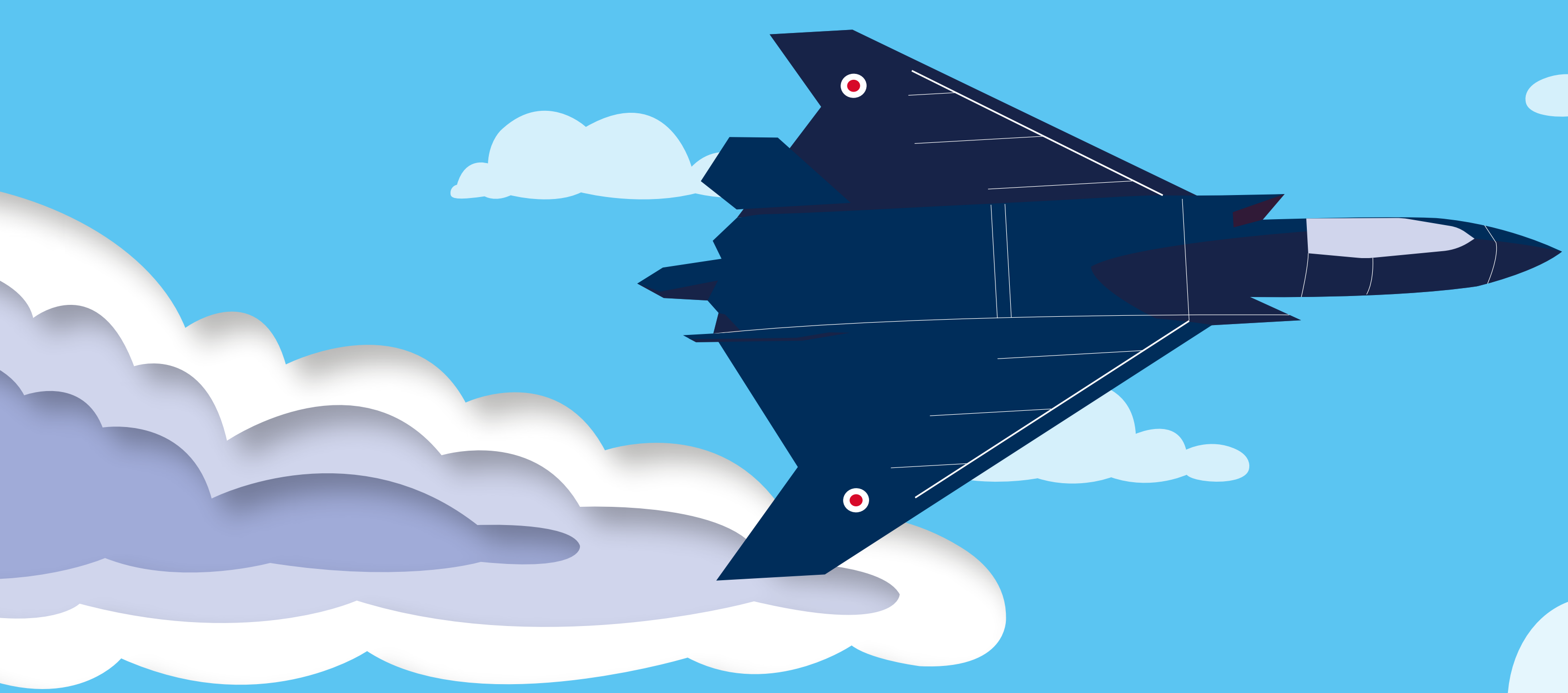
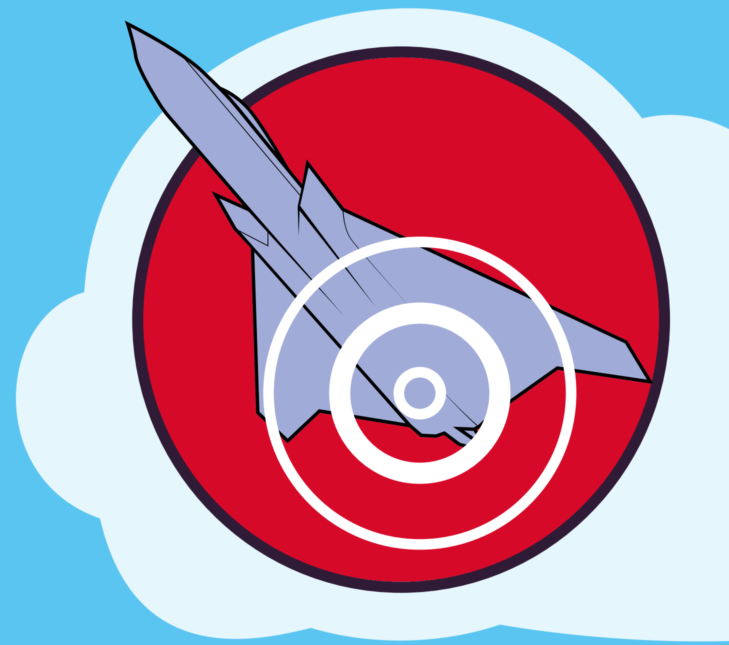
Future of flight:

Engines





Royal Academy of Engineering

THIS IS ENGINEERING

TEAM TEMPEST

Introduction

Engines produce the thrust required to make the aircraft fly, therefore are a crucial part of the aircraft's design.

