Understanding how a product is assembled

GETTING STARTED

Have you heard of the term reverse engineering? With a partner, discuss the reasons why design engineers may need to disassemble a product to find ways of improving it.

One method of developing a product is to look in detail at what is already available. This can be done in a number of ways, although one of the most effective methods is known as reverse engineering.

Reverse engineering

Reverse engineering is the process of disassembly and analysis of a product to investigate how it was manufactured and the purpose of the components from which it is made.

Reverse engineering can include some, or all, of the following:
- disassembling the product down to its component parts
- analysing the design features of the product and its components.

When reverse engineering a product, remember to do this logically and record all stages of the process

Disassembly

Disassembling a product is the first stage of a reverse engineering exercise. It is good practice to lay out all the component parts of the product so that they can be analysed in turn. Do the following:
- If possible, locate any assembly drawings for the product you are disassembling.
- Make sketches, or take photographs, of every stage of the process.
- Note down details of each component, especially any numbers, values or marks that they may have.
- List the tools and equipment used at each stage of the process. Your records should be good enough to allow another person to be able to put the product back together again.

ACTIVITY

Practise disassembly on a product that has at least six components (perhaps an old unimportant product that is no longer required).

1. Disassemble the product, making notes of all the tools and equipment used at each stage.
2. Produce sketches to show the order of disassembly.
3. Use your sketches and notes to produce a plan for the reassembly of the product.

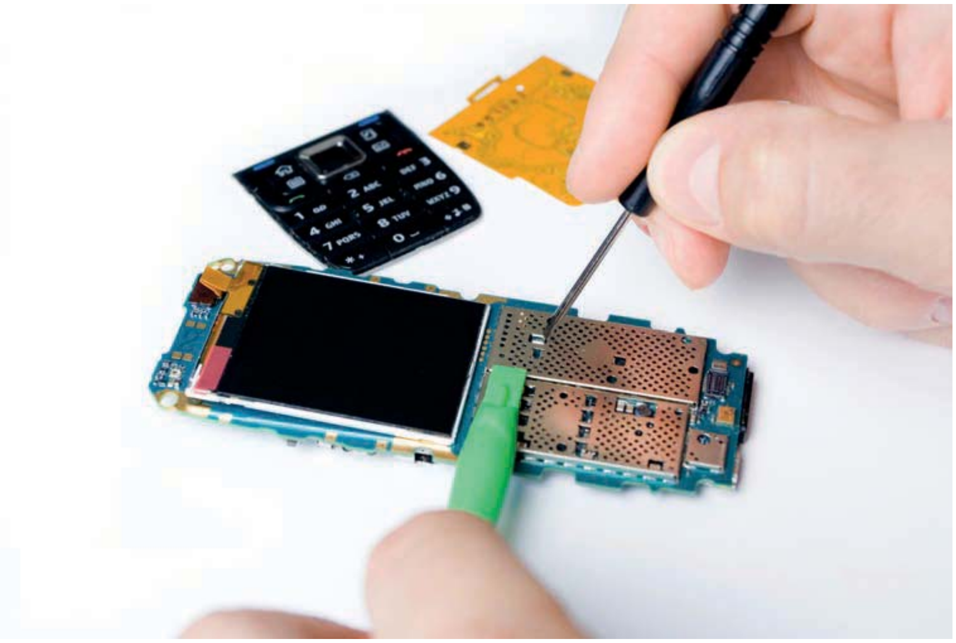
Disassembling a product can be a vital stage in the development of something new. While you are not going to copy the design, it will give you an idea of how the original product was made, what the components are and what they are used for, and the stages of manufacture.

You can use a product disassembly exercise to help plan production and redesign components or a whole product. Whenever possible, you should make sketches of the parts of the product and the stages you have completed. These could be used to produce exploded diagrams and assembly drawings, which will be covered later.

Make a list of all the components and the order in which you have removed them from the product. It could be a problem if you have taken a motor apart and then find, when you think you have finished putting it all back together again, that there are three screws and a spring left over!

LINK IT UP

Later in Component 3, different methods of presenting engineering information, including exploded diagrams, will be investigated.



Disassembling a product can also help if you need to repair the product later

DID YOU KNOW?

Reverse engineering is not just used to analyse an existing product to see how it works. Many classic cars, steam railway engines and old aircraft are still in use today only because of reverse engineering. It has allowed engineers to manufacture replacements for obsolete components.

CHECK MY LEARNING

You have learned about the reasons why an engineer might want to disassemble a product.

Working in pairs, think about the different tools you will need to use when disassembling an engineered product.

Handling and using materials, equipment and machinery

GETTING STARTED

Make a list of the types of metals that you think can be used in an engineered product.

Materials can be categorised in different ways. In engineering, we often think about metals, polymers, composites and smart materials.

Using materials

LINK IT UP

In Component 2: Learning aim A, you looked at various materials that are used to make engineered products.

KEY TERM

Alloys are mixtures of two or more metals that have improved properties and characteristics..

Ferrous metals

These are metals that contain iron. Other metals are often added to iron to produce ferrous **alloys**. Materials such as stainless steel and high carbon steel are examples of ferrous metals.

Non-ferrous metals

These are metals that do not contain any iron. They can be pure metals, such as copper or titanium, or they can be alloys, such as brass and bronze. Sometimes non-ferrous metals are alloyed with ferrous metals, as is the case with stainless steel. Normally, the alloying process improves the properties of a material – for example, to make it stronger or more resistant to corrosion.

Thermosetting polymers

These are polymers that can be heated and formed once, but after that they cannot be re-formed. They are useful for applications where a lot of heat is produced, such as in electrical fittings or domestic appliances, e.g. kettles.

Thermoforming polymers

Unlike thermosetting polymers, thermoforming polymers can be heated time and time again and re-formed each time. Some of the common thermoforming materials you may have come across include acrylic and polystyrene.

Safe handling of materials

For each type of material, there are specific handling methods that need to be followed carefully. For example, when handling sheet steel, you will need to wear protective gloves because of the sharp edges, safety boots because of the weight (in case you drop the material), and work overalls to protect your skin and prevent clothing from becoming dirty.

If materials are hot, you will need to wear heat-proof safety gloves. Safety glasses should be worn to protect your eyes whenever you are cutting materials or handling awkward or long lengths of material that could catch you in the eye.

The form and shape of the material supplied can impact on safe handling procedures. Most metals are purchased in a specific form. However, polymers can be supplied as a resin or a powder. This can lead to a whole different set of safety hazards and safe working requirements.

Many material forms are supplied with a safety data sheet, which will give information on:

- safe handling and storage requirements
- PPE that should be worn
- what to do if there is an accident or spillage.

You should always try to transport and use materials in their safest form. For example, if you are able to cut a 3 m length of bar material into smaller sections before moving it from stores to where it is needed, then you should try to do this.

Using equipment and machinery

You should only use equipment and machinery that you have been instructed how to operate, so you are aware of the safe working practices that need to be followed.

Some equipment and machines can only be used with certain materials. It is therefore important to check that the equipment or machinery is suitable for the process. Always get permission before using any piece of equipment or machinery.

ACTIVITY

Engineers work with many different types of material, each with different handling requirements.

1. Research methods of handling a range of metallic and polymer materials.
2. List the safe working practices advised for each material.
3. Record the PPE that should be used and the reasons for its use.

Materials are available in many forms and shapes

CHECK MY LEARNING

You have revisited the types of material that can be used to make an engineered product. You have also looked at forms of supply for materials.

In a small group, discuss why specific equipment is used with certain materials.

Recording the process

GETTING STARTED

Working in a small group, discuss and make a list of the values you think would be important when collecting data for engineered components – for example, the material that components are made from and their dimensions.

KEY TERMS

Accuracy depends on the way in which measurements are taken and how they are recorded.

Degree of accuracy is half a unit on either side of the unit of measure; if the unit is 1, then any measurement between $9\frac{1}{2}$ and $10\frac{1}{2}$ will be measured as 10.

Reliability depends on there being only small variations in data and measurements being within tolerance.

Precision refers to the closeness of two or more measurements to each other. For example, if you weigh a given substance five times, and get 3.2 kg each time, then your measurement is very precise.

Measuring and recording data

For the results of investigations to be useful, data must be recorded correctly. This means that information must be recorded with accuracy and precision, categories need to be decided, and you should use the correct units for measurements.

Accuracy

When you record data, it is important to record values with **accuracy**. This means that any measurements are within an agreed tolerance level. For example, the measurements of the length of a machine screw could be recorded in millimetres instead of taking measurements to a fraction of a millimetre. This is also known as **degree of accuracy**. It is important that you also record values against the correct data group, otherwise the results will be unreliable.

Reliability is important when analysing information. If there are mistakes in measurements or recorded data, the results will not be reliable and could lead you to draw the wrong conclusion and thereafter make decisions that are not appropriate. When you collect and record data, you need to make sure that your data are both accurate and reliable.

Precision

When you are recording data, one of the decisions that you will need to make is the degree of **precision** required. This will depend on what you want to use the data for. If it is to find out the average time it takes to complete a task, then the level of precision will be quite high; if you need to find out how many pan head machine screws you have, then the level of precision will be low – unless you want to know how many of each different length you have.

When you decide on the level of precision needed for your data collection, you should think about the following questions:

- Can the data be divided in more than one way?
- How important is it to divide the data into very small groups?

Units of measurement

When you record data from investigations, you need to choose units of measurement that are sensible and appropriate. For example, if you were timing how long it takes a ball to roll down a ramp, a sensible unit of measurement would be seconds, not minutes or hours. The lengths of fixings would be sensibly measured in millimetres, not metres or kilometres. However, the distance a car travels in an hour would be better measured in kilometres.

LINK IT UP

Component 2: Learning aim B covered practical skills for measuring diameters and linear dimensions and methods to find out the values of electronic components.

Tabulation of data

When you collect data, you will also need to record it. This is probably best done using a table where you can include the categories the data are split into and the units of measurement. It is probably easiest to use a tally chart, as shown in Table 3.1, to record sets of data where large quantities are involved.

You could also record exact values in a data collection chart like the one shown in Table 3.2, which has been used to record data on the load applied to and the resultant extension of a metal component.

Table 3.1: Tally chart

Diameter of screw (mm)	Tally	Total
4	𝍸 𝍸 𝍸 III	18
5	𝍸 𝍸 II	12
6	𝍸 𝍸 𝍸 𝍸 III	23
8	𝍸 𝍸 𝍸 IIII	19

Table 3.2: Data collection chart

Load–Extension data								
Load (newtons)	50	75	100	125	150	175	200	225
Extension (mm)	14	26	38	50	62	74	86	98

ACTIVITY

Working with a partner, collect a random selection of either mechanical fixings or electronic components. Separate the components into groups or categories and carry out investigations into the following (record the results with accuracy so that they are reliable):

1. Take measurements using suitable measuring equipment, or read the values of the components.
2. Record the results of the investigation in a table.

Once complete, discuss what you think the information from the results shows.

CHECK MY LEARNING

You have learned about different methods of presenting data, including the use of tabulation.

Using a set of data related to either mechanical or electronic components, tabulate the data by categorising the components and recording the numbers of each. With a partner, discuss how accurate your results are, how good your chosen categories are, and whether and how you could improve the accuracy of the results if you were to undertake the same activity again.

Displaying data using charts and graphs

GETTING STARTED

In pairs, see if you can identify any **trends** in the data from the previous lesson, either in the raw data or in the tabulated form.

KEY TERMS

Trends are patterns in data, e.g. values might increase for one variable as the values decrease for another.

Charts are usually used when data are being presented in groups.

Graphs are used to plot individual data values.

We have looked at ways in which data can be recorded from investigations. Next we discuss how the data may be displayed. This can be done graphically using **charts** and **graphs**.

When deciding which type of graph or chart to use, you need to think about the type of data you are showing and what information about the data you want to share. For example, the results of an investigation into the diameter of screws could be presented in a graphical chart, where shapes are used to represent data. Alternatively, a graph could be plotted for the load–extension investigation in Table 3.2, with a line graph used to represent the data.

There are many types of chart and graph that are used to present data. Some are listed in Table 3.3.

Table 3.3: Types of chart and graph

Chart type	Graph type
Pie chart	Line graph
Bar chart	Scatter graph
Pictograph	

Types of chart

To compare the types of chart, look at how the data collected for the diameter of screws in Table 3.1 can be presented in different ways:

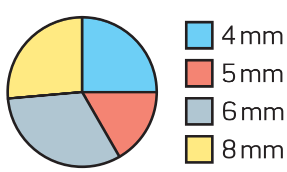


Figure 3.2: Pie chart

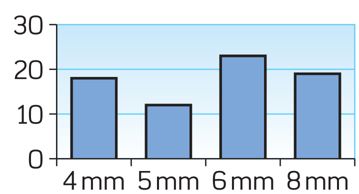


Figure 3.3: Bar chart

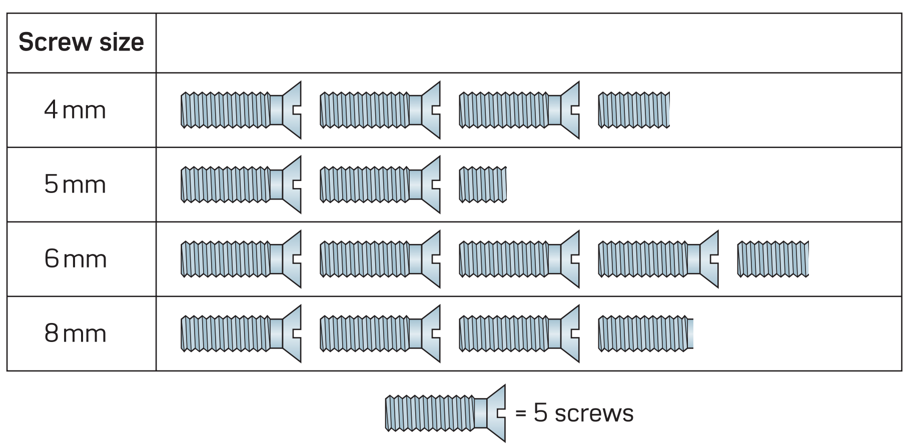


Figure 3.4: Pictograph

Pie charts are good for showing the relationship between individual groups of data and the total amount of data. They show each group as a proportion of the total. In Figure 3.2, each sector, or slice of the pie, represents the quantity of each size of screw as a proportion of the total number of screws.

Bar charts are useful for identifying trends, such as what is most popular or what happens the most. In Figure 3.3, it is easy to see that there are more 6 mm screws than the other sizes. The **scale** of the chart is important, so check the scale on the *y*-**axis** and try to use scales that are easy to interpret. Vertical bar charts are also known as column charts.

Pictographs show data by using images. In Figure 3.4, each picture of a screw represents five actual screws, which can be confusing when the data is not in groups of five. Pictographs can be useful if you are presenting data about numbers of items or activities completed, but it is important to choose a sensible value for each image to represent. If each screw represented one actual screw in Figure 3.4, then you would need to draw 23 screws for the 6 mm screw size, which would be time-consuming. Alternatively, if each image of a screw represented 100 actual screws, the values would be hard to work out because the images of partial screws would be small and very similar to each other.

KEY TERMS

Axis is the name of either the horizontal or the vertical line that is used to show the scale of the graph or chart.

A **scale** on a graph is used to show the quantity of each group.

ACTIVITY

Using data you have collected or that your teacher has provided, produce an example of each different type of chart. It is important that you present the results of the investigation with accuracy. You will need to:

1. create a pie chart, with a key to represent each group of data
2. draw a bar chart to represent the values of the different groups of data
3. draw a pictogram that represents each group of data using a suitable symbol for the values
4. write a review of the graphical methods used, stating which is most effective for the data and why.

Discuss with your partner.

Types of graph

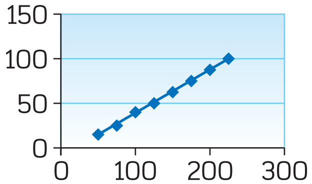


Figure 3.5: Line graph

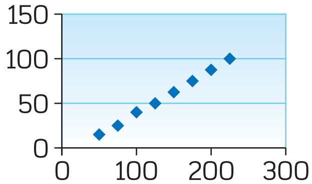


Figure 3.6: Scatter graph

Line graphs, as shown in Figure 3.5, are useful for showing how things change over a period of time or where one value is being compared to another – for example, the extension of a spring relative to the load applied or the distance travelled as a function of time.

Scatter graphs, as shown in Figure 3.6, can be useful if you are collecting lots of measurements from an investigation. A scatter graph can be used to produce a line of best fit. Scatter graphs and lines of best fit are covered in the next lesson.

Remember, when you are deciding on the type of chart or graph to use, think about the following questions.

- How many groups of data are there?
- What do you want the chart or graph to show?
- What is the information going to be used for?

CHECK MY LEARNING

You have looked at the types of graph and chart that can be used to present data.

Using some examples of charts and graphs, discuss as a class group why each type of graph/chart was chosen to present that data, and which methods are most effective.

Displaying data using lines of best fit

GETTING STARTED

Lines of best fit were mentioned in the previous lesson. Do you know what they are? Discuss with your class.

So far, we have looked at data that:
- can be sorted into groups
- follow a trend or pattern.

Unfortunately, when we carry out investigations into how a material or component reacts to different conditions, the data often cannot easily be grouped or presented as perfect straight-line graphs.

To ensure that the data from an investigation is valid, the same test is often repeated. This means that there will be a number of different values for each test (see, for example, Table 3.4), and these values are best presented using a scatter graph.

Scatter graphs

Once you have created a scatter graph (see, for example, Figure 3.7), the results are presented visually, but they are not always very effective at communicating information. For example, it is difficult to identify trends or patterns that might be useful or conclusive to the extent you require when investigating an engineered component or material.

Table 3.4: Example of data from a practical investigation

	Length (mm)				
Mass (g)	Test 1	Test 2	Test 3	Test 4	Test 5
50	10	12	11	8	10
100	14	15	13	17	15
150	19	20	21	21	19
200	26	25	27	24	26
250	32	30	29	30	28
300	34	35	37	33	35

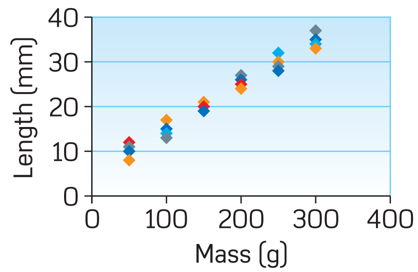


Figure 3.7: Scatter graph for the data in Table 3.4

ACTIVITY

Carry out an investigation to see how much a spring extends under different amounts of loading. You will need to measure the extension of the spring for each load five times. Use the data from the investigation to produce a scatter graph.

Lines and curves of best fit

When you look at the scatter graph in Figure 3.7, the large number of individual points plotted can be difficult to interpret. To make it easier to understand the message a scatter graph is trying to tell us, we use the plotted data to draw a line of best fit.

A line or curve of best fit can pass through some of the plotted points, sometimes most of them, or sometimes none of them! A line of best fit can also help to identify values that have been measured incorrectly.

