What impact have advances in Materials Science had on boat design?

Task
Your task is to answer the Big Question above using a wide range of information.

You may find the information available in this document helpful. These resources are all inspired by INEOS TEAM UK, the British challenger for sailing’s America’s Cup.

How to begin
1. Use the mind map sheet to plan how you will answer the Big Question
2. Read through the video transcripts listed below and make notes about what you have learned
3. Communicate your learning by choosing your preferred presentation method.

There is no single correct answer to the question. Answering the question involves research and independent learning in order to be able to present your findings to your teacher and class. You can also use information from other sources to help answer the question.

This investigation is an extended project and you should aim to spend 5-8 hours on it. Keep your project log up to date to make a note of all your hard work!

Video Transcripts
These video transcripts will give you some relevant background information about the America’s Cup and INEOS TEAM UK, the British challenger for sailing’s America’s Cup.

This is the transcript taken from the video – Britain’s INEOS TEAM UK officially challenge for the 36th America’s cup.

Read the following transcript for information on the background of the America’s Cup, the world’s oldest sporting trophy.

Britain’s INEOS TEAM UK officially Challenge for the 36th America’s cup

‘1851, the year of the great exhibition, the year we challenged America to sail around the Isle of Wight. The year the upstarts won and Britannia no longer rules the waves. The New Yorker’s yacht was called ‘America’ giving the cup its name.

The new world triumphed over the old and that cup hasn’t seen our shores for 169 years, not that we didn’t try. We challenged many times, harnessing the forces of nature. Pushing ourselves to the limits and beyond. But the New Yorkers were unbeatable. And then the Aussie’s sailed and opened the floodgates. Next it was San Diego, then the Kiwis, the San Franciscans and the Swiss. What did these giants have in common? The resources to innovate, technology as supreme in this the Formula One of sailing. There was the winged keel, the plastic fantastic and like a bird on the wing the foiling catamaran; flying above the water virtually frictionless and faster than the wind that carries it. Fitted with sensors, connectors, analysed, tweaked to perfection, designed by the people who made spacecraft
and aeroplanes, And then there’s the skill of the heroes who sail them; cranking, pulling, tacking, spinning the helm. First at one side then the other, less they end up in the water rather than on it. So what will it take to bring the ‘Auld mug’ back home? Only the best designers, engineers, boat builders and know-how the world has to offer. With the funding and tenacity to see a winning strategy through until the job is done. Then there’s Ben; Sir Ben Ainslie, the most successful Olympic sailor in history. He has the taste for victory and the team that can help us achieve it. All we have to do is to design, build and sail the fastest 75ft carbon fibre mono-hull in the world and then win a few races on it. Let’s bring the America’s Cup back home where it belongs.’

The following ‘Materials and their uses’ video transcript will help you answer the Big Question:

**Materials and their uses video transcript**

- High performance depends on precision design and the very best materials, so every part of the boat has the properties it needs to deliver at top speed.
- The AC 75 has one 75ft hull designed to cut through the water and air with as little resistance as possible.

- It needs to be very light, but also extremely strong so it can retain its precise shape, even when under powerful forces from the wind or sea.
- The boat’s aluminium honeycomb core is sandwiched between thin sheets of carbon fibre, using epoxy glue which sets to form a really strong bond.
- This makes it light-weight but also tough and rigid under pressure.
• The mainsail is a double-skinned soft sail that is attached to a rotating mast. The ideal material for the mast is carbon fibre which is light-weight and strong.
• Then there are the ropes on board. These need to be very strong but light-weight and flexible.
• The ideal material for these is Dynema or Spectra. Weight-for-weight, these materials are 15 times stronger than steel. They are resistant to abrasion or scratching; don’t absorb water and they float.

![Image of ropes](image)

• Crew members themselves need to take advantage of some high-tech materials, because even what they wear can affect the boat’s speed.
• We must reduce drag and clothing is part of that, we have materials like lycra and neoprene which are figure-hugging.
• Crew members also wear buoyancy aids with a lot of safety equipment, so it’s about shaping the lycra and neoprene around our kit to successfully reduce the drag.
• Rather than traditional waterproofs each crew member wears a smooth neoprene suit a bit like a wetsuit, that’s formed into foam sheets with a smooth under surface. The suits don’t absorb water and keep the crew warm.