The future aircraft engine will utilise the latest innovative technologies and materials – check out the single crystal turbines on page 7 – producing plenty of thrust as efficiently as possible, reducing the amount of fuel required, whilst also ensuring the engine is extremely reliable and is easy to maintain.

The engine of a Tempest future aircraft is set to be not just a propulsion system but a complete integrated power system. As we continue to use more advanced electronic systems, the engine will play a huge role in providing us with electrical power.

The future aircraft will not only provide electrical power, but we are moving closer to a fully electric aircraft. Take a look at our 'Environment' booklet for more!

Case study

Iñaki de la Puerta Vallejo

Aerothermal Engineer at Rolls Royce

Since I was a kid I've always been a very curious person about most of the things that surrounded me. Mostly about things that moved, flew or swam, and even more if they were able to do these three simultaneously. After watching Star Wars, I couldn't stop building my own LEGO® spacecrafts!

I studied an MEng in Mechanical Engineering in my hometown, Bilbao, Spain. Whilst at university, I was involved in projects within the Aeronautics Manufacturing Centre. I guess this is what made me realise my real interest in the Aerospace Industry.

During my last year of my Master's, I was granted a scholarship to study an MSc in Aerospace Propulsion at Cranfield University. There, I began collaborating with the Rolls-Royce University Technology Centre. Thanks to this opportunity, I was able to continue with an Internship within Rolls-Royce in the Innovation Hub, which was very exciting.

After this internship, I got the amazing opportunity to join the Tempest Team, and I didn't think it twice!

I am now part of a team who takes care of the engine's Turbine. It is exciting to be part of the next generation of flight technology.

> **"I love to see how my work can contribute to my teams and how this fits into the bigger picture of designing the engine of the future!"**

Future of flight: The engine

How does a jet engine work?

A jet engine is a machine that converts energy-rich, liquid fuel into a powerful pushing force called thrust. The thrust from one or more engines pushes an aircraft forward, forcing air past its wings to create an upward force called lift that powers it into the sky.

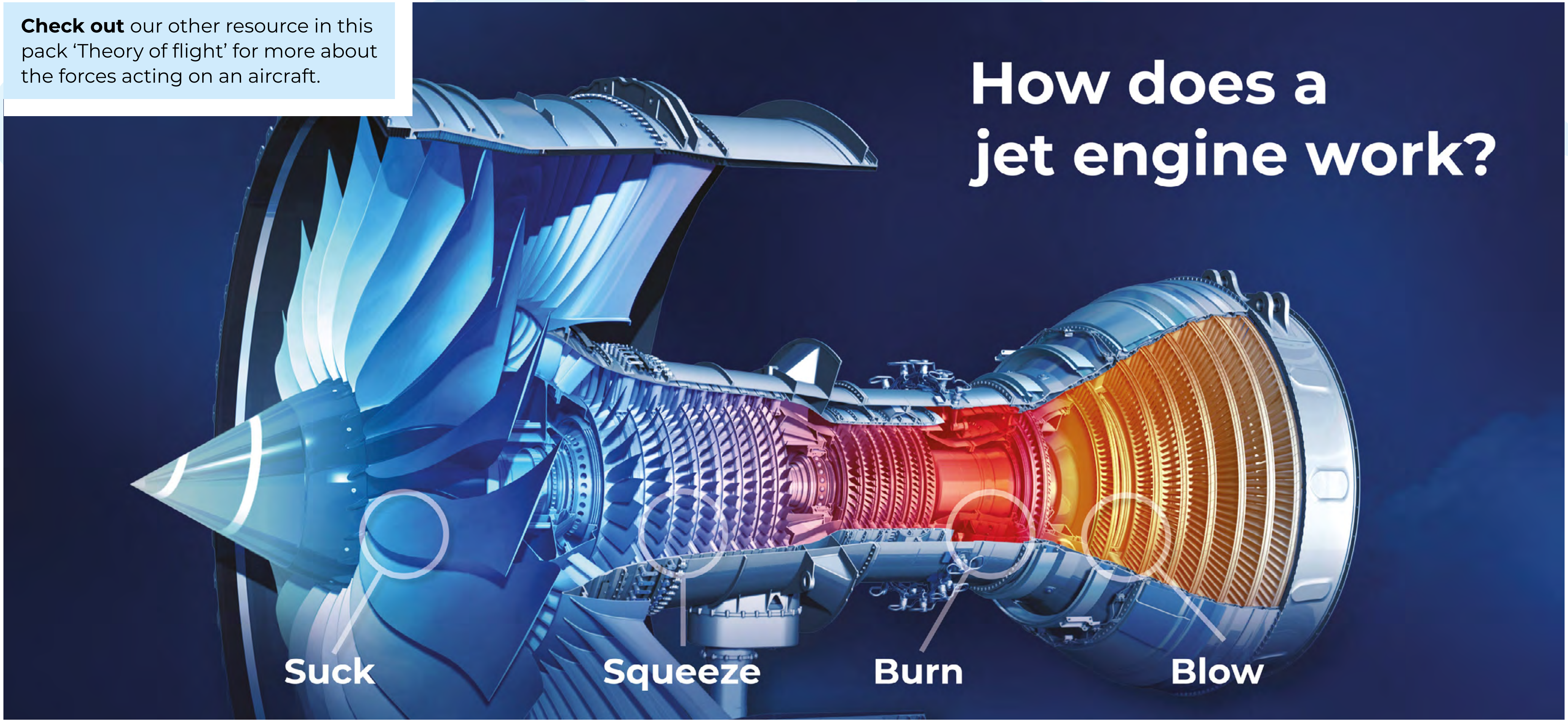
Every action has its equal and opposite reaction – Isaac Newton

