

$A = 0.005\,m^2$

eg 0.5m x 10mm



Check assumption that the critical σ is at the root

$$I > \frac{My}{\sigma_y}$$

$f = 3x^2 - x^3$
$f' = 6x - 3x^2$
max when $\underline{x = 2}$

$$I_0\frac{\cancel{x}}{R} > \frac{d_0\frac{\cancel{x}}{\cancel{L}}}{\sigma_y} R^2 F_{\text{max}}\left(\left(\frac{x}{L}\right)^2\frac{1}{2} - \left(\frac{x}{L}\right)^3\frac{1}{6}\right)$$

Worst case when $\frac{x}{R} = 1$, ie. at root as assumed

3(b)(ii) Deflection $(F_m = F_{N\,MAX})$

$$\frac{d^2y}{dx^2} = \frac{M}{EI} = \frac{R^2 F_m \left(\left(\frac{x}{R}\right)^2 \frac{1}{2} - \left(\frac{x}{R}\right)^3 \frac{1}{6}\right)}{E\; I_0 (x/R)} \qquad \frac{Nm^{-1}.m^2}{Nm^{-2}m^4}$$

$$= \boxed{\frac{R^2F_m}{EI_0}\,\frac{1}{6}}\,(3X - X^2) \qquad X = \frac{x}{L} \qquad \boxed{F_m = F_{N\,max}}$$

$$=\lambda \qquad \frac{dX}{dx} = \frac{1}{L}$$

$$\frac{dy}{dx} = R\lambda\left(\frac{3X^2}{2} - \frac{X^3}{3}\right) + k \qquad \text{put } X = 1,\ \frac{dy}{dx} = 0$$

$$= R\lambda\left(\frac{3X^2}{2} - \frac{X^3}{3} - \frac{7}{6}\right) \qquad \lambda \to \frac{Nm^{-1}\cancel{m}^{\cancel{2}}}{\cancel{m^4}\,\cancel{Nm^{-2}}} = m^{-1}$$

$$y = R^2\lambda\left(\frac{3X^3}{6} - \frac{X^4}{12} - \frac{7}{6}X + \frac{9}{12}\right) \qquad X = 1,\ y = 0$$

$$\left(\frac{6 - 1 - 14}{12} = -\frac{9}{12}\right)$$

$$y_{tip} = \lambda R^2 \cdot \frac{9}{12}$$

i.e. $$\delta = \frac{1}{{}_2\cancel{6}}\,\frac{R^2F_m}{EI_0}\,\frac{\cancel{9}^{\,\cancel{3}\,1}}{\cancel{12}\,4}\,R^2$$

$$I_0 = \frac{1}{8}\frac{F_m R^4}{E\delta} = \frac{1500 \times 30^4}{8 \cdot 70\times10^9 \times 0.5}\ \frac{Nm^{-1}m^4}{Nm^{-2}.m}$$

$$= 0.0043\ m^4$$

Deflection is critical

Need $I_0 > 0.0043\ m^4$ [A = 0.096
1m × 96mm
- rather thick]

2023 2P8 Section D

Section D, Q1

(a) Increasing turbine entry temperature raises the specific net work of a GT cycle and hence the thrust of a turbojet or turbofan. For real engines, with irreversible components, raising turbine entry temperature also increases the cycle efficiency. Increasing the temperature of the flow in the turbine has required advances in materials and also in turbine cooling (internal and external film cooling).

(b)

$$T_{02} = T_a(1+0.5(\gamma-1)M^2) = 216.7(1+0.5\times 0.4\times 0.86^2) = 248.8\text{ K}$$

$$p_{02} = p_a(T_{02}/T_a)^{\gamma/(\gamma-1)} = 19400(248.8/217.6)^{\gamma/(\gamma-1)} = 31441\text{ Pa}$$

$$T_{03s} = T_{02}(p_{03}/p_{02})^{(\gamma-1)/\gamma} = 248.8\times 25^{(\gamma-1)/\gamma} = 624.0\text{ K}$$

$$T_{03} = T_{02} + (T_{03s}-T_{02})/\eta = 248.8 + (624.0-248.8)/0.89 = 670.4\text{ K}$$

(c)(i)

$$T_{05} = T_{04} - (T_{03}-T_{02}) = 1600 - (670.4-248.8) = 1178.4\text{ K}$$

$$T_{05s} = T_{04} - (T_{04}-T_{05})/\eta = 1600 - (1600-1178.4)/0.91 = 1136.7\text{ K}$$

$$p_{04} = p_{03} = 25p_{02} = 786000\text{ Pa}$$

$$p_{05} = p_{04}(T_{05s}/T_{04})^{\gamma}/(\gamma-1) = 78600\times(1136.7/1600)^{\gamma}/(\gamma-1) = 237500\text{ Pa}$$

$$T_9 = T_{05}(p_a/p_{05})^{(\gamma-1)/\gamma} = 1178.4\times(19400/237500)^{(\gamma-1)/\gamma} = 576.0\text{ K}$$

$$V_j = \sqrt{2*c_p*(T_{05}-T_9)} = \sqrt{2\times 1004.5\times(1178.4-576.0)} = 1100.0\text{ ms}^{-1}$$

$$V = M\sqrt{\gamma RT_a} = 0.86\times\sqrt{\gamma 287\times 216.7} = 253.8\text{ ms}^{-1}$$

$$\eta_p = 2V/(V+V_j) = 2\times 253.8(1100.0+253.8) = 0.375$$

(c)(ii)

$$\eta_{th} = 0.5(V_j^2-V^2)/c_p(T_{04}-T_{03}) = 0.5\times(1100.0^2-253.8^2)/(1004.5\times(1600-670.4) = 0.613$$

(d)

$$\frac{\dot{m}\sqrt{c_pT_{02}}}{Ap_{02}} = \frac{\gamma}{\sqrt{\gamma-1}}M\left(1+0.5(\gamma-1)M^2\right)^{(-0.5(\gamma+1)/(\gamma-1))} = 0.806$$

$$A = (\dot{m}\sqrt{c_pT_{02}})/(0.806p_{02}) = 35\times\sqrt{1004.5\times 248.8}/(0.806\times 31441) = 0.691\text{ m}^2$$

$$h = A/(2\pi r_{mid}) = 0.692/(2\pi\times 0.42) = 0.262\text{ m}$$

(e) In turbine, pressure is reducing in the direction of the flow. In a compressor, pressure is increasing. Turning is toward tangential in turbine; more turning = more pressure drop = higher loading. Turning is toward axial in compressor; more turning = more pressure rise = higher loading. In turbine, where pressure is falling, boundary layers stay thin and are less likely to separate, hence more loading is possible. In a compressor, we are limited by boundary layer separation and so a smaller amount of turning (and hence loading) is allowed per stage.

Section D, Q2

(a) Applying the SFME between nozzle exit (station 19) and downstream where $p = p_a$ and the jet velocity is V_j:

$$\dot{m}V_{19} + p_{19}A_N = \dot{m}V_j + p_aA_N$$

$$\dot{m}V_{19} + p_{19}A_N = F_G + p_aA_N$$

If we assume the propelling nozzle is choked (very likely due to pressure rise across fan, and in the engine intake due to flight speed) then the LHS is set by the engine operating point (determined by p_{02}, T_{02} and $\dot{m}_f$). Hence the expression for the non-dimensional group $\tilde{F}_G$ has a physical basis.

(b) sl = sea level

$$F_{Nsl} = mg(1/(L/D) + \sin\theta)/2 = 350000 \times 9.81(1/10. + 0.03) = 51.5 \text{ kN}$$

$$F_{Gsl} = F_{Nsl} + \dot{m}_{sl} \times V_{sl} = 51500 + 120 \times 90 = 62.3 \text{ kN}$$

(c)(i) At high altitude, p_{02} is lower for same take-off Mach number so available thrust is reduced when operating at same non-dimensional condition as at sea level. For the same lift coefficient, less lift is available at same V due to reduced density (need to increase V, or change lift coefficient or wing area using flaps).

(c)(ii) h = at altitude

$$V_h = V_{sl}\sqrt{\rho_{sl}\rho h} = V_sl\sqrt{p_{sl}/p_h} = 90\sqrt{(}101325/61400) = 115.6 \text{ ms}^{-1}$$

(c)(iii)

$$T_{02sl} = T_{asl} + V_{sl}^2/(2c_p) = 288.15 + 90^2/(2 \times 1004.5) = 292.2 \text{ K}$$

$$p_{02sl} = p_{asl}(T_{02sl}/T_{asl})^{\gamma/(\gamma-1)} = 101325(292.8/288.15)^{\gamma/(\gamma-1)} = 106400 \text{ Pa}$$

$$\tilde{F}_G = (F_{Gsl} + p_{asl}A_N)/(A_Np_{02sl}) = (62300 + 101325 \times 1.3)/(1.3 \times 106400) = 1.403$$

$$T_{02h} = T_{ah} + V_h^2/(2c_p) = 288.15 + 115.6^2/(2 \times 1004.5) = 294.8 \text{ K}$$

$$p_{02h} = p_{ah}(T_{02h}/T_{ah})^{\gamma/(\gamma-1)} = 61400(294.8/288.15)^{\gamma/(\gamma-1)} = 66510 \text{ Pa}$$

$$F_{Gh} = \tilde{F}_GA_Np_{02h} - p_{ah}A_N = 1.403 \times 1.3 \times 66510 - 61400 \times 1.3 = 41.49 \text{ kN}$$

$$\dot{m}_h = \dot{m}_{sl}(p_{02h}/p_{02sl})\sqrt{T_{02sl}/T_{02h}} = 120 \times (66510/106400) \times \sqrt{292.2/294.8} = 74.69 \text{ kgs}^{-1}$$

$$F_{Nh} = F_{Gh} - \dot{m}_hV_h = 41490 - 74.69 \times 115.6 = 32.8 \text{ kN}$$

(d) At high ambient temperature T_{04} is increased, compared to standard sea level conditions, for the same engine non-dimensional operating point. If this cannot be tolerated (due to material limitations in the turbine that would then lead to reduced turbine life), then the operating point of the engine must be changed; this would reduce the available take-off thrust and hence the allowed payload. To make sure the raised T_{04} is OK, the engine must be designed with enough cooling for the turbine (and material properties including blade coatings) to tolerate short duration exposure to these increased temperatures.

