MET1 Paper 1 2007
Design and Manufacture
CRIB (J. Moultrie)

Crib: Question 1

a) If we define x along the axis of the tapered shell structure, y traverse to it and z upwards, there are three major degrees of freedom required for the movement.

- an unknown number of metres (several) in the y direction, depending on the separation of the two half moulds
- a lifting in the z direction of perhaps 3 metres, enough to be able to let something over 3m wide and perhaps 1 m deep be picked up and rotated 180 degrees on its axis and then be raised to that what was the top side and is now the bottom side is higher than the top side of the other half mould.
- a rotation of at least 180 degrees about the x-axis
- some degree of freedom to enable the lifting frame to grasp and control the half-mould, e.. a short (say half a metre) movement in the x direction to enable a lifting bar to be slid over the two pins at the broad end of the half mould and a lifting ring to be slid over the one pin at the narrow end of the half mould.

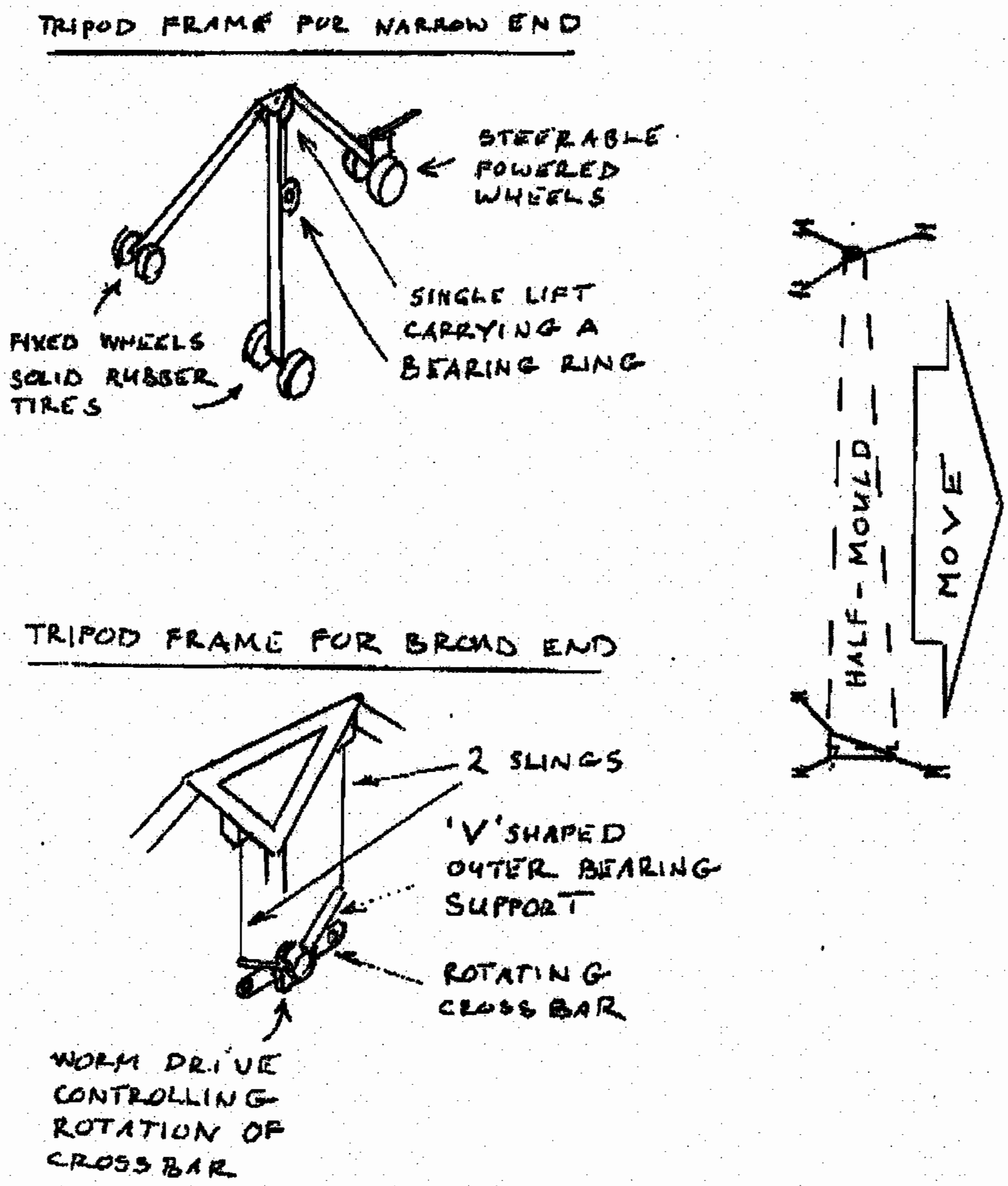
b) If we imagine, in lowering one half-mould on to the other, that the two mating faces come together, located by three tapering pins going into three mating locating holes, the half mould being lowered will not be exactly in the right place, so there needs to be ...

- controlled freedom of movement of the half-mould over a few tens of millimetres in the x direction at each end
- ditto but differently at each end of the half-mould in the y direction
- controlled freedom of movement in the z direction at all three pin locations to allow the two mating faces to come together smoothly. Note that this could be a simple vertical movement at the narrow end where there is one locating pin and it could be a vertical movement and a rotation (or two independent vertical movements essentially over the two pins) at the broad end

c) Essentially, because any crane involves the item to be moved being slung on sometimes quite lengthy cables (including separate lifting cables at each end of the half-mould say), the slight swing and toration available in the slinging allows all the detailed x and y movements to take place (and the z axis rotation). But this therefore also presents the need to control these swinging movements of something which is heavy. This involves skill and some physical manual input.

