STEM ACTIVITY 5
TEACHER NOTES

HELICOPTERS

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EQUIPMENT REQUIRED PER PAIR OF STUDENTS:

- A motor mounted on a battery box and assorted plastic propellers (see Technician notes)
- Two thin 8 cm circular discs, propeller adaptor and two nuts (see Technician notes)
- A top-pan balance reading capable of reading to 0.1g or better
- A tape measure or ruler
- Scissors
- Marker pen
- Protractor
- Safety goggles

PREPARATION REQUIRED

Before carrying out the activity you may need to download the accompanying video: *The Jet Age and Helicopters*. For each pair/ group of students you will need to cut out a few discs of aluminium foil and mount a battery box to a motor and two nuts onto a propeller adaptor (see technician notes).

HEALTH AND SAFETY NOTE

THE PLASTIC AND THIN ALUMINIUM PROPELLERS USED IN THIS ACTIVITY WILL ROTATE AT HIGH SPEED. PROVIDE SAFETY GOGGLES TO PROTECT EYES AND WARN STUDENTS NOT TO TOUCH THE TIPS OF SPINNING BLADES TO AVOID CUTS AND BRUISES.

PHYSICS CURRICULUM LINKS: CONTROLLING VARIABLES; FORCES AND MOTION

STEM ACTIVITY: SPINNING BLADES

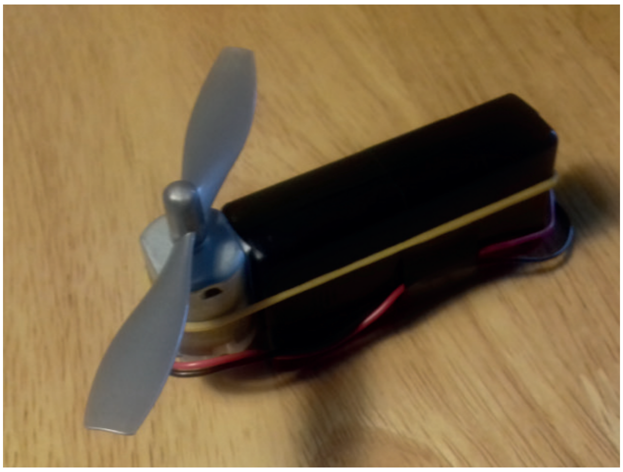
In this activity, students compare thrust forces produced by propellers with different designs and investigate how a blade's angle affects a propeller's performance.

Introduce the activity by playing the accompanying video: *The Jet Age and Helicopters*. Explain that a propeller consists of two or more twisted blades connected via a central hub to a motor on an aircraft. When the blades spin they push the air to create a force called thrust.

Students should follow the STEM instructions and investigate the upward thrust produced by a propeller attached to a motor mounted on a battery box (see figure 1). When they place the battery box on a top pan balance and switch it on, the reading on the top pan balance will reduce. They will also notice that the battery box will try to spin in the opposite direction to the propeller. They should use a loop of masking tape – sticky side out – to secure the bottom of the battery box to stop the battery box rotating (see next section for how this problem is solved in real helicopters). If, when they switch on their motor, the reading on the balance increases rather than decreases, they should take off the propeller and attach it the other way round.

FIGURE 1:
ROTOR UNIT

Each pair of students will need a motor mounted to a battery box with a propeller attached (see technician notes).



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To produce an upward thrust the propeller must push air downwards (Newton's third law). If this downward travelling air hits the top pan balance the reading will not be accurate. Make card and/or other materials available to allow students to come up with their own solutions. They could simply overhang the motor in an attempt to minimise the amount of air hitting the balance or decide to make something more elaborate such as an "air deflector" (see figure 2).

After taking readings with one propeller they should test the performance of the others. To change propeller they will need to pull the one attached to the motor off the motor shaft and push a new one on to the shaft. To ensure that they don't pull the motor off the battery box they should grip the motor in one hand and the propeller in the other. They can check that they have not dislodged the motor by spinning the blades by hand before switching on. If the blades hit the battery box they can try gently twisting the motor to make it vertical again or push it to raise its position on the battery to increase the gap between blades and box.