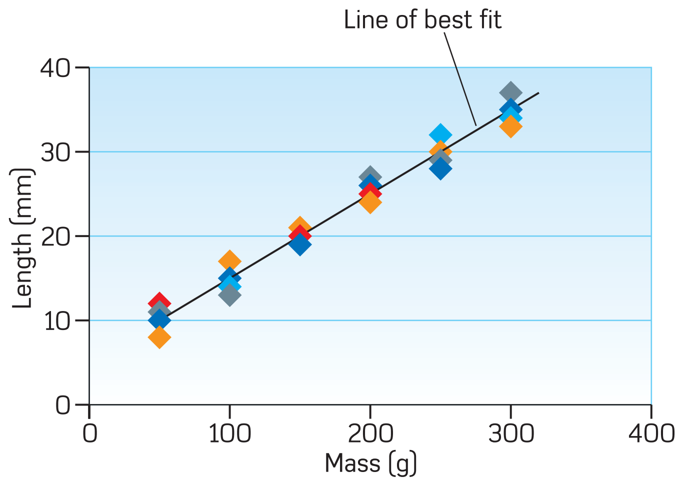


Figure 3.8: Line of best fit for the information in Table 3.4

As you can see in Figure 3.8, drawing a line of best fit shows that there is a straight-line relationship between the load and the length of the extended spring.

When plotting a graph, you need to ensure that you use the most precise scale that you can, using graph paper with 1 mm or 2 mm squares if possible. Draw your *x*-axis and *y*-axis clearly. Normally, times would be on the *x*-axis and distances would be on the *y*-axis.

Make sure you **label** the axes of your charts and graphs clearly to indicate what is being shown.

It is important to use your observational skills when looking at the data/results of practical activities; it could be that one of the measurements you made was inaccurate or a component was faulty. This will be covered in more detail in the next lesson.

KEY TERM

Labelling should be used to identify groups of data clearly.

CHECK MY LEARNING

You carried out an activity to collect some data from a spring load–extension experiment. Take the scatter graph you produced and try to draw a line of best fit. What do the results show you?

With a partner, think about and discuss the reasons why tabulated data and scatter graphs are useful in engineering investigations.

Interpretation of data

GETTING STARTED

Look at some examples of tabulated data. With a partner, discuss what you each think the data is telling you. Do you and your partner have the same opinion or interpretation?

When you look at a table of data, it is not always obvious what information the data are telling us, especially if the categories that the data is divided into are not equal. It is important, however, that we are able to interpret and understand the data so that we can use it to help design or redesign engineered components or products.

Comparison of trends and patterns

Sometimes a table of data alone can be enough to allow us to compare results and identify a trend or pattern; for example, in Table 3.5 it can be clearly seen that as time increases, the distance from the start point also increases.

Table 3.5: Distance travelled compared to time

Distance–time comparison								
Time (seconds)	0	5	10	15	20	25	30	35
Distance (metres)	0	10	20	30	40	50	60	70

The data in Table 3.5 also show that for every 5 seconds of travel, the distance increases by 10 metres. Therefore, we have a linear (straight-line) relationship between distance and time, and there is probably no need to draw this as a graph. Sometimes, however, the results of an investigation can be harder to interpret as patterns may not be so clear.

V (V)	*I* (A)
0.00	0.00
1.50	0.40
3.00	0.78
4.50	1.00
6.00	1.15
7.50	1.28
9.00	1.42
12.00	1.62

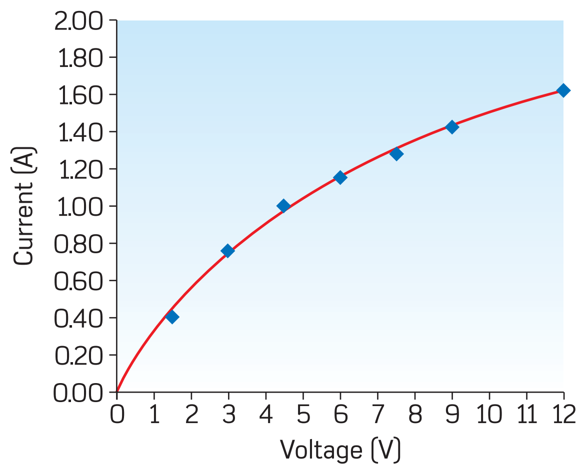


Figure 3.9: Table and chart showing current measured against voltage

In the table in Figure 3.9, you can see that as the voltage (*V*) increases, the current (*I*) also increases, but the rate of increase is not constant or linear. This tells us that we would not get a straight-line graph. The graph in Figure 3.9 shows all of the points plotted as a scatter graph with a curved line of best fit. The line indicates that there is a trend: as the voltage increases, the current increases but the rate of increase becomes slightly less.

ACTIVITY

Find a table of data from the internet (or obtain one from your teacher). Make sure that there are around ten rows in the table; this should be enough to identify a pattern.

1. Look at the data in the table. Can you see a trend or pattern? Write down your initial thoughts.
2. Plot the data on a scatter graph and draw a line of best fit.
3. Compare the graph with your initial thoughts. Did you successfully identify the trend?

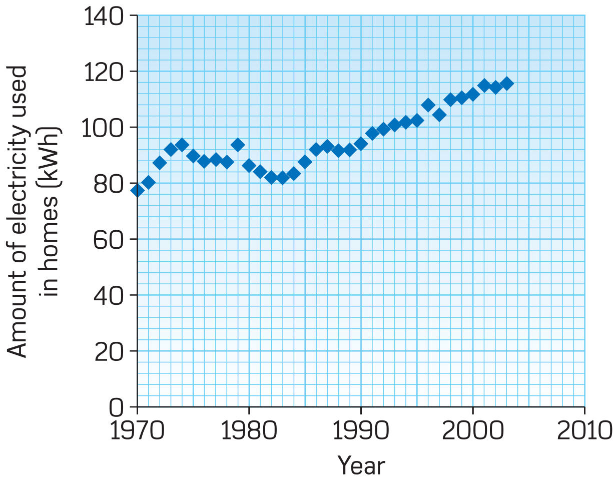


Figure 3.10: Scatter graph showing the use of electricity in homes

Figure 3.10, even though the values do not show an exact pattern, indicates that there is an upward (increasing) trend over a period of time. It would be possible to draw a line of best fit from the value in 1970 to the value in 2004, but this would not be an accurate representation of the information. This graph also shows an example of an anomalous result, which can be seen for the year 1979, where there was a large increase in the use of electricity compared with the years before and after.

Identifying anomalous results and sources of error

An anomalous result is one that does not fit the expected pattern or trend. Usually when we are carrying out an investigation, an anomalous result is caused by a mistake in taking readings or a faulty sample. To remove the possibility of anomalous results causing problems in an investigation, we take more than one reading for each value, as we did with the loaded spring investigation. This helps us to identify errors and find the possible sources such as, for example, an inaccurate measurement or a component with a flaw. It can be difficult to identify anomalous results in a table of data; however, when the data is presented in a scatter graph, they are easier to identify. In the scatter graph in Figure 3.11, anomalous results are circled.

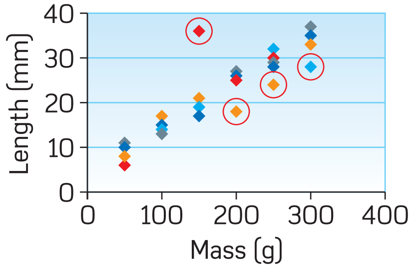


Figure 3.11: Scatter graph with anomalous results identified

CHECK MY LEARNING

You have learned about the comparison of trends and patterns in data and about the identification of anomalous results from investigations, as well as the potential causes of these results. With a partner, examine some scatter graphs from practical investigations and see if you can identify any anomalous results.

Evaluating processes, drawing conclusions and making recommendations

GETTING STARTED

Working in pairs, think about the types of test that can be carried out to evaluate and improve engineered components and products and associated manufacturing processes.

We have previously looked at how data can be collected and presented. The next stage is to interpret and analyse the data and use the results to recommend improvements to a product or process.

Data can be used for a range of purposes, including finding out how components perform, checking the properties of materials, and determining whether parts will fit together. You can collect such data using a range of methods, including the use of measuring equipment and gauges.

Measuring equipment

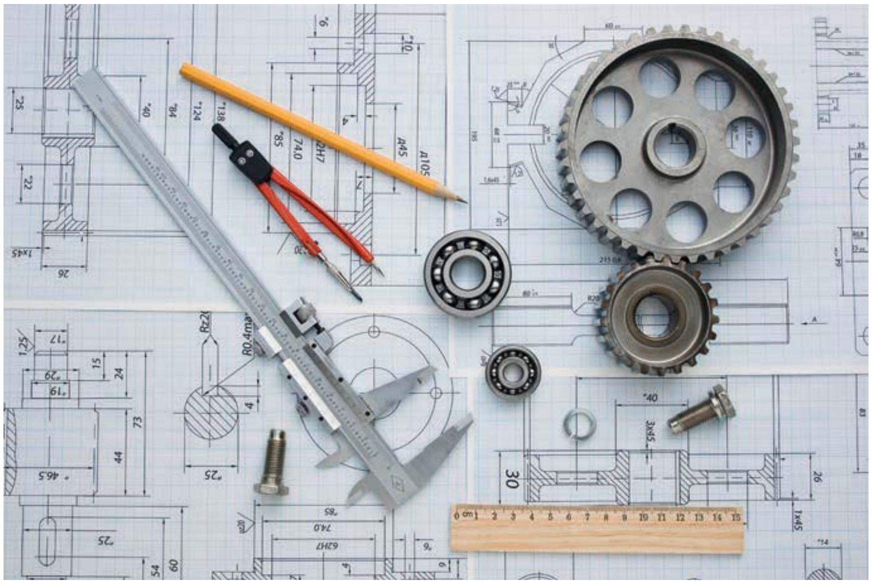
Depending on what you need to measure, you will use a range of measuring equipment. Some examples are shown in Table 3.6.

Table 3.6: Types of measuring equipment

Measurement	Equipment
Length/diameter	• Ruler: used for measuring lengths to a precision of 1 mm • Vernier callipers: used to measure the length or diameter of smaller components, to a precision of 0.02 mm. Vernier callipers are used for very accurate measurements • Micrometer: used to measure the dimensions of small components to a precision of 0.001 mm • Tape measure: used for larger length measurements
Mass	• Balance: used to measure the mass of an object, e.g. beam balances for large masses and digital balances for smaller masses
Time	• Stopwatch: used to measure time, to a precision of 0.01 seconds. (In reality, accuracy depends on the person operating the stopwatch.) • Electronic systems: automatically start and stop when a sensor is actuated and are more accurate

LINK IT UP

Revisit the measurement skills covered in Component 2: Learning aim B.



A range of measuring equipment is usually needed to check components and parts

Sometimes it is not necessary to measure the exact size of a component. For instance, you may simply need to know whether a component and any of its features are correct, such as whether a drilled hole has a large enough diameter. To carry out checks like this, you could use a simple gauge.

Gauges

Gauges provide a simple method of checking whether or not a component or part is fit for purpose and is within tolerance. One of the most common types of gauge for engineering activities is a go/no-go gauge.

Go/no-go gauges can be used for checking the diameters of holes.

- The 'go' gauge, coloured green, must be able to fit through the hole. If the 'go' gauge does not fit, the hole is too small. This would tell us that the hole needs to be drilled larger.
- If the 'no-go' gauge, coloured red, fits through the hole, this means the hole is too large and a smaller drill bit should have been used.
- If the hole is within tolerance, the 'go' gauge will fit in the hole and the 'no-go' gauge will not.

Measuring equipment and gauges can be used to check the lengths of components, the thicknesses of materials or the overall dimensions of a part. If parts are separated into those that are too small, those that are within tolerance, and those that are too big, then it will be easier to identify the causes of faults. This can help you to draw conclusions from the data.

In an engineering workshop where more than one person is making parts, it could be that a machine has been set up incorrectly or the wrong materials have been used. You can collect and analyse data and use the conclusions drawn to make recommendations to improve manufacturing processes.

ACTIVITY

Working with a partner, check the accuracy of a sample of parts. For this, you need a go/no-go gauge and components created using engineering tools. Check the lengths of the components and divide them into categories of 'too small', 'too big' and 'within tolerance'.

Write down the reasons why you think the components were either 'too small' or 'too big'.

CHECK MY LEARNING

You have looked at different methods of making and using measurements.

With your partner, think about how measured data can be used to make recommendations to improve manufacturing processes and outcomes.

Learning aim A: assessment practice

How you will be assessed

In this component, you will be assessed by completing a set task that consists of two parts, worth 60 marks in total. The task will be set and marked by Pearson examiners, and you will complete both parts of the assessment during a period of one week. You will be supervised during the assessment period, and you will have two hours for Part 1 and one and a half hours for Part 2.

For Part 1 of the set task, you will need to carry out a practical activity and then complete a task and answer booklet. You will be given a brief with all the necessary information you need to carry out the practical task, including a table in which to record your results and observations. These results are important as you will need to refer to them when carrying out the practical activities.

You will then carry out three activities based on the practical task. An additional task, consisting of two activities, will target higher-order planning, redesign and evaluation skills, and will relate to given scenarios. During the set task, you will need to show that you understand how to interpret information and use this to suggest improvements to an engineered product.

Note: You must always observe safe practices when carrying out practical activities.

Remember that the examiner who will be marking your set task does not know you, and the only way they will be able to assess your engineering skills is through the work that they see you have completed.

CHECKPOINT

Strengthen
- Describe four methods of presenting data graphically.
- Give an example of one type of work instruction and what it is used for.
- Which methods can be used to improve an engineered product?

Challenge
- Explain why an engineer might use a gauge when carrying out quality checks.
- Describe two advantages of using mechanical fixings for engineering products.
- Explain what should be done if data show anomalous results.

ASSESSMENT ACTIVITY | LEARNING AIM A

You will be given information about how to prepare for and set up your investigation.

A scenario will be given to you, along with a list of the equipment that you will need.

Your teacher will demonstrate how you need to carry out the investigation, and then you will complete the set task on your own.

TIP

When you are working on Part 1 of the set task, make sure that you watch the demonstration closely and set up the equipment that you will need correctly.

TAKE IT FURTHER

Check that you have set up the equipment correctly and that you have recorded values with accuracy. Try to identify any patterns or trends in the data you have collected.

Interpretation of a given brief for an engineered product

GETTING STARTED

Working in a small group, discuss and make a list of the types of information that will be needed in a design brief for an engineered product.

LINK IT UP

In Component 1: Learning aim B, you looked at engineering design briefs as a part of the design process.

When designing engineered products, it is important that you can interpret a design brief and then explore design ideas that provide a solution to the brief. To do this, you need to understand the information included in the design brief and know how to address each point of the brief in your designs.

Analysing the existing product with reference to the design brief

All products, from a simple coat hook to an aeroplane engine, are produced from a design brief

A design brief for an engineering product will include a range of factors, including:

- physical requirements
- aesthetics
- size
- function
- performance requirements.

The amount of information for each factor will vary depending on the type of product. For example, a component that is going to fit inside an engine will probably have fewer aesthetic requirements than it has performance requirements.

Physical requirements

Does the design need to meet any specific physical requirements? Will the component need to be able to hold a specific loading or be connected to another component in a specific way?

Does the component need to offer any form of protection to other components or features? Do the materials used for the component need to perform in any specific way?

Aesthetics

You will need to think about why the product is shaped in the way that it is. Is the component designed in a specific shape and style for a particular reason, or simply to make it look good?

Size

How big does the component or product need to be? Are there any maximum or minimum size requirements for the product?

You might be designing a component that is going to be a direct replacement for something that already exists. In this case, the size of the new component will be the same as the current one.

Function

You need to think about what the product or component is designed to do. This could be a list of statements. For example, a light switch must control electrical current to a light fitting and must also enclose all the wires and prevent the user from getting an electric shock. In lots of cases, there will be an overlap with performance requirements.

Performance requirements

You need to think about how the success of the product is measured. Does it need to last for a set time or be able to move a specified distance? Performance requirements will be different for each product, but they can often be thought of as targets that need to be met for the product or component to be termed a success.

ACTIVITY

Research an engineered product, either by looking on the internet or by examining a physical product.

Write out a design brief for the product. You need to include the following:

1. physical requirements
2. aesthetics
3. size
4. function
5. performance requirements.

Exchange your design brief with a partner and see if they can identify what the product is just from the description in the brief.

CHECK MY LEARNING

In this lesson, you have analysed an existing engineered product with reference to its design brief.

Working with a partner, analyse one product that is in your workshop or classroom and write a design brief for the product.

Features of engineered products

GETTING STARTED

Working with a partner, examine a component from an engineered product that you are familiar with. Make a list of what you think the features of the product are.

When you are investigating an existing engineered product to help with the design of something new, you will need to consider the features of the product. There are different types of feature that products can have.

ACTIVITY

Working with your partner, research an example of a fabricated component.

1. Sketch the component.
2. Label the features of the component.
3. Highlight the features of the component that you think are most important for it to work as intended.

Dimensions

The dimensions of a product are very important. If a dimension is too big, it will probably not fit in the space it is designed for; if it is too small, then connections to other components will not be possible. This is known as tolerance, which can be linear (straight-line) or radial (for circular features).

When you examine a product to check its dimensions, you will use one of the following measuring tools.

- Steel rule – steel rules are used for measuring lengths to a precision of 1 mm.
- Micrometer – these can be used to find the dimensions of small components to a precision of 0.001 mm.
- Vernier callipers – these are used to measure the length or diameter of smaller components to a precision of 0.02 mm. Vernier callipers are used for very accurate measurements.
- Tape measure – these are used for larger dimensions where precision is less important.

When you are selecting measuring equipment to collect data, you need to think about the following points.

- How precise do the measurements need to be?
- How many measurements will you need to take?
- What is the reason for taking the measurements?
- The size and shape of the component to be measured.

You should always record length measurements in millimetres (mm).

Tolerances

For component parts of an engineered product to fit together properly, they need to be produced to an agreed tolerance. Sometimes there are slight variations in the sizes or positions of features when components are made. Providing these are within tolerance, the parts will fit together and work as intended.

Surface finishes

The surface finish of an object says how smooth its surface is. Surface finish is measured in micrometres (μm). 1 μm = 0.0000001 m.

The finish applied to the component will have a significant impact on how the component looks, but will also influence how resistant the component will be to wear and damage, or to corrosion, e.g. rust. As with dimensions, there are tolerances for surface finish – for example, how smooth a feature must be or how thick a paint finish should be.

Many different surface finishes can be applied to materials to change their appearance

Physical form

The physical form of a component is the shape it takes. Try to be descriptive about the form of an object; think about whether it is a regular shape, such as a cone, cube or cylinder, or an abstract shape that is harder to describe. Consider using terms such as 2D, 3D, flat and curved to support your descriptions.

Try to describe the form using a combination of shapes. In the case of the component in the photograph, a description could be that it has a long rectangular body that is connected to an approximately square plate with a hole in its centre.

Consider other physical attributes that might cause problems, such as injury from impacting sharp corners or moisture traps in which water could collect and damage the product.

CHECK MY LEARNING

You have learned about the types of feature an engineered product can have. In your class group, discuss what you understand by tolerances and the importance of these for engineered products.

Selecting engineering materials

GETTING STARTED

Write down as many examples of materials as you can think of for each of the following material categories: ferrous and non-ferrous metals, and thermosetting and thermoforming polymers.

LINK IT UP

To remind yourself of the range of engineering materials used in manufacturing engineered components and products, go back to Component 2: Learning aim A.

Most of the materials you will encounter when investigating existing solutions will be similar to the four material categories that you have already covered.

Categories of material

The following is a review of the general properties and characteristics of each material group and how these influence material choices.

Ferrous metals

Ferrous metals contain iron. Ferrous metal alloys also contain other metals to give them the properties required. For example, stainless steel is corrosion resistant because it contains other metals such as chromium and nickel (see Table 3.7).