Section D, Q3

(a) To maintain a constant lift coefficient, as the aircraft weight reduced due to fuel being burned, ρV^2 must also reduce. $\rho V^2 = \gamma p M^2$ so to cruise at constant M, p must reduce which means increasing altitude.

(b)

$$p_{a1} = m_1 g/(0.5 C_L A M \gamma) = 260000 \times 9.891/(0.5 \times 0.5 \times 450 \times 0.85 \times 1.4 = 19050 \text{ Pa}$$

$$p_{a1}/p_{sl} = 19050/101325 = 0.1880$$

Interpolating in databook table, altitude = 12120 m

(c)(i)

$$dm/dt = -\text{sfc}\, mg/(L/D)$$

$$dm/m = -\text{sfc}\, g/(L/D)$$

$$\ln(m_2/m_1) = -\text{sfc}\, g/(L/D)\, t = -9.81 \times 0.015/1000/20 * 6 * 60 * 60 = -0.1589$$

$$m_2 = m_1 \exp(-0.1589) = 221800 \text{ kg}$$

$$m_f = m_1 - m_2 = 38200 \text{ kg}$$

(c)(ii)

$$p_{a2} = m_2 g/(0.5 C_L A M \gamma) = 221800 \times 9.891/(0.5 \times 0.5 \times 450 \times 0.85 \times 1.4 = 16253 \text{ Pa}$$

$$p_{a1}/p_{sl} = 16253/101325 = 0.1604$$

Interpolating in databook table, altitude = 13130 m

(c)(iii)

$$V = M\sqrt{\gamma R T_a} = 0.85\sqrt{(}\gamma 287 \times 216.7 = 250.8 \text{ ms}^{-1}$$

$$s = Vt = 250.8 \times 6 \times 60 \times 60 = 5418 \text{ km}$$

(d)

$$\eta_p \eta_{th} = V/(\text{sfc}\,\text{LCV})$$

so, with all other parameters constant, increasing η_p by a factor of 1.1 will reduce sfc by a factor of 1.1:

$$m_{2new} = m_1 \exp(-(sfc/1.1)\, g/(L/D)\, s/V) = 225000 \text{ kg}$$

$$m_{fnew} = m_1 - m_{2new} = 34980 \text{ kg}$$

$$m_f - m_{fnew} = 3228 \text{ kg}$$

(e) The propulsive efficiency could have been increased by increasing the bypass ratio of the turbofan. The difficulties with this are the increased nacelle size, which increases the installed drag of the engine, and also the increased engine weight.

2P8, E.

i.

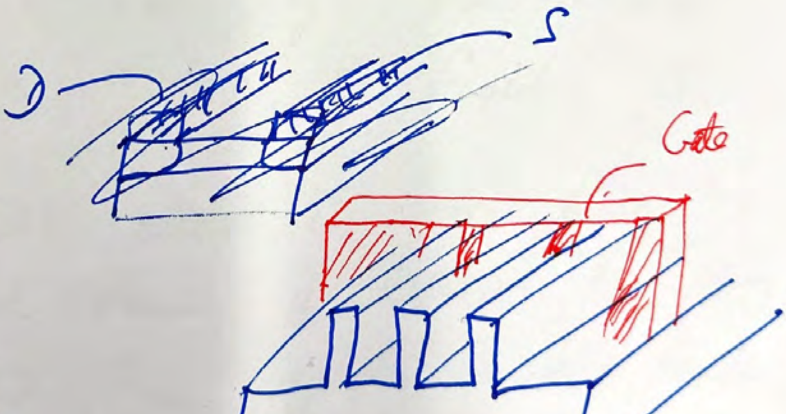
(a) planar gate, FinFET & GAA MOSFETS.

These are the 3 most recent FET Structures, ~~starting~~ with planar gate, which was an architecture that enabled integrated circuits.

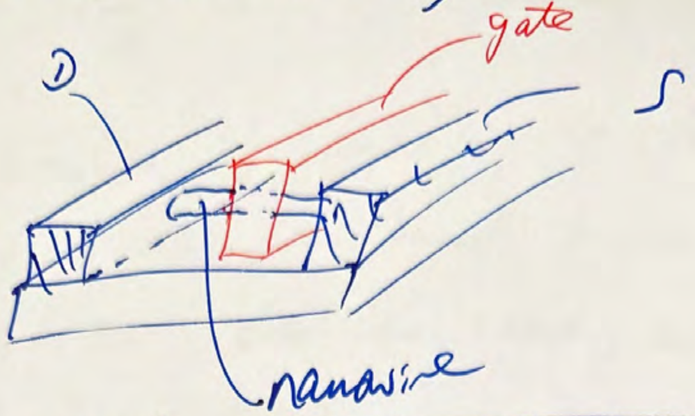
i) The planar FET is the structure we encountered in 1A!

ii) FinFET:

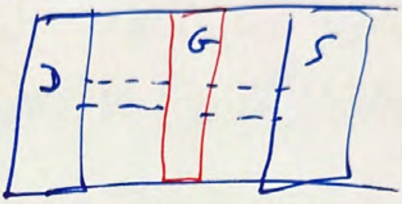
Typically 3 Si "fins", which are embedded in the gate metal. This structure is required as the channel shrinks,



iii) GAA (Gate all-around)



top view:



Side view

i.e. a cylindrical channel, which is completely enclosed by the metal gate, for a uniform E-field.

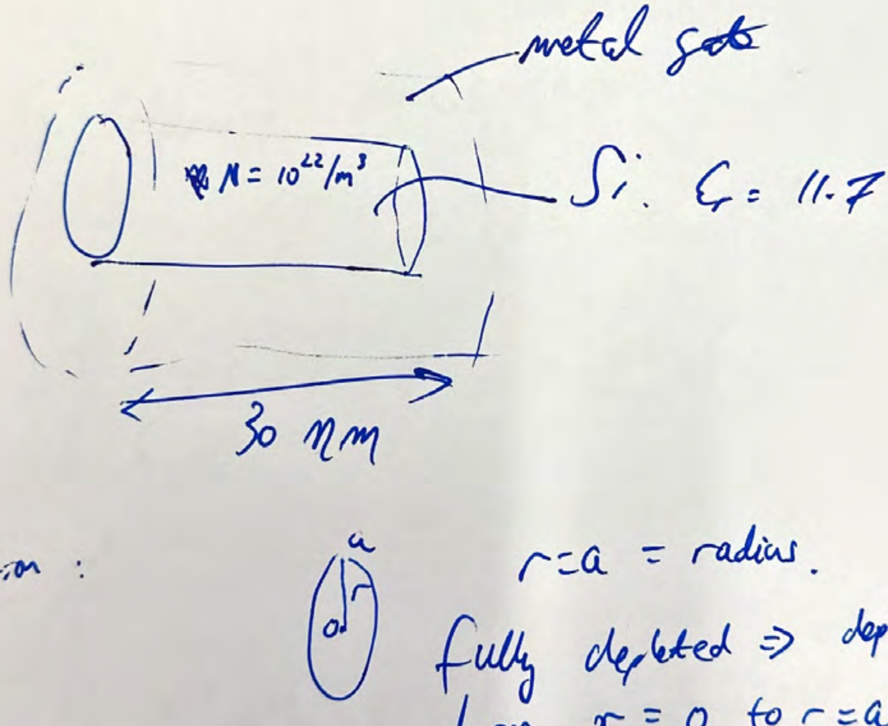
b) The FinFET allows us to have a greater areal density of transistors than planar by going from 2D to 3D. They typically have shorter channels, below 30 nm.

To further increase packing density, we move towards GAA structures, where the gate is wrapped around the channel, which is a nanowire.
Some issues around fabricating reliable

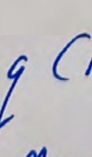
Contacts to there nanowires are needed to be resolved before they can be routinely fabricated

c) Reliable formation of contacts to both ends of the nanowire channel. Surface effects and defects are also an issue, and the reproducible fabrication of Si nanowires with diameter < 10 nm is not yet possible with sufficient yield.

d)



Assumption:



$r = a$ = radius.

fully depleted ⇒ depleted from $r = 0$ to $r = a$

charge density $\rho = q\,(N_D + p - N_A - n)$

n-type, $N_D >> n_i \Rightarrow \rho = q\,N_D$

$$\Rightarrow \cancel{\varphi}\ \frac{dE}{dr} = \frac{\rho}{\varepsilon} = \frac{qN_D}{\varepsilon}$$

$$\Rightarrow E = \int \frac{qN_D}{\varepsilon}\,dr = \frac{qN_D r}{\varepsilon} + C$$

@ $\cancel{x} = a$, $E = 0$ (metal) $\Rightarrow 0 = \frac{qN_D a}{\varepsilon} + C$

$$\Rightarrow C = -\frac{qN_D a}{\varepsilon}$$

$$\Rightarrow E(r) = \frac{qN_D}{\varepsilon}(r-a)$$

Wish to determine potential, φ.

Now: $E = -\frac{d\varphi}{dr} \Rightarrow \varphi = -\int E\,dr$

$$= -\int_0^a \frac{qN_D}{\varepsilon}(r-a)\,dr = -\frac{qN_D}{\varepsilon}\left(\frac{r^2}{2} - ar\right)\Bigg]_0^a$$

$$= \frac{qN_D}{\varepsilon}\frac{a^2}{2}$$

$$= \frac{1.6\times10^{-19} \times 10^{23} \times \left(10^{-8}\right)^2}{11.7 \times 8.85\times10^{-12} \times 2} = 7.7\ \text{mV}$$

Seems like a rather small voltage to achieve depletion, close to k_BT, which means is likely to have fluctuating conductance.

Also, we have ignored the length, and the fact that the D & S contacts will alter the charge density. ~~Even if~~.

