Activity One: Design a Foam Rocket With Stabilizing Fins

Educator Notes

Challenge

Students will work together in pairs or small teams to design fins for a foam rocket to increase its stability.

Suggested Time

60 to 90 minutes

Learning Objectives

Students will

- Apply the steps of the engineering design process to successfully complete a team challenge.
- Design, build, and test their own foam rocket.
- Collect data for comparison with other groups.
- Improve their fin design to increase rocket stability.
- Understand the relationship between a rocket's stability and its trajectory.

Curriculum Connection

Science and Engineering (NGSS)	
Disciplinary Core Ideas • MS-PS2-2 Motion and Stability: Forces and Interactions: Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object. – PS2.A: Forces and Motion: The motion of an object is determined by the sum of the forces acting on it; if the total force on the object is not zero, its motion will change. The greater the mass of the object, the greater the force needed to achieve the same change in motion. For any given object, a larger force causes a larger change in motion. • MS-ETS1-1 Engineering Design: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. – ETS1.A: Defining and Delimiting Engineering Problems: The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. • MS-ETS1-3 Engineering Design: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success. – ETS1.B: Developing Possible Solutions: There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. – ETS1.C: Optimizing the Design Solution: Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. • MS-ETS1-4 Engineering Design: Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. – ETS1.B: Developing Possible Solutions: A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. Models of all kinds are important for testing solutions. – ETS1.C: Optimizing the Design Solution: The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution.	*Crosscutting Concepts* • Cause and Effect: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering. • System and System Models: A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems. • Structure and Function: The way an object is shaped or structured determines many of its properties and functions. • Interdependence of Science, Engineering, and Technology: Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems. *Science and Engineering Practices* • Asking Questions and Defining Problems: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested. • Developing and Using Models: A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations. • Analyzing and Interpreting Data: Scientific investigations produce data that must be analyzed in order to derive meaning. Because data patterns and trends are not always obvious, scientists use a range of tools—including tabulation, graphical interpretation, visualization, and statistical analysis—to identify the significant features and patterns in the data. Scientists identify sources of error in the investigations and calculate the degree of certainty in the results. Modern technology makes the collection of large data sets much easier, providing secondary sources for analysis. • Using Math and Computational Thinking: In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. They are used for a range of tasks such as constructing simulations; statistically analyzing data; and recognizing, expressing, and applying quantitative relationships. • Construct Explanations and Design Solutions: The products of science are explanations and the products of engineering are solutions.
Technology (ISTE)	
Standards for Students • Knowledge Constructor: Students critically curate a variety of resources using digital tools to construct knowledge, produce creative artifacts, and make meaningful learning experiences for themselves and others. – 3d: Students build knowledge by actively exploring real-world issues and problems, developing ideas and theories, and pursuing answers and solutions. • Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions.	*Standards for Students (continued)* – 4c: Students develop, test, and refine prototypes as part of a cyclical design process. • Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally. – 7c: Students contribute constructively to project teams, assuming various roles and responsibilities to work effectively toward a common goal.
Mathematics (CCSS)	
Mathematical Practices • CCSS.MATH.PRACTICE.MP1: Make sense of problems and persevere in solving them. • CCSS.MATH.CONTENT.MP3: Construct viable arguments and critique the reasoning of others.	*Mathematical Practices (continued)* • CCSS.MATH.PRACTICE.MP5: Use appropriate tools strategically.