Because a gantry has powered movement along the building and the lifting unit has powered movement across the gantry, and can lift o the height of the gantry in the building, the major movements present few difficulties. However, depending on the orientation of the moulds in the building, it requires two gantries, or one gantry with two lifting units, and subsidiary equipment to control the mould rotation. These gantries require structure, rails, power and so on, which are the size of the building. This is very expensive on the one hand and at the same time restricts products to being smaller than the size of the building.

d) Lifting with cables from a little higher than the maximum lift point seems to have many advantages of allowing all the small movements to happen and be manually controlled. Tripod lifting frames on solid rubber wheels seem appropriate, one each end, one with one lifting frame having a ring which picks up the pin at the narrow end of the half mould, the other with two lifting units lifting a cross bar on which is mounted a controlled rotating head carrying another cross bar which picks up the two lifting pins at the broad end of the half-mould. The tripods are arranged to ensure that the lifted weight cannot tip the tripods over.



End of Crib for Question 1

Crib: Question 2

a)
The finger hold, which needs to be an interference fit into the pivot, allows the user to grip the compasses and rotate them.

The spring holds the two legs on to the pivot but also provides a moment about the pivot holding the two legs apart. This means that the thread interfaces between the screwed shaft and the inserts and also the interfaces between the inserts and the legs, are constantly preloaded one way, so there is no loose play.

The angular movement of the pivot (and of the inserts) is tens of degrees so it needs to be a close fitting smooth cylindrical interface.

The wheel allows the user to set the width between the compass point and the lead. It must be an interference fit on the screwed shaft.

The screwed shaft must have a plain section in the middle to mate with the wheel. Importantly, the two halves of the shaft must have a right hand and a left hand thread so that the legs are moved together or apart by the rotation of the shaft.

This means that the inserts are not identical, as one must have a right hand thread and the other a left hand thread. They must have a close, smooth cylindrical interface with the legs (see above).

The end pieces must be an interference fit on the threads.

The legs must have parallel, smooth, close-fitting cylindrical interfaces for the pivot and the inserts, and accurate locating grooves to locate and grip the point and the lead. It would appear that the point and the lead are of different diameters. If so, the two legs are not identical. They are also not identical because the clamping screw and nut detail is handed. This means that the threading, which has to be in only one half of the "C" shaped clamp detail, is in the opposite half of the "C" in the two legs.

The clamping screw and nut is presumably in fact a small assembly with a screw as an insert into the leg, threaded into the far face of the "C" and in a clearance hole through the near face of the "C".

The point needs to be sharpened and be a close sliding fit in the groove in its leg.

The lead needs to have a chisel end cut on it to give an accurate end point and it needs to be set in the slot in the leg so that the flat of the chisel is in the right orientation to give a thin pencil line when used. The lead also needs to be protruding the right amount to touch the end of the point when the two legs are closed together.

b)
The compasses are an assembly of 15 components (17 if the clamping screw and nut ate seen as two components) with rotating interfaces to allow the movement to take place. The following sketch makes the two legs and the spring as one pressing from thin steel, with the two legs given shape to sustain their stiffness and the section in between kept flat to act as a spring.

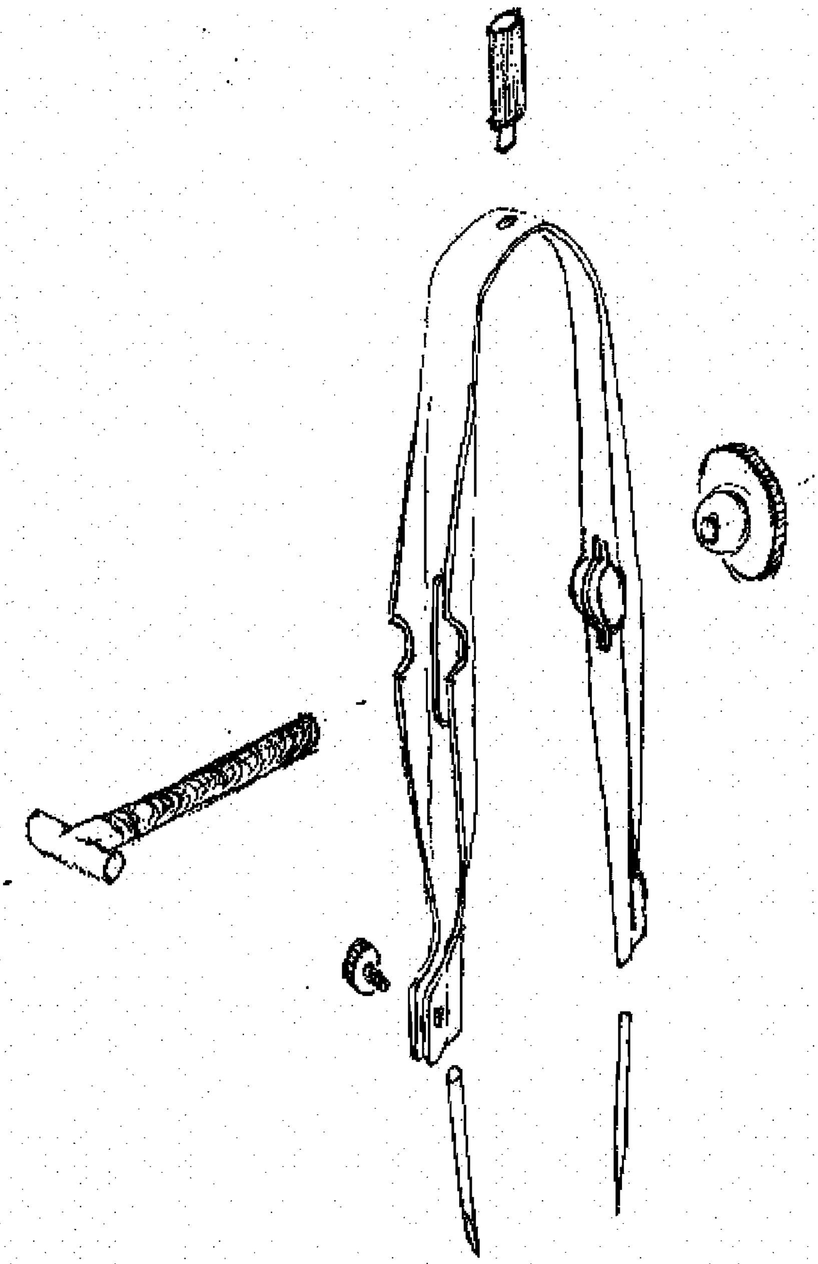
On one side, a cylindrical seating is pressed, with a slot through, to act as a seating for a hammerhead on a threaded rod. On the other side, a spherical seating with a similar slot through is pressed, to act as a seating for a finger wheel.

