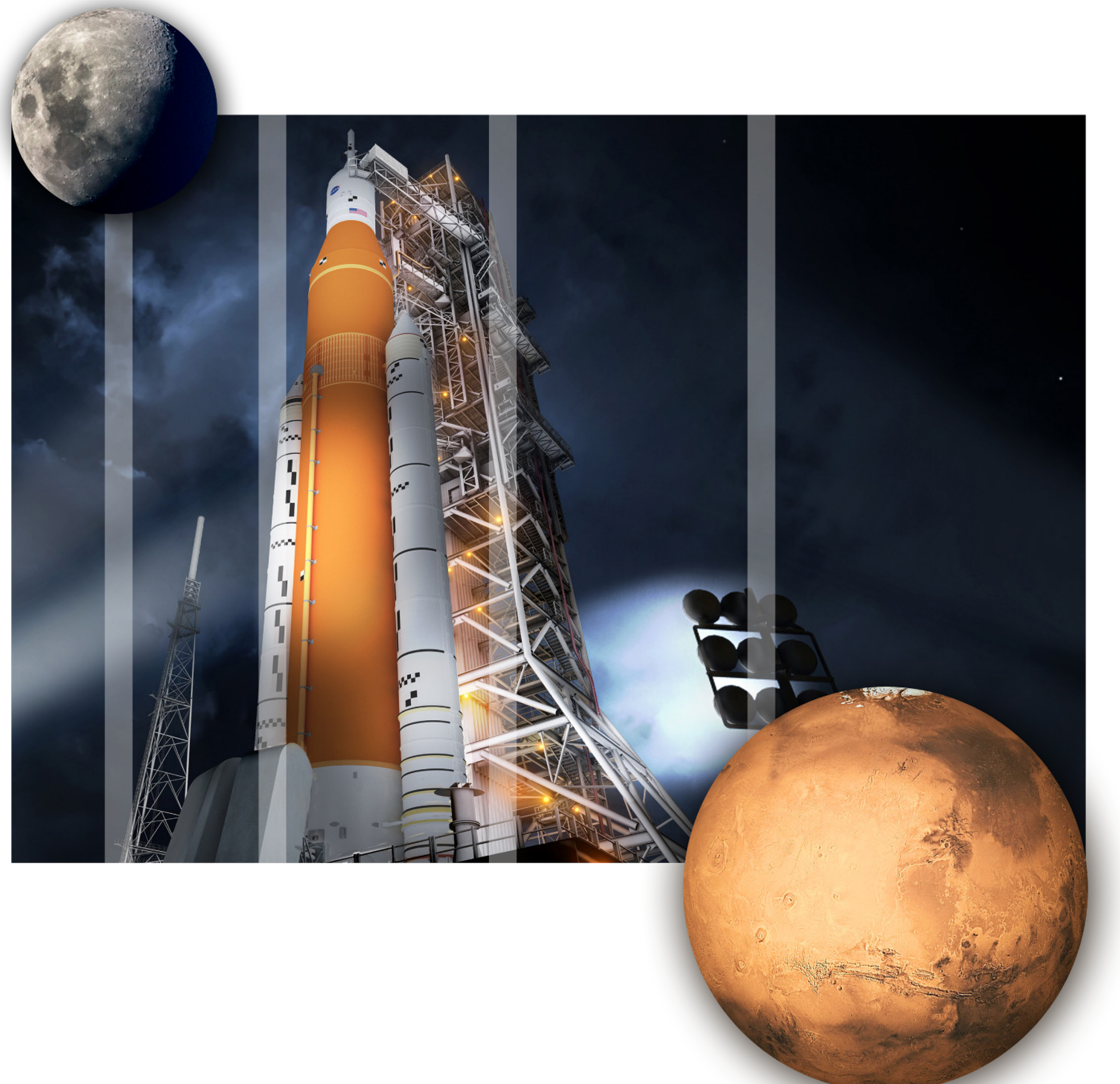
National Aeronautics and
Space Administration

Propulsion With the Space Launch System

Educator Guide



Educator Guide	
Educators and Students	Grades 6 to 8

Contents

Preface

Propulsion With the Space Launch System was published by NASA's Office of STEM Engagement as part of a series of educator guides to help middle school students reach their potential to join the next-generation STEM workforce. The activities can be used in both formal and informal education settings as well as by families for individual use. Each of these activities is aligned to national standards for science, technology, engineering, and mathematics (STEM), and the NASA messaging is current as of September 2019.

STEM Education Standards

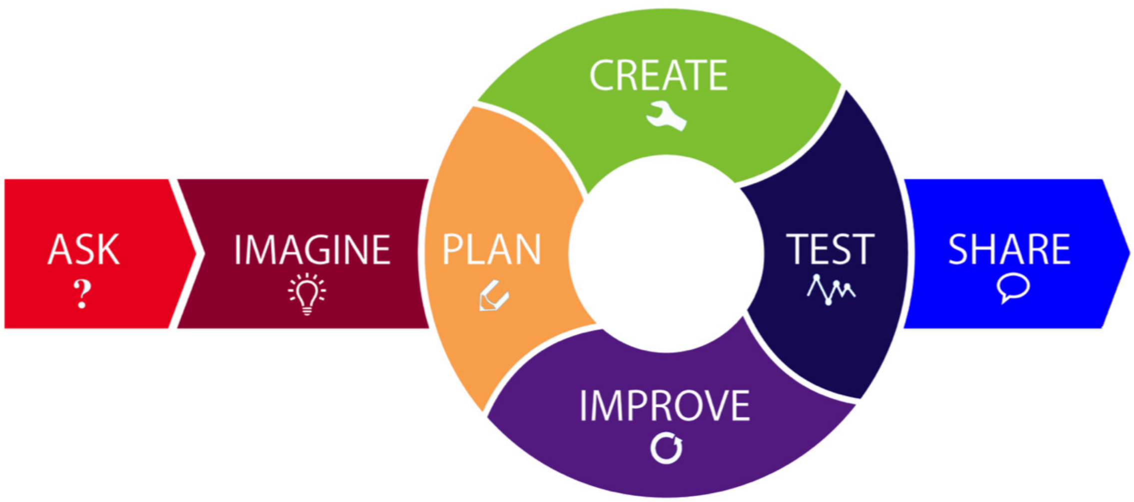
The STEM disciplines matrix shown below aligns each activity in this module to standards for teaching STEM according to four primary focus areas within each discipline. The four focus areas for science were adapted from the Next Generation Science Standards (NGSS) middle school disciplinary core ideas. The four focus areas for technology were adapted from the International Society for Technology in Education (ISTE) Standards for Students. The four focus areas for engineering were adapted from the National Science Teaching Association (NSTA) and NGSS science and engineering practices. The four focus areas for mathematics were adapted from the Common Core State Standards (CCSS) for Math middle school content standards by domain. Find additional matrices in the Appendix: STEM Standards and Practices.

Activity	STEM Disciplines															
	Science				Technology				Engineering				Math			
	NGSS Disciplinary Core Ideas				ISTE Standards for Students				NSTA and NGSS Practices				CCSS Content Standards by Domain			
	Physical Sciences	Life Sciences	Earth and Space Sciences	Engineering, Technology, and the Application of Sciences	Knowledge Constructor	Innovative Designer	Computational Thinker	Global Collaborator	Ask Questions and Define Problems	Develop and Use Models	Plan and Carry Out Investigations	Construct Explanations and Design Solutions	Ratios and Proportional Relationships	The Number System	Statistics and Probability	Geometry
Design a Foam Rocket With Stabilizing Fins	✓			✓	✓	✓		✓	✓	✓		✓				
Track the Altitude of a Rocket					✓		✓	✓						✓		
Build a Multistage Balloon Rocket	✓			✓		✓	✓	✓	✓	✓	✓	✓			✓	
Optimize a Water Rocket Engine	✓			✓				✓	✓	✓	✓	✓			✓	

Engineering Design Process

The engineering design process (EDP) is crucial to mission success at NASA. The EDP is an iterative process involving a series of steps that engineers use to guide them as they solve problems. The steps outlined below can be used by student teams to solve the challenges in this activity guide. Learn more about the EDP with NASA's Educator Professional Development Collaborative at https://www.txstate-epdc.net/models-of-the-engineering-design-process/.