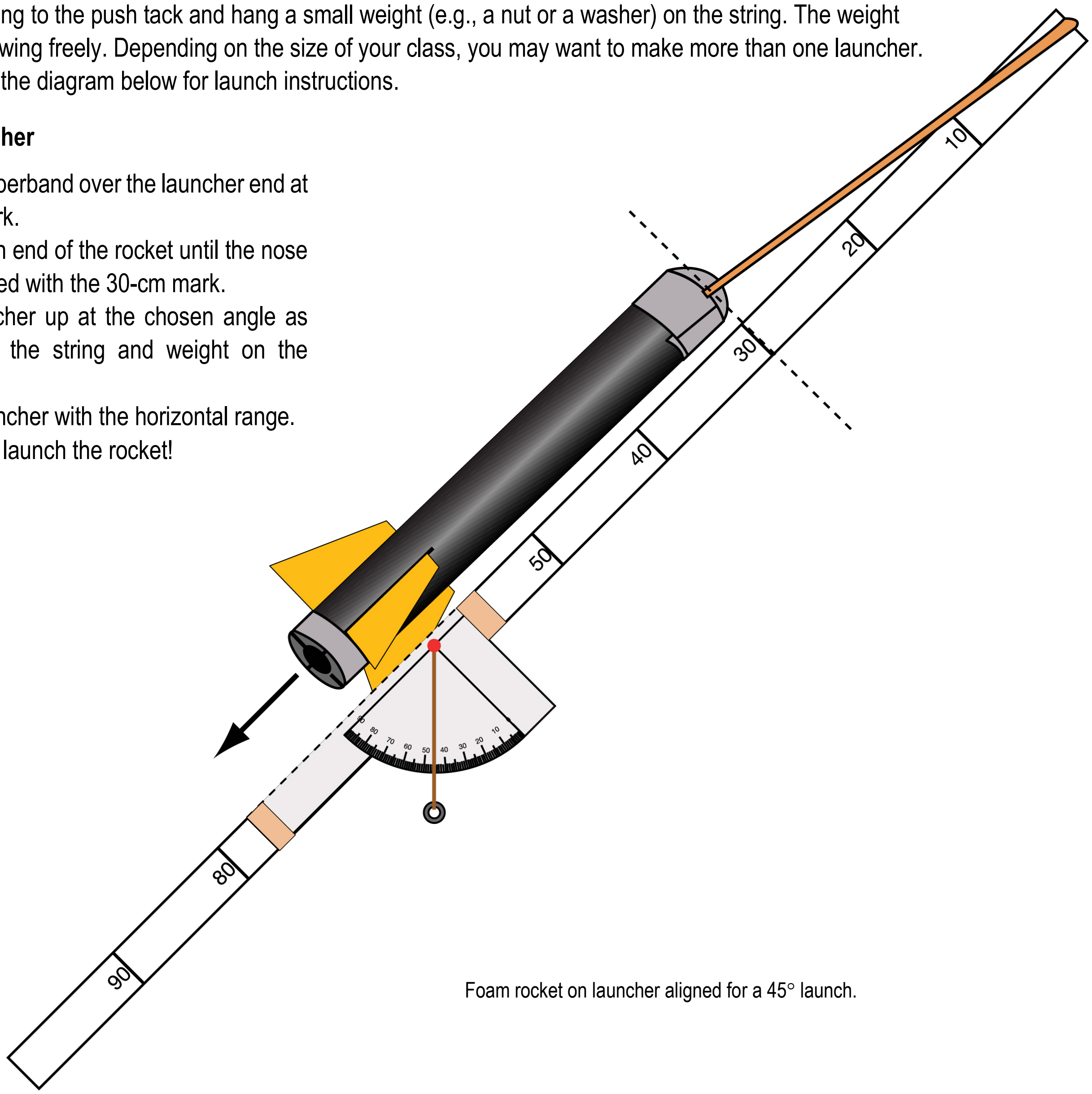
Preparation Time

30 minutes

- Read the Introduction and Background, Educator Notes, and Student Handout to become familiar with the activity.
- Gather and prepare all supplies listed on the materials list.
- If presenting videos or web-based resources, test the links and the classroom technology ahead of time.
- Prepare an area for launching the rockets with little to no wind. A gymnasium or wide hallway with a high ceiling is ideal. The activity can be performed outside, but the trajectory of the rocket is affected by wind.
- Prepare the horizontal range. Secure a long tape measure, or a string or rope with markings, along the ground in a straight line to indicate the planned path of travel for the rocket trajectory. Teams will launch from the start of the range and try to land their rocket downrange as close to this line as possible.
- Make the launcher ahead of time using the following directions:
    1. Print the launcher quadrant template on cardstock paper. (The template is provided at the end of the Educator Notes.)
    2. Cut out the template and fold it on the dashed line.
    3. Tape the quadrant to the meterstick with the black dot directly over the 60-cm mark on the stick.
    4. Press a push tack into the black dot.
    5. Tie a string to the push tack and hang a small weight (e.g., a nut or a washer) on the string. The weight should swing freely. Depending on the size of your class, you may want to make more than one launcher.
    6. Refer to the diagram below for launch instructions.