The finger hold is an interference fit in a hole in the centre of the spring section between the two leg sections of the pressing.

The point is made an interference fit in the pressed "C" shape of that leg.

The lead, and the clamping screw and nut can be essentially as before, but with the "C" shape pressed not cut. It would be good if the clamping screw was made integral with the nut. To do this it might be of larger thread diameter than the current design.

This is now 7 components.



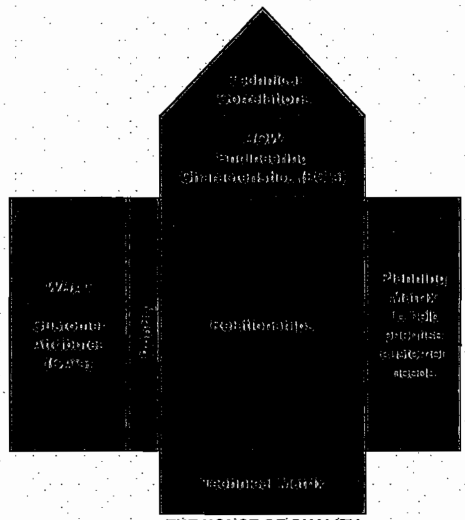
End of Crib for Question 2

Crib: Question 3

a) Students should first state the basic principles of QFD as a tool used by firms to help structure product planning and design, providing a set of planning and communication routines. In practice, the first step receives the most attention – "The House of Quality" (HOQ). The HoQ aims to relate customer needs to technical characteristics, to ensure customer needs are focused on throughout a design project – First during concept design and then to manufacture and market. These customer attributes can then be used to help select and prioritise design parameters. QFD is based on the belief that products should be designed to reflect customer's desires and tastes.

Students should be able to describe the HoQ as shown …

- **Several related matrices**
- **Central and most used aspect of QFD**
  1. **What - Customer attributes**
  2. ***How* - Engineering characteristics**
  3. **Relationships**
  4. **Technical matrix**
  5. **Technical correlations**
  6. **Planning matrix**



THE HOUSE OF QUALITY

In a good answer, students will brainstorm a (short list) of potential customer attributes, engineering characteristics and complete a portion of the HoQ, as below:

◎ STRONG RELATIONSHIP (9)
○ MODERATE RELATIONSHIP (3)
△ WEAK RELATIONSIP (1)

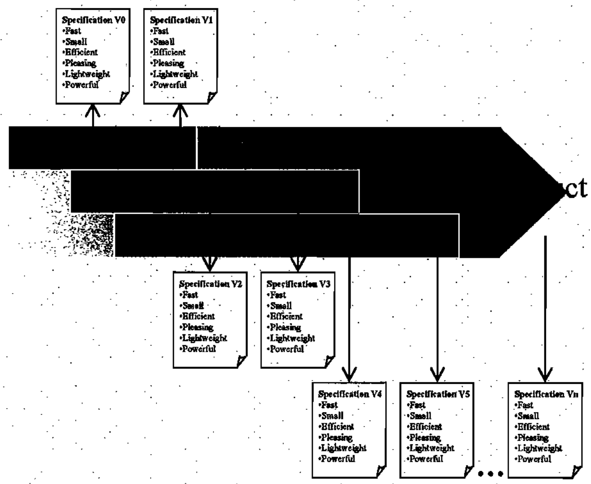
			Dimensions		Ergonomics			Maintenance		Performance		Life		
		PRIORITY	Weight	Size	Effort to operate switch	Location of switch	Size of switch	Time to replace batteries	Time to replace bulb	Beam spread	Beam range	Shock loading	Battery life	Shelf life
Ease of operation	Ease of handling	5	◎	◎						△	△		△	
	Ease of operating switch	3			◎	◎	○					○		
Performance	Life	3	○	○				△			○		◎	◎
	Brightness	4	○	○				△		◎	◎		○	
	Resistance to impact	2	◎		△	△	○					◎		
Ease of servicing	Ease of replacing batteries	2	△					◎			△	△	△	○
	Ease of replacing bulb	1							◎					
			86	66	29	29	15	27	9	41	52	27	46	33
			500 gms Max	0.004 Cu M Max	100 gms Max	See diagram - marked area A	1 sq cm Min	10 secs Max	20 secs Max	500mm Diam at 1m	10 lux min at 50 m	Standard 1m drop test	5 hours continuous usage	500 hours min

[50%]

b) The technical specification should be drawn from the analysis of part (a). It should list key product attributes and provide guidance on the range of acceptable parameters.

A good answer will recognise that the system and sub-systems need specifying and comment on the need for either quantification or qualification of all attributes. Students should also comment on the iterative nature of the specification, and that it should be updated as the design progresses.

Students may produce a table of key attributes, with desirable, acceptable and unacceptable performance.



[25%]

c) Here, the students should draw up at least one concept design for each of the three 'styles', annotating the sketches to describe why the style is appropriate and how it communicates the visual values intended.

"robust and rugged": the design should be blocky, metallic and dull colours, with large, chunky features, visually emphasise the robustness of the design.

"fast and fun": fast is perhaps best represented as a tapered design, suggesting motion, sharp angles and perhaps streamlining – or go faster stripes. The fun element could be communicated through bright colours, or perhaps turning the light into a character. Materials might include moulded plastics.