As jets of gas shoot backward from the exhaust nozzle, the engine and the aircraft are thrust forward.

Action and reaction

The action of the exhaust gas shooting backwards is equal and opposite to the reaction which causes the aircraft to move forwards.

Check out our other resource in this pack 'Theory of flight' for more about the forces acting on an aircraft.



What is a jet engine and how does it work?

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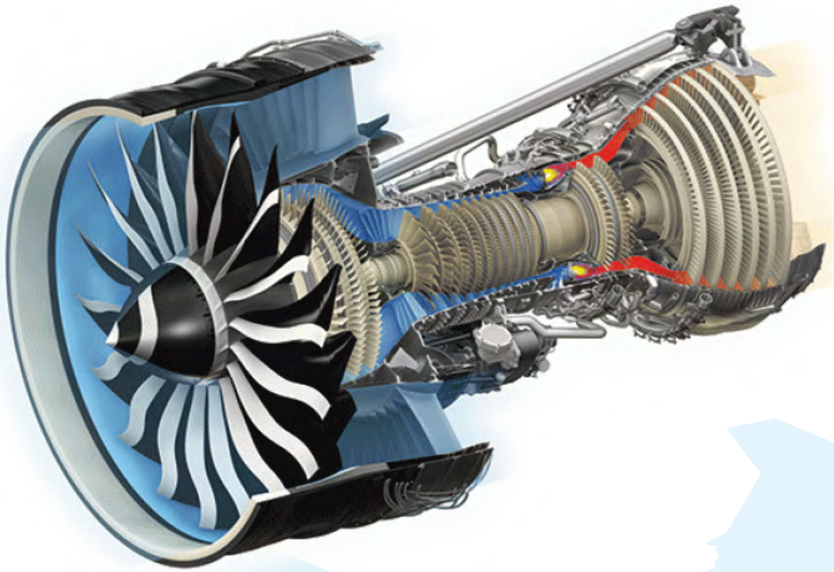
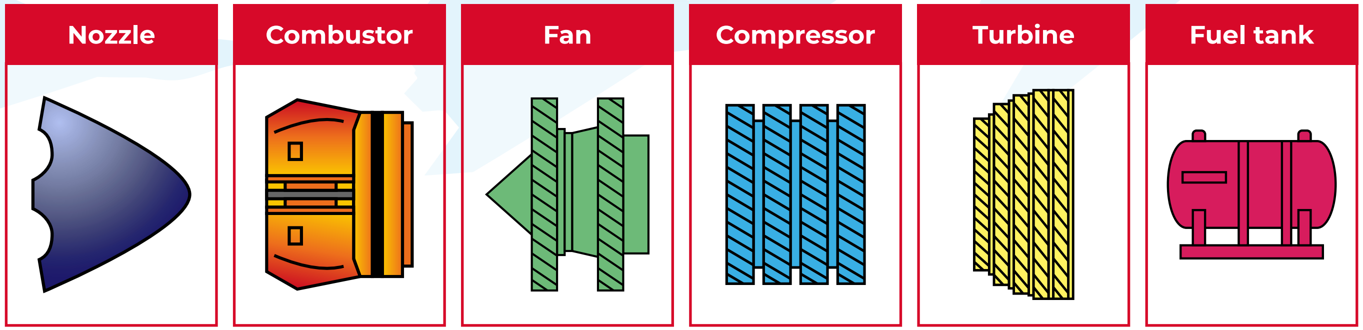
The parts of a jet engine are shown below.

Using the explanation given about how a jet engine works, put the parts in the correct order to build your jet engine.

1. The engine sucks air in at the **front** with a **fan**.
2. A **compressor** raises the pressure of the air by forcing it through increasingly small spaces.
3. Kerosene (liquid fuel) is **injected** into the engine from a **fuel tank**.
4. In the combustion chamber (**behind** the **compressor and fuel tank**) the kerosene mixes with the compressed air, causing a controlled explosion and dramatic increase in temperature.
5. The exhaust gases rush past a set of **turbine blades**, spinning them like a windmill.
6. The turbine blades are connected to a **long axle shaft** that runs the length of the engine. The **compressor** and **fan** are also connected to this **axle shaft**, so as the **turbine blades** spin, so do the **compressor** and the **fan**.
7. The hot gases **exit** the jet engine through an **exhaust nozzle**, travelling over twice the speed of the cold air entering at the front.