Using the Launcher

1. Loop the rubberband over the launcher end at the 0-cm mark.
2. Pull on the fin end of the rocket until the nose cone is aligned with the 30-cm mark.
3. Tilt the launcher up at the chosen angle as indicated by the string and weight on the quadrant.
4. Align the launcher with the horizontal range.
5. Release and launch the rocket!



Foam rocket on launcher aligned for a 45° launch.

Materials

- ☐ Polyethylene foam pipe insulation for 1/2-in.-size pipe (one 30-cm piece per group)
- ☐ Rubberbands (size 64)
- ☐ Foam food trays, cardboard, or stiff posterboard
- ☐ Duct tape
- ☐ Scissors
- ☐ Copies of Student Handout and blank paper
- ☐ Meterstick
- ☐ Masking tape
- ☐ Press tack
- ☐ Washer or nut
- ☐ Long tape measures and/or rolling measuring wheel (used to indicate the horizontal rocket range and to measure distances to where the rocket landed)
- ☐ Safety glasses
- ☐ Launcher quadrant template printed on cardstock

Introduce the Challenge

- Provide context for this activity using the Introduction and Background information in this guide. Discuss what it means for rockets to be stable versus unstable, and how rocket stability will affect its planned trajectory. Explain that well-designed fins will increase the stability of a rocket while creating minimal aerodynamic drag.
- Explain the role of engineers in designing technology to solve problems. Share the NASA for Kids video Intro to Engineering and introduce the engineering design process.
- Introduce any new terminology (e.g., aerodynamics, drag, range, stability, and trajectory).
- Remind students of lab safety (e.g., wear eye protection and do not stand downrange during launch).
- Distribute the Student Handout and blank paper and explain the challenge and any design constraints.

Design Constraints

1. Each team will receive the same materials and instructions to construct a foam rocket and fins. Each team is to design its own fins, choosing the size, shape, and profile.
2. Each team must follow instructions for launching a foam rocket that will land downrange as close as possible to the planned path of travel.
   - The planned path of travel is the horizontal range indicated by the long tape measure. The actual path of travel is the straight-line distance from the end of the launcher to where the rocket landed. The more stable the rocket, the less it will deviate from its planned trajectory and the closer it will land to the tape measure.

Facilitate the Challenge

Ask, Imagine, and Plan

Engage the students with the following discussion questions:

- What problems or obstacles do you anticipate during this challenge?
- What are some ideas you have for your fin designs?
- What physical forces will come into play during this challenge?
- What is the means of propulsion for the foam rocket?

Share With Students

Brain Booster

Launching the SLS relies on Newton's third law of motion, which states that for every action there is an equal and opposite reaction. The RS–25 rocket engines produce thrust with liquid hydrogen-oxygen propellants. When the propellants burn, hot gases flow through a nozzle and accelerate out of the engine. In reaction, a thrusting force is produced in the opposite direction of the escaping gases, launching the SLS into space.

Learn more: https://blogs.nasa.gov/Rocketology/tag/newtons-third-law/

On Location

A pair of huge machines called crawler-transporters have carried rockets and spacecraft to the launch pad at NASA's Kennedy Space Center in Florida for more than 50 years. Each is the size of a baseball infield. Powered by locomotive and large electrical power generator engines, these crawler-transporters stand ready to keep up the work for the next generation of launch vehicles to lift astronauts into space.

