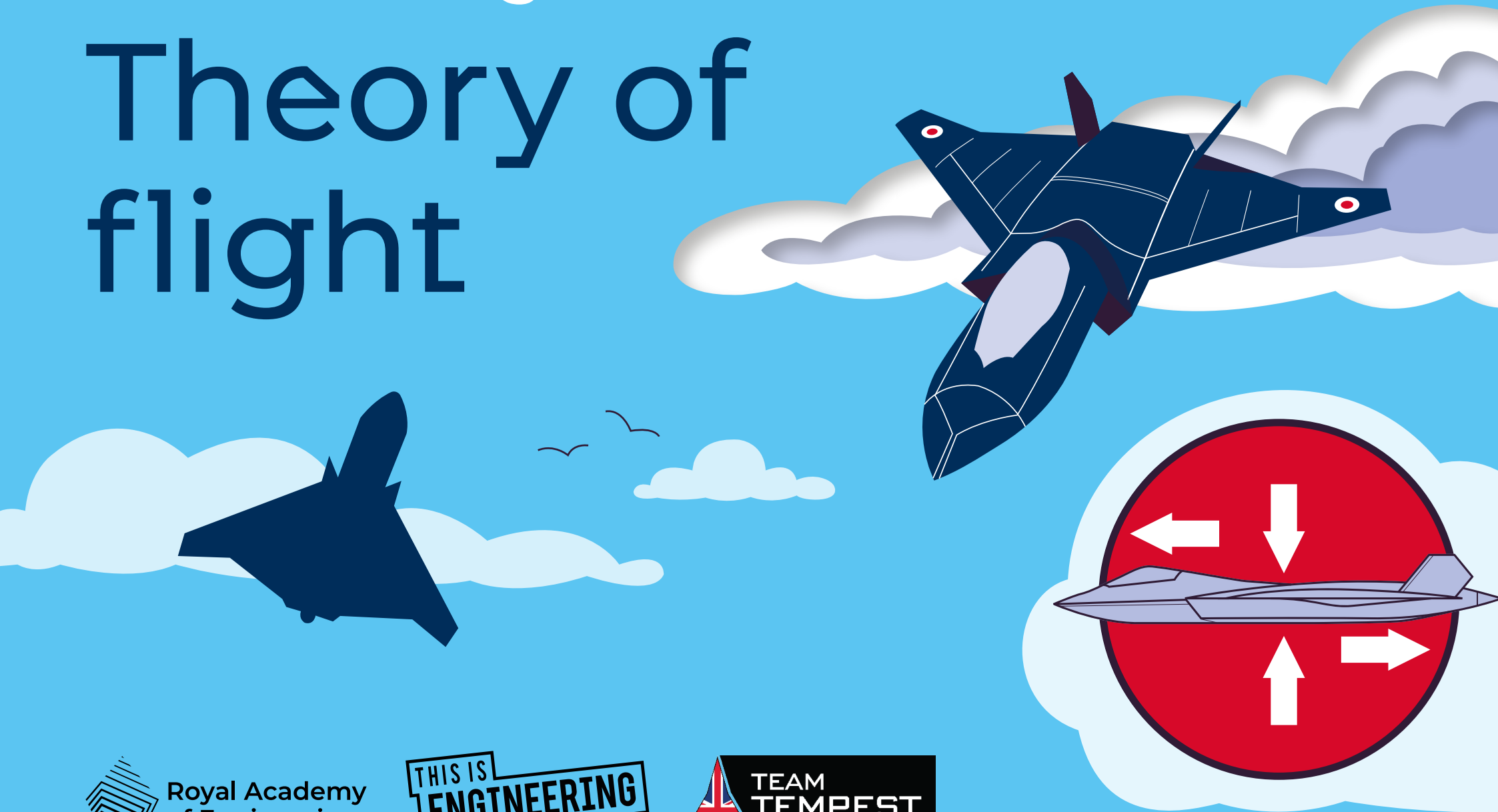


Future of flight: Theory of flight



Royal Academy
of Engineering

THIS IS
ENGINEERING



TEAM
TEMPEST

Introduction

Engineers are using the latest research and technology to develop an aircraft that is the best it can be, that is adaptable for a wide range of operations and that can keep the pilot safe.