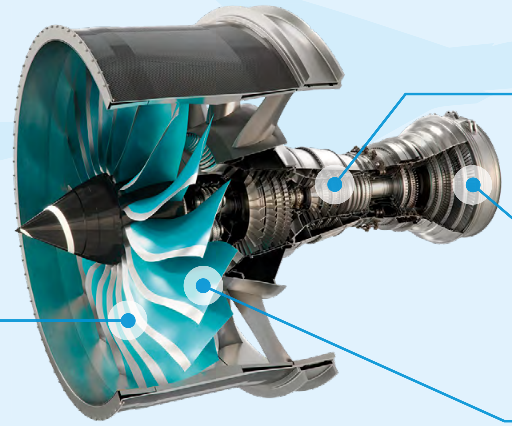


Build your own 3D Trent Engine

Rolls-Royce's Trent engine is one of the most powerful and complex machines at work today.

Although the real thing contains an amazing 18,000 parts, one of their engineers has simplified the design so you can make a 3D model for yourself. Just follow the step-by-step instructions to build your own version of the engine that powers the modern world!

How it works



1 **Suck:** The engine sucks in huge amounts of air through the fan blades.

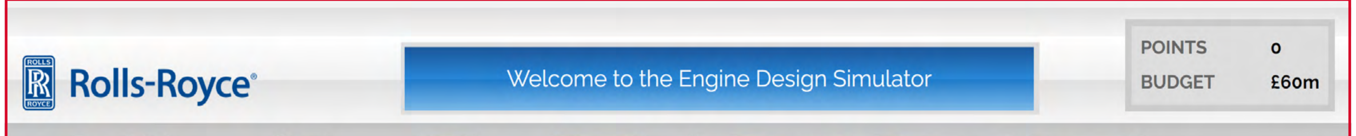
2 **Squeeze:** This air is squeezed inside the engine to increase the pressure.

3 **Bang:** Fuel is then added to create a continuous explosion.

4 **Blow:** This explosion generates huge thrust at the other end.

There is one hard-copy of the 3D Trent engine in each STEM box.

You can also find a PDF of the 3D Trent Engine on the STEM page on the Rolls Royce website.



Design your own engine, making critical decisions that will maximise your engine's success for a customer.

At the end of the process you will have a score card to see how well you did.

Find the 'Engine design simulator' on the Rolls Royce website.

Journey through a jet engine. Find this on the Rolls Royce website.

Stage 1

Explore the parts of the Trent engine

Find out about the parts, materials and manufacture of a jet engine.

Stage 2

Watch the Trent engine being build

A time-lapse film of a Trent engine being assembled and tested before delivery.

Stage 3

Take a journey through a jet engine

A fly-through of a Trent engine with details of temperature, pressure and speed.

Stage 4

Test your engineering suitability

A quiz to find out how much you have learned about jet engines.

Balloon craft race

Time to investigate

The balloon powered car is a good example of Newton's Third Law. The force of the air leaving the balloon (action) pushes the car forward (reaction).

Time to design and build

Design and build a balloon-powered vehicle using recycled materials and different size balloons.

Materials

The following materials are included in the Future of Flight box. If you do not have the box, you can still do this challenge using recycled materials and other materials that can be easily found at home/ school and in stationary shops.

What could you use to create your balloon craft car? Get creative!

- Balloons (try with different size and style balloons too)
- Corriflute
- Balloon pump
- Wheel hub
- Axle
- Nozzle

Wheel design

We have provided you with wheel hubs in the box. Design and make wheels that will attach to these.

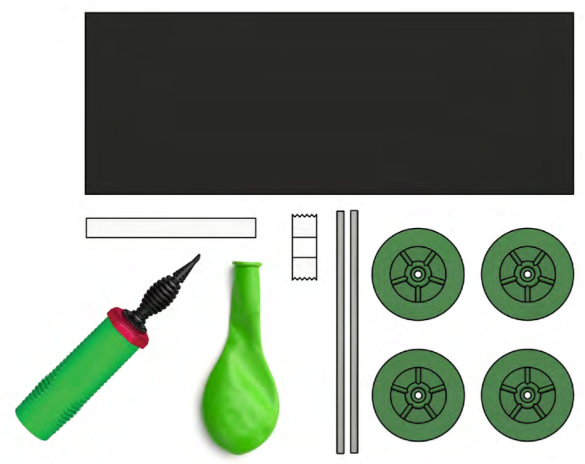
Things to consider when choosing materials and designing your vehicle.