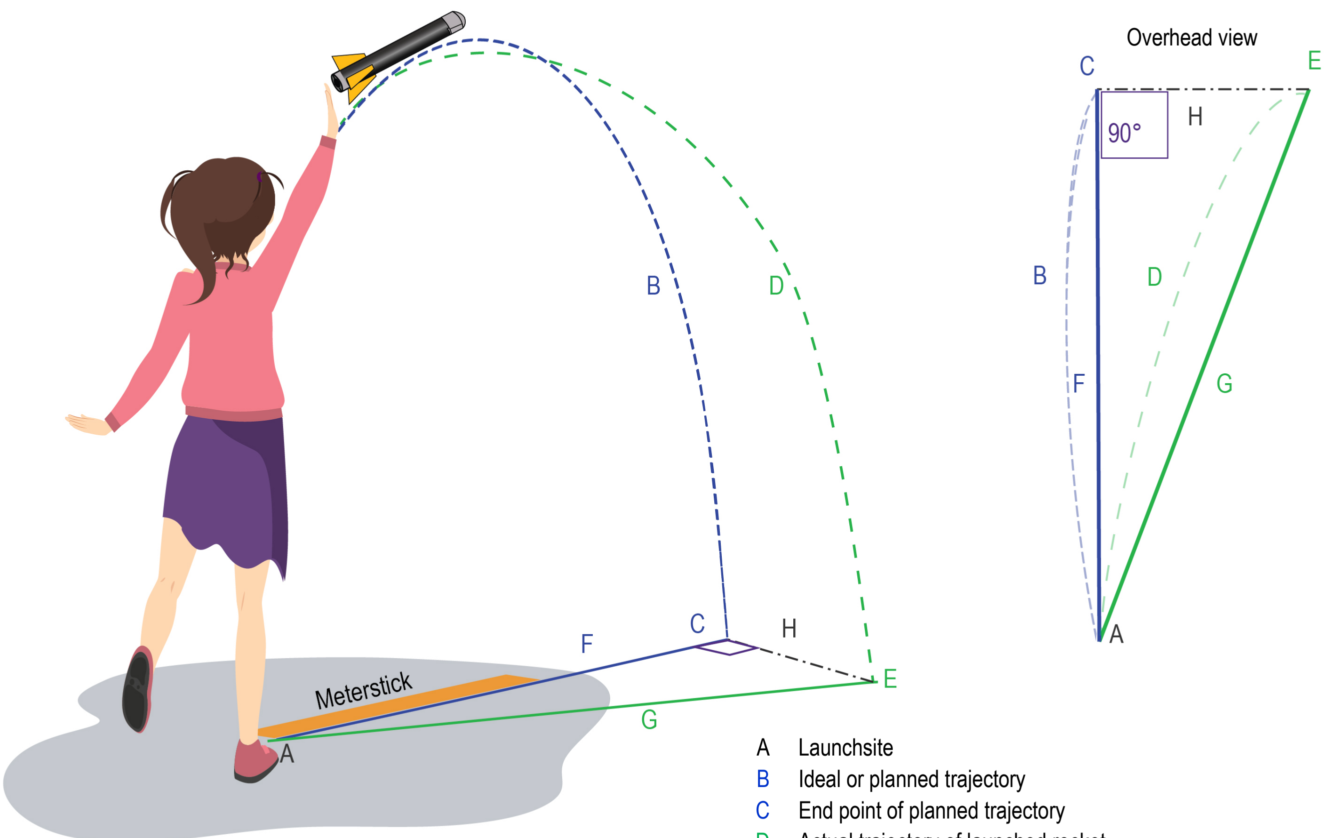
Learn more: https://www.nasa.gov/content/the-crawlers

Create

- Each team will build a foam rocket using the instructions on the Student Handout.
- Students may need assistance with making “nesting” fin pairs. Explain how the notches are on opposite ends of the fin (top and bottom) and demonstrate how the two pieces slide together to make four fins.

Test

1. Demonstrate proper launch technique.
   - Each team will launch their rocket three times at three different angles (30°, 45°, and 60°).
   - When launching the foam rocket, pull the rocket back until the nose cone is at the 30-cm mark, tilt the launcher to the correct angle for each test, and make sure the launcher is aligned with the horizontal range or the straight line indicating the planned path of travel for the rocket trajectory. Teams will launch from the start of the range and try to land their rocket downrange as close to this line as possible.
   - For consistency, consider placing the bottom edge of the launcher on a table to ensure that the vertical launch height remains constant.
2. Demonstrate proper measuring technique.
   - Teams will measure and record two distances.
   - First, they will find the **downrange distance (Line segment F)**, or how far the rocket traveled horizontally from the front of the launcher to the point where the rocket first hit the ground before sliding or bouncing.
   - Second, they will find the **distance off course (Line segment H)**, or how far off the rocket was from the planned trajectory. This is also measured from where the rocket first hit the ground before sliding or bouncing. Remind students that to measure the distance between a point and a line, they must find the perpendicular line segment joining the two.