---

3. LPCVD is likely to be chosen

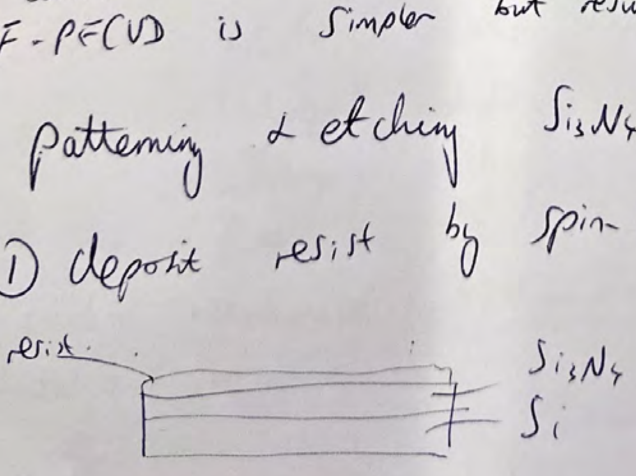
a) as it results in low-strain Si_3N_4.

The process parameters requiring control are the pressure of the chamber, the temperature of the substrate & the flow rate & ratio of reactants.

To grow Si_3N_4; we typically have SiH_2Cl_2 & NH_3 in the ratio 1:6.
The substrates are typically heated to 800°C to induce a chemical reaction on the surface to convert the reactants to Si_3N_4.
RF-PECVD is simpler but results in low-quality, strained films.

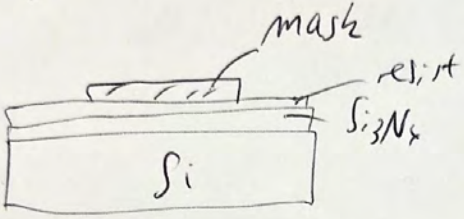
b.) patterning & etching Si_3N_4

① deposit resist by spin coating.



As Si_3N_4 is only 500 nm thick, resist will be ~ 500 nm - 1μm thick.

2) Structures are large, so optical lithography will be used. We are removing Si_3N_4, so it makes sense to use a positive resist. Possibly AZ5214E.



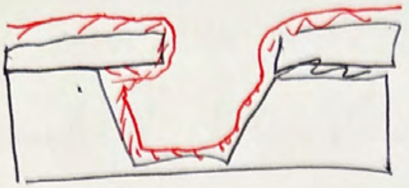
③ Etching : either a wet etch with phosphoric acid or a dry etch with CF_4/O_2. Dry etch (reactive-ion etch) is better as is more reliable due to the steady flow of gas which removes reaction products.

C.) We need an etching technique which will selectively etch Si rather than Si_3N_4.

Options! Isotropic etching
Anisotropic etching
RIE.

I would recommend KOH → it's anisotropic and is reliable and inexpensive.

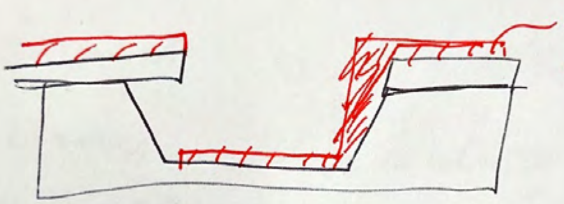
d) i)



ALD

ALD is a vapour-phase method which leads to coating of all surfaces.

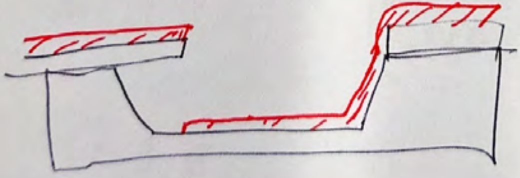
ii)



meant to be relatively conformal.

Thermal evaporation : line-of-sight coverage

iii) rf magnetron sputtering



Similar to thermal evaporation, but better uniformity. Normally used for oxides though?

I'd suggest that for such a thin film, 20nm, Thermal evaporation may be better, as long as the sample doesn't get too hot..

②

(a) Effective mass, m^* is a concept that essentially takes account of the fact that electrons and holes behave differently (i.e. respond to applied electric fields) in a material than outside. This is due to the band structure, which arises from the periodic lattice potential.

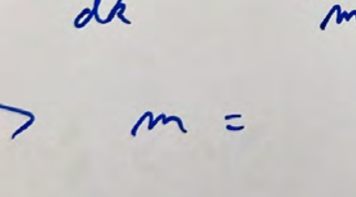
It is important as it determines how quickly carriers will accelerate and how fast they will move.

Basic idea: $K.E. = \frac{\hbar^2 k^2}{2m^*}$

$$\Rightarrow \frac{dE}{dk} = \frac{\hbar^2 k}{m^*} \quad \Rightarrow \frac{d^2E}{dk^2} = \frac{\hbar^2}{m}$$

$$\Rightarrow m = \hbar^2\left(\frac{d^2E}{dk^2}\right)^{-1}.$$ i.e. inversely related to curvature.

b)



A: following the convention above, $\frac{dE}{dk} = \text{Constant}$

$$\Rightarrow \frac{\partial^2 E}{\partial k^2} = 0$$

$$\Rightarrow m_A = \infty$$

However... when E vs k is linear, we no longer have $E = \frac{\hbar^2 k^2}{2m}$ ... we have $E = \hbar k v_F$

In this case, it is implicit that $m^* = 0$.

So.... which is it?

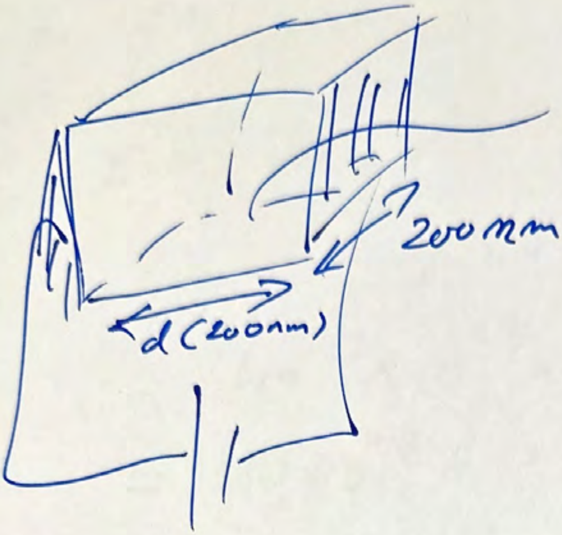
B & C : both are parabolic, and B has higher curvature than C, i.e. $\frac{d^2E}{dk^2}_B > \frac{d^2E}{dk^2}_C$

$\Rightarrow m^*_B < m^*_C$.

i.e. The material with greatest m^* is C

And the one with smallest m^* is A.

c).



$m^* = 0.3 m_e$

doping level = $10^{22} \, m^{-3}$

$\mu = 1000 \, cm^2 V^{-1} s^{-1}$

$= 0.1 \, m^2 V^{-1} s^{-1}$

i) $\mu = q\tau / m^* \Rightarrow \tau = \frac{\mu m^*}{q}$

$$= \frac{0.1 \, m^2 V^{-1} s^{-1} \times 0.3 \times 9.1 \times 10^{-31}}{1.6 \times 10^{-19}}$$

$= 1.7 \times 10^{-13} \, s. \quad = 0.17 ps.$

ii) Drift velocity $v_{dn} = \mu_n E \simeq \mu_n \frac{V}{d}$

$$= \frac{0.1 \, m^2 V^{-1} s^{-1} \times 10^{-2} V}{200 \times 10^{-9} m} = 5 \times 10^3 \, m/s$$

time taken = $\frac{\text{distance}}{\text{speed}} = \frac{d^2}{\mu V} = \frac{200 \times 10^{-9}}{5 \times 10^3} s$

$= 40 \, ps$

(iii) $J = qnV_{dn}$

$\Rightarrow \quad I = JA = qnV_{dn}d^2$

$= qnVd$

$= 1.6\times10^{-19}\times10^{22}\times10^{-2}\times200\times10^{-9}$

$= 320\times10^{-8}$ A $= \underline{\underline{3.2\,\mu A}}$

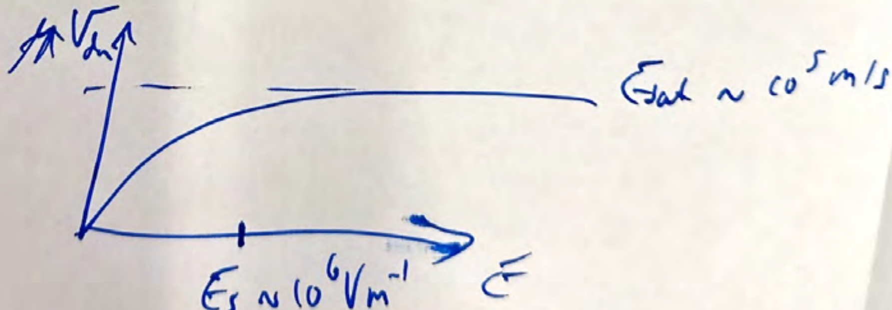
iv) Presumably the Q is if V↑ then I↑ (not V).

The magnitude of the field for V = 10mV

$\sim \frac{10\,mV}{200\,nm} = \frac{10^{-2}}{2\times10^{-7}} = 5\times10^{4}$ V/m

if we increase V, we will start to approach the saturation field for Si which is of order 10^6 V/m.

i.e.



$\Rightarrow$ if we increase V from 10mV to 100mV, I will increase by less than ×10.

1 (a) (i) (i) $y = \sigma(w^T x + b)$; (ii) $y = \sigma(w_3^T \sigma(w_2^T \sigma(w_1^T x + b_1) + b_2) + b_3)$; (iii) $y = \sigma(w_3^T \text{FLATTEN}(\sigma(w_2^T * \sigma(w_1^T * x + b_1) + b_2) + b_3))$. The FLATTEN operator converts the 3D (width, height, channel) output of the convolutional layer into a 1D vector (or, in the case where the model is processing a batch of b inputs, instead of a single input, a 4D output into a 2D matrix of b vectors).

(ii) Let $||$ denote the number of scalar parameters for a given parameter. (i) $|\theta| = |w| + |b| = 3 \times 100 \times 100 + 1 = 30001$; the size of the input is $100 \times 100 = 10,000$ pixels with 3 color channels each, so $|w| = 30000$. (ii) $|\theta| = |w_1|+|b_1|+|w_2|+|b_2|+|w_3|+|b_3| = 30000\times n+n+n\times n+n+n\times 1+1 = n^2+30003n+1$. (iii) $|\theta| = |w_1|+|b_1|+|w_2|+|b_2|+|w_3|+|b_3| = 11\times 11\times 3\times k+k+11\times 11\times k\times k+k+(100-(11-1)-(11-1))\times(100-(11-1)-(11-1))\times k\times 1+1 = 121k^2+6765k+1$.