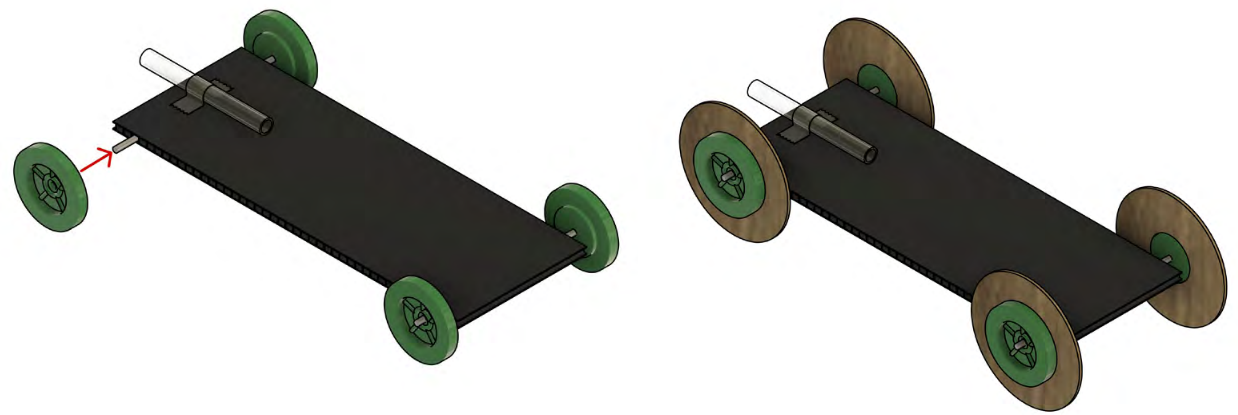
- Which materials for the wheel will be most sturdy?
- Which materials for the wheels will weigh less/more?
- Will this affect the speed? Will this affect the distance?
- What impact will increasing the air in the balloon have?
- What impact will increasing the speed that the air leaves the balloon have?
- What impact will the position of your nozzle have?

Changing the design of your chassis

How could you adapt the design of the balloon car chassis (the skeleton of your cart) to improve the sturdiness and speed?

Top tip! Cut the corriflute that is used for the chassis using a cutting mat and craft knife or scissors.





Example balloon craft cart with wooden wheels.
How could you improve on this design?

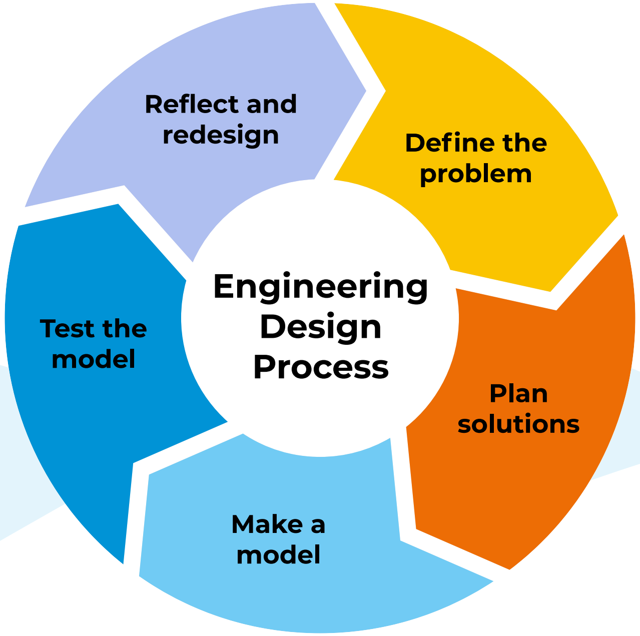
Balloon craft race

A large part of any engineer's role is to test, question, review and improve!

- **Define** the problem
- **Plan** solutions
- **Make** a model
- **Test** the model
- **Reflect** and redesign

Build at least three different balloon car models.

Use the table below to **test**, **review** and **improve** your design.



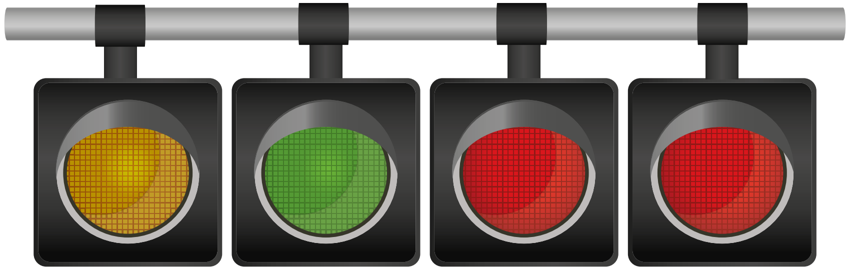
Model (image/ name)	Materials used	Weight	Distance travelled	Time travelled	Speed travelled	Other comments

Based on our testing, we found model ____________ to be most successful because ____.

Time to race!

Choose your group's best design and challenge other teams in your class to a race.