A Launchsite
B Ideal or planned trajectory
C End point of planned trajectory
D Actual trajectory of launched rocket
E Point where rocket landed
F Downrange distance traveled
G Straight line from launchsite to point where rocket landed
H Distance off course

Improve

- Give each team additional supplies to redesign and build another set of fins. Ask them to consider the stability and trajectory of their first set of launches and think of what improvements could be made to their fin design.
- Discuss different variables that may impact their results, including the elasticity of the rubberband.
- The goal is to increase the stability of their rocket, which is measured by how close they are to landing near the tape measure or meterstick without a significant decrease in the range of their rocket or how far the rocket traveled from the launchsite.
- Teams will repeat steps 4 to 6 of the rocket building procedure, conduct three launches, and then compare the results of their redesigned fins with the results of their original design.

Share

Engage the students with the following discussion questions:

- Why was it important to launch from different angles in the tests?
- Did your redesigned fins improve the stability of your rocket in all three test launches? If not, why?
- What were some tradeoffs or compromises that you had to make in your fin design?
- What was the most innovative solution in the class?

Extensions

- Allow time for additional iterations of the engineering design process.
- Ask students to consider center of mass and investigate how it impacts rocket stability.
- Measure the dimensions of each fin and use geometry to find the area. Gather data from the entire class. Plot a graph comparing area of a fin with horizontal distance traveled by each rocket.
- For advanced students, apply the rules of sine, cosine, or tangent to find angle CAE (in degrees) between the planned path of travel and the actual path of travel for the rocket. By finding angle CAE, teams can compare results across different fin designs, launch angles, and so forth.
- For advanced students, capture video of the launch and use the open-source Tracker Video Analysis and Modeling Tool (https://physlets.org/tracker) to collect data about position, velocity, or acceleration.