Table 3.7: Examples of ferrous metals

Material	Properties
Mild steel	• Good tensile strength • Good levels of malleability and ductility
Stainless steel	• Very tough • Corrosion resistant
Wrought iron	• Very tough • Corrosion resistant • Good levels of malleability and ductility

Non-ferrous metals

Non-ferrous metals do not contain iron. Unlike ferrous metals, they are not magnetic and usually have better corrosion resistance (see Table 3.8).

Table 3.8: Examples of non-ferrous metals

Material	Properties
Aluminium	• Soft and malleable • Good conductor of heat and electricity • Corrosion resistant
Titanium	• Low density • Quite good levels of ductility
Copper	• Tough material • Very ductile • Very good electrical conductor

Thermosetting polymers

Thermosetting polymers have a rigid molecular structure that is made up of lines of molecules that are heavily cross-linked. They can be heated and shaped once, but they cannot be reshaped, because they become permanently stiff and solid after being heat treated (see Table 3.9).

Table 3.9: Examples of thermosetting polymers

Material	Properties
Phenol-formaldehyde	• High electrical resistance • High heat resistance • Hard wearing
Polyimides	• Hard and tough with good rigidity • Self-lubricating • Resistant to oil, fuels and chemicals
Polyurethane	• Good hardness properties • High tensile and compression strength • Impact and abrasion resistant

Thermoforming polymers

Thermoforming polymers have fewer cross-links than thermosetting polymers. This means that when they are heated they become soft and can be formed into a variety of shapes and forms. When they cool, they become stiff and solid again. However, the process can be repeated many times (see Table 3.10).

Table 3.10: Examples of thermoforming polymers

Material	Properties
Polyethylene	• Excellent chemical resistance • Good fatigue and wear resistance
Polypropylene	• Quite high tensile strength • Good resistance to stress and cracking
Acrylic	• Very stiff material • Good durability • Good electrical insulator

ACTIVITY

Find an example of an engineered product (from the internet or from your teacher) and examine the product to identify the materials used to make it.

1 Name all materials used in the product and what they are used for.
2 Research the properties of these materials.
3 Suggest alternative materials that have similar properties to the existing materials.

CHECK MY LEARNING

You have learned about the properties of some of the materials used in engineered products.

In a small group, discuss and explain the reasons why you chose the alternative materials for the engineered product you looked at in the main lesson activity.

Manufacturing processes

GETTING STARTED

Working in groups, disassemble an engineered product. Write a list of the processes that you think have been used in the manufacture of the product.

LINK IT UP

Go to Component 1: Learning aim B and Component 2: Learning aim A to review processes used in manufacturing.

When an engineered product is manufactured, a range of processes, generally divided into four groups, is used to make sure that it is produced to the highest possible standard.

Cutting processes

Cutting involves the removal of unwanted material. Sometimes you are left with more than one piece, such as when you use a saw. Other processes only leave swarf or filings, such as drilling and filing. Table 3.11 lists some examples of cutting processes.

Table 3.11: Examples of cutting processes

Process	Examples of use
Drilling	• Making holes through a material • Counterboring to allow components to sit below the surface of a workpiece • Producing blind holes and flat-bottomed holes that do not go all the way through material
Sawing	• Mechanical or manual methods can be used • Hacksaws are generally used for metallic materials and have different blade types for different thicknesses of metal • Coping saws can be used for cutting many polymers
Filing	• Used to remove burrs or sharp edges from the surface of metal • Can be used to add a round edge or chamfer to a cut material • Can be used to make holes bigger or to shape them to specification
Shearing	• Used to produce straight cuts • Can be used on sheet material or bar and angle stock

Shaping processes

Shaping processes are most often used with metals. They involve using cutting tools to remove material and produce the shape of the component required by the design. Table 3.12 lists some examples of shaping processes.

Table 3.12: Examples of shaping processes

Process	Examples of use
Turning	• Producing flat faces that are a square end to a bar • Producing a range of diameters on bars, including parallel, stepped and tapered • Adding features to the outside of a bar, including screw threads, knurling and chamfers
Milling	• Producing flat, square and parallel features • Machining shoulders, steps, slots, grooves and recesses

Forming processes

Forming processes often involve the use of heat, changing materials from one form to another. For example, polymer pellets are first heated and then injection moulded to form products. Table 3.13 lists some examples of forming processes.

Table 3.13: Examples of forming processes

Process	Examples of use
Casting	• Sand casting is used for large components, where dimensional accuracy is less important • Die casting is used for large batches and where tolerances are tight • Investment casting is used for very complex shapes, where dimensional tolerances are very important
Forging	• Drop forging is used for smaller shapes, where production rates are high • Upset forging is used for simple products, such as the head of a bolt • Press forging is used for large objects
Extruding	• Extruding is a process used for polymers. Complicated hollow sections can be made by forcing soft polymers through a die
Moulding	• Injection moulding is used for complex shapes, such as housings for electronics • Blow moulding is used for hollow containers, such as bottles • Vacuum forming is used for simple hollow containers and enclosures

Joining and fabrication processes

Once component parts have been manufactured, they need to be joined together. These joining processes can be permanent or temporary and may depend, for example, on whether maintenance requires the parts to be taken apart. Table 3.14 lists some examples of joining processes.

Table 3.14: Examples of joining processes

Process	Examples of use
Fastening	• Fastenings provide a mechanical joint between components. Most are temporary, e.g. screws, nuts, bolts and clips • Permanent fasteners include rivets
Bonding	• Bonding is similar to gluing, giving an adhesive joint between materials • Factors that influence the strength of bonding include the pressure applied, the materials to be joined and the temperature
Soldering	• This process is used for joining electronic components to circuit boards • A soldering iron is used to melt solder, which solidifies to make the joint
Brazing	• A process similar to soldering but at a much higher temperature • Used to join different metals together, e.g. in heating systems

ACTIVITY

Examine an engineered product and investigate the manufacturing processes used to make it.

1 Name all of the processes used to manufacture the product.
2 Research two contrasting production processes – for example, one forming and one joining.
3 Create a short presentation that describes the two processes.

CHECK MY LEARNING

As covered in this lesson and in Components 1 and 2, different types of manufacturing process can be used. In a small group, discuss the different options that can be used to manufacture an engineered product.

Redesign

GETTING STARTED

Select a few objects from your classroom or workshop, such as a. pencil sharpener and a plastic chair. Sketch the objects from one view and then compare your sketches with those drawn by a partner.

LINK IT UP

The three views of orthographic projections – front, side and plan views – were covered in Component 1: Learning aim B.

LINK IT UP

Go to Component 1: Learning aim B for more information on design briefs and the performance requirements of an engineered product.

Before you begin to think about ways in which you can redesign an existing product, you need to identify any issues there are with the existing design.

Identifying issues with existing designs

This is an important part of the engineering design process and often involves asking questions such as:

- Are the existing materials suitable?
- Has the product been manufactured using the most suitable processes?
- Are there any weak points in the design?
- Is the product too complicated – how many parts are used in the assembly?
- Does the product make the most efficient use of materials?

Issues may be identified during the design stage, while prototyping or testing, or by the end user over a period of operation of the product. When trying to identify issues with an existing design, you should refer to and consider the original design brief for the product.

Once you have identified potential issues with an existing design, you can then start to look at methods to develop and share your redesign ideas.

Concept 2D sketching

One of the first steps is to produce some sketched ideas. Usually, this involves drawing 2D sketches that show the design proposal from one view only.

There are no right or wrong approaches; the only limit is your creativity.

ACTIVITY

Look at some design sketches for the redesign of an existing product. Figure 3.12 shows an example. Although the ideas might have many features in common, there may also be a lot of variation in approach.

1 Make a list of all the similarities and differences between the designs.
2 Think about the reasons why some parts of the designs are similar.
3 Produce a small selection of alternative sketched ideas for the product.

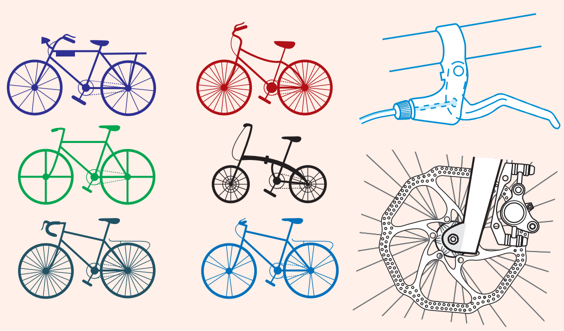


Figure 3.12: Sketched ideas for a new type of bicycle

Practising sketching

To develop your sketching techniques, you need to practise making sketches of a variety of objects and design ideas. Remember to include **annotations** to explain the features of your designs. Annotations can provide information about:

- materials
- processes
- dimensions.

Annotations will help others to understand your design thinking and will also help to explain how something is to be made or the reasons why a particular material is to be used.

KEY TERM

Annotations are labels used by engineers to give information about designs.

ACTIVITY

Find some images of engineered components using the internet.

1. Print out images of the components.
2. Sketch out the components using only 2D views.
3. Add annotations to the sketches to explain the different features of the components.

When you are producing 2D annotated sketches, you should think about:

- which view will show the most information about the component
- what information needs to be explained in the annotations
- making sure that sketches are large enough to show all the details you want to share.

CHECK MY LEARNING

You have looked at ways of identifying issues with existing designs and practised sketching techniques that you can use to explain the features of products you are designing.

In pairs, evaluate the sketches you made in the previous activity and discuss how effective sketches are at representing given components.

3D sketching

GETTING STARTED

Can you remember what you researched about 3D sketches in Component 1, Learning aim B: Generating final design drawings – for example, the differences between oblique and isometric projections and perspective drawings? Discuss with a partner.

LINK IT UP

In Component 1: Learning aim B, you used a range of 2D and 3D sketching techniques to present ideas for solutions to an engineering design brief.

KEY TERM

Assembly drawings are used to show how components are put together.

There are limitations on the amount of information that can be shown by 2D drawings. To show all the features of a component, you might need to produce at least three different 2D sketches. Another way is to use 3D sketches to represent three-dimensional objects.

Using 3D sketching

There are three methods of 3D sketching that are often used as part of the design process. These are oblique and isometric projections and perspective drawings.

Oblique projection

With an oblique projection, you draw one full face of an object or component. This is drawn either full size or to scale. Lines are then projected back at 45° from the corners to show the depth of the object. Sometimes these lines are drawn full size (or to scale), although it is common for them to be drawn at around half their length so that the proportions of the drawing look correct. The example in Figure 3.13 is a scaled oblique projection.

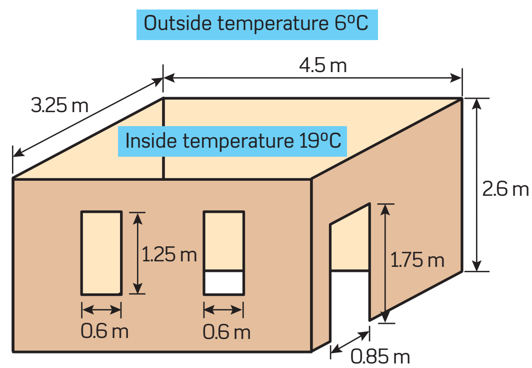


Figure 3.13: Oblique projection

Isometric projection

Unlike an oblique projection, an isometric projection has all the sides drawn at an angle. Vertical lines always remain vertical. However, all horizontal lines are drawn at 30° to the horizontal, as can be seen in the example shown in Figure 3.14. Isometric drawings are good for showing how things fit together, as in **assembly drawings**, and dimensions are either drawn full size or scaled. One of the disadvantages of isometric drawings is that circles appear as ellipses and curved edges can be hard to draw.

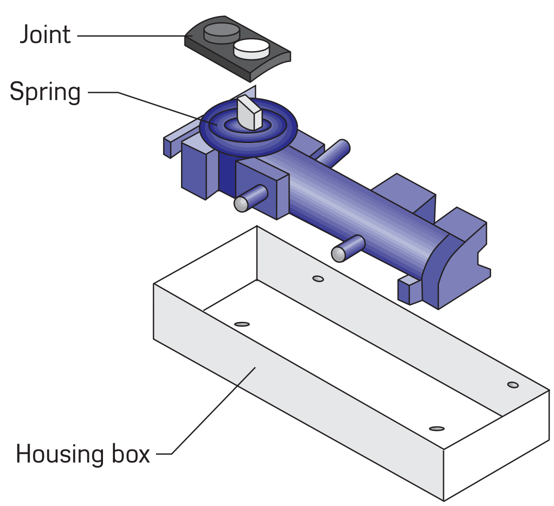


Figure 3.14: Isometric projection

Perspective drawings

There are three types of perspective drawing: one-point, two-point and three-point perspectives. One-point perspective is similar to an oblique projection, with a front face being drawn in full. Two-point perspective is probably the most useful representation method, as it can be drawn to show whichever features of the component need to be emphasised. As with isometric projections, vertical lines remain vertical, but all horizontal lines project to **vanishing points**, as shown in Figure 3.15.

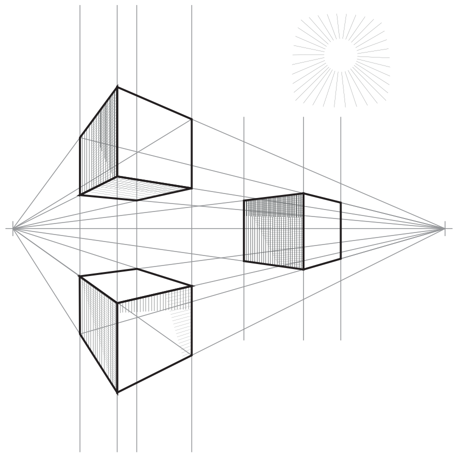


Figure 3.15: Two-point perspective drawing

KEY TERM

Vanishing points are points on an imaginary horizon where all projection lines in a perspective drawing are drawn from.

Table 3.15 lists some advantages and disadvantages of these 3D drawing types.

Table 3.15: Advantages and disadvantages of the 3D drawing types

3D drawing type	Advantages	Disadvantages
Oblique projection	• Gives an accurate view of one face • Gives an impression of depth or thickness of components • Measurements can be taken from the front face	• Circles are shown as ellipses except on the front face • The component can look distorted due to the perspective
Isometric projection	• Shows three sides of a component clearly • No changes to the proportions of the drawing • Easy to interpret by most people	• Can be hard to add dimensions or take measurements from • Circles are drawn as ellipses
Perspective drawing	• Gives a realistic view of the product or component • Allows the component to be shown from any angle	• Due to the perspective, some details may be hard to see • Difficult to add dimensions • Circles and curved edges are hard to show

ACTIVITY

Select some simple engineered components. Sketch them using each of the three techniques: oblique projection, isometric projection and perspective drawings.

CHECK MY LEARNING

You have learned about the differences between three types of 3D sketch commonly used in engineering. In a small group, discuss which of the three methods you think shows an engineered product most realistically.

Exploded diagrams

GETTING STARTED

Looking at an exploded diagram, see if you can sketch what you think the fully assembled engineered product looks like.

Although 3D sketches are useful for showing how an engineered product looks when it is completed, they have limited use when you want to explain how the individual parts of a product fit together.

Exploded diagrams are usually drawn as isometric projections that show each of the individual parts and how they are joined together to produce the finished product.

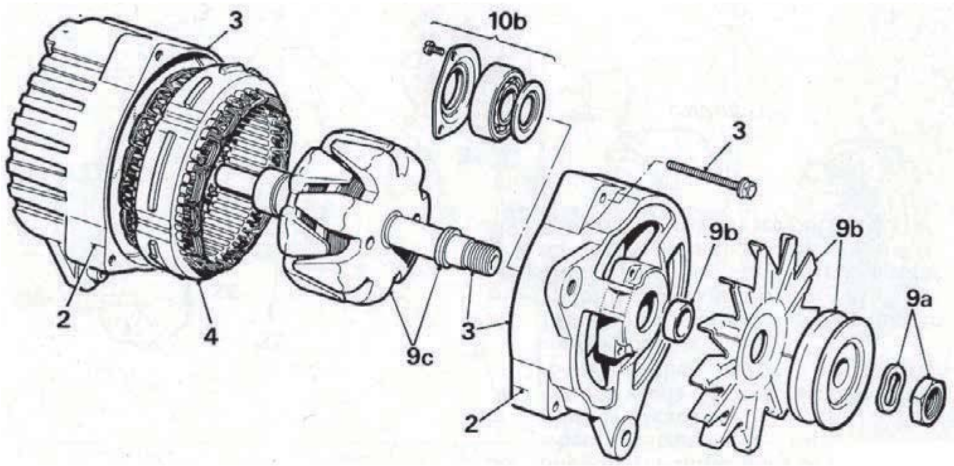


Figure 3.16: An exploded diagram of a an alternator.

When producing an exploded diagram, there are some guidelines that should be followed:

- Parts should always line up with each other, to show exactly how they fit together in the finished product.
- Parts should be easy to identify, using either the part names or a reference number system (as in the alternator drawing in Figure 3.16).
- If a part cannot be shown in line with where it fits into the assembly, add projection lines to show where the part needs to be placed. This can be seen for the component parts numbered 10b in Figure 3.16.

One of the main advantages of an exploded diagram is that each of the parts can be shown in full, and components that are inside the assembled product can be seen – for example, parts 9c and 10b in the water pump assembly.

Labelling and annotations

When you produce an exploded diagram, it is important that you clearly identify the individual components so that someone else can understand the diagram. However, this also depends on the purpose of the diagram. For example, if you are producing the diagram to explain what the parts are (as shown in Figure 3.17) and/or what they do, then you could use annotations that are detailed or name the individual parts.

If the purpose of the diagram is to provide instructions, then using a number or letter reference system would be more effective as this will make the diagram easier to understand. If you use this method, you will also need to provide a parts list.

ACTIVITY

For an engineered product that you have investigated and disassembled previously, produce an exploded diagram to show how it is assembled.

1. Refer to sketches for each of the individual parts – draw these if not already available.
2. Produce an exploded diagram to show how the components line up and fit together in the finished assembly.
3. Add notes or labels to identify each of the individual parts.

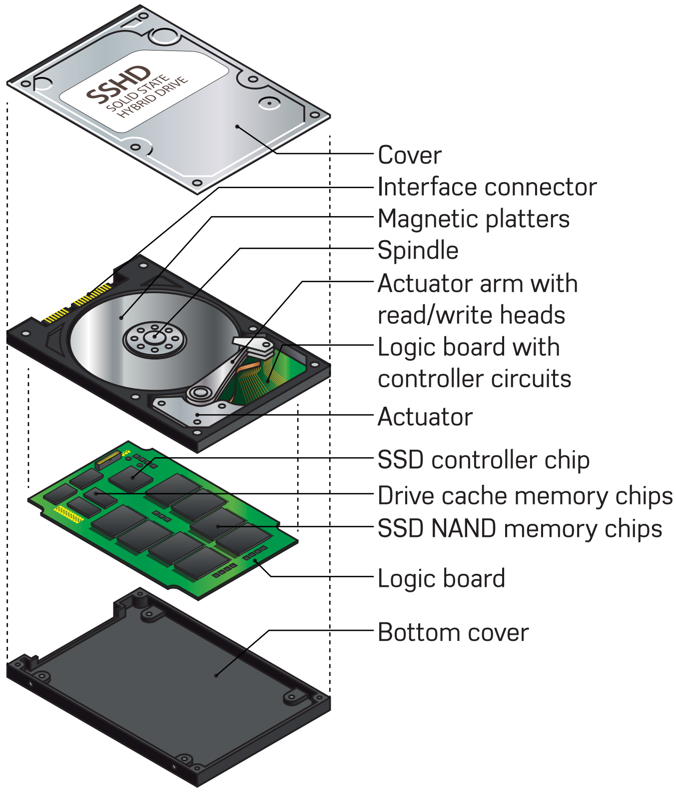


Figure 3.17: Exploded diagram of a solid state hard disk

Parts lists

Parts lists are documents used to provide information about the individual parts or components used in a product. They will usually feature:

- the reference number used in the exploded diagram
- the component's identifiable part number
- the component's description
- information on the component's materials
- quantities of each component.

