



advanced air mobility

drones



urban air mobility

air  
taxis

**STEM LEARNING:**

**Advanced Air Mobility: Rubber  
Band Helicopter Engineering  
Challenge Student Guide**

[www.nasa.gov](http://www.nasa.gov)

# PART 1

Imagine looking out your window and seeing a taxi fly by. Or, imagine you could go into your backyard and a drone would be delivering food from a local restaurant. These may seem like something from a science fiction movie or cartoon, but it isn't as farfetched as you might think. Within the next few years, people will actually be riding in flying taxis! And, in some places, drones are already making deliveries.

With this revolutionary new type of aviation comes the need to monitor and control the airspace they fly in. NASA is working with its partners to develop a system called Advanced Air Mobility (AAM). This system helps monitor and control the movements of small, low-flying aircraft, such as drones and air taxis operating in both urban and rural areas. To minimize their environmental impact, these aircraft are electrically powered and use propellers to create both lift to move up and thrust to move forward.

In this activity, you will explore how propellers create lift and the resulting torque that is also created. You will be designing the body, or fuselage, of a helicopter to minimize the effect of torque.

Read through the background information below and answer the questions that follow it.

## BACKGROUND INFORMATION



Figure 1. The blades on a helicopter create lift that moves it upward. Credit: NASA/ Dan Casper

### Newton's Third Law of Motion

Sir Isaac Newton came up with three laws to describe the motion of objects. His third law states that for every action there is an equal and opposite reaction. We see this law in action frequently. For example, if an inflated balloon is released, the air comes out one end and the balloon moves in the opposite direction. The escaping air is the action, and the movement of the balloon is the equal and opposite reaction.

Newton's third law also applies to rotary winged aircraft, such as helicopters or drones, because their spinning blades create both lift and torque. The blades on a helicopter or drone create a downward force by pushing the air down. The equal and opposite force is the upward force of lift. Assuming lift is a stronger force than the gravity, it moves the aircraft up.

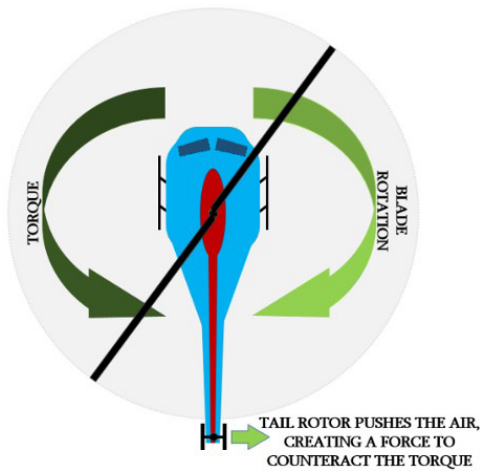


Figure 2. The force created by the tail rotor balances out the torque.

### Propellers

Unmanned Aerial Vehicles, or UAVs, usually fly below 400 feet, are electrically powered, and use rotating propellers to provide both lift and thrust. The propeller size varies according to the size of the aircraft. Small package carrying drones only require small, relatively slow propellers whereas larger air taxis require larger, faster rotating ones. Propellers on some larger aircraft are even capable of being rotated to provide lift like a helicopter's blades or thrust like an airplane's propeller.

### Torque

In addition to lift, a rotating propeller creates a force in the direction it rotates. According to Newton's third law of motion, there must also be an equal and opposite force. This force, called torque, acts in the direction opposite of the propeller's rotation. As shown in figure 2, when the blades rotate clockwise, the torque acts in the opposite direction, counterclockwise. If left unbalanced, the torque causes the fuselage of the helicopter to rotate. Engineers have devised several ways to compensate for torque. In the helicopter shown in figure 2, the tail rotor creates a force to balance out the torque which keeps the fuselage from rotating.