The aircraft needs to be capable of flying with a variety of different different payloads such as sensors, and needs to be highly manoeuvrable in a range of different environments. The Theory of Flight considers the four forces acting on the aircraft: lift, thrust, drag and weight, to develop a design that meets all the needs of the aircraft.



Case study

Sophie

Aerodynamics engineer at BAE Systems



Find out more about Sophie by visiting [This is Engineering](#) website.

Growing up, I had no idea what job I wanted to do. Careers advisors suggested all sorts of jobs like accountant, teacher and even costume designer. My family doesn't have a science background and I didn't know any engineers, or really know what engineering was, I thought it was something that involved spanners and hammers!

It was only when I met astronaut Dr Helen Sharman, the first British person in space, that I realised that becoming an engineer was my route.

I did a Masters degree in Mathematics at the University of Nottingham, and then joined BAE Systems on their graduate scheme.

I am now an Aerodynamics and Performance Engineer and experiment with future concept military aircraft.

This means that I use maths to work out whether designs for future aircraft will fly and, if they do, how fast or how far will they fly, and what I can do to improve their performance.

I love knowing that there are aircraft flying in the sky with designs I have worked on, and that the incredible technologies I work with could help make holidays in space a reality.



“

For me, engineering is all about being part of a team that shares a goal to build something amazing for the future, and through doing that you get to leave a legacy.

”

Flight in nature

Time to think

In small groups, discuss the following questions and share your answers with your teacher and the rest of your group.

- What makes a bird a bird?
- How do birds fly?
- Why do birds fly?

Is it a bird? Is it a plane?

Aircraft have been designed to have similar capabilities to birds.

Look at the images of the different birds and aircraft on the next page and describe the following:

- Wing span
- Shape of beak
- Height and length
- How they fly
- Why they fly?

What do you think makes the features of birds and aircraft so well adapted to flying?

Match the bird and aircraft based on how and why they fly.

Teacher note: Cut out the cards with the images and descriptions of the birds and aircraft to use for the matching activity.

Flight description	Bird	Aircraft
Speed		
Gliding		
Manoeuvring		
Endurance		
Hovering		
Soaring		

Explain your choices – you might have different solutions to your classmates, and it is important to be able to justify your decisions.

Peregrine falcon



Peregrine falcons are the fastest animals on earth (reaching speeds of over 320kph). They can tuck their wings in to reduce **drag**.

Godwit



Migratory birds like **godwits** have long narrow wings equipped for long ranges and endurance at a relatively fast speed.

Albatross



Wandering **albatrosses** have the longest wingspan of any bird. The long, narrow, pointed wings coupled with low wing loading enable the birds to glide effortlessly on up draughts – sometimes for months at a time.

King vulture



Long and wide wings allow **king vultures** to spend hours in flight, soaring slowly without flapping their wings. They search for carcasses while riding thermals.

Hummingbird



Hummingbirds have the ability to hover in one place by rotating their wings.

Hawk



Hawks' wings are wide and rounded at the ends. This, elliptical shape with separated or slotted feathers at the end allows them precise manoeuvrability.



Spitfire

The elliptical shape of the wings gives the **Spitfire (WWII fighter plane)** excellent manoeuvrability. They allow the plane to turn sharply while still flying at speed.



Tempest

This **Tempest Aircraft concept** has highly swept wings to make it more efficient for travelling **supersonically**. Supersonic means travelling faster than the speed of sound.



RAF Air Cadets Viking

A **glider's** long, slim wings and low wing loading maximises lift, enabling the gliding action.