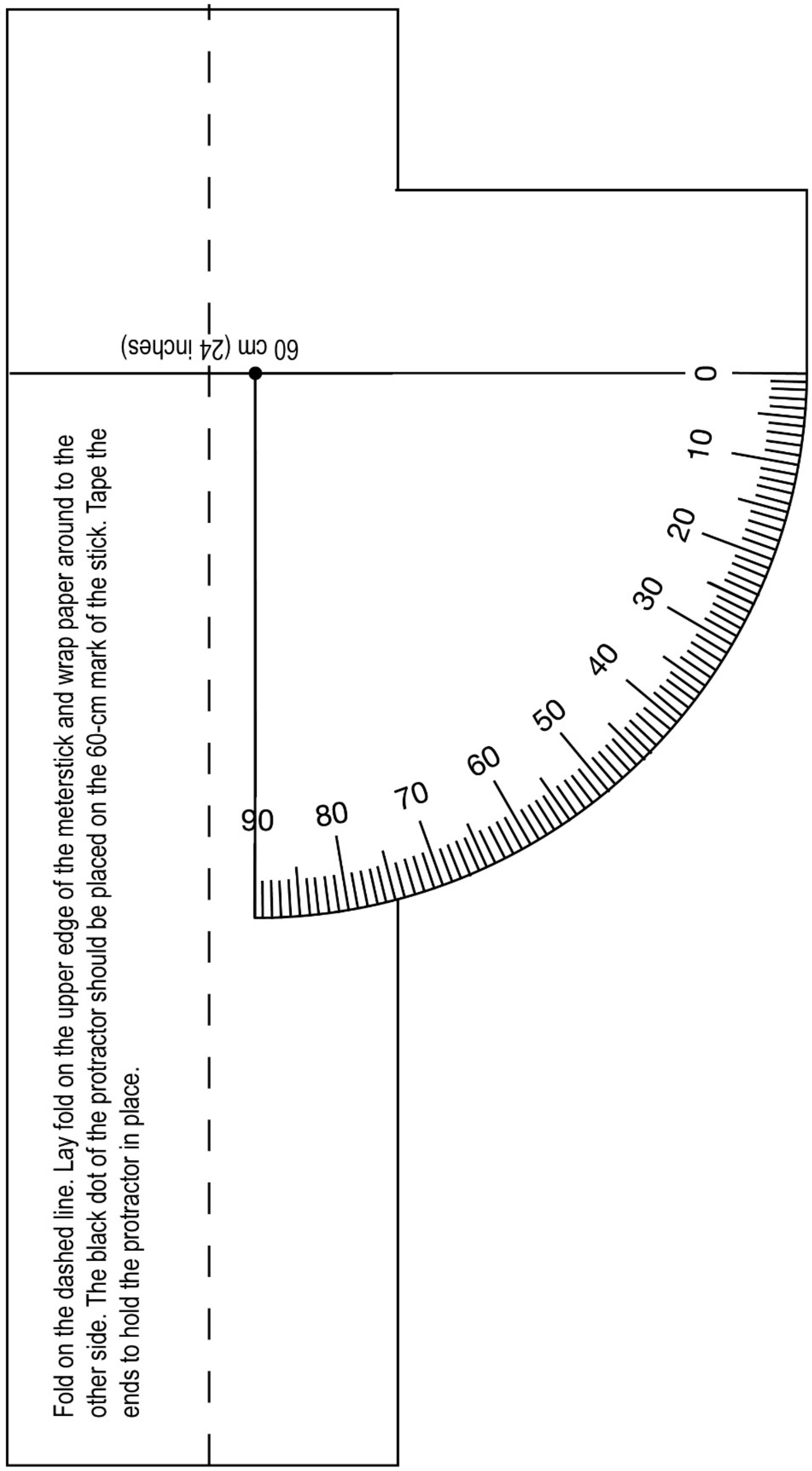
Reference

Modified from Rocket Activity: Foam Rocket. https://www.nasa.gov/pdf/295787main_Rockets_Foam_Rocket.pdf

Additional Resources

- Video: The Hardware for NASA's Artemis 1 Mission Comes Together. https://www.youtube.com/watch?v=Gdu1ROHLDrk
- 3,2,1 … Lift-Off of the Artemis 1 Mission to the Moon. https://www.youtube.com/watch?v=7VvozsSG23w
- Digital Badging: Online NASA STEM Learning. https://www.txstate-epdc.net/digital-badging/

Launcher Quadrant Template
(Actual Size)



Activity One: Design a Foam Rocket With Stabilizing Fins

Student Handout

Your Challenge

Design fins for a foam rocket to increase its stability.

Design Constraints

1. You are only allowed to use the supplies provided by your teacher. You must follow instructions for constructing the foam rocket. However, your team is to design your own fins, choosing the size, shape, and profile.
2. Your team must follow instructions for launching a foam rocket that will land downrange as close as possible to the planned path of travel.
   - The planned path of travel is the horizontal range indicated by the long tape measure. The actual path of travel is the straight-line distance from the end of the launcher to where the rocket landed. The more stable the rocket, the less it will deviate from its planned trajectory and the closer it will land to the tape measure.

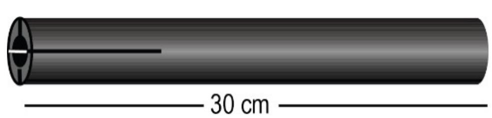
Ask, Imagine, and Plan

- How do you think the size, shape, weight, or location of the fins on a rocket can affect its stability?
- How does rocket stability affect trajectory?
- What questions do you have about today's challenge?

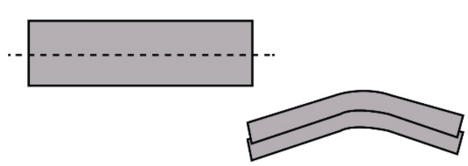
Create

Your team will build a foam rocket using the following procedures. You must follow the procedures carefully, along with any additional instructions from your teacher.

1. Cut four equally spaced slits at one end of the foam tube. The slits should be about 12 cm long. The fins will be mounted through these slits.



2. Cut approximately 12 cm of duct tape down the middle to make two 12-cm-long pieces. Place one piece over the other, sticky side to shiny side, to make the tape doubly strong.



Fun Fact

American college professor and scientist Robert Goddard built and flew the world's first liquid propellant rocket on March 16, 1926. Although its flight was unimpressive, climbing only 12.5 m, it was the forerunner of the Saturn V Moon rocket 43 years later.