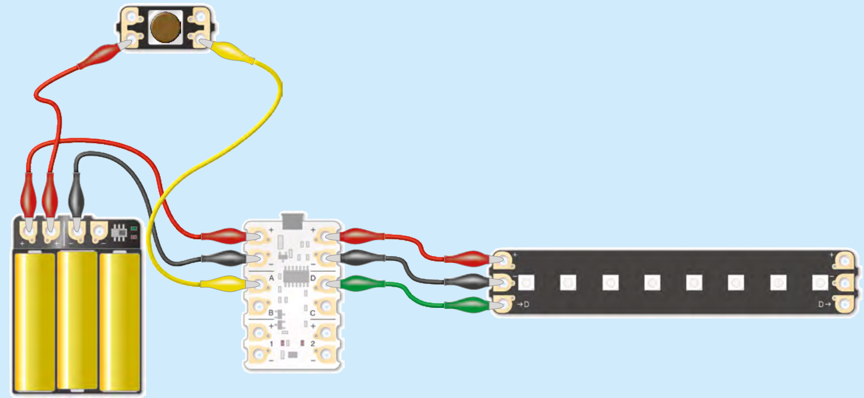
Ready, steady, race...



Once you have your balloon cars ready to race, use the Crumble to program and build racing lights that can be used to create a light countdown to start the race.

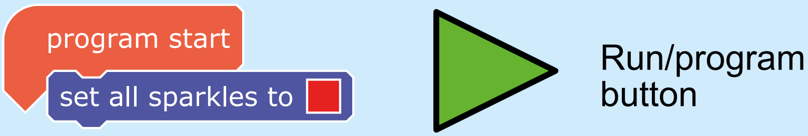
Time to program

1



Connect the Crumble, Sparkle Baton, battery-pack and push-button switch.

2



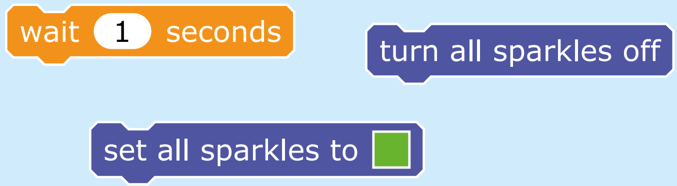
Test the Sparkle Baton with this simple program. When you click the run button, all the LEDs should light up red.

3

We want our start lights to flash red three times and then green (for go).

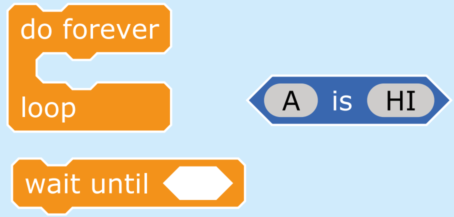
Can you add the blocks shown to the program to get three red flashes?

4



Now add these blocks to get a single, longer, green flash at the end.

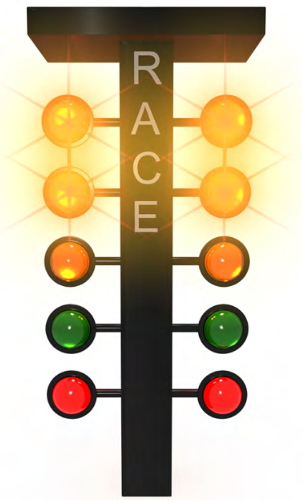
5



Rather than having to press 'Run' each time, we want our sequence to be triggered by a button so that a connection to a computer isn't necessary.

When the button is pressed, the value of A will go from LO to HI. Use the blocks shown to wait for the button before going through the sequence and loop the program so that it restarts automatically.

6



Build something to hold your sparkle baton as part of your race track.

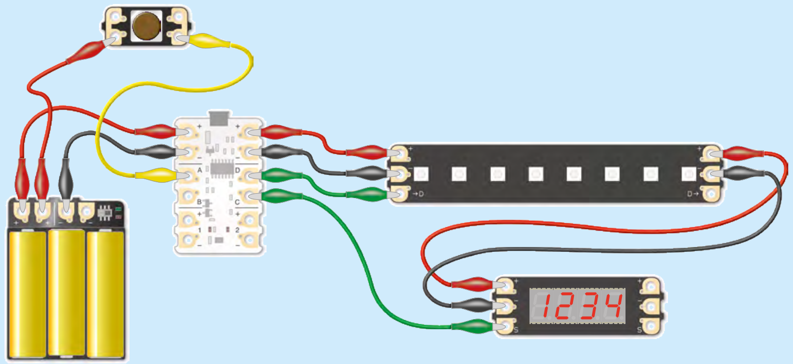
And the winner is...

To get an accurate measure of race time, digital watches are often used.

These are usually set up in such a way to time each individual racer automatically using sensors.

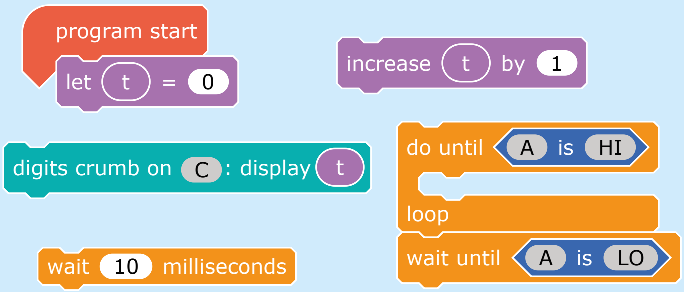
Time to program

1



Connect the Crumble, Digits Smart Crumb, Sparkle Baton (optional), battery-pack and push-button switch.

