Paper Mars Helicopter

Overview:
In this activity, students will experiment with simple paper helicopter designs, engaging in the engineering design process that NASA engineers use every day.

Goals:
- Learn about Ingenuity, the Mars Helicopter.
- Learn how NASA engineers use the Engineering Design Process.
- Learn the roles of gravity and lift in how a helicopter flies.

Materials:
- Plain paper OR a copy of the template
- Scissors
- Measuring tape
- Pencil
- Student Worksheet
- (Optional) 3-meter length of lightweight ribbon and/or smartphone camera

Background:
Ingenuity is a small autonomous aircraft and was designed perform the first tests of powered flight on another world. It traveled to Mars with the Perseverance Rover in July 2020. Ingenuity performed the first powered flight on Mars on April 19, 2021. As of April 16, 2023 Ingenuity has completed a total of 50 flights. (updated flight information can be found at: https://mars.nasa.gov/technology/helicopter/#Flight-Log)

Video: Ingenuity First Flight: https://www.youtube.com/watch?v=wMnOo2zcjXA

Ingenuity's performance during these experimental flights will help inform decisions about the future use of small helicopters for Mars exploration. Future Mars helicopters could serve as robotic scouts, surveying terrain from above, or they could function as stand-alone science craft carrying instrument payloads.

Video: Learn how JPL engineers built a helicopter that could make the first powered flight on mars: https://www.youtube.com/watch?v=vpBsFzjyRO8

Designing a helicopter to fly on Mars was no small task. The Mars atmosphere is only 1% the density of Earth's atmosphere, so generating enough lift to overcome the gravity of Mars is a challenge. The helicopter had to be lightweight with extremely fast rotors to be able to generate enough lift. Though a full outdoor test couldn't be done on Earth, engineers were able to simulate conditions on Mars inside a test chamber at NASA's Jet Propulsion Laboratory in Southern California. To do this, they offset Earth's gravity by attaching tethers to the helicopter that support about 62% of its weight. Then, they performed flight tests inside a vacuum chamber that pumped out approximately 99% of the air, leaving a very thin atmosphere. Months of design, testing, redesign, and retesting went into the development of the Ingenuity Mars helicopter.

Procedures:

1. Have students begin by filling in the What I Know column of the “Helicopters” KWL chart on their worksheet.
2. Lead a group discussion: Ask students to describe how a helicopter flies. Elements of their description should include fast-moving, horizontal, rotary blades.
3. Have students fill in the second column of their KWL chart by writing down questions they have about helicopters.
4. Explain that the rotary blades are slightly angled so they can push against the air and lift the helicopter off the ground.
5. Ask students what else rotates and pushes against air (e.g., a fan). Ask students to compare and contrast a fan with a helicopter. For example, both move air in similar manners, but the helicopter moves a large volume of air downward while a fan usually moves a smaller volume of air toward us.
6. Explain that a helicopter moves so much air with its large, fast-moving blades, that the force of the blades against the air can overcome the weight of the helicopter and push it up off the ground. The helicopter is working against the force of gravity – which is constantly pulling the helicopter down toward the ground – and generating an upward force called “lift” by rotating its blades through the air. When the force of lift is greater than the force of gravity, the helicopter rises from the ground and flies.
7. Ask students if a helicopter might fly differently on the Moon or Mars and why. Note: The Moon doesn’t have an atmosphere in which to generate enough lift to fly. Mars has a very thin atmosphere that may be able to support a small helicopter with very fast-moving blades. NASA’s Mars Ingenuity helicopter was designed to test if this is feasible. Ingenuity is a technology demonstration. In other words, the goal is to see whether it can fly on the Red Planet and study how the design could be improved for a future Mars helicopter. Ingenuity arrived on Mars on Feb 18, 2021.
   Video: First Flight: https://www.youtube.com/watch?v=wMnOo2zcjXA&t=5s
8. Explain to students that engineers had to do a lot of testing to figure out what design worked best. Show students this video about testing Ingenuity at NASA’s Jet Propulsion Laboratory:
   Video: Footage of tests of the Ingenuity Mars helicopter at NASA's Jet Propulsion Laboratory in Southern California. Credit: NASA/JPL-Caltech
   https://www.youtube.com/watch?v=nAQxNd3uBN0&t=1s

   Explain to students that they will now experiment with building a paper helicopter and try to create the best design.
9. Have students cut along the solid lines of the helicopter template.
10. Have students fold the propeller blades, A and B, in opposite directions along the dashed lines. The C and D panels fold toward the center, and E is folded upward to give the body of the helicopter rigidity and lower its center of gravity for more stable flight.