(iii) (i) Advantage: Logistic regression is a very simple model, making training and inference cheap and quick. Disadvantage: it has limited capacity and cannot model the data or generalise well. (ii) Advantage: MLPs are capable of modelling a nonlinear decision boundary, which is typically necessary for computer vision problems. Disadvantage: training and inference are more expensive, and the MLP may overfit the training data. (iii) Advantage: CNNs, like MLPs are capable of modelling nonlinear decision boundaries; they also encode translation invariance, which is a useful inductive bias for this problem, and parameter sharing can make the model more sample efficient. Disadvantage: the convolution operator can be expensive to compute, making training and inference take longer.

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

(i) $11 \times 11 = 121$.

(ii) $21 \times 21 = 441$. The receptive field is wider than for the first layer, since every location in the feature map (the output of the convolutional layers) attends to an 11×11 patch.

(iii) The output of the average pooling operator depends on all of its inputs, and reduces the size of the feature maps (i.e. the activations) by a factor of 2 in each spatial dimension. We can reason backwards from the output of a neuron in the 2nd convolutional layer; it depends on an 11×11 patch in the previous feature map (which is the output of the pooling layer). Each location in this patch depends on 2 of the locations in the previous feature map (which is the output of the first convolutional layer), and since the pooling is non-overlapping, this means it depends 22×22 patch of the activations in this feature map. Each of these activations depends in turn on an 11×11 patch of the input, and these patches overlap, so the total receptive field is $22 + (11 - 1) \times 22 + (11 - 1) = 32 \times 32$.

(iv) The convolutional filters cannot detect features larger than their receptive field. So if the receptive field is too small, then they may fail to detect some important features.

(c) This question is about overfitting.

(i) Overfitting is when a model learns a function that does not generalize well to new data, e.g. because it has memorized the training data instead of detecting genuine patterns in the inputs.

(ii) Overfitting can be detected by monitoring the performance on a validation set of unseen examples throughout training. If validation performance starts to decrease, we can say that overfitting is occurring.

(iii) Overfitting can be addressed by using more data, using a simpler model, or applying regularization.

END OF PAPER

2P8: Computer Vision

2023 Question Crib Sheet

1. (a) i. **Solution:**
The use of *differentiation* in the detection of edges is particularly sensitive to noise. This can be seen by noting that differentiation is a Linear-Time Invariant operator (and can thus be described by its frequency response): $X(j\omega) \to j\omega$, which amplifies higher frequencies. This noise can be reduced by convolution with a 2D Gaussian:

$$S(x,y) = G_\sigma(x,y) * I(x,y) = \frac{1}{2\pi\sigma^2}\int_u\int_v \exp\Big(-\frac{u^2+v^2}{2\sigma^2}\Big) I(x-u, y-v)dudv$$

ii. **Solution:**
Convolution can be implemented by exploiting the separable property of the Gaussian:

$$G_\sigma(x,y) * I(x,y) = g_\sigma(x) * [g_\sigma(y) * I(x,y)]$$

Since the kernel is 7×7 and we are employing valid convolution, the total size of the output image is $(1280 - 6) \times (720 - 6) = 1274 \times 714$. Each output requires 7×7 multiplications for a naive implementation, so the total cost in multiplications is:

$$1274 \times 714 \times 7 \times 7 = 4,4572,164 \tag{1}$$

The most efficient separable implementation performs convolution vertically first, to produce an output of size 1280×714, before the second produces an output of size 1274×714. The total cost of the efficient approach is therefore:

$$\begin{aligned}&1280 \times 714 \times 7 \times 1 + \times 1274 \times 714 \times 1 \times 7\\&= 6397440 + 6367452\\&= 1,276,4892\end{aligned}$$

The reduction in compute cost is therefore $(4,4572,164 - 1,276,4892)/4,4572,164 = 71.36\%$. Near the boundaries of the image, the separable approach does more work in relative terms. Therefore, as the image to be denoised gets larger, the relative cost of convolutions at the boundary of the image is diminished, and the cost savings % reduction is improved (increased).

(b) i. **Solution:**
The *aperture problem* refers to the fact that motion can only be recovered normal to an edge feature, and thus it is difficult to achieve invariance to 2D position (a problem that can be resolved by using *corners*). An advantage that edge features have over blobs is that they can recover orientation.

ii. **Solution:**
The reproducing property of the Gaussian tells us that:

$$G(\sigma_1) * G(\sigma_2) = G\Big(\sqrt{\sigma_1^2 + \sigma_2^2}\Big)$$

The convolution to be performed is $S(x, y, \sigma_{i+1}) = I(x, y) * G(x, y, \sigma_{i+1})$, where:

$$G(\sigma_{i+1}) = G(\sigma_i) * G(\sigma_{k_i})$$

We use the reproducing property to note that:

$$\sigma_{k_i} = \sqrt{\sigma_{i+1}^2 - \sigma_i^2} \quad \text{by the reproducing property}$$

$$\sigma_{i+1} = 2^{1/s}\sigma_i \quad \text{by definition}$$

$$\sigma_{k_i} = \sqrt{2^{2/s}\sigma_i^2 - \sigma_i^2} = \sigma_i\sqrt{2^{2/s} - 1}$$

This is efficient because we can compute s distinct small filters (corresponding to each σ_{k_i}). Incremental blurs with these filters avoid the use of blurring with large kernels. Additionally, they need to be computed only once.

iii. **Solution:**

Other computational mechanisms that the efficient identification of the scales and locations of blobs include:

(1) The use of *sparse sampling*, rather than dense sampling of the scale space, with images in each octave spaced logarithmically.

(2) The use of *image pyramids*. Every time the scale doubles (corresponding to an octave), we can subsample the image by a factor of 2 without loss of information (since we know that our sampling rate will remain $\geq 2\times$ the highest frequency, the Nyquist rate, and will avoid aliasing). This is cheaper because we process far fewer pixels and we avoid the use of very big kernels to smooth the image at large scales.

(3) A third computational mechanism is the use of the Difference of Gaussians filter as an approximation to the scale-normalised Laplacian of a Gaussian:

$$G(x, y, k\sigma) - G(x, y, \sigma) \approx (k - 1)\sigma^2\nabla^2 G(x, y, \sigma)$$

This allows us to compute responses by subtracting one member of a pyramid level from the level directly above it (avoiding the need for differentiation).

(c) i. **Solution:**

(1) By extracting each SIFT descriptor from a 16×16 pixels patch at the characteristic scale of a keypoint detection, it is normalised with repsect to scale to support feature matching across scales (scale invariance).

(2) By extracting each SIFT descriptor at the location of a keypoint detection, it is normalised with repsect to location to support feature matching across locations (location invariance).

(3) By storing the orientation of a SIFT descriptor relative to the orientation of a keypoint detection, it is normalised with repsect to orientation to support feature matching across orientations (orientation invariance).

(4) The SIFT descriptor is L2-normalised, providing some invariance to affine changes in illumination when matching descriptors.

(5) After truncation, the descriptor vector is renormalised to provide some further invariance to non-linear illumination changes (such as those caused by camera saturation).

ii. **Solution:**

A few examples of nuisance factors (among the many possible valid answers to this question):

(1) On a different day of the week, there may be significant differences in the number of pedestrians on the pavements and traffic on the street, causing partial occlusions that hinder correspondences. In a five-minute window, it may be reasonable to expect pedestrian and traffic density to be relatively similar.

(2) Significant differences in cloud cover (and hence illumination) are relatively unlikely in the photographs taken 5 minutes apart, but quite likely in the photographs taken 24 hours apart.

(3) In photographs taken 24 hours apart, there may be differences in the reflectance characteristics of the gate materials (and surrounding buildings) if there are substantially different

levels of moisture. This is much less likely to be the case in images taken 5 minutes apart. SIFT can fail in the presence of partial occlusions, and thus the presence of pedestrians (or other occluding objects) may heavily affect the matching performance of SIFT.

3) a) ad hoc dynamic programming — Bellman
Set is fixed at each step
Bellman-Ford — complete n iterations
Dijkstra — Because algorithm is correct.

b) eg using ad-hoc DP: see figure (distances in red)