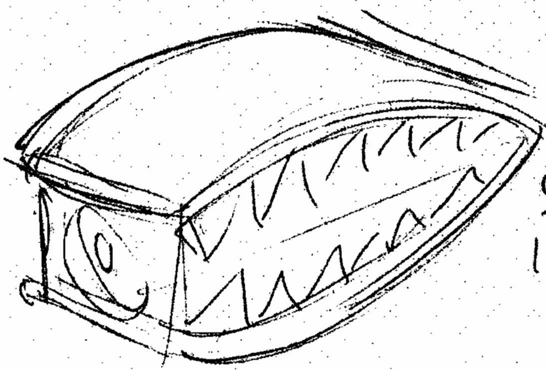
[25%]

Fast and Fun.

fast: Streamlined, go faster stripes

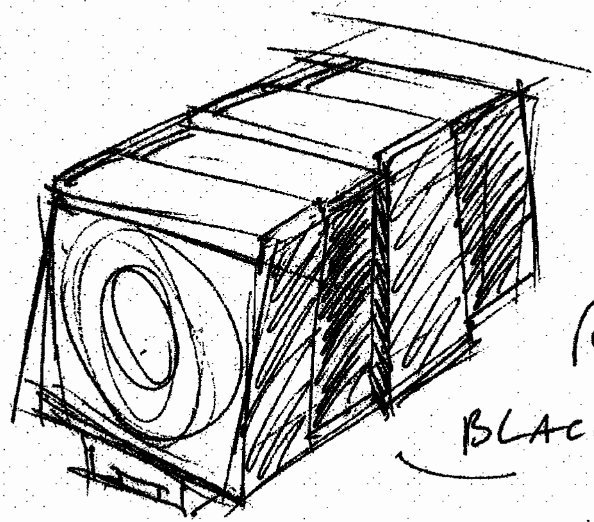
fun: bright colours, character.

– fast animal – jaguar, cat



Robust + Rugged

Blocky, metallic, dull colours
large, chunky features.

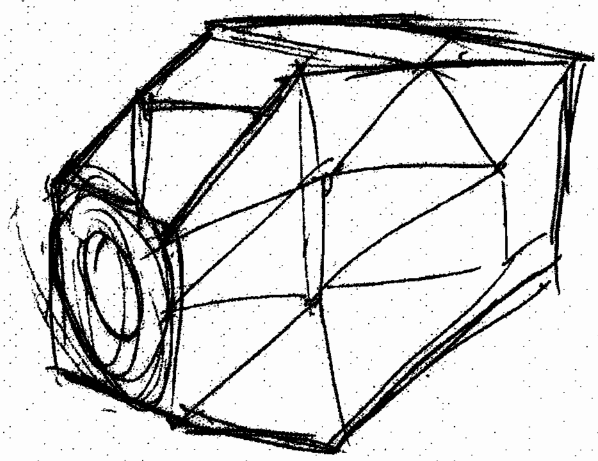


Taper – to emphasise stability

Ribbed side plates.

BLACK

or maybe draw inspiration
from "stealth" or power tools



facetted sides

End of Crib for Question 3

Crib: Question 4

a) Manufacturing process …

> Raw material: could either be bar stock or rectangular section, to size of part – probably rectangular section.

> Turn spigot A and face both faces of rectangular block.

> Might need to add a radius where the spigot meets the block (or an undercut). Might not want to produce the precise h6 fit all the way along the spigot.

> If made from round bar stock, might change the shape of the outside of the rectangular block to a diam 50 – to enable it to be turned.

> On milling machine, create rectangle and drill & c/sink holes

> The spigot might need cylindrical grinding

> Deburr

> Mask areas that don't need painting

> Paint

> Inspection processes could be at any time, but min at end.

b) From data book, the tol – 10h6 should be 10.000-9.991. Could achieve this through turning – however, the spigot is quite long and might need to be located in a centre. Depending on surface finish, it may need cylindrical griding.

c) Geometric tolerance …

Hole of 10H6 – 10.009 to 10.000

Part could not fit due to errors in straightness, parallelism, roundness etc.

Would expect to see a sketch drawing to show how each of these would be represented. Some answers may comment on using run-out or cylindricity, but should also then discuss the weaknesses of this approach.

d) Process capability

Batch 1: process capability, Cp = 0.467, Cpk = min(0.374 and 0.561) = 0.374 – indicating that the process is on the very limits of capability – and that you would expect to see some parts fall outside the USL and LSL, even though the process is well centred. Good students will produce a simple distribution curve to indicate the proportion within the +/- 3 sigma values.

Batch 3: process capability, Cp = 2.121, Cpk = min (2.357, 1.886), indicating that the process is capable of producing the parts, and not offset.

There is clearly some variation during the day. Good students will produce a simple distribution curve to indicate the proportion within the +/- 3 sigma values.

Good students will plot a control chart for the day's production and calculate the Upper Control Limit and the lowe control limit, UCL=9.999 and LCL=9.993

It is evident that the day's production is eratic, but that the process is basically capable. Care needs to be given to ensuring accurate mean values, given that the spread is not too large. This might be to do with set-up, tool wear or similar.

End of Crib for Question 4

Crib: Question 5

a) Companies need time standards for:

- production planning: measuring capacity, loading work to machines / departments, scheduling, line balancing
- Basis for costing and estimating
- Means of comparing between alternative methods
- Basis for incentive and payment schemes

b)

i) From the data, 59.1, 62.2, 58.4

$\xi = 59.9$

$s = 2.02$

95% confidence when $\xi \pm (t\ s) / (\text{sqrt } n)$

at $t_{97.5}$ 2 degrees of freedom = 4.303

Thus, $59.9 \pm (4.303 \times 2.02) / (\text{sqrt } 3)$ = 64.9s, 54.9s

ii) The learning curve has form $y = K x^{-A}$

% learning relates to A by $p = Z^{-A}$ (where 100p - % of learning curve)

Hence p = 0.9 ... A = 0.152

Substitute y = 59.9 and x = 100

(assuming that the statistical fluctuations are much greater than then learning affects between components 99 to 101 and hence ξ is best estimate for time for 100th components.)

Gives ... $K = (59.9) / (100^{-0.152}) = 120.6$

Total time for next 100 components (i.e. parts 102-201) is ...

Integral between limits 101.5 and 201.5 of ... $\int 120.6\ x^{-0.152}\ dx$

$= (120.6 / 1\text{-}0.152)\ [\ x^{(1-0.152)}\ ]$ limits 201.5 -101.5

Note ... limits as we are using a continuous function to approximate to sum discrete values.