RAF Chinook

The **helicopter** can rotate its rotor-blades, enabling it to hover in one place, to take off and land without a runway and to move people and things around.



RAF Protector Remotely Piloted Air System

The long wings of the **Protector** allow it to move slowly, not using much energy. This means it can stay airborne for some time while spying out the land.



RAF Voyager A330

Aircraft such as the **Voyager** with long and thin wings have long ranges and endurance times at fast speeds, to allow it to catch up with other aircraft to give them fuel.



Time to observe

If you get the opportunity to go outside in nature, whether in school or at home, find birds and observe them in their natural habitat.

Using a pencil and paper:

- Draw the shape of the wings
- How does the width compare to the length of their wings (aspect ratio)?
- What do you think the flight capability is of this bird?

The natural world is full of incredible feats of engineering. For many years, we have been learning from these biological marvels to develop our own technology and innovations. This is a process called **biomimicry**.

Time to research

Using a smartphone, laptop, computer or tablet go to the [Biomimicry Institution website](https://www.biomimicryinstitute.org/) and find four examples of advancements in engineering and technology that have been inspired by nature.

For example, scientists learned how cats were able to turn their bodies in mid-air when falling so that they always land on their feet. They used biomimicry to imitate this action for astronauts, which became an important part of space travel and moving through zero-gravity.



Watch this video, [Designed by nature](#), on BBC Teach, which introduces biomimicry and how we learn from nature.

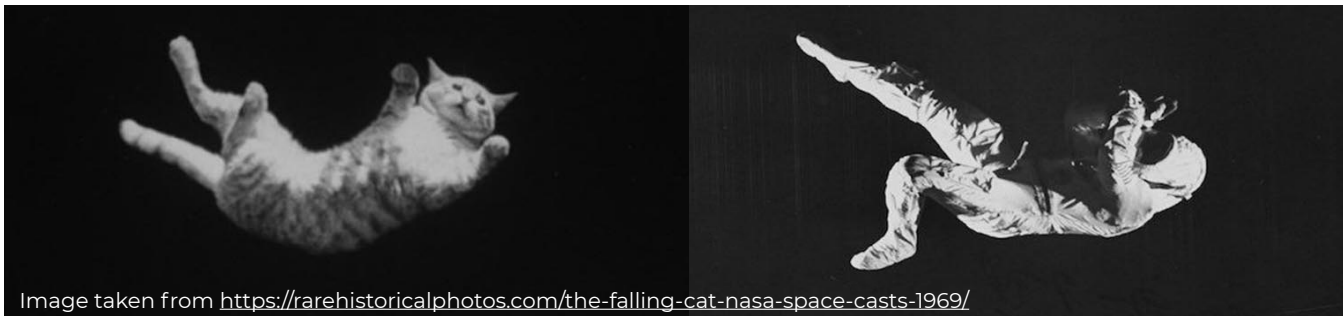
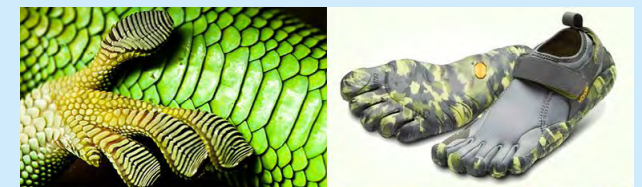
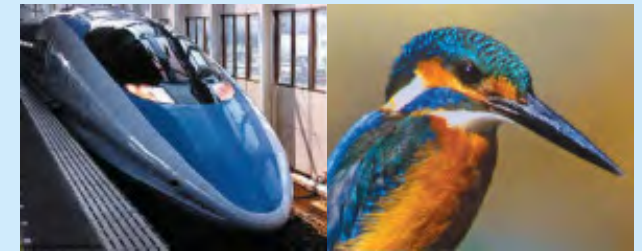


Image taken from <https://rarehistoricalphotos.com/the-falling-cat-nasa-space-casts-1969/>

What is the relationship between the living thing and the technology?