Parts lists, like the one shown in Figure 3.18, are also sometimes known as a bill of materials.

12	6	BOLT1	BOLT	STEEL
11	4	5MM SCREW1	SCREW	STEEL
10	6	WASHER1	WASHER	COPPER
9	1	SHIELD1	SHIELD	STAINLESS STEEL
8	1	GEAR2	GEAR2, BEVEL	STAINLESS STEEL
7	1	GEAR1	GEAR1, BEVEL	STAINLESS STEEL
6	1	FLANGE2	FLANGE	STEEL
5	2	2MM SCREW1	SCREW	STEEL
4	1	SHAFT1	SHAFT, INPUT	STEEL
3	1	BASE1	BASE	STEEL
2	2	PLATE2	PLATE, OUTPUT	STAINLESS STEEL
1	1	HEAD1	HEAD, GRINDER	ALUMINIUM
FIND NO.	QTY	PART NUMBER	DESCRIPTION	MATERIAL
			HEAD ASSY, GRINDER	

Figure 3.18: Typical parts list

CHECK MY LEARNING

You have learned about exploded diagrams, labelling and annotations, and parts lists, and how these can be used to help show the assembly of an engineered product.

With a partner, use an exploded diagram of an engineered product assembly to create a simple parts list for the product.

Electronic circuit diagrams

GETTING STARTED

Working with a partner, find some images of electronic circuits. Make a list of the components in the circuits that would be easy to draw, as well as those that would be more difficult.

We have looked previously at ways in which engineered products and components can be drawn, using methods and techniques that make the drawings and diagrams as realistic as possible and easy to understand.

As an engineer, it is very unusual to be given a pictorial drawing of an electronic circuit and then be asked to manufacture it. It is more usual for you to be given a circuit diagram that uses symbols to represent components.

Compare the two drawings shown in Figures 3.19 and 3.20, which both represent a simple electronic circuit consisting of one battery cell, one resistor and one light bulb. Now, imagine if there were 20 or 30 components in the circuit – how much more complicated and difficult to understand would a pictorial drawing be?

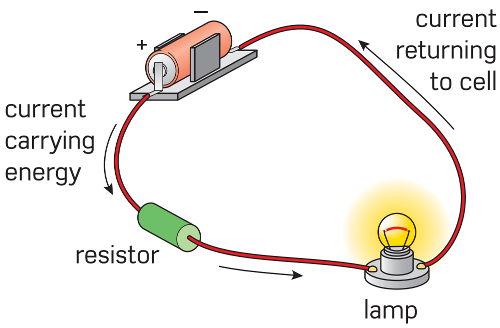


Figure 3.19: Pictorial drawing of a circuit

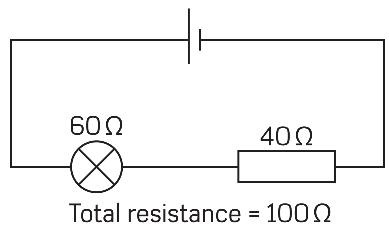
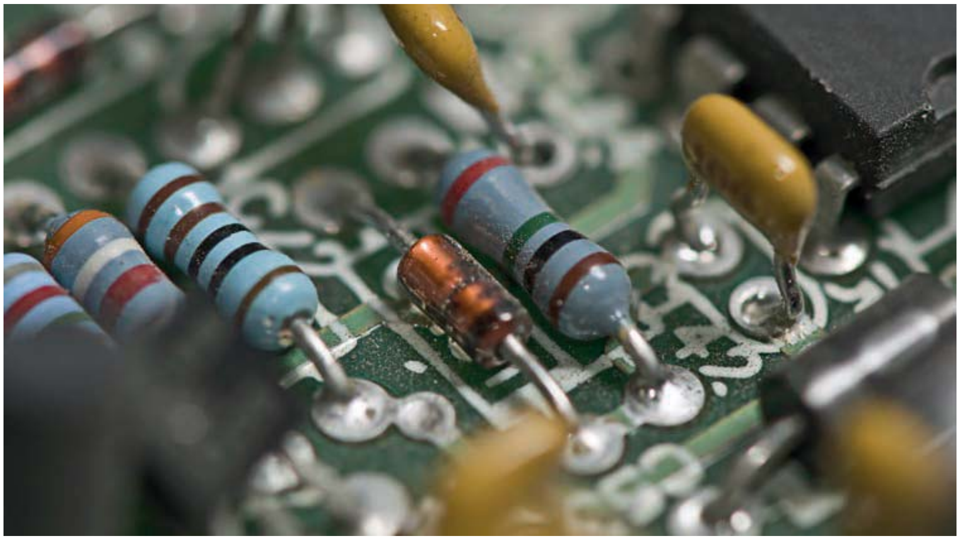


Figure 3.20: Schematic diagram of the circuit

Things would be even more complicated if the circuit were manufactured using a printed circuit board (PCB) that contained resistors, capacitors, integrated circuits and transistors. In a circuit schematic diagram, each of these components has a specific symbol to represent it.



Electronic components on a PCB

DID YOU KNOW?

The London Underground map was developed by an engineering draughtsman called Harry Beck, who based the map's design on electronic circuit diagrams.

Electronic component symbols

Electronics engineers use a range of symbols to represent each type of electronic component that can be used in an electronic circuit.

ACTIVITY

Use the internet to research the symbols used for a range of electronic components. Create a table that includes:

1 the description/name of each component
2 an image of the actual electronic component
3 the electronic circuit schematic symbol for the component.

When you draw a circuit schematic diagram, it needs to meet international design standards; so you must use the correct symbols. It should be possible for anyone who understands circuit schematic diagrams to manufacture the circuit from the schematic diagram.

When you are drawing an electronic circuit schematic diagram, you should:

- use straight horizontal and vertical lines
- draw all component symbols at the same scale
- avoid having symbols too close together, making sure that it is clear how the different components are connected.

CHECK MY LEARNING

You have learned how to produce circuit schematic diagrams using the correct circuit symbols.

1 Collect images, or physical examples, of some electronic circuits.
2 Draw the circuit schematic diagram for each circuit.
3 Produce a parts list of the components in the circuits.

Design for manufacture

GETTING STARTED

Think about the engineering activities and processes you carried out previously. How important has it been that processes are carried out in a specific order or parts put together in a certain way?

While designers who develop concepts for new mobile phones or for cars consider mostly how the product will look or the features it will have, engineers who plan the manufacture of the product need to be able to interpret designs and identify the most appropriate materials, processes and tools required to produce the necessary parts.

Prototype design for a sports car

KEY TERMS

Chamfers are features that remove sharp corners to make something safer and easier to assemble.
Radius (or **radii**) refers to a smooth, rounded corner, like a chamfer, typically used on external corners.

When you are redesigning a product or component, it is important that you consider how it will be made and assembled. For example, if two parts of a product need to be joined together with pins, then it would be helpful for the assembly process if a **chamfer** or **radius** is added to both the pins and the holes through which the pins will pass.

Design approaches

There are different approaches that can be used when designing for manufacture:

- reduce the number of parts
- design components for assembly
- use standard sizes and fixings
- avoid sharp corners.

Other approaches can be used, but for the majority of simple engineered products, the above design approaches are likely to achieve the best improvements to a design.

Reduce the number of parts

If possible, reduce the number of parts, which will probably reduce both the weight and the amount of material used. Components fabricated from individual parts could possibly be cast or moulded in one piece. This removes the need for fixings and allows components to be manufactured more efficiently.

Design components for assembly

Removing the possibility of mistakes occurring during assembly is one way to improve any product. Designing components so that it is only possible to assemble them in the correct way will help prevent faulty products being made, which is especially important when considering the time and effort associated with producing machined components.

Designing components for assembly allows semi-skilled workers to put products together. This is also important for self-assembly products that have components that need to be finally assembled by end users and where mistakes during assembly could easily damage the product.

Use standard sizes and fixings

Redesign a product to use popular standard sizes of components and fixings that are more readily available. This will eliminate the need to design and make new fixings. It should also allow product end users to carry out equipment repairs themselves.

It is also a good idea to use only a small range of types and sizes of mechanical fixing and to avoid using smaller sizes as much as possible, all of which will make fabrication less complicated.

Avoid sharp corners

When you design an engineered product, you need to ensure that it will perform as you expect it to. One way of doing this is to ensure that you avoid sharp corners and edges as much as possible by using generous **fillets** or radii to produce a smooth transition from one face of the component to another. Sometimes you cannot avoid a sharp corner, such as, with a fabricated container. However, for cast, forged or formed components, adding radii can make a component less likely to fail in service.

KEY TERM

Fillets are similar to radii, but feature on internal corners and are used to reduce stresses in a joint.

ACTIVITY

Find an example of an engineered product that is made from two or three components that fit together.

1. Disassemble the product.
2. Identify one component that you think could be improved, which will improve the overall product.
3. Sketch two or three improvements to the design of the component.
4. Explain how the component would be manufactured to the improved design.

When complete, compare your ideas with those of a partner.

CHECK MY LEARNING

You have learned about some of the methods used to improve the design of a product and allow it to be manufactured more efficiently.

In a small group, investigate some engineered products. Discuss ways in which the product could be improved to make it easier to manufacture.

Variations in form to solve a problem

GETTING STARTED

Look around the room you are working in. How many products have a variety of forms, yet perform the same function (e.g. different models of mobile phone)? Make a list of the features that the product designs have in common with each other.

An engineering design brief is produced to make sure that new products perform the function they are intended to do. However, this does not mean that there is only one approach that can be taken to solve the design problem.

It is important to ensure that each of the criteria in the design brief and product design specification is met, but how this is achieved could be very varied.

Imagine a design brief that asks you to come up with a solution to the problem of fixing a camera to the handlebars of a bicycle. Possible approaches could include:

- a bracket that is welded to the handlebars
- a removable case attached using a clamp
- clips that allow the camera to be easily fixed/removed.

Examples of a desktop and a laptop computer

Consider two examples of computer shown in the photographs. While both perform the same function, the way in which this is achieved is quite different. The laptop computer is more versatile, as it can be transported from one place to another, allowing someone to work on the move. The desktop computer can be fitted with multiple hard drives and interfaces, thus allowing the user to be more productive.

ACTIVITY

You have been asked to design an engineered product that can be used to support a portable hard disk drive when it is used with a laptop computer. You need to:

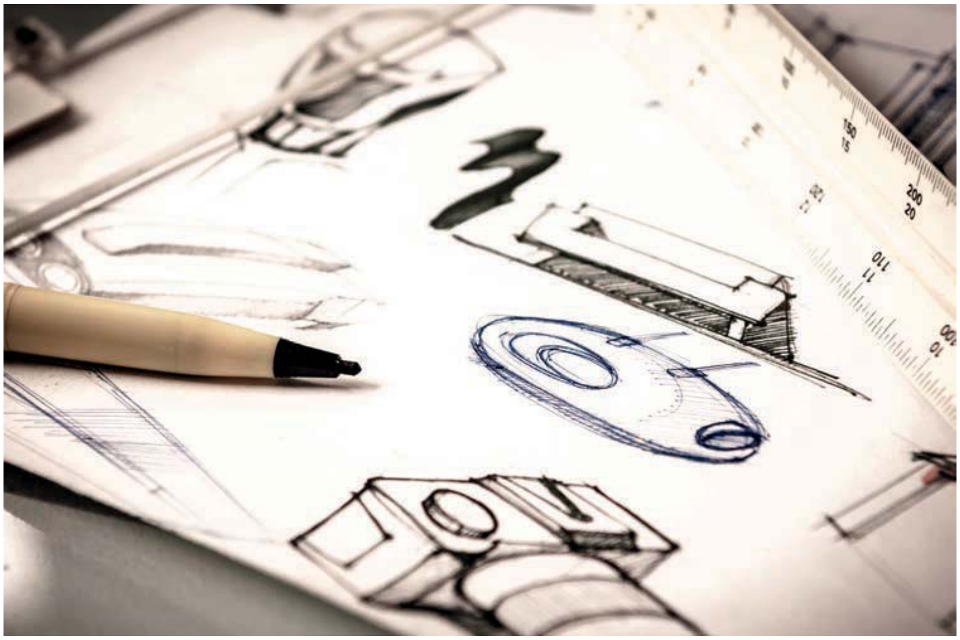
1. Research the dimensions of portable hard disk drives.
2. Research any existing products that meet the design brief.
3. Produce five or six different ideas that will meet the design criteria.

When producing design ideas for a product, you need to think about how you can change the form of the product – in other words, the shape and look of the product. Some ways of doing this include:

- swapping or substituting materials or processes for something different, perhaps to make the engineering product easier to produce
- combining features from different designs to produce a solution that makes an engineering product more useful

- adapting an existing design that fulfils a different purpose and making it suitable for the problem you are solving
- modifying the look of the design – perhaps make it tall and narrow, or short and wide, or change its shape; does it need to be a regular shape or might other shapes be more efficient?
- putting the product to another use – would the product still work if it were used for another, but similar, purpose?
- eliminating parts that are not needed – could you use fewer materials or processes, or make the product simpler, or reduce it in size and weight?
- reversing parts of the design – could you produce a solution that works in completely the opposite way but still meets the needs of the brief?

These are just some of the methods that you could use when redesigning a product. It is always important to think about how the component parts will be made and assembled.



Examples of design sketches and concepts for an engineered product

LINK IT UP

In Component 1: Learning aim B, you created design sketches as part of a design and make process.

CHECK MY LEARNING

You have learned about how the form of an engineering product can affect how effective the product is at meeting its design brief.

As a group, produce a mind map that shows the factors an engineer should consider when changing the form of an engineered product.

Variations in approach to solve a problem

GETTING STARTED

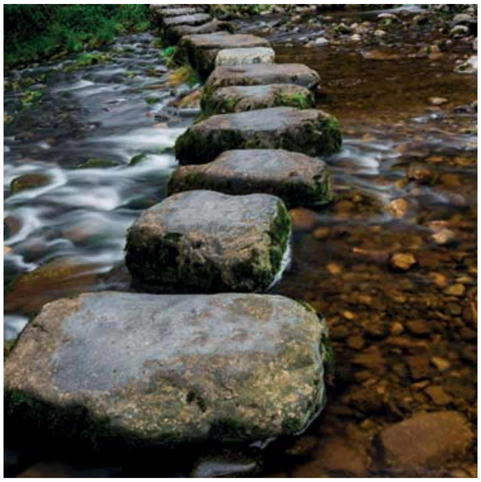
With a partner, think of as many ways as you can to solve a certain problem, such as designing a device that allows you to control the lighting in a room.

It is important to ensure that the solution chosen meets the engineering design brief, but there are many ways in which engineers can find a solution that satisfies the brief. Sometimes, the solutions can be very complex; at other times they may be quite basic. However, most of the time the solution is only as complex as it needs to be.

Example

The photographs showing stepping stones and a suspension bridge are two examples of a solution to the following design brief:

- Provide a method of crossing a river so that the users do not get wet.



Stepping stones

Suspension bridge

Sometimes, a very simple solution can be found, like the solution using the stepping stones. But a simple solution may not meet all the needs of the potential users of the crossing. For example, it would be difficult for a person on a bicycle, or pushing a child in a buggy or pushing a wheelchair user, to cross the river.

Alternatively, the suspension bridge is a complex solution to the same problem. This approach allows people to cross in many ways, including using motor vehicles. The solution, however, will take a long time to construct and will also be very expensive to build.

Factors such as the overall benefits of a design, as well as the cost, time and techniques required to manufacture the proposed solution, all need to be considered carefully when selecting the most appropriate solution to meet a design brief.

ACTIVITY

Find a range of engineered products that meet the same general design requirements – for example, types of mobile phone or bicycle.

1. Research different examples of these products, each taking a different approach to solve the problem.
2. Make notes to explain how each idea meets the design requirements.
3. Sketch the parts of each design that are effective in meeting the design requirements.

Although it is possible that a range of ideas can meet a design brief, there are likely to be some aspects of a design that are more effective than others. Think again about the stepping stones and the suspension bridge: while both make it possible to cross the river without getting wet, only the bridge allows a wide range of different users to cross the river.

Rating systems

One way of measuring the effectiveness of a design is to use some form of rating system. This could be simple – for example, giving each design a mark out of 10 (or any value you choose) or using what is known as a RAG (red-amber-green) rating system. This system can be used to rate how well a design meets the design brief, using the following criteria:

- red – does not meet the brief in any way
- amber – partially meets the brief
- green – fully meets the brief.

Each individual part of the design can be RAG rated and then the results presented in graphical or tabular form (see, for example, Table 3.16).

Table 3.16: RAG ratings for four types of mobile phone

Design	Make phone calls	Send text messages	Pocket-sized	Long battery life	Waterproof	Smash-proof screen
1	green	green	green	red	green	green
2	green	green	green	amber	green	amber
3	green	green	amber	green	green	red
4	green	green	red	red	amber	red

Using the RAG rating system, it can be easily seen that Design 1 is the best design in terms of meeting the highest number of criteria.

You can also use RAG rating systems to identify design criteria that none of the design proposals can meet. You might then consider whether these criteria could be removed, or their relevance reduced, if they are less important to the overall function of the product.

ACTIVITY

Revisit the examples of engineered products you investigated in the previous activity.

1. For each product, give a RAG rating against each of the design requirements.
2. Present the results of the RAG rating in graphical or tabular format.
3. Use the RAG ratings to decide which design meets the design brief the best.

LINK IT UP

Refer to Component 1: Learning aim B and the use of creative thinking and evaluation techniques to choose the best solution to a problem.

CHECK MY LEARNING

You have investigated methods that can be used to compare different approaches to solving a problem.

With a partner, use a RAG rating approach to evaluate and compare how two products meet their intended purpose – for example, a pencil sharpener or an item of workshop equipment.

Using different componentry

GETTING STARTED

Select one of the engineered products that you have examined previously and investigate whether there are any parts or components that could be substituted and still allow the product to function as originally designed.

Some of the engineered products we use daily are manufactured in a variety of factories and in different locations. This means that although the final product might look the same, the actual parts used are often different from one model to another.

DID YOU KNOW?

On a visit to Europe, Henry Ford saw two examples of vans that looked almost identical. One was manufactured in Britain, the other in Germany. However, the parts used to build the vans were not interchangeable – the British version used parts with imperial measurements; the German van's parts were metric.

Sometimes engineering components can be substituted for each other without any notable change in how the product is made or how it functions.

Nuts, bolts, screws and other fixings can often be substituted

When considering the redesign of a product, you should think about whether you can standardise the components used. For example, it is good practice to limit the range of screw heads and diameters (or sizes) of screw used. This reduces the machine tooling requirements for producing holes and, if necessary, threaded holes in components; plus there is the additional advantage of needing only a limited range of tools to assemble the product.

This approach to standardisation can be used to make manufacturing and assembly processes more efficient. Time savings achieved by reducing the number of tool changes can soon add up and allow components to be made more quickly.

ACTIVITY

For a simple engineered product, investigate the possible use of alternative components as part of a product redesign.

1 Analyse the product to see which components are used to make it.
2 Research alternative appropriate components that could be used.
3 Produce annotated sketches for some alternative designs.

There are other ways in which alternative components can be used. These include:

- manufacturing the component from a different material
- using a different manufacturing process to produce the component
- redesigning the component to reduce its weight or volume
- using common components that can be used for many different purposes
- replacing two or more components with one that can perform the same functions – this is called **parts integration**.

