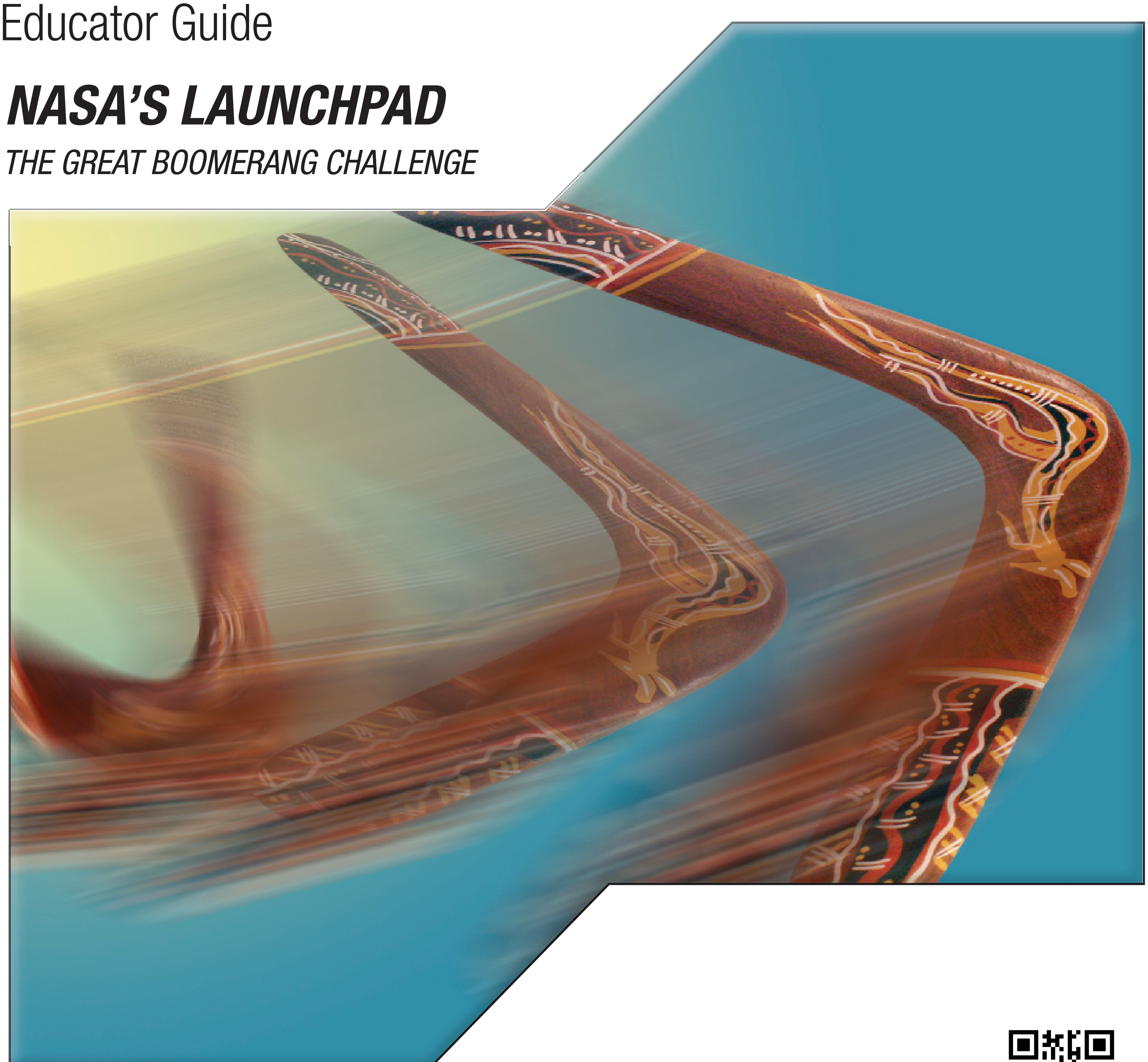
National Aeronautics and Space Administration

NASA eClips™

Educator Guide

NASA'S LAUNCHPAD

THE GREAT BOOMERANG CHALLENGE



Partner

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https://nasaeclips.arc.nasa.gov/

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NASA eClips™

The Great Boomerang Challenge

NASA LAUNCHPAD

Grade Level:
9-12

Subject:
Physical Science
Physics

Teacher Preparation Time:
30 minutes

Lesson Duration:
One 25-minute class and three 50-minute classes

National Standards:

Next Generation Science Standards (NGSS)

Physical Science

- Motion and Stability: Forces and Interactions

Science and Engineering Practices

- Asking questions (for science) and defining problems (for engineering)
- Constructing explanations (for science) and designing solutions (for engineering)

International Technology and Engineering Educator Association (ITEEA)
Design

- Students will develop an understanding of the attributes of design.
- Students will develop an understanding of engineering design.
- Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

Instructional Objectives:

Students will:

- work through the eight steps of the design process to complete a team challenge;
- research and explain how airfoil shape affects flight characteristics; and
- work through the steps of the engineering design process to complete a team challenge; and
- demonstrate and explain how basic aerodynamic forces, including those that arise from Bernoulli's Principle, influence the flight characteristics of their designs.

Lesson Overview:

Students think and act like engineers and scientists as they follow the eight steps of the engineering design process to successfully complete a team challenge. Within this task, students design, build, test, and re-design a boomerang. Once the boomerang is built, students explain and demonstrate how different forces affect its flight. Students research and explore basic aerodynamic forces and explain their applications to boomerang flight. Students compare what they observe with a NASA eClips™ video segment to learn more about how boomerangs react in a near zero gravity environment.

To complete this lesson, students must have a basic understanding of vectors.

Icons flag four areas of interest or opportunities for teachers.

- **Technology** highlights opportunities to use technology to enhance the lesson.
- **Resource** relates this lesson to other NASA educator resources that may supplement or extend the lesson.

Materials List:

Per student

- Secondary Engineering Design Packet available at

  https://nasaeclips.arc.nasa.gov/resources/download/45

- Copy, on cardstock, the four wing boomerang found at this link

  https://www.nasa.gov/sites/default/files/atoms/files/boomerang.pdf

- scissors

Per group of three - construction materials for the boomerang

- sheets of craft foam (foam with adhesive backing preferred. Craft foam is available in local craft stores.)
- cardboard
- card stock
- glue or other adhesive
- metal duct tape (to add weight. Metal duct tape is available at local hardware stores.)
- regular duct tape
- permanent markers
- ruler or straight edge

- scissors or a craft knife
- computer with Internet access

Per class

- Tape measure of at least 5 meters
- Stopwatch
- String or rope with marks at every meter

Teacher Prep

Set up the test flight area in an inside area (such as a gym or open cafeteria) or outside on a field or basketball court. Use tape or chalk to mark the center launch location and to mark a one meter ring, two meter ring, and a three meter ring around the launch location by extending a rope or string with meter marks from the center-of-launch point.

Boomerangs

Boomerangs have been used as tools of war and hunting for over 20 millennia. It wasn't until the 1970's that boomerang throwing became an organized sport. Each year, competitors design and fly their boomerang creations in regional, national and international competitions. The boomerang has been associated with Australia and one might assume that they would be the most accomplished in competition but the United States has held the majority of championships since 1984 thanks in part to NASA technology. While boomerangs vary greatly in shape, they all have one thing in common; they are airfoils, like wings on a plane. NASA research on wing design has allowed boomerang designers like Ted Bailey to design and produce winning fliers. He credits NASA's technology reports with giving United States boomers a competitive edge.

Figure 1. Ted Bailey and some of the boomerangs he has designed. **Image Credit**: NASA

A boomerang is essentially an airfoil, a structure shaped to produce lift when moving in air. Just like the wing of an airplane, a boomerang's upper and lower surfaces

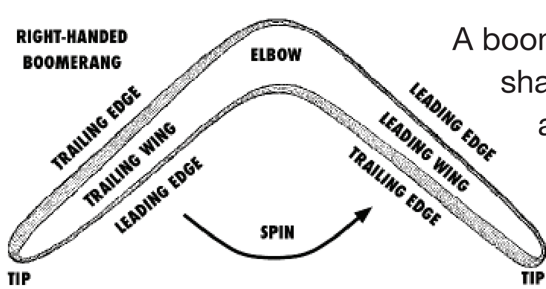

Figure 2. Parts of a boomerang.
Image Credit: http://www.boomerang.org.au

can be shaped to give it certain flight characteristics. The forces that act on a wing in motion relative to the air are called aerodynamic forces. These forces dictate the flight characteristics of any wing, including a boomerang. The basic aerodynamic forces are lift, drag, thrust and weight.