at node g: $8 = \min(5+3, 2+10, 7+14)$ etc

c) to/from B, as A will be encountered before many nodes to its left are

d) $\text{dist}(A,B) \leq \text{dist}(A,s) + \text{dist}(s,B)$ by Δ inequality

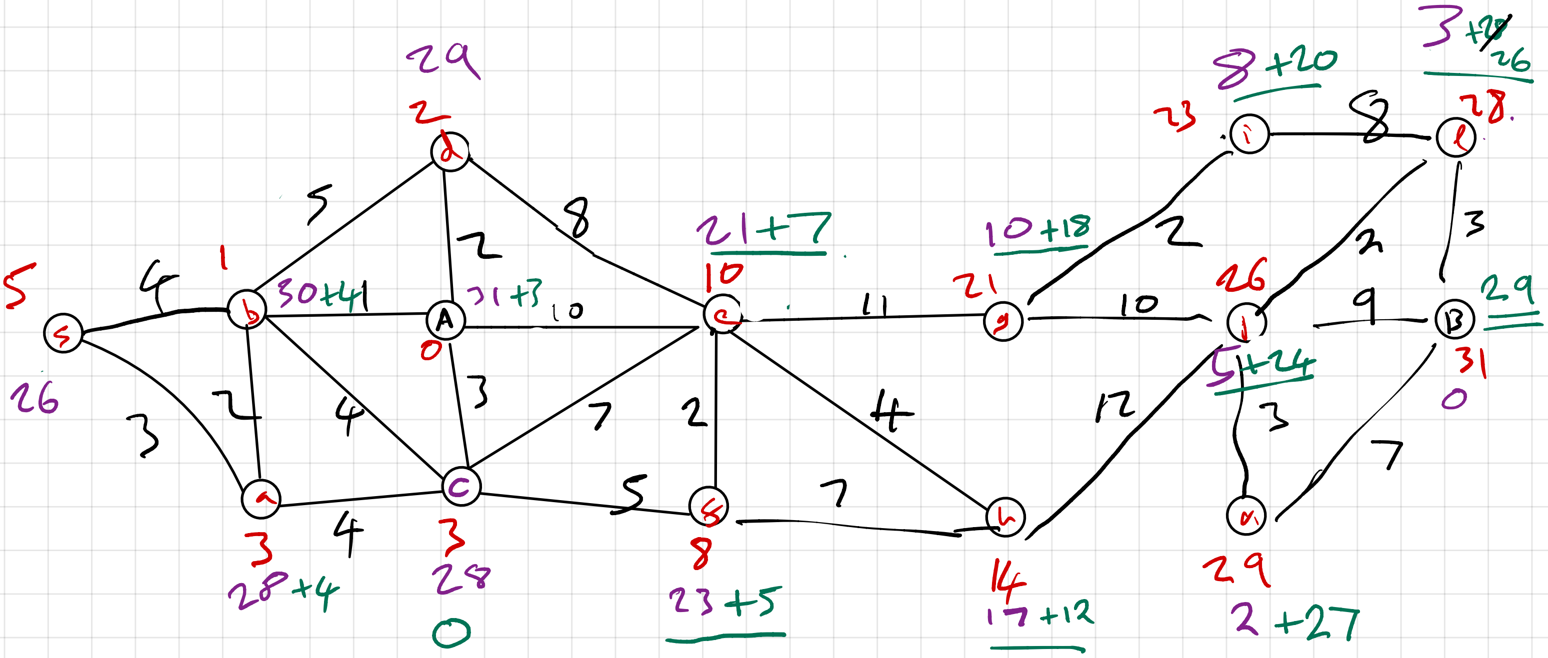
& rearrange.

Heuristic shown in purple. (purple + red $= 31$)

A^* ~~thus~~ visits nodes in order
f, e, g, i, h, j, l

by choosing node with min (heuristic + tentative distance - shown in green) at each step.

other nodes are not visited



EGT1
ENGINEERING TRIPOS PART IB

Wednesday, 14 June 2023 09.00 to 11.40
09.00 to 10.40 Foreign Language Option

Paper 8 – CRIB

SELECTED TOPICS

*Answer **all** questions from Section A. In addition:*

> *If you are not taking the Foreign Language option, answer **four** questions, taken from only two of sections B–H. Not more than **two** questions from each section may be answered.*
>
> *If you are taking the Foreign Language option, answer **two** questions from one of Sections B–H.*

All questions in Sections B–H carry the same number of marks.

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

*Write your candidate number **not** your name on the cover sheet.*

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

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Engineering Data Book

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

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

You may not remove any stationery from the Examination Room.

Version ML/3 – CRIB

SECTION A: *The Engineer in Business*

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

SECTION B: *Civil and Structural Engineering*

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

SECTION C: *Mechanics, Materials and Design*

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

Version ML/3 – CRIB

SECTION D: *Aerothermal Engineering*

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

SECTION E: *Electrical Engineering*

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

SECTION F: *Information Engineering*

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

SECTION G: *Bioengineering*

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

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

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

Answer: The round-trip distance is 4 cm.

The speed of light in water is $c_\text{n} = c/n = c/1.33 \simeq 2.26 \cdot 10^8$ m/s.

The round-trip times are therefore:

0.04 m / 1480 m/s = 27 μs for an acoustic pulse

0.04 m / $2.26 \cdot 10^8$ m/s = 177 ps for an optical pulse

While the round-trip "echo" time for sound is easy to resolve with conventional detection electronics and amplifiers, the speed requirement for an optical pulse would be challenging for state-of-the-art instrumentation.

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

Answer: Up to 6 marks for any reasonable differences

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

Answer: $L_\text{c} \simeq 0.44\,\lambda_0^2 \,/\, \Delta\lambda = 0.44\ (800)^2\ / 50 = 5.632\ \mu\text{m}$

This is the maximum z-axis/lateral spatial resolution

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

Answer: We can write the Doppler frequency shift (= the beat frequency) as

$\Delta f = 2\, f_0\, v/c = 2\, v\, \lambda_0 = 2\ (5)\ 800 \cdot 10^{-9} = 12.5 \cdot 10^6$ Hz

The frequency response of a detector is equated with its power bandwidth, which is defined as the frequency at which the electrical output falls to -3 dB, or 50%, of the low-frequency output. The roll-off is generally such that the response at half that frequency is close to 100%. Thus, to maintain linear response, the minimum required frequency response should generally be twice the beat frequency to be measured.

Twice the beat frequency = 25 MHz.

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

Answer: Depth approx. = $1/\mu_s = 0.1$ cm

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

Answer: 800 nm has been chosen because biological tissue is relatively transparent in the near-infrared due to:

Losses due to absorption (primarily by hemoglobin) are much lower in the NIR.

Losses due to scattering are lower at longer wavelengths. Although the OCT signal itself requires backscattering by structural interfaces, noise due to general Rayleigh scattering by very small distributed structures varies with the negative-fourth power of the wavelength.

Lower-cost broadband light sources are available at NIR wavelengths.

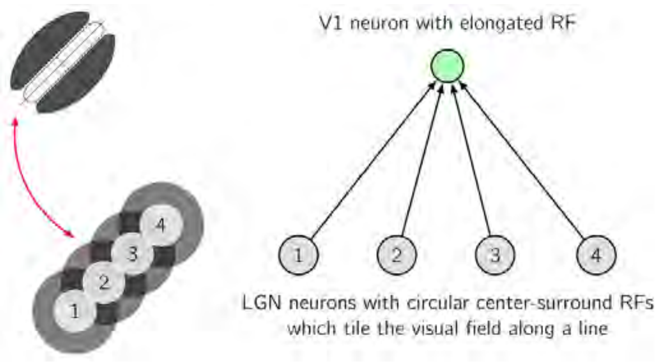
(g) What is an OCT scan used for and what conditions can it detect? [3]

Answer: OCT can obtain high resolution cross-sectional images of the retina. The layers within the retina can be differentiated and retinal thickness can be measured to aid in the early detection and diagnosis of retinal diseases and conditions such as:

- Glaucoma
- Diabetic retinopathy
- Detached retina
- Age-related macular degeneration
- Macular hole

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

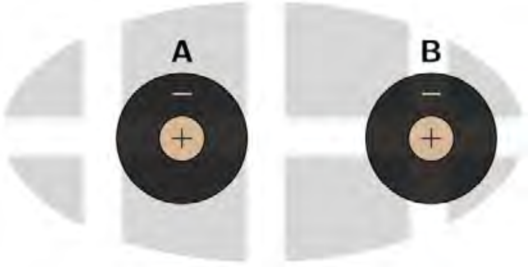
Answer: V1 simple cells of this type have localised, elongated and oriented receptive fields as shown in the diagram below (top left). Spots of light falling in the central white (resp. flanking dark) region of the RF increase (resp. decrease) the cell’s firing rate. Responses are linear, in that they obey the superposition principle. Hubel and Wiesel proposed that this RF structure might arise from such cells receiving inputs from LGN neurons whose own circular ON-center OFF-surround RFs line up in space, as shown in the rest of the diagram below.



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

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

Answer: This illusion has been proposed to be driven by the response properties of retinal ganglion cells (RGCs) with ON-center and OFF-surround RFs, two of which are depicted below. Those RGCs whose RFs are centered at an intersection between two white lines (B) will have more light falling in their surround, relative to cells whose RF is centered elsewhere on a white line (A). Therefore, one would expect (B) to fire less than (A), putatively explaining the illusion of a dark spot at the intersection. This theory is further corroborated by the fact that the illusion appears only in the visual periphery, but not in center of gaze – consistent with RGCs in the fovea having much smaller RFs which are fully contained within the white area no matter whether or not they lie at the intersection.



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

Answer: Yes, this observation is consistent with the theory outlined in (b)(i): the very same arguments can be made for this contrast-reversed version of the Hermann grid, now appealing to the RF properties of OFF-center/ON-surround RGCs.

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

Answer: No – this version of the grid appears to invalidate the original argument made in (b)(i). Indeed, this grid variant is such that it "does not materially affect the putative differential responses of the RGCs" considered in said (Schiller et al, 2016, *The Hermann grid illusion revisited*); the same argument that was made in (i) therefore ought to apply here too, yet the illusion nearly vanishes.

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

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

Answer: Two lenses: the 'objective' and the 'eyepiece', the retina (consisting of 5-7 receptors), and muscles to move the bottom apparatus (which is formed by the retina and the 'eyepiece' together).

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

Answer: The small number of photoreceptors in the retina (5-7) results in an extremely small field of view (3°) and thus an effectively 0-dimensional retina.

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

Answer: The eye is oriented upwards, the bottom apparatus moves along one dimension thus scanning the environment horizontally, while relevant objects (plankton) sink slowly downwards in the water thus adding a second effective dimension of scanning and hence effective vision.

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

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

Answer: It refers to the fact that, in order to achieve efficient coding (under suitable assumptions), the response of ganglion cells needs to have a power spectrum that is independent of spatial frequency, and therefore has the same characteristics as white noise.

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

Answer: Ganglion cells.

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

Answer:

1. The population of retinal ganglion cells maximises the (mutual or Shannon) information between the visual stimulus and their joint response (infomax).
2. Noise in ganglion cell responses can be neglected, so that noise entropy is diminishingly small, and thus maximising mutual information is equivalent to maximising response entropy (max entropy).
3. The constraints under which entropy (information) is maximised is the same for all neurons (probability equalisation).
4. Response statistics of order higher than 2 can be ignored in ganglion cell responses (responses are jointly normally distributed), so that a factorial a population code with identical marginals is considered equivalent to a population code in which the (signal) covariance of responses is diagonal with uniform variance across neurons (decorrelation and variance equalisation).
5. Neural responses can be formalised as the result of simply applying a linear filter to the visual stimulus.
6. All ganglion cells use the same filter except for the location of their filter in visual space.
7. Visual stimuli have spatially stationary (translation-invariant) statistics.