= 5642s

= 94 mins

NB, if limits of 102-202 are used, then will get 5639. If Limits 102-201 are used will get 5585

iii) Learning curve model would give:

Time for 500th component … 47s

Time for 1000th component … 42s

Time for 5000th component … 33s

Basic time for batch of 500 approx = 7.6 hour

Basic time for batch of 1000 approx = 13.8 hours

Basic time for batch of 5000 approx = 54 hours

Without knowing the specific nature of the operation, we can only raise the issues. These are

a) at what point does the learning cease to follow the same curve. Any sensible discussion about physical limits to speed of natural movements would be acceptable here.

b) What is the effect of forgetting? Should comment on batch 500 will take longer than 1 shift [if basic time is 7.6 hours, standard time would be in the region of 1.15 x 7.6 = 8.8 hours). A batch of 5000 will take longer than a week. Sensible discussion about the effects of forgetting from one day to the next and over a weekend break would be acceptable.

End of Crib for Question 5

Crib: Question 6

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

SELECT	the work to be studied.
RECORD	all the relevant facts about the present method by direct observation
EXAMINE	those facts critically and in ordered sequence
DEVELOP	the most practical, economic and effective method
DEFINE	the new method so that it can always be identified.
INSTALL	that method as standard practice.
MAINTAIN	that standard practice by regular checks

b) The Principles of Motion Economy can be grouped as follows

- Use of the Human Body,
- Design of the Workplace, and
- Design of Tools and Equipment.

Below is a full description, it is unlikely that students will cover in such depth, but would expect most of the main points in each category.

Use of the Human Body

1. The two hands should begin and complete their movements at the same time.
2. The two hands should not be idle at the same time except during periods of rest.
3. Motions of the arms should be symmetrical and in opposite directions and should be made simultaneously.
4. Hand and body motions should be made at the lowest classification at which it is possible to do the work satisfactorily. The classification of movements is:

1. **First Joint**.	Knuckle	**Moving**	Finger
2. **First Joint**.	Wrist	**Moving**	Hand and Finger
3. **First Joint**.	Elbow	**Moving**	forearm hand and finger
4. **First Joint**.	Shoulder	**Moving**	upper arm, forearm hand and finger
5. **First Joint**.	Trunk	**Moving**	Torso, upper arm, forearm hand and finger

5. Momentum should be employed to help the worker, but should be reduced to a minimum whenever it has to be overcome by muscular effort.
6. Continuous curved movements are to be preferred to straight-line motions involving sudden and sharp changes in direction.
7. "Ballistic' (i.e. free-swinging) movements are faster, easier and more accurate than restricted or controlled movements.
8. Rhythm is essential to the smooth and automatic performance of a repetitive operation. The work should be arranged to permit easy and natural rhythm whenever possible.
9. Work should be arranged so that eye movements are confined to a comfortable area, without the need for frequent changes of focus.

Arrangement of the workplace

1. Definite and fixed stations should be provided for all tools and materials to permit habit formation.
2. Tools and materials should be pre-positioned to reduce searching.

Hand tools should be picked up with the least possible disturbance to the rhythm and symmetry of movements. As far as possible the operator should be able to put down a tool as the hand moves from one part of the work to the next without making a special journey. Natural movements are curved, not straight; tools should be placed on the arc of movements but clear of any material   Tools should be easy to pick up and replace; as far as possible they should have an automatic return, or the location of the next piece of material to be moved should allow the tool to be returned as the hand travels to pick it up.

3. Gravity feed, bins and containers should be used to deliver the materials as close to the point of use as possible. If similar work is being done by each hand, there should be a separate supply materials or parts for each hand
4. Tools, materials and controls should be located within the maximum working area and as near to the worker as possible.
5. Materials and tools should be arranged to permit the best sequence of motion
6. "Drop deliveries" or ejectors should be used wherever possible, so that the operative does not have to use his hands to dispose of the finished work.

   Finished work should be—

   (a) dropped down a hole or a chute ideally when the hand is starting the first motion of the next cycle;

   (b) put in a container placed so that hand movements are kept to a minimum;

   (c) if the operation is an intermediate one, placed in a container in such a way the next operative can pick it up easily.

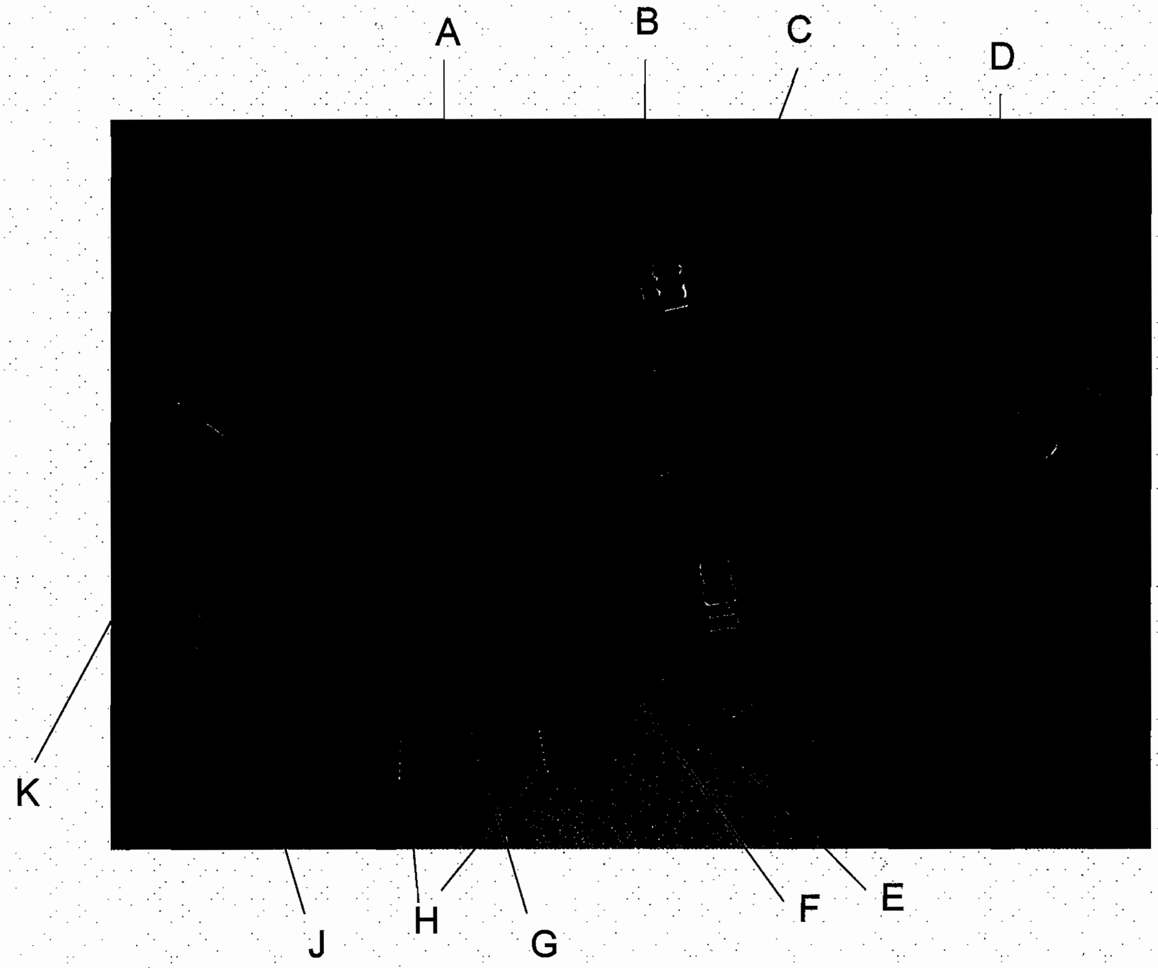
7. Provision should be made for adequate lighting, and a chair of the type and height to permit good posture should be provided. The height of the workplace and seat should be arranged to allow alternate standing and sitting.
8. The colour of the workplace should contrast with that of the work and thus reduce eye fatigue.