Parts integration has a number of benefits, including reducing the overall number of parts, lowering costs and making assembly faster.

Once you start to look at replacing components with alternatives, this often leads to discovering other aspects of a design that could be improved. Using alternative components is only one way to improve a design solution. It is usual to combine this with some of the other approaches looked at previously, such as changing the form of the design or considering design for manufacture.

When redesigning a product, you should try to do the following:

- Standardise components and use only a limited range of sizes. Try to use common components and stick to these.
- Reduce the number of tooling changes that are needed. This means that the assembly of a product can be completed more efficiently.
- Think about using the same material for as many components as possible, provided this does not make the product less effective. This can allow for material to be bought in bulk and prevents issues caused by having materials that react with each other.

LINK IT UP

In Component 2: Learning aim A you learned about different types of component, including proprietary components and standardised components.

Another method of using different componentry is to combine multiple components into one; for example, a threaded bar with a nut at both ends could replace the use of two nuts and two bolts, or a bracket could be designed with three faces to replace two angle brackets.

An approach that you could follow is to:

1. select at least two components that are joined together in some way
2. produce a few sketches to show how the components could be integrated into one part.

For electronic circuits, you could consider the use of programmable integrated circuits (PICs) to reduce the number of individual components in a circuit and make the assembly of a PCB more efficient.

CHECK MY LEARNING

You have investigated methods of reducing or improving the componentry within an engineered product. This includes standardising and/or combining components.

In pairs, discuss the approaches that could be used to improve the componentry for a given engineering problem.

KEY TERM

Parts integration is the ability to combine different parts.

Evaluation

GETTING STARTED

In a small group, find some examples of engineered products that all provide a solution to the same problem – they have the same functionality. Compare the products and decide which one the group as a whole thinks is the best.

LINK IT UP

Refer to Component 1: Learning aim B to remind yourself of the evaluation techniques that can be used.

It is very unusual for any one solution to a problem to be perfect and meet all the requirements of the design brief and the product design specification. This is where the use of evaluation techniques becomes useful. However, the evaluation of design proposals is one part of the design process that can either solve problems or create them.

Reviewing the credibility of design ideas

If you carry out a detailed evaluation of each of your design proposals, this process should allow you to choose the one idea that best meets the design specification or to develop a solution that combines the features of a range of proposals.

Making the right decisions

The reason for evaluating design proposals is to ensure that you make the correct design decisions. One method is to consider the strengths and weaknesses of designs relative to each other and against the specification. You will need to analyse your proposals and make development decisions about:

- the materials and components to be used and the effectiveness of their use
- the manufacturing processes to be used.

Analysis of ideas

Look at each of the designs you have produced, including your preferred design solution. You can take different approaches to analysing and testing the ideas, including:

- discussing the ideas with other members of the group. You should prepare a number of questions related to your specification; for example, do group members think the design proposals would function as you want them to do?
- producing a prototype to check if the design proposals will function as intended; for example, if a bracket needs to join two parts together, will it actually fit?
- being critical about the designs. You need to be honest: perhaps take the approach that you are looking at something designed by others instead of by yourself.
- comparing your ideas with those that are already available in the marketplace. Do your solutions offer improvements? If not, why not? How can the ideas be improved?
- seeking expert opinions. Perhaps ask a practising engineer, one who works for a company that manufactures similar products, for their opinions, or someone who would be making use of the product on a regular basis.

ACTIVITY

In previous lessons, you looked at generating ideas to solve an engineering problem. Now, you need to look at evaluation of these ideas. To do this:

1 Select the ideas that you think are most likely to meet the needs of the problem.
2 Sketch each idea in the form of a mind map (similar to that shown in Figure 3.21).
3 Annotate the map to explain how the idea meets specific aspects of the design brief.

When you have finished your mind maps, discuss your results with a partner. Ideally, you need to find ways of further improving the designs to see if you can satisfy more aspects of the brief.

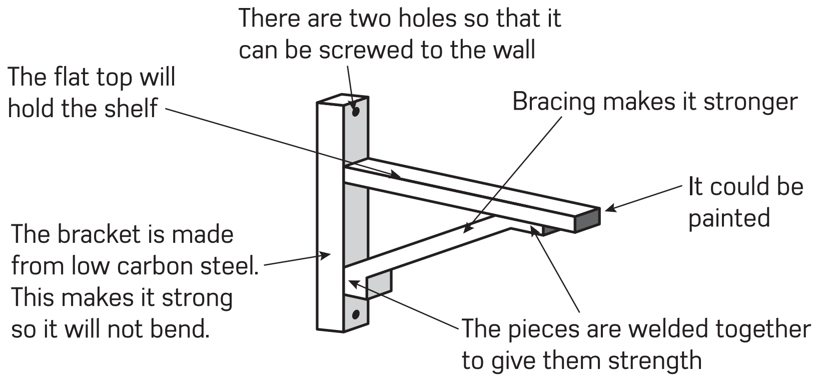


Figure 3.21: Annotated sketch of an idea analysis

When you are evaluating your ideas:

- Be honest – if a design brief/specification point has not been met, then say so.
- Be critical – if something can be improved, explain how it can be improved.
- Be thorough – check each specification point, looking at your ideas in depth.

CHECK MY LEARNING

You have learned about why it is necessary to review the credibility of design ideas against the requirements of a design brief.

As a group, evaluate an example of a design idea analysis produced by one member of the group. Do you all agree or disagree with the comments made by the designer?

Selecting and justifying the most appropriate design solution

GETTING STARTED

With a partner, discuss ways of justifying the most appropriate design solution for an engineering problem.

DID YOU KNOW?

At least six variations of the initial concept idea were considered for the space shuttle during its development by NASA in the 1970s (see Figure 3.22). The actual final design selected can be seen to have elements of most of the alternative approaches.

When designing a solution to an engineering problem, if you have approached the process logically, you will have produced a number of ideas that all meet the design brief fully, but in different ways. It is an important part of the design process to review each idea in order to develop a solution to the problem. To some extent, you have done this previously when you produced a mind map to analyse each of your ideas. The next stage is to carry out a critical analysis of the results and then select the most appropriate solution.

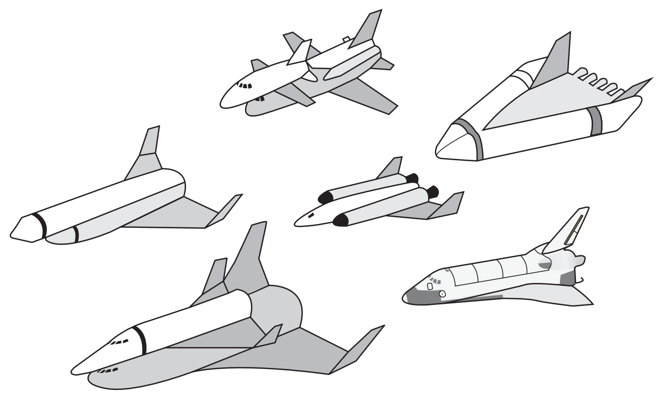


Figure 3.22: Concept designs for the space shuttle

As part of the evaluation of design ideas, you need to consider how effective each idea is at meeting the needs of the design brief and design specification. It could be that you, like NASA and many other engineering companies throughout history, will need to take elements from more than one of the design proposals you have produced and combine them into a final design.

When you are reviewing the analysis of your ideas, think about each specification point and rate ideas against individual points – think about the RAG rating approach covered in an earlier lesson. Make notes on your design work to explain how specification points are met, and think about which specification points are most important.

Justification of the design solution

When you review your ideas, it is worth looking back at the specification for the engineered product. For example, if the specification for a shelf bracket includes the points listed below, you need to think about which ones are the most important.

Specification

The shelf bracket must be able to:

1. hold a shelf that is 250 mm wide
2. support a loading of 10 kg
3. be manufactured in small batches
4. have multiple holes to allow screw fixings to be used
5. be made from durable materials
6. be finished with a range of finishes.

For a shelf bracket to do the job it is designed to do, it must meet specification points 1 and 2 fully, otherwise it will not be **fit-for-purpose**. Similarly, if point 4 is not met, then it will be difficult to fix the bracket to the wall.

In comparison, specification points 3 and 5 are not as vital for the design of the shelf bracket, but because they impact on manufacturing decisions, a solution that could not be made in batches using durable materials would be inappropriate.

Specification point 6 is more cosmetic and would generally be achieved by most designs.

When reviewing a final solution, you should explain how the specification points are met. For example, the following design proposal meets specification points 1 and 2:

- the top of the bracket is 250 mm wide and can therefore hold the shelf
- the cross member is triangulated to provide enough strength to support the load. This is welded together to provide a permanent joint.

KEY TERM

Fit-for-purpose is the term used to describe whether a product can perform the job it was designed to do.

ACTIVITY

You have previously learned about how to identify the strengths and weaknesses of design ideas. Now it is time to select and justify which design is the most effective solution.

1. Use the given specification to review the effectiveness of each idea.
2. Identify the most effective solution to the problem.
3. Write a short report explaining how your chosen design meets the requirements of the specification and why you selected it as the most appropriate design.

CHECK MY LEARNING

You have investigated methods of selecting and justifying the solution to an engineering problem.

As a group, discuss the approaches that should be taken when justifying the selection of an effective solution.

Justification of the processes to be used

GETTING STARTED

With a partner, examine an engineered product or component that is in your classroom or workshop. Make a list of the different processes that you think have been used to make the product, and discuss why these processes would have been selected.

Drilling is an example of a cutting process

When you produce designs to solve an engineering problem, you need to think about and justify the types of manufacturing process that should be used to manufacture the design idea.

Types of process

As we have looked at before, manufacturing processes can be grouped into the following four categories:

- cutting processes
- shaping processes
- forming processes
- joining and fabrication processes.

When you think about processes that could be used to manufacture a new or an improved design, you need to understand how each process is carried out. Sometimes these processes will be familiar to you, such as drilling, but at other times you might need to consider a process that you have never tried for yourself, such as sand casting.

To justify if a process is suitable, you will need to do some research. Sources of information include:

- textbooks
- the internet
- your class notes.

Questions to consider when deciding on processes include:

- How many products need to be made? Will it be one-off, batch or mass production?
- Which materials will be used? Not all processes are suitable for every material.
- Are there any features essential to the design that might make it impossible to manufacture using certain processes?
- What quality standards need to be met?
- How long do you have to manufacture the product?
- Are there any cost implications that you need to consider? Is there a budget that must be kept to? How do the costs of alternative processes compare?

ACTIVITY

You have previously produced a range of ideas to solve a problem. Now you need to think about how these designs could be made.

1 Which materials can be used?
2 Which processes can be used?
3 Give reasons why these materials and processes are suitable.

Folding metal with a sheet metal press

There will be some processes that you can carry out in a small workshop, such as bending sheet metal to fabricate parts; on an industrial scale this would be done using a press, like the one shown in the photograph.

To justify the processes you have decided to use, you need to think about the following:

- How many items of the product are you planning to produce? Different processes will be needed for a one-off product compared with a mass produced product.
- Investigate processes that would be suitable for the materials you have chosen and the scale of production. For example, die casting would not be appropriate for a one-off product.
- Examine the processes used for similar products. For example, if you are redesigning the casing for a games console, look at the materials and processes used for small electrical devices.

CHECK MY LEARNING

You have investigated methods of justifying the engineering processes used to manufacture a component or product.

Working in the same pairs as in the Getting started activity, discuss alternative processes that could be used to manufacture a product or a component you looked at and give reasons for the selection of whichever process you believe to be most suitable.

Learning aim B: assessment practice

How you will be assessed

In this component, you will be assessed by completing a set task that consists of two parts, worth 60 marks in total, marked by Pearson examiners. Learning aim B is assessed mainly through Part 2 of the set task, which will take place over one and a half hours.

Part 2 will consist of two activities that target higher-order planning, redesign and evaluation skills, and which relate to given scenarios. The first section of Part 2 of the set task assesses your ability to interpret information and to use this to suggest improvements to an engineered product.

You will be assessed on how detailed your evaluation of the existing design is. If you make very basic points only, or ones that are not relevant to the problem, you will receive marks in the lowest marking band. If, however, you identify relevant issues with the design that you are presented with, and then evaluate these issues in detail to show that you fully understand the existing design and how it relates to the design brief, you will be awarded marks in the highest marking band.

Unlike in the practice activities, you will only be asked to produce one design idea in the external assessment, so you need to make sure that this one idea meets all the requirements of the brief and addresses all the areas for improvement you have identified in your evaluation.

If these aspects are not included in your responses, then you will not be able to achieve the higher marks. It is important that you annotate your work clearly to ensure that the person who is marking your designs can understand what you have done.

Remember that the examiner who will be marking your set task does not know you, and the only way they will be able to assess your engineering skills is through the work that they see you have completed.

CHECKPOINT

Strengthen
- Identify four factors that come together to form a design brief.
- Give two ways in which an engineer can vary a design to make improvements.
- Why are exploded diagrams used by engineers?

Challenge
- Explain what is meant by the term 'design for manufacture'.
- Describe two ways in which the credibility of a design can be assessed.
- Explain the reasons why engineers might use alternative components to improve a design.

ASSESSMENT ACTIVITY LEARNING AIM B

You will be given a brief for an engineered product and an example of a design for the product.

You will need to evaluate the existing product to identify its strengths and weaknesses, as well as its limitations and constraints. This will be completed during the first part of the set task.

Your teacher will give you an example of an engineered product, along with details of how the product has been manufactured. Using this information, you will need to:

1. Explain the issues with the design of the product.
2. Think about how the product is made and how it will be used.
3. Annotate the drawing of the product to identify any issues.

Note: You will use your evaluation to help you redesign the product for the second part of the set task.

TIPS

When you begin your analysis of the existing product, make sure you add annotations to the drawing to explain how the product has been made, the problems you have identified with the product, and parts of the design that you think could be improved.

TAKE IT FURTHER

To gain the higher marks for this assessment, you need to make sure that the issues you identify with the existing design are relevant. You should justify these by making reference to the given drawing and the design brief.

Use technical engineering language when writing your justification and always make links with the design brief.

Analysing engineering information associated with the problem

GETTING STARTED

Working in a group, discuss why engineers use many different types of information and data as part of their quality control checks.

Engineers use a combination of different types of information to manufacture an engineered product, including specific details of manufacturing processes, to ensure that the product is made to the correct size and from the correct materials.

LINK IT UP

Refer to Component 1: Learning aim B for information on quality requirements and quality control.

Types of engineering information

Engineering information can include work instructions, production data/plans, job cards, test reports and engineering drawings.

Work instructions

Work instructions describe how a part or component should be manufactured. They provide information on how to complete a task one step at a time.

Some manufacturer's manuals include information similar to work instructions, such as describing how to repair, assemble and test an engineered product by following step-by-step instructions.

Production data/plans

When manufacturing a component in a workshop, it is likely that you will use a production plan to guide you through the various stages that need to be completed. This ensures that you do not miss out any stages or complete them in the wrong order.

The complete process is broken down into stages, known as operations. Descriptions are given for each stage or operation of the process and will include information about:

- the required materials and components
- the tools and equipment to be used
- **speeds** and **feeds** to be used on machines, such as drills, lathes or milling machines
- quality control checks to be completed
- timings for each operation.

KEY TERMS

Speeds and **feeds** refer, respectively, to the 'spindle speed' (the speed at which a machine spindle rotates) and the 'feed rate' (the rate at which a machine tool moves across a 'workpiece', i.e. the material being machined).

Job cards

A job card is a form of work instruction (see Figure 3.23), as is an operations sheet. Engineering organisations use job cards as a way of showing all the requirements that need to be carried out for an activity. This may include the tools, materials and components needed, the amount of time that the activity should take, staffing details, and other details about the tasks to be completed.

Works Order No:			
Part no: Description:		Sales order no:	
Customer name:		Customer standards apply:	
Customer acc no:		Certificate of conformity required:	
Customer ref:		Check issue:	
Quantity:		Check drawing:	
Required by:			
Scheduled for:		Issued by:	
Scheduled completion:		Signature:	
Materials: Req qty	Item code	Product description	
Mat spec	Issued qty	Batch no	Initials

Figure 3.23: An engineering job card

When using production documentation, you should make sure that:

- you read and understand the information fully and use it to select the correct materials, tools and equipment
- you follow the instructions in the correct order
- you ask for further guidance if you are not sure about anything.

ACTIVITY

Following the details on an instruction sheet you are given, such as a job card, produce a small engineered component by doing the following:

1. List all the materials, tools and equipment needed.
2. Obtain the materials needed.
3. Access the tools and equipment needed.
4. Follow the instructions to manufacture the component.

Test reports

A test report must be completed when an engineered product or component needs to meet specific performance requirements. You can use test reports to help identify patterns and trends within production activities.

CHECK MY LEARNING

You have looked at some types of engineering information that can be used when carrying out an engineering activity.

With a partner, discuss how you would use work instructions, production plans, job cards and test reports.

Types of engineering working drawing

GETTING STARTED

Working with a partner, make a list of the types of drawing that would need to be used to provide full details of an electronic games console design.

We have looked at how engineering drawings can be used to present ideas and communicate information to other engineers and customers. In most cases, you will need to use a combination of drawing types to be able to communicate a design clearly.

In addition to the different formats of drawing, there are specific types of working drawing that can be used to provide particular details of a design.

Component drawings

A component drawing includes the information needed to make that particular component, including the materials to be used, dimensions of the component, any surface finishes that are required, and information about specific processes, such as producing threaded holes or counterbores. Examples of components that component drawings are generally used for include nuts, bolts, screws, integrated circuits, rivets and mechanical components such as bearings and gears.

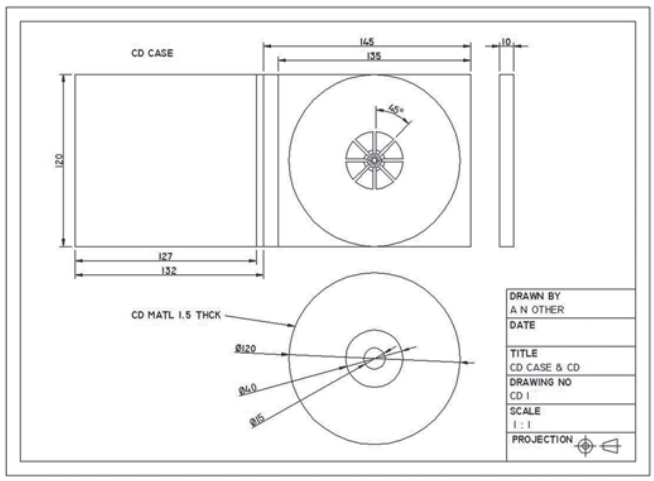


Figure 3.24: Example of an engineering component drawing

Component drawings, such as the one shown in Figure 3.24, must be sufficiently clear for an engineer other than the designer to be able to follow. These drawings contain the minimum information needed to produce the part. They do not show how individual components interact or combine with each other. For this, you need an assembly drawing.

Assembly drawings

To show how component parts fit together, you need an assembly drawing. Assembly drawings, such as the one shown in Figure 3.25, are used by engineers to make sure they do not assemble components in the wrong way. These drawings do not, however, show individual details of components, and therefore assembly and component drawings need to be used together.

There are variations of assembly drawings that may be needed when developing an improved solution to a problem. These include:

- sub-assembly drawings that show how components fit together to form a larger component such as an alternator, which is a sub-assembly of a car engine assembly

- fabrication assembly drawings that show details of joining methods required for structures manufactured from sheet materials, and may also include details of welds or fixings.