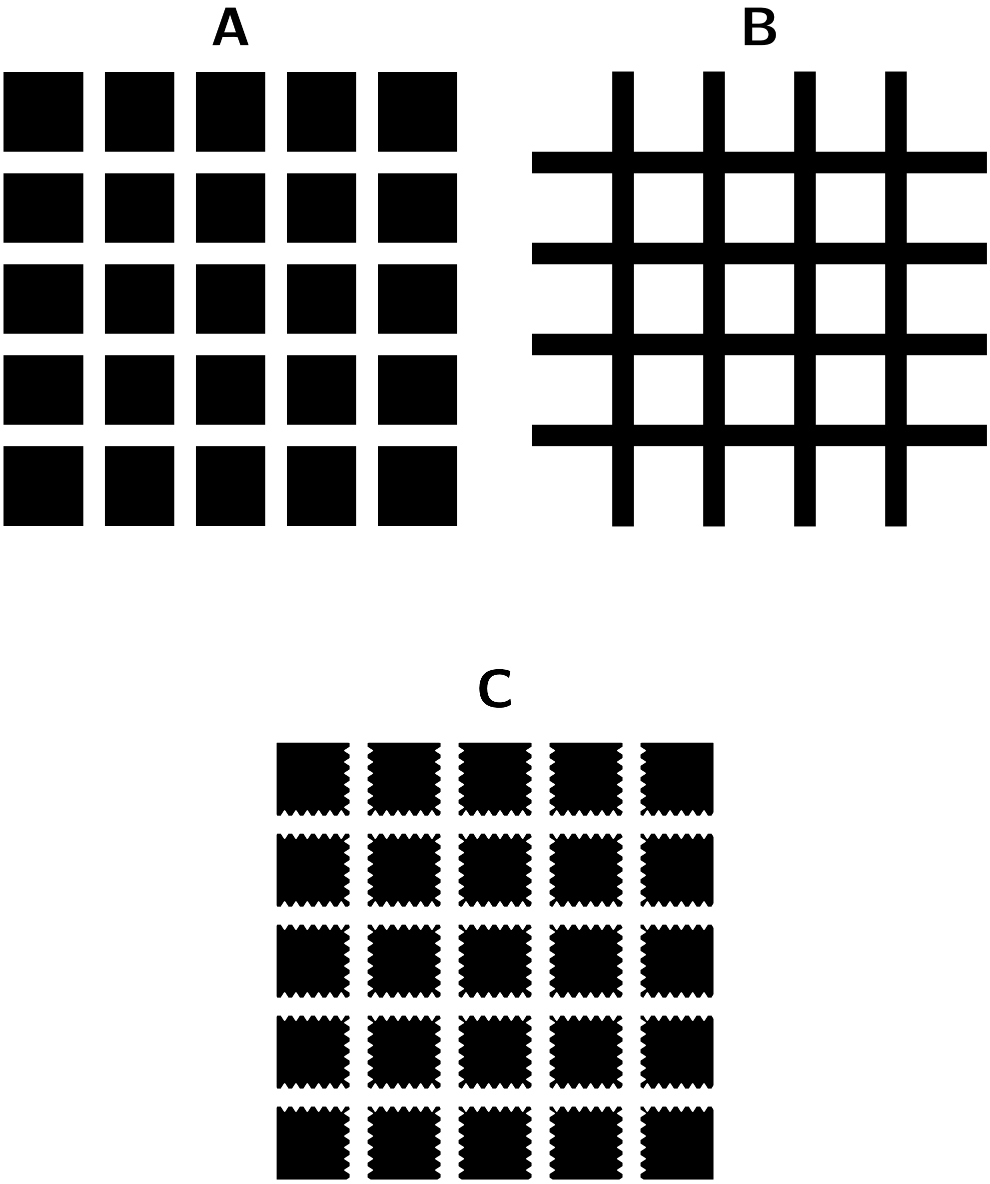


Fig. G.1

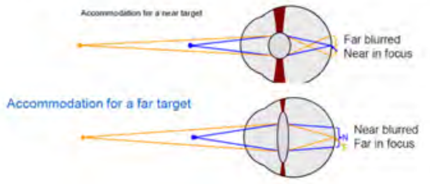
3 (a) What are the three layers of the wall of the eye? How does each layer contribute to the focusing ability of the eye? [4]

Answer: The wall of the eye is made up of three layers namely: The outer layer, which consists of the cornea and sclera. The middle layer, which consists of the iris, the ciliary body, and the choroid. The inner layer, which consists of the retina. The cornea contributes the majority (2/3) of the eye's focusing power but is fixed focus. The ciliary muscles in the mid-layer changes the shape of the lens (which contributes to 1/3 of the focusing power) thus, the focal distance of the eye. The inner layer, i.e. the retina does not contribute to the focusing ability of the eye.

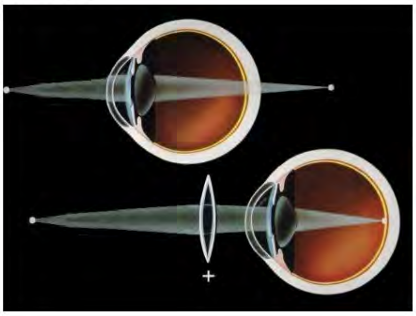
(b) Give an example of how aging can change the tissue properties of an eye component, and how this change can cause deteriorated physiological function of the eye. In addition, suggest a suitable strategy to augment or repair the deteriorated eye function, and discuss the strategy's operation principle.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

Answer: The lens continually grows throughout life, laying new cells over the old cells. There appears to be no protein turnover in the nucleus throughout lifespan. The lens is thus prone to age related changes, in particular stiffening. Nucleus and cortex of lens becomes stiffer with age, leading to orders of magnitude increase in stiffness. The lens also becomes larger. Lens stiffening over age: harder to deform and focus. this leads to Prespyopia. Presbyopia, or "old man's eyes," affects almost all people by the age of 50. Loss of accommodative ability is accompanied with Prespyopia, where near field focusing becomes impossible. A simple strategy to augment prespyopia is to wear a pair of glasses with convex curvature.

- "Amplitude of accommodation" is the max amount that the lens can accommodate in diopters (D), equal to the reciprocal of the focal length measured in metres.



Hyperopia and Presbyopia = farsightedness, an inability to view close-up objects in focus; this is corrected with **convex** lenses



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

Answer: No vasculature in the lens and cornea to ensure transparency – the aqueous humour nourishes these regions. Regulation of aqueous humour generation of outflow also regulates intraocular pressure (IOP). Two drainage routes, principal route are (1) at conjunction of iris, cornea and sclera – trabecular meshwork, and (2) Schlemm's canal.

For (1) the proteoglycan-rich gels in the trabecular meshwork, experiments show an immediate increase in IOP with increased perfusion of media. But IOP then returns to baseline after 150 hours. Perfusate collected from experiments contained increased gelatinase A (MMP-2). Suggests that ECM material and its degradation is linked to control of IOP.

For (2), the wall shear stresses experience by the endothelial lining of the Schlemm's canal are expected to lie in the range of shear stresses which will cause the alignment of endothelial cells. Thus, the endothelial cells can potentially sense shear stresses through mechanotransduction which in turn changes its morphology to regulate the flow of aqueous humour.

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

Answer: Basic criteria are transparency, biocompatibility for the duration of use, and ability to be made into the right lens shape for correcting eyesight. Other desirable criteria are softness, breathability, and environmental-friendliness.

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

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

Answer: decreased collagen density in the sclera

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

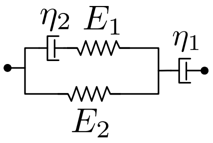


Fig. G.2

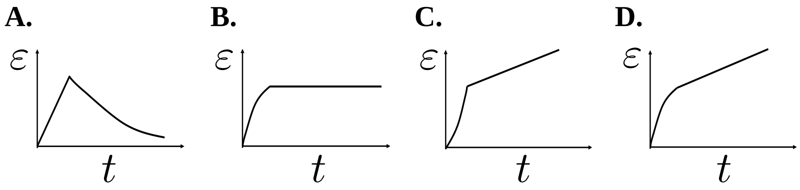


Fig. G.3

Answer: D

SECTION H: *Manufacturing and Management*

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

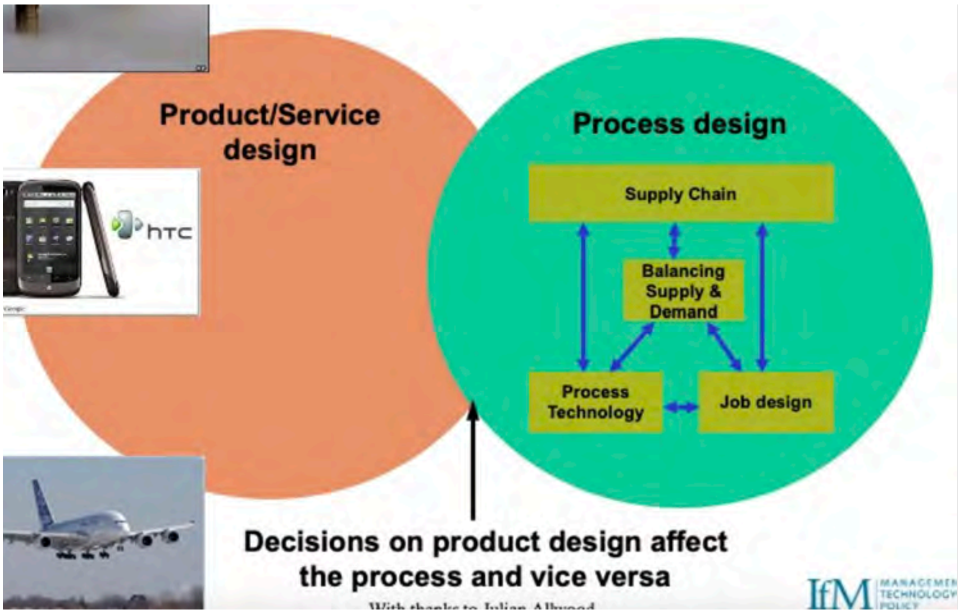
END OF PAPER

THIS PAGE IS BLANK

CRIB

Question 1.

a. The students should have referred to the fig below and particularly to the 4 main operations design issues in the green bubble: 1) balancing supply and demand; 2) Designing the supply chain and coordinating it; 3) decide what technology to introduce in the manufacturing process; 4) how to balance the technology with the skills and capabilities of the workforce (Job design). These choices are intimately tied to choices in the design of the product itself.



