Version MP/2

SECTION A: The Engineer in Business

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

1 Ten equally sized companies make cars for a particular segment of the UK car market. They make low rates of return. We observe one of the companies reducing their prices, when the others do not. This is likely to be an example of what type of pricing behaviour?

(a) Collusive Pricing;

(b) Price Discrimination;

(c) Competitive Pricing;

(d) Predatory Pricing;

(e) None of the above; [2.5]

Answer: e. None of the above. This is clearly not predatory pricing as there has to be an expectation of long run profits, which if there are ten firms cannot be expected to be profitable. The firm reducing prices is making a mistake, which is not the situation in (a) to (d).

2 Which of these statements is consistent with a Marxist view of the firm?

(a) Firms in the consulting sector benefit from economies of scale;

(b) Firms in the consulting sector pay the employees a salary equal to the value of their output;

(c) Firms in the consulting sector rotate employees between clients to reduce their client specific knowledge;

(d) Firms in the consulting sector favour growth of sales over profitable maximisation;

(e) None of the above; [2.5]

Answer: c. a. is a reference to Chandler's work on the history of capitalism. b. is definitely not Marxism, it is the opposite of it. c. the deskilling of workers in order to capture surplus value for the firm is the Marxist theory of the firm. d. is an application of the Marris model where managers maximised growth at the expense of profits.

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

(a) GDP falls by 2%, technological opportunity increases by 3%, managerial experience increases by 3%;

(b) GDP falls by 2%, technological opportunity increases by 2%, managerial experience increases by 2%;

(c) GDP falls by 1%, technological opportunity increases by 2%, managerial experience increases by 3%;

(d) GDP falls by 1%, technological opportunity increases by 3%, managerial experience increases by 3%;

(e) None of the above; [2.5]

Answer: b. GDP falling by largest amount, technological opportunity rising by least and managerial experience rising by least are all reasons for reduced firm growth. b. dominates other options in at least one dimension.

4 BYD is a Chinese manufacturing firm, initially manufacturing batteries. Recently it has become a major producer of electric vehicles. Which of the following best describes this growth 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: b. This an example of growth by forward integration (car components into cars).

5 All of the following are accurate descriptions of modern marketing, EXCEPT which one?

(a) Marketing is the creation of value for customers;

(b) Marketing is managing profitable customer relationships;

(c) Selling and advertising are synonymous with marketing;

(d) Marketing involves satisfying customers' needs;

(e) Marketing is used by for-profit and not-for-profit organizations; [2.5]

Answer: c. Modern marketing is characterized by "customer orientation" which means all marketing practices aim at better satisfying customers' needs, while selling and advertising reflect a clear "company or product orientation".

6 Apple Watch was launched in 2015 and it has quickly become the global market leader in the smartwatch category. Customers described this product as "ease of use", "stylish", "powerful", "convenient", "cool" and so on. Based on customers feedback of Apple Watch, we can say that Apple Watch successfully satisfy customers':

(a) tangible and intangible needs;

(b) radical and incremental needs;

(c) financial and non-financial needs;

(d) rational and emotional needs;

(e) None of the above; [2.5]

Answer: d. Successful products tend to satisfy customers' both rational need (e.g., ease of use, powerful, convenient" and emotional needs (e.g., stylish, cool). Apple Watch is a clear example of this product "duality".

7 Climeworks is the leading Direct Air Capture (DAC) company helping companies to achieve their Net Zero goal by removing the carbon dioxide emissions these companies cannot reduce in other ways. They have recently developed a marketing strategic plan to further expand their business. As an ESG-centred organization, which of the following is one of the element of their marketing plan?

(a) Situation analysis;

(b) Marketing segmentation;

(c) Targeting and ESG-centred positioning;

(d) ESG-centred marketing mix;

(e) All of the above; [2.5]

Answer: e. A genuine ESG-centred marketing strategic planning and practices emphasize the fact that ESG should be the focal point of every step or element of such a marketing plan and subsequent implementation. Otherwise, any ESG efforts can quickly turn themselves into greenwashing which is detrimental to both the organization and the society at large.

8 At the start of Microsoft's partnership with OpenAI, this was an example of managers following

(a) Porter's ideas about reinforcing activity systems through tradeoffs;

(b) Barney's ideas about leveraging core resources;

(c) McGrath's ideas about organisational agility;

(d) Adner's ideas about ecosystem keystones;

(e) c and d; [2.5]

Answer: e. A is not correct because there are no obvious tradeoffs involved, B is not correct because this was not YET a leverage of MSFT's reach.

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

(a) They can identify opportunities to grow;

(b) They can identify new ways to negotiate with suppliers;

(c) They can identify relevant sets of competitors;

(d) They can identify core competences;

(e) They can block new entrants; [2.5]

Answer: c. 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 NOT a product of VRIO analysis?

(a) A list of core competences;

(b) Sources of temporary advantage;

(c) Points of parity with other firms;

(d) An analysis of the activity system;

(e) An understanding of what has generated firm profits in the recent past; [2.5]

Answer: d (which is associated with positional strategy theory.) The others are all products of VRIO analysis.

END OF SECTION

 (TURN OVER

(a) Manufacturing defects — eg poor resin flow or cure or poor fibre orientation
Fix: careful quality control and monitoring as well as design of manufacturing

Foreign object impact: need to ensure that the leading edge is strengthened + testing

Lightning strike: allow for lightening conduction

Bond failure: careful manufacturing and testing

Tower deflection: should be easy to avoid with good design

Fatigue failure: could be difficult to predict, especially with overloads. Needs careful design and testing

Control failure. storm overload protection will be critical to avoid deflection and fatigue failure.

Need robust manufacturing and software quality control

(b) Different parts have different mechanical requirements and the layup can be used to tailor the properties.

For example use UD in the spar and in the leading and trailing edges to give bending stiffness.

The web will need to take shear so use ±45 plies.

Over the rest of the shell buckling resistance and impact resistance will need a mix of fibre orientations.

(c) UD ⇒ 100% 0° material, $E = 160$ GPa

75% ±45, 25% 0°, 0% 90 ⇒ $E = 53$ GPa

(d)

S/MPa	0-100	100-200	200-300
N/month	8.66×10^{5}	1.2×10^{5}	1.6×10^{4}
N_f	$1.15\times10^{+18}$	8.0×10^{10}	3.8×10^{6}
N/N_f	7.5×10^{-13}	1.5×10^{-6}	4.2×10^{-4}

(first two N/N_f values: negligible)

$\Sigma N/N_f \approx 4.2\times10^{-4}$

$$N_f = \left(\frac{S}{S_0}\right)^{-m}$$

- use S as mid-value
- may be rather inaccurate

$m = -15$

$S_0 = 800$ MPa

$$\text{Lifetime} = \frac{1}{4.2\times10^{-4}} = 2400 \text{ months} = 200 \text{ years}$$

Clearly with the lifetime dominated by the higher loading this will be significantly inaccurate, with the coarse sampling.

(e)

N_T = total number of cycles

$N = N_T \phi(S)\, dS$

Failure when $1 = \sum \frac{N}{N_f}$

$$\Rightarrow 1 = N_T \int_0^\infty \frac{\phi(S)\, dS}{N_f(S)} = N_T \int_0^\infty \frac{\frac{1}{\bar{S}} \exp\left(\frac{-S}{\bar{S}}\right) dS}{(S/S_0)^{-m}}$$

Put $x = S/\bar{S} \Rightarrow dx = \frac{1}{\bar{S}} dS$

$$1 = N_T \int_0^\infty \frac{1}{\bar{S}} (S_0)^{-m} \exp(-x) \frac{(1/\bar{S})^{-m}}{(S/\bar{S})^{-m}} \bar{S}\, dx$$

$$1 = N_T \left(\frac{S_0}{\bar{S}}\right)^{-m} \int_0^\infty \exp(-x)\, x^m\, dx = N_T \left(\frac{S_0}{\bar{S}}\right)(m!)$$

For $\bar{S} = 50$ MPa, $S_0 = 800$ MPa, $m = 15$

$$N_T = \frac{1}{15!} \left(\frac{50}{800}\right)^{-15} = 880{,}000$$

Lifetime = 25 months = 2 years

This predicted lifetime is much smaller because of the presence of higher stress loading in the fitted function. Also the coarse tabular data will have underestimated the effect of the higher stresses.

For example for $S = 500\text{-}600$ MPa, $\phi dS = 3.3 \times 10^{-5}$ $N = 33$ cycles/month

$N_f = 276$ (not high cycle fatigue)

$N/N_f = 0.12$ so much more impact than the value of 4.2×10^{-4} for $S = 200\text{-}300$ MPa

In practice avoid loading with the 'tail' of the distribution.

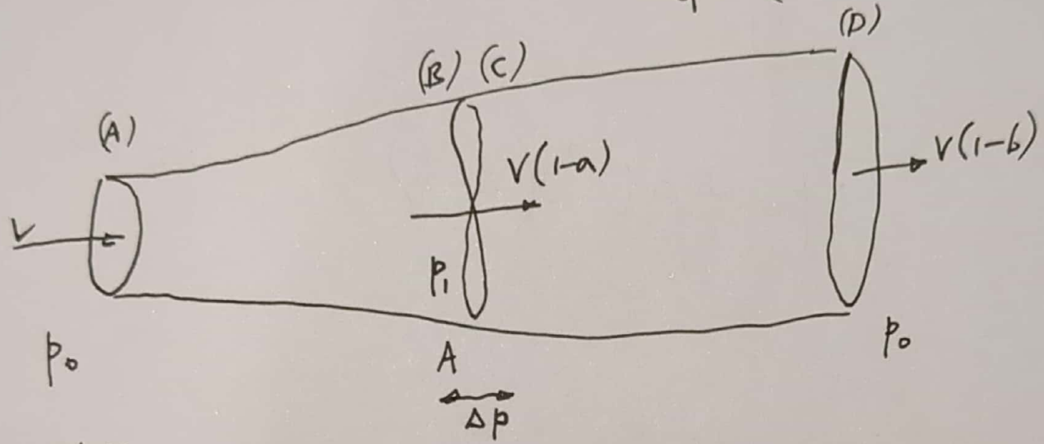
2(a) to get marks you need the three *'s

* Continuity (mass flow) $\dot{m} = \rho A V(1-a)$ ①

* Bernouilli (A) → (B) $p_0 + \frac{1}{2}\rho V^2 = p_1 + \frac{1}{2}\rho V^2(1-a)^2$

(D) → (C) $p_0 + \frac{1}{2}\rho V^2(1-b)^2 = p_1 - \Delta p + \frac{1}{2}\rho V^2(1-a)^2$

$\therefore \quad \frac{1}{2}\rho V^2(1-(1-b)^2) = \Delta p = \frac{1}{2}\rho V^2 b(2-b)$ ②



*Momentum

$\Delta p A = \dot{m} V - \dot{m} V(1-b) = \dot{m} V b$ ③

③ & ① → $\Delta p A = \rho A V^2 b(1-a)$

$\therefore \Delta p = \rho V^2 b(1-a)$

and with ② → $\frac{1}{2}\rho V^2 b(2-b) = \rho V^2 b(1-a)$

$\therefore 2-b = 2(1-a) \quad \therefore \boxed{b = 2a}$

$\therefore \boxed{\Delta p = 2\rho V^2 a(1-a)}$

Power = Force × velocity $= \Delta p A V(1-a) = 2\rho V^3 A a(1-a)^2$

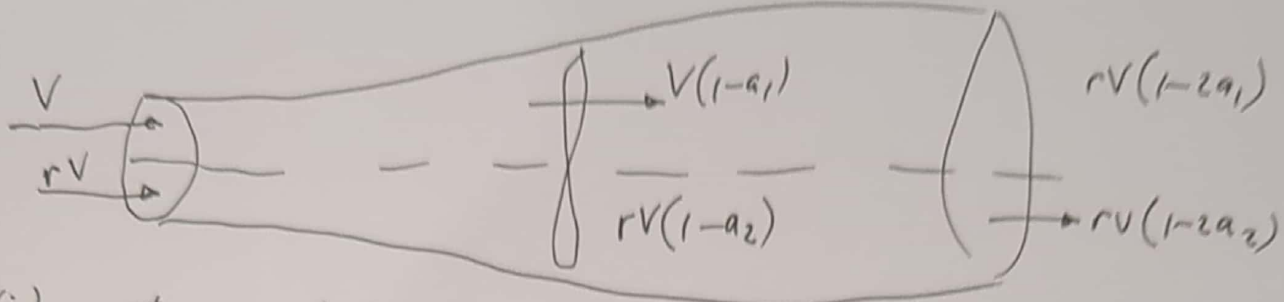
"Ideal" power $= \frac{1}{2}\rho V^3 A$

$C_p = \frac{2\rho V^3 A a(1-a)^2}{\frac{1}{2}\rho V^3 A} = 4a(1-a)^2$

Max C_p ∴ $\frac{dC_p}{da} = 0 \quad \therefore (1-a)^2 - a\,2(1-a) = 0$

$\therefore 1-a = 2a \quad \therefore a = \frac{1}{3}$

Betz limit $C_p(a=\frac{1}{3}) = \frac{16}{27}$



(i) There can't be a pressure difference across the flat central plane – streamlines are parallel.

