

## How can we use resistance to movement to create movement?

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### Learning objectives

Through this activity, pupils should learn and appreciate:

- What is 'fluid drag' (i.e. air or water resistance);
- How air and water resistance are used both in nature and in engineering;
- That every action (or force) has an equal or opposite reaction (force) – otherwise known as Newton's Third Law of Motion – and that this is very useful to us!

### Lesson plan and slideshow

| Slide # | Subject                 | Description and script                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Time (total) /mins |
|---------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
|         | Prep                    | Complete any necessary pre-class admin.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 5 (5)              |
| 3       | Group thinking activity | <p>What do each of these things do and what do they have in common?</p> <p><i>Activity:</i><br/><i>Slide shows four images: a duck, a ship with sails, a wind turbine, and an aeroplane.</i><br/><i>Encourage pupils to suggest what these four very different things might have in common. Should hopefully produce some interesting answers!</i><br/><i>Encourage broad and lateral thinking.</i></p> <p><i>Collate a range of answers and, if not already given, explain...</i></p> <p>A duck quacks and swims and eats...<br/>...a ship sails on the high seas...<br/>...a wind turbine spins and creates electricity...<br/>...an aeroplane flies people all over the world.</p> <p>All four of these things make use of 'fluid drag'.</p> | 5 (10)             |

| Slide # | Subject      | Description and script                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Time (total) /mins |
|---------|--------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| 4       | Introduction | <p>What is fluid drag?</p> <p>'Fluid' means either a liquid (such as water) or a gas (such as steam).<br/> 'Drag' describes the resistance to motion experienced by a moving object.</p> <p>Therefore, fluid drag is the resistance that a moving object experiences when passing through a liquid or a gas.</p> <p>Just imagine the resistance that you feel when you're swimming and trying to move your hands, arms and legs through the water – it can be pretty tiring can't it? That's because of the drag from the water that you experience.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 5 (15)             |
| 5-6     | Case studies | <p>How does a duck use fluid drag?</p> <p><i>Activity:</i><br/> <i>May work well as a prompted Q&amp;A type session, or however you think will get the most engagement from the class.</i></p> <p><i>Making links with biology and evolutionary theory, the class can be prompted to answer and discuss questions like...</i></p> <p>How does a duck move through the water?<br/> (By kicking its legs / feet – similar to how human beings swim)</p> <p>How is a duck adapted to do this?<br/> (It has webbed feet that allow it to swim more easily – like scuba divers who wear flippers)</p> <p>Ok, but how does it actually swim? What causes the duck to move forwards through the water?<br/> (This is where it might get tricky. The duck uses its own energy (that it gets from its food) to push its legs / feet backwards through the water. By pushing through the water the duck is exerting a force on the water. The water pushes back!)</p> <p>The duck is pushed forward by the water with exactly as much force as the duck pushes the water backward</p> | 10 (25)            |

| Slide # | Subject      | Description and script                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Time (total) /mins |
|---------|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
|         |              | <p>with.</p> <p>This can be stated as '<u>every action has an equal and opposite reaction</u>' - otherwise known as Newton's Third Law of Motion.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                    |
| 8-9     | Case studies | <p>How does a sailing ship use fluid drag?</p> <p><i>Similar to before but, in this case, there is no 'effort' being exerted by the sails of the ship (unlike the feet of the duck). In this case the force comes from the air, blown by the wind, being caught in and dragging on the sails. Once this has been established, you might highlight to the pupils that...</i></p> <p>In the previous example, the duck has to use energy so that it can swim but the sailing ship does not. While the duck has to constantly consume more food to carry on swimming, the energy required for the ship to move is free and <u>renewable</u>.</p>                                                                                                                                                                                                                                                                                 | 5 (30)             |
| 10-11   | Case studies | <p>How does a wind turbine use fluid drag?</p> <p><i>Similar to the sailing ship, the force on the blades of a wind turbine comes from the drag or air resistance as the wind blows past them. There are key differences here though...</i></p> <p>The wind turbine spins (or rotates) rather than moving in a straight line (like a duck or a ship). This happens because the blades are all attached to a central shaft or axle so the force from the air is directed into causing it to rotate. The blades are angled and shaped so that a greater drag force is created in one direction (e.g. clockwise vs anti-clockwise).</p> <p>Much like the sailing ship, the movement of the wind turbine is 'free' but, rather than the energy being used just to create movement, we are able to convert and capture the <u>kinetic energy</u> in the wind into <u>electrical energy</u> that we can then use in other ways.</p> | 5 (35)             |
| 12-13   | Case studies | <p>How does an aeroplane use fluid drag?</p> <p>How aeroplanes fly is (weirdly!) related to both ducks and wind turbines.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 5 (40)             |