1. ASK: Identify the problem, requirements that must be met, and the constraints that must be considered.
2. IMAGINE: Brainstorm solutions and research what others have done in the past.
3. PLAN: Select and sketch a design.
4. CREATE: Build a model or a prototype.
5. TEST: Evaluate solutions by testing and collecting data.
6. IMPROVE: Refine the design.
7. SHARE: Communicate and discuss the process and solutions as a group.



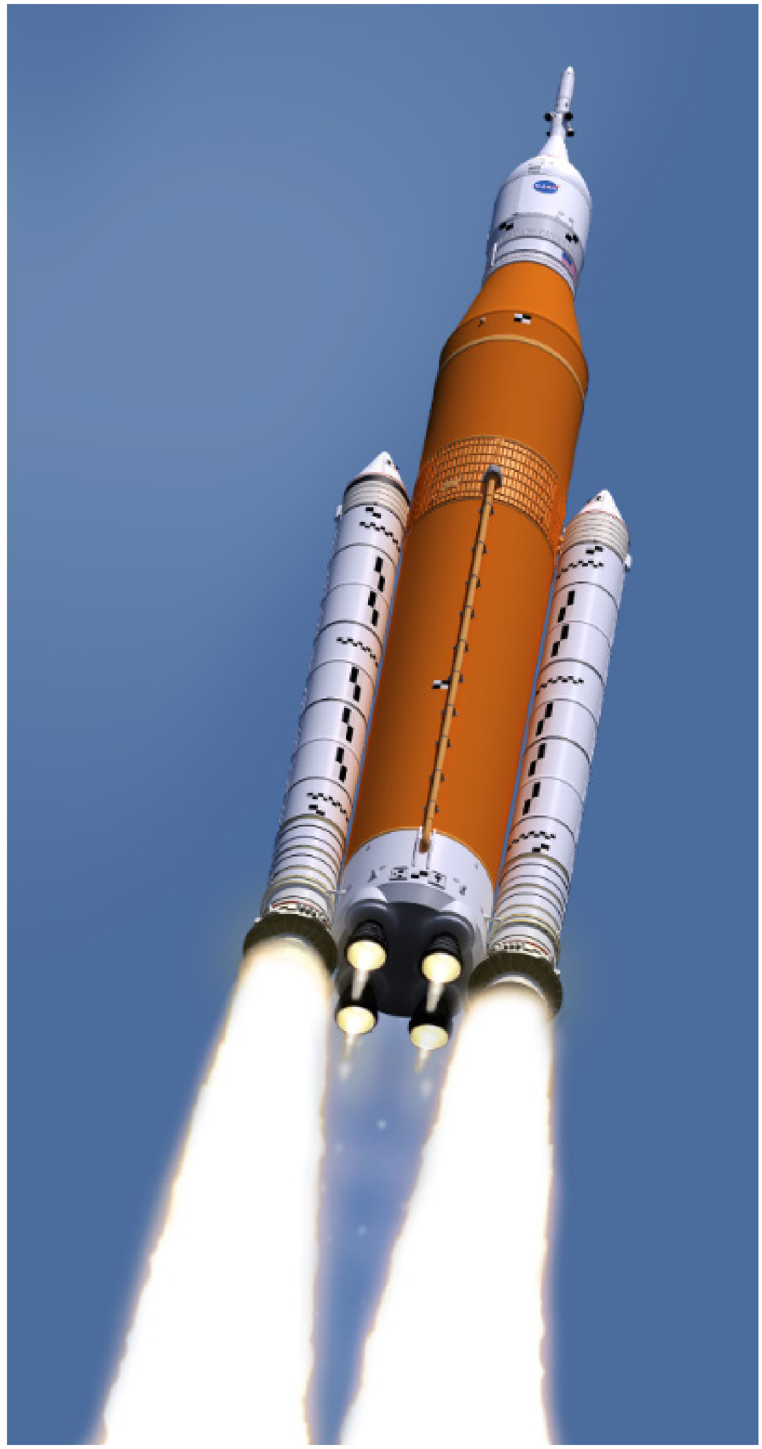
Tip: In order to manage the dynamics within each team, it may be helpful to assign each student within the group a specific task, such as materials manager, design engineer, fabrication engineer, communications specialist, or team manager. Having each team member in charge of a different element of the task may reduce internal conflict within teams.

Introduction and Background

NASA's Space Launch System, or SLS, is an advanced launch vehicle that provides the foundation for human exploration beyond low Earth orbit. With its unprecedented power and capabilities, the SLS is the only rocket that can send the Orion spacecraft, astronauts, and large cargo to the Moon on a single mission. The SLS team is producing NASA's first exploration-class rocket built since the Saturn V.

To fill NASA's future needs for deep space missions, the SLS is designed to evolve into increasingly more powerful configurations and offer more payload mass, volume capability, and energy to speed missions through space than any current launch vehicle. This flexible design will open new possibilities for payloads, including robotic scientific missions to places like Mars, Saturn, and Jupiter.

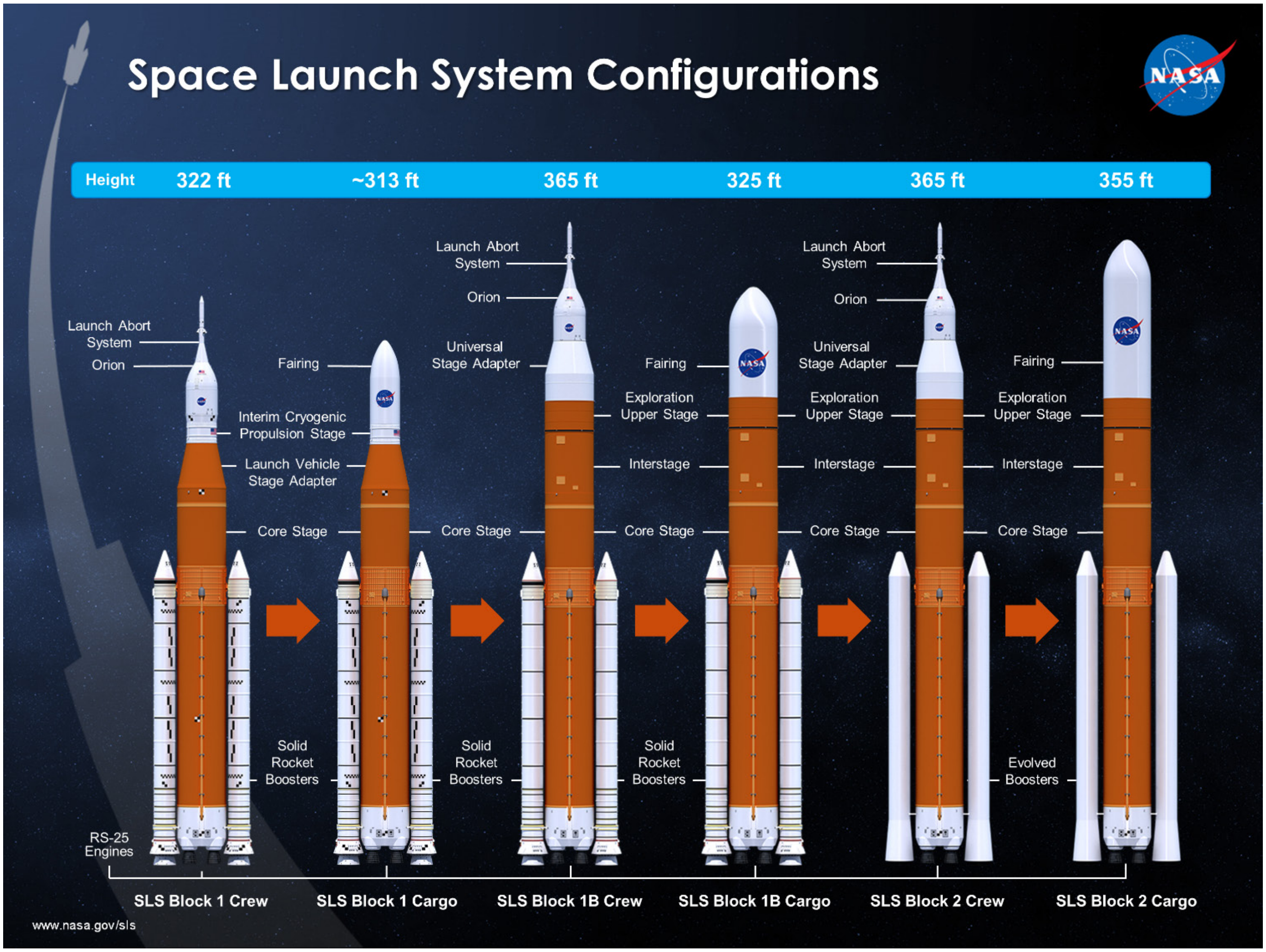
This evolvable design concept allows NASA to provide the Nation with a rocket able to pioneer new human spaceflight missions and revolutionary scientific missions in the shortest time possible, while continuing to develop configurations that are more powerful. The next wave of human exploration will take explorers farther into the solar system—developing new technologies, inspiring future generations, and expanding our knowledge about our place in the universe.