(ii) Using result in (a)(ii) above for each half

$$\Delta p = 2\rho a_1(1-a_1)V^2 = 2\rho a_2(1-a_2)r^2V^2$$

and with $a_2 = \frac{1}{3}$ (Betz in lower half)

$$\therefore \quad a_1(1-a_1) = \frac{2}{9}r^2$$

$$\therefore \quad a_1^2 - a_1 + \frac{2r^2}{9} = 0$$

$r=1 \quad \therefore \quad a_1 = \text{"}\frac{-b \pm \sqrt{b^2-4ac}}{2a}\text{"} = \frac{1 \pm \sqrt{1-\frac{8}{9}}}{2}$

$$= \frac{1 \pm \frac{1}{3}}{2} = \frac{1}{3}, \frac{2}{3}$$

a_1 can't be greater than $\frac{1}{2}$ because then $b_1 > 1$ $\therefore$ flow reverses. So take $a_1 = \frac{1}{3}$

As expected, whole turbine is at Betz limit

(iii) $r = \frac{2}{3} \quad \therefore a_1 = \frac{1 \pm \sqrt{1 - \frac{4\times 2}{9}\left(\frac{2}{3}\right)^2}}{2} = \frac{1 \pm \sqrt{1-\frac{32}{81}}}{2} = \frac{1 \pm \frac{7}{9}}{2}$

$$= \frac{1}{9} \text{ or } ~~\frac{8}{9}~~$$

$$\therefore a_1 = \frac{1}{9} = 0.111$$

(iv) Power $= \Delta p \frac{A}{2}\left((1-a_1)V + (1-a_2)rV\right) = \Delta p \frac{AV}{2}\left((1-a_1)+r(1-a_2)\right) = \rho A V^2 a_1(1-a_1)\left((1-a_1)+r(1-a_2)\right)$

"Ideal" Power $= \frac{1}{2}\rho V^3 \frac{A}{2} + \frac{1}{2}\rho (rV)^3 \frac{A}{2} = \frac{1}{4}\rho V^3 A(1+r^3)$

$\therefore$ "C_p" $=$ ~~$4a_1(1-a_1)(1+$~~ $\frac{4\left[a_1(1-a_1)^2 + a_2(1-a_2)^2 r^2\right]}{1+r^3}$

and for $a_1 = \frac{1}{9}$, $a_2 = \frac{1}{3}$, $r = \frac{2}{3}$

$C_p = 0.4741$ not bad.

Elective crib (HRS)

Q?

(a) (i) Average power = 0.33 x 300 = 100MW. Power density = 100/50 = 2 MW/km^2 (or 2 W/m^2)

Assume size of square turbine array is L x L; each turbine occupies an area L^2. Hence the power density is $2/L^2$ MW/km^2, and hence L = 1km. This is 10x the blade diameter.

The air flow through turbines causes greater interference with the performance of those directly downstream, so with a prevailing wind direction, the spacing is larger parallel to the prevailing wind, and closer in the direction perpendicular to the prevailing wind.

(ii) Average power per panel = 0.15 x 350W = 52.5W. Ground area per panel = (2 x 1) x 3 = $6m^2$, so solar farm power density = 52.5/6 = 8.75 W/m^2. So for the site as a whole, power density = 2 + 8.75 $\approx$ 11 W/m^2.

The nuclear power station has a power density of 2 GW/km^2 = 2000 W/m^2, around 200 times greater. The implication is that large areas of land are needed for wind or solar, to provide the equivalent power output.

(iii) Concrete – large quantity of buried concrete at the base cannot be recycled, or economically removed: left where it is as in-situ landfill.

Steel – the towers are readily recovered as scrap, for recycling – the energy and cost penalties of transport and re-melting being competitive compared to production of virgin steel.

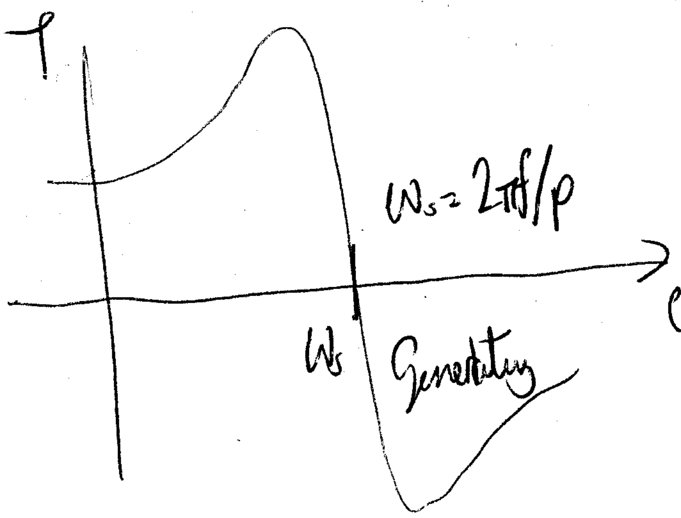
CFRP – the blade material is based on thermosetting resins and carbon fibres, so the only options are burning for energy (with undesirable emission) or landfill.

Neodymium – used in the permanent magnets of the power generating unit. This is a ‘critical material’, i.e. demand is growing and is high as a fraction of known reserves, plus the world supply is dominated by China. It is therefore essential to recover the magnet materials for re-processing/re-use.

b) Optimal power coefficient is only achieved at optimal tip-speed ratio, so $\omega \propto v$ for maximum power extraction.

Doubly-fed induction generators feed slip-frequency currents into the rotor, and enable the torque-speed curve to be shifted so that zero torque occurs over a range of speeds. It mimics rotor resistance control, but allows the power to be recovered rather than wasted. [2]

c)



Steepness of torque-speed curve means that generator speed varies very little with torque in the safe range of operation, hence essentially fixed speed. [2]

d) (i) $\omega_r \approx \omega_s$ since operation will be on the steep part of the torque-speed characteristic.

$\omega_r = \omega_s = \frac{2\pi f}{p} = \frac{100\pi}{15} = \underline{20.9 \text{ rad s}^{-1}}$ (= 200 rpm)

$T\omega_r = P$ so $T = -1\times10^6/20.9 = \underline{-47.7 \text{ kNm}}$

Use $T \approx \frac{3V_s^2 s}{R_2'\omega_s} \Rightarrow -47.7\times10^3 = \frac{3\times\left(\frac{3300}{\sqrt{3}}\right)^2 s}{0.3\times 20.9}$ so $\underline{s = -0.0275}$

$$\bar{I} = \frac{3300/\sqrt{3}}{\left(0.4 + \frac{0.3}{-0.0275}\right) + j2} = \frac{1905}{-10.52 + j2} = \underline{177.9\angle -169^\circ \text{ A}}$$ [4]

ii) $P_{loss} = 3I^2(R_1 + R_2') = \underline{66.5 \text{ kW}}$ so $P_{out} = P_{in} - P_{loss} = 1 \text{ MW} - 66.5 \text{ kW}$

$= \underline{933.5 \text{ kW}}$ $\quad \eta = \frac{P_{out}}{P_{in}} = \underline{93.4\%}$ [3]

iii) Gearbox ratio $= \frac{n_g}{n_t} = \frac{200}{10} = \underline{20:1}$

$\lambda = \omega R / v \Rightarrow 5 = \frac{\left(10 \times \frac{2\pi}{60}\right) \times 43}{v} \Rightarrow v = ~~5.6~~$ 9.0 ms^{-1} [2]

2024 2P8 Section D

Section D, Q1

(a)

$$T_{02} = T_a(1+0.5(\gamma-1)M^2) = 216.7(1+0.5\times0.4\times0.82^2) = 245.8 \text{ K}$$

$$p_{02} = p_a(T_{02}/T_a)^{\gamma/(\gamma-1)} = 19400(245.8/217.6)^{\gamma/(\gamma-1)} = 30171 \text{ Pa}$$

$$p_{04} = p_{03} = p_{02}\times45 = 1358 \text{ kPa}$$

$$\frac{\dot{m}\sqrt{c_pT_{04}}}{Ap_{04}} = \frac{\gamma}{\sqrt{\gamma-1}}M_4\left(1+0.5(\gamma-1)M_4^2\right)^{(-0.5(\gamma+1)/(\gamma-1))} = 0.629$$

$$A_4 = (\dot{m}\sqrt{c_pT_{04}})/(0.629p_{04}) = 250\times\sqrt{1004.5\times1300}/(0.629\times1358000) = 0.334 \text{ m}^2$$

(b)

$$T_{03s} = T_{02}\times45^{(\gamma-1)/\gamma} = 729.5 \text{ K}$$

$$T_{03} = T_{02}+(T_{03s}-T_{02})/\eta = 245.8+(729.5-245.8)/0.9 = 783.2 \text{ K}$$

$$T_{05} = T_{04}-(T_{03}-T_{02}) = 1300-(783.2-245.8) = 762.6 \text{ K}$$

$$T_{05s} = T_{04}-(T_{04}-T_{05})/\eta = 1300-(1300-762.6)/0.9 = 702.9 \text{ K}$$

$$p_{05} = p_{04}(T_{05s}/T_{04})^{\gamma}/(\gamma-1) = 1358000\times(702.9/1300)^{\gamma}/(\gamma-1) = 157.8 \text{ kPa}$$

$$\frac{\dot{m}\sqrt{c_pT_{05}}}{Ap_{05}} = \frac{\gamma}{\sqrt{\gamma-1}}M_5\left(1+0.5(\gamma-1)M_5^2\right)^{(-0.5(\gamma+1)/(\gamma-1))} = 0.956$$

$$A_5 = (\dot{m}\sqrt{c_pT_{05}})/(0.956p_{05}) = 250\times\sqrt{1004.5\times762.6}/(0.956\times157800) = 1.748 \text{ m}^2$$

(c)

$$h_4 = A_4/(2\pi r_{mid}) = 0.334/(2\pi\times0.6) = 0.085 \text{ m}$$

$$h_5 = A_5/(2\pi r_{mid}) = 1.748/(2\pi\times0.6) = 0.463 \text{ m}$$

The increase in blade height, at the same mid-height radius, is due to the reduction in density of the air as it flows through the turbine.

(d) We assume the engine is at the same non-dimensional operating point at sea level and in flight.

$$\frac{N_{sl}}{\sqrt{\gamma RT_{02,sl}}} = \frac{N_f}{\sqrt{\gamma RT_{02,fl}}}$$

$$N_f = 7400\times\sqrt{(}245.8/288.15) = 6835 \text{ rpm}$$

(e) This blade row is turning the flow toward axial and so is like a stator blade in a compressor. As the flow is turned from tangential to axial, the flow area increases and so the pressure rises. This makes the blade surface boundary layers more likely to separate. To prevent this, sufficient blades must be used and the blades carefully designed.

Section D, Q2

(a)

$$\eta_p = \frac{\text{Power to aircraft}}{\text{change in KE of air through engine}}$$

$$\eta_p = \frac{2VF_N}{\dot{m}_a(V_j^2 - V^2)} = \frac{2V\dot{m}_a(V_j - V)}{\dot{m}_a(V_j^2 - V^2)} = \frac{2V}{V + V_j}$$

(b) Equal core and bypass jet velocities will reduce mixing losses between the two streams.

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

$$V_j = 2V/\eta_p - V = 380.6\ \text{ms}^{-1}$$

(c)

$$\Delta T^b_{0\text{fan}} = \frac{V_j^2 - V^2}{2c_p\eta_f} = (380.6^2 - 253.8^2)/(2c_p \times 0.9) = 44.5\ \text{K}$$

(d)

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

$$T_{023s} = T_{02} \times 1.3^{(\gamma-1)/\gamma} = 268.1\ \text{K}$$

$$T_{023} = T_{02} + (T_{023s} - T_{02})/0.9 = 270.3\ \text{K}$$

$$\Delta T^c_{0\text{fan}} = T_{023} - T_{02} = 21.5\ \text{K}$$

Energy balance for LP shaft:

$$\Delta T_{0\text{LPT}} = \Delta T^c_{0\text{fan}} + \text{BPR} \times \Delta T^b_{0\text{fan}}$$

$$\Delta T_{0\text{LPT}} = 21.5 + 7 \times 44.5 = 333.2\ \text{K}$$

$$w_{x,\text{LPT}} = c_p \Delta T_{0\text{LPT}} = 334.7\ \text{kJ kg}^{-1}$$

(e) Reducing fan pressure ratio will reduce the bypass jet velocity. From the T-s diagram, as fan efficiency approaches 1, we have:

$$V_j^2/(2c_p) = V^2/(2c_p) + w_{x,\text{fan}}/c_p$$

Reducing V_j will increase propulsive efficiency. For the same thrust, we will need more bypass mass flow, hence a higher bypass ratio. Increasing bypass ratio has disadvantages such as: increased nacelle drag, increased weight (for same core size), increased fan tip speed, possible ground clearance challenges for the engine under the wing.

Section D, Q3

(a)

$$p_{a1} = m_1 g/(0.5 C_L A M^2 \gamma) = 1700000 \times 9.81/(0.5 \times 0.5 \times 350 \times 0.85^2 \times 1.4) = 18843 \text{ Pa}$$

$$p_{a1}/p_{sl} = 18843/101325 = 0.1860$$

Interpolating in databook table, altitude = 12197 m

(b) Steady, level flight. Constant M, hence constant V at fixed T_a (tropopause). L/D constant.