| Slide # | Subject     | Description and script                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Time (total) /mins |
|---------|-------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
|         |             | Like ducks, aeroplanes use their own energy from fuel to move them forwards (through either propellers or jet engines). Some of this energy is converted into <u>lift</u> by the wings because of fluid drag and the shape of the wings causing them to be a greater upward force.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                    |
| 14      | Evaluation  | <p>What have we learned?</p> <p><i>Activity:</i><br/> <i>Provide the worksheets to the pupils. Everyone should complete their own worksheet but they should be encouraged to discuss what they've learned in pairs or small groups. The worksheet asks the pupils to recall a number of the questions already discussed and to label pictures for each of the case studies showing the forces that cause them to move.</i></p>                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 15 (55)            |
| 15      | Wrapping up | <p>How can we use resistance to movement to create movement?</p> <p><i>Depending on time, you may wish to do this as another interactive segment or by providing the pupils with a summary...</i></p> <p>We can use resistance to movement to create movement because every force has an equal and opposite reaction...</p> <p>...a duck pushes on the water, with its webbed feet, and the water pushes back...</p> <p>...the wind is caught (or pushed back) by the sails of a ship, so the wind pushes the ship forwards...</p> <p>...the blades of a wind turbine get in the way of the wind, so the wind pushes the turbine blades around and around – from this we can make electricity...</p> <p>...and the engines of an aeroplane push it forwards, causing its wings to push on the air, which in turn pushes the wings upwards and allows the aeroplane to fly!</p> | 5 (60)             |

## Media

Duck Feet Under Water, (2014), YouTube user: JasminesMom4691

<https://youtu.be/VXrOdyRKoF4>

In this clip you can see how the duck moves its feet to push itself forwards through the water. By using one foot or the other the duck can turn left or right. If you look closely you can see how the webbed parts of each foot flexes (like a ship's sail) when the duck is pushing with it. This actually makes it more efficient than if the web was much stiffer.

The Physics of Sailing, (2008), YouTube user: KQED

<https://youtu.be/yqwb4HlrORM?t=4m38s>

From 4m38s to 5m53s shows a really clear illustration of the forces on a modern sailing yacht. A bit more complicated than a traditional sailing ship where the sails tended to point mostly forwards. In this case, the force on the sail would drag the yacht sideways but is balanced by the force on the keel under the water. This leaves the resultant force that pushes the yacht forwards.

Wind turbine aerodynamics, IN 60 SECONDS, (2017), YouTube user: DOB-Academy studio

<https://youtu.be/uK7ubLWvnbE>

In this short clip it is shown how similar the design of wind turbine blades and aeroplane wings are, in that they both have cross-section profiles designed to generate lift. It illustrates how this lift force is used to cause rotation of the wind turbine and how the blade profile is varied along its length for maximum efficiency for the oncoming air flow.

How Does A Wing Actually Work? (2012), YouTube user: Veritasium

<https://www.youtube.com/watch?v=aFO4PBolwFg>

There are actually two theoretical explanations for the lift that a wing generates, one based on pressure and Bernoulli's equation and one based on Newton's Third Law. This clip quickly illustrates how both are correct! From 1m04s to 1m32s gives a quick summary of the Newtonian approach.