Artist's rendering of NASA's Space Launch System. (NASA)

Rocket Configurations

The first SLS vehicle configuration is called Block 1. It weighs 2.6 million kg (5.75 million lb) when fueled and stands 98 m (322 ft) tall. That is taller than the Statue of Liberty. The SLS will produce 39.1 million newtons (8.8 million lb) of thrust at liftoff, equivalent to more than 160,000 Corvette engines. The initial Block 1 configuration of the SLS can send more than 26 metric tons, or 57,000 lb, to orbits beyond the Moon. It will be powered by twin five-segment solid rocket boosters and four RS–25 liquid propellant engines. After reaching space, the Interim Cryogenic Propulsion Stage (ICPS) is capable of sending Orion on to the Moon. Using the Block 1 configuration, the first SLS mission, Artemis I, will launch an uncrewed Orion spacecraft to a stable orbit beyond the Moon and bring it back to Earth. This mission will demonstrate the integrated system performance of the SLS rocket, the Orion spacecraft, and ground support teams prior to a crewed flight. The second SLS mission is Artemis II, and it will launch Orion with a crew of up to four astronauts to a distance near the Moon that is farther than humans have ever ventured.



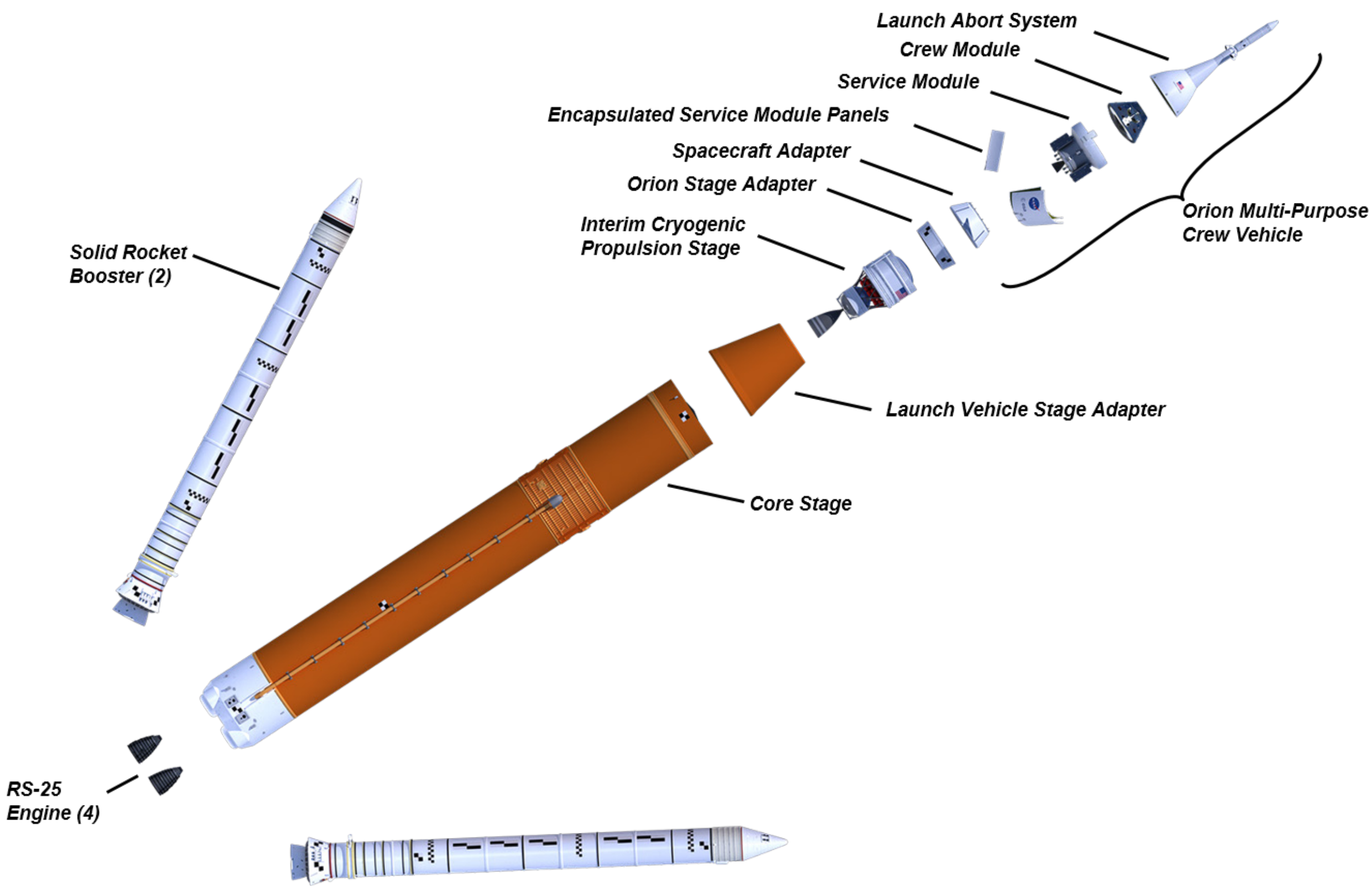
Space Launch System (SLS) configurations. (NASA)

The next planned evolution of the SLS, the Block 1B crew vehicle, will use a new, more powerful Exploration Upper Stage (EUS) to enable more ambitious missions to the proving ground of space near and beyond the Moon, where NASA will test systems needed for future missions to Mars. In a single launch, the Block 1B vehicle can carry the Orion spacecraft along with exploration systems such as a small deep space habitat module, or it can fly dedicated missions carrying larger exploration systems or science spacecraft under a payload fairing. The Block 1B crewed configuration will be approximately 111 m (364 ft) tall, which is taller than the Saturn V rocket that took astronauts to the Moon.

A later evolution, Block 2, will provide 52.9 newtons (11.9 million lb) of thrust and will be the workhorse vehicle for assembling a human mission to Mars and sending cargo to the Moon, Mars, and other deep space destinations. SLS Block 2 will be designed to lift more than 45 metric tons (99,000 lb) to deep space.

Rocket Technologies

The Boeing Company in Huntsville, Alabama, is developing the SLS core stage, including the avionics that will control the vehicle during flight. Towering more than 60 m (200 ft) tall with a diameter of 8.41 m (27.6 ft), the core stage will store 2.76 million L (730,000 gal) of super-cooled liquid hydrogen and liquid oxygen that will fuel the RS–25 engines for the SLS. The core stage is being built at NASA's Michoud Assembly Facility in New Orleans using state-of-the-art manufacturing equipment, including a friction stir welding tool that is the largest of its kind in the world. At the same time, the rocket's avionics computer software is being developed at NASA's Marshall Space Flight Center in Huntsville, Alabama.