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

$dt = ds/V$, so,

$$dm/ds = -\text{sfc}\, mg/(VL/D)$$

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

$$\ln(m_2/m_1) = -\text{sfc}\, g/(VL/D)\, s$$

$$s = (VL/D)/(\text{sfc}\, g)\ln(m_1/m_2)$$

(c)

$$\text{overall efficiency} = \frac{\text{power to aircraft}}{\text{rate of heat supply from fuel}}$$

$$\eta_{ov} = \frac{VF_N}{\dot{m}_f \,\text{LCV}} = \frac{V}{\text{sfc}\,\text{LCV}}$$

$$s = \eta_{ov}\,\text{LCV}\,(L/D)/g \ln(m_1/m_2)$$

Assume all fuel is used in cruise, so $m_1 = m_e + m_p + m_f$ and $m_2 = m_e + m_p$.

$$s = \eta_{ov}\,\text{LCV}\,(L/D)/g \ln(1 + m_f/(m_e + m_p))$$

$$m_f = (m_e + m_p)\left[\exp\left(\frac{sg}{\eta_{ov}\,\text{LCV}\, L/D}\right) - 1\right]$$

(d)

$$m_f/(m_1 - m_f) = \exp\left(\frac{sg}{\eta_{ov}\,\text{LCV}\, L/D}\right) - 1 = A$$

$$A = \exp(8000 \times 10^3 \times g/(0.42 \times 43 \times 10^6 \times 20)) - 1 = 0.2427$$

$$m_f = m_1 A/(1+A) = 170 \times 10^3 \times 0.2427/1.2427 = 33.2 \text{ tonnes}$$

$$p_{a2} = (m_1 - m_f)g/(0.5 C_L A M^2 \gamma) = (170 - 33.2) \times 10^3 \times 9.81/(0.5 \times 0.5 \times 350 \times 0.85^2 \times 1.4) = 15162 \text{ Pa}$$

$$p_{a1}/p_{sl} = 15162/101325 = 0.1496$$

Interpolating in databook table, altitude = 13588 m

(e) Hydrogen has a greater LCV than conventional aviation fuel. For the same energy transfer from the fuel, the mass of hydrogen required is less than the mass of conventional aviation fuel, so the increase in altitude during cruise will also be reduced. The energy density (kJ released in combustion per unit volume of fuel) is 4 times larger for conventional aviation fuel than for liquid hydrogen, so more volume is required for fuel tanks. If ‘retrofitting’ liquid hydrogen to an existing aircraft, the increase in fuel volume is likely to reduce the volume available for payload, and hence reduce m_p. The cryogenic tanks required are heavier than conventional tanks, so m_e will increase.

1 (a) All matter has a wavefunction that must satisfy the Schrodinger equation and which becomes significant when the physical size of the system that the particle is in is of the order of the wavelength. As the wavefunction must exist, it must have an energy that is non-zero. The lowest energy is called the ground state.

(b) $\psi(x) = A_0 \exp\left(\frac{-\alpha^2 x^2}{2}\right)$ where $\alpha^2 = \frac{cm}{\hbar^2}$

$$\therefore \frac{\partial \psi}{\partial x} = -A_0 \alpha^2 x \exp\left(-\frac{\alpha^2 x^2}{2}\right) = -\alpha^2 x \psi$$

$$\frac{\partial^2 \psi}{\partial x^2} = A_0 \alpha^2 (\alpha^2 x^2 - 1) \exp\left(\frac{-\alpha^2 x^2}{2}\right) = \alpha^2(\alpha^2 x^2 - 1)\psi$$

$$\therefore E\psi = \frac{-\hbar^2}{2m} \frac{\partial^2 \psi}{\partial x^2} + V\psi$$

$$E\psi = \frac{-\hbar^2}{2m} \alpha^2 (\alpha^2 x^2 - 1)\psi + \frac{cx^2}{2}\psi$$

$$E = \left(\frac{c}{2} - \frac{\hbar^2 \alpha^4}{2m}\right)x^2 + \frac{\hbar^2 \alpha^2}{2m}$$

E is a simple number, so

$$\frac{c}{2} = \frac{\hbar^2 \alpha^4}{2m}$$

$$\therefore \alpha^2 = \frac{\sqrt{cm}}{\hbar} \Rightarrow \underline{\text{valid solution}}$$

(c) $E = \frac{\hbar^2 \kappa^2}{2m} = \frac{\hbar^2 \sqrt{cm}}{2m\hbar} = \frac{\hbar}{2}\sqrt{\frac{c}{m}}$

$$= \frac{1.054 \times 10^{-34}}{2} \cdot \sqrt{\frac{3}{9.109 \times 10^{-31}}}$$

$$E = 9.56 \times 10^{-20}\,\text{J}$$

$$\underline{E = 0.60\,\text{eV}}$$

$$\int_{-\infty}^{\infty} A_0^2 \exp\left(\frac{-\alpha^2 x^2}{2\omega}\right) dx = 1$$

Standard integral $\int_{-\infty}^{\infty} \exp(-ax^2)dx = \sqrt{\frac{\pi}{a}}$

$$\therefore \int_{-\infty}^{\infty} A_0^2 \exp(-\alpha^2 x^2)dx = A_0^2 \sqrt{\frac{\pi}{\alpha^2}} = 1$$

$$A_0^2 = \frac{\alpha}{\sqrt{\pi}}$$

$$= \frac{1}{\hbar}\sqrt{\frac{CM}{\pi}}$$

$$= \frac{1}{1.054 \times 10^{-34}} \cdot \sqrt{\frac{3 . 9.109 \times 10^{-31}}{\pi}}$$

$$A_0^2 = 9.41 \times 10^{24}$$

2 a. ~~TFT~~ AMLCD:

TFT is used to charge the LC to the voltage on the data line ~~& the gates~~ and then to prevent charge leakage back to the data line. It requires a very low off-state current so high off-state resistance. Only low currents in on state, so no need for high μ or high W/L.

AMOLED:

OLED TFT is used to control the current through the OLED and hence the brightness of the pixel. It needs a high current capability so high μ and W/L is needed. The other TFT programs the gate of the first TFT to get the right drive current. Only charging a capacitor so low μ and W/L.

b.

$$I_{DS} = \mu \frac{W}{L} C_{ox} \left[(V_{gs} - V_T) V_{ds} - \frac{V_{ds}^2}{2} \right]$$

If $V_{ds} \ll V_{gs} - V_T$

$$I_{DS} = \mu \frac{W}{L} C_{ox} \, (V_{gs} - V_T) V_{ds}$$

$$V_{DS} = \frac{I_{DS} L}{\mu W (V_{gs} - V_T) C_{ox}}$$

$$\therefore \frac{\partial V_{DS}}{\partial I_{DS}} = R_{TFT} = \frac{1}{\mu (W/L) C_{ox} (V_{gs} - V_T)}$$

$$\frac{W}{L} = \frac{1}{\mu R_{TFT} C_{ox} (V_{gs} - V_T)}$$

$\tau = RC \quad \therefore$

$$R_{TFT} = \frac{3\tau}{C} = \frac{10 \times 10^{-6}}{0.2 \times 10^{-12}}$$

$$\underline{R_{TFT} = 5 \times 10^{7} \, \Omega}$$

$$\frac{W}{L} = \frac{1}{0.8 \times 10^{-4} \cdot 5 \times 10^{7} \cdot 350 \times 10^{-6} \cdot 2.8}$$

$$\underline{\frac{W}{L} = 3.92}$$

c In saturation $V_{ds} = V_{gs} - V_T$

$$\therefore \quad I_{DS} = \mu \frac{W}{L} \frac{C_{ox}}{2} (V_{gs} - V_T)^2$$

~~= 70~~

$$\frac{W}{L} = \frac{2 I_{DS}}{\mu C_{ox} (V_{gs} - V_T)^2}$$

$$= \frac{2 \cdot 1 \times 10^{-6}}{10 \times 10^{-4} \cdot 800 \times 10^{-6} \cdot (1.5)^2}$$

$$\frac{W}{L} = 1.1$$

3 a The three requirements are that the system must

i) exist stably in one of two states

ii) be able to be switched between the two states.

iii) have a measurable difference between the states.

Ferromagnets have magnetic domains where dipoles are all aligned. Futhermore, there are specific 'easy directions' related to the crystal structure where the alignment is in a particularly low energy state. A thin film ferromagnet can be expected to have two specific easy directions. Switching can be achieved through the application of a external field. The direction can also be externally measured as there is a flux leaving the film.

b

$$\tau_n = \tau_0 \exp\left(\frac{Kv}{kT}\right)$$

$$\ln\left(\frac{\tau_n}{\tau_0}\right) = \frac{Kv}{kT}$$

$$K = \frac{kT}{v}\ln\left(\frac{\tau_n}{\tau_0}\right)$$

1.6×10^{15} bits m^{-2} means 1 bit occupies $6.25\times10^{-16}\ m^2$

Hence for a 50nm thick film the volume is

$3.125\times10^{-23}\ m^3$

$$\therefore\ K \geq \frac{1.381\times10^{-23}\cdot 298}{3.125\times10^{-23}}\ln\left(\frac{10\times365.25\times24\times60\times60}{1\times10^{-9}}\right)$$

$\underline{K \geq 5.3\ kJ\ m^{-3}}$

c Sputtering would be best. Need to control the rf power and Ar gas pressure in the process.

d. The seed layer controls the grain orientation of the sputtered alloy and so hence the easy direction.

e. An insulating, thin tunneling layer is sandwiched between two ferromagnetic layers. The field from the disk significantly alters the tunneling current allowing the absolute B-field to be measured rather than the change in B-field for the inductive system.

2P8: Computer Vision

2024 Question Crib Sheet

1. (a) We reduce noise in each image by smoothing with a Gaussian kernel:
   - $S(x,y) = G_\sigma(x,y) * I(x,y) = \int_{-\infty}^{\infty} G_\sigma(u,v) I(x-u, y-v) du dv$
   - Here, the Gaussian kernel is $G_\sigma(x,y) = \frac{1}{2\pi\sigma^2}\exp\left(-\frac{x^2+y^2}{2\sigma^2}\right)$
   - To implement this on a computer, we use truncated summations:

   $$S(x,y) = \sum_{u=-n}^{n}\sum_{v=-n}^{n} G_\sigma(u,v) I(x-u, y-v)$$

   - A popular heuristic is to truncate the Gaussian kernel so that discarded samples are less than $1/1000^{th}$ of the peak value, so that, for example, for a $\sigma = 3$ Gaussian, the kernel size is 23.
   - A further efficiency gain comes from decomposing a 2D convolution into two applications of a 1D convolution by exploiting the separability of the Gaussian:

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

   For a 2D kernel of size $(2n+1)^2$, this gives a computational saving of $\frac{(2n+1)}{2(2n+1)}$.

   (b) i. **Invariance:** A feature is *invariant* to a given transformation if the feature is unchanged when the transformation is applied to its input. Mathematically, for some input signal $\mathbf{x}$, a feature f is invariant to a transformation g if $f(\mathbf{x}) = f(g(\mathbf{x}))$
   Distinctiveness: A feature is *distinctive* with respect to some transformation if the feature *does change* when the transformation is applied to its input. Mathematically, for some input signal $\mathbf{x}$, a feature f is distinctive to a transformation g (where g is not the identity mapping) if $f(\mathbf{x}) \neq f(g(\mathbf{x}))$
   There is a tension between invariance and distinctiveness because they are opposing properties. In the context of feature matching, we aim to create keypoints and descriptors that are invariant to *nuisance factors* (such as change of viewpoint, illumination) and distinctive to the unique characteristics of a particular visual feature (such as its shape).

   ii. Scale.

   iii. **Overview of SIFT keypoint detection.** SIFT keypoints provide location, scale and orientation invariance by explicitly estimating these parameters—each keypoint is associated with a particular location (x, y coordinates), scale and orientation.
   - Locations and scales that correspond to the greatest *local* response to a scale-normalised Laplacian of Gaussian filter define the location (blob centre position) and scale ("characteristic scale") of keypoints.
   - To identify the location and characteristic scale, we construct a "scale space" for the image (a 3D function of intensity over location and scale, defined via $S(x,y,\sigma) = G(x, y\sigma) * I(x,y)$, where $G(x,y,\sigma) = \frac{1}{2\pi\sigma^2}\exp\left(-\frac{(x+y)^2}{2\sigma^2}\right)$).
   - Construction of a full scale space would be expensive in computation (many convolutions) and memory (many images to store), so we use multiple techniques to reduce cost.
   - **Sparse sampling:** We use a discrete set of low-pass filtered images with logarithmically-spaced scales $\sigma_i = 2^{i/s}\sigma_0$.
   - **Image pyramids:** Each time the scale doubles (one full octave) in scale space, we subsample the image by a factor of 2 (Nyquist's theorem assures that this will avoid aliasing). Blurring smaller images involves smaller kernels and processes fewer pixels.