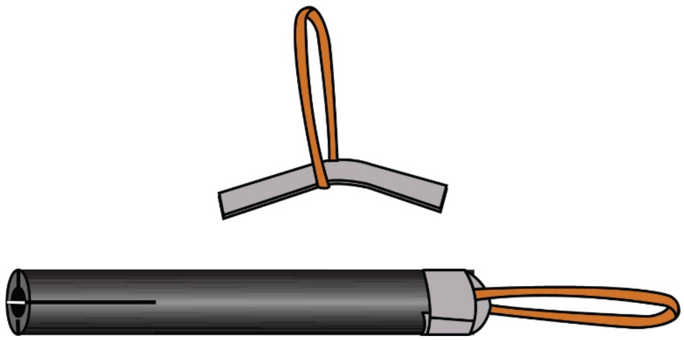
Learn more: https://www.nasa.gov/centers/goddard/about/history/dr_goddard.html

Career Corner

We are NASA! It is the power of team spirit at NASA that moves us forward. NASA's people have a wide variety of knowledge and skills. Every SLS team member brings an essential piece of the puzzle to ensure mission success. We invite you to explore several career profiles that will help launch the SLS to a whole new era of lunar exploration and help us learn what we need to send astronauts safely to Mars.

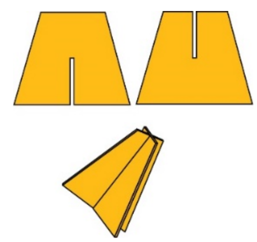
Learn more: https://www.nasa.gov/exploration/systems/sls/profiles.html

3. Slip a rubberband over the tape and press the tape around the nose end of the rocket (opposite the end with the fins). Press the tape tightly and reinforce it with another length of tape wrapped around the foam tube.



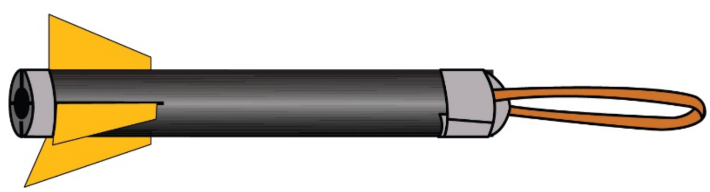
4. Design fin pairs by drawing them on your own sheet of paper.

5. Create the fin pairs using a foam food tray, stiff cardboard, posterboard, or other materials provided by your teacher. Both fin pairs should be notched so that they can "nest," or slide together, as shown here. Different fin shapes can be used, but they should still nest together.



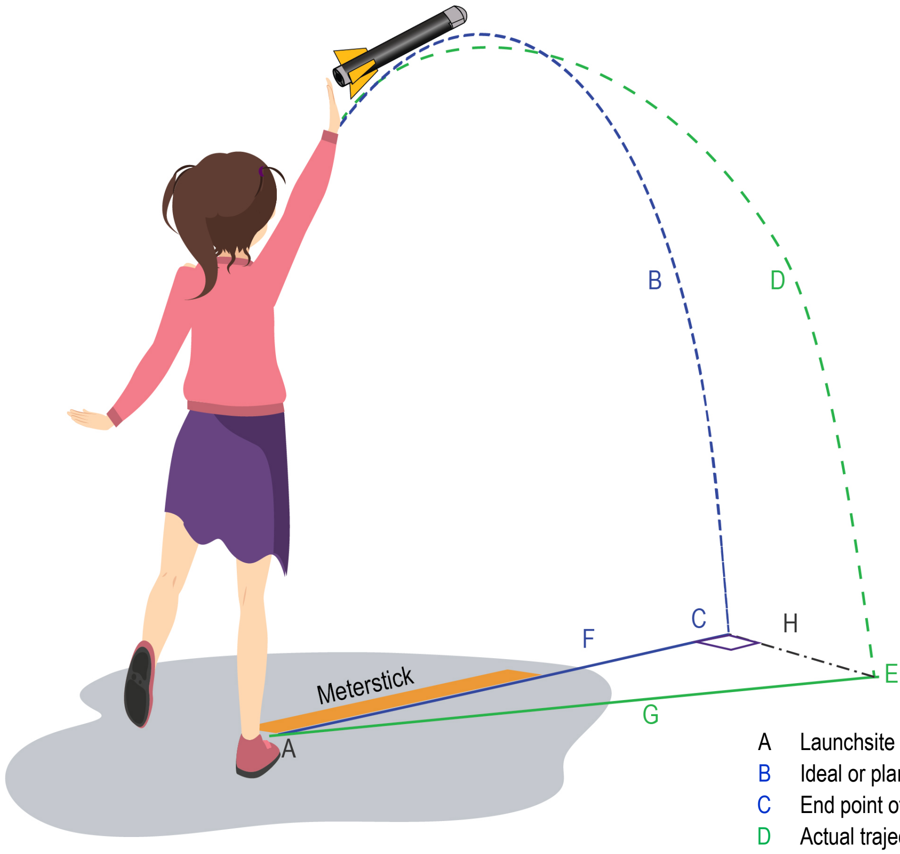
6. Carefully nest your fin pairs together and adjust them until they are even and at right angles to each other. Then slide the nested fins into the slits cut in the rear end of the rocket.