Decisions on product design affect the process and vice versa

1) There are different requirements for products in terms of how much variety and which volumes should be produced. The operations design depends greatly on where the company is on this volume-variety curve. The choices are: One off production, Job shop; Batch production, Mass production. Whilst mature companies require taking these decisions and designing the processes based on the product design only, the decision for young companies often start at the low volume/high variety end, moving progressively towards more mass-manufacturing, if appropriate, as they grow (e.g., Dyson). This is because towards the mass manufacturing end, a company requires a large investment of funding to setup operations which typically young/small firms do not have. Further these investments constrain the company in term of flexibility, and young firms might require innovating the products to perfect them for the market needs.
2) The choice of the production technology for both production and distribution of the products. These relate to a) production technology (e.g. casting, 3D printing); b) how to improve communication in the supply chain to make sure

that supply-demand curves are smoothened and c) what operations should be automatised vs which should be done by humans.

3) The balance needs to keep into account the pros and cons of technology for automating operations (pros: fast production; cons: High setup-costs, inflexibility, complexity and needs to consider how to maintain it efficient) and those related to designing jobs which can be done effectively by humans. (People learn and invent improvements, they can be way more flexible than machines and do not require high capital to start but require looking after (good HR policies). The cost of humans running ops applies over time, whilst the automation technology costs become absorbed the longest the tech is used, but it requires high initial investments and maintenance costs (e.g. replacing machines).
4) The choice of operations size (how much are we able to produce) depends on the balance between supply-demand. This is very hard to strike as all the stakeholders in the supply chain have different aims. At the extremes, customers would like to be able to buy any volume of a product without delay, whilst the owners of the business would like to see all their resources fully and efficiently used all the time without having to pay any of the costs associated with holding stock. This trade-off can (partly) be achieved with techniques which counteract the peaks and troughs of market request as well as approaches to keep operations busy at times of low demand.
5) Companies need to manage suppliers on one side, to incentivise the timely delivery of the right amount of material and on the other improve the way their operations work efficiently and not wastefully (neither in terms of time nor in terms of material). Decisions on where the flexibility in the supply chain requires high coordination and contractual power with suppliers, as well as capability to decide where the stock should be kept for minimising delays if the market increases demand unexpectedly. Digital technologies help with communicating and sharing information across the supply chain.

b. The main types of innovation refer to:

1) Product or services – this refers to launching new products or services – e.g. a new model of a Tesla is a product innovation. Netflix adding gaming in their offering is a new service innovation.
2) Processes (either production or business) – this refers to changing how products or services are made or how they are delivered to customers. Changing wire cutters with laser cutters in a manufacturing plant is an example. Operations changes fall in this category (e.g. relying on an external distributor for our products, rather than distributing directly to customers).
3) Placement – this refers to changing the market target for our products. Amazon used to be a book seller, moving to using its

platform to distributing a variety of different products, outside the bookselling industry.

4) Paradigm – this refers to changing what the company does – Google used to be a 'search engine'. Now it is selling advertisement, mobile OS and services (e.g., cloud storage).

Each of these innovation types could be 'small' innovation steps – i.e., incremental, or more 'radical' innovation steps.

c. Design rights (DR) a special type IP protection which protects shapes/forms/appearance of an innovation, rather than its function (for this latter, traditional patents are more appropriate methods of protection). For example, DR could be used to protect the shape, colour of an innovation and prevent companies from copying and launching something looking similar, but made of different material. To obtain this type of rights, the appearance should be novel (i.e., not publicly available anywhere prior to registration, although there is a 12-months period for the innovation to be tested in the market for an application could be filed) and to be judged novel by an informed user (not a professional designer). Once given, these rights are registered for up to 25 years. There are anomalies/limitations to DR: unregistered DR, similarly to copyrights, protect the 3D shape of innovations for up to 10 years without applications or registration. In the EU, using the unregistered community design, allows for 3 years of protection. Topographies (maps, arrangements of components which are not functionally dictated), are also protectable by DR. When the topography instead depends or impacts on functionality (e.g. to make components compatible with each other), DR cannot be enforced. Examples of important design rights include the original Apple design for flat electronic devices with round edges that was one of the patents that started the "patent wars" between Apple and Samsung. Design rights do not protect the underlying function, which is what patents protect. In contrast to patents, who are examined extensively before being granted, the examination process of design rights is much less extensive and shorter. Also, the duration of design rights tends to be shorter than for patents. Similar to trademarks, design rights are often used complementary to patents and/or when patents have expired, such as in later lifecycle stages of an industry. For instance, we have seen design rights becoming increasingly important in the automotive industry, where the underlying technologies increasingly are standardized or commoditized, but companies differentiate their cars from competitors by their appearance. Also, design rights are used in industries where patents do not have such importance, e.g. in the furniture or fashion industries.

Question 2

a. The identification of what users want would allow the company to setup the design specifications for their platform. As first important steps, the company would need to identify the key stakeholders around this idea. Hopefully the students will realise that this type of service requires a dual market to exist, and hence at least the perspectives of two types of ‘users’ and hence two sets of stakeholders would be required: the students and the providers of social work opportunities. Both types of users could be segmented in different ways, which would require to consider the different dimensions upon which this might be a success (e.g. speed, age/level of education, types of organisation etc) For example, the students seeking social work internships could be ‘segmented’ in at least 3 groups (during school, during gap year, at university), the providers of social work opportunities could be for instance providing local, national, international opportunities or to be government, non-government or private organisations. Broadly speaking, there are two approaches 1) use more quantitative methods in which they seek insights from many users, but the insights are comparatively shallow. 2) use more qualitative methods where to seek inputs from fewer stakeholders but of a greater level of depth.

   Then the answer should give an example or two of what specific methods one might choose to use and their strengths or limitations. For example, a survey would allow them to find information from a large group of potential users. Surveys are good for testing views or opinions but are less good for establishing motivations or more subtle insights. Conversely, they could run a focus group or do some interviews which would provide a greater level of insight.

b. There are 6 types of trademark ™ (Word, figurative, Figurative with letters, 3D shape, colour per se and sound) and they are used to prevent famous established products being substituted by generic ones.

To obtain a TM, an application should be filed and examined first, then it needs to be published to be exposed to oppositions from competitors. It is only after the opposition period is finished that the registration is carried out and finally the TM is published.

To obtain a TM the mark must be distinctive of the goods and services of the trader without being deceptive or misleading or easily confused with another TM. The TM must not be a description of the goods to which it is applied (e.g. Orange could be used for a telecom company but not for the fruit) and could not resemble symbols such as flags or hallmarks.

Many examples exist of trademarks for technical products. For instance, the Apple iPhone is protected by a family of trademarks. Companies tend to employ trademark strategies where they combine trademarks on different levels, such as the company level (e.g. Apple), the product level (e.g. iPhone), but maybe even component levels (e.g. Bluetooth). In many cases companies use trademarks to protect their brands. Many examples exist of trademarks for technical products. For instance, the Apple iPhone is protected by a family of trademarks. In many cases companies use trademarks to protect their brands. Thereby, trademarks represent another instrument for companies to protect their technologies, even though more indirectly (i.e. via the artefacts that embed technologies) and thereby represent complementary instruments that companies can use in addition to patents. Trademarks tend to be more relevant later in product/technology development processes than patents, particularly when technologies (e.g. embedded in product/service offerings) are launched on the markets. Companies also tend to build their brands while patents are in place so that customers are loyal to the brand when patents expire. In other words, companies IP strategies change from relying on patents to relying on trademarks at later stages in product/technology lifecycles.

c. All four elements of process design will be impacted by technology:

- Supply chain – increased digital connectivity increasing visibility of data.
- Balancing supply and demand – better customer insights help smooth out peaks and troughs
- Processes - casting, forming, subtractive, additive – each of these technologies is developing continuously, offering new opportunities and challenges for manufacturers.
- Automation is having complex impacts on job design – from production lines to logistics.

- there are fundamentally 4 different types of process technologies to make artefacts: Casting, Forming, Subtractive and Additive. The product design and specification would indicate the best type of technology to be adopted for manufacturing. However, as products are often made of many components, it is likely that all types of technologies are employed somewhere in the making of a complex product.

- product components are in fact not just manufactured in isolation, but also need to be assembled and distributed. Hence technologies play a great role in the design of the operations to manufacture and distribute products.

- Beyond the technologies used to manufacture each component, considerations relating to technology apply to how and where technologies are integrating or substituting humans. Technologies such as CAD/CAM support humans in the design of products and computer-aided manufacturing technologies integrate with human input to allow the factories to control the operations, manage the production (e.g. scheduling and coordinating with suppliers). More currently AI is increasingly used in design as well as in production, where technologies could take over humans in the handling of the products via robotics (e.g. manufacturing, assembling parts).

- Hence there is a tension between the adoption of technologies to automate production and the design of jobs. whist adding production capacity. Increasing automating technology increases the costs of plants and the money required upfront, (robots do not need to rest overnight, their costs can be abated the more the technologies are exploited). However, humans allow more flexibility to manufacturing.

- New digital technologies in manufacturing are combining with additive technologies, potentially revolutionising the way in which the balance between volume and variety could be obtained (pushing the variety volume curve up!)

- Technologies allow also to communicate and coordinate needs across the supply chain and to help the smooth run of operations across sites and companies (e.g. anticipate inventory or maintenance problems).