If the eyes are used to select material, as far as possible the material should be in an area where the eyes can locate it without there being any need to turn the head. (The nature and the shape of the material obviously influences its position in the layout.)

Design of tools and equipment

1. The hands should be relieved of all work of "holding" the workpiece where this can be done by a jig, fixture or foot-operated device.
2. Two or more tools should be combined wherever possible.
3. Where each finger performs some specific movement, as in typewriting, the load should be distributed in accordance with the inherent capacities of the fingers.
4. Handles such as those on cranks and large screwdrivers should be so designed that as much of the surface of the hand as possible can come into contact with the handle. This is especially necessary when considerable force has to be use on the handle.
5. Levers, crossbars and handwheels should be so placed that the operative can use them with the least change in body position and the greatest "mechanical advantage"

Components on diagram should be labelled. Suggestion ..



The workstation is laid out to enable where possible simultaneous use of both arms. Components positioned within the optimum working area and in sequence of use working from middle. Fixed stations for all tools and materials.

Components supplied in magazines which present subsequent parts in identified position, except screws which are bulk or ideally automated feed to air drivers.

Gravity allows next part to position as previous part removed.

Typical assembly sequence:

LH	RH
(remove previous)	Load F to fix
Pick and insert J in F	Pick and insert E in F
Pick and insert A in F	Pick and place G in F
Pick and place B in F	Pick and move C to F
Hold B	Clip C to E and B
-	Pick and place D on F
Close fixture to clamp	Hold
Rotate fix through 180deg	Pick K

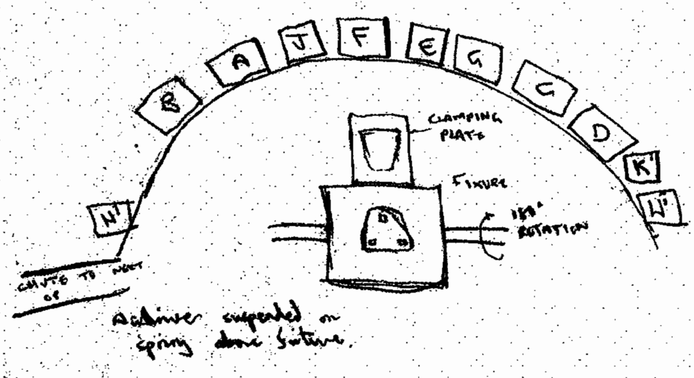
Get Airdriver 1	Locate K
Drive K to torque, release	-
Pick and place H	Pick and place H
-	get Airdriver
-	Drive both H to torque, release
Rotate & unclamp fix	-
Remove assembled plug	(load F)

Assembled plug placed on a chute feeding into and outer packing machine or other operation, maintaining orientation. Note overlap with next op starting.

It is not expected that detailed fixture design be done.

Some standards might suggest fixtures allowing simultaneous assembly of several plugs, this would probably speed the operation at increased tooling cost.

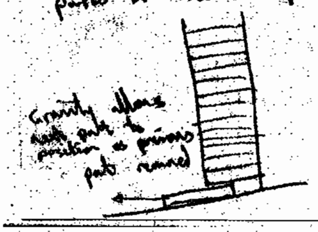
General Arrangement



[i) No. needed of air drivers with auto screw feed used]

The workstation is laid out to enable where possible simultaneous use of both arms. Components positioned within the optimum working area, and in sequence of use working from middle. Fixed stations for all tools & materials.

Components supplied in magazines which present subsequent parts in identical position, except screws which are bulk or ideally automated feed to airdrivers



End of Crib for Question 6

Crib: Question 7

a)
Blank Design. Scrap reduction is the primary concern in blanking operations. Poorly designed parts will not nest effectively leaving a considerable amount of scrap between successive blanking operations. Tool and die tolerances are also critical for the production of sharp edges with minimum tearing and edge rounding.

[5%]

Bending. Bending operations are the main cause of fracture and wrinkling in sheet metal forming. Relief notches are usually applied to flange section blanks to avoid tearing and wrinkling. Holes near bend lines should be avoided as the bend area is highly stressed zone that will often distort nearby holes. The tool design must take into account Springback effects that will occur after processing.

[5%]

Stamping and Progressive Die Operations. In progressive die operations, the cost of tooling and number of stations are determined by the number of design features and their spacing. The number of features must be held to a minimum to reduce tooling costs.