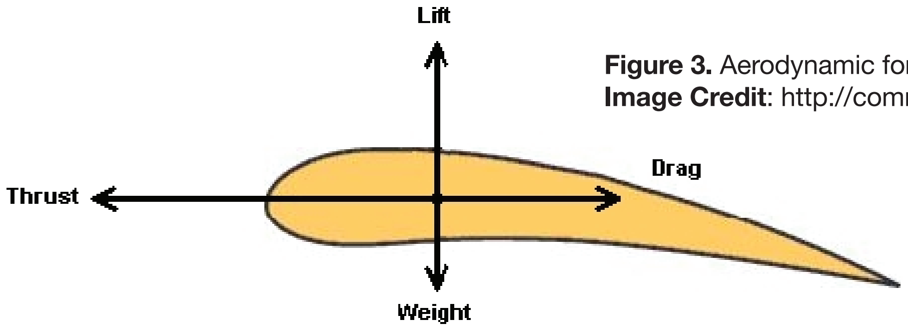

Figure 3. Aerodynamic forces.
Image Credit: http://commons.wikimedia.org

Weight is the force generated by the gravitational attraction of Earth on an object. For a wing, weight is a force which is always directed towards the center of the earth. The magnitude of this force depends on the mass of the wing.

For a wing to travel through the air a force must be generated to overcome weight. This force is called lift. Lift is generated as the wing moves through the air. Air flows over the wing and is forced downward. Newton's Third Law of Motion states that for every force created there is always a counterforce created in the opposite direction. Air that is forced down by the wing pushes back up creating the lift on the wing. Lift is directed perpendicular to the direction of flight.

The angle that the wing makes to the oncoming airflow, termed the angle of attack, also influences the lift. As this angle increases, more air moves downward, increasing the amount of lift. Lift continues to increase until the angle of attack is 15°. At angles of attack above this value the lift begins to decrease.

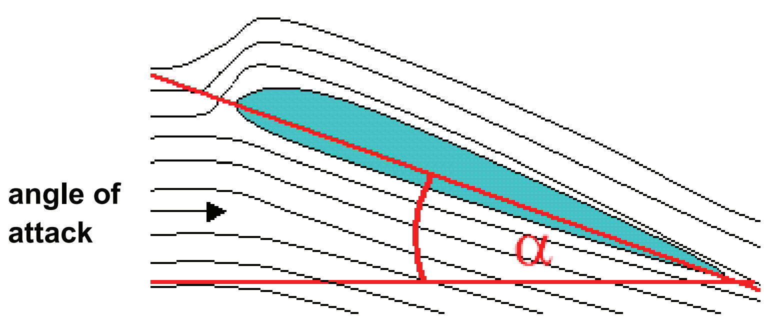

Figure 4. Airflow over a wing and angle of attack.
Image Credit: http://commons.wikimedia.org

As the wing moves through the air, another aerodynamic force acts upon it. The air itself resists the motion of the wing. This resistance force is called drag. There are many factors that affect the magnitude of the drag force including the shape and speed of the wing. The direction of drag is always opposed to the flight direction.

To overcome drag, the wing must somehow be propelled by a force called thrust. Thrust is a mechanical force. In an airplane, thrust is generated most often by an engine. The engine takes in air, accelerating it in the opposite direction that the nose of the airplane is pointing. This results in the airplane accelerating in the opposite direction. With a boomerang, thrust is produced by a person throwing it.

Other factors must also be taken into account when designing a boomerang. The designer must consider variables such as number of blades, length of blades, blade thickness and camber. Camber is the difference between the top and bottom curves of an airfoil. In Figure 3 above, notice that the curve of the top of the airfoil is different than the curve of the bottom of the airfoil. The designer must even decide if the boomerang is going to be thrown left handed or right handed because, as indicated in Figure 2, the leading and trailing edges of the boomerang will be different.

For more background on Newton's Laws and flight testing visit
https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/newtons-laws-of-motion/

5E Inquiry Lesson Development

ENGAGE - Engineering Design Process, Boomerang Challenge, Boomerang Research (25 minutes)

Explain that students will be working in teams of three to solve a design problem. Show students the graphic of the engineering design process found on page 1 of the Secondary Engineering Design Packet. Introduce the steps the students will be using to solve their boomerang challenge.