Figure 3. On some aircraft, the propellers can rotate to provide upward lift or forward thrust. Credit: NASA

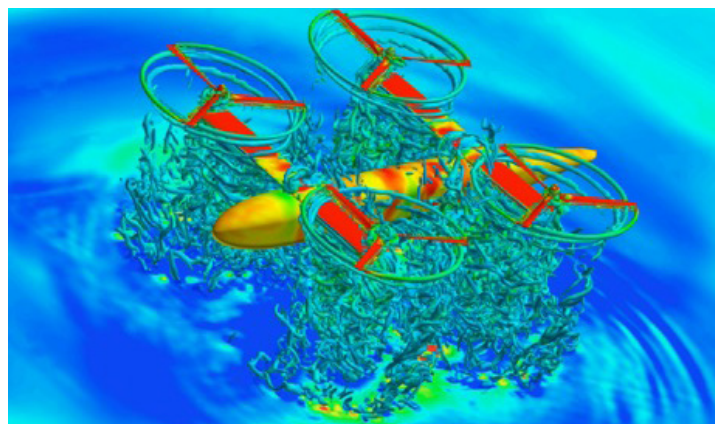


Figure 4. This computer simulation shows the movement of air caused by the rotating of a quadcopter's propellers. Credit: Seokkwan Yoon, NASA/Ames

Relative to the direction an aircraft is moving, propeller blades are angled. The angle, or pitch, of the blades determines the direction the air is pushed. The speed at which the propellers rotate, along with the pitch of the blades, determines how much air is pushed.

Reversing the direction of a propeller's rotation reverses the direction the air is pushed. Think of it like a screw—if it is turned in one direction, it moves down; and if it is turned the other way, it moves up.

## QUESTIONS

1. Explain how the plane shown in figure 5 demonstrates Newton's third law of motion.



Figure 5. Hot gases coming out the back of a jet create thrust. Credit: NASA

2. The V-22 Osprey is an aircraft that creates lift using two propellers that tilt to face upwards. Keeping in mind that propellers create torque, how is it possible that this aircraft can operate without a tail rotor? (Hint: Look closely at the propeller blades in figure 6 and think about what you learned about pitch in the Background Information.)



Figure 6. The V-22 Osprey can tilt its rotors up for takeoff and landing. Credit: U.S. Navy photo by Mass Communication Specialist 3rd Class Vincent E. Zline

## PART 2

### Build Your Helicopter

**Materials needed:** craft stick, propeller, paper clip, rubber band, piece of cardstock, pair of scissors, ruler, and tape.

#### Directions:

1. Gather all materials.
2. Bend paper clip so it forms about a 45 degree angle.
3. Using tape, attach paper clip to one end of the craft stick.
4. Attach propeller to other end of the craft stick.
5. Attach rubber band to both the propeller and the paper clip.
6. Cut out pieces of cardstock, one for each of the following centimeter (cm) dimensions:
  - a. 3 cm x 4 cm
  - b. 6 cm x 8 cm
  - c. 9 cm x 12 cm
  - d. 12 cm x 16 cm



Figure 7. Completed helicopter before attaching fuselage.

### Conduct Baseline Testing

In part 1 of this activity, you learned that there must be a force counteracting the torque created by the rotating propellers. The helicopter you just built doesn't have a tail rotor to create this counteracting force. Because your helicopter is so small and light, you will be using air resistance to counteract the torque.

If left unbalanced, the torque causes the craft stick to rotate, using too much energy and making it difficult for your helicopter to fly. So, you will be adding a fuselage in the form of a piece of cardstock. The size of your fuselage determines the amount of air resistance—the larger the fuselage, the more air resistance it creates.

#### Directions:

1. Wind the propeller clockwise about 20 rotations and let the propeller go while still holding the helicopter, noting which direction the propeller pushes the air.
2. Repeat step 1, but rotate the propeller counterclockwise this time.
3. For the remainder of this activity, always rotate the propeller in the direction that results in the propeller pushing the air downward.
4. With no paper attached to craft stick, wind the propeller 35 rotations and let the helicopter go.
5. Record what you observe.
6. Repeat steps 4 and 5 for a total of three trials.
7. One at a time, attach each piece of cardstock to the helicopter, wind it 35 times, let the helicopter go, and record what you observe. Conduct three trials with each sized piece of cardstock. After completing the trials, remove the cardstock before attaching the next piece.

#### Hypothesize:

How does the size of the fuselage (piece of paper attached to the craft stick) affect the performance of the helicopter? Why?

