MET1 Paper 1 2008-9 Crib

SECTION A: Question 1

a) Operating principles for the bell mechanism

- The lever pivots around the pin in the base. It is able to rotate, and is held with the push surface towards the user, via the spring.
- When the lever is pushed, the spring is placed in tension. The gear on the lever drives part 11. Part 11 rotates, and the rotation is transmitted to component 5. The gearing of the mechanism means that part 5 rotates rapidly.
- Two washers are sandwiched between parts 5 and 7. They are free to move, but are constrained by the pins projecting from part 5.
- As part 5 rotates, the washers naturally move outwards, and during the rotation, hit the dimple on the bell component, creating a ringing noise.
- The spring returns the mechanism to its resting state.

b) Functionality of each component

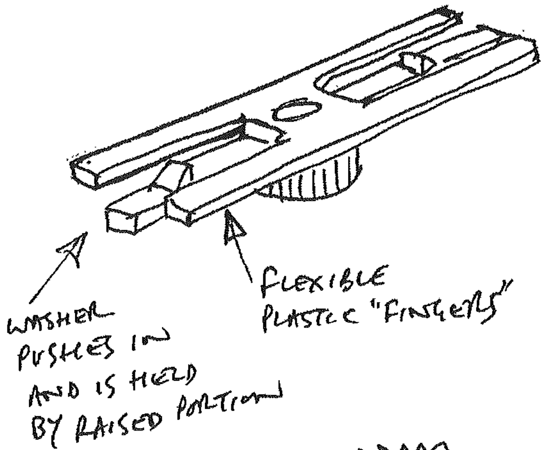
Part No.	Part name	Relative Movement	Different material	Adjustment	Primary/secondary
1	Bell base	-	-	-	Primary
2	Activation lever	Y	-	-	Primary
3	Spring	Y	N	N	Secondary, although there is relative movement, this functionality could be integrated with the lever
4	Spacer	N	N	N	Secondary
5	Geared ringer	Y	-	-	Primary
6	Washer	Y	-	-	Primary
7	Plain ringer	N	N	N	Secondary: could be integrated with the geared ringer
8	Nut	N	N	N	Secondary
9	Bell	N	N	Y	Needs to be separate to enable assembly
10	Spacer	N	N	N	Secondary
11	Drive gear	Y	Y	Y	Primary: Plastic gear

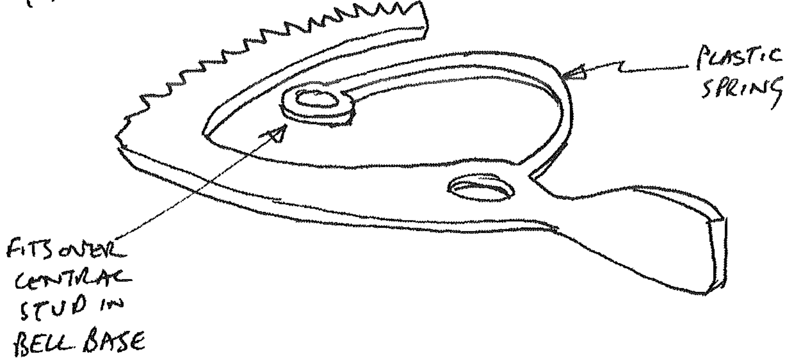
The total number of primary components is 5, therefore the design efficiency is: 5/11 = 45%. Thus, there is room for improvement.

c) Some design alternatives to enable simplification should be presented.

- Components 4, 10, 7, 8 can all be eliminated. The spacers can be integrated into other parts.
- The 'plain ringer; can be integrated with component 5, as an injection moulding.

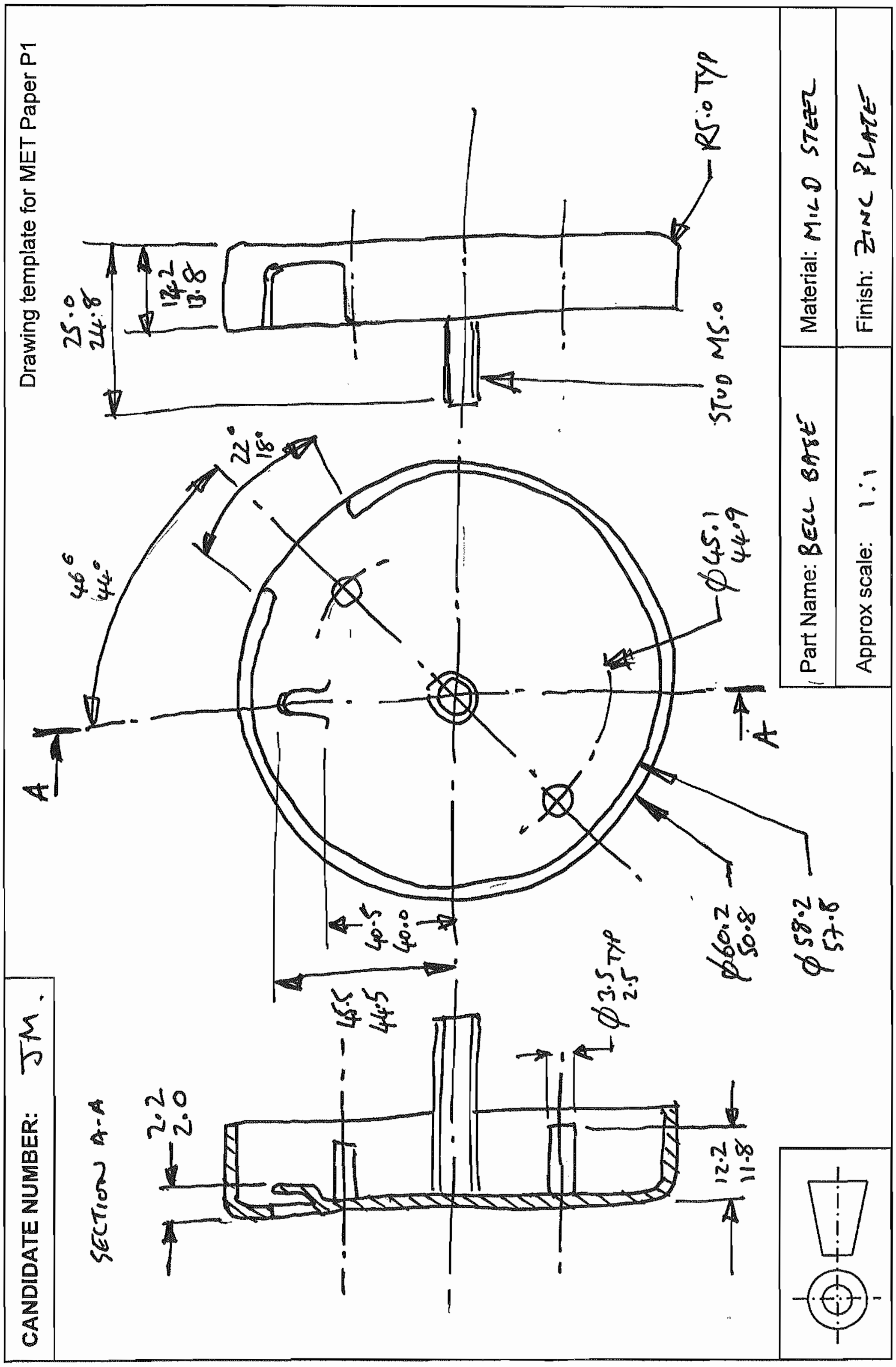
- The spring and activation lever can be integrated, with the spring as a plastic spring.
- The nut is not needed, as the bell can provide this functionality.