1. Identify the problem.
2. Identify criteria and constraints.
3. Brainstorm possible solutions.
4. Select a design.
5. Build a model or prototype.
6. Test and evaluate the model.
7. Refine the design.
8. Share the design.

1. Introduce students to the challenge, have them read page 2 of the Design Packet and then break the students into groups of three.

   Boomerang Design Challenge: Design and construct a returning boomerang which will allow for the greatest flight distance relative to the accuracy of boomerang return.

2. In their groups, have students discuss what they need to know to complete this challenge. Explain that they are continuing to identify the problem and addressing its criteria and constraints. Ask students to define the terms criteria and constraints, then have the students list questions so that they will know the criteria and constraints for the present challenge.
   a. Criteria – Criteria are conditions that must be met to solve the problem.
   b. Constraints – Constraints are anything that might limit a solution, such as cost, availability of materials, and safety.

3. Ask students to create a list of questions relating to the problem to research. The research will be done for homework or in the next class. Some questions students might ask include:
   a. What shape is a boomerang? *Have students conduct research on the Internet to find various boomerang designs.*
   (**RESOURCES**) Background information about how NASA technology has been used in boomerang design can be found at
   https://ntrs.nasa.gov/api/citations/20020083196/downloads/20020083196.pdf
   b. How can a boomerang's flight path be adjusted? *The flight path of a boomerang may be adjusted by bending the arms of the boomerang up or down, by twisting the arms of the boomerang, or by adding weight to the boomerang either on the arms or in the middle.*
   c. What is flight distance and accuracy of return? *Flight distance is the furthest distance away from the launch point that the boomerang travels before it begins its return flight to the launch site. Accuracy of return is how close the boomerang is to the original launch site when it lands*.
   d. What materials are available? *Give students the list of materials from the materials section. The boomerang must be constructed of no more than a 21.6 cm x 27.9 cm (8.5 in x 11 in) sheet of material. The total amount of metal tape allowed is limited to 60 centimeters*.
   e. How will the boomerang designs be evaluated? *The boomerang that travels the furthest and returns closest to the launch point will be the winning boomerang. Use the following formula to score the flight*:

Score = Furthest distance traveled ÷ distance from launch point to the landing point

For example, the score for a boomerang that traveled a distance of 3.5 meters away from its launch and then landed just inside the 1 meter ring is:
Score = 3.5/.9 = 3.9

4. What are the rules that all teams must follow?
Have students establish rules BEFORE beginning the challenge. Some suggested rules might be:
   a. All teams will build a boomerang starting by cutting out and tuning the four- armed boomerang paper framework supplied by the teacher.
   b. Final boomerangs may be made in any design agreed on by the team.

5. Team roles may include the following.
   a. One person serves as the *Research/Design Specialist*. This person locates sources of boomerang designs, leads the team to select the best design, and documents results of test flights.
   b. A second person is the *Materials and Construction Specialist*. This person leads the team in the construction and tuning of the boomerang, and records the steps used during the design and building of the boomerang.
   c. The third person will be the *Flight Specialist*. This person uses knowledge of atmospheric conditions to plan and record the angle and direction of boomerang flight and actually throws and catches the boomerang.

   Have students complete a group and self-assessment to ensure that all students contribute to the project.

6. Ask students to **Brainstorm possible solutions**. Students should complete the **identify the problem**, **criteria and constraints**, and **brainstorm** in the Design Packet (or record this work in a science notebook). Encourage the use of illustrations and diagrams to help students document the engineering design process.

EXPLORE – Select, Build, and Test a Boomerang Design (50 minutes)
IMPORTANT SAFETY NOTE: Use caution when throwing and catching boomerangs and wear eye protection. Notice who is around you. Remember, YOU are the target. Research catching boomerangs.

1. Use the *Design Packet* to guide students through the next three steps of the engineering design process:

- **Select a design**
- **Build a model or prototype**
- **Test the model and evaluate**

2. Before students "Test the model and evaluate," have them discuss and develop a set of rules, or criteria, for testing the boomerang. Some rules might include:
   a. During the official testing period, the Flight Specialist must stay within the designated launch location.
   b. In order for a boomerang flight to count, its initial flight must be at least 3 meters from the launch area at the center ring.
   c. Each team will get three official trials. The scores of the three trials will be averaged to determine the final score for the team.