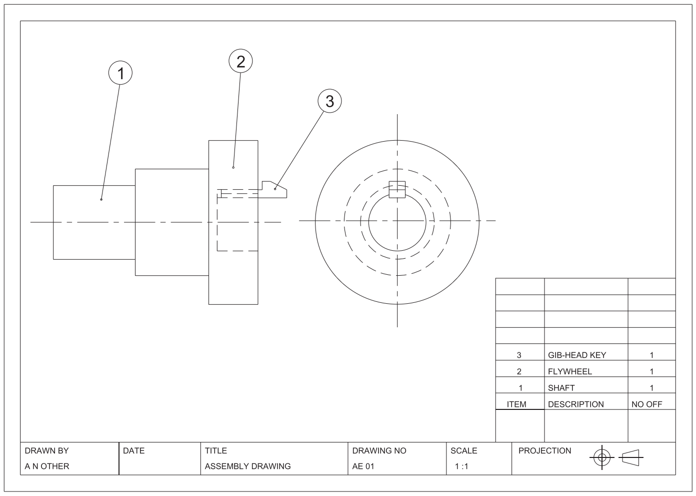


Figure 3.25: Example of an engineering assembly drawing

Repair and modification drawings

Sometimes repairs or modifications need to be made to a component. For example, additional holes may need to be drilled, or part of a component removed, to allow it to fit within an assembly. In these instances, there is only a need to produce a modification or repair drawing with details of the specific changes required.

Installation diagrams

Installation diagrams are used to show how a component should be installed in its final location – for example, how to install a hot water boiler or piece of machinery.

Wiring diagrams

Wiring diagrams are similar to circuit diagrams, except that they show how electrical circuit components, such as switches and other electrical equipment, are actually connected together. You can find examples of these types of diagram for the wiring of the machinery in a workshop.

ACTIVITY

Imagine that you have been tasked with designing a prototype digital camera that is suitable for water sports.

1 Research the types of drawing that you will need to use.
2 Prepare a presentation to show what information each type of drawing will provide.
3 Include an explanation of why each type of drawing is useful.

CHECK MY LEARNING

You are now aware of some of the types of drawing an engineer could use to share information.

In a group, explain what each type of drawing shows and when each type is usually needed.

Drawings and information

GETTING STARTED

Make a list of the types of information you would need to produce an engineered product in a workshop. With a partner, discuss why some engineering drawings may be difficult to interpret.

KEY TERM

Conventions are the rules used to present information such as drawings; for example, BS8888 is the standard set of rules for working drawings. They cover line types, symbols and layouts of drawings.

Engineering drawings can contain lots of information. Often these drawings may appear confusing and difficult to interpret if you are unfamiliar with the different drawing **conventions** used.

Drawings are extremely useful for showing how parts fit together, whether the parts are male or female, and how any specific connections need to be made.

Materials and components

One easy way of remembering whether a part is male or female is to think about a nut and a bolt.

- A bolt has a thread on the outside – an external thread. Parts with an external thread are termed 'male'.
- A bolt is usually assembled with an accompanying nut, which has a thread on the inside – an internal thread. Parts with an internal thread are termed 'female'.

A working drawing, or assembly drawing, will show, where applicable, details of how male and female parts fit together. Similarly, an electronic circuit diagram will show the typical values of the components within it. These could include current, voltage and resistance values. You will need to think about these details when selecting components to use.

Dimensions

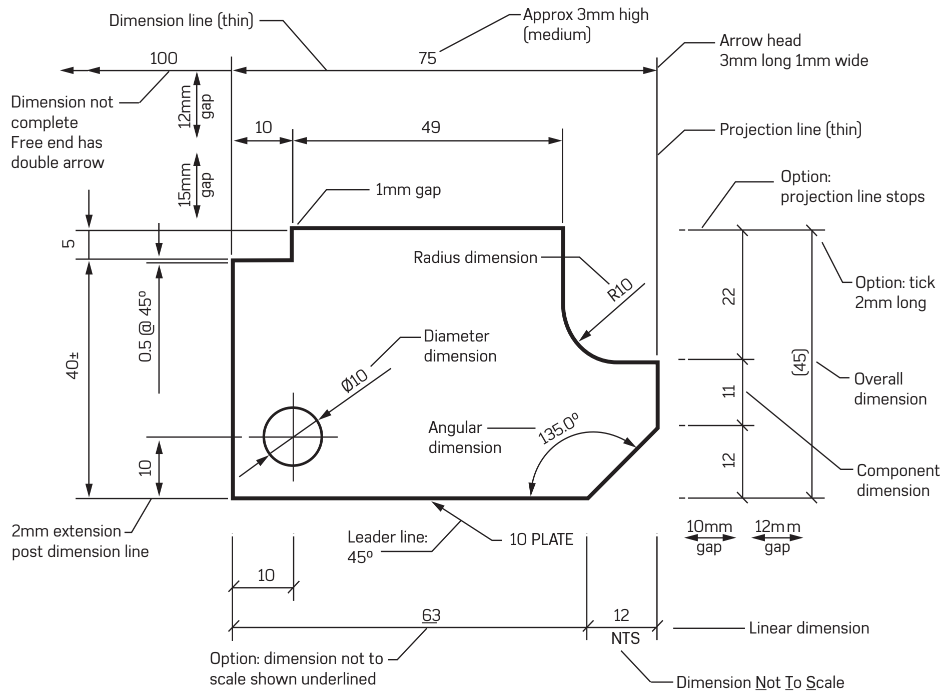


Figure 3.26: Engineering drawings often include information about radii, diameters and tolerances among other manufacturing information

Look at the example of an engineering component drawing shown in Figure 3.26. There are a range of features on the drawing that you need to understand in order to interpret correctly the information being shown.

One of the most important features of any engineering drawing is the dimensions marked on it. To interpret these, you must be able to understand the abbreviations and conventions used.

Some of the more common abbreviations and symbols are shown in Table 3.17.

Table 3.17: Abbreviations used in drawings

Abbreviation or symbol	Meaning
∅ or dia	Diameter
R	Radius
NTS	Not to scale

You also need to remember the following points about dimensions.

- Dimensions always show the true size of a component, although sometimes components are drawn to a different scale.
- Dimensions are usually shown only once on a drawing – this means that you may need to transfer dimensions from one side of a component to the other.
- Different line types are used for dimensioning on a component drawing – these are shown as dimension lines, extension lines and leader lines.
- Short dimensions should be labelled closest to the component – this prevents lines overlapping.
- Dimensions should never appear on top of a drawn object; they should always be to the side, away from the object.
- Try to group dimensions together wherever this is possible.
- Horizontal dimensions should appear above the dimension line.
- Vertical dimensions should be to the left or right of the line and preferably orientated so that they are written along the dimension line.

ACTIVITY

Assemble an engineered product using only engineering drawings. Make a note of any problems that you have with interpreting the drawing information and any parts of the assembly that you found easy to complete.

Take photographs, annotating them to highlight the problem areas. Discuss with a partner.

CHECK MY LEARNING

The ways in which information such as drawing dimensions and abbreviations can be added to a drawing have been covered in this lesson.

In a small group, think about and discuss the reasons why drawing conventions are important and must always be followed.

Identifying issues and causes associated with a problem

GETTING STARTED

Working in a small group, think about the types of problem that could be encountered with the design and manufacture of an engineered product such as a mobile phone or a bicycle.

As an engineer, it is important that the products and components you design and make perform as expected. It would be inconvenient if a hook designed to hold tools in a garden shed was not able to support the weight of a spade; it could be dangerous if the tyres on a car could not cope with travelling at motorway speeds.

Identifying problems

Engineers use data from tests to identify potential problems or faults and then find solutions to these problems.

We have seen the scatter graph in Figure 3.27 previously, but what if the circled test values are accurate and not the result of measurement errors or false readings?

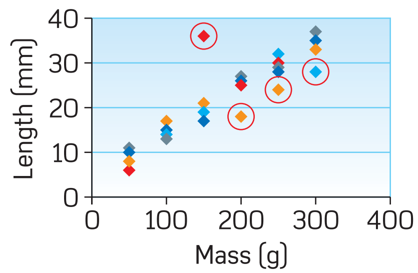


Figure 3.27: Results from a load–extension test for springs

Looking at the graph, one of the springs extended to nearly twice the length of the others with a load of 150 g. This could lead an engineer to think that the material used is of a different quality, or perhaps of a thinner gauge than specified. By noting these anomalies in results, engineers can investigate the causes of a problem.

ACTIVITY

Look at the results for the load–extension test in Figure 3.27.

1. Think of reasons why some of the springs did not perform as expected.
2. Identify possible stages in the production of the springs where mistakes could have led to the differences in performance.
3. Suggest ways to prevent the same problems happening in the future.

Typical causes of faults

Faults can be divided into two types:

- random faults
- systematic faults.

Random faults

Random faults are often associated with the materials or the equipment used to make a component. Causes of random faults include the following:
- poor-quality materials that do not meet the specification
- flaws in materials that cause the materials to fail
- blunt or damaged tools and work-holding devices
- damaged gauges and measuring equipment.

The analysis of data can help to trace random faults; for example, if a number of faulty components were produced on one machine and none on other machines, then inspections could be carried out to check for damage to that individual machine.

Systematic faults

Systematic faults are usually the result of human errors at some stage in the production process. These include:
- incorrect materials being selected for a component
- incorrect cutting speeds and feeds being used
- marking-out errors
- inaccurate use of tools and equipment.

In most cases, systematic faults will not be noticed through the interpretation of data, other than perhaps to notice trends for individual machine operators.

Interpreting patterns and trends related to engineering information

You need to be able to look at engineering information and identify whether there are patterns or trends. We have looked at the use of scatter graphs earlier, but sometimes you need more information to help identify and solve problems. For example, think about other factors such as when a component was manufactured or where it was made.

CHECK MY LEARNING

We have looked at ways of identifying problems and faults that can occur within engineering processes.

Write down as many random and systematic faults as you can think of that can impact on an engineering process.

Selecting a solution

GETTING STARTED

Imagine that you have been asked to redesign a torch that has already been prototyped using metallic materials. With a partner, make a list of all the factors that need to be considered when redesigning for manufacture.

There are many ways in which the design of a product can be improved, such as by changing the materials and/or reducing the weight or volume. However, whichever changes are made to a design, you must ensure that it will still be possible to manufacture the product.

A range of approaches can be used to make a product easier to manufacture. We have looked at some of the approaches in the lesson on using alternative components, and in many ways the approaches are similar.

Prototype of an LED torch

With a product prototype, the materials and processes are often chosen because they are suitable for one-off production methods. This means that if the product is going to be manufactured on a larger scale, decisions will need to be made about the materials and processes to be used for the increased scale of production.

Approaches that can be taken

There are a number of aspects that you will need to consider when redesigning a product for an increased scale of production.

- Consider using standardised components.
- Design components so that they can be manufactured using as few processes as possible.
- Reduce the number of different materials in the product.
- Reduce the number of different components in the product.
- Avoid unnecessary features that do not improve the product.
- Consider the use of automated processes when selecting manufacturing methods.

Components

There are two ways in which you can redesign the componentry to make a product more efficient for manufacture.

Use of standardised components

This means using the same component in a range of products or in different combinations within the same product. In some cases, the same component can be used both in different combinations within one product and in other products.

Limit the number of different types of part in a product by standardising their design. For example, if brackets are included as part of the design, avoid having four or five different types. It is good practice to have only one design for each type of component as this reduces the time needed for processing and manufacturing and allows for ease of maintenance in the future. If there are fewer designs of a part to make, fewer tool set-ups are required, and the associated number of jigs, templates and formers can also be reduced.

Reducing the number of components

You could also reduce the overall number of components in a product. Instead of joining several parts together, consider using different processes and/or materials. For example a fabricated metal container could be replaced by a container made from injection-moulded polymers. The product can then be manufactured more quickly as fewer processes will be involved.

Materials and manufacturing processes

You should aim to reduce the number of different materials and manufacturing processes used. By limiting the range of raw materials, they can be used more efficiently and processes can be completed faster. If component parts need to be joined together using thermal processes such as welding, using the same material for all components will make assembly easier because it can be difficult to weld different metals together.

Using the same types of polymer for different components would also allow the same processes to be used to manufacture them. For example, high-density polyethylene (HDPE) could be used for various injection-moulded parts.

It is also more efficient to reduce the number of different pieces of equipment needed. The use of CNC or automated machinery should be encouraged wherever possible. These various considerations can be summarised as follows.

- Limit the number of different materials that you specify.
- Think of processes that are more efficient for manufacturing.
- Avoid using lots of different sizes and thicknesses of material.
- Think about ways in which you can include CNC processes.

ACTIVITY

Use the internet to find an image of a prototype engineered product.

1. Sketch the existing design and annotate your sketch with details about the materials used in the prototype.
2. Produce a range of 2D and 3D sketches to show how the product would be made in quantity.
3. Annotate your sketches to explain how the product would be made.

CHECK MY LEARNING

You have learned about the approaches an engineer can use to improve the design of a product by using different materials, components or processes.

With a partner, discuss the factors you need to consider when replacing a polymer material used for a prototype design with a metallic material for the actual product.

Possible engineering solutions

GETTING STARTED

Think of a simple everyday product that you are familiar with. Write down any flaws or problems with the design that you can think of.

Most existing products and components, no matter how small or simple, can be improved in some way. However, producing the ideal solution is often not economic: it would cost more to redesign some components than the money an engineering company would save as a result of the design changes.

When you investigate products to identify potential improvements, you need to think about the following factors:

- the design of the product or component
- the tooling used for manufacturing the product or component
- the manufacturing processes used to make the product or component.

In most cases, improvements to one aspect of the product will have a knock-on effect on other aspects. If you change the design of a product, there are likely to be changes needed to the tooling used and potentially also to the manufacturing processes.

Example of a component that has been redesigned using computer-aided design (CAD) and then produced in titanium using 3D printing

The component shown in the photograph, part of an axle assembly for a go-kart, was originally manufactured from stainless steel plate and then stamped out and deformed in one process.

The manufacturing company that makes this component has identified a number of faults with the existing design, including large quantities of waste material being produced and offcuts of materials that are hard to recycle.

The company decided to make some small changes to the design of the component to allow it to be manufactured using a different process. The new process chosen is 3D printing and the material has been changed to titanium. This reduces the amount of material wasted because, with an additive process, no waste materials are produced.

When you are redesigning a product, think about the concepts we have covered before and remember the acronym KISS – 'Keep It Simple, Stupid'.

Do not overcomplicate things – a simple design will probably perform better than a complex one.

- Design components so that they can be manufactured using as few processes as possible.
- Reduce the number of different materials in the product.
- Reduce the number of different components in the product.
- Avoid unnecessary features that do not improve the product.
- Consider the use of automated processes when selecting manufacturing methods.

All these factors link up with the concept of keeping the design simple.

DID YOU KNOW?

Albert Einstein once said: 'Everything should be made as simple as possible, but not simpler' (*Yale Book of Quotations*). He meant that you should make the design of a product as simple as possible while meeting the specifications, and success will be achieved when the product is as simple as it can be.

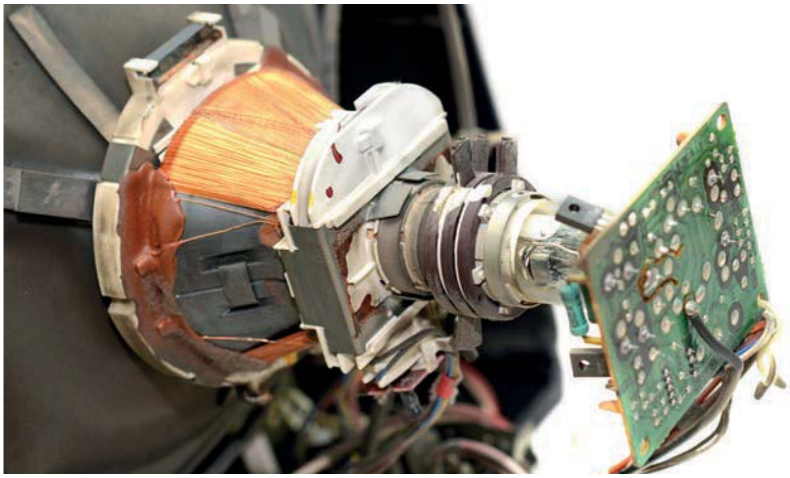
ACTIVITY

Examine an engineered product, either a physical example or an image of one.

1 Write down any issues that you think there are with the design.

2 Make notes about any problems that you think there could be with tooling or manufacturing processes.

3 With a partner, discuss potential ways to improve the design and improve the product.



Sometimes developments in technology can allow for radical changes in designs

It is possible that there are new technologies that could help simplify the product you are being asked to redesign. It is worth doing a little research to see if any new processes or technologies are being developed that would help improve your design. The image above shows what the inside of a television used to look like – think about how thin and lightweight televisions are now because of the new technologies that have been invented since then.

You also need to think about the extent to which your engineering solutions have fulfilled their primary purpose. In other words, does the solution do what it is supposed to do? For example, while a smartphone has many functions, its primary purpose is to allow people to communicate.

CHECK MY LEARNING

You have learned about methods that you could use to make a design simpler, yet still perform its primary purpose.

Working with the same partner as in the previous activity, think about another product that you are both familiar with, one that has more than one function. Discuss which approaches will lead to the greatest benefit in making the product more effective.

Wider factors that need to be considered

GETTING STARTED

Do you know what batch-produced means? Working with a partner, make a list of engineered products that you think are batch-produced.

You may be asked to redesign a product or component that has been made as a one-off so that it can be produced in larger batches. This means that a different approach will need to be taken for the design and the manufacturing methods.

One-off production

One-off production is used either when you are making a prototype of a product or when a customer wants something that is specially made for them. Often these one-offs are made by just one person, but sometimes small groups of people will work together to produce them. In both cases, the same people work on the complete product from start to finish. One-off products are unique, which makes them expensive to produce because of the amount of time spent on manufacturing them.

Batch production

If a number of products or components are needed that are all from the same design, then they can be made in a batch. Unlike one-off production, batch production offers opportunities to use automation. The production process allows for changes to be made – for example, to make the products in a different size. Often a production line is used to make one type of product, and then the line is adapted to produce a different type of product.

Alloy wheels are an example of a batch-produced product

Table 3.18 gives a summary of the differences between one-off production and batch production.

Table 3.18: Characteristics of one-off and batch production

	One-off production	Batch production
Unit costs	High	Medium
Tools and equipment	General use	**Specialised equipment**
Initial investment	Low	Medium
Production efficiency	Low	Medium/high
Labour type	Skilled	Skilled/semi-skilled
Labour cost	High	Medium

KEY TERMS

Unit costs in this context are the costs associated with the manufacture of an individual product.

Specialised equipment can be used for more than one product or component, but can only be used to carry out a limited range of processes.

ACTIVITY

Imagine you are an engineering designer. You have been asked to analyse an existing batch-produced product.

1 Investigate the materials and processes used to make the product.

2 Produce a short presentation that includes information about:

a) resources needed

b) reasons for batch production

c) safety factors

d) environmental impacts.

Environmental impacts

Environmental impacts of production must be considered when designing an engineered product. These include the following.

Use of energy during production

Energy will always be used during the production of engineered products. However, different sources of energy will have differing impacts on the environment. With fossil fuels, such as coal, oil and gas, there are impacts from the extraction of the fuel source and the burning of these fuels to produce energy. Other sources – renewable energy such as solar and wind power – can be used to generate cleaner energy. The source of the energy and the amount used are important when considering the impact of production on the environment.