Initial Block 1 Configuration Concept for the Space Launch System. (NASA)

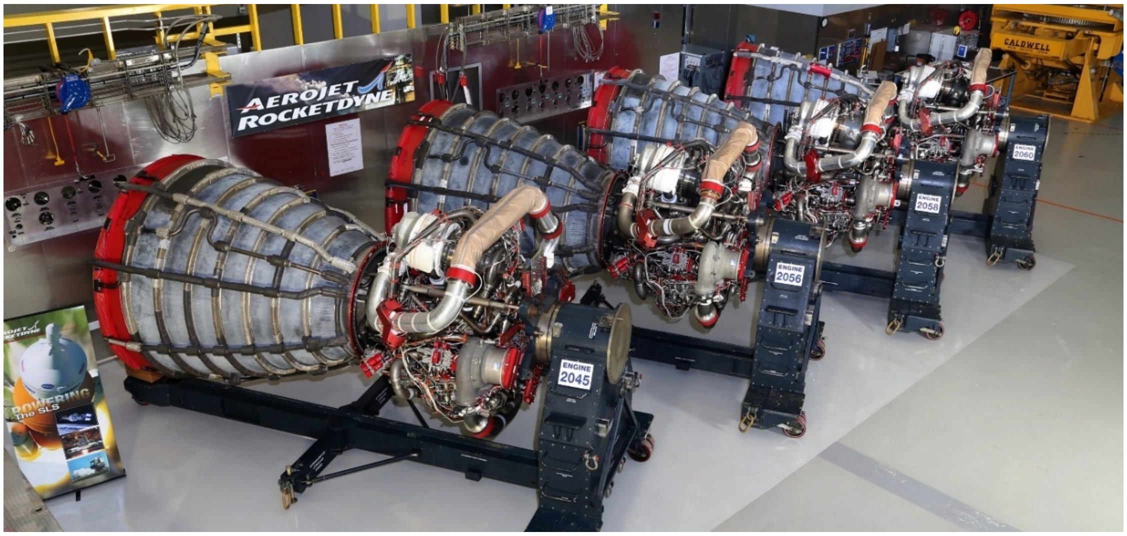
In each configuration, the SLS will continue to use the same core stage design with four RS–25 engines for propulsion. Aerojet Rocketdyne of Sacramento, California, is upgrading an existing inventory of 16 RS–25 space shuttle engines to SLS performance requirements, including a new engine controller, nozzle insulation, and required operation at 1.8 million newtons (418,000 lb) of thrust, instead of the 1.76 million newtons (395,000 lb) of thrust used for the space shuttle.


RS–25 engine undergoing a hot-fire test. (NASA)

Two shuttle-derived solid rocket boosters will be used for the initial flights of the SLS. Each one provides 16 million newtons (3.6 million lb) of thrust. Northrop Grumman is a company headquartered in Dulles, Virginia, and the prime contractor for the boosters. To provide the additional power needed for the rocket, they had to modify the boosters from the shuttle's configuration, which used four propellant segments, to a five-segment version. The design also includes new avionics, propellant design, case insulation, and elimination of the recovery parachutes. Northrop Grumman has successfully completed a full-duration booster qualification ground test.

The initial capability to propel Orion out of Earth's orbit for Artemis I will come from an ICPS, which was modified from the successful second stage of the United Launch Alliance's Delta IV family of rockets. Cryogenic propellants are fluids chilled to extremely cold temperatures and condensed to form liquids that can be used to provide high-energy propulsion. The ICPS will generate 110,093 newtons (24,750 lb) of thrust. The big in-space push comes from one RL–10 engine, which was the Nation's first liquid hydrogen-oxygen engine used in the upper stages of the Apollo-Saturn program.

Propulsion With the Space Launch System

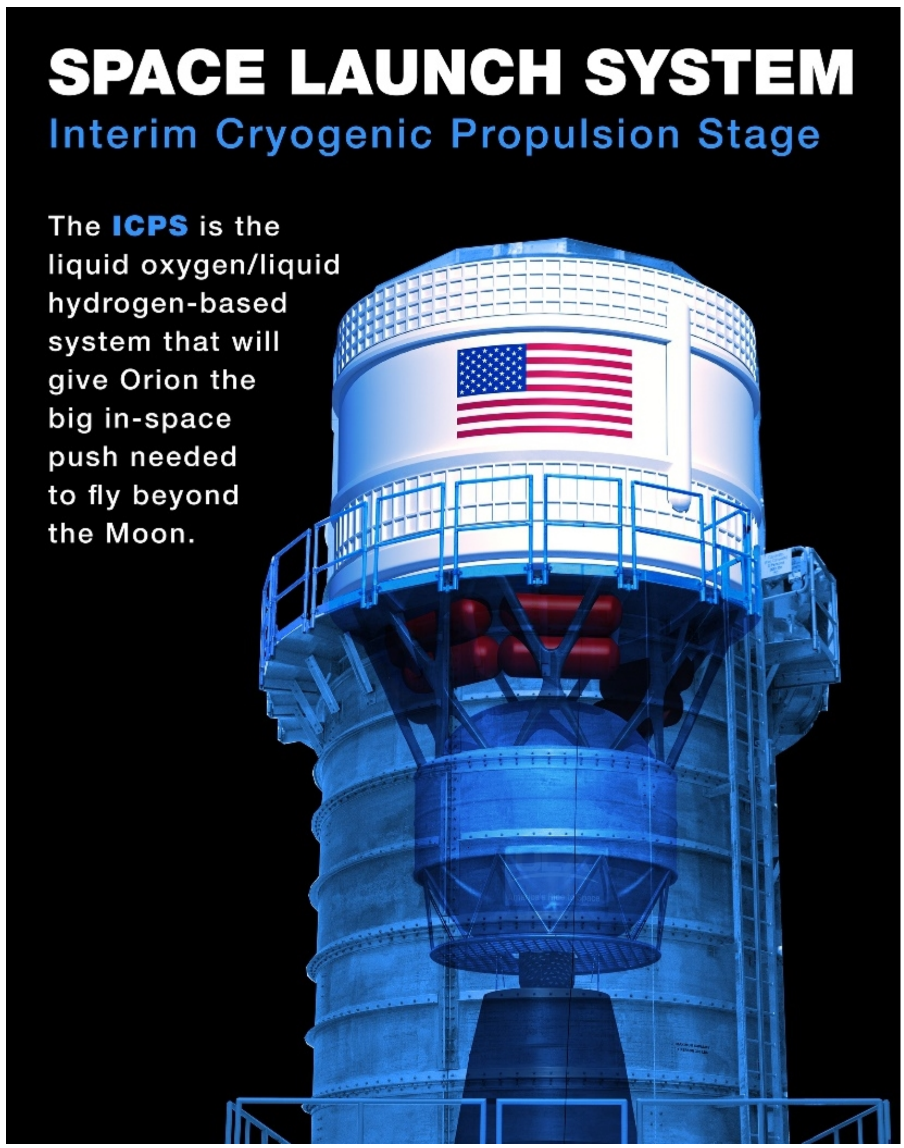


Four RS–25 engines that will power the Space Launch System. (Aerojet Rocketdyne/NASA)

While work progresses on the initial Block 1 SLS, an advanced development team is investing in new systems and technologies that will make the SLS even more powerful, while improving affordability and increasing reliability. This evolved, flexible approach lets the SLS carry out a wide variety of missions sooner, while incrementally increasing the power of the vehicle.

Future configurations of the SLS will include the larger EUS for more capable human and robotic missions to deep space. The EUS will replace the Block 1 ICPS and utilize an 8.4-m- (27.6-ft-) diameter forward liquid hydrogen tank and a smaller diameter liquid oxygen tank.