[5%]

Deep drawing. . In deep drawing operations the Springback effect can be minimised by using relief angles of at least 3degrees on each wall of the punch and die. Sharp radii are very difficult to produce and deep cups often require ironing operations.

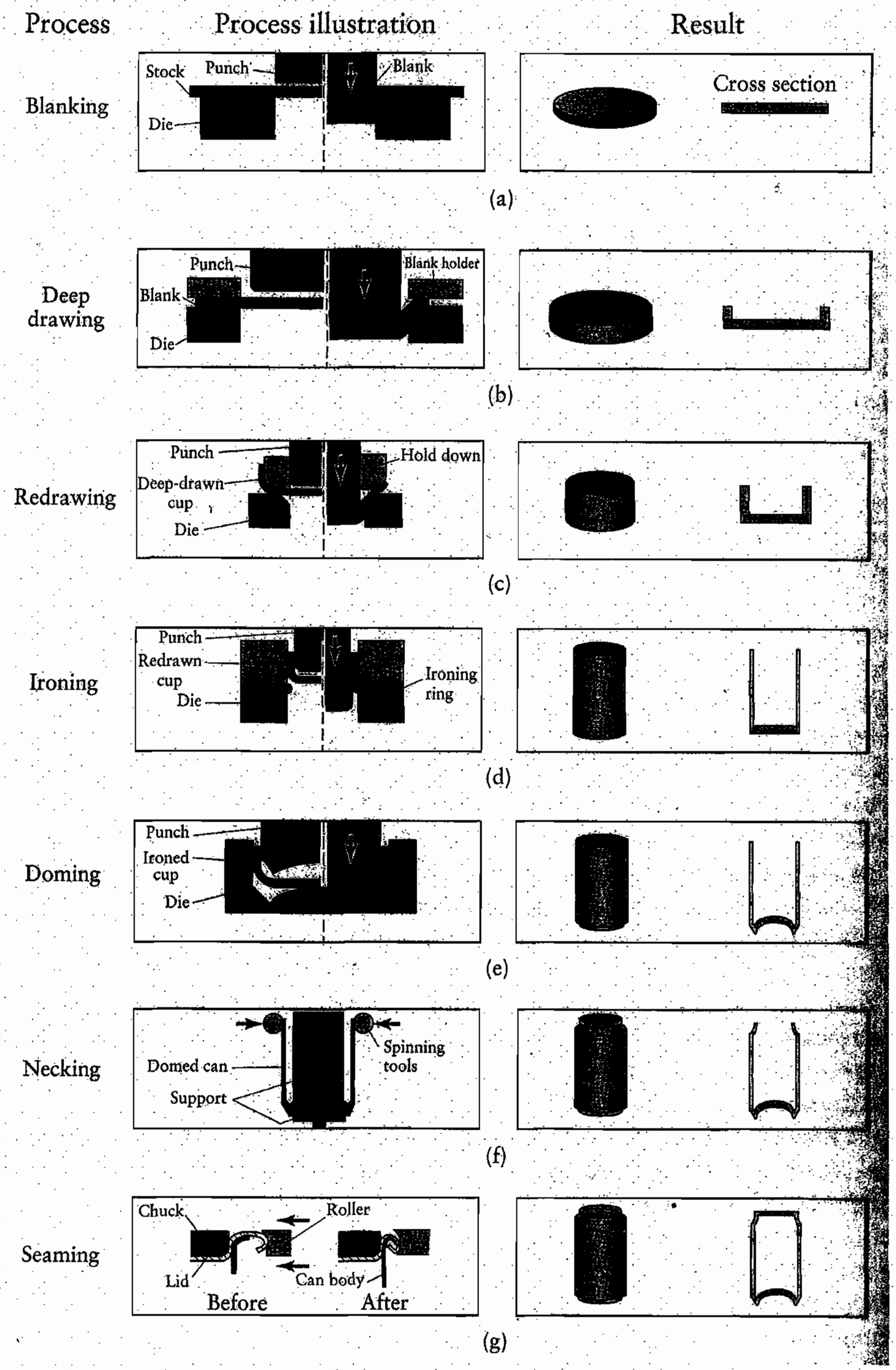
[5%]

b)
A sequence of operational steps for a two-piece aluminium can manufacture is as follows. Modern cans are generally produced through a mechanical process that involves punching a flat blank from very stiff cold-rolled sheet. This sheet is typically alloy 3104-H19, which is aluminum with about 1% manganese and 1% magnesium to give it strength and formability. The flat blank is first formed into a cup about three inches in diameter using drawing and re-drawing processes. This cup is then pushed through a forming process called "ironing" which forms the can. The bottom of the can is then domed. The metal has now formed into the shape of an open-top can. The side of the can is significantly thinner than either the top and bottom areas, where stiffness is required. One can-making machine can turn out about 500 cans per minute.

Plain lids are stamped out from a coil of aluminum and are transferred to another press that converts them to easy-open ends. The conversion press forms an integral rivet button in the lid and scores the opening, while concurrently forming the tabs in another die from a separate strip of aluminum. The tab is pushed over the button which is then flattened to form the rivet that attaches the tab to the lid.

Finally, the top rim of the can is trimmed and pressed inward or "necked" to form a taper where the can is filled and the lid (usually made of an aluminum alloy with magnesium) attached by a roller seaming process.

Sequence of Manufacturing Operations:



Score 5% for each process step. Score 15% for correct description of can lid manufacture.

c)

The workpiece to be bent or formed is heated by a laser in a restricted area. The thermal expansion of the heated section is restrained by the surrounding cold material; as a consequence compressive stresses are generated. Within the period of heating the yield stress in the heated area is reduced and thereby the compressive stresses cause permanent compressive plastic strains after reaching the yield stress. After switching off the laser the workpiece cools and is shortened laterally by free thermal contraction, the sheet bending towards the laser system. Necessary requirements for the thermally controlled laser bending are a comparatively high laser power P_L in correlation with a small focus diameter d_L and a high laser scanning velocity v_L. The proportion of focus diameter to sheet thickness should be in the range of 3–4. Typically bending angles of between 1° and 2° can be reached within one irradiation.

[20%]

Thermally controlled laser bending is used in a number of applications;

Microsystems alignment.