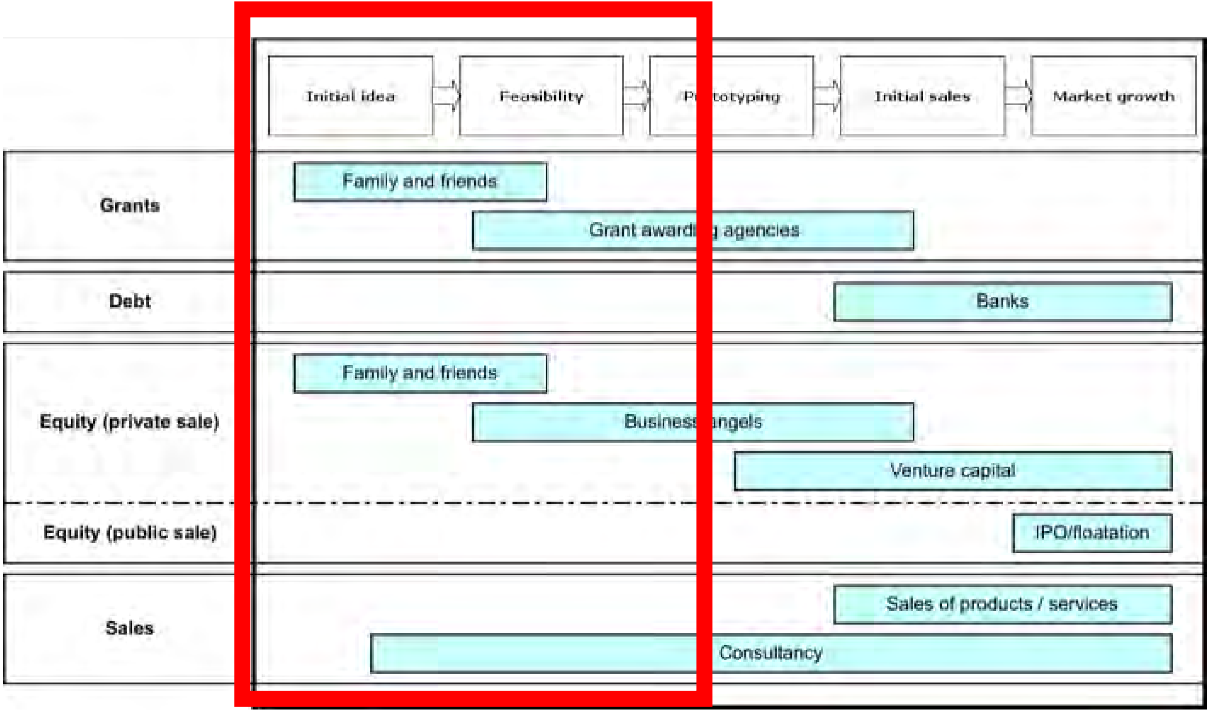
3.

a) IPR defines the allocation of ownership. This is an important determinant for functioning markets. Allocating ownership for inventions through rights put the owner in the position to make decisions about what happens to the inventions. One of the biggest misconceptions is that patents as such prevent progress and prevent others from using the technology. This is not necessarily true as patents only put the owner in a position to make decisions about what happens (e.g. whether persecute infringers or not). Companies typically try to prosecute infringers selectively, e.g competitors, but this could also be certain actors, such as defense firms or certain companies that not necessarily share the same values as the patent owners, e.g. with regards to sustainability. The owner might very well choose who can use the invention amd in some cases to let others use the invention for free. There are various examples of so-called patent pledges. For instance, in 2014 TESLA made a public announcement to let others use their patents for free. This basically means that TESLA is actually not giving up the ownership of its patents, but rather provides some free licensing. While some pledges come with some strings attached for users, this should just be seen as an example that owners are in charge of what to do with their patent. In a way, the same goes for open-source software. Most of it is made available for usage through licensing constructs while typically the inventors still maintain the ownership of the software, which is typically not protected by patents but copyright. Hence, IP rights allocate ownership to the inventors/creators so that they are empowered to make decisions about the use of their invention. Without claiming the IP rights, inventors will find it more difficult to control what happens to their inventions.

b)

i. The First thing to consider is how much funds would I need. This would give a sense of the type of funding sources that may be available and also of how I could stagger them (e.g. where would a certain amount from one type of source lead me to, and what I would need next).

Considering the four types of funding -gifts, equity, debt and sales - several combinations are possible, but roughly a staggered map for when it is appropriate to access funds is shown below. As this is a newly funded company it is likely that the funding sources in the red block will apply first.

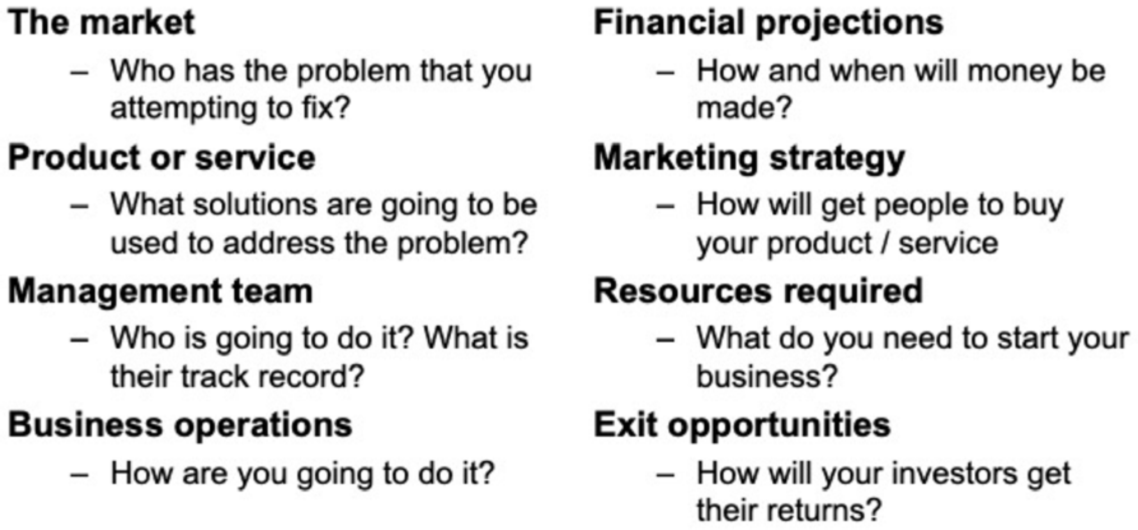


- The debt sources (i.e. banks loans) could be excluded, unless the start-up means to create a very traditional business which banks would feel confident could grow according to known market trends. Even in these circumstances, until there is a cash-flow, they would need to persuade banks the startup owns enough ‘collaterals’ that the bank could repossess if the startup will not be able to repay the debt.

- the gift sources (i.e. Family or friends or grants) might not be able to cover all that the startup needs, but they would be a great way to start when the startup is developing the initial idea through to a feasibility test. Family/friends are great sources (if they can spare the money), but the risk is that, if the startup is not successful, personal tensions might emerge with people in the private sphere. Being successful with Grants would be excellent, but the downside is that there are many grants, all quite specific and finding the appropriate one plus fully have the characteristics that fulfil the eligibility of each might be hard.

- Family and friends might be happy to enter the business by buying equity as they trust the owners.

- Business Angels (in earlier stages) and Venture Capitals (VCs) after the company has more clear projected trajectory are also sources of funding that will want to possess part of our startup (take an equity) in exchange for funds. They are a pivotal source of funding capable of substantially contributing from the feasibility through to starting the sales in earnest. On top of funding, these sources provide coaching, connections and strategy formulation help. BA and VCs need to be persuaded that the startup can grow. The startup requires being quite clear about its plans (clear business plan where the answer to the following questions should be clearly laid out). Business Angels invest their own money and hence tend to be relatively flexible and invest in project they are passionate about as well as seeing the business opportunity. VCs need to respond to their own investors, so they particularly want a startup to be very successful in a short time so that they can 'exit' and get their returns fast.



The market
  - Who has the problem that you attempting to fix?

Product or service
  - What solutions are going to be used to address the problem?

Management team
  - Who is going to do it? What is their track record?

Business operations
  - How are you going to do it?

Financial projections
  - How and when will money be made?

Marketing strategy
  - How will get people to buy your product / service

Resources required
  - What do you need to start your business?

Exit opportunities
  - How will your investors get their returns?

- The startup, particularly if technology based, could consider making money from exploiting their own knowledge early (i.e. sales are sources of funds also during the feasibility stage). This is very positive not just in financial terms, but as it also gives confidence that the startup's knowledge is needed in the market (and so it is a great contribution to persuading VCs and investors). There are several ways to sell what the startup knows: e.g. in case of a technology startup, it is possible to sell knowledge as consultancy services or training to others from the very early stages of the technology development. Selling products requires great investments in the manufacturing infrastructure first, so it might come quite late as a source of funds.

If the startup becomes very successful, the company might consider selling equity in the market (i.e with an IPO).

Crowdfunding could also be an option – see below

bii.

With crowdfunding, funds can be gathered from a crowd of individual independent investors. Thanks to the diffusion of the internet, crowdfunding has become increasingly popular. Crowdfunding emulates the mechanisms of the sources listed in b)i. The most common use of crowdfunding is to gather funds as gifts (i.e. there is no commitment to return the investment) through sites such as kickstarter. In this case, startups often use the opportunity to reach early a market of lead users, interested to test and support the development of new ideas. Increasingly the other types of funding (Debt and Equity) are becoming popular. The peer-to-peer lending via crowdfunding is a system which has substituted banks for startups which have less strong credential in traditional terms (e.g., small businesses in less developed countries). Equity via crowdfunding is only a recent opportunity, since the US's law has allowed this form of fund gathering. However, crowdfunding is a source of funding that comes from non-financial institutions, and non-experienced investors. it is an additional source of investment only at the early stages of development – and it comes with its own challenges (managing campaigns, not always regulated, etc).

c) Radical innovation means that the innovation is really new both in terms of what the company knows (new to the company) and sometimes even to the world knows (new to the market). So, the experienced consultant knows that radical innovation is very risky and could fail. This is because it requires time and often a lot of iteration before the innovation can be fully functional or might require other innovations to be sufficiently diffused in the market to fully function (e.g. fuelling stations needed to be available for cars, before the users could feel that it was a good investment to buy a new car). Hence the market is not initially tuned to adopt a new radical technology which does not perform very well or that requires users to change significantly how do they behave. It is difficult to attract a large number of customers initially (and bridge the Moore's chasm). Most large companies will have large number of ongoing innovation projects and managers balance the investments in projects considering the cost and risk of each innovation with the potential reward. They will be wary of investing and launching products that their current market doesn't understand. They would need to acquire a lot of confidence that they can make it work, not tarnishing their reputation in the process, and be able to earn as much as with current innovation from it. To make a radical new product for example, a large company would need to plan operations and change their current business and oprations as well as acquire new competences. Hence large companies are likely to support few radical projects at any one time, whilst radical innovation is more likely to come from new companies that are formed to take a radical technology to the market.