Once they have determined which of the propellers produces the most thrust they should consider how their designs vary. Differences that they can measure include number of blades, blade length, blade width (eg at widest point) and mass. Other differences could include blade smoothness, camber, twist and angle. They should come to the conclusion that there are too many design variables for their small sample size to come to a meaningful conclusion. To develop a better understanding of how different propeller design features effect thrust they should investigate one variable at a time.

FIGURE 2:
MEASURING THRUST

To minimise the air hitting the top pan balance students can overhang the motor.

A more effective method is to make an air deflector.

Blade		Reading on balance		
Number	Length	Motor off	Motor on	Change
2 blades	4.4cm	84.1g	74.8g	**9.5g**
2 blades	7.4cm	86.4g	76.4g	**10.0g**
3 blades	6.1cm	87.4g	72.9g	**14.5g**

Typical results for the propellers suggested in Technician notes.

FORCE UNITS

Although not needed for this activity students can convert their readings to newton (N) using:

Force (N) = Reading (g) ÷100

For the final part of the activity students should make a simple two-bladed propeller out of a thin aluminium disc and attach it using the propeller adaptor. When cutting it out they will need to leave the central part of the disc intact to form a hub. Have spare discs of aluminium available in case they accidently cut their propellers in half. They should then use a marker pen to draw an arrow on each blade to mark its direction of rotation, twist the blades and take measurements using a protractor and the top pan balance to determine which blade angle produces the greatest thrust (see figure 3).

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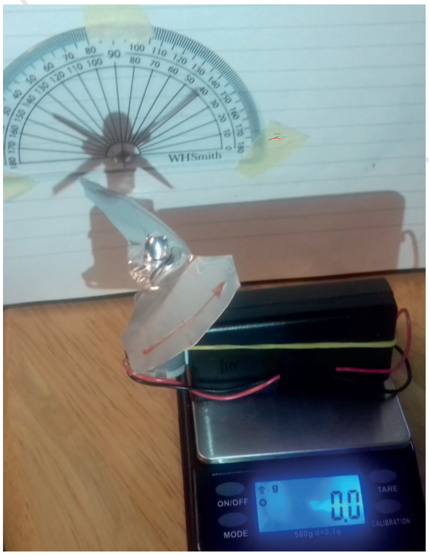
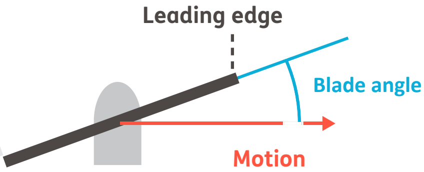
FIGURE 3:
ALUMINIUM BLADES

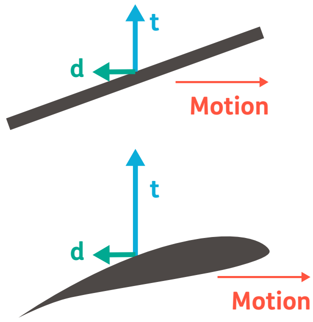


The two bladed aluminium propeller attached to the motor using a propeller adaptor. Both blades need to be twisted so that their leading edges point up.



Blade angle	Change in reading
0	0.0g
10	0.1g
20	0.7g
30	1.8g
40	7.2g
50	7.0g
60	5.7g
70	2.9g

FIGURE 4:
THRUST TO DRAG RATIOS



A flat blade has a poor thrust to drag ratio. A curved shape produces more thrust for a given motor speed and blade angle.

LINKING TO THE STEM ACTIVITY

Students may have noticed that the sound pitch of the motor changes at high blade angles. The motor pitch is lower because the drag forces on the aluminium blades slow the motor.