What other examples can you think of?

Forces of flight

What is a force?

A force is a **push** or **pull** on an object in a particular direction. A force can cause an object to accelerate, slow down, remain in place or change shape.

All forces come in pairs – if you push on something (action), it pushes back (reaction).

Four forces act on an aircraft while it is in flight.

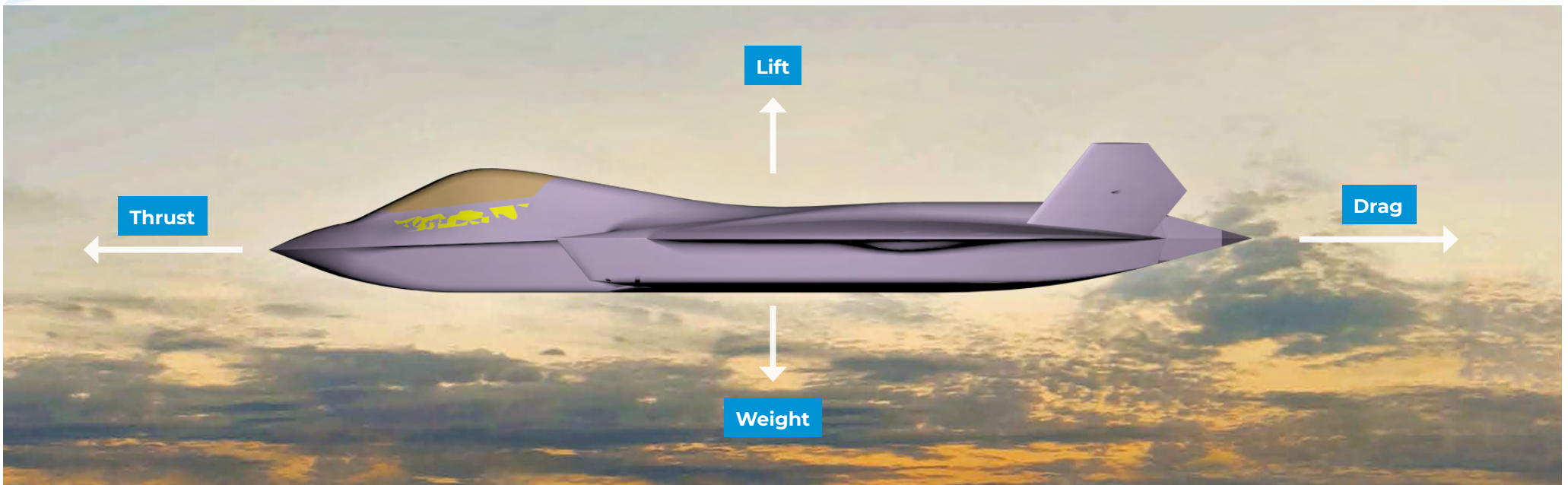
- Two forces (lift and thrust) **create** flight
- Two forces (drag and weight) **prevent** flight

Lift and thrust must be greater than drag and weight for flight to occur.

Build your own glossary

Match the force to its definition.

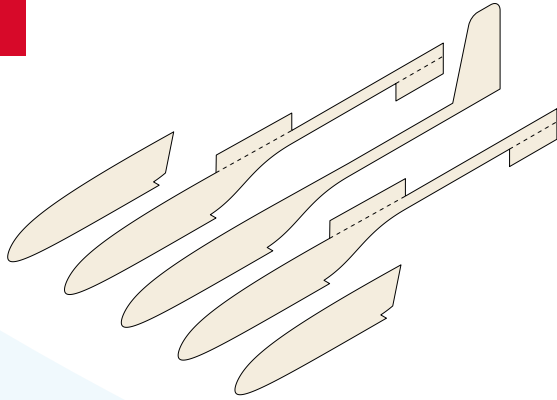
Lift	is the force that moves an aircraft through the air. It overcomes the drag and weight of an aeroplane. Aircraft engines generate this force through the propulsion system (propeller or jet engine).
Thrust	is the force generated by the gravitational attraction of the earth on the aircraft. This is the only force not controlled by the design of the aircraft.
Drag	is the force that directly opposes the weight of an aircraft and holds it in the air. It is generated by every part of the aircraft, but mostly through the wings.
Weight	is a form of friction known as air resistance. This is the force that opposes an aircraft's motion through the air. Every part of the aircraft generates this force, even the engines. It acts in the opposite direction to the motion of the aircraft.