d) See drawing below

Good answers produced a complete engineering drawing, that would enable the part to be made. Good answers also made a clear connection between the component functionality and whether the part was primary. Good answers also provided improvements to the design without modifying the functionality. Thus, a design which operates on fundamentally different principles is not a good solution.



Drawing template for MET Paper P1

CANDIDATE NUMBER: JM.

Part Name: BELL BASE

Material: MILD STEEL

Approx scale: 1:1

Finish: ZINC PLATE

--------------End of crib for question 1 --------------

SECTION A: Question 2

a) See drawing below

Need to dimension the bearing seatings. Assuming a bearing ID of 30mm, and a tight clearance fit (e.g. H6 g6):

From the data book, recommended bearing fits:

Bearing bore diameter: 0, -10 = 30.000-29.990

Shaft diameter, at g6: -7, -20 = 29.993-29.980

Bearing width = 13mm (from data book)

Diameter of inner shoulder approx = diam 33 (judgement).

b) For low production volumes, the shaft would be produced using standard machining methods, starting from bar stock. The external profile would be turned, the Hole drilled, and the ends tapped. It may be necessary to grind the bearing seatings, and potentially the tapers. This would have low fixed costs, but high variable costs.

For high production volumes, the component would most likely be cast, potentially investment cast. There may still be a need to grind the bearing seatings. In this case, the fixed costs would be higher, due to tooling costs, but the variable costs would be low (i.e. low individual costs per part).

Annual production volumes of 10,000, estimate unit cost:

c) Unit cost = Total manuf cost (per period) / No. units (per period). Thus, need to know sales volumes/period.

Need to thus make assumptions about both the period under consideration and also the number of units being made in that period.

Thus, for the assembly, need to identify purchased materials:

- processing costs: the raw material cost per part, the tooling cost (tooling life amortised over some period – tool life or parts per tool).
- Purchased materials: would need to estimate purchase costs based on likely purchase volumes. Would also need to allocate overheads. Typical overhead rate 10% cost of parts.
- Assembly costs – specialist assembly tooling, estimate of assembly time, assembly rate and also assembly overhead – can be around 80% of direct assembly cost.

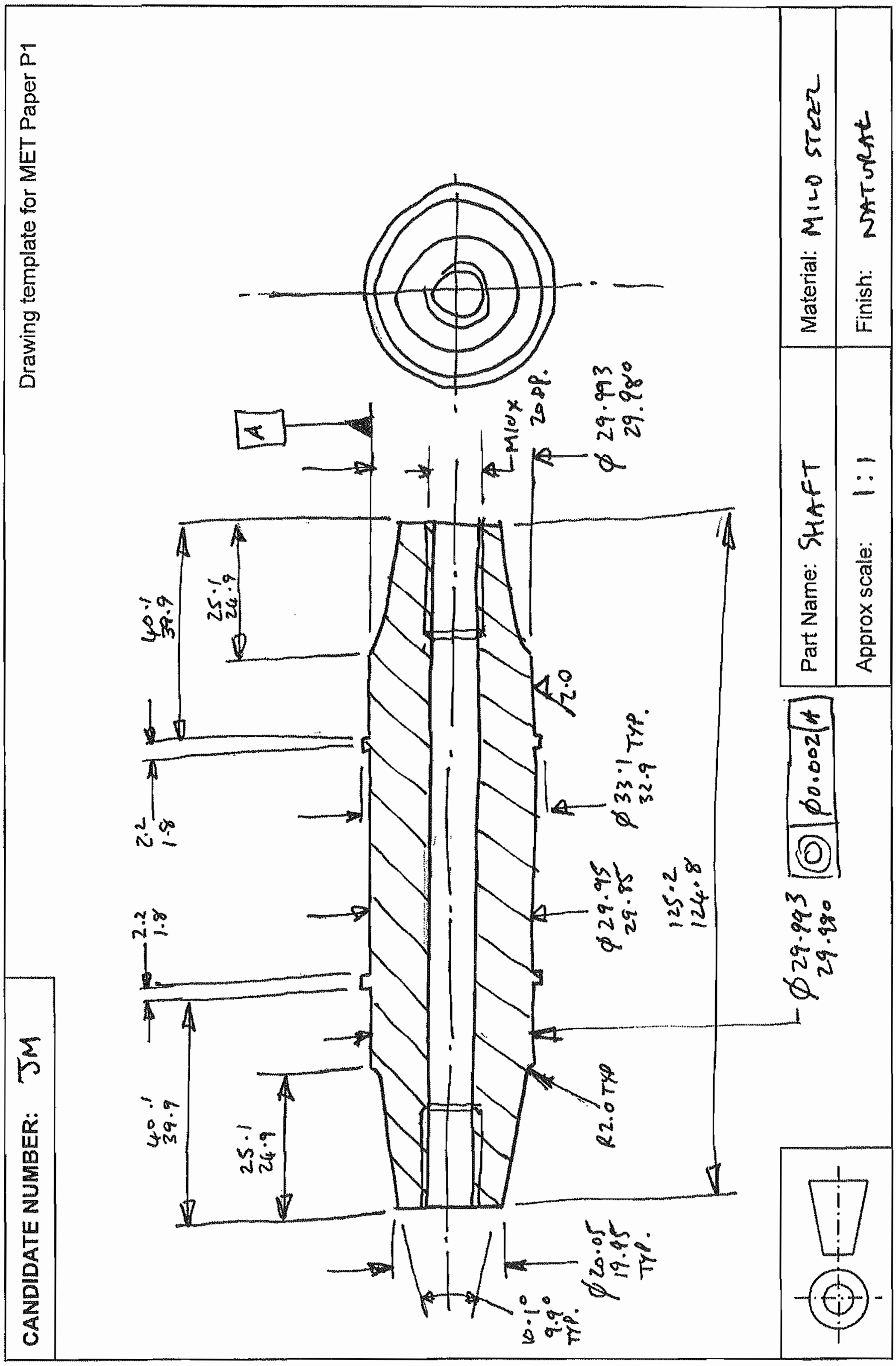
A Good answer would distinguish between direct costs, unit variable costs, unit fixed costs, and overhead cost per unit.

