National Aeronautics and Space Administration

STEM LEARNING:

Advanced Air Mobility: Rubber Band Helicopter Engineering Challenge Educator Guide

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OVERVIEW

In this lesson, students build a rubber band powered helicopter and use it to explore Newton's third law and how it's seen with the torque caused by rotating propellers. Using the engineering design process, students will experiment with, test, and modify their helicopter to achieve a goal.

Objectives

Students will be able to:

- Explain how Newton's third law of motion plays a role in rotary-winged flight
- Describe how a propeller's design determines the direction of the thrust it creates
- Use the engineering design process to modify a design to achieve a prescribed goal

Student Prerequisite Knowledge

Before beginning this lesson, students should be familiar with:

- Newton's third law of motion

Standards

Next Generation Science Standards

Disciplinary Core Ideas

- MS-PS2-2 Motion and stability: Forces and interactions

Cross Cutting Concepts

- Systems and system models
- Cause and effect

Science and Engineering Practices

- Developing and using models
- Constructing explanations and designing solutions

Materials

Each group requires the following materials:

- Propeller
- Rubber band
- Craft stick
- Paper clip
- Tape
- Cardstock
- Scissors

Preparation

- [ ] Print one student guide for each group or provide access to it digitally
- [ ] Gather enough materials for each group
- [ ] Place two piece of painter's tape above the launch point to represent bounds of the helicopters' goal. One should be 1.5 meters above the launch point and the other should be 2 meters above the launch point.

Lesson Modifications

Materials:

- The propellers can be ordered fairly inexpensively online. Alternatively, a search of the internet will provide methods for making them. Please note that making them so that they work correctly is difficult.

Figure 1. This is an example of a propeller that works well for this activity.

- Reusing the propellers for this activity helps keep the cost down when doing this activity with multiple classes or during different years.
- Set aside a designated test area in the room for helicopter flights. Make sure students know that this is the only location in the room for launching the helicopters.
- Any type of stiff paper, including recycled non-corrugated cardboard, can be used in place of the cardstock.
- Rubber bands must be slightly tensioned when connecting the propeller to the paperclip. Also, thick rubber bands do not work well for this activity.
- An alternative for the goal is to have the students' helicopter fly up to the ceiling without touching it. If using this method, test that the ceilings are low enough that this is feasible.

Designs

- When improving their designs, there are several factors that students may change. These include, but are not limited to: how many times they wind the propeller, the area/shape of the fuselage, and the position of the paperclip.
- Students need to record any changes they make.

Grouping Students

This activity can be completed either as a team or individually, as time, materials, and preference allows. Grouping strategies during the engineering design challenge can be used to efficiently break up tasks, help promote student engagement, and appeal to a variety of learning styles and student strengths. Below are some recommended group roles for this activity. Students should understand that they need to be active participants in their group, not just doing their main task.

- **Project manager**—keeps the team on task, asks clarifying questions of the teacher, and is the team's spokesperson for class discussions.
- **Technical writer**—writes down test data, takes notes, and writes the final evidence and reasoning portions of the assignment (with input from the rest of the team).
- **Engineer**—collects materials and coordinates the building of the initial and subsequent design(s).
- **Test pilot**—winds the propeller, reports data to the team, and launches/recovers the helicopter.

BACKGROUND INFORMATION

Figure 2. The blades on a helicopter create lift that moves it upward. Credit: NASA/ Dan Casper

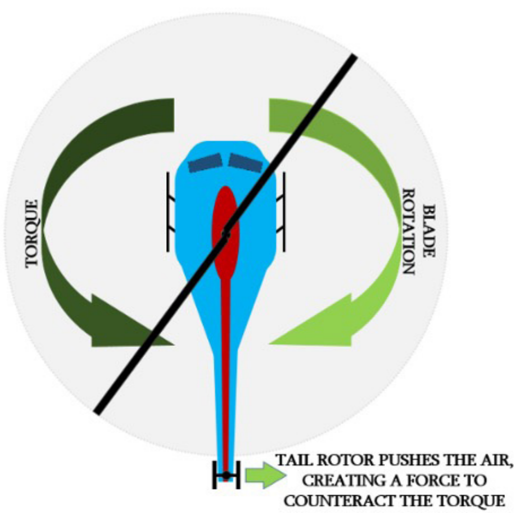

Figure 3. The force created by the tail rotor balances out the torque. Credit: NASA

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 the lift is a stronger force than the gravity, it moves the aircraft up.