Reaching the SLS's full potential will require many advanced technologies, including boosters with a significant increase in performance over existing boosters. NASA has engaged with industry teams to research benefits, new technologies, and strategies for liquid and solid advanced boosters that reduce risks while enhancing affordability, improving reliability, and meeting performance goals of the future.



Infographic showing Interim Cryogenic Propulsion Stage (ICPS).

Artist's rendering of Space Launch System liftoff. (NASA)

Infographic summarizing features of the Space Launch System's solid rocket boosters.

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.

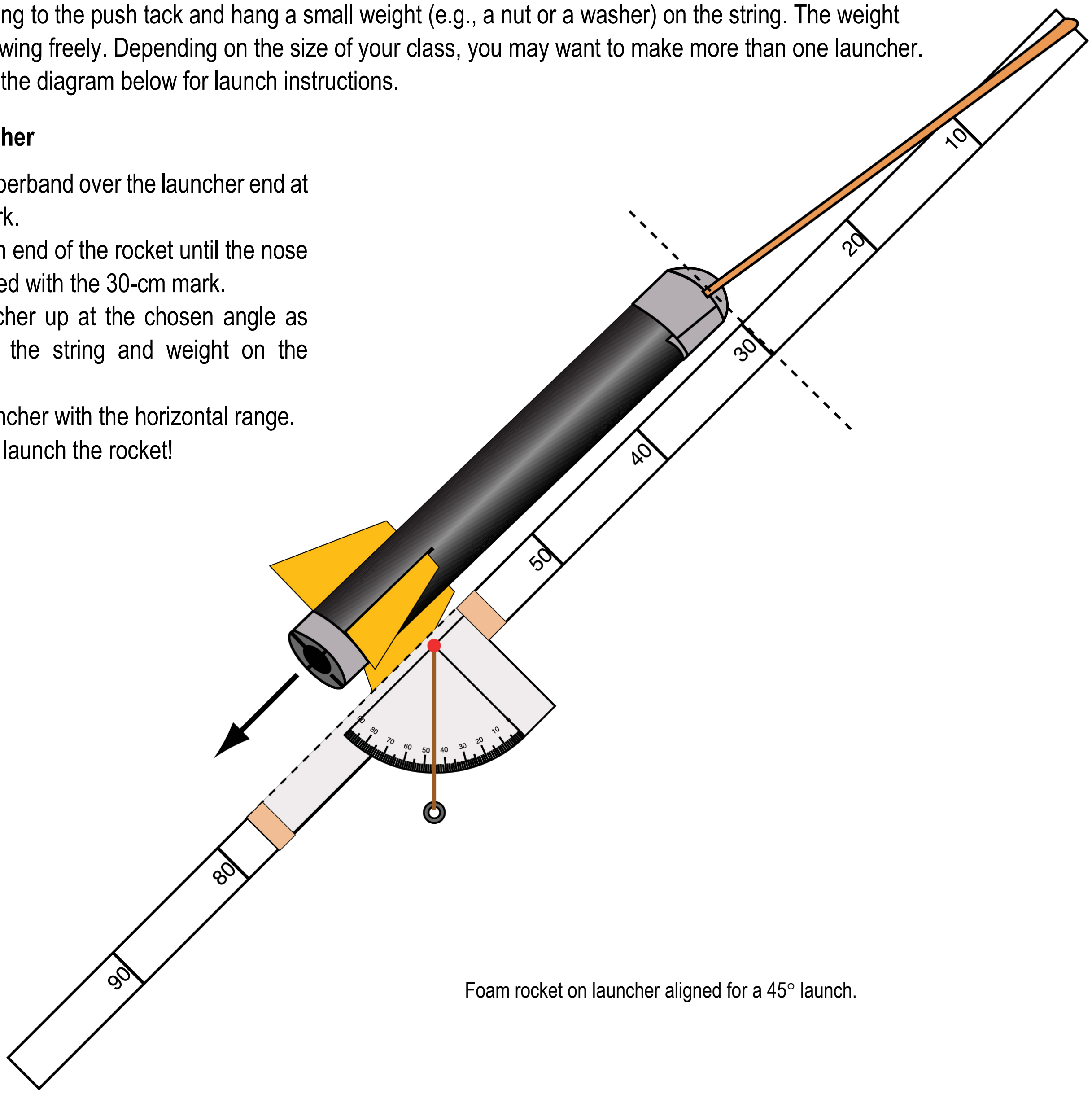
Preparation Time

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.

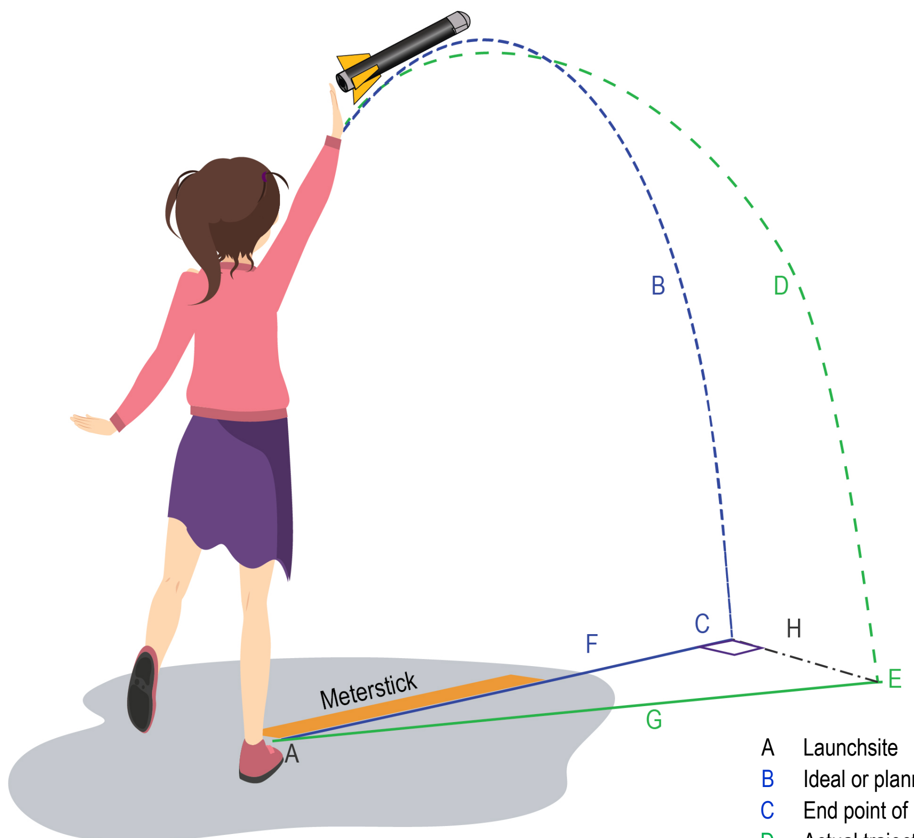
Learn more: https://www.nasa.gov/content/the-crawlers

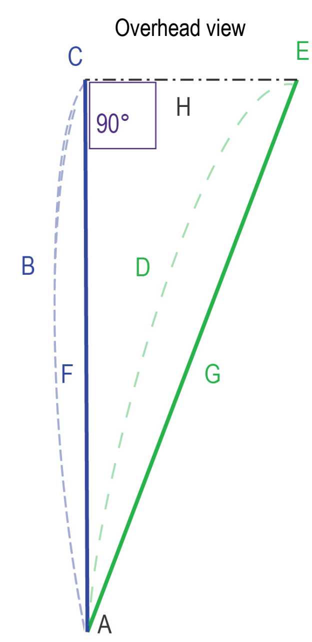
Create

- 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.