2

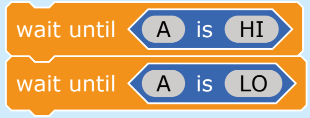


Use these blocks to create a program that counts up from zero every 10ms and displays the value until the button connected to A is pressed.

This will be the basis for our timer.

Note the final ‘wait until A is LO’ block will cause the Crumble to pause until the button is released – this will be useful later.

3



Now add the blocks shown to start the timer when the button is pressed. Notice we have included a block to wait for the button to be released.

What would happen if we didn’t included this block?

4

Adjust the condition in the ‘do until’ ‘loop, so that the Crumble stops counting at 6000 (60 seconds).

5

Finally, place the whole program in a ‘do forever’ loop so that it will restart automatically.

Single crystal turbine blades

Turbine blades need to withstand a tremendous amount of force and heat.

They are being pulled extremely hard by their own weight due to the speed at which they are travelling – over 12,000 revolutions per minute (rpm)!

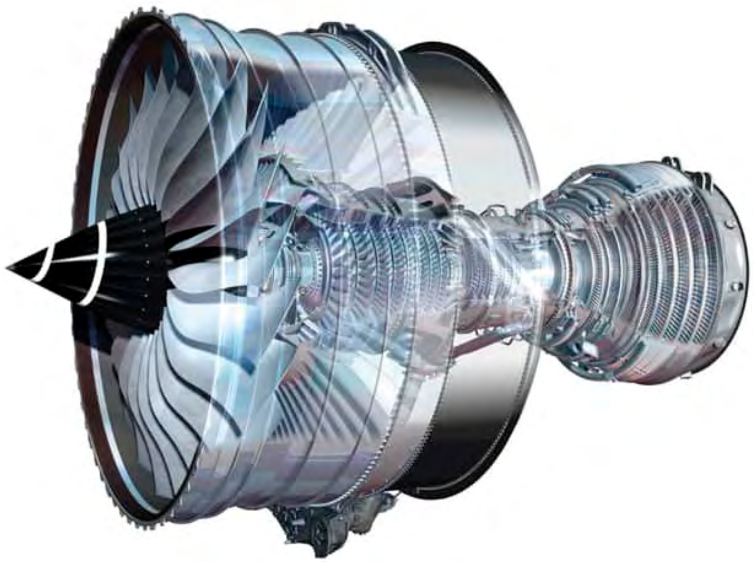
The air in the turbine reaches temperatures much higher than the blades' melting point – over 1,700°C. This is the equivalent of keeping an ice cube cool in an oven!

Engineers have found ways to solve this problem by wrapping cooler air from the compressor around each turbine blade (this comes out of the little holes you can see in the turbine blade image), to work as their own mini cool box! The complex cooling mechanisms mean that the metal is never above its melting point, even though the environment is.

When they were first created, jet engines were made entirely from steel. Now turbine blades are grown from a single crystal, which means that there are no boundaries between metal crystals in the part, making it much harder for a crack to form.

Check out the materials booklet in this resource pack for more activities on composite materials.

Turbine



Turbine blade

Growing crystals

From the sugar in your food to snowflakes in winter, crystals are all around us. Even salt (known also known as sodium chloride or halite) is a crystal.

A crystal is a solid whose atoms are arranged in a 'highly ordered' repeating pattern. These patterns are called crystal systems, and are much too small to see with the naked eye. There are seven categories of crystal structures, which are called lattices or space lattices.

Time to build crystals

Because of their structural characteristics, you can actually grow crystals!

Table salt is made of many tiny crystals. When you mix these salt crystals with water, they dissolve, losing their crystalline form. When the water **evaporates**, the salt crystals form once again. The science of crystals, calls crystals shaped like these "cubic." This shape is determined by the way the individual atoms in salt pack together.

Materials

- Table salt – sodium chloride – NaCl
- Stove (use a kettle if you can't use a stove or burner)
- Water
- Clean clear container that can hold boiling water
- Short string
- Thread
- Pencil
- Small weight (e.g. nail or paperclip)
- Food colouring (optional)
- Magnifying glass (optional)

1. Place the container on a safe surface where it can remain undisturbed for a few days, or even weeks.
2. Bring water to the boil. Or use a kettle to boil water.
3. Slowly add salt to the water, mixing with a spoon to help dissolve. If you are using a kettle, you will need a another container to mix create your solution. Add food colouring now if you want.

What happens to the boiling water's appearance?