Investigating forces

Investigate the forces acting on an aircraft with this glider activity. There are cardboard gliders included in the resource box.

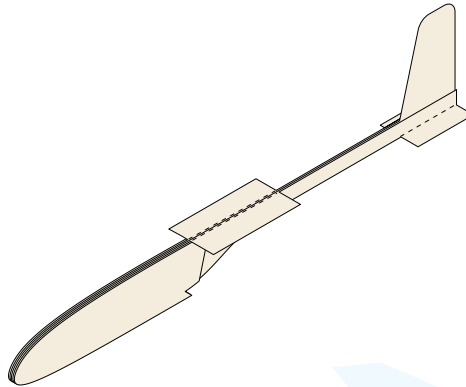
1



Glue fuselage pieces together.

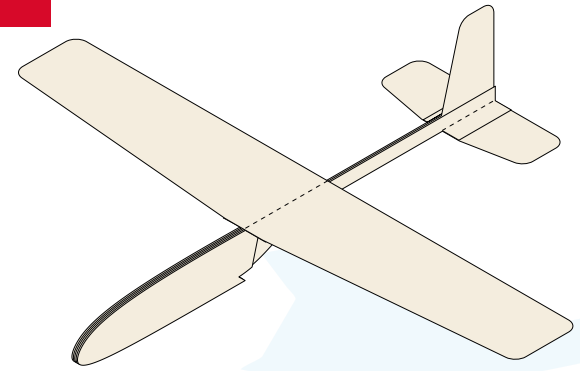
Try to avoid getting glue on the outside faces and tabs.

2



Fold out the tabs for the wing and tail pieces.

3



Apply glue to the tabs and attach wing and tail.

Throw your aircraft to watch it glide.

- How far does it travel?
- How steady is the journey?

Investigate the forces of flight and find out what impact they have on your flight path.

Control and stability

How stable is your glider when you launch it?

Almost all aircraft now have **dihedral**. This is the upward angle of wings and it adds stability to an aircraft by keeping the wings level.

Adjust the **dihedral angle** of your glider. What impact does this have?

Anhedral (inverse dihedral) = downward angle of wings



Investigate the forces of flight

Weight and balance

- Change the weight of your glider by attaching paperclips and/or Blu Tack along the **fuselage** (the body of an aircraft).
- Investigate balance and weight distribution by changing where you place the weights on your glider.

Thrust

- Try throwing the glider with different levels of force
- How does this impact how far it travels?
- How does this impact how steady it travels?
- Is there an optimum force to throw your glider?

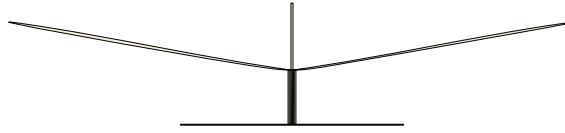
Lift

- Add **camber** to the wings by gently curving the wing as shown in the picture. Camber is a slight arch or curvature to the aerofoil of the wing.
- Adapt the wing design of the glider.