![Image of neoprene suit](image)

• Every crew member also wears a helmet to protect their head. This combines a soft inner foam with a strong outer shell made from thermoplastic – a type of polymer that can be shaped when heated.
• Together these high-tech materials make for a strong, light-weight boat and a safe high-performing crew.
The following ‘Modern Materials video transcript will help you answer the Big Question:

**Modern Materials Video Transcript (Supported by Lloyd’s Register Foundation)**

- Here at INEOS TEAM UK, we’re in a race to win the America’s Cup for Great Britain.
- In order to do that, we need to use the latest materials and design to develop a winning boat.
- Our new 75ft America’s Cup boat is capable of doing 60mph powered only by the wind.

![Image of INEOS TEAM UK boat](image)

- In parallel with the formation of the classification rules by Lloyd’s Register, since the 19th century, designers have to utilise advances in technology.
- INEOS TEAM UK’s designers and engineers continually exploit developments to make the highest performing race boat possible.

![Image of welder working](image)

- Traditionally, the America’s Cup boats were made from wood and iron. The decks were waterproofed with cotton canvas fabric. Detailed plans kept by Lloyd’s Register allow us to see how much technology has moved on and what can be learned from the past.

![Historical plans and modern design](image)
• The modern America’s Cup designs would not be possible without the use of modern materials.
• One way to improve the properties of materials is to combine it with another material.
• In 1868 rules for composite ships to find these has been won with iron frames and planks of wood. This made vessels very strong indeed.
• In modern day terms, a composite is a combination of two or more distinctly different materials.
• This is different to an alloy because in an alloy the different elements are chemically bonded together. If you cut through the material you can’t see the separate materials it contains.
• In a modern composite, fibres or fragments of the material are surrounded by a matrix, acting as a binder holding the two materials together. If you cut through the materials you can still make out the different materials.

![Alloy, Traditional Composite, Modern Composite](image)

• Composites have been used for thousands of years to improve the characteristics of materials. Early examples include adding straw to bricks and steel rods to concrete to increase their tensile strength.
• More recently and particularly useful for boat building, we’ve seen the use of glass reinforced plastic often referred to as glass fibre or GRP and carbon reinforced plastic.
• These are both made by using strands of fibre to strengthen the matrix of liquid epoxy or polyester resin which hardens to form the composite.

![Composite Example](image)

• Fibre glass is light and stronger than plastic, it is used for things like skis, surfboards, and boats.
• GRP is not used on the America’s Cup boats anymore because there is now a lighter, stronger composite - carbon fibre reinforced plastic.
• Carbon fibre reinforced plastic combines the strength of carbon fibre with the rigidity of polyester resin matrix.

• Carbon fibre is also used in Formula One cars, race bikes and aircraft, as it is three times stronger and stiffer than aluminium and 40% lighter!

• Although they vary slightly, the process for forming carbon fibre and GRP are similar.
• First, a mould is made of the required shape. The carbon fibre pre-impregnated fibres are often used to achieve a very thin and strong layer.
• The layers are built up until the necessary strength is achieved.
• The component of the boat hull is placed in a vacuum and heated, to allow it to cure and fit perfectly to the mould before being removed and the edges trimmed.
• This process is often done by hand which means it can be time-consuming and expensive.
• A recent advance in composites is the use of nano-technology to make carbon nano-tubes.
Nano science is the science of the very small, it’s about controlling matter at the atomic level to form it into material with different properties.

The very small particles made by nano-technology normally have dimensions less than 100 nanometres; about a $1,000^{\text{th}}$ of the diameter of a human hair!

Engineered smart materials can be combined with other materials to make composites with improved properties.

The lenses of eye protection worn by the crew can be coated in a layer of nano material that repels water and dirt, making it easier for the sailors to see whilst they’re out on the water.