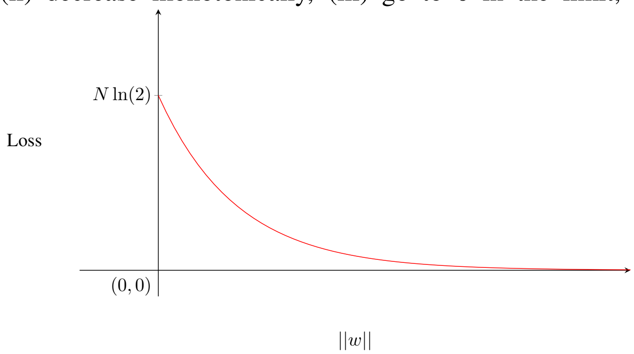
- **Incremental blurs:** Gaussian blurring can be done incrementally by exploiting the *reproducing property of the Gaussian* $G(\sigma_1) * G(\sigma_2) = G(\sqrt{\sigma_1^2 + \sigma_2^2})$. This enables the use of small kernels that can be re-used each octave.
- **Difference of Gaussians:** We can efficiently approximate the Laplacian of Gaussian response with the difference of Gaussians, via the relation $G(x, y, k\sigma) - G(x, y\sigma) \approx (k-1)\sigma^2\nabla^2 G(x, y, \sigma)$. This allows us to estimate the LoG response by subtracting neighbouring layers of the image pyramid.
- Finally, we identity keypoints by finding local extrema via a local search over the 26 neighbour responses of each point.
- Keypoint orientations are calculated by computing histograms of oriented gradients at the corresponding scale of the pyramid. Specifically, we build a histogram with 36 bins (covering 360 degrees) of edge orientations weighted by gradient magnitudes in the neighbourhood of the keypoint. This is smoothed by a 2D Gaussian of size 1.5σ scale for the keypoint. The highest peak in the histogram provides the dominant orientation (refined through interpolation by fitting a parabola to the values of the bin and its two neighbours).
- If there is no clear maximum orientation, the keypoint is given several dominant orientations (several copies of the keypoint with different orientations are used).

(c) i. (1) **Partial occlusions** (for instance, caused by a pedestrian stepping in front of the camera or a bird flying past).
(2) **A small change in 3D viewpoint** (since the photographer is using a hand-held camera, the 3D viewpoint will not be identical between the images).
(3) **Change in overall lighting contrast** (for instance, caused by a change in the depth/number of clouds blocking the sun between the first and second photograph).
(4) **Bright glare/specular highlights** (for instance, as the sun moves out from behind any clouds, these could appear on glass/metalic window components).

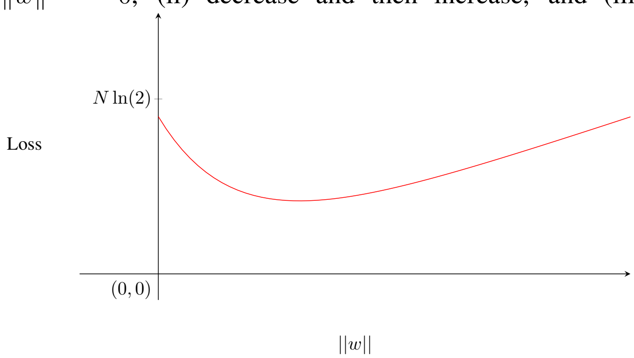
ii. (1) When computing the SIFT descriptor, the orientation histograms are weighted by a Gaussian window with a σ corresponding to 0.5 times the scale of the keypoint at the centre of the patch. This assigns higher weight to inner pixels (those closer to the keypoint) to minimise the influence of partial occlusions.
(2) By dividing the descriptor patch into cells, gradients can move around by a small amount within the descriptor window and still contribute to the same directional histogram. This contributes a small degree of 3D viewpoint invariance.
(3) The descriptor vector is L2 normalised to provide invariance to gradient magnitude change (and thus provides some invariance to contrast changes).
(4) Values are truncated (all values in the unit vector are truncated to 0.2) and then renormalised to minimise the effects of non-affine lighting changes, such as those coming from strong specular highlights.

iii. To find a strong match, we want to find a feature in our database that is a *uniquely* good fit for the query feature (rather than many features that lie close to the query features, which might be the case if the query feature is highly generic and lacks any uniquely identifying characteristics). This can be achieved by ensuring that the nearest neighbour is "significantly nearer" than the second nearest neighbour. In practice, this is achieved by comparing the ratio of the two distances and assessing if the ratio is less than a threshold (set as a hyperparameter, typically to 0.7).

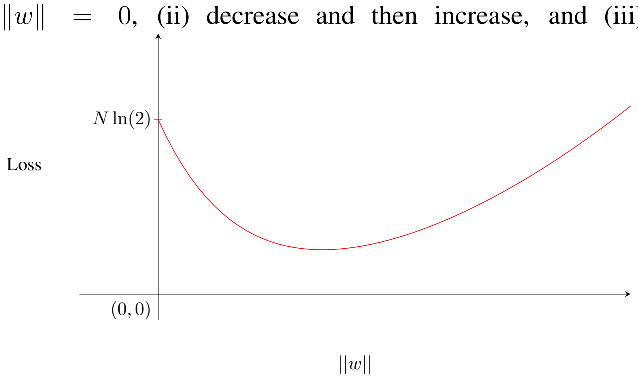
1. (a) For full marks, the plot must: (i) show the correct value for $\|w\| = 0$, (ii) decrease monotonically, (iii) go to 0 in the limit, and (iv) be concave up.



(b) The loss approaches $k\|w\|$ as $\|w\| \to \infty$, since the limiting behaviour of the negative log-likelihood is linear for incorrectly classified examples, and the negative log-likelihood on the correctly classified examples goes to 0. For full marks, the plot must: (i) show the correct value for $\|w\| = 0$, (ii) decrease and then increase, and (iii) increase unboundedly.



(c) The loss approaches $\beta\|w\|^2$ as $\|w\| \to \infty$, since the log-likelihood term goes to 0. For full marks, the plot must: (i) show the correct value for $\|w\| = 0$, (ii) decrease and then increase, and (iii) increase unboundedly.



(d) The first plot shows that learning might set the weights to very large values if all of the training examples can be predicted correctly (i.e. if the data is "linearly separable"). (i) The regularizer would prevent this from occurring, as demonstrated by the 3rd plot. (ii) This would reduce the confidence of the trained model's predictions. (iii) If the model predicts test examples incorrectly, the loss would go to infinity as $\|w\| \to \infty$ (as in the 2nd plot), since the log-likelihood penalizes confident, incorrect predictions; adding the regularizer ensures that training loss is not minimized as $\|w\| \to \infty$, even if the training data is linearly separable.

2. (a) (i) Local connectivity encodes the inductive bias that image features (such as edges) are likely to be composed of pixels that are near one another. (ii) Tied weights encode the inductive bias that similar features (again, such as edges) are likely to appear in different locations in the image. (iii) Pooling encodes the inductive bias that small differences in the position of features are unlikely to change the semantic content of an image.

   (b) (i) Local connectivity reduces the number of parameters per filter. (ii) Tied weights reduce the total number of filters (thus also reducing parameters). (iii) Pooling reduces the size of the output, thus reducing the computation needed to process it further in higher layers.

a) Q-learning : Initialise $Q(s,a) = 0$, all s,a

Pick s,a and set $Q(s,a) = r(s,a) + \gamma \max_{a'} Q(s',a')$

(ie learning rate = 1)

& then repeat with randomly chosen s,a

b) optimal policy is clearly to take action 1 in state 1 with reward $3(1+\gamma+\gamma^2+\dots) = \frac{3}{1-\gamma} = 30 = V^*(s_1)$

and action 2 in state 2 with reward

$V^*(s_2) = 0 + \gamma V^*(s_1) = 27$

$V^*(s_1) = 30 = \max(3 + 0.9 V^*(s_1), 2 + 0.9 V^*(s_2))$ ✓

$V^*(s_2) = 27 = \max(0 + 0.9 V^*(s_1), 1 + 0.9 V^*(s_2))$ ✓

$\Rightarrow$ optimal.

c) $s_1, a_1, 3$; $s_1, a_2, 2$; $s_2, a_1, 1$; $s_2, a_1, 1$ ... etc

d)

$Q(s_1,a_1) = 3 + 0 = 3$

$Q(s_1,a_2) = 2 + 0 = 2$

$Q(s_2,a_1) = 1 + 0 = 1$

$Q(s_2,a_1) = 1 + 0.9 \times 1 = 1.9$ etc

$\Rightarrow$ eventually $Q(s_2,a_1) = 10$

e)

a_1 greedy in s_1

a_1 greedy in s_2 $\Rightarrow$

$s_1, a_1, 3, s_1, a_1, 3$ etc

$\Rightarrow Q(s_1,a_1) \to 30$

f) Correctly finds optimal policy in state 1, but not state . ϵ-greedy action selection could allow s_2, a_1 to be explored.

SECTION G: ***Bioengineering***

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

1 (a) A spectral Optical Coherence Tomography (OCT) system designed for imaging the eye has a centre wavelength λ and bandwidth $\Delta\lambda$, and uses a linear array of 1000 photo-diodes.

(i) What range of λ would be appropriate for this task, and what are the consequences of using different values for λ? [3]

Answer: A sensible range of centre wavelengths would be about 500 nm to 1400 nm. Using a higher wavelength will increase the resolution slightly (but not so much as using a wider bandwidth), but it will also increase the amount of attenuation, which reduces the depth to which we can see, since some light has to return from a given depth to be able to image it.
Different anatomical structures also respond differently to different wavelengths of light, hence the features in an OCT image and also the contrast are affected by what wavelength is used. The optic nerve head is particularly visible at 500 nm, for instance.

(ii) Derive an approximate expression for the spacing of depth samples, in terms of λ and $\Delta\lambda$. Assume that the photo-diodes are set up to sample the reflected light appropriately, and that $\Delta\lambda \ll \lambda$. [5]

Answer: Depth samples are spaced at tc, where t is the sampling period and c is the speed of light in the tissue. So if Δd is the depth sample spacing, then:

$$\begin{aligned}
\Delta d &= tc \\
&= \frac{c}{\Delta F} \\
&= \frac{c}{\frac{c}{\lambda_{\text{min}}} - \frac{c}{\lambda_{\text{max}}}} \\
&= \frac{1}{\frac{1}{\lambda - \frac{1}{2}\Delta\lambda} - \frac{1}{\lambda + \frac{1}{2}\Delta\lambda}} \\
&= \frac{(\lambda + \frac{1}{2}\Delta\lambda)(\lambda - \frac{1}{2}\Delta\lambda)}{(\lambda + \frac{1}{2}\Delta\lambda) - (\lambda - \frac{1}{2}\Delta\lambda)} \\
&= \frac{\lambda^2 - \frac{\Delta\lambda^2}{4}}{\Delta\lambda} \\
&\approx \frac{\lambda^2}{\Delta\lambda}
\end{aligned}$$

(iii) What approximate bandwidth $\Delta\lambda$ should be used if it is required to image to a depth of 6 mm, and is this achievable? Presume a sensible choice for λ. [2]

Answer: There are 1000 photo-diodes, but we can usually only make use of half the total possible imaging depth since we need to use the inverse FFT but we only have half the information we need: i.e. only the real part of the samples, rather than the full complex signal. So the total depth d is:

$$d = \frac{1}{2} \times 1000 \times \frac{\lambda^2}{\Delta\lambda}$$

Re-arranging in terms of $\Delta\lambda$:

$$\Delta\lambda = 500 \times \frac{\lambda^2}{d} \qquad (1)$$

and evaluating with $d = 6\,\text{mm}$ and $\lambda = 600\,\text{nm}$, gives $\lambda \approx 30\,\text{nm}$. Alternatively, evaluating with $\lambda = 1200\,\text{nm}$, gives $\lambda \approx 120\,\text{nm}$. Both these values are within an achievable range of bandwidths.

(iv) What else affects the resolution of this system other than the photo-diode array? [2]

Answer: The various optical lenses have a strong affect on the radial resolution as well as a minor one on the depth resolution, dependent on how tightly they can focus the laser beam. Note that the light also has to pass through the lens within the eye as well, and this may well contain aberrations which also affect the resolution. Dividing the reflected light spectrum by the spectrum of the laser pulse will also improve the resolution, whilst making the system more sensitive to changes in pulse shape due to dispersion.

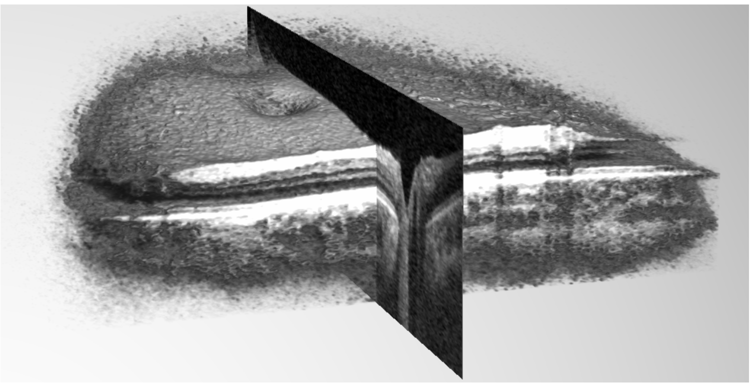


Fig. G.1

(b) Figure G.1 shows a visualisation of some OCT data.