Use of resources during production

It is best to avoid non-renewable materials, such as oil-based polymers, or materials that cannot be recycled at the end of their useful life.

Production waste and pollution

Try to avoid wasting materials. This can be achieved by using alternative processes such as 3D printing or casting, or through the recycling of waste materials and offcuts. Sometimes it is unavoidable that waste is produced, for example when turning a workpiece on a lathe or vacuum forming a polymer sheet to produce a moulding. The most effective way of reducing waste, though, is to make sure that production is '**right first time**'.

KEY TERM

Right first time is often quoted in terms of quality control and refers to when something is done without errors so that no time and money are wasted.

CHECK MY LEARNING

You have learned about some of the issues that need to be considered when designing a product for manufacture, such as the requirements of batch production and environmental issues that should be considered.

In small groups, discuss the outcomes of the investigation you carried out in the lesson activity – how would your findings impact on your redesign of the product?

Ways to improve the solution

GETTING STARTED

Working with a partner, think about the reasons why some products need to be redesigned.

There are many reasons why a product or component might need to be redesigned. For example, it may need to be redesigned so that it still fits another component that has also had to be redesigned, or the manufacturer might have considered that the processes used are not environmentally friendly.

Evaluating an existing design

Designers will normally be given the reasons why a product needs to be redesigned, or why the features need to be improved to make the product more effective at meeting its design requirements.

ACTIVITY

You have been asked to redesign a batch-produced shelf bracket. The manufacturer of the bracket has had complaints from customers that the bracket bends and cannot hold the loads it is designed to support.

The existing bracket is made from aluminium and is shown in the image below.

1 Use the internet to find out information about the materials and processes that are used to make the existing bracket.
2 Evaluate the existing bracket design to identify issues that could be causing it to fail and not meet the design brief.

The evaluation of an existing design will need to bring together information about various factors and review it to form a conclusion, drawing on evidence from the design brief and engineering drawings; it should include the strengths and weaknesses of the existing design.

When evaluating an existing design, you need to do the following tasks.

- Read through the original design brief for the product.
- Highlight the key points that the design must meet.
- Look at the existing design and circle features that you think could be an issue – this will ensure that you do not forget anything when you are writing your evaluation.
- Consider using subheadings in your evaluation, one for each product feature, and give reasons why you think the feature is going to be a problem. Try to include some information about each of the following factors in your evaluation:
  - physical requirements
  - aesthetics
  - size
  - function
  - performance requirements.

Remember that you need to justify your reasons and use connectives – for example: 'The bracket might not support the weight of the shelf because the material is very thin.'

LINK IT UP

In Component 1: Learning aim B, and earlier in this component, you looked at engineering design briefs. Use your understanding of the various factors included in a design brief to help you evaluate an engineered product.

Your evaluation will help you to decide which features of the product need to be redesigned and how to plan for the production of an improved design. This process should give you an opportunity to identify limitations and constraints associated with the existing design.

- Limitations are factors that impact on how well the design functions – for example, the maximum weight that could be supported by a bracket or the number of fixings needed to keep something secure.
- Constraints include things such as materials, costs, space available for the product or other parts that it must fit together with. A USB connection lead would be useless if the plug was a different size and shape from the port it needed to plug into – for the connection to work, the lead and the plug must fit together (this is an example of a constraint).

CHECK MY LEARNING

You have learned about some of the issues to be considered when evaluating an existing engineering solution to a problem.

With a partner, look at a product that you use as part of your daily life – for example, a watch, a mobile phone or even an item of clothing – and identify the strengths and weaknesses of the product's design.

Producing an alternative design solution

GETTING STARTED

Working with a partner, think about ways in which an engineered product you have evaluated previously could be redesigned to make it more effective.

You will need to use your evaluation of an existing product to develop an alternative design solution that meets the requirements of the design brief. It is a good idea to think about different approaches before starting to sketch out designs on paper.

We have already looked at methods that can be used to redesign a product or component, but some of these approaches are not always suitable. In the case of a support bracket, like the one in the previous lesson, we cannot simplify the design by reducing the number of components because it has only one component to begin with.

ACTIVITY

Look at an existing engineered product that you have evaluated previously and think about the following:

1. How could the performance of the product be improved?
2. What could be changed to make the design more effective?
3. Can the materials be changed?
4. What alternative processes could be used?

When producing an alternative design solution, you will need to answer these types of question and think about how you could include all these factors in a design solution.

You need to produce design ideas that:
- meet the design brief in full
- show an improvement on the original design
- include justifications of the alternative design solution – this will link to your evaluation
- include justifications of the processes to be used in manufacturing.

Remember that if you are asked to produce one design idea only, you need to ensure that your idea meets all the requirements of the design brief and addresses all areas of improvement that you have proposed in your evaluation.

It is important that you annotate your design work clearly to ensure that other people can understand what you mean and the design features intended.

Justification of your solution

It is normal for the **justification** of the proposed solution to be presented in a written report, so you need to ensure that points are made clearly and linked to both the design brief and your evaluation of the existing design.

KEY TERM

Justification is the reason or evidence to support an idea or design.

You will need to choose a solution based on the advantages and disadvantages of each design idea. As we have seen before, this could be done by checking how much of the design brief is met by each of the ideas and how much of a variation from the original design your new proposal would involve. Make sure you show links between the disadvantages of the existing design and the advantages of your improved new design. Remember to support your comments with reasons.

You could use a best-fit approach to select the best solution. This is similar to the RAG rating that we looked at earlier. You will need to consider the strengths and weaknesses of each of your design ideas and compare them against the design brief.

Some aspects of a design brief are more important than others, so you should identify a solution that meets all the criteria satisfactorily.

Your solution should show that you have a good understanding of engineering theory and processes.

When you are generating initial ideas, think about any limitations or constraints associated with the design. Does the design solution have to fit in a certain space or does it need to be a particular colour? You must be sure that your improved design meets all the constraints that are given.

As a further example of a constraint, suppose that the shelf bracket previously mentioned must have three holes to attach it to a wall, and these must be in the same location as the existing holes.

Finally, you should also identify the limitations of your design; for example, if you plan to make the product from medium carbon steel, then a protective coating will be needed, otherwise it will corrode.

CHECK MY LEARNING

You have learned about some of the factors that need to be considered when justifying a design solution. With a partner, discuss the following questions:

1. How can you check if a design meets the brief?
2. Why is material choice important?
3. How can you support the decisions that you make?

Reflecting on your design solution

GETTING STARTED

Look at the shelf bracket we have been investigating and redesigning. Make a list of the reasons why you think the manufacturer selected the materials and manufacturing processes used in the original bracket design.

We have looked at some of the things that you need to consider when justifying your design solution, including the reasons for your choice of design idea. You also need to justify the approach you propose to take for manufacturing the new design.

When selecting materials for the redesigned product, there are a number of factors that you should think about:

- material properties
- material cost and availability
- the processes that you plan to use
- the environment.

Material properties

There will be an expected level of performance from the material selected so that it will do the job it is designed to do. This could be related to the mechanical properties of the material, such as strength or durability. If the material properties are not suitable for the purpose, then the product or component will fail.

LINK IT UP

Go to Component 2: Learning aim A for information on material properties.

Material cost and availability

The cost of materials that you plan to use must be appropriate for the product. While materials such as titanium might offer improved properties compared to mild steel, if, for example, the application is a coat hook, then the cost of titanium is probably too high.

Materials must also be readily available; there is little point in specifying a material that cannot be easily obtained.

Processes to be used

Selection of materials must be linked with how you intend to manufacture the product; for example, which cutting, shaping, forming, and joining and fabrication techniques are you considering? The material choices must be suitable for the processes you plan to use.

LINK IT UP

You have investigated a range of cutting, shaping, forming, and joining and fabrication techniques in Component 2: Learning aim A.

The environment

You need to think about where the product is to be used and the effect that the environment will have on the product; for example, a shelf made from polymer materials would not be suitable for use inside an industrial oven.

Conversely, you also need to think about the effect that the materials and the manufacturing processes used will have on the environment. Casting, for example, uses a lot of energy to heat the materials. However, very little waste is produced during the casting process. You will need to weigh the advantages and disadvantages of using a particular material against the environmental impacts.

Another environmental factor to consider is whether it is possible to reuse or recycle waste produced either during the manufacturing process or at the end of the life of the product.

Making recommendations for improvements to the best solution

Your selection of the best manufacturing process to use is also important because it needs to be suitable for the product you are designing. You will need to make recommendations for improvements to allow the best solution to be produced.

Consider the advantages and disadvantages of alternative processes; for example, a coat hook could be cast in aluminium, or it could be formed by cutting and then bending strips of aluminium. The process chosen will need to take into account the scale of production, such as whether the component needs to be made in a batch, and the complexity of the design. The most important thing to remember is that you must always be able to justify your decisions.

ACTIVITY

Review your chosen design solution for an improved engineered product.

1 Justify your choices of materials.

2 Justify your choices of manufacturing processes.

Make sure that you link your justifications to the improvements you have suggested for the design as well as the original design brief for the product.

CHECK MY LEARNING

You have investigated some of the factors that need to be considered when making decisions about the materials and manufacturing processes to be used to improve an engineered product.

With a partner, discuss the following questions:

1 Why are the properties of a material important when making decisions about its use?

2 Why does the environment need to be considered when choosing and justifying a design solution?

3 What factors can influence the choice of processes?

Resources required and their use

GETTING STARTED

Working in a small group, examine a piece of equipment in your classroom or workshop. Write down all the types of resource that you think would be required in the manufacture of this equipment.

Having selected your design solution, you then need to think about specific details of the solution, especially the resources required to produce the product. These resources include the materials, tools and tooling, components, equipment and apparatus needed.

Materials

It is not only the type of material that is important, but also the form of supply, the sizes needed and any surface finishes or textures that will be required. Materials can be supplied in a range of forms, depending on the material category, as shown in Table 3.19.

Table 3.19: Material forms of supply

Metals	Polymers and composites
Ingots	Powders
Castings	Pellets
Forgings	Extrusions
Pressings	Mouldings
Bars or rods	Sheets
Sheets	Resin
Plate	Films
Pipe or tube	Pipe or tube
Wire	
Rolled sections	
Extrusions	

Tools and tooling

The types and forms of selected materials will affect the tools and tooling that need to be used. For example, if polymers are selected for the product, and they are to be supplied in pellet form, then the manufacturing processes that can be used will be limited, with injection moulding being the most likely choice.

In reality, decisions about materials, their forms of supply and manufacturing processes will be made jointly as each decision impacts on the others. The decision about the most suitable methods for manufacturing a component will take into account the features that need to be produced; this in turn will have implications for tooling. If die casting is suggested, then a die will need to be produced and metal heated until it melts and can be poured. If a turning process is suggested, then a lathe will be needed, along with appropriate cutting tools depending on the type of metal being turned and the features to be produced (see Figure 3.28).

The choice of tools and tooling also needs to be suitable for the scale of production expected.

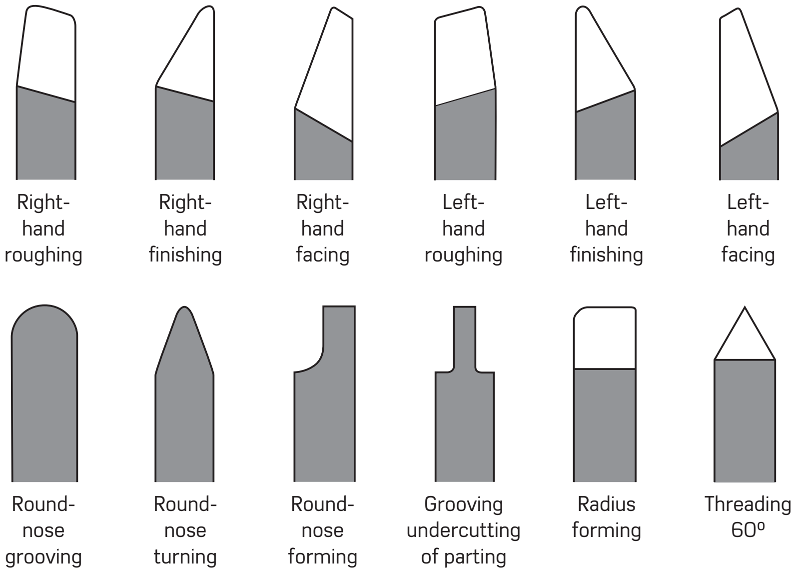


Figure 3.28: Lathe tools should be selected depending on the feature to be produced

Components

Components have been considered at a number of stages in the design process. However, when deciding on the components to be used for a redesigned or improved solution, the choices may not be that simple.

You need to ensure that, if necessary, any alternative components are compatible with the existing design. This is especially important if the new component is a replacement for an existing, different component. It may still be possible to standardise on the type of component – for example, using the same type of screw head or standard dimensions and values of electronic components.

Equipment and apparatus

Sometimes there will be a need to use specialist equipment or apparatus when producing a redesigned product or component. It might be that specific instruments will need to be used to check the surface finish of a component, or sensors will need to be used to check if an electronic circuit has the required levels of sensitivity.

The equipment resources to be considered might include work-holding devices such as machine clamps to hold workpieces in place when they are being milled or drilled; soldering irons and related hand tools for soldering activities; or measuring equipment to ensure that components fit together as specified.

ACTIVITY

You have been asked to plan the manufacture of an engineered component that has features that need to be produced by either milling or turning.

1 Carry out some research into the tools and equipment that will be needed, and list these.

2 Write a short report to explain and justify your choices of resources.

Example

To manufacture a redesigned shelf bracket, mild steel could be chosen as the material and shearing, drilling and bending processes used to shape it. Specifying a standardised drill size (e.g. 8 mm) allows standard components to be used, and using a jig ensures that all brackets will be bent to the correct angle.

CHECK MY LEARNING

You have learned about the resources that you are likely to need when manufacturing an engineered product. With a partner, make a list of the following types of resources for the manufacture of an engineered product you are familiar with:

- materials
- tools and tooling
- components
- equipment and apparatus.

Presenting your solution

GETTING STARTED

Make a list of the different 2D and 3D presentation techniques that can be used to communicate a design solution.

In addition to justifying a design solution and the processes and materials that you plan to use, it is important to consider the methods that can be used to present the solution.

When selecting presentation methods, you will need to consider a range of techniques and decide which will be the most appropriate. These can include both sketching and formal presentation drawings. We have looked at each of these in detail earlier in this component.

Drawings

An isometric drawing, as in Figure 3.29, allows the features of a design to be shown in three dimensions so that another engineer or a potential user can visualise what it will look like in real life.

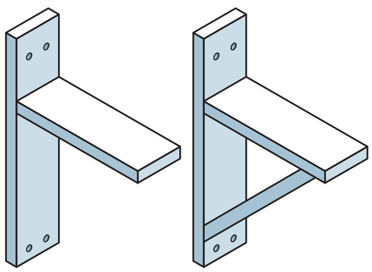


Figure 3.29: Isometric drawing of a redesigned shelf bracket

One of the limitations of isometric drawings is that they do not always provide enough information for someone to produce a product or component directly from them. Often, you will need to use another drawing or document to provide the full information.

If the idea you have produced is complicated, it might be better to use an isometric drawing to show the overall shape and form of the design proposal and also use orthographic projections to show details of the design features.

An orthographic drawing, as in Figure 3.30, allows construction details to be added, such as dimensions, both linear and angular, and notes about surface finishes and joining methods.

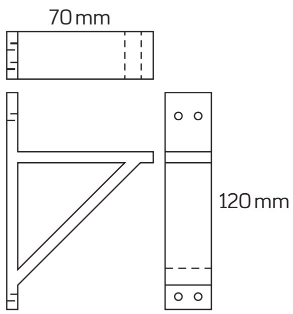


Figure 3.30: Orthographic drawing of a redesigned shelf bracket

Remember that when producing an orthographic drawing, you need to ensure that details are absolutely clear.

You will also need to use the correct line types for hidden details, outlines, centrelines and dimensions. Don't forget that you should always show dimensions in millimetres (mm).

Also think about the scale of the drawing. If the product or component is small, then it may be better to produce a drawing to a larger scale, one which shows the item at a larger size than in real life.

ACTIVITY

Previously, you made sketches of a redesigned shelf bracket. Now produce the following two drawings of your solution:

1. an accurate isometric drawing
2. an orthographic drawing.

Remember to add annotations and dimensions to your drawings to explain the features of the design.

LINK IT UP

You have investigated the use of CAD software to produce drawings in Component 1: Learning aim B.

Think about the methods used to present 3D CAD models, and try applying these same approaches in your presentation of ideas.

Annotations

Annotations are very important in design work. You must ensure that you add appropriate annotations to design information so that they clearly explain:

- the features of your solution and how it meets the design brief
- the materials and processes that you would use, including the reasons why
- details of how the solution will work; for example, if there are any moving parts, then explain how these will operate.

CHECK MY LEARNING

You have practised different methods of presenting an engineering design using different kinds of drawing.

Working with a partner, look at ways in which your drawings could be improved. Some starting points you could think about are:

- accuracy
- the amount of detail included
- size and scale.

Make processes to create a prototype solution

GETTING STARTED

With a partner, make a list of the advantages and disadvantages of producing prototype models when developing a new product.

LINK IT UP

In Component 2, you looked at the making skills associated with the production of a product.

When developing a new product, there are a number of reasons for making a prototype, including:

- trialling ideas to see if they work as expected
- testing a product to check that it functions as intended
- gaining a better understanding of the problem.

There are different ways of producing a prototype, including the use of rapid prototyping and traditional physical modelling.

Processes to follow and use

You will need to think about processes in relation to using tools and equipment, health and safety, and manufacturing processes like casting, forging, welding and the use of jigs and tools.

3D printing – additive manufacture (AM)

You could create a CAD drawing of a component and then send this to a 3D printer to be manufactured. This enables an accurate model of the design to be produced, which can then be used to test whether or not the design would work. It is even possible to produce 3D printed models with parts that move.

You should experiment with and practise producing accurate CAD drawings of engineered components. If a 3D printer is available, use simulation software to view the models onscreen and then manufacture the component.

Physical modelling

A physical model can be made using a range of modelling materials. These include card, wood, plastics and parts reclaimed from disassembled products.

As already considered in Component 1: Learning aim B, 3D models may be viable if they are made by hand. Prototype models can be made easily from materials that are easy to shape and easy to modify.

In some cases, you can produce a model that incorporates 3D printed parts, with other aspects of the design made using traditional physical modelling methods.

Different materials can be used to produce models for the same solution

If prototypes for the same design are made from different materials, it can help with the selection of material forms and manufacturing techniques.

ACTIVITY

Make a small model of the design for a shelf bracket that you developed in previous lessons, using either 3D printing or physical modelling.

If you do this by physical modelling, use materials that are easy to work with, such as cardboard, and then check that the model fits the physical dimensions required for the shelf bracket.

Following correct processes

Whenever you are modelling or carrying out any part of an engineering investigation, you should follow the correct processes. Think about manufacturing on a larger scale and for the actual product. This could involve casting, forging and welding, along with the use of other tools and jigs. You may need to research how certain processes are carried out and whether they are suitable for your design.

It is especially important to follow correct procedures when using tools and equipment. You should only ever use tools and equipment that you have been given permission to use and shown how to use safely. The engineering saying, 'If in doubt – ask!' applies to all parts of an engineering activity: if you are not sure how to do something, then ask for help.

Also ensure that you work safely at all times and follow the health and safety rules for the equipment you are using. Remember to follow instructions and use the correct PPE to carry out each process.

CHECK MY LEARNING

You have learned about the processes that can be used to produce both prototypes and final products.