Nano-composites are expensive to make but are very useful materials.

For all types of composite it can be very difficult to separate out the components at the end of their useful life, and many may end up in landfill.

For this reason, some people believe composites are not environmentally friendly materials. However, INEOS TEAM UK are working with ELG Carbon Fibre who operate the world’s first and largest carbon fibre recovery plant in Coseley, West Midlands in the UK, to recycle all their carbon waste.

At INEOS TEAM UK we’re working hard with the latest knowledge of modern materials so we can design and build the boat to win the America’s Cup for Great Britain.
The following ‘Speed, Distance, Time’ video transcript will help you answer the Big Question:

**Speed, Distance, Time Video Transcript**

- Speed is key for INEOS TEAM UK in our attempt to win the America’s Cup for Great Britain.
- It’s all about crossing the finish line first.

- In yacht racing, teams cover different distances according to how they sail the course. So, it’s not only about sailing quickly, it’s about making the distance as short as possible...

- \[ \text{Speed} = \frac{\text{Distance}}{\text{Time}} \]

‘The speed = distance/time equation is really important in sailing in general. Certainly in the America’s Cup, where our race course is confined by boundaries. We really need to be very good at understanding how far we have until the next boundary, or next manoeuvre. Whether that be a tack or a jibe and for our crew, our sailing team to know that as well, and understand what it means in terms of preparing the boat and then in terms of performance of the boat.

Of course, the faster we’re going is great, but we’ve got to be going towards the next mark in the shortest possible distance and time. So, these equations are something that are always going on for us. It’s a big part of manoeuvring the boat, the performance of the boat and the overall tactics and strategy’. Sir Ben Ainslie, Team Principal INEOS TEAM UK
• We use the speed, distance, time equation in almost everything we do.
• Every boundary, every mark rounding, every tack, every jibe. You work at the speed that you are going, the time it’s going to take you and the distance that you’re going to travel and that comes into everyday life here at the America’s cup, just as it does at school.

• To find out the speed, the team needs to measure the distance the boat travels and the time it takes to do it.

• If the boat takes 10 seconds (speed) to travel 100m (distance), then they know they’re moving 10m/s (metres per second). If it takes 5 seconds to travel that same 100m, then they’re doing even better; 20 m/s.

• So, that’s it! Achieving the best time on race day relies on making the most of the relationship between speed, distance, time.

The following ‘Life Cycle Assessment Video Transcript will help you answer the Big Question:

**Life Cycle Assessment Video Transcript**

• From the boatshed floor to the design offices, we use hundreds of products day-in, day-out as our team designs, builds and trains its way towards the cup.
• When selecting products there are many different factors to consider, including performance and sustainability, but one thing is the same - all products have an impact on the environment during their lifecycle.
• In order to understand and reduce our impact on the environment, we carry out something called a Life Cycle Assessment.
• A Life Cycle Assessment attempts to put value on the environmental impact of the product.
There are four main stages of a product’s life cycle: 1) Extracting and processing raw materials; 2) Manufacturing and packaging process; 3) Product use and operation; 4) Disposing of the product at the end of its useful life.

At every stage we need to consider the use of raw materials, including water and the use of energy, and the release of waste substances into the environment.

Firstly, we assess the environmental impact of extracting and processing of raw materials; many of the products used by the Team (just as in everyday life) contain a number of different materials including metals, plastics and natural materials.

Extracting metals takes a huge amount of energy. Firstly, the ore must be dug out of the mine and transported to the processing plant.

The metal then has to be extracted from the ore. This can use a large amount of energy and produce toxic waste.

Once the raw material has been produced, the product then needs to be manufactured, packaged and transported.

Polymers such as plastic are produced using crude oil or increasingly natural gas as the raw material.
• The oil or the gas must be extracted from the ground and then transported to a refinery. The hydro-carbons must be separated then cracked.
• Finally, the polymer is produced.