(i) What anatomy is shown in the image and what are the approximate dimensions? Also name four different anatomical structures which are visible in this image and describe where you can see them. [3]

Answer: Unsurprisingly, this is an image of the back of the eye, or the Fundus. The whole data set is about 1 cm deep with about a 5 cm diameter, though the various retinal layers are only a few millimetres apart. Many structures are visible, for instance the small dimple at the top is the fovea, the optic disc and nerve is visible on the reslice image, the retina (upper layer), choroid (next layer down) and schlera (below that) are all visible, and it is also possible to see a few retinal blood vessels, although these are less clear.

(ii) Explain how this visualisation has been created from the image data. [6]

Answer: This image is a mixture of a volume rendering (most of the back of the eye) and either a reslice or one of the original sections through the data. It is clearly not a surface rendering, since the changes in intensity over the surface are not just consistent with the surface orientation, and towards the edge of the image it is clear that some parts are nearly transparent: for instance the reslice is partially visible through the volume rendering.
The volume rendering is created by tracing a ray through the data for each image pixel. Each data value is assigned a colour (here just an intensity level since it is a grey-scale image) and also a transparency value. The ray through this data accumulates light as if it is passing through material with that transparency and colour. In addition, any gradients in the data which are sufficiently high are rendered

as if they are surfaces, with appropriate lighting: this effect is apparent on the top surface of the fundus.

The reslice is created by interpolation from the original data, though it isn't possible to see from this image what interpolation might have been used. It is then displayed *in situ* in 3D as an opaque plane, with intensity purely determined by the original data.

It is also clear that some of the data must have been cropped out of the volume rendering, since the reslice extends beyond it. In fact there is a cropping plane orthogonal to the reslice, such that the front of the volume rendering looks a little bit like another reslice (though it is not: there are clear gaps in this plane).

(iii) Describe two imaging artefacts you can see in the image and explain how they arise. [4]

Answer: The volume rendering very obviously fades out at the edges, whereas the actual retina is spherical. This is partly because the imaging technique is tomographic, so it only records data on planes through the back of the eye. In addition, more light will have reached (and will be reflected from) the centre of the Fundus than the edges.

There should be more data at the bottom of this image, but the attenuation means that the light can't penetrate to that depth (the light is from the top in this visualisation), which leads to the choroidal layers apparently having little underneath them.

There is also shadowing visible at the cropped front edge of the volume rendering on the right-hand side, where overlying blood vessels or other features have reflected most of the light with the result that everything underneath is darker than it should be. These appear as several vertical dark streaks in the volume rendering.

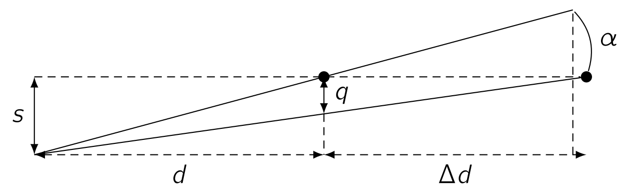
2 (a) Write short notes on the visual contrast sensitivity function, including how it can be measured experimentally using a two-alternative forced choice task. [4]

Answer: A 2AFC task can be used whereby in each trial, the subject is presented with a pair of visual stimuli: one is a grating with some spatial frequency f and contrast c, the other one is blank (zero contrast), and which one is which is fully randomised across trials. The subject is asked to tell which of the two stimuli has non-zero contrast. By varying c for fixed f, one can estimate the subject's psychometric function (percentage of correct answers as a function of c) and extract the detection threshold c_{thresh}. The contrast sensitivity function is $c_{\text{thresh}}(f)$, and has a U shape: low and high spatial frequencies are harder to detect (i.e. require greater contrast) than medium frequencies.

(b) Locusts see the world through a pair of compound eyes (Fig. G.2, on the next page; viewed from the top). The inter-ommatidial angle in the horizontal plane, α, is estimated to be 0.5° (vastly exaggerated in the figure for clarity), which is small. The horizontal separation between the forward-looking regions of the two eyes is $2s = 4$ mm.

(i) Suppose a small prey is located at a distance d from the eyes in the horizontal plane, such that it projects onto a single ommatidium. If the prey was located at a distance $d + \Delta d$, it would recruit the neighbouring ommatidium. Derive an expression for $\frac{\Delta d}{d}$ as a function of d, s and α. You may neglect the size of the eye relative to d, and use a small-angle approximation for α. What do you conclude about relative depth perception at long distances? [4]

Answer: Consider the following diagram:



Geometrically, by looking at the two similar triangles in the lower-right part of the diagram, we have $\frac{d+\Delta d}{d} = \frac{s}{s-q}$ such that $\frac{\Delta d}{d} = \frac{q}{s-q}$. Given that $\alpha \ll 1$, we have $q \approx d\alpha$ (with α measured in radians). Therefore, $\frac{\Delta d}{d} \approx \frac{\alpha d}{s-\alpha d} \approx \frac{\alpha d}{s}$. This quantity represents the relative precision of depth perception at distance d. We see that this grows linearly with depth, such that locusts have very poor depth perception at long distances.

(ii) Explain why, according to Fig. G.2 on the next page, locusts should in fact be unable to perceive *any* relative depth beyond a critical distance $d_{\max}$, and give the value of d_{max} to the nearest centimetre. [3]

Answer: Suppose an object is located sufficiently far that, if it were any more distant, it would hit the ommatidium pointing directly ahead. Beyond that point, it does not matter how much further the object is located, it will always recruit this front-facing ommatidium – in other words, nothing can be said about depth beyond that critical point. This occurs at $d_{\text{max}} \approx s/\alpha$ with α measured in radians. This gives a value $d_{\text{max}} \approx 23$ cm.

(iii) As it turns out, locusts are capable of accurately jumping onto small preys located up to a metre away. These jumps are mostly ballistic with little room for in-flight adjustments; therefore, locusts do in fact perceive depth accurately even at such distances. Indeed, just prior to jumping, locusts engage in a stereotypical behaviour called 'peering'. An example of peering is depicted in Fig. G.3 (on the next page: see in particular the time course of angles β and γ). In the diagram, B and H are fixed centres of rotation on the body and head respectively, and the two dashed lines are parallel. Explain by what principle 'peering' might enhance depth perception, and give a brief explanation of this principle. [4]

Answer: Peering is such that the body undergoes substantial rotations whilst the head remains front-facing – this means that the head undergoes sideways translation, thus engaging "motion parallax', a well-known principle of depth perception discussed in lectures. As the head moves sideways, just how fast the projection of the prey moves on the array of ommatidia depends directly on how far the prey is located. Thus, moving the head sideways allows locusts to garner additional information about prey depth.

(iv) Suppose you have access to a camera that can track the movements of a locust in real time, and that you can show this locust virtual preys anywhere on a horizontal monitor. Outline an experiment that could test your answer to (b)(iii). [4]

Answer: One could imagine displaying a prey at a distance $d > d_{\text{max}}$ (say 50 cm), dynamically tracking the peering behaviour of the locust in real time prior to the jump, and using these measurements to displace the prey congruently with the locust's head in such a way as to mimic the motion parallax that a prey at some other distance d' would produce. If this feedback loop biases the ensuing jump of the locust towards the prey located at d', then one would conclude that locusts do indeed use peering to engage motion parallax and obtain depth information.

(c) For each of the following optical solutions, name one animal whose eyes use it:

(i) negative lens; **Answer**: Eagle

(ii) reflective mirror; **Answer**: Scallop

(iii) three lenses in the same eye; **Answer**: Pontella (males)

(iv) an eye in which all the optical power is in the lens; **Answer**: Seal (or penguin)

(v) scanning telescope; and **Answer**: Copilia

(vi) more than ten lenses in the same eye. **Answer**: Any species with a compound eye (e.g. fly, or locust) [6]

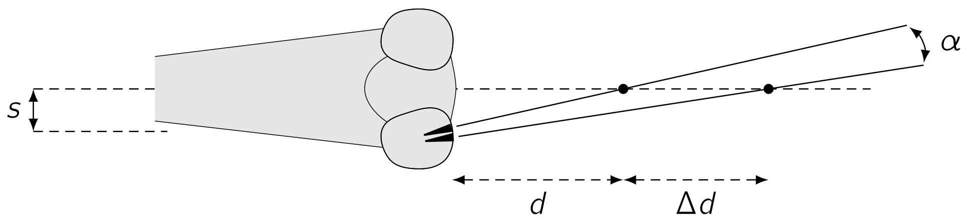


Fig. G.2

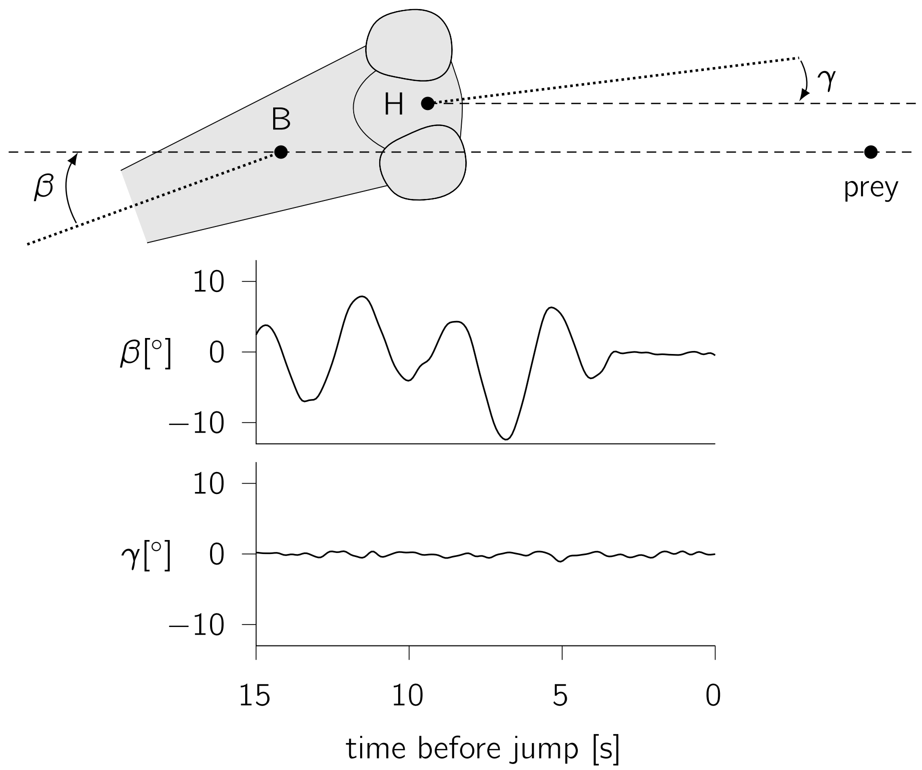


Fig. G.3

3 (a) (i) How is IntraOcular Pressure (IOP) regulated in the eye? [2]

Answer: IOP is controlled by the outflow of the aqueous humour through the trabecular mesh network, and perhaps through a mechanotransduction mechanism in which endothelial cells in the Schlemm's canal can sense shear stress.

(ii) Describe the clinical procedure for *Goldmann tonometry* in measuring IOP. [4]

Answer: Goldmann tonometry measures IOP indirectly by deformation of the cornea. The clinical procedure is as follows:

•anaesthetize cornea

•place head on cornea with force W

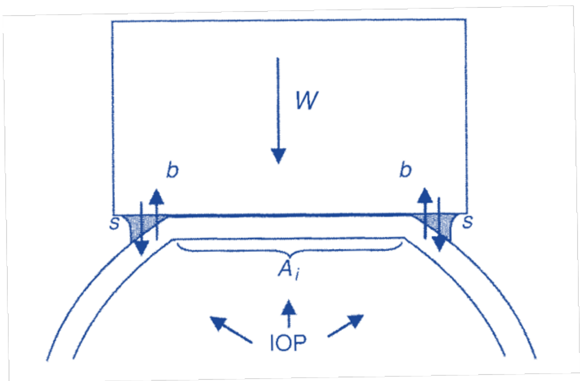
•flattened area A

•IOP = W/A

•correction needed for tear film and bending stresses

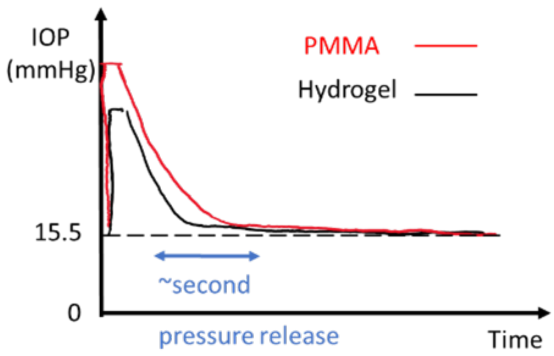
•empirically noted that these cancel out when A = 7.35 mm2

•further correction for abnormal corneal thickness.