ABOUT PROPELLERS AND THRUST VECTORS

Depending on the students' age and attitude you may want to include more discussion about force components and how these relate to a propeller and rotor design.

The forces on propeller blades of constant cross-sections are shown in figure 4. The component of the force perpendicular to the direction of motion is useful; it contributes to the thrust produced by the propeller. The force component in the direction of motion of the blade is not useful. It is a drag force that will slow the motor. The amount of thrust that a blade produces for a given blade angle and motor speed depends on the shape of the blade. Propellers are usually designed to have a curved shape (an aerofoil) as these have a better thrust to drag ratio.

Different sections of a blade move at different speeds. The tip is furthest from the hub and so moves the fastest. For a blade with a constant cross-section this means that the tip will make a bigger contribution to the thrust. The uneven loading on the blade will cause it to bend and that could cause the tip to snap off. The propellers used in aeroplanes usually have a "twist" so that the load is spread more evenly across the length of the blade (see figure 5).

Aeroplane propellers produce a forward thrust force. The upward lifting force needed to get airborne is provided indirectly by the airflow over the wings (if the students have done STEM activity 1 you could link this to the requirement to throw the glider in order to make it fly). Helicopters have vertically mounted propellers known as rotors. A helicopter rotor provides a direct lifting force and so helicopters can take-off without a runway (see figure 6).

The helicopter rotor head however needs to be more complex than an aeroplane propeller hub. Rotor heads need to be hinged to allow the rotor blades to move independently of each other so that the rotor can provide both a vertical and a horizontal thrust force component (see figure 7).