• Although there is little waste from all these processes, they do use a large amount of energy.
• Even using natural materials like cotton still requires growing and harvesting of the cotton crop before it is processed, spun, and woven into fabric. All of this requires energy and chemicals and produces waster products.

Environmental impact
• Now we need to assess the environmental impact of the product's use during its lifetime. For example, the race boat travels up to 60mph using only the wind to power it and therefore has almost no environmental impact when sailing.
• Whereas team radios use electrical energy provided by batteries. In order to reduce the environmental impact, rechargeable batteries are used rather than a large number of single-use batteries. The longer you can use a product before disposing of it, the better.
• Even things you might not think use resources - like team kit - still require washing and drying, both of which use energy and resources.
• We’re also increasingly aware of the risk to the environment from the leakage of microfibres from clothes during the washing process.
• Finally, we need to assess the disposal of the product at the end of its useful life.

‘The boat hull and many of its components are made from carbon fibre as they need to be very light and incredibly strong. However, carbon fibre traditionally has been very hard to recycle and often ends up in landfill at the end of its life. The team has worked with British company, ELG, to develop ways of recovering the carbon fibre, and have used it to make carbon fibre chopsplan mat. This material can then be re-used for the boat moulds and cradles, greatly reducing the environmental impact. However, the process still requires energy. Many modern products can contain several different materials including possibly harmful chemicals. These chemicals must be disposed of carefully. Again, this may require a lot of energy. It also takes energy to transport used products for disposal of recycling.’

Alan Boot, Naval Architect, INEOS TEAM UK
Lifecycle Limitations

- Now that we have an idea of the different stages, let’s have a look at some of the limitations of the Life Cycle Assessment.
- As you can see, making products requires lots of different steps and it’s difficult to measure all of them.
- We can measure the use of energy and water; we can also measure the production of some waste products.
  
  ![Energy, Water, Waste Usage](image)

- The problem is we can’t always be certain how damaging these are to the environment.
- For example, how do we compare the production of particulates that cause lung disease with greenhouse gases that contribute to global warming?
- This means in some cases we may have to make estimates or value judgements and these may not always be accurate.
- The other problem is that because Life Cycle Assessments are so complex, they can be biased to support claims that may choose to focus on one area of the Life Cycle Assessment and ignore others to suit their purpose.
- We all have a responsibility to look after the planet that we live on, so it’s important we think about the whole impact of the products we use and how we use them from minimising the energy we use and making products last longer.

  ![Earth](image)

- So how can you apply your knowledge of Life Cycle Assessments to make changes for a more sustainable future?

Presenting your work

Here at STEM Crew HQ we have a focus on creativity. So why not be creative with how you present your project? Here are some ideas to get you started:

- Keep it formal and use the accompanying student workbook to record your work.
- Create a written log to record as a vlog when you have access to a computer later.
- Really impress your teachers by creating a folder of your ideas, notes and work, explaining all of your thought processes on how you answered the Big Question.
Mind Mapping

Focus the question to a more specific point – for example, which materials do you want to study in more detail, or which manufacturing methods have changed in recent years? Remember you can use a combination of multiple factors.

What impact have advances in Materials Science had on boat design?

Why have you come to this conclusion? Back up your opinions with evidence.

How can the team learn from previous experiences to help them when choosing materials for the yacht? Which team members may have experience in this?

How can we learn from the materials science the team uses to influence our lives?

What is the end goal of INEOS TEAM UK? Why might we want to advance our material choices? How might this influence what we do?

What are the key parts of the boat that the engineers will look at using advances in materials science to improve? Would we use the same materials for all parts of the boat?

Decide how you want to present your project. There are some ideas listed above to provide inspiration, but do not feel like you are limited to these. Be as creative as you can!

Would all the engineers do the same job? What specialists might be needed to design a winning boat?
**Project Log**

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<th>Research and investigation completed:</th>
<th>Time taken</th>
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<td>23.3.20</td>
<td>Read through video transcripts and made my own notes about history of America’s Cup</td>
<td>30 mins</td>
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**Other information used**

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**STEMCREW**

Supported by INEOS

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stemcrew.org