(iii) How does the attachment of a contact lens to a normally-functioning eye change the eye's IOP? Use sketches to illustrate the change of IOP over time for a contact lens made of: I. hydrogel; and II. PolyMethyl MethAcrylate (PMMA). Label key features (e.g. approximate IOP values and time scales) and state your reasoning. [6]

Answer:



During the initial action of lens attachment, mechanical deformation is exerted to the eye (in a way like blinking and rubbing), and IOP is expected to rise above 20 mmHg. When the lens is in place in the eye, the total volume of the eye is slightly decreased (i.e. the front of the eyeball is slightly flattened). For a normal functioning eye, the eye's autoregulation mechanism will make the IOP go back to a set point of 15.5 mmHg. For the volume change needed to accommodate the contact lens (similar to what was calculated in one of the Examples questions), the IOP is expected to equilibrate in seconds. The use of different materials for the lens, e.g. hydrogel versus PMMA, will change the elevated IOP level during lens attachment and the times taken for IOP equilibration (as hydrogel is soft and deformable, and PMMA is stiff and non-deformable). However, the quasi-steady state IOP is expected to be the same for both PMMA and hydrogel contact lenses.

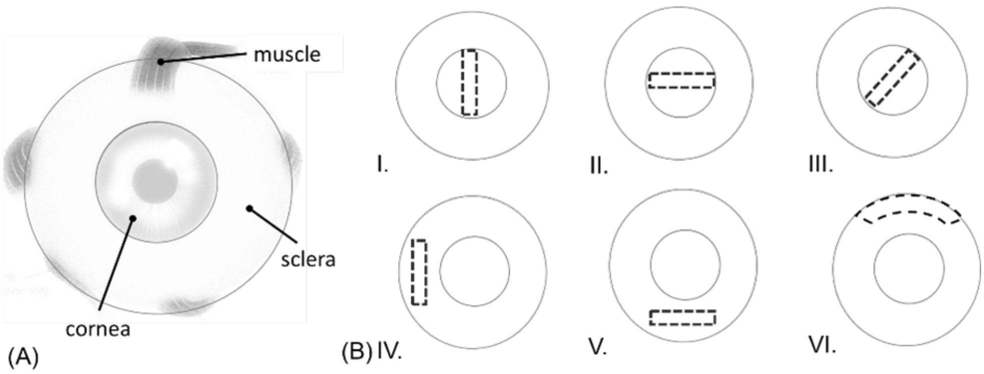
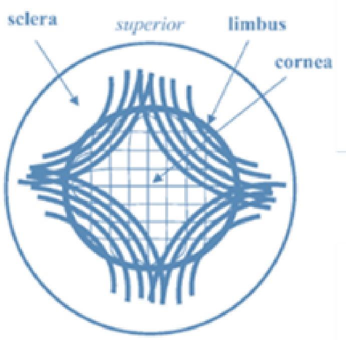


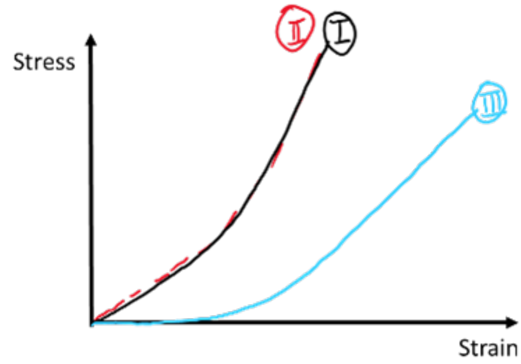
Fig. G.4

(b) Figure G.4 shows selected external features of an eyeball. Sample strips are taken out of the Fig. G.4(A) eyeball configuration, from the cornea region (shown in Fig. G.4(B)I to III) and from the sclera region (shown in Fig. G.4(B)IV to VI). The sample strips are then flattened and clamped at the two ends of the long-axis, and subjected to uniaxial tensile testing to determine each sample's stress-strain curve.

(i) Sketch, on one plot, the stress-strain curves for samples I to III. Describe and explain the key features and the differences between the three curves. [5]

Answer:

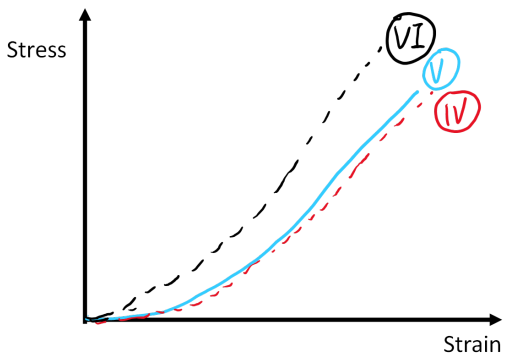




The cornea has a basket weave structure of collagen fibrils in the central region, where the fibril pattern provides support. Thus strip-I and strip-II (taken out from the principal fibril alignment directions) could exhibit similar stress-strain responses. Strip-III which is taken out at approximately 45 degrees to the principal axis of alignment, will have lower stiffness than strip-I/II. For all the three plots, the stress-strain curve is non-linear, due to the effect of reorientation and sequential "recruitment" of collagen fibrils during the stretching process.

(ii) Sketch, on one plot, the stress-strain curves for samples IV to VI. Describe and explain the key features and the differences between the three curves. [3]

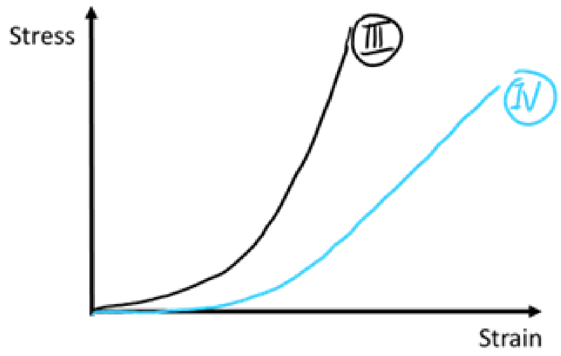
Answer:



The sclera is composed of more random webs of collagen fibrils, with low levels of interweaving between layers. Thus, although the three strips are extracted from different areas, the three plots could present similar levels of stress-strain curves considering practical sample preparation uncertainties. Strip-VI could exhibit slightly more stiff tensile properties due to the fibrils' preferred circumferential alignment in the sclera. For all the three plots, the stress-strain curve is non-linear, due to the effect of reorientation and sequential “recruitment” of collagen fibrils during the stretching process.

(iii) Sketch, on one plot, the stress-strain curves for samples III and IV. Explain the differences between the two curves. [2]

Answer:



Cornea sample-III is expected to exhibit a stiffer tensile property than sclera sample-IV, as the collagen fibrils in the cornea are more organised and tightly packed.

(iv) List the major uncertainties associated with using this testing method to determine the elastic moduli of sclera and cornea in general. [3]

Answer:

- small features/inhomogeneity
- anisotropy
- inconvenient shape
- ethical/practical procurement problems
- complex loading
- in vitro behaviour not representative of in vivo
- time-dependence
- specimen/person variability
- species variability

END OF SECTION

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Numerical Answers:

Q1:	(a) (i)	λ between $\approx 500\,\text{nm}$ and $1400\,\text{nm}$
	(a) (ii)	depth spacing $\approx \frac{\lambda^2}{\Delta\lambda}$
	(a) (iii)	$\Delta\lambda \approx 30\,\text{nm}$ for $\lambda = 600\,\text{nm}$ to $120\,\text{nm}$ for $\lambda = 1200\,\text{nm}$
	(b) (i)	$\approx 5\,\text{cm}$ diameter and $1\,\text{cm}$ depth
Q2:	(b) (i)	$\frac{\Delta d}{d} \approx \frac{\alpha d}{s}$
	(b) (ii)	$d_{\text{max}} \approx 23\,\text{cm}$

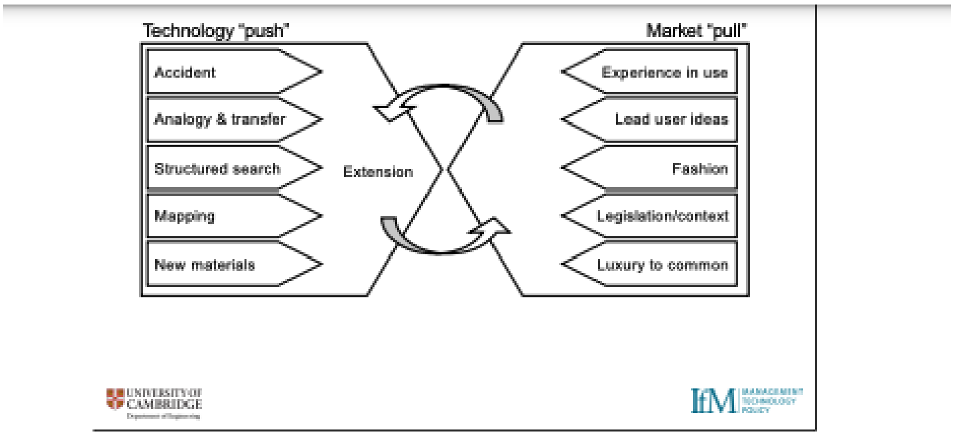
2024 2P8 Section H – Manufacturing and Management

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

1 (a) Explain what is meant by *market pull* and *technology push*. Give four sources for each. Provide one example for each source.

[5]

Students should be able to explain four from each of the five given in the lecture material shown below.



It is impossible to categorise all sources of invention but the following list demonstrates how many such sources there are:

- Most new inventions are extensions to existing products (for instance through increased performance or power or reduced price) or upgrades (related to colour, texture, size etc.)

Many inventions arise from the realisation that 'we can do it'

- The post-it note arose by **accident**
- The dvd player arose by **analogy** and the Dyson was a **transfer** of an existing industrial technology to a new domestic applications
- The domestic breadmaker arose from a **structured search** for new kitchen appliances
- The 'inerter' arose due to a gap in an existing **map** of possibilities
- **New materials** allowed the hair dryer to move from an expensive metal body to a cheaper plastic body.

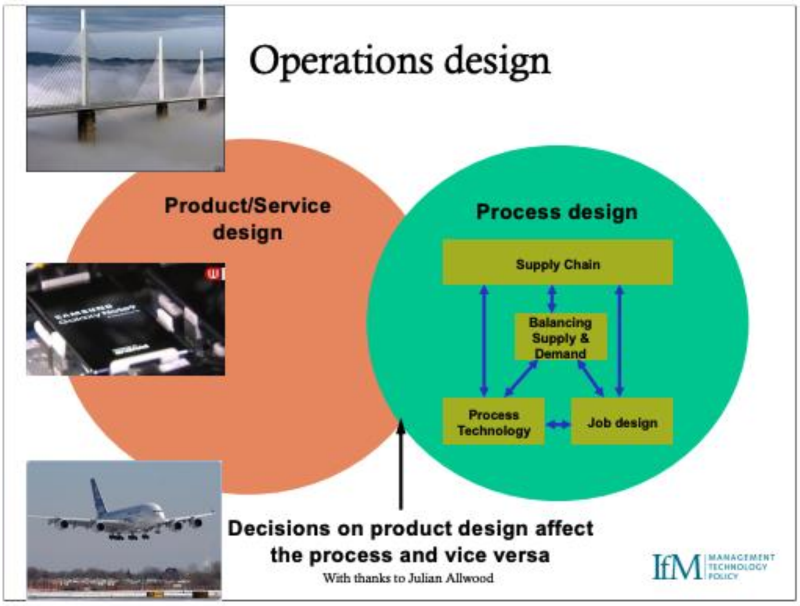
The difficulty of inventions of this type is that they may reflect the inventors belief that "this ought to be useful" rather than a group of customers' statement that "we want that." So an alternative source of inventions is driven by customers:

- The 'aural' thermometer for babies arose from the difficult **experience of using** conventional mercury thermometers measuring babies temperatures with
- The chopper bicycle arose from modifications to existing bikes by enthusiastic **users**
- Fridges and washing machines are now sold as **fashion** items as the kitchen has become the main entertaining room
- The ink-jet printing industry around Cambridge has grown due to **legislation** on sell-by dates for food
- The model-T Ford was successful because Ford found ways that by making cars cheaper he could turn a **luxury product into a common** one

(b) Discuss the relationship between *product specification* and the design of a *manufacturing process* for that product.

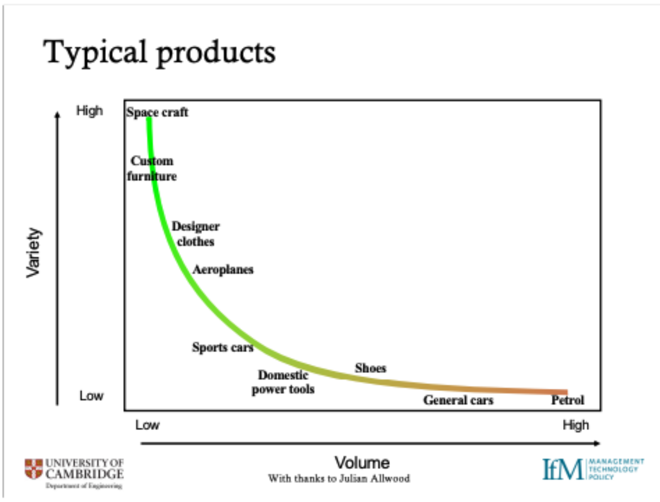
[10]

The answer requires students to discuss the key features of what is summarised in this figure, linked to the characteristics of the specifications, which covers all the aspects in the design mix.