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 3, when the blades rotate clockwise, the torque acts in the opposite direction, counterclockwise. If left unbalanced, the torque causes the body, or fuselage, of the helicopter to rotate. Engineers have devised several ways to compensate for torque. In the helicopter shown in figure 3, the tail rotor creates a force to balance out the torque which keeps the fuselage from rotating.

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 turned to point upward or forward to provide lift like a helicopter's blades or thrust like an airplane's propeller.

Figure 4. On some aircraft, the propellers can rotate to provide upward lift or forward thrust. Credit: NASA

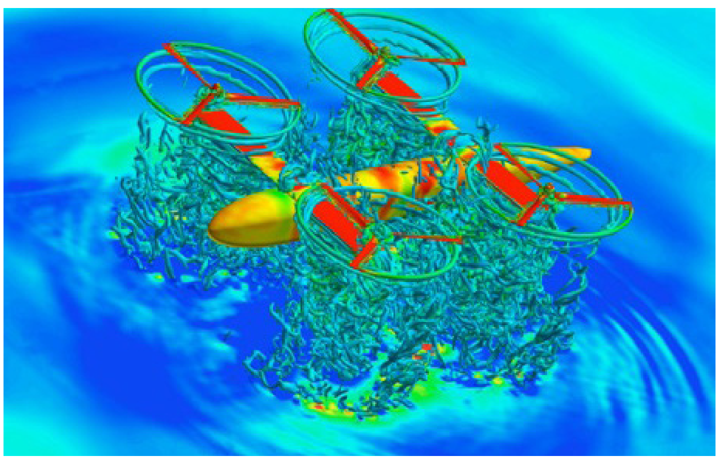

Figure 5. This computer simulation shows the movement of air caused by the rotating of a quadcopter's propellers. Credit: Seokkwan Yoon, NASA/Ames

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.

TEACHER DIRECTIONS

1. Use a warm-up or other method to engage students in a discussion about rotary-winged flight and how the principles of rotary-winged flight would apply to quadcopters.
2. Use the "Background Information" section of the student and educator guides to aide students in learning about Newton's third law, torque, and propeller pitch.
3. Host a class discussion to ensure every student understands how torque and propeller pitch affect rotary aircraft.
4. Have students build the helicopters and conduct the baseline testing.
5. Have students hypothesize how the size of the paper affected the flight of the helicopter.
6. Host a class discussion about how varying the paper size affected air resistance and how that affected balancing out the torque created by the propeller.
7. Introduce the design challenge to students, including criteria and constraints. Describe and assign group roles, if applicable.
8. Ask teams/students to generate a list of factors they could change on their helicopter and how each would affect its flight. Have a brief discussion to share and compile a list of the top 3–5 factors. Some recommended factors include: how many wind up turns, size of paper used for the fuselage, shape of fuselage, and tension caused by the angle of the paper clip.
9. Have teams/students sketch an initial design for their helicopter, specifying their proposed design for each of the top factors. If students are submitting one student packet per group, distribute additional scratch paper so that every student can sketch.
10. Have the group examine the designs their group members came up with. Then, discuss the pros and cons of each and pick one that they want to build.
11. Give students about 20 minutes to build and test their prototype.
12. After the first test, students can refine one factor of their design if they have time in preparation for the final class test.
13. Have students present their models, then test one at a time and record their final results.
14. After the final test, give students time to answer questions about their own models and evaluate what features from the other models worked well. Inevitably, there will be groups that will want to modify and test another iteration. You can choose whether or not you have time for this.

ANSWERS TO QUESTIONS (STUDENT GUIDE)

1. As a jet airplane flies, it burns fuel; these hot gases come out the back of the airplane. This is the action. And, according to Newton's third law of motion, there must be an equal and opposite force created. This equal and opposite force is the reaction, the thrust that propels the plane forward.

2. On the V-22, there are two rotors with three blades apiece. The pitch of each of the three blades on a rotor is the same. However, the pitches of the blades are opposite for the two different rotors. This means one has to rotate clockwise to create lift and the other has to rotate counterclockwise to create lift. By spinning in opposite directions, the torques created by the two rotors, while equal in magnitude, are in opposite directions. As a result, they cancel each other out and the plane's fuselage is not rotated by the torque.

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EP-2020-04-510-HQ