d) Rough estimate: it is the thought process that matters here, not the final result.

Component	Purchased Materials	Processing (materials + labour)	Assembly (labour)	Total variable cost/unit	Tooling	Tooling life (units)	Total fixed cost / unit	Total unit cost
Crank & Pedal Assembly	3	0	2	5	100000	100000	1	6
Clamp nut (x2)	0.05	0	0.05	0.1	0	0	0	0.1
Shaft	2	1		3	20000	100000	0.5	3.5
Shaft nut (x2)	0.05	0	0.05	0.1	0	0	0	0.1
Ball bearing (x2)	3	0	0.1	3.1	0	0	0	3.1
Housing	1	1		2	20000	100000	0.5	2.5
Total direct costs	9.1	2	2.11	13.21	140000		2	15.21
O/head driver	10%	80%	80%					
Overheads	0.9	1.6	1.6	4.1				4.1
Totals	10	3.6	3.76	17.31				19.31

e) Improvement to the design. The design might be difficult to assembly, due to the need to access from both sides. The assembly might not be rigid ,the clamp-nuts provide an additional mating surface, and the shaft could be clamped more simply. The crank and pedal assemblies are complicated. The hole through the shaft is not necessary.

A good answer included an engineering drawing which was complete. Good answers expanded on the basic lecture notes on costing and reflected sensibly on how the design could be improved, not just the methods that could be followed to improve it.



--------------End of crib for question 2 --------------

SECTION B: Question 3

e) The question calls for 3 principles, with 2 examples of each. Five principles are described below:

- **Constraints** prevent unwanted actions: Eg Asymmetric batteries prevent erroneous insertion. High door handles prevent child access.
- **Affordances** indicate possible actions: Perceived and actual properties that determine (or suggest)how a thing can be used. A door handle affords pulling. A slot affords inserting (coins, ATM cards). A button affords pushing.
- **Mapping**: arrangement of controls, indicators etc has an intuitive correspondence to the elements they relate to. Eg position of cooker hob controls, or light switches in a room, should be arranged to correspond (but often do not). iPod thumb wheel maps intuitively to the scrolling screen display. Car indicator stalk corresponds to steering wheel turning direction.
- **Visibility & layering**: Complex controls can be simplified by having commonly used elements at the surface, with more expert or rarely used items hidden on sub-layers. Eg, TV remote control with sliding cover, iPod menu system, most software menus.
- **Learnability / Memorability**: Use of a product should be quick to learn and/or very memorable. Eg have just a few steps, or built-in guidance eg TV menu system, washing machine.
- **Conventions**: Even if something is hard to learn, non-intuitive or complex (eg driving a car), conventions reduce errors, eg gear box / gear stick arrangement. Software symbols, icons etc should use well recognised standard conventions, eg an envelope for e-mail, a globe for internet.

f) Men between 170 and 180 tall, looking for the 50th Percentile, which is 500.

Men over 180cm, the 25th Percentile, i.e. 250. Note Note there is ambiguity in the use of the words 'between' and 'taller than', as some may be exactly 170 or 180 cm tall.

g) Since all dimensions are non-critical, we can assume a wide tolerance of acceptability around precise figures:

(i) See illustration below for analysis

h1 Assuming comfortable pushing height is **hip height** ±10cm

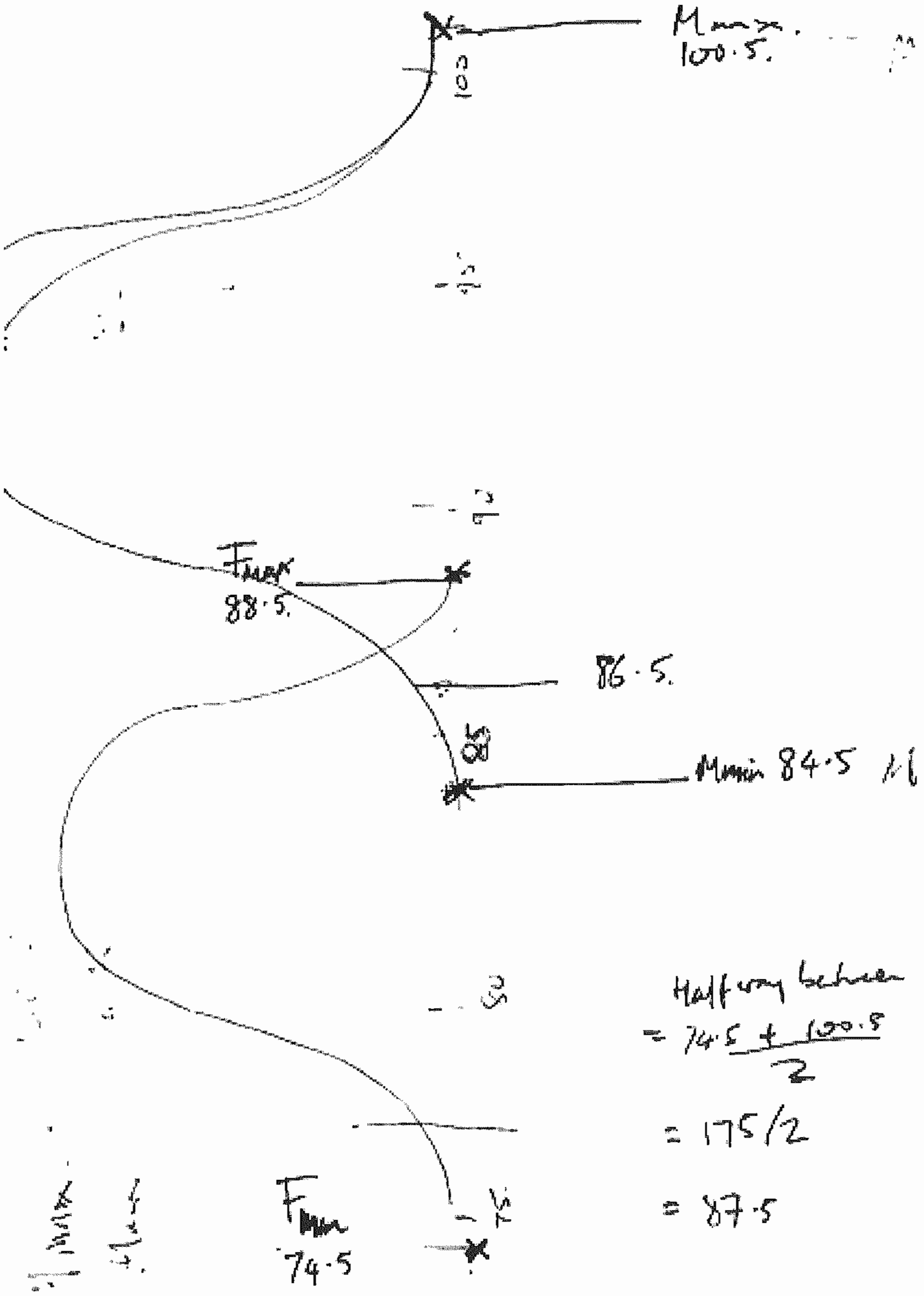
Hip height 84.5 92.5 100.5 74.5 81.5 88.5

Max Female (88.5) is taller than Min Male (84.5) so overlap, midway between (mean) ie. **h1=86.5cm**

This height is below hip height for majority of males, (50%ile =92.5) and above for most females (50%l=81.5) but for all, falls within a 10cm 'comfort zone'.

Alternative answer:

h1 Assuming comfortable pushing height is **hip height** ±10cm, median hip height (MinF+MaxM)/2=**87.5cm** is within comfort zone for majority of M and F



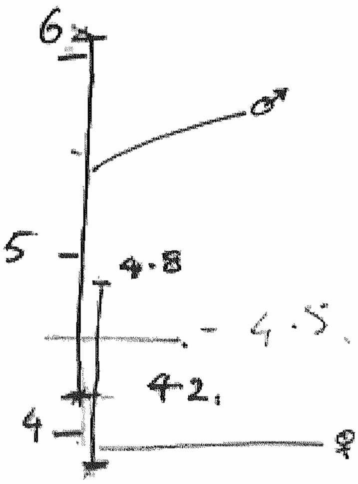
Halfway between

$= \frac{74.5 + 100.5}{2}$

$= 175/2$

$= 87.5$

(ii) Max Female (4.8) is wider than Min Male (4.2) so overlap is 'safe' zone. Midway between (mean) ie. **4.5cm**



(iii) Assuming comfortable grip separation=shoulder breadth. Minimum handle width is important, but handle can be wider than separation of hands, so there is no max width. If w>51cm, then all Female and 95% Male can hold comfortably. Adding a further (arbitrary) margin, **55cm** would likely accommodate 99%ile of Male.

(iv) Basket top height needs to be considered relative to the basket bottom, so that one can reach items at the bottom.

Let h2-h3= basket depth d_b < arm length. Shortest arm reach=65.5.

Assume h3 should be no lower than half knee height for ease of reach. Tallest knee height=60cm, so h3=**30cm**

Therefore h2 should be less than 95.5cm, but handle height h1 is 86.5cm, so basket height can same, **86.5 cm**

(v) **30cm** (see above)

Note: There are many acceptable answers to this question. Good answers are well reasoned, with sensible assumptions being explicitly made.

h) Other factors might include: storage capacity - a shopper wants to be able to carry all they need when they shop, and it is in the shop's interest too to allow more goods to be collected easily. However, width should not be so great as to prevent easy passage in shop aisles. Size also may have a bearing on the manoeuvrability - a famously unpopular aspect of the trolley.

i) A shop might consider several sizes for different shopper's needs.

- Stepped base, so an area is raised nearer to the lip
- Lower side in one area to reduce bending required by user.
- Fold down side to ease transfer to till and car boot.

Good answers included a well argued case for the different dimensions and sensible design sketches for the redesign options.