Compact disc read heads contain a lens that is mounted on a pressed steel bracket. Laser bending is used to align the lens for optimum precision. The operation is performed at high speed and can be used to align the lens in three dimensions.

<u>Sheet formed</u> parts can be re-aligned to reduce Springback effects, this application is used for final alignment prior to laser blank welding operations.

<u>The arts and crafts</u> world use laser forming to produce complex three-dimensional forms without contact tooling.

Score [10%] for any of the above examples

End of Crib for Question 7

Crib: Question 8

a)

1 Tolerances.

While moulds and dies can be made to close tolerances, the great sensitivity of dimensions to processing conditions, post-processing changes (polymerisation, crystallization, loss of plasticiser, aging, relief of residual stresses) dictates that tolerances be as wide as permissible for the given application.

[5%]

2 Parting line.

As in die casting and forging, the parting line must be chosen to minimize the complexity of the mould, avoid unnecessary undercuts that would necessitate complex movable inserts and cores, and minimize the cost of removing flash, for example, by allowing flash removal by tumbling. Distortion is minimized when the gate is placed so as to give symmetrical mould filling.

[5%]

3 Wall thickness.

The removal of gases (produced by reactions or entrapped during the compaction of particulate starting materials) must be allowed and encouraged. This sets a practical limit of *100-200* mm to the maximum thickness attainable without gross porosity. The low heat conductivity of plastics limits heating rates and thus also the economical thickness of thermoformed parts, typically to below 6 mm. The minimum attainable wall thickness *is* limited in moulding by the difficulty of removing very thin parts from the mould, and also by the high pressures required to fill at a high width-to-thickness ratio. Large wall-thickness variations are just as undesirable as in metal casting.

[5%]

4 Ribs.

Distortion is often minimized by ribbing larger surfaces. The width of ribs is kept small to prevent the creation of large hot spots. Doming is an attractive alternative, especially in cylindrical parts.

[5%]

5 Drafts and radii.

Release from the mould requires a draft of *0.5-2°*, and even larger drafts on ribs and bosses. Tight corners can be filled, but generous radii increase die life and prevent stress concentrations in service. Minimum radii of 1-1.5 mm are recommended.

[5%]

6 Holes.

Through-holes are limited only by the strength of the core pin and are usually held below a length-to-diameter ratio of 8. Freely extending core pins are needed for blind holes; therefore, such holes are limited to a depth-to-diameter ratio of 4 for $d > 1.5$ mm and to a ratio of 1 for smaller holes. Threaded holes of 5-mm diameter and over can be moulded directly, preferably with a coarse thread. Smaller holes are best drilled.

[5%]

7 Inserts.

The use of moulded-in metal inserts greatly expands the scope of application for plastics and very often eliminates problems in subsequent assembly, although at some expense. Threaded inserts, binding posts, electric terminals, anchor plates, nuts, and other metallic components are moulded into plastics by the millions. Some precautions are necessary, however. The shape of the metal part must ensure mechanical interlocking with the plastic, for example, by heavy knurling, since there is no adhesion between metals and plastics-at least not without special surface preparation. The thermal expansion of plastics is much larger than that of metals; this helps to shrink the plastic onto the insert, but could also cause cracking of a brittle plastic. The wall thickness around the insert must therefore be made large enough to sustain the secondary tensile stresses.

[5%]

b)

Material Choice

Injection moulds are mainly made of Al alloys, conventional alloy steels and tool steel alloys such as H10 and H13 grades. The choice of material is largely determined the by the number of parts that are required. Al alloys are good for most polymer materials although the lifetime of the tool is restricted to tens of thousands of parts depending on the material being injected. Alloy steels such as C-Mn steels are good for a few hundred thousand parts. Tool steel moulds can produce many millions of parts before significant wear is observed. Another advantage of tool steel is the ability to hold a very high quality finish; this provides the opportunity to produce parts with optical quality surfaces. Given the need to produce millions of parts, the correct choice of material would be H10 or H13 tool steel.

[6%, 1 mark for each material, 3 marks for choosing tool steel]

Manufacturing routes

Tool steel mould cavities are often die sunk using EDM (Electric Discharge Machining) processes that progressively approach the final cavity geometry using a number of shaped electrodes each one having a progressively better finish. The last electrode will have a surface finish equal to that required on the polymer part. The final cavity is polished to achieve the required surface finish. In this case a high grade tool steel mould would be used as it can achieve a surface finish with a Ra of less than 0.2 microns. Modern high speed milling machines, operating with a tangential cutter velocity greater than ~100m/s, can machine heat-treated tool steels directly. This approach is used for the production of shallow toolsets and toolsets with low complexity.

[7% for identifying EDM processes and multiple electrodes; 7% for identifying high speed milling for cavities with lower complexity]

c)

When using aggressive compounds such as glass filled nylons, it is very often found that there is erosion near the gate. Those parts of the mould subject to wear should be easily exchangeable. Various plastics also produce volatile constituents during moulding, some of which can be deposited on the cavity surface and mating faces. In both cases the mould and vents must be cleaned at regular intervals or during normal maintenance programmes. A hard mould surface facilitates easy cleaning. Moulds tend to become damaged with use, leading to poor quality mouldings. Tell-tale signs are an increasing amount of flash on the parting line. Regular inspection of the parts can provide an early sign of tool wear.

[4% for identifying gate erosion, 4% for blocked vents, 4% for contaminated surfaces, 8% for identifying tool wear through the observation of excessive flash at the parting line]

d)
Rapid Tooling is a means of transferring non-functional models constructed from the range of rapid prototyping techniques into a functional prototype part. Rapid Tooling can utilise rapid prototype models in two ways, as a master for the production of casting moulds or as a sacrificial pattern for one casting. At this stage of the manufacturing process the rapid prototype model becomes less significant than the next step, the development of tooling. Tools need to be manufactured to specification and must be durable enough to last a certain number of injections.

[15%]

Production Routes:
Metal spray
Electroforming
Silicone Moulding
Selective laser sintering
Laminated object manufacturing
Slip casting
Resin moulding

[2% for each correctly identified method, score maximum of 10% here]

End of Crib for Question 8