3. Budget time for student teams to test their boomerangs. After each test, students should record observations and make notes about how they tuned (adjusted) their boomerang. Student should record observations and notes in tables of their own design.

4. (**TECHNOLOGY**) If cameras are available, ask students to record the design/build/test process.

EXPLAIN - Bernoulli eClips™ Video, Student Research, Discussion of Aerodynamic Forces (20 minutes)

1. (**TECHNOLOGY**) Show the NASA eClips™ video segment *Launchpad: Bernoulli's Principle On-Board the International Space Station* (7:17) to the students. This segment can be found on the NASA eClips™ page of the NASA web site:
   https://nasaeclips.arc.nasa.gov/video/launchpad/launchpad-bernoullis-principle-on-board-the-international-space-station
   The video may be streamed or downloaded from the nasa.gov web site; a captioned version is also available at the nasa.gov site. This video may be streamed from the NASA eClips You Tube™ channel:
   https://youtu.be/J4WRd7OAt0A

2. Have students research the terms below and share definitions and diagrams with the class. Review the concepts of Bernoulli's Principle and its effects observed in the video segment.
   a. **aerodynamics** – Aerodynamics is the study of how efficiently air flows around an object.
   b. **airfoil** – An airfoil is a surface, such as a wing or propeller, designed to aid in lifting and controlling an aircraft by means of air currents.

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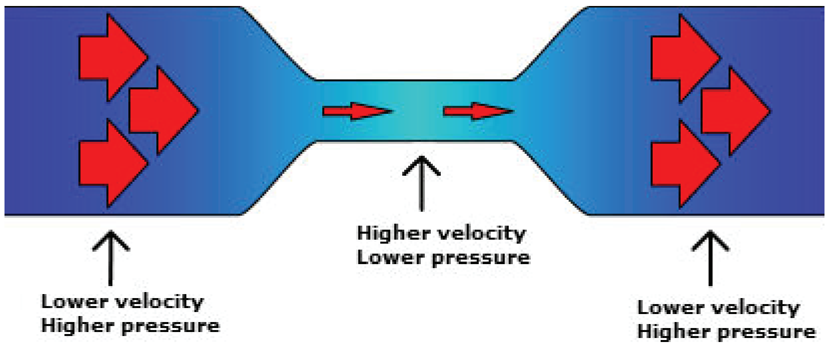
c. **Bernoulli's Principle** - Bernoulli's principle states that as the velocity of a fluid (such as air) increases, the pressure exerted by that fluid decreases.

Figure 5. Bernoulli's principle.



d. **camber** – Camber is the difference between the top and bottom curves of an airfoil. Airplane wings tend to have a longer curve on the upper than the lower wing surfaces (although the opposite is true of supersonic jets).
e. **drag** – Drag is the resistance to movement through a fluid.
f. **force** - A force is an action (such as a push or pull) or agent that causes a mass to accelerate, decelerate, or change its velocity. Note that it's possible for an objects to have several forces acting on it, with a net (total) force equal to zero.
g. **lift** – Lift is an upward force resulting from pressure differences (e.g. different pressures on the top and bottom of a bird's or an aircraft's wing moving through a fluid) due to the air above the wing traveling faster than the air below the wing, because the upper surface is longer than the lower surface.
h. **thrust** – Thrust is a force that propels an object.

3. Within groups, have students compare the proposed boomerang designs. Allow students to explain reasons for selecting particular designs using the aerodynamic terms discussed in class.

4. Ask students to answer the following questions related to Bernoulli's Principle and the forces of flight.
   a. At the beginning of the NASA eClips™ video you saw a demonstration involving a funnel, a balloon, and a rubber ball. Use Bernoulli's principle to explain why the ball does not fall out of the funnel when the funnel is inverted. (*The air escaping the balloon is moving quickly around the rubber ball while the air on the side of the ball opposite the funnel opening is not moving. According to Bernoulli's principle, the air on the opposite*

side of the ball from the opening is exerting more pressure than the air moving around the ball. The higher air pressure on the ball holds the ball in place.)

b. An aircraft sits motionless on a runway. If that plane starts to move down the runway, it means that there must be a force acting on it. Of the four main forces that act on aircraft, which one is most likely to cause the forward motion down the runway? (*The force of thrust is causing the aircraft to move*.)