-------------End of crib for question 3 -------------

SECTION B: Question 4

a) Modernism (Europe and USA, 1st half of 20thC.) founded on ideas of truth and integrity, efficiency, 'scientific,' objective. Derided ornament as vulgar and dishonest. Conceived by an intellectual elite but with ideas of quality available to the masses, embracing technology and mass production for the 'greater good'. Post-Modernism - 'anything goes' -rejoices in a freedom to play with any influences, references, make visual puns, jokes. to break rules and challenge assumptions of archetypes.

Modern designs are often geometric and stark, rectilinear (eg a Corbusier building, Mies' Barcelona pavilion) using materials of industry (concrete, steel tube, glass) without embellinshing or disguising, and with little added colour.

Post-modern designs often have whimsical, playful element, maybe brightly coloured, cartoon-like (eg Alessi products) or irregular, without apparent order (Gehry, Rodgers).

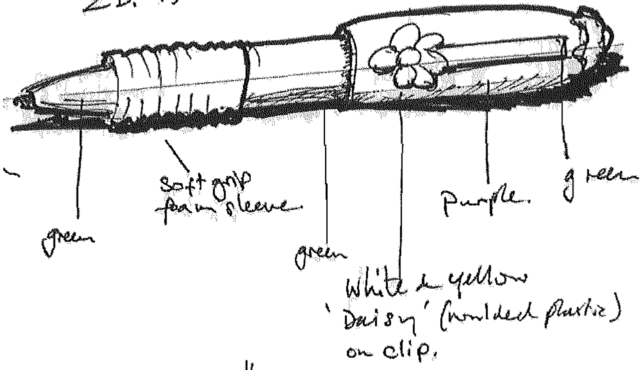
b)

i) Aim for something 'fun' and playful, more 'cartoon-like' : Make barrel and cap fatter, and pleasant to hold with a moulded sleeve, ridged soft-grip foam, in bright colours, purple, green, red.

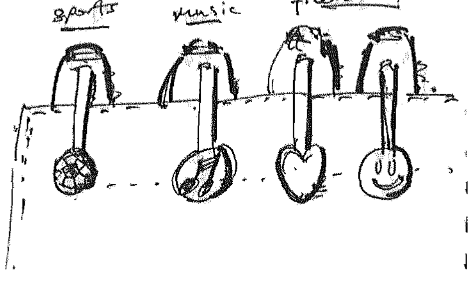
Graphics reflecting current popular trends for the age group can add a theme (maybe licensed from a TV show or pop band). But be aware this is an age very sensitive to appearing babyish.

Clip could have an adornment, moulded plastic flower, football, musical note, heart.

2b. i)

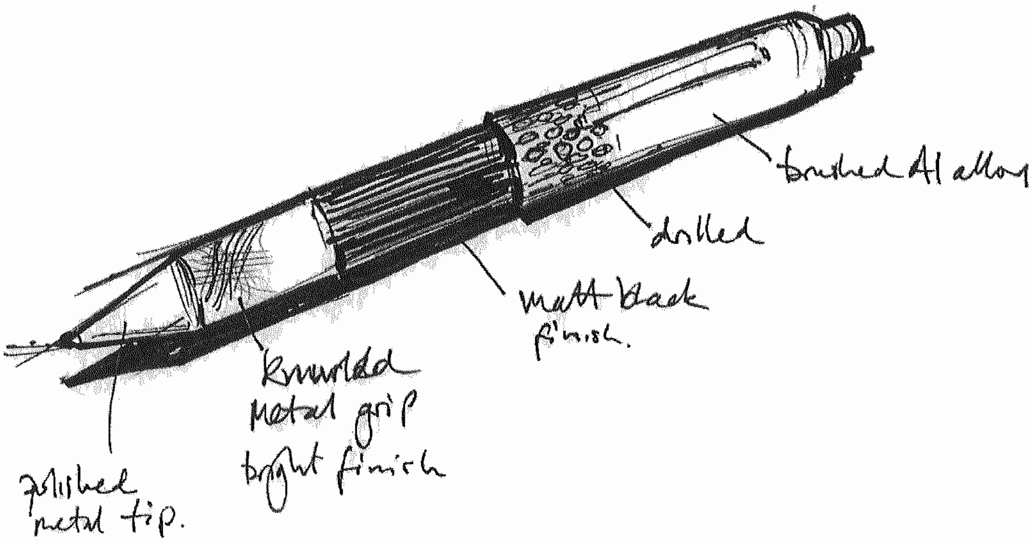


could be other themes:



ii) Overall impression of seriousness, precision, class

Detail expressed precision and machine tooling, eg drilled out barrel evokes weight saving in aerospace, slim size suggests sophistication. Finish in brushed or polished metal (eg Al alloy), matt black paint.



c) There are a number of possible ways to gain customer input, as described below:

- Visual models: as realistic as possible, show to small sample of potential customers or focus groups. They get accurate experience of the proposed design, and can discuss their reaction thoroughly. Only small sample. Expensive process.
- Questionnaire: to many potential customers with images (CAD or photos of model) to gauge if response is favourable. Could easily gauge preference between, say, 3 alternative CAD renderings. Many respondents, but limited experience for them to assess, and limited depth of findings in questionnaire method.
- Could also make fully working prototype to lend or give to test users in exchange for feedback.

Good answers did not fall back too much on stereotypical responses to the design problem, assuming that an engineering manager is male. Excellent answers expanded on the brief and provided multiple options.

-------------End of crib for question 4 -------------

SECTION C: Question 5

a) The basic procedure for method study is as follows:

SELECT the work to be studied. The **selection** of work to be studied can arise from many sources. Obvious areas are bottlenecks- where a particular operation is restricting output, labour intensive operations, operations involving much material handling, operations with high scrap or wastage, etc. A pareto analysis of operations cost or labour requirement can help in the selection.

RECORD all the relevant facts about the present method by direct observation. The **recording** of facts is facilitated by means of charting techniques, eg Process Charts, (although video recording is now replacing manyof the process charting techniques), Multiple Activity Charts, Layout Charts, string diagrams.