Answers should unpack some of the issues in the right-hand circle (design of supply chain, the process technologies required, and nature of the jobs to do completed to make the product, and how this needs to take place in the context of potentially variable customer demand.

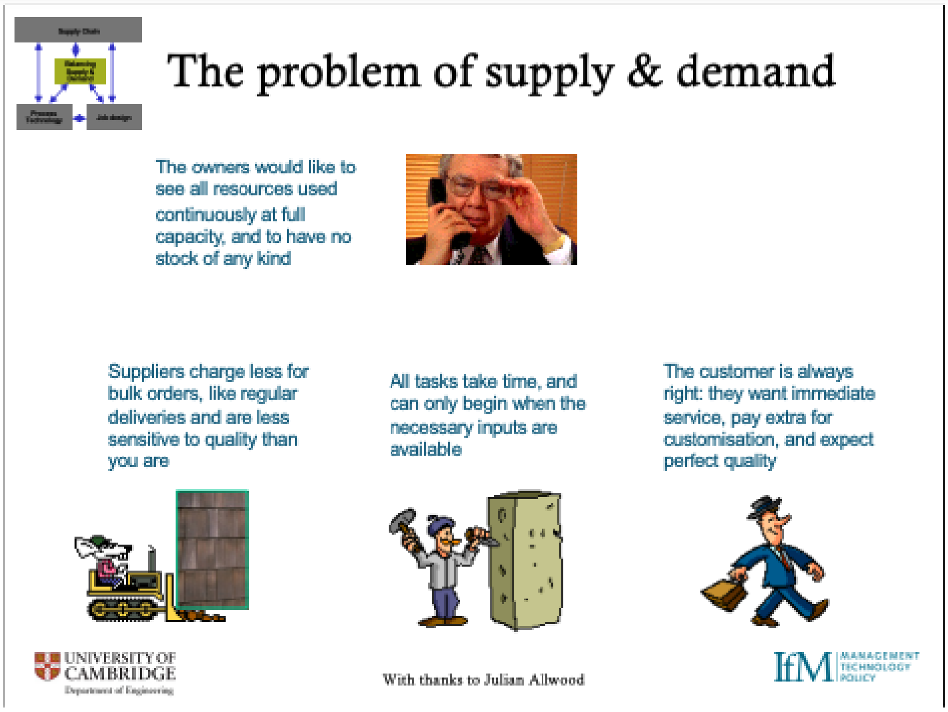
Students could then build upon this to explain how issues such as the number of products being produced, and scale and complexity of what is being produced will dictate the nature of the facility required to run the production itself, as shown in the figure below.



(c) Explain why it is so challenging for a manufacturing business to balance supply and demand. Discuss possible strategies for managing supply and managing demand to keep things in balance. Use examples to support your answer.

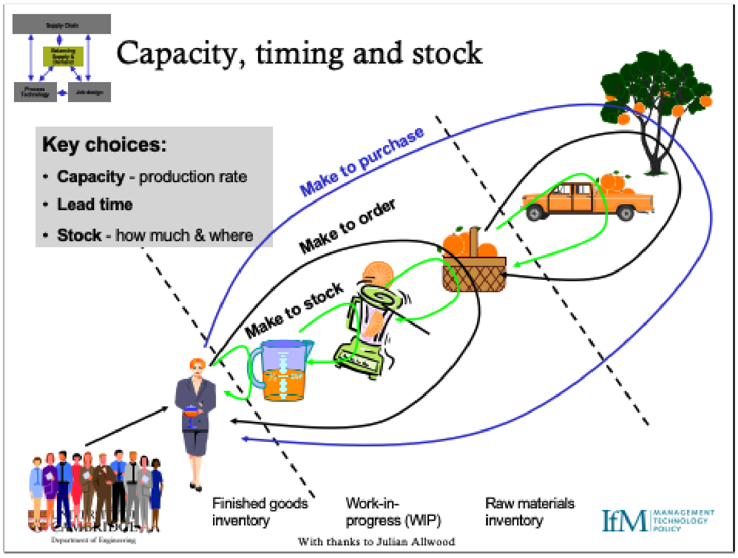
[10]

For the first part of the question, the basic answer is a summary of this slide.



The basic problem of supply and demand is illustrated above: the process of producing the product takes time – both due to production and due to the need to acquire the materials and components required to make it. If the customer is not prepared to wait for this process to occur, a stock of finished goods must be held so that whenever a customer arrives, there is a complete product ready to be bought. However, this stock of finished goods is expensive – all the costs of production have been paid for, and extra costs are incurred due to the need to store the product. The ideal is clearly that a steady stream of customers should arrive at exactly the same rate as the factory produces the products – so all the factory's resources are continuously in use, but no stock is kept.

Better answers would then use the example used in the lecture – or similar from elsewhere – to expand up this in more detail and look at issues of capacity, timing and stock, as shown in the slide below:



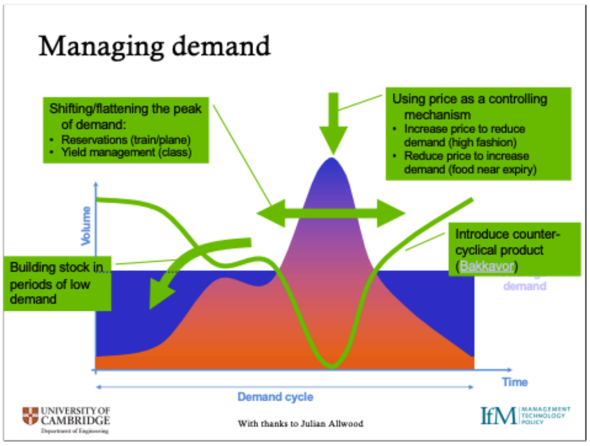
This point is further illustrated above, where two supply-demand relationships are shown – between customer and business, and between business and supplier.

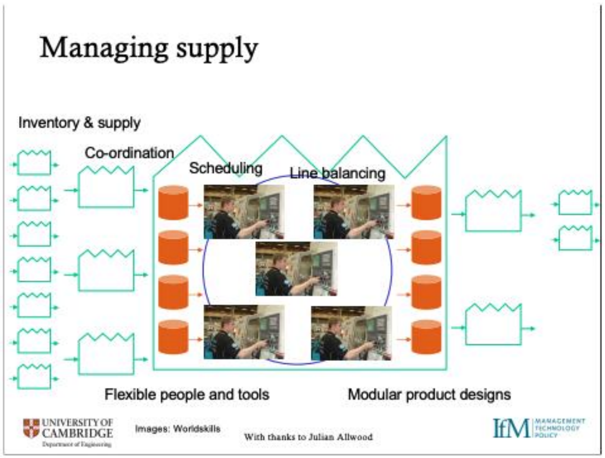
If the customer is prepared to wait, having placed her order, the business can take her money, then buy raw materials, make the product and deliver it. This is ideal, and means that the company always has cash in hand. It is also rare, although mail-order companies, luxury car makers and aircraft manufacturers can operate in this way.

More typically, the customer wants the product immediately, or at best will wait only for production to occur. Thus, in general, the factory will have three types of stock, or inventory: raw materials inventory – components and materials that have been paid for but not yet processed; work in progress (WIP) – of work currently being done; finished goods inventory – of products ready to be sold but not yet paid for.

The desire to avoid holding stock while keeping all resources fully busy is the motivation for wanting to balance supply and demand in the business.

Strategies for dealing with this can be split into two: Managing demand and managing supply. Students should be able to discuss both for these, and present examples of each, drawing upon the material shown in these figures. For example, students should be able to provide examples of how using of counter-cyclical products (soup in winter, salads in summer) can help manage demand. For the supply side, students should be able to discuss the use of more flexible equipment, and multi-skilled staff can allow a greater range of products to be produced.





2 You have designed a novel bike lock that is going to be targeted at students.

(a) Describe the four ways in which you can segment any market.

[4]

- By the **benefits** that are delivered: what benefits do customers and users derive from the product? For a hedge trimmer, it might be a neat hedge, or perhaps versatility, or perhaps a great service deal.
- By particular **product attributes**: perhaps the easiest way to segment a market is to compare product attributes. This however tends to say little about the customers and is often the weakest approach. For lawn mowers, this could include product performance, width of cut etc.
- By **characteristics of the consumer**: this can be split to include demographics, and psychographics. Demographics relates to aspects such as social class, age, house size, sex etc. Psychographics relates to the user's attitudes and beliefs, what they feel, their lifestyle etc.
- And by **product use**: describing ways in which a product is used. There might be strong customer loyalty, products might be used rarely or frequently, it could describe purchase behaviour (e.g. Distress purchase, seasonal patterns or regular upgrades etc).

(b) Draw a *perceptual map* and explain your rationale for the axes chosen.
Show how your design fits this map.

[7]

Students would be expected to use the processes explained in lectures for developing an appropriate perceptual map = "*[..] useful way of visualising the ways in which a market can be segmented and enables comparison of directly competitive products*". To do this, students should think about the nature of the product (bike lock) and possible users (students). In this context, the students need to find a way to identify segments that are 'real' (i.e. provide a useful classification) and 'substantial' (i.e. contain enough people to be worthwhile targetting).

Drawing upon the answer to part (a), students could potentially use something like the following. The key issue will be to demonstrate that they have followed the process, and can **explain their rationale for the axes chosen + s**howing the segments and the examples, also focussing specifically on segmenting the student's market (not the whole market).

For illustration, the axes could be:

Benefits delivered – security, value for money, etc
Product attributes - weight, ease of use, simplicity of use, cost, etc
User/consumer - novice or experienced, in Cambridge for one year (Masters) or 3-4-more years.
Usage - 'just get to lectures' or 'serious cyclist', frequent use or occasional use.

It would be appreciated if answers complied with the following

- price as a dimension is never preferabl and can be considered as an element of other dimensions.
- the segmentations based on features are the least useful.

(c) Discuss the strengths and weaknesses of different forms of *prototyping*.
Describe how each form of prototyping could be used in the development of your new bicycle lock design.

[6]

Students would need to summarise and discuss the content of these two tables, applied to the process of designing the lock.

TYPE	USES
Simple Sketch	The simplest, cheapest and quickest way of evaluating lots of ideas for form, technical arrangement and usability. Often highly under-utilised.
Block model	Primarily for early testing of usability, ergonomics and form. Also useful to quickly evaluate a product's physical arrangement. Mainly use easy to work and cheap materials.
Visual (physical) model	Enables evaluation of visual and form aspects. Produced to look as realistic as possible. Good for testing product feel and form.
3D CAD model	Evaluation of overall form, assembly sequence, component fit and production issues. Can also plug into a range of complex analytical models.
Functional (technical) model	To test specific performance aspects. Not necessarily representative of production processes. Good for evaluating reliability, durability, performance, failure etc.
Production prototype	To evaluate all elements of performance, function, form, use and producibility. Made with processes representative of the final production method. Fully functional.
Analytical / virtual models	Mathematical models to support component and assembly optimisation. Often used for safety critical elements. Can be costly and answers are always approximations.

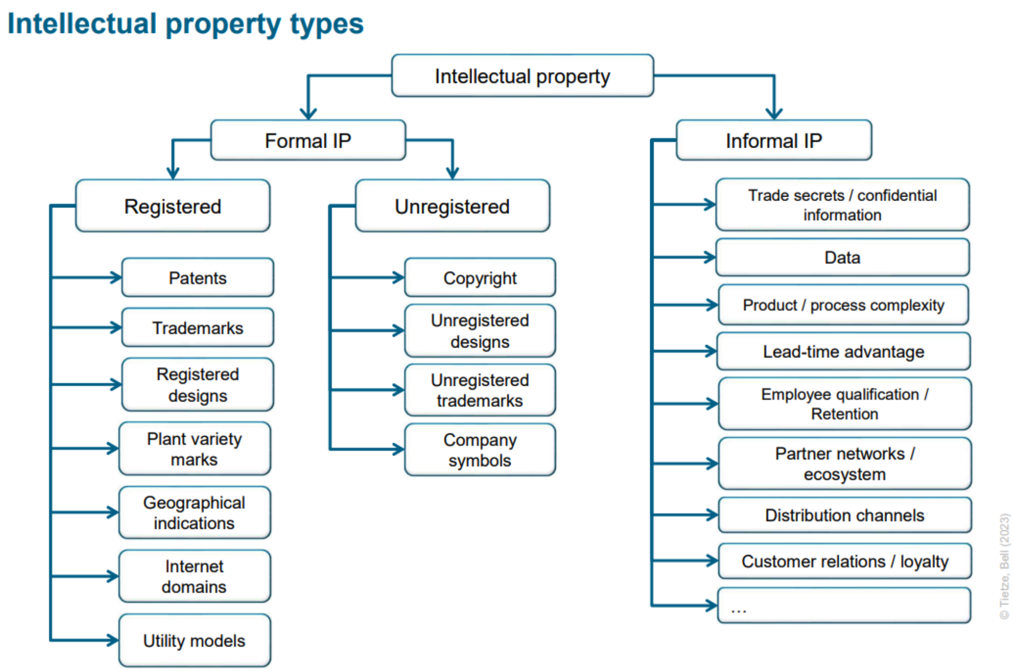
Fidelity vs. cost

Type of prototype	FIDELITY				Cost
	Function / performance	Appearance	Producibility	Usability	
Simple sketch	Low	Medium	Low	Low	Zero
Sketch model	Medium	Medium	Low	Medium	V Low
Block model	Medium	Medium	Low	Med-High	Low
Appearance model	Low	High	Low	Medium	Medium
3D CAD model	Low	High	Medium	Low	Low-High
Functional (technical) model	High	Low	Medium	Medium	High
Production prototype	High	High	High	High	High
Analytical (virtual) model)	High	Low	Low	Low	Varies

(d) Discuss the options you would have for protecting the *intellectual property* relating to your new bicycle lock. Explain the advantages and disadvantages of each type of *intellectual property rights (IPR)* relevant for this product.