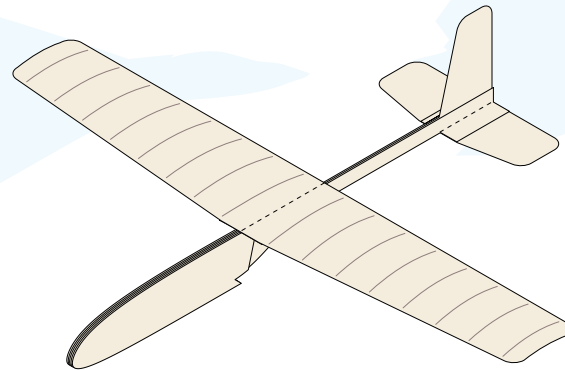
Drag

- Which part of the glider design might cause the most resistance? How could you reduce this?
- Use the templates to cut in flaps. How does this impact drag? How does this impact the flight path?

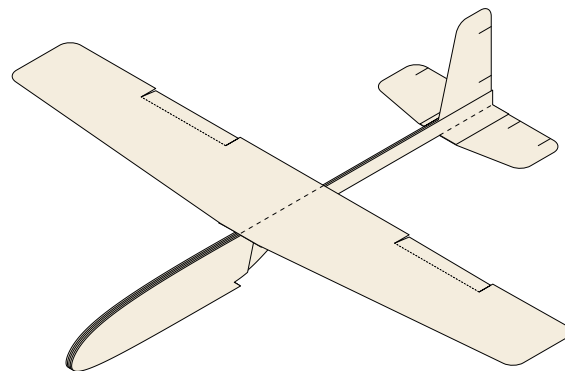
Find a template of the glider you can print out yourself on the '[Future of Flight](#)' page on our STEM resource hub.



Dihedral angle



Gently curve the wing to add camber.



Cut in the flaps on your glider.

Stealth

Many aircraft are designed in such a way that makes them **less visible** to others.

Design your glider so that it is less visible.

Would this change depending on where you use it?



Testing forces in a wind tunnel

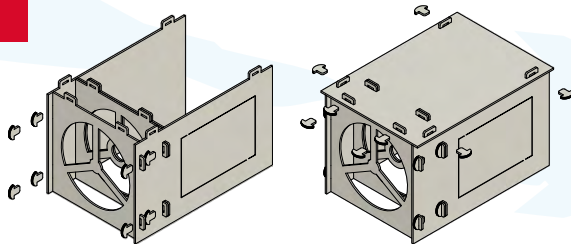
Wind tunnels are large tubes with air moving inside.

The tunnel is used to copy the actions of an object in flight. Wind tunnels come in a lot of sizes. Some are only a few inches square, and some are large enough to test a full-size aircraft.

Some wind tunnels test aircraft at very slow speeds. But some wind tunnels are made to test at hypersonic speeds. That is more than 4,000 miles per hour!

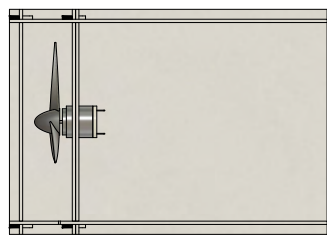
Time to build your wind tunnel

1



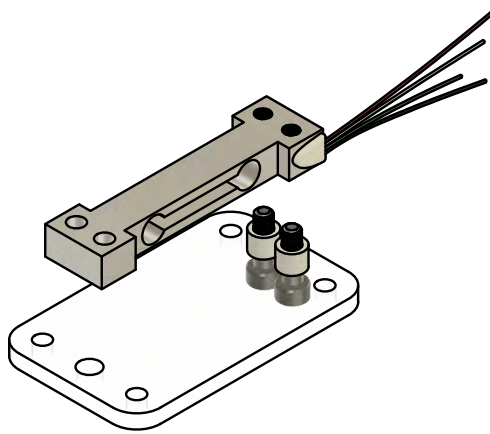
Assemble the main structure of the wind tunnel.

2



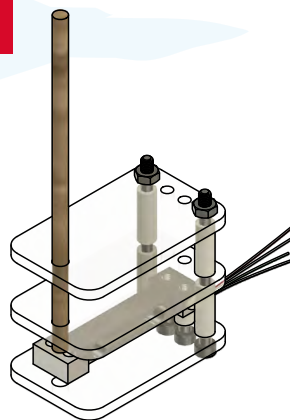
Fix the fan to the structure.