EXAMINE those facts critically and in ordered sequence. Having recorded a method the next step is a critical examination. The activities generally fall into two main categories, namely:

- those in which something is actually happening to the material under consideration, i.e. it is being worked upon, moved or examined
- those in which the material is not being touched, ie delay or storage

The Activities in the first category may be further subdivided into three groups:

- "MAKE READY" activities required to prepare the material or work and set it in position ready to be worked on.
- "DO" operations in which some transformation is made to the material
- "PUT AWAY" activities during which the work is moved from the workplace, this may include inspection.

Clearly the aim must be to maximise the ratio of "DO" operations as these are the only things that add value to the product, and ultimately provide the basis for the business.

All activities are subjected to a systematic questioning technique as follows:

- the PURPOSE for which the activity is undertaken
- the PLACE at which the activity is undertaken
- the SEQUENCE in which the activity is undertaken
- the PERSON by whom the activity is undertaken
- the MEANS by which the activity is undertaken

with a view to ELIMINATING, COMBINING, REARRANGING or SIMPLIFYING those activities-

- Query PURPOSE with the initial view of elimination: What is actually done, what is achieved? Why is the activity necessary at all?
- Query PLACE, SEQUENCE and PERSON with the view of combining or rearranging: Where is it being done? Why is it done at that particular place? When is it done? Why is it done at that particular time? Who is doing it? Why is it done by that particular person?
- Query MEANS with a view to simplifying: How is it being done? Why is it being done in that particular way?

A second stage of questioning then inquires:

- What else might be done? And, hence: What should be done?
- Where else might it be done? Where should it be done?
- When might it be done? When should it be done?
- Who else might do it ? Who should do it ?
- How else might it be done? How should it be done?

DEVELOP	the most practical, economic and effective method. The next stage is to develop an improved method. This requires some creative thinking around the areas explored in the critical examination. If the examination has been thoroughly carried out it is likely that improvements are already evident. Guidelines such as Gilbreths 'Principle's of Motion Economy' can be useful here.
DEFINE	the new method so that it can always be identified.
INSTALL	that method as standard practice.
MAINTAIN	that standard practice by regular checks

Having developed the improved method it is then necessary to DEFINE it so that it can always be identified, INSTALL it as standard practice and MAINTAIN that standard practice by regular checks. These stages may in fact be the most difficult of all for they rely on getting people, workers and management alike to accept and implement change.

a) Light assembly results:

(i) The times become progressively shorter due to learning curve effects. There are many factors that contribute to learning, but the main factors at work here are practice and individual feedback – 'getting the knack'. (we are told that the operation has been subjected to method study so that all the general factors that contribute to learning – better methods, better tools and equipment, coaching etc. do not apply in this case. Students who list all these should not be given credit for them). Practice has the effect of converting conscious to sub-conscious motions, removing superfluous movements and allowing operators to develop a 'knack' for the more difficult parts of the assembly by personal feedback with slightly differing techniques.

(ii) The times follow the standard learning curve model: $y = K x^{-A}$

K and A are constants that can be found from the data in various ways: log-log plot, log- log regression, substituting values into equation and solving simultaneously, via % learning. All ways will work although more marks should be given for approaches that make use of all the data, not just taking two points.

K= 300, A=0.2 This corresponds to a % learning of 87%

In order to find total times we need to integrate the expression:

Total time to assembly N units = $\int_{0.5}^{N+0.5} K x^{-A} dx$

(note: the limits as we are approximating a finite sum by integrating a continuous function)

Hence an expression for the total time is = $(K/(1\text{-}A)) [x^{1-A} - 0.5^{1-A}]$

Substitute for A and K $= 300/0.8 [x^{0.8} - 0.5^{0.8}]$

$= 375[x^{0.8} - 0.5743]$

By substituting values of K, A, and x=1000, total time = 94018s., or, just over **26 hours**

(iii) Assuming that learning does not continue beyond 4 hours. Here we need to find how many assemblies get done in 4 hours, and the cycle time for the the last assembly within 4 hours.

Setting total time =14400 (4 hours) we solve for x. (=97)

Substitute into $y = K x^{-A}$, gives y=120

Total time = 14400 + (903*120) =122760s, or approximately **34.1hours**

(iv) After 4 hours, time per assembly 2 mins. If learning continues, after 1000 assemblies, the time would be 75secs. In this case, we are coming up against physical limitations to speed of movement. It would be unrealistic to expect an operator to achieve this level of performance. There are many other limits to the learning curve, but this is the only one applies in this case.

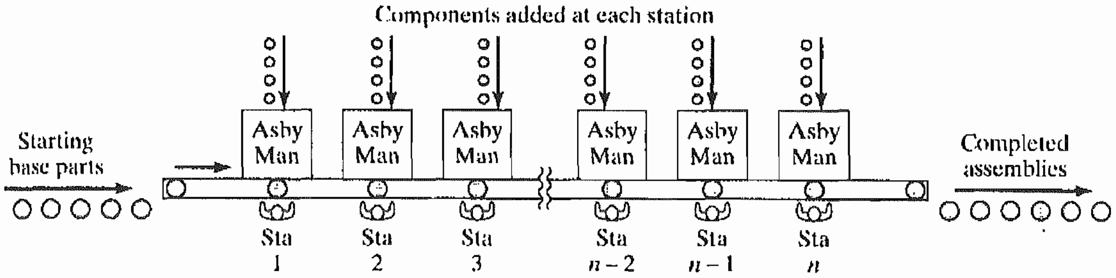
Section iv provided the differentiator between students in many cases, as the calculations were generally completed very well. Better students also provided a clear and concise summary of the stages of method study, with a clear emphasis on the examination stage.

-------------End of crib for question 5 -------------

SECTION C: Question 6

6 a) A production line:

Line production is a form of factory organization where the processes are laid out in sequence and the works flows from process to process having operations performed upon it, transforming it step by step towards a finished product. A common form of line production is the assembly line. See diagram.