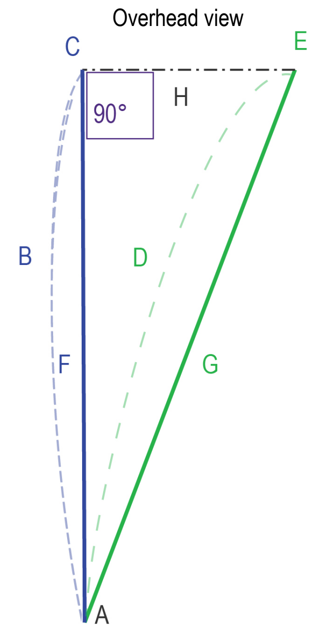
7. Wrap a piece of duct tape around the end of the foam tube to secure the fins. The rocket is finished and ready to launch.



Test

1. On a sheet of paper, make a Fin Design Launch Tests table like the one that follows here to record your test results.
2. Follow your teacher's instructions for how to properly launch the rocket at the correct angle. This will be Trial 1.
3. Try to launch your rocket straight down the tape measure or meterstick. This is the planned path of travel along the horizontal range. Refer to the launch diagram to help determine your measurements.
4. After each launch, record the downrange distance (Line segment F), or how far your rocket traveled horizontally from the front of the launcher (Point A) to the farthest point along the planned trajectory (Point C). This point will be straight across from where the rocket first hit the ground (Point E) before sliding or bouncing.
5. Next, measure the distance off course (Line segment H), or how far off the rocket was from the planned trajectory. This is the shortest distance between the tape measure (Point C) and the point where your rocket first hit the ground (Point E) before sliding or bouncing.
6. Make notes in your table of anything you observed about your rocket's stability and trajectory.





A Launchsite
B Ideal or planned trajectory
C End point of planned trajectory
D Actual trajectory of launched rocket
E Point where rocket landed
F Downrange distance traveled
G Straight line from launchsite to point where rocket landed
H Distance off course

Fin Design Launch Tests

	Launch angle, deg	Downrange distance traveled (Line segment F)	Distance off course (Line segment H)	Notes
Trial 1 (First fin design)	30			
	45			
	60			
Trial 2 (Redesigned fins)	30			
	45			
	60			

Improve

The purpose of fins on a rocket is to increase the rocket's stability and keep its trajectory on course. However, fins can also create aerodynamic drag that can slow down the rocket and affect its range. Your goal is to redesign your fins to improve your rocket's performance, indicated by its ability to stay on course with little or no impact on the distance traveled.

1. Sketch your redesigned fins on the paper provided by your teacher. Indicate how to make the notches so your fin pairs will nest together.
2. Remove the original fins and repeat steps 5 to 7 from the **Create** section.
3. After installing the redesigned fins, repeat the test launches. This will be Trial 2.
4. Record your Trial 2 results in your Launch Tests table.
5. Create a Launch Tests Comparison table like the one below and use it to compare the results of your two sets of launches.

Launch Tests Comparison

Launch angle, deg	Which rocket (Trial 1 or 2) had a greater downrange distance?	By how much?	Which rocket went farther off course?	By how much?	Were the redesigned fins an overall improvement for this launch angle? Why or why not?
30					
45					
60					

Share

- Why was it important to launch from different angles in the tests?
- Did your redesigned fins improve the stability of your rocket in all three test launches? If not, why?
- What were some tradeoffs or compromises that you had to make in your fin design?
- What was the most innovative solution in the class?