[8]

The basic answer should demonstrate awareness of the range of IP options available (as shown in the figure below) and how different aspects of this do or do not apply to this device.



For this bike lock design, students should discuss, framing their answer in the context of **IP ownership creation** and **IP usage**.

Registered:
Could be patentable if there is novelty and search reveals no prior art. This could give strong protection and allow for various options for different business models, but there is cost and effort required to gain and enforce this protection.

Other registered aspects could be: the name of the lock could be trademarked, the appearance of the lock design could be protected, the website domain relating to the product. However, all registered forms of IP require registration (with fees) and enforcement (requiring professional legal services) if they are to be effective.

Unregistered:

Copyright could apply to any promotional content, whether in paper, electronic or on-line. Could also consider unregistered design rights, and unregistered trademarks, but hard to enforce as 'weaker' forms of IP.

Informal IP:

Could keep idea secret (cheap), but need to be able to ensure secrecy – can use NDA/ CDAs but these need to managed, some people are reluctant to sign. Almost all the other options for informal protection could, in theory, be used in relation to this product – even data rights, if the lock includes some data capture technology (location, movement, etc), could be used in relation to this product.

The core information on which the students could draw was provided in this table from the lectures, and the associated examples:

Intellectual property rights overview

	Patents	Trade Secret	Copyright	Database Right	UK Registered Trade Mark	Passing Off	Community Trade Mark	UK Registered Design Right	UK Unregistered Design Right	Community Registered Design Right	Community Unregistered Design Right
What does it cover?	New inventive products and methods excluding (among others) mathematical methods, computer programs and presentations of information.	Confidential information that has not been made publicly available that is subject to an obligation of confidence	Original expression, film and sound recordings	Collection of independent material arranged in a systematic way	Sign that is capable of distinguishing goods/services	Any mark or get-up	Sign that is capable of distinguishing goods/services	2D or 3D design with novelty and individual character, that is not purely functional or "must-fit"	Original 3D shape and configuration that is not "must-fit" or "must-match"	2D or 3D design with novelty and individual character, that is not purely functional or "must-fit"	2D or 3D design with novelty and individual character, that is not purely functional or "must-fit"
How it's obtained	Application to European Patent Office (EPO) for bundle of national patents; Application to UK Intellectual Property Office for UK only patents; PCT application for applying for individual national patents around the world.	An obligation of confidence can be imposed by: Express agreement; or Implied agreement; or Due to the confidential nature of the way it is imparted	Automatic upon recording of work	Automatic provided substantial investment in obtaining, verifying or presenting contents	Applied for at UK Intellectual Property Office	The right to bring a passing off action arises when mark has goodwill or reputation; There has been misrepresentation by defendant to public; and Damage to claimant	Applied for at OHIM	Applied for at UK Intellectual Property Office	Automatic upon record of design in document or article	Applied for at OHIM	Automatic upon design being in public domain
Who owns it?	Inventor unless developed in course of employment, or subject to an agreement	Developer unless in course of employment, or subject to an agreement	Author unless in course of employment, or subject to an agreement	Author unless in course of employment, or subject to an agreement	Whoever is named on register	Company/ person with whom the goodwill is associated	As named on register	Designer unless in course of employment, or subject to an agreement	Designer unless in course of employment, or subject to an agreement, or the design qualifies because of first marketing in the UK when the first owner is the person who first marketed.	Designer unless in course of employment, or subject to an agreement	Designer unless in course of employment, or subject to an agreement
How long it lasts?	Up to 20 years (further extension possible for some pharmaceutical related rights)	Until no longer confidential	Depends on work -generally author's lifetime +70 years for films, literary, artistic and musical works; +50 years for computer generated works	15 years from creation but extended upon substantial change	Forever provided renewal fees paid	As long as goodwill/ reputation can be established	Forever provided renewal fees paid	Up to 25 years	10-15 years	Up to 25 years	3 years

Note: [illegible]

3 An early-stage, start-up company with five employees has developed a new low-cost, internet-connected sensor for monitoring air quality on public transport. It will allow passengers to monitor the air quality via their mobile phones. The sensors will be made in very high volumes and sold to train and bus companies using a product plus service business model. The start-up company has just completed a successful trial of the technology with a large potential customer.

(a) Explain the advantages and disadvantages of a *product plus service* business model in comparison to other possible business models.

[4]

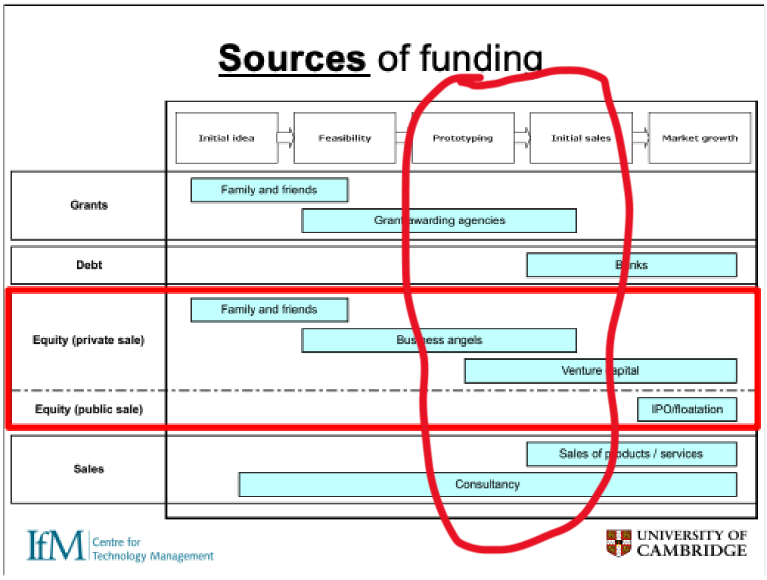
Advantages = there is synergy between the two. Long-term revenues can be gained on the back of the sale of each product + continued engagement with the customer may spur request for new products updates and generate stimulus for innovation.

Disadvantages = Need the infrastructure to provide services on top of products – which may require a whole different set of skills and resources – which will not only need to be set up, but also managed (management requires continuous alignment between product and service selling). Selling product requires manufacturing strength, service is powered by people who need to be expert. Service can mostly be scaled up by hiring more people.

(b) The start-up company is seeking to raise funding to support the growth of the business. List and compare the funding options available to the start-up.

[8]

Students should be able to refer to the information contained in the figure below and reason on the case under examination. The key context point is that this firm has not received substantial funding, is very small, but is seeking to grow (and it is likely to require quite a bit to move into production and hire also the people to deliver the services). It has run a first trial in the market – i.e. they have a working prototype which has attracted interest in the market. On that basis, equity funding could be the most appropriate if rapid growth is sought (e.g. from VCs, Angels or even the bus company as the first customer), though if a slower, more organic growth, then debt financing could be also an option (there is already a customer – banks are more likely to support than if they were an earlier stage startup as it can be surmised that there is a market and the size of the market). The startup can also consider consulting other firms on how to develop sensors (selling services) or selling licenses of their technology or running training (e.g. on how to create sensors for gas) commercialising their knowledge.



This chart presents one view of when different **sources** of funding may be appropriate / available at the different stages of a company's development.

Sales:

This may be provided from customers by doing consultancy work, or by customers providing payment in advance of receiving a product.

Grants:

Typically the main providers of this type of financing are governments (e.g., in the UK through the DTI's 'Grants for R&D') or charities (e.g., NESTA awards for innovation)

Equity:

Business Angels are wealthy individuals who choose to invest some of their own money in new business ventures. The term 'smart' is used to refer to those business angels who are able to bring not only money but also expertise of particular technologies, markets and industries, based upon their own experience.

Venture Capital Funds (known as 'VCs') are a form of high risk, high return investment. VCs raise money from large institutions such as pension funds and then re-invest portions of this money in high growth potential businesses. They know that a number of their investments will fail, so they seek to ensure that those that do succeed do so in such a manner that not only covers the costs of the failed investments, but also generates the very high levels of returns required to please their investors and cover the VC fund's own management costs.

IPO ('Initial Public Offering') refers to the selling of shares in a business on a public market such as the London Stock Exchange or NASDAQ. This is usually only done when the company as a track record, but can happen at the early stages of development of a business. During the 'dot com' investment boom of the late 1990s, this was quite a common route to getting money into a new business.

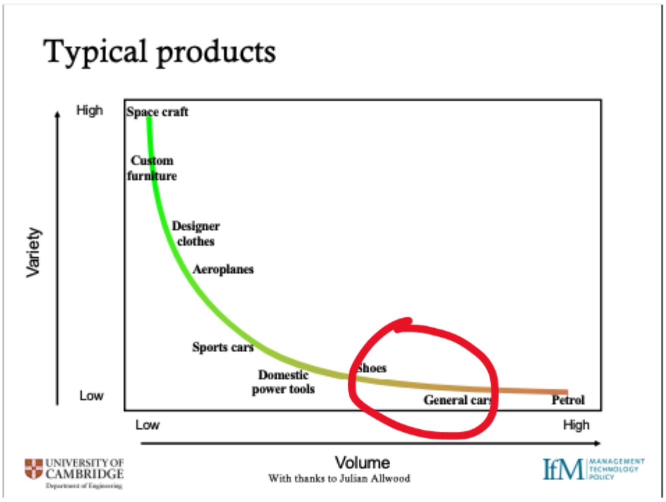
Debt:

Banks hardly ever lend money to early stage ventures as they regard them as too risky. Banks need to be able to apply measures to a company based upon their past performance so that they can assess the likelihood of them being an acceptable risk for lending. Start-ups have no track record, so banks cannot assess them.

(c) Discuss some of the issues likely to arise in the design and operation of a manufacturing system to produce these low-cost sensors in very high volumes.

[8]

Students should be able to position their system on this curve:



The discussion should demonstrate awareness of:

1. Need to move from one off (prototype) to automation – likely to start with batch production to test and perfect the config of the manufacturing whilst they are perfecting the product
2. High volumes mean lower variety.
3. Need to standardise production at an appropriate level of cost, quality and speed of production.
4. Is likely to be a process requiring automation and will require substantial investment to set up. They might have designed a product for their trial that was manually assembled (very common for small product runs), and so product might not be 'designed for manufacture' in high volumes, and by machines.
5. For a small firm this could be a prohibitive cost, and so they are likely to get someone else to do the manufacturing for them. But by doing so, they have to learn how to deal with subcontractors, who may not be used to working with very small, new firms, and may be located far away.

(d) Discuss the type of challenges that might arise when this very small company works in partnership with very large bus and train operating companies.

[5]

This is the classic 'elephant and mouse' / 'shark and minnow' problem. Students would be expected to demonstrate knowledge of the material covered in the following lecture material, and to be able to put this in specific context – i.e. new,, young, tech-focused start-up working with large transport service delivery companies (likely to be old, large, bureaucratic, risk averse, etc).

Size difference and proximity – There are some basic practical issues around bringing together a company with a few employees with one having tens of thousands. Who should you talk to in the larger company? How to deal with the fact that people frequently change roles within larger firms? Also, if the two companies are located at opposite sides of the world, this can lead to some real management problems. One quote from a start-up that had many problems working with a larger company reveals how this situation can feel: "We felt like s a small speedboat trying to dock with a supertanker".
Strategy and business models – Both sides of any partnership will have their own strategy and business models. Partnerships are formed when there is mutual strategic need. But

strategies and business models tend to be dynamic. What happens when one partner's strategy changes?
Sector and organisational 'clockspeed' – Companies and industries have particular 'clockspeeds'. For example, in business to business selling, the time between making first contact with a customer and receiving payment may be either a few days to several months (for aerospace, it may be years). If one company is used to operating at the short deal cycle end and the other at the long deal cycle end, this can cause practical cash flow problems.
Resources and funding – Partnerships take a lot of time to make them work. For a small company with very few people, the proportion of time that they are devoting to making the partnership work can be very significant, and may lead to insufficient time being available for other management tasks. For the bigger firm, they may be able to devote substantial resource to making the partnership work. For the smaller firm, the partnership may be come so time consuming and distracting that it becomes harmful to the overall success of the business.
Partnering capability – The ability to work with other firms has become a key skill for many Issues Start-up specific issues Strategy and business model Technology readiness Organisational asymmetry Setting up the deal Managing the relationship high tech firms. The level of skill is often linked to amount of experience the companies have at managing partnerships, and whether lessons learned are converted into management practices. For a start-up, a good question to ask of a big firm is 'Have you ever worked with a company small as ours?