## PART 3

**Your Goal:** Modify your helicopter so that it will rise between 1.5 and 2.0 meters after being launched.

**Criteria:** Your helicopter should rise at least 1.5 meters and no more than 2.0 meters.

**Constraints:** After designing, building, and testing your prototype, you may change one factor.

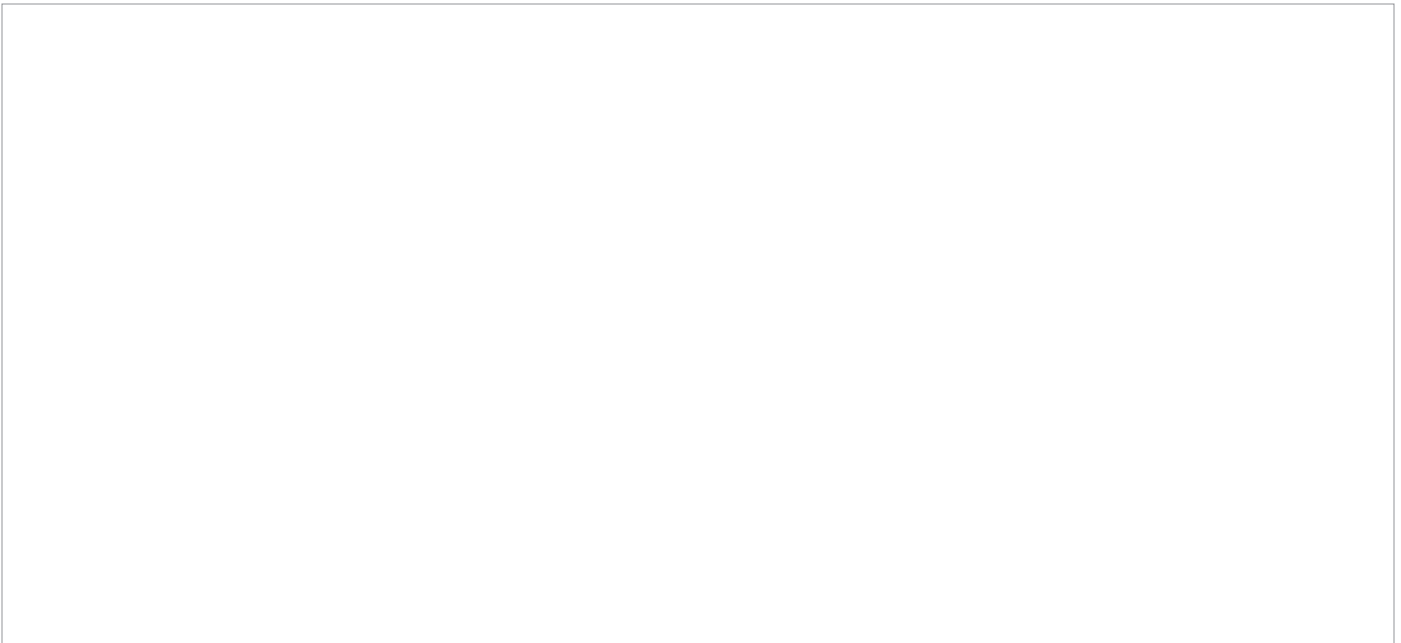
### Ask

What factors can be changed on your helicopter to affect how high it rises?

After you list the factors you can think of, brainstorm with your group or class to develop a list of factors that may be changed during the improve stage. List the factors your class brainstormed:

**Imagine / Plan**

Determine the size and shape of your fuselage (piece of cardstock) and how many times you plan on winding the propeller. Sketch your design below and label the size. Then, indicate how many rotations you will wind it:



Wind it \_\_\_\_\_ rotations.

**Create / Experiment****Directions:**

1. With your group, agree upon a design. Then, cut out the fuselage you planned and attach it.
2. Conduct up to three test flights to judge your helicopter's performance.

**Answer:**

How well did your helicopter perform and did it perform approximately the same during each test flight?

From the list of factors your class agreed upon, choose one factor that you think should be adjusted on your design. Which factor did you choose, how will you modify it, and why did you choose that factor?

**Improve**

Modify your design by changing only **one** factor.



### Share

Share your design with the class. Explain why you designed it as you did. Then, explain what factor you changed and why. After sharing, conduct your final flight.

Answer the following questions individually:

What worked well with your design?

What other factor(s) would you change if you could?

What design features did you see in the other teams' helicopters that you thought were especially good?

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