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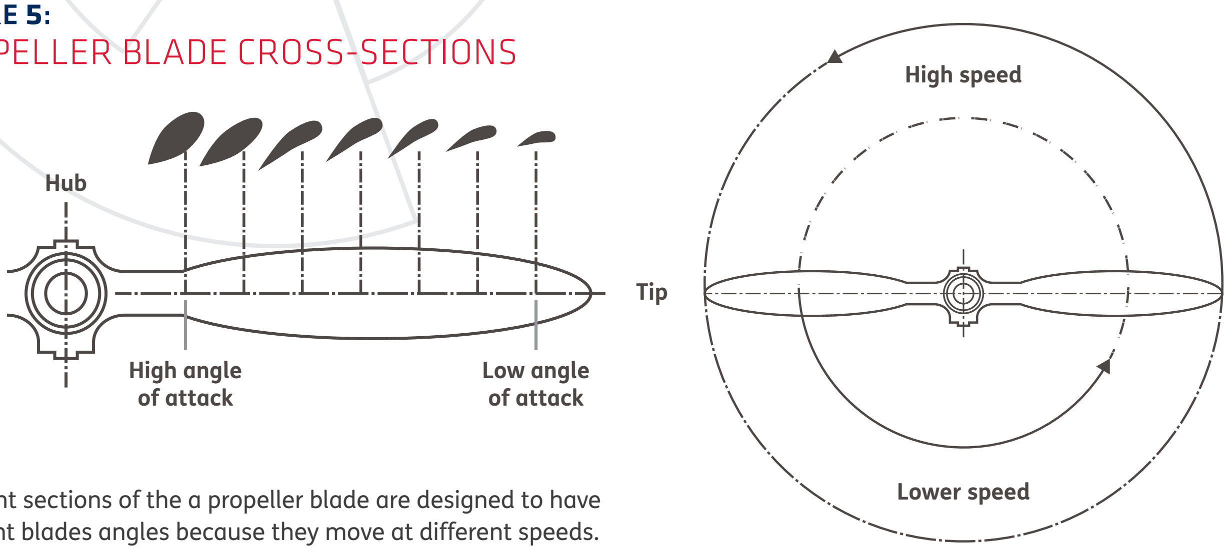
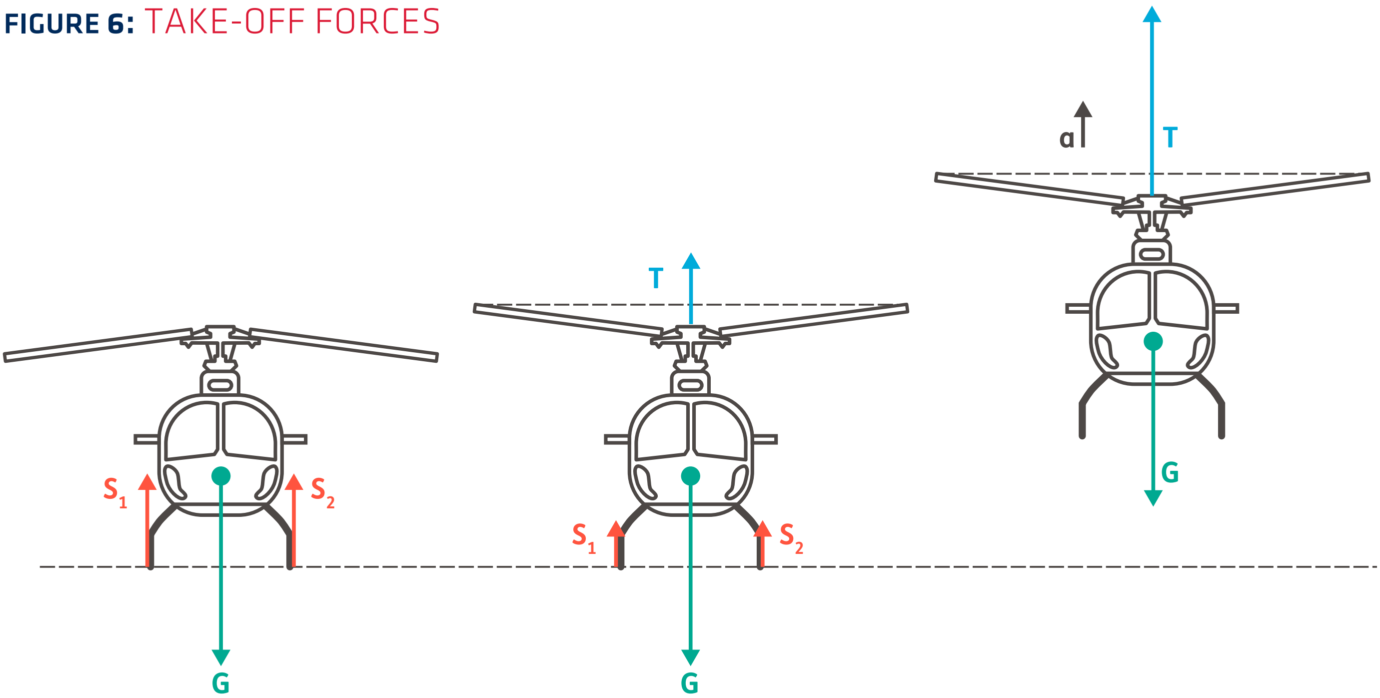
FIGURE 5:
PROPELLER BLADE CROSS-SECTIONS



Different sections of the a propeller blade are designed to have different blades angles because they move at different speeds.

FIGURE 6: TAKE-OFF FORCES



When the motor is off the gravitational force **G** is balanced by contact force due to the ground: S_1+S_2.

When the motor is on, the contact forces reduce because of the thrust force **T**.

If the thrust force is bigger than the gravitational force the helicopter will have an upward acceleration **a**.