With a partner, thinking about the model you made in the previous activity, answer the following questions:

1 What are the advantages and disadvantages of additive manufacturing?

2 What are the advantages and disadvantages of physical modelling?

Then discuss which method would be best for prototyping two vastly different design solutions, such as a bridge structure and a small clamp.

Collecting and analysing data

GETTING STARTED

With a partner, make a list of the types of data that could be collected from engineered products. Discuss which of these types of data can be used to improve outputs.

We have already looked at the collection of data from engineering activities, including the dimensions of components, and methods for determining whether or not a component is within specified tolerances.

Collecting data

ACTIVITY

Collect at least ten of the same type of component or product that nominally have the same dimensions – for example, machine screws or mass-produced components such as injection-moulded bottle lids.

1 Measure and record the dimensions of each of the components you collected.
2 Plot the dimensions of the components on a line graph.
3 Write a short summary report to explain your findings.

Table 3.20: Example of data collected for a component that has a required length of 25 mm

Test number	Length measurement (mm)
1	25
2	25
3	25
4	23.5
5	27
6	26
7	24
8	27
9	26
10	23

Once you have collected and recorded your data, as shown in Table 3.20, for example, plot the measurements on a line graph. This will help you to identify any trends or patterns.

The raw data do not show trends easily. However, by plotting the points on a graph, you can spot if there are any patterns or erroneous values that need to be investigated further.

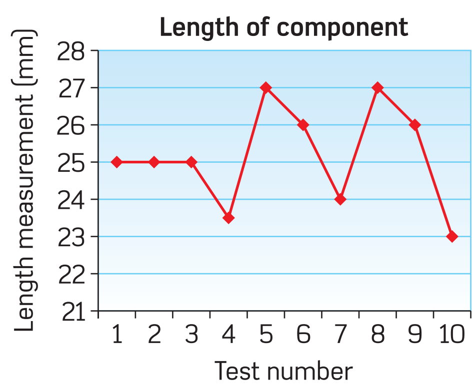


Figure 3.31: Chart showing the results from Table 3.20 in inspection order

Although the data shown in Figure 3.31 are representative of the results found in the sequence of tests during the inspection, it can be more useful to present the data in a more logical way.

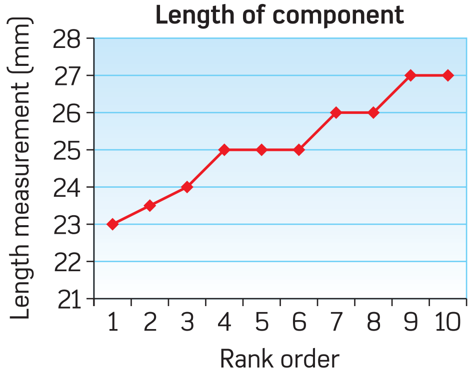


Figure 3.32: Chart showing results in rank order

Looking at the two ways of presenting the same data, the graph in Figure 3.32 allows us to see more easily that three components are smaller than the nominal length and four components are longer than the required length.

Quantitative and qualitative data types

Quantitative data relate to information that is expressed in numbers, such as an item's height, the number of products, or the length of a component, like the example in Table 3.20. These are numerical quantities that can be measured.

Qualitative data give information about a product's characteristics, and are used to describe features of an item, such as the colour or shape of a product. These data are difficult or impossible to measure and are not expressed in terms of numbers. However, if you were to count, for example, the number of red products, then the data would become quantitative.

In engineering, data collected for analysis of statistical trends and patterns generally fall within the quantitative data type, but both types of data are useful and important to know about.

Analysing data

Analysing the results in Figures 3.31 and 3.32 does not really show any trends, so it is more than likely that the differences in size are down to marking-out errors or operator mistakes.

Remember to present your data in a way that is easy to interpret. It is generally a good idea to present data in rank order so that any trends and patterns can be identified more easily.

We looked at the causes of faults in production earlier in Component 3, and classified faults as being either random or systematic. It is much easier to identify systematic faults, and therefore devise solutions for this type of fault, than to identify random faults, so this is where efforts need to be concentrated. A systematic fault will usually give rise to a pattern or trend.

You should analyse data, first, to decide if faults are random or systematic and, second, to think about solutions to the problem.

CHECK MY LEARNING

You have examined different sets of data and looked at the methods used to present data to make them easier to interpret.

Think about the best way to present each of the following types of data:

- the length of time taken to set up a pillar drill
- the number of faults in an electronic circuit
- the actual measured resistance values of resistors.

Safety considerations

GETTING STARTED

Risk assessments were covered in Component 2: Learning aim B. Can you remember the main aims of a risk assessment?

All aspects associated with the manufacture of engineered products will have some elements of risk. These include the materials, substances and processes used to manufacture the products. As part of the manufacturing process, it is important that you are aware of the hazards and risks associated with each of these. One way of approaching this is to carry out a risk assessment.

Risk assessments

The Health and Safety Executive (HSE) is responsible for regulating workplace safety. All employers, including manufacturing companies, can try to keep their employees safe by conducting and using risk assessments. For any employer that has more than five members of staff, these risk assessments need to be recorded in writing.

The HSE recommends that a risk assessment is carried out in five steps:

1. Identify the hazards.
2. Decide who might be harmed and how.
3. Evaluate the risks and adopt associated control measures.
4. Record and action your significant findings.
5. Review your assessment and update if necessary.

An example of a risk assessment is set out in Table 3.21.

Remember that for hazardous substances, you should make sure that control measures meet with the requirements of COSHH (Control of Substances Hazardous to Health) Regulations 2002.

You should also think about the length of time people will be exposed to risks; for example, ear defenders are acceptable for short-term exposure to noise, but for long-term exposure, a permanent method of reducing noise would be better.

LINK IT UP

Each stage of the risk assessment process has been explained in detail in Component 2: Learning aim B. It is important that all stages of the process are completed in full and are accurate in detail.

Table 3.21: Example of a risk assessment

What are the hazards?	Who might be harmed and how?	What are you already doing?	What further action is necessary?	Action by whom?	Action by when?	Done
Tools on the floor in an untidy workshop	Staff or visitors to the workshop might trip over or slip on the tools on the floor causing serious injury	Daily housekeeping at the end of the shift	Better housekeeping – ensure tools and equipment are cleared away immediately after use and not left until the end of the day	Production supervisor	Now	01/09/17
			Improve tool and equipment storage in the work area	Site maintenance manager	14/09/17	01/09/17

ACTIVITY

Investigate the materials and processes you have proposed for use in the manufacture of your chosen design solution.

1. Carry out a risk assessment to identify hazards and decide who might be harmed.
2. Identify suitable control measures.
3. Record your risk assessment in a suitable format.

The use of appropriate PPE is one way of providing control measures for machine operators

DID YOU KNOW?

PPE should not be relied on as the only type of control measure for hazards.

Wherever possible, you should try to eliminate hazards. If this is not possible, see if you can use alternative materials or methods that pose less of a risk.

Considering timescales

You will need to be aware of the timescales that you have to keep when designing an improved engineering product. You will only have a limited amount of time in your external assessment, so you will need to manage this time well. You should avoid spending too much time on one activity, and make sure you attempt each part of the assessment activity.

CHECK MY LEARNING

You have thought about the hazards that can be present during an engineering process and you have investigated control measures, including the use of PPE.

With a partner, write out a risk assessment for one engineering process, such as a turning operation on a lathe. When you have finished, compare your risk assessment with that of another pair in your class group – are there any risks or actions they included that you didn't? Think about and discuss the reasons for any differences.

Learning aim C: assessment practice

How you will be assessed

In this component, you will be assessed by completing a set task that consists of two parts, worth 60 marks in total, and marked by Pearson examiners. Learning aim C is assessed mainly through Part 2 of the set task, which will take place over one and a half hours.

Part 2 will consist of two activities that target higher-order planning, redesign and evaluation skills and which relate to given scenarios. In the set task you will show that you understand how to interpret information and use this to suggest improvements to an engineered product.

You will be assessed on how detailed your evaluation of the existing design is. If you make very basic points only, or ones that are not relevant to the problem, you will receive marks in the lowest marking band. If, however, you identify relevant issues with the design that you are presented with, and then evaluate these issues in detail to show that you fully understand the existing design and how it relates to the design brief, you will be awarded marks in the highest marking band.

Unlike in the practice activities, you will only be asked to produce one design idea in the external assessment, so you need to ensure that this one idea meets all the requirements of the brief and addresses all the areas for improvement you have identified in your evaluation.

If these aspects are not included in your responses, then you will not be able to achieve the higher marks. It is important that you annotate your work clearly to ensure that the person who is marking your designs can understand what you have done.

Remember that the examiner who will be marking your set task does not know you, and the only way they will be able to assess your engineering skills is through the work that they see you have completed.

CHECKPOINT

Strengthen
- Identify four types of engineering drawing.
- Give two reasons why engineers make prototypes.
- Why do engineers use risk assessments?

Challenge
- Explain the difference between a random fault and a systematic fault.
- Describe two approaches to improve an engineering solution.
- Explain why it is important to consider scale of production when improving a design.

ASSESSMENT ACTIVITY LEARNING AIM **C**

In the first section of Part 2 of the set task, you were given a brief for an engineered product and an example of a design for the product. You then evaluated the existing product and identified its strengths and weaknesses, as well as its limitations and constraints. You will use this evaluation to help redesign the product for this second section of Part 2 of the set task.

Your teacher has previously given you an example of the engineered product, along with details of how the product was manufactured. Using this information and your previous evaluation, you need to:

1 Produce one idea for the product that shows an improvement on the original design.
2 Justify why your design idea is an improvement and explain which processes you would use to make the redesigned product.

TAKE IT FURTHER

When you explain the processes that you would use to make your design idea, you should justify their use by taking into consideration the materials that you have chosen, the intended purpose and function of the product, and also the scale of production, if this is included in the brief.

TIPS

When you redesign the given engineered product, make sure that the design shows an improvement on the original and that you justify your design solution fully.

Draw your designs clearly and make sure that all the details are shown. Sometimes it is better to draw a number of 2D views rather than produce only one 3D drawing.

Glossary

Abrasion the process of wearing something away.

Accuracy depends on the way in which measurements are taken and how they are recorded.

Alloys mixtures of two or more metals that have improved properties and characteristics.

Ancillary equipment covers any items of equipment required by the main equipment system to be a complete system.

Annotations labels used by engineers to give information about designs.

Annual turnover the amount of money relative to the value of the products and services a company sells over a year.

Assembly drawings used to show how components are put together.

Assembly line a process where engineers and machines assemble a product in a specified sequence.

Axis the name of either the horizontal or the vertical line that is used to show the scale of the graph or chart.

Blind hole a hole that does not break through to the other side of the workpiece.

Blow moulding a manufacturing process by which hollow plastic parts are formed.

Brainstorming an open group discussion of ideas to find solutions.

Branding of a product or company name is a way of distinguishing it so that it is easily recognisable.

Capacitors electronic devices that store electrical charge.

Chamfers features that remove sharp corners to make something safer and easier to assemble.

Chargehand a worker put in charge of others.

Chartered engineer registered with the Engineering Council as a person who has academic qualifications, technical training and knowledge, and practical experience. They are permitted to use the abbreviation CEng after their name.

Charts usually used when data are being presented in groups.

Chuck a specialised kind of clamp.

CNC stands for 'computer numerical control'. A CNC lathe is one that runs automatically.

Cold working when a material is reshaped while at a low temperature.

Commissioning the final testing and verification of the equipment's functionality.

Complex brackets brackets that have been designed for a specific purpose and often have complicated shapes that allow them to fit around other components but still remain strong.

Composite materials formed when two or more materials are bonded to produce a material with different properties from the original materials.

Compressible when the volume of a fluid can change when pressure is applied to it.

Compressive strength the ability of a material to resist a pushing force without being crushed.

Conductivity the ability of a material to conduct electricity.

Conductors materials that transmit heat or electricity.

Conform and **conformance** both mean meeting specified standards, regulations or laws.

Control valves automatic devices used to control fluids in a pipe.

Conventions the rules used to present information such as drawings; for example, BS8888 is the standard set of rules for working drawings. They cover line types, symbols and layouts of drawings.

Customised parts engineering products made or modified to meet the customer's specified requirements.

Deadline the latest date that the solution of a problem, e.g. an engineered product, needs to be completed by.

Degree of accuracy half a unit on either side of the unit of measure; if the unit is 1, then any measurement between 9½ and 10½ will be measured as 10.

Die a tool used to create a specific shape as part of the manufacturing process. A die is custom made for each specific job so that an exact shape can be made.

Diodes electronic devices that can be used to allow electrical charge to flow in only one direction.

Ductility the ability of a material to be deformed by bending, twisting or stretching. This ability increases in metals at higher temperatures.

Electroplating a process in which an electrical current is run through a solution between a zinc anode and a steel conductor.

Engineered products items produced using suitable engineering production processes.

Engineer's blue a quick-drying ink used to help the marking-out process on metals.

Ergonomics the science associated with the design and arrangement of equipment so that it is more comfortable and safer for people to use.

Ethical something that is morally good or right to do.

Fabrication the process of manufacturing something.

Feedback when you receive information, good and/or bad, from someone else about what you have done.

Ferrous metals contain iron. Typical types of ferrous metals include mild steel, wrought iron and stainless steel.

Fettling trimming or cleaning the edges of a metal casting.

Fillets similar to radii, but feature on internal corners and are used to reduce stresses in a joint.

Fit-for-purpose term used to describe whether a product can perform the job it was designed to do.

Fluid a gas or liquid.

Fuselage the main body of an aircraft, where passengers sit or freight is carried.

Galvanising the process of providing a protective zinc coating to steel. Products tend to be hot-dipped to provide the coating.

Graphs used to plot individual data values.

Gyroscopes wheels or discs that spin freely on their axes to find their orientation by themselves.

Handover possession of the equipment is passed to the customer.

Hazards things that could be dangerous to someone's health and safety.

Hot working when a material is reshaped while at a high temperature.

In-house activities are carried out by employees of the company.

Indentation the process of making a notch or scrape in a material.

Integrity the quality of having moral principles.

Interconnection the close connection between, or the joining of, two or more things.

Interpretation an opinion of what something means; when you interpret something, you are deciding what you believe to be the meaning.

Iteration repeating a process until the best solution is identified.

Justification the reason or evidence to support an idea or design.

Labelling used to identify groups of data clearly.

Lathes tools that rotate a workpiece to perform functions such as shaping, cutting and sanding.

LED stands for 'light emitting diode' and produces light when a voltage is applied to it.

Lifespan a product refers to how long it will last once a consumer begins using it for its primary purpose.

Logistics the organisation and implementation of an operation, usually involving a lot of detail.

Longevity a long life.

Machine shop where engineers use machine tools and cutting tools to make parts.

Malleability the ability of a material to be permanently deformed in all directions without breaking apart.

Marketplace a term used to describe the activities associated with the sale and purchase of a product.

Milling machines used to shape materials, but the material is fixed and the cutting tool rotates.

Nanotechnology the branch of engineering technology that deals with extremely small things, including the manipulation of atoms and molecules.

Non-compressible a fluid that cannot be compressed.

Non-ferrous metals do not contain iron. Typical non-ferrous metals include aluminium, titanium, copper, silver and zinc.

NVQ stands for National Vocational Qualification: a practical qualification gained through employment.

Orientation of an object is its direction or relative position.

Outsourced functions are carried out by someone outside the company.

Parts integration the ability to combine different parts.

Patent the sole right of a person or company to make or sell a product.

PDF stands for portable document format and is used for creating electronic documents.

Permanent something intended to last unchanged forever.

Pilot hole a small hole drilled ahead of a full-sized hole as a guide.

Plating a thin coating of gold, silver or other metal.

Precision the depth of information that is included in the data: how far the information is broken down.

Products things produced for sale, usually by a manufacturing process.

Qualitative comparisons a type of analysis used when the data collected are circumstantial (very detailed).

Quality control the set of procedures that are followed to ensure that the quality of a product is maintained and manufacturing errors reduced or eliminated.

Radius (or **radii**) refers to a smooth, rounded corner, like a chamfer, typically used on external corners.

Recesses internal grooves, also known as pocket cuts.

Recycling the process of converting waste material into other usable products.

Re-forming changing something from one shape to another.

Reliability depends on there being only small variations in data and that measurements are within tolerance.

Resistance to wear means that something is not easily damaged over time.

Resistors electronic devices that restrict the flow of an electric current.

Resolution a term used to describe how clear an image is.

Right first time often quoted in terms of quality control and refers to when something is done without errors so that no time and money are wasted.

Risers occur where excess metal from the moulding escapes from the casting box. They will also solidify, and so need to be removed at the end of the process.

Risk the probability of a hazard causing harm to someone's health.

Risk assessment a process used to document that all hazards have been considered and appropriate measures put in place to deal with them.

Runners used to allow metal to flow from one moulding to another so that multiple parts can be cast at the same time.

Rusting when a metal becomes covered in a reddish-brown, flaking coating of iron oxide. Rusting affects iron and steel.

Scale the ratio of the model compared to its actual physical size. For example, if a model is ten times smaller than in real life, the scale of the model is 1:10.

Sector a term used for a particular type of industry within the nation's overall economy.

Semi-permanent something will not last forever, but will last for a long time.

Services the actions of providing something for a customer, usually performing work or a process.

Setpoints target values for a process value, e.g. maximum temperature, minimum flow rate.

Shank the shaft of a tool.

Shear force arises from forces that act in opposite directions.

Skill set the range of skills and abilities that a person has.

Specialised equipment can be used for more than one product or component, but can only be used to carry out a limited range of processes.

Speeds and **feeds** refer, respectively, to the 'spindle speed' (the speed at which a machine spindle rotates) and the 'feed rate' (the rate at which a machine tool moves across a 'workpiece', i.e. the material being machined).

Sprue the hole that molten metal is poured into when casting. When the casting solidifies, the sprue needs to be removed.

Surface roughness a measure of the deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth.

Sustainability the ability of something to be maintained at a specific level.

Swarf the small chips or pieces of metal removed by machining processes such as grinding, turning or milling.

Team building a method of getting employees to work together as an effective team.

Teeth the grooves on engineering tools.

Tensile something is capable of being stretched out.

Tension the pulling force or forces on an object.

Thermosetting polymers materials that cannot be reshaped with the application of heat. Typical thermosetting polymers include phenol-formaldehyde, polyimides and polyurethane.

Thermoforming polymers materials that can be reshaped with the application of heat. Typical thermoforming polymers include polyethylene, polypropylene and acrylic.

Thinking outside the box to think in an original or creative way.

Thread a raised structure on a screw or bolt that follows a helical path and allows parts to be joined together.

Tolerances the allowable variation of a specified dimension, normally associated with machining operations but can also apply, for example, to equipment that needs to be set up exactly level for it to operate correctly.

Transparent polymer allows light to pass through it in such a way that objects behind it can be easily seen.

Trends patterns in data, e.g. values might increase for one variable as the values decrease for another.

Troubleshooting the identification and correction of faults and problems.

Unit cost the cost of one item, e.g. if 10 m of pipe costs £20, the unit cost is £2 per metre.

Unit costs the costs associated with the manufacture of an individual product.

Vanishing points points on an imaginary horizon where all projection lines in a perspective drawing are drawn from.

Velocity the object's direction and speed of movement.

Virtual reality computer technology that uses special equipment such as headsets to create images, sounds and other sensations that simulate a user's physical presence in a virtual or imaginary environment.

Welding heating the surfaces of two objects to the point of melting and then joining them together.

Workpiece a piece of metal or other material that is in the process of being worked (cut or shaped) by a hand tool or machine.

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