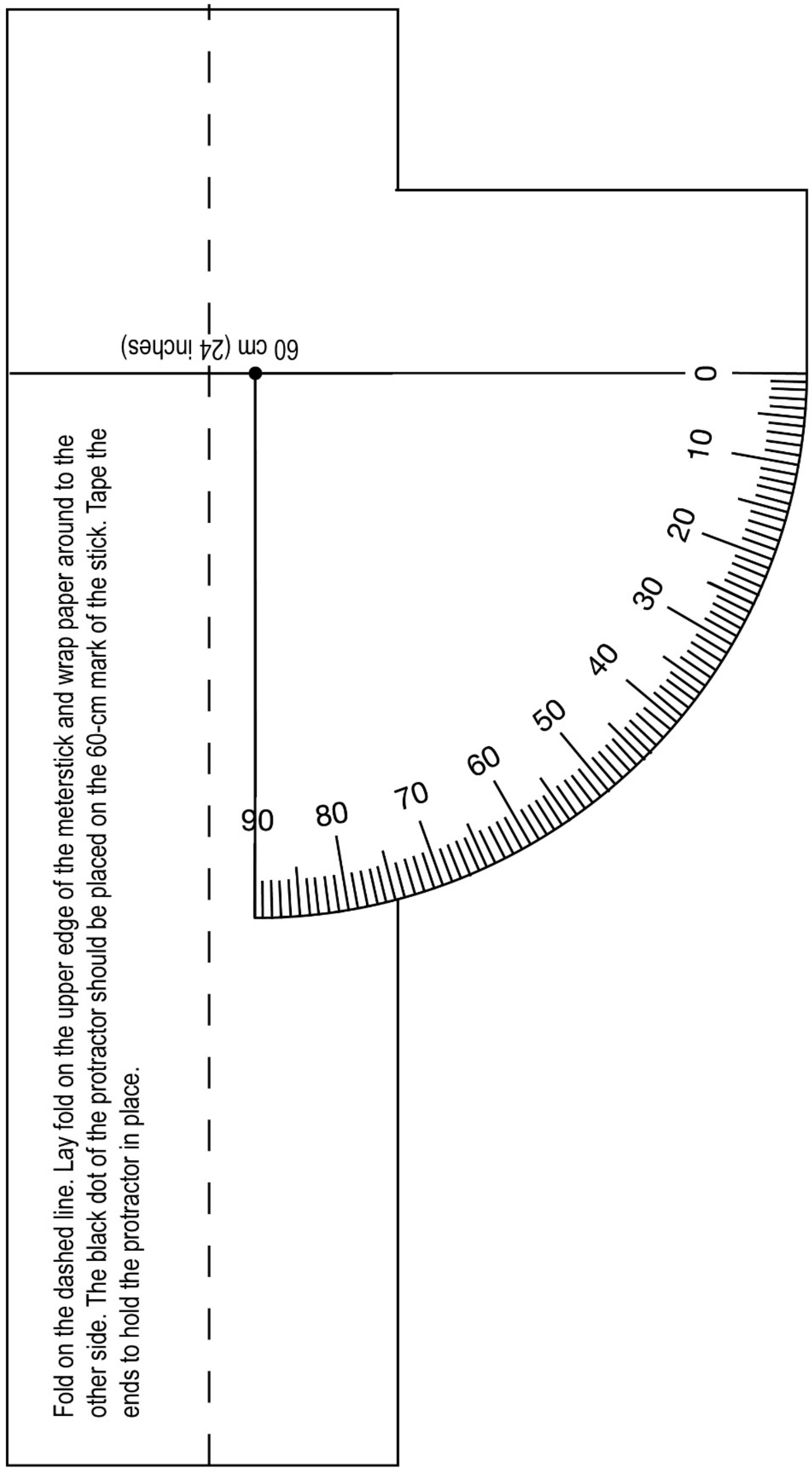
Reference

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.

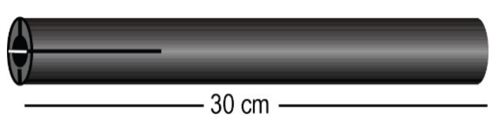
Ask, Imagine, and Plan

- 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?

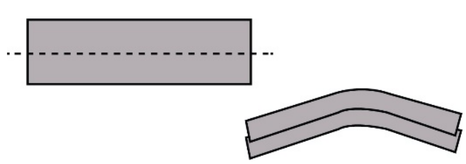
Create

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.

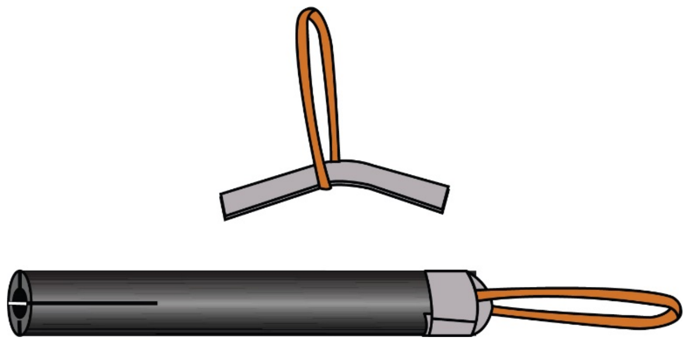
Learn more: https://www.nasa.gov/centers/goddard/about/history/dr_goddard.html

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.

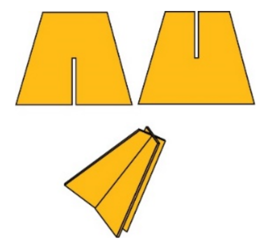
Learn more: https://www.nasa.gov/exploration/systems/sls/profiles.html

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.



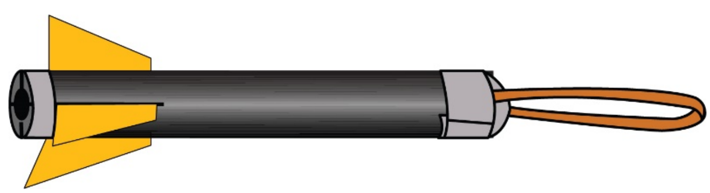
4. Design fin pairs by drawing them on your own sheet of paper.

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.



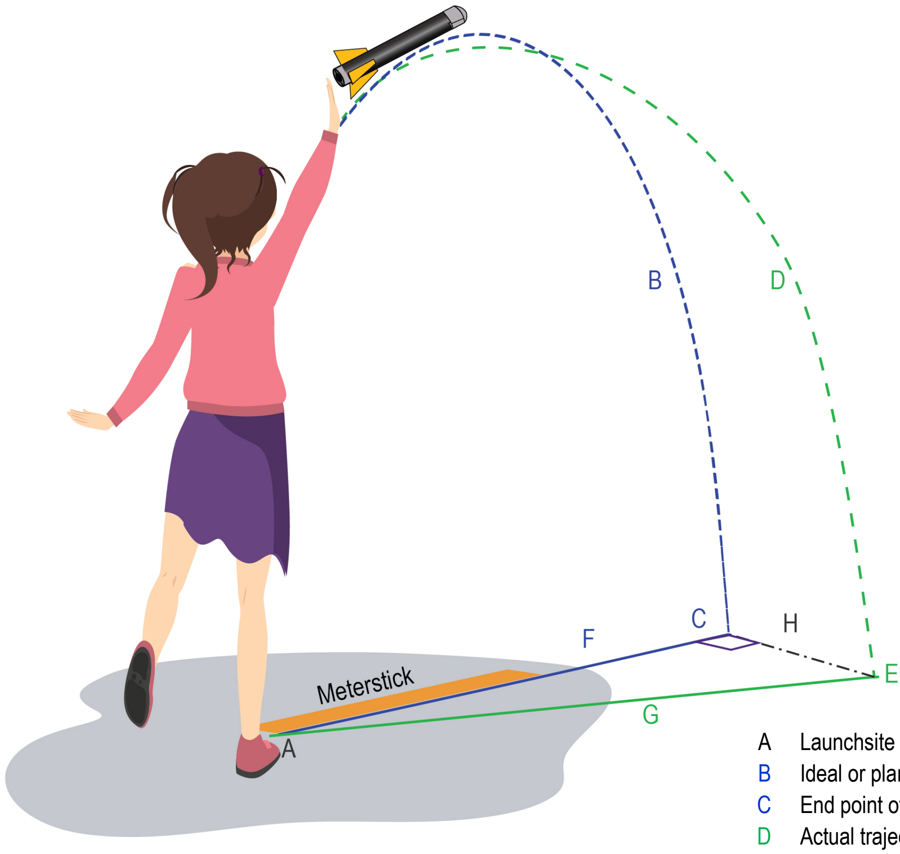
6. Carefully nest your fin pairs together and adjust them until they are even and at right angles to each other. Then slide the nested fins into the slits cut in the rear end of the rocket.