LINKING TO THE STEM ACTIVITY

Explain to the students that the reading on the top pan balance reduces when the motor is on because the top pan balance measures the contact force: S_1+S_2

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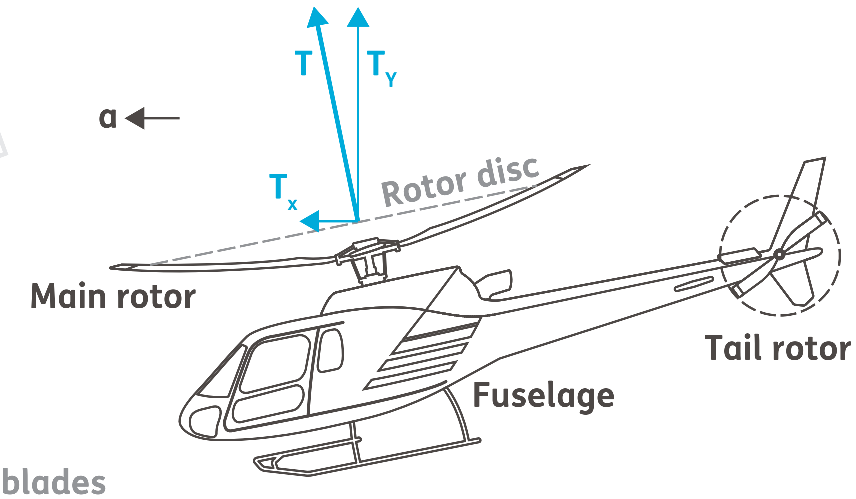
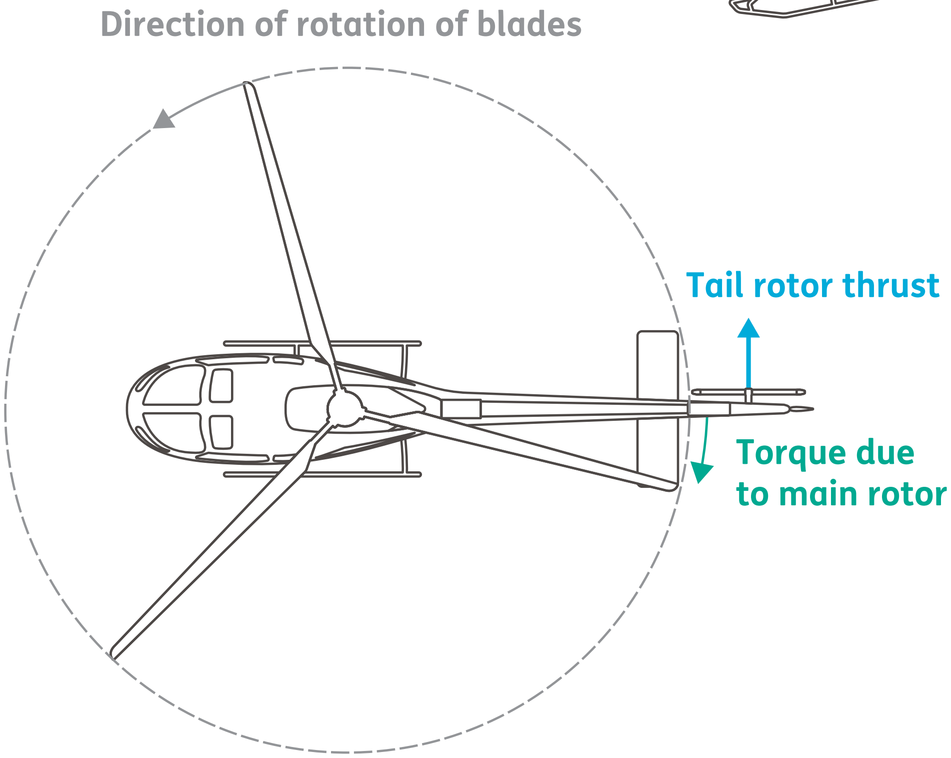
FIGURE 7: THRUST COMPONENTS AND TAIL ROTORS

In order to move forward the pilot needs to tilt the rotor disc to create a forward thrust component (T_x)





Helicopters usually have a tail rotor to stop the fuselage rotating

FURTHER INFORMATION

For more information about helicopter design see **bit.ly/RAF-Helicopters**. For more information about teaching force components see Supporting Physics Teaching (14-16): **bit.ly/RAF-Components**