4. Continue adding salt until no more will dissolve. Turn off the heat. You now have a **supersaturated solution**.

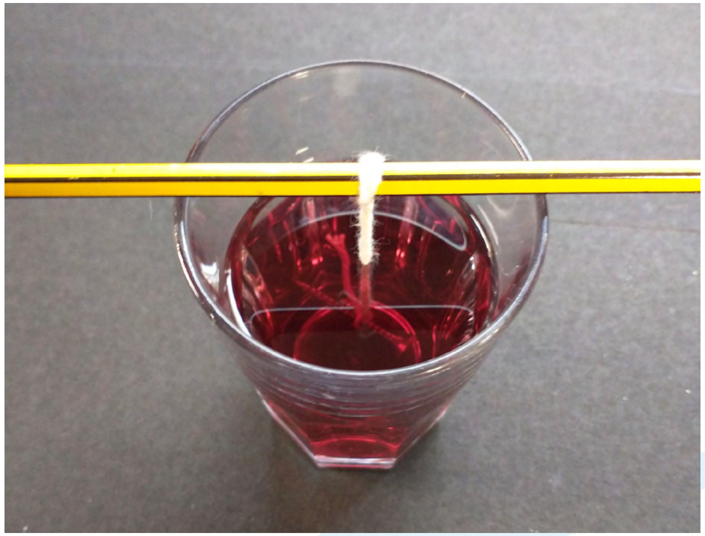
What does the solution look like now?

5. Carefully pour the solution into your container.
6. Tie your weight to one end of the string and the other end to a pencil. Lower this into your container.

What purpose do you think the string serves? What do you notice happen?

7. Leave the container undisturbed.

What happens after one hour? One day? Two days? One week? Three weeks?



Further investigation

What happens if you let your solution cool faster/slower?

Try putting it in the fridge. Try putting it by a sunny window.

Look at your salt crystals with a magnifying glass. *What do you notice?*

Try this experiment using different length strings, or several pieces of string tied together.

Try with different types of salt. What do you notice? Try this experiment with sugar. What do you notice?

Health and safety. This activity uses boiling water so ensure you have adult supervision. Wear goggles.

Growing a single crystal

You have grown several smaller crystals. Team Tempest have taken this one step further to grow one single crystal to increase the strength of their turbine blades!

- Create a **saturated solution** as you did in the previous method. Leave the water in a container without a string or pencil.
- The solution will slowly evaporate (this will take a few days). As the water evaporates, the **solute** in the **solution** will **precipitate**.

*A **precipitation reaction** is one which substances in solution are mixed and an **insoluble product** (will not dissolve) is made. This product is called a **precipitate**.*

- Crystals at the bottom of the container will start to grow.
- Dry your crystals off using a paper towel. Choose one that is a decent size which will be used as your **seed crystal**.
- Prepare a clean, clear container and place it somewhere where it will not be disturbed.
- Create another **supersaturated solution** and pour into your container.
- Tie a piece of thread around your seed crystal and tie this to a pencil or lollipop stick. This will be used to balance at the top of your container. Lower slowly into your solution.
- Cover your container to keep dust out and avoid temperature fluctuations.
- Leave the container undisturbed.

What happens after one hour? One day? Two days? One week?

Grow your seed crystals in a supersaturated solution.

Images courtesy of: https://www.wikihow.com/Make-Salt-Crystals

Choose a seed crystal.

Suspend the seed crystal in your supersaturated solution.

Faster than the speed of sound

The latest engine technologies in development are seeking to allow flight at five times the speed of sound, known as Mach 5.

That's more than twice as fast as the cruising speed of the Concorde, the fastest passenger aircraft, which travelled at twice the speed of sound, known as **Mach 2**.

The average flight time between London and New York is approximately eight hours. The Concord did it in approximately three and a half hours!

Time to calculate

Sound waves travel at approximately 340 metres per second in air.

- How fast did the Concorde travel?
- What is the average speed of a passenger aircraft?

When will you hear the One O'Clock Gun?

The One O'Clock Gun is fired every day at 1pm from the Edinburgh Castle.

The map shows the time the sound reaches different places.

Each circle represents one second.

Use the map to calculate:

- The distance between Arthur's Seat and Edinburgh Castle.
- The distance between Port of Leith and Edinburgh Castle.

www.edinburghcastle.scot/see-and-do/highlights/one-oclock-gun

Notes

Royal Academy of Engineering

The Royal Academy of Engineering is harnessing the power of engineering to build a sustainable society and an inclusive economy that works for everyone.

In collaboration with our Fellows and partners, we're growing talent and developing skills for the future, driving innovation and building global partnerships, and influencing policy and engaging the public.

Together we're working to tackle the greatest challenges of our age.

What we do

Talent & diversity

We're growing talent by training, supporting, mentoring and funding the most talented and creative researchers, innovators and leaders from across the engineering profession.

We're developing skills for the future by identifying the challenges of an ever-changing world and developing the skills and approaches we need to build a resilient and diverse engineering profession.

Innovation

We're driving innovation by investing in some of the country's most creative and exciting engineering ideas and businesses.

We're building global partnerships that bring the world's best engineers from industry, entrepreneurship and academia together to collaborate on creative innovations that address the greatest global challenges of our age.

Policy & engagement

We're influencing policy through the National Engineering Policy Centre – providing independent expert support to policymakers on issues of importance.

We're engaging the public by opening their eyes to the wonders of engineering and inspiring young people to become the next generation of engineers.

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