3



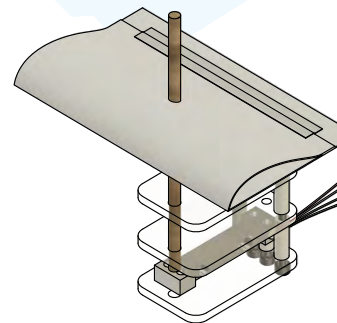
Connect the load cell to the bottom plate.

4



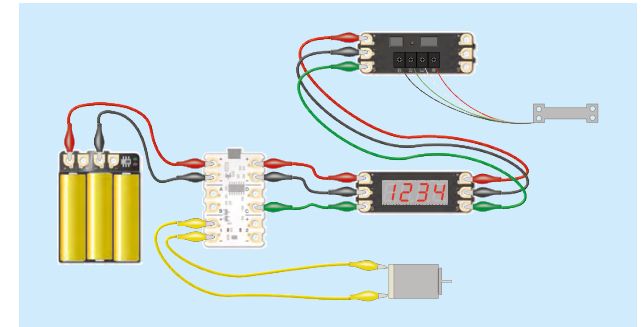
Connect all remaining plates. Place a rod in the hole through the plates so it sits on the load cell.

5

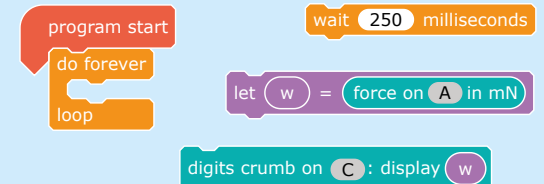


Fix the object you are testing to the rod. You could use blue tack to secure it in place.

Time to program



Connect the Digits Smart Crumb, force sensor, motor, Crumble, and battery pack.



First test the load cell by displaying the force reading on the Digits Smart Crumb.

The force is measured in millinewtons (mN).

On Earth, a mass of 1 gram will experience a force due to gravity (i.e. its weight) of 9.81 mN.

Use the blocks shown to read the force and display it four times per second.

force crumb on C : set to zero

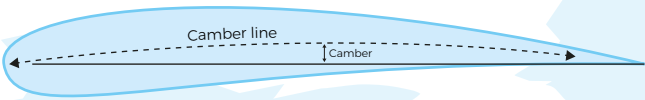
We want to measure the force due to lift when the fan is turned on. We can use the block shown to 'zero' the sensor before we run the experiment.

Add this block to your program, and check the readings start at zero.

motor 1 FORWARD at 100 %

Now we just need to turn the motor on so we can measure the lift of our aerofoil design.

Note: you may get a negative reading for an upwards force.



Testing wings for lift

Wings are designed in such a way that they create lift. This shape is called an **aerofoil**.

Make different style aerofoils, as well as other shapes in your wind tunnel.

What do you think will happen with each shape?
What actually happened?

How to make an aerofoil

- Make an aerofoil by folding a piece of paper in half, but not creasing it.
- Create an upwards camber by pushing the paper back slightly from the end.
- Stick the top down with tape.



Try making an aerofoil with more/less camber.
Try making an aerofoil by increasing/decreasing the thickness.

Shape tested	Prediction	Test
Aerofoil		
Triangular prism		
Cylinder		

Time to reflect

Aircraft wings are designed in different shapes and sizes depending on what they will be used for.

- How do you think each of the aircraft shown will be used?
- Identify which wing type each aircraft has.
- What are the advantages and disadvantages of having low-speed wings and high-speed wings?





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.

Royal Academy of Engineering
Prince Philip House
3 Carlton House Terrace
London SW1Y 5DG

Tel: +44 (0)20 7766 0600
www.raeng.org.uk
Registered charity number 293074