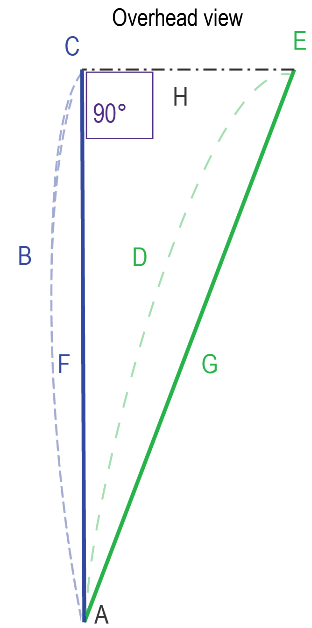
7. Wrap a piece of duct tape around the end of the foam tube to secure the fins. The rocket is finished and ready to launch.



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?

Activity Two: Track the Altitude of a Rocket

Educator Notes

Challenge

Students will construct and use an altitude tracker and altitude calculator to estimate the height of a rocket at apogee (the highest point of the trajectory of the rocket).

Suggested Time

120 minutes

Learning Objectives

Students will

- Construct and use an altitude tracker to collect and analyze data from the flight of a rocket.
- Construct and use an altitude calculator to estimate the height of a rocket at apogee.
- Use a tangent table to estimate the height of the rocket at apogee and compare the result to that of the altitude calculator.

Curriculum Connection

Science and Engineering (NGSS)	
Crosscutting Concepts • 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* • 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.	*Science and Engineering Practices (continued)* • 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. • Obtaining, Evaluating, and Communicating Information: Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity.

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. • Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions.	*Standards for Students (continued)* – 5c: Students break problems into component parts, extract key information, and develop descriptive models to understand complex systems or facilitate problem solving. • 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)	
Content Standards by Domain • CCSS.MATH.CONTENT.6.NS.B.3: Fluently add, subtract, multiply, and divide multidigit decimals using the standard algorithm for each operation. • CCSS.MATH.CONTENT.7.NS.A.2: Apply and extend previous understandings of multiplication and division and of fractions to multiply and divide rational numbers. – CCSS.MATH.CONTENT.7.NS.A.2.C: Apply properties of operations as strategies to multiply and divide rational numbers.	*Content Standards by Domain (continued)* • CCSS.MATH.CONTENT.7.NS.A.3: Solve real-world and mathematical problems involving the four operations with rational numbers. *Mathematical Practices* • CCSS.MATH.PRACTICE.MP4: Model with mathematics. • CCSS.MATH.PRACTICE.MP5: Use appropriate tools strategically. • CCSS.MATH.PRACTICE.MP6: Attend to precision.

Preparation Time

15 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.
- Print the two templates for the altitude calculator onto heavyweight paper or glue the templates onto lightweight posterboard for each team. (Templates can be found at the end of the Educator Notes.)
- A teacher aide or older student should place the front template for the altitude calculator on a cutting surface and cut out the three oval windows. A sharp knife or razor works best.
- Students will be constructing the altitude trackers for this activity, so no preparation work is needed for this item.

- Determine which rocket activity you would like to pair with this challenge (e.g., Activity One foam rocket, Activity Four water rocket, or NASA's online Pop! Rocket activity).
- Set up tracking station locations at 5-m intervals from the launchsite. The more powerful the rocket, the farther away each station should be from the launchsite. Depending upon the expected altitude of the rocket, the tracking station should be 5, 15, or 30 m away. (Generally, a 5-m distance is sufficient for foam or Pop! Rockets, a 15-m distance is sufficient for water rockets, and a 30-m distance is sufficient for model rockets.)

Materials

- ☐ Altitude tracker template
- ☐ Altitude calculator template
- ☐ Copy of tangent table
- ☐ Copies of Student Handout and blank paper
- ☐ Thread or lightweight string
- ☐ Cardboard or posterboard
- ☐ Glue
- ☐ Clear tape
- ☐ Small washers
- ☐ Milkshake straws
- ☐ Brass paper fasteners
- ☐ Scissors
- ☐ Razor blade knife and cutting surface
- ☐ Meterstick or metric tape measure
- ☐ Rocket and launcher (e.g., water rocket, foam rocket, or Pop! Rocket)

Introduce the Challenge

- Introduce any new terminology (e.g., altitude, angle of elevation, apogee, baseline tangent, and trajectory).
- Discuss different methods for determining the height of a rocket during launch.
- Explain that determining the altitude of a rocket is a team activity. While part of the team prepares and launches the rocket, the other team members will measure the angle of elevation of the rocket at the highest point of its trajectory from a tracking station. The angle measurement is then used with an altitude calculator and/or tangent table to determine the height at apogee. Roles should be reversed so everyone gets a chance at both activities.
- Distribute the Student Handout and blank paper and explain the challenge.

Facilitate the Challenge

Ask, Imagine, and Plan

Engage the students with the following discussion questions:

- At what angle should you launch your rocket for maximum altitude?
- What would happen if you changed the launch angle?
- Besides launch angle, what other factors will impact the trajectory of your rocket?
- What are some possible sources of error in this activity? How could your team eliminate or reduce them? (One recommendation is to set up multiple tracking stations and average the results from those measurements.)

Share With Students

Brain Booster

The markings on the outside of the SLS's solid rocket boosters look like black-and-white checkerboards and serve as "targets" for cameras located in strategic locations on and around the vehicle. These markings will be used for photogrammetry, the science of using photography to help measure distances between objects. These targets will enable photogrammetrists to measure critical distances during spaceflight, including booster separation from the core stage.

Learn more: https://www.nasa.gov/exploration/systems/sls/space-launch-system-solid-rocket-boosters-on-target-for-first-flight.html

On Location

The Boeing Company in Huntsville, Alabama, is building the SLS core stage, including the avionics that will control the vehicle during flight. Towering more than 60 m (200 ft) with a diameter of 8.4 m (27.6 ft), the core stage will store 2,760,000 L (730,000 gal) of super-cooled liquid hydrogen and liquid oxygen that will fuel the RS–25 engines.

Learn more: https://www.nasa.gov/sites/default/files/atoms/files/sls_core_stage_fact_sheet_01072016.pdf

Create

- Tip: The altitude tracker is simple enough for everyone to make their own, but they can also be shared.

Test

- Ask the teams to determine the maximum altitude that can be measured with their altitude tracker at each of the three tracking station locations (5, 15, and 30 m).

Share

Engage the students with the following discussion questions:

- What was the greatest challenge for your team today?
- Were there any differences in the measurement of the altitude of the rocket for each trial using the altitude calculator versus the tangent table? Why or why not?
- What factors affected your team's ability to determine the rocket's altitude? How might you adjust this experiment to get more accurate results?

Extensions

- Challenge your students to demonstrate their proficiency with altitude tracking by sighting on a fixed object of known height and comparing their results.
- Employ two or more tracking stations from different perspectives or different distances. Compare measurements from each station and calculate the average.
- Apply basic trigonometry to calculate the height of the rocket at apogee. Compare the results to those of the altitude calculator and tangent table.
- Experiment with different launch angles and graph angle versus altitude.