c. Which of the four forces causes the airplane to become airborne? (*Lift causes the aircraft to become airborne*.)

d. Once the aircraft is airborne, which force opposes the force of thrust? (*The force of drag counters the force of thrust*.)

e. As the aircraft travels at constant velocity, it burns fuel, which decreases its weight. In response to this decrease, how might the aircraft respond? (*The aircraft will need less thrust to maintain its speed since the weight of the craft has decreased, thus thrust, drag, and lift will all decrease to maintain equilibrium with the lower aircraft weight. If the speed isn't lowered, the lift will be greater than the weight and the plane's altitude will increase*.)

f. Predict what effect the following flight conditions would have on an aircraft.
  - The force of drag is greater than the force of thrust. (*The aircraft slows down*.)
  - The force of lift is greater the force of weight. (*The aircraft rises*.)
  - The force of thrust is greater than the force of drag. (*The aircraft accelerates*.)
  - The force of weight is greater than the force of lift. (*The aircraft descends*.)

5. (**TECHNOLOGY**) (**RESOURCES**) Students can learn more about wing design and Bernoulli's Principle by using the Foil Sim III computer simulation. To download the Applet or learn more about this simulation go to *https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/foilsimstudent/*
6. For more information about aerodynamics go to *https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/learn-about-aerodynamics/*

EXTEND – Boomerangs on Earth vs. Aboard ISS (30 minutes)

1. Ask students to think about the principles that allow a boomerang to work. In small groups, have students discuss whether or not a boomerang would

operate the same way onboard the International Space Station (ISS) in a microgravity environment. Ask students to explain their answers in their science notebooks.

2. (**TECHNOLOGY**) Show the NASA eClips™ video, ***Launchpad: The Lighter Side***. The third segment in the video is an on-orbit demonstration of a boomerang on the ISS. This video can be found on the NASA eClips™ page of the NASA web site:
https://nasaeclips.arc.nasa.gov/video/launchpad/launchpad-the-lighter-side
The video may be streamed or downloaded from the nasa.gov web site; a captioned version is also available at the nasa.gov site. This video may be streamed in high definition from the NASA eClips You Tube™ channel:
https://youtu.be/lAJ47pU_KMk

EVALUATE – Boomerang Redesign and Testing (50 minutes)

1. Guide students to complete **Refine the Design** in the *Design Packet.*

2. Using what they have learned about aerodynamics, ask students to diagram, describe, and give reasons for changes they would make to improve their boomerang performance (using the vocabulary words presented in the Explain section).

3. If time permits, allow the students to build and test their refined designs.

4. Guide students to complete the final step of the engineering design process– Share the design.

5. (**TECHNOLOGY**) Encourage students to use available technology resources to organize their findings. They may, for example, create electronic posters, digital collages, or video documentaries to share.

6. Use the **Evaluation Checklist** in the *Design Packet* to have students self-evaluate their understanding of the engineering design process and related content knowledge and skills.

RESOURCES

Learn strategies for engaging learners completing the The Great Boomerang Challenge in the video *NASA eClips Best Practices: The Great Boomerang Challenge Demonstration*.
https://youtu.be/V6SaQA6Tpdw

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The concepts covered in this guide are explained in the video Best Practices: Aerodynamics Overview.
https://youtu.be/Sx8zobveOOA

Learn about the contributions to aviation made by NASA scientists, engineers, programmers, test pilots, facilities managers, strategic planners, educators, graphic designers, and communications specialists. Read the NASA STEM Careers in Aeronautics PDF.
https://www.nasa.gov/sites/default/files/atoms/files/nasa-aero-stem-careers-flyer.pdf

Visit the National Museum Australia to learn about the history of the boomerang in Australia.
https://www.nma.gov.au/defining-moments/resources/earliest-evidence-of-the-boomerang-in-australia

Student Airfoil Interactive
With this simulator, Student Airfoil Interactive, you can investigate how an aircraft wing produces lift and drag by changing the values of different factors that affect lift and the factors that affect drag.
https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/foilsimstudent/

ALLSTAR Network
The Florida International University's Aeronautics Learning Laboratory for Science, Technology, and Research (ALLSTAR Network), has multiple entry levels of information on the forces affecting flight at
https://web.eng.fiu.edu/allstar/index.htm