11. Have students do a test flight by standing up, holding the helicopter by its body, raising it to shoulder height and drop it. Ask them: What do you observe? Which way do the blades turn? Have students hold the helicopter as high as they can and drop it. How does the performance change?
12. Ask students what they might change about their helicopter to affect its performance. Encourage them to make one change to their helicopter and do another drop. If students have a hard time thinking of changes, suggest they try making one more fold on the bottom of their helicopter, or try shortening or changing the shape of the blades. How does the performance change? Why does the chosen change have this effect? Have students share their changes and results.
13. Have students choose one of the following challenges and design a helicopter to meet that challenge:
    - How can you make their blades turn faster or slower?
    - How can you make the blades turn in the opposite direction?
    - How does a different kind of paper affect performance?
    - How big of a helicopter can you make that will still work?
    - How small of a helicopter can you make that will still work?
    - How do helicopters with different blade sizes compare in performance? What size works best? How do you define "best performance"?
14. Discussion:
    - Which helicopters reach the ground sooner: those that rotate faster or slower?
    - How does the speed of rotation affect the flight of a real helicopter? How might this be important when designing a helicopter for Mars?
    - How was your experience designing and testing a paper helicopter similar to how NASA engineers designed and tested the Ingenuity Mars helicopter?
15. Have students complete the What I Learned column of their KWL chart by filling in things they learned about helicopters in this activity.

Extension:
1. Have students investigate how the height the helicopter is dropped from will affect the number of rotations the blades make.
2. Ask students what happens to the helicopter when they drop it from higher locations. Most students should say that the blades rotate more.
3. Ask students to drop one of their helicopters and try to count how many times the blades rotate. It's impossible! Ask how they might solve the problem of counting rotations. Older students may have smartphones and be able to record a slow-motion video. Younger students may be stumped by the challenge.
4. Have students with access to a slow-motion video proceed in that direction. Have other students attach a straight ribbon to the bottom of their helicopter, stand on the end of the ribbon to hold it securely in place on the floor and drop their helicopter as before. Once the helicopter comes to rest on the ground, have them count the twists in the ribbon to determine how many rotations their helicopter made.

5. Have students design an experiment that will allow them to predict the number of spins their helicopter will accomplish from an unknown height. Ask students to measure several heights to drop from, using a measuring tape or nonstandard unit of measurement. Have them start dropping from the lowest point possible – usually about two feet from the ground – and recording the number of turns. Have them make a t-chart to record the distance they dropped from and the number of turns.
6. Have students repeat measurements for a variety of heights that they can easily reach.
7. Have students graph their results.
8. Have students add the height of a step stool or stairs to the height they can reach and use their graph to estimate the number of turns their helicopter will achieve on a drop from that height. Have older students develop a rule for computing the number of turns from a given height.
9. After they've recorded their estimate, have students get on the step stool or stairs and drop their helicopter. They will need a peer or family member to hold the bottom of the ribbon steady on the floor.
10. As time permits, have students experiment with different helicopter designs and count and graph rotations. What designs rotate slowest and which rotate fastest?

Adapted from the following lesson:

- Make a paper Mars Helicopter: https://www.jpl.nasa.gov/edu/teach/activity/make-a-paper-mars-helicopter/
- 4-H Aerospace Lesson Round & Round: https://fyi.extension.wisc.edu/wi4hpublications/files/2015/10/Round.pdf

Learn more about Mars Exploration and the Ingenuity Helicopter:

- NASA Mars Exploration Missions : https://mars.nasa.gov
- Mars Ingenuity: https://mars.nasa.gov/technology/helicopter/#helicopter