Trafalgar duck, (2009), Flickr user: Gagilas

<https://www.flickr.com/photos/gagilas/3624873763/>

Hanse Sail 2011 – Fregatt-Volschiff “Shtanart”, (2011), Flickr user: Yetdark  
<https://www.flickr.com/photos/yetdark/6386383615/>

Wind turbine, (2018), Flickr user: ako\_law  
<https://www.flickr.com/photos/114240786@N08/41532254121/>

F-GKXI, (2015), Flickr user: airlines470  
<https://www.flickr.com/photos/airlines470/16244766059/>

## Teacher's handout

"To every action there is always opposed an equal reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts."

- Isaac Newton, 1687

In modern language: "Every action has an equal and opposite reaction."

Newton's Third Law of Motion allows for a huge variety of ways for engineers to exploit forces of nature, such as the wind, or to exploit our physical environment, such as the air or water around us. Nature has been exploiting Newton's Third Law for far longer than human beings have... and from long before it was called Newton's Third Law!

It's common for Newton's Third Law to be taught on the basis of solid (and often static) objects – e.g. a block resting on the ground applies a force to the ground, which results in an equal and opposite force from the ground to the block (hence the block does not sink or float, it just stays where it is). In this case the force is equal to the block's weight, or the force of gravity acting on its mass ( $m_{\text{block}} \times g$ ).

However, the same principle applies in fluid mechanics and its sub-disciplines of hydro-dynamics (that concerns the movement of water) and aero-dynamics (that concerns the movement of air). Engineers typically refer to the applied force and the resultant force. If the resultant force is defined as the one that causes the motion of interest (such as the movement of the duck or the ship; the rotation of the wind turbine or the increase in altitude of the aeroplane), then the four case studies can be summarised as follows:

| Case study            | Applied force                                                                                                                                                                  | Resultant force                                                                                                                                      |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Duck swimming         | The duck pushes backwards on the water through its webbed feet                                                                                                                 | The water pushes forwards on the duck through its webbed feet                                                                                        |
| Ship sailing          | The ship pushes backwards on the air through its sails<br><i>This may seem counter-intuitive but if the sails were not present then the air would carry on moving forwards</i> | The air pushes forwards on the ship through its sails                                                                                                |
| Wind turbine rotating | The wind turbine blades push (mostly) either clockwise or anti-clockwise on the air due to their shape                                                                         | The air pushes (mostly) anti-clockwise or clockwise on the blades and the turbine rotates because the blades are attached to a central axle or shaft |
| Aeroplane climbing    | The plane pushes its wings forwards through the air using its engines...<br>...the wings push (mostly) downwards on the air due to their shape                                 | The air pushes (mostly) upwards on the plane through its wings                                                                                       |

The resultant force causes motion according to Newton's Second Law of Motion, which states that the rate of change of velocity (or the acceleration) of an object is directly proportional to the ratio of the force to the object's mass ( $F = m \times a$ ). Using the example of the sailing ship, this relationship can be experimentally explored in the classroom using a simple set up involving a reusable hull (such as plastic bottles) with interchangeable sails (that could be made of different sized pieces of paper) and a desk fan. The greater the size of the sails, the greater the air resistance and therefore the greater the acceleration of the ship. A plastic tray full of water could be used for the sailing trials and a stopwatch used to time how long it takes for the ship to cover a fixed distance measured by a ruler. The ship that covers the distance in the shortest time has the highest acceleration and therefore the greatest force on its sails.

It's sometimes said that engineers exploit natural resources for our benefit but this misses a key point. What's really important is for engineers (and everyone else) to learn how to sustainably use the resources around us. This often means finding renewable sources of energy. Sustainable development is so important to engineers that it's a required competence under the UK Standard for Professional Engineering Competence – the standard that professional engineers and technicians (CEng, IEng and EngTech) must meet:

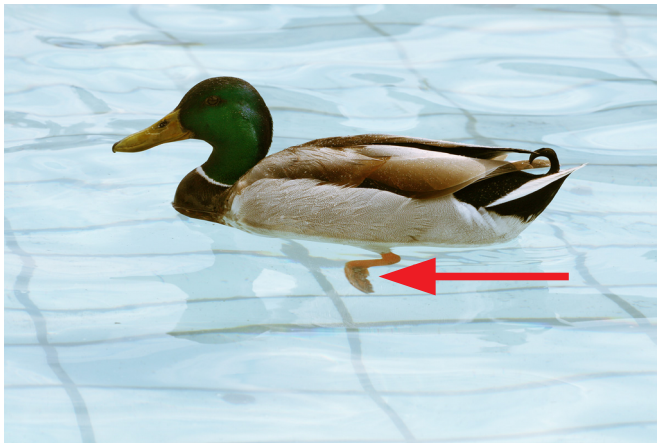
<https://www.engc.org.uk/ukspec> (competence E3)

The examples of both the duck and the aeroplane are (arguably) unsustainable in that they both need to consume more resources (food or fuel) to keep on swimming or flying. Human beings are the same (but let's not get into that philosophical debate). However, a sailing ship or a wind turbine uses energy that is freely available (i.e. the energy in the wind that is driven by thermal energy from the Sun). Other examples include tidal turbines (that make use of the energy provided by the motion of water due to the Moon's gravitational pull), solar panels (that make use of the light energy provided by the Sun) and hydroelectric dams (that make use of the potential energy provided by captured rain water flowing downstream due to the force of the Earth's gravity).

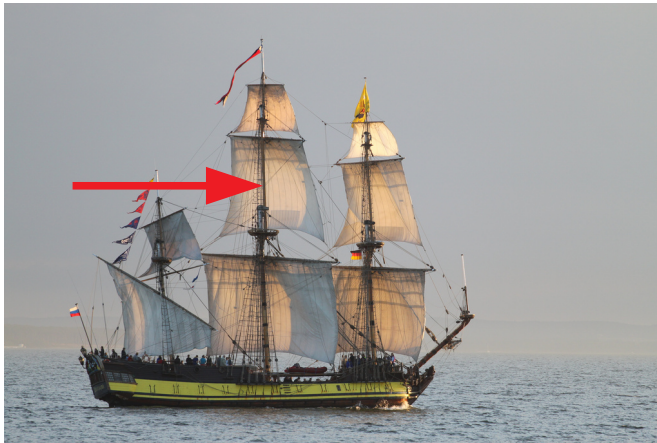
## Evaluation assessment

Worksheet questions (and suggested answers – teachers may adapt to fit National Curriculum terminology as required):

1. How does a duck move through the water?  
(By kicking its legs and feet – similar to how people swim).
2. How is a duck adapted to swim?  
(It has webbed feet that allow it to swim more easily – like scuba divers who wear flippers).
3. Draw an arrow on the picture of the duck to show the direction of the force applied by the water on the duck as the duck pushes its feet backwards through the water.



4. Where does the duck get the energy it requires to move its feet and push on the water?  
(From the food that it eats).
5. Newton's Third Law of Motion. Complete the following sentence:  
Every action has an equal and opposite \_\_\_\_\_.  
(reaction)
6. Draw an arrow on the picture of the sailing ship to show the direction of the force applied by the air on the sails that causes the ship to move forwards.



7. Draw a curved arrow on the picture of the wind turbine to show the direction that it rotates (you can choose either clockwise or anti-clockwise). Draw one or more straight arrows on the picture to show the direction of the force applied by the air on the turbine blades that causes the wind turbine to rotate in your chosen direction.



8. Where does the energy come from that allows the ship to move forwards and the wind turbine to rotate?  
(From the wind).
9. Draw an arrow on the picture of the aeroplane to show the direction of the force that is caused by the engines that causes the aeroplane to move forwards. Now draw two further arrows on the picture that show the direction of the air flow towards the wings and the direction that the wings cause the air to take. Finally, draw an arrow that shows the direction of the force applied by the air on the wings that causes the aeroplane to climb.



10. Where does the energy come from that allows the aeroplane to move forwards?  
(From its fuel).