Asby = assembly, Man = manual, Sta = workstation, n = number of stations on the line

The advantages of line production include:

- specialization of operations – both labour and machinery
- low WIP and hence fast throughput
- line pacing
- visibility and control
- All leading to low unit marginal cost

The disadvantages of line production include:

- product rigidity – not easy to incorporate significant product change
- often duplication of equipment
- often high capital cost
- operational inefficiencies at volumes different to design volume
- lack of flexibility to operator sickness, absence
- lack of flexibility to cope with equipment failure – often causes line stoppage.

Major design issues

- line balancing
- positioning and sizing of buffers
- methods of work transport

- operational routines to cope with operator absence or m/c malfunction – potential redundancies in equipment

b) Activity sampling is used for finding the percentage occurrence of a certain activity by statistical sampling and random observations. The basic principle is that if a number of random observations (N) are made of an event and n of these observations are of an outcome i, then the expected proportion of times that the outcome i will occur is n/N.

Although usually used for determining proportions of time spent in various states the process can also be used to establish time standards. This is done by determining the utilization of a workstation (from activity sampling) and counting the number of products produced in a given time interval, say one day. From this

Cycle time =Time worked* utilization/number products produced

To determine the cycle time for each workstation the steps would be:

- Make a preliminary estimate of the % utilisation of each workstation done by carrying out a pilot study.
- Design the main study. Determine how many observations are required, (see below) hence determine how many observers and how long the study should take. Plan the observation method being sure to randomize the observation times. With a 6 station assembly line, one observer should be sufficient as the line should be relatively compact and the observer should be able to record at a glance which stations were working and which were not. To determine number of observations:

  From statistics, and the normal approximation to the binomial distribution

  Number of Observations = 1.962/ 0.12 * (1-P)/P where P is the utilization of each workstation found from the pilot study. (1.96 is the standard normal variate, relating to 95% confidence and 0.1 is the allowed error limit)

- Carry out study according to above plan, summarising the data at the end of each shift. Use both control charts and cumulative plots.
- Check the accuracy at the end of the study.

c) Advantages and Disadvantages of Activity Sampling:

Advantages

- A simultaneous activity sampling study of several operators or machines may be made by a single observer. A work study engineer is needed for each operator or machine when continuous time studies are made.
- It usually requires fewer man-hours and costs less to make an activity sampling study than it does to make a continuous time study or to apply (Predetermined Time Standards, PTS.
- Observations may be taken over a period of days or weeks, thus decreasing chance of day-to-day or week-to-week variations affecting the results.

- It is not necessary to use trained work study engineers as observers for activity sampling studies unless performance sampling is required.
- An activity sampling study may be interrupted at any time without affecting results.
- Activity sampling measurements may be made with a preassigned degree of reliability.
- Activity sampling studies are less fatiguing and less tedious for the observer.
- Activity sampling studies are often preferred to continuous time studies by the operators being studied. Some people do not like to be observed continuously for long periods of time.
- A stop watch is not needed for activity sampling studies.

Disadvantages

- The major disadvantage of activity sampling is accuracy
- Time study permits a finer breakdown of activities and delays than is possible with activity sampling. Activity sampling cannot provide as much detailed information as one can get from methods such as time study or PTS systems.
- An activity sampling study obviously produces average results, there is no information about individual differences, no account is taken of rate of working.
- Generally no record is made of the method used by the operator. Therefore, an entirely new study must be made when a method change occurs in any element.

The best way to set time standards for a high volume assembly line is using some form of PTS system, such as MTM – X.

Reasons for this are

- These detailed systems produce a more detailed description of the work than other methods.
- As each basic motion is described along with its variables, so alternative methods can be readily compared using time as a criterion.
- Methods can be developed and standards established before production operations start.
- PTS do not require the assessment of rate of working and the use of the stop watch as is required in time study. This can remove one of the impediments to good industrial relations.
- PTS are objective and consistent

PTS systems are costly to apply, but for a high volume line this cost is justified by the way it allows optimization of the process.

--------------End of crib for question 6 --------------

SECTION D: Question 7

7 a) Changes in manufacturing processes:

i) The main causes of variation in the output of a process can be attributed to:

- Material variations such as physical properties, or initial geometry.
- Equipment variations such as non-repeatable, long term wear, deflections
- Operator variations such as inconsistent control, excessive "tweaking"
- Environment variations such as temperature and handling inconsistencies

ii) In order to determine the means by which a manufacturing process can be controlled. It is useful to consider a simple process variation equation which is given as

$$\Delta Y = \frac{\partial Y}{\partial \alpha}\Delta \alpha + \frac{\partial Y}{\partial u}\Delta u$$

Where ΔY is the change of the process output, Y, α is a process parameter and $\Delta\alpha$ it's disturbance, u is a process input, and Δu is the input variation. A process can be brought under control by minimizing ΔY. This can be achieved a number of ways:

- We can hold *u* fixed and bring $\Delta u = 0$, this can be achieved by effecting tight control over operating inputs, the provision of steady state machine performance, and adherence to standard operating practices. In addition, $\Delta\alpha$ must be kept to a minimum, this is the goal of *Statistical Process Control,* the identification and minimization of disturbance.
- Another method is to hold *u* fixed and bring $\Delta u = 0$ as above, in addition, the sensitivity of the process, $dY/d\alpha$ must be minimized, this can be achieved through *Process Optimisation*
- Or one can manipulate Δu by measuring ΔY such that

$$\frac{\partial Y}{\partial \alpha}\Delta \alpha = -\frac{\partial Y}{\partial u}\Delta u$$

this describes the process of Feedback Control, compensating for the disturbances (not eliminating them).