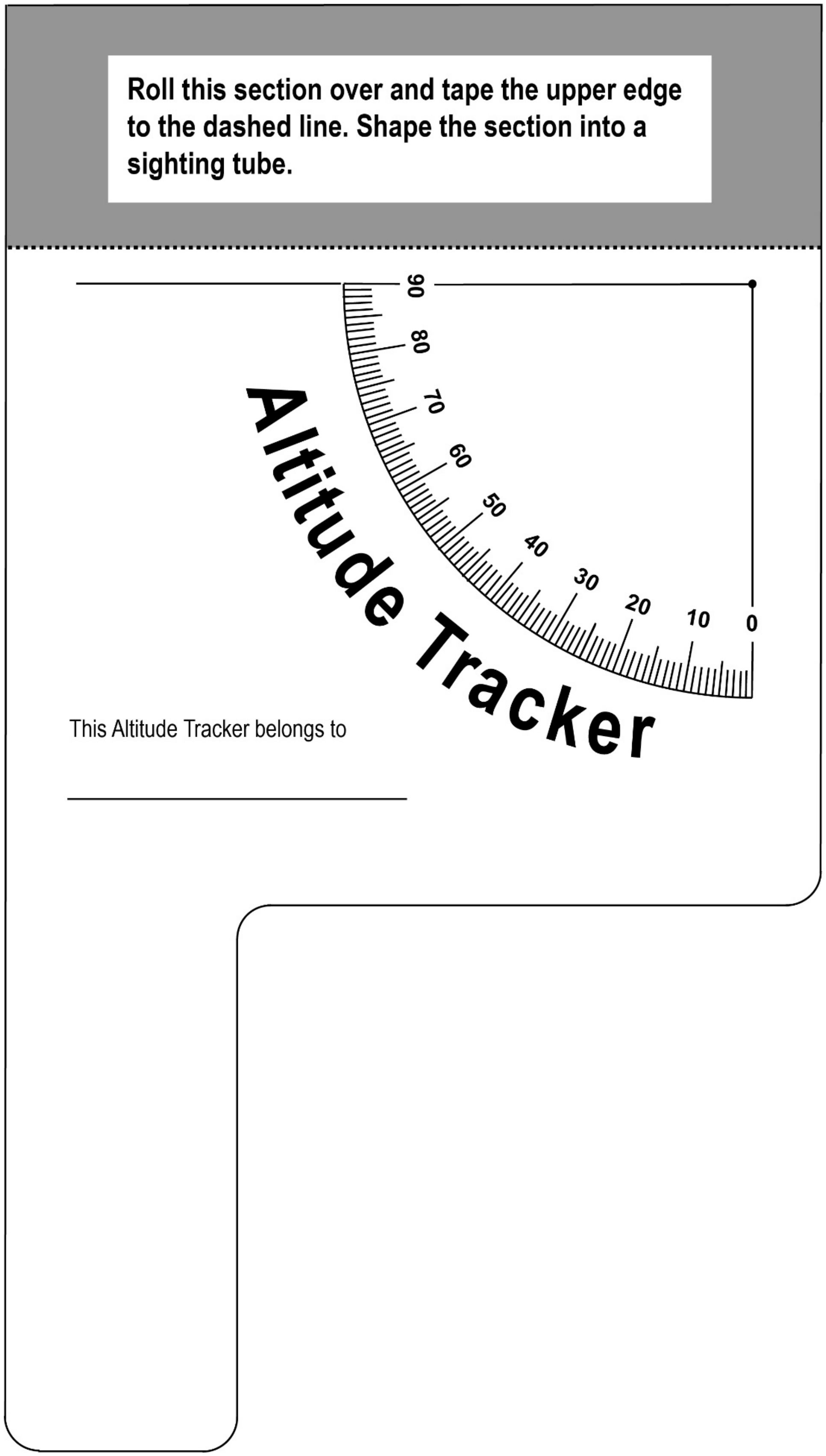
Reference

Modified from Altitude Tracking: https://er.jsc.nasa.gov/seh/Altitude_Tracking.pdf

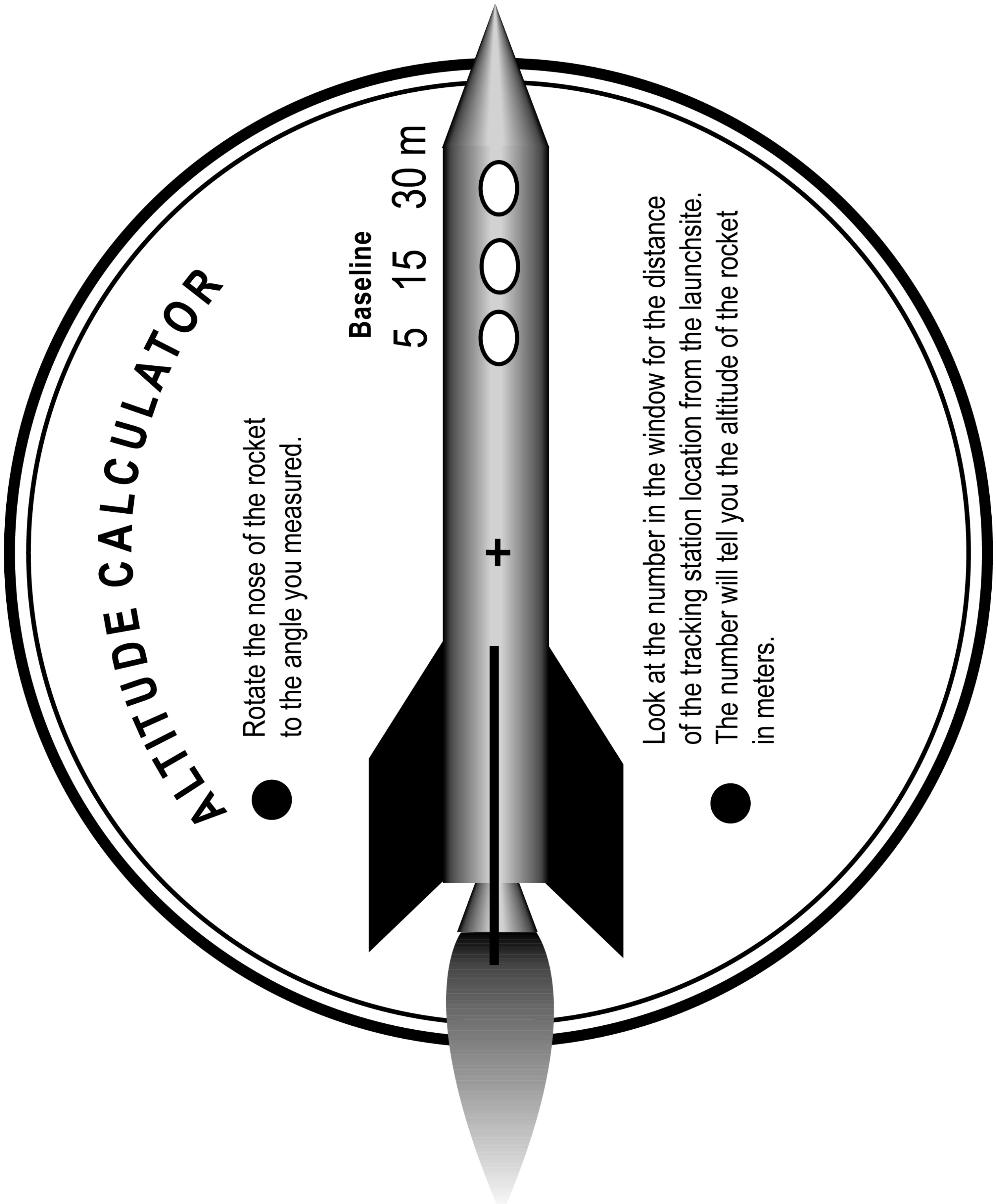
Additional Resource

- Activity: Pop! Rocket. https://www.nasa.gov/stem-ed-resources/pop-rockets.html
- Digital Badging: Online NASA STEM Learning. https://www.txstate-epdc.net/digital-badging/