In summary, a process can be brought under full control by:

- *Reducing disturbances* with the aid of standard operating practices, statistical analysis, identification of sources of error and feedback control of machines.
- *Reducing the sensitivity* of the process by increasing its robustness through use of optimised parameters. Measure sensitivities through design of experiments.
- *Process feedback control*, measure the output of a process and manipulate the inputs.

b) i) The output is then given by

$$x = KC_{HF}e^{AT}t$$

The influential process parameters are C_{HF}, T and time t. The sensitivity quotients are therefore:

$$\frac{\partial x}{\partial C_{HF}} = Ke^{AT}t$$

$$\frac{\partial x}{\partial T} = KC_{HF}e^{AT}At$$

Where variation in process output due to variations in process parameters is given as:

$$\Delta x = \frac{\partial x}{\partial C_{HF}}\Delta C_{HF} + \frac{\partial x}{\partial T}\Delta T + \frac{\partial x}{\partial t}\Delta t$$

Assuming that the time to complete the process is t_o, the variation equation for this example is

$$\Delta x = Ke^{AT}t_0\Delta C_{HF} + KC_{HF}e^{AT}At_0\Delta T + KC_{HF}e^{AT}\Delta t$$

ii) For fixed T and C_{HF}, the variation in process output is

$$\Delta x = \frac{\partial x}{\partial t}\Delta t = 0.005 * .02 * e^{0.05(300)} * 4 = 1307.6\,nm$$

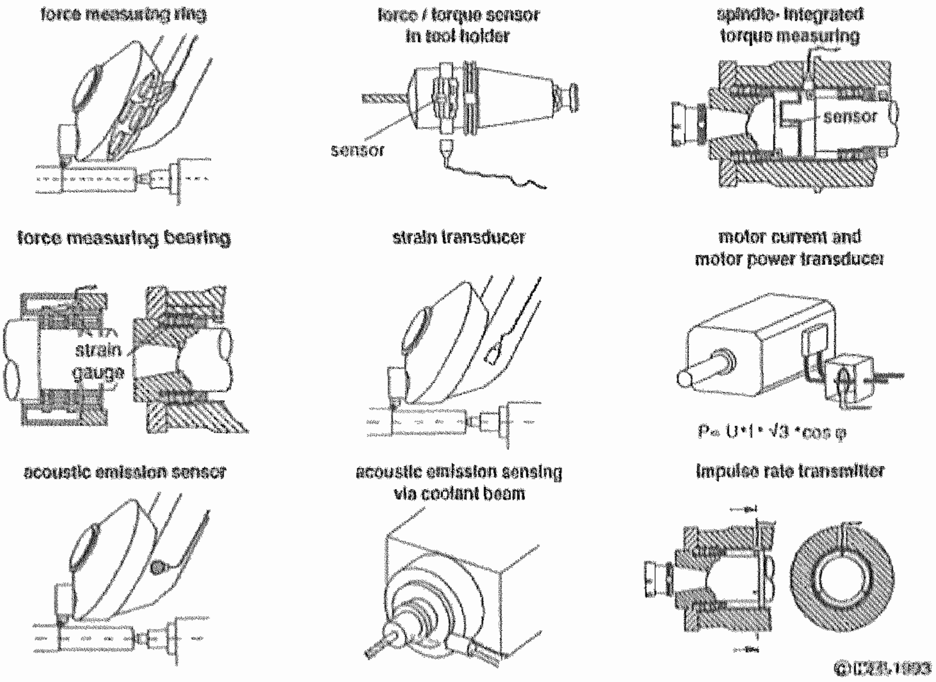
or 13 μm

Most students completed this question very well, with almost full marks on the calculation stage. For this reason, the percentage allocated to sections (a) was slightly increased relative to the later parts.

--------------End of crib for question 7 --------------

SECTION D: **Question 8**

(a) Six methods by which you could monitor the condition of a cutting tool in a machining centre:



b) 2 Manufacturing lines that deliver precision Al_2O_3ceramic washers for a new type of tap fitting.

(i) Manufacture of the washer: Given that the material is Al2O3, which is pretty hard material. There are a number of options.

- Obtain ceramic bar stock of the correct diameter (or powder met to rough shape, then implement step c)
- Diamond cut the washers near to the required thickness (n.b this will not produce the correct surface quality, a finishing process will be required)
- Use grinding, followed by diamond based lapping and polishing to deliver the correct thickness and finish as required. Note despite the subject of part a) answers involving single/multiple point machining are not correct.

ii) What are the Cp and Cpk values of each line, and percentage of parts within specification limits?

Line 1:

$$C_p = \frac{3.52 - 3.18}{6 * 0.07} = 0.81$$

$$C_{pk} = \frac{z_{\min}}{3} = \frac{3.35 - 3.18}{3 * \sigma} = 0.81$$

$$Z_{UCL} = \frac{UCL - \mu}{\sigma} = \frac{3.52 - 3.35}{0.07} = 2.43$$

$$Z_{LCL} = \frac{LCL - \mu}{\sigma} = \frac{3.18 - 3.35}{0.07} = -2.43$$

Using the tables for a normal distribution (data book)

P (z<zUCL) = 0.9925

P(z<zLCL) = 0.0075

Percentage of parts within the specification limits:

P=(0.9925-0.0075)*100% = **98.5%**

Line 2:

$$C_p = \frac{3.52 - 3.18}{6 * 0.05} = 1.13$$

$$C_{pk} = \frac{z_{\min}}{3} = \frac{3.52 - 3.43}{3 * \sigma} = 0.6$$

$$Z_{UCL} = \frac{UCL - \mu}{\sigma} = \frac{3.52 - 3.43}{0.05} = 1.8$$

$$Z_{LCL} = \frac{LCL - \mu}{\sigma} = \frac{3.18 - 3.43}{0.05} = -5$$

Using the tables for a normal distribution (data book)

P (z<zUCL) = 0.9641

P(z<zLCL) = 0

The percentage of parts within the specification limits:

P=0.9641*100% = **96.41%**

(iii) Implications and possible improvements.

Line 1 produces parts with less variation in size, but there is an offset error. In contrast, line 2 is more centred, but has greater variation. To improve these two lines, it would be necessary to explore the similarities and differences in set-up and also the machine itself. Line 1 has a more consistent set-up process, whereas the offset errors in line 2 might be due to poor set-up practices.

--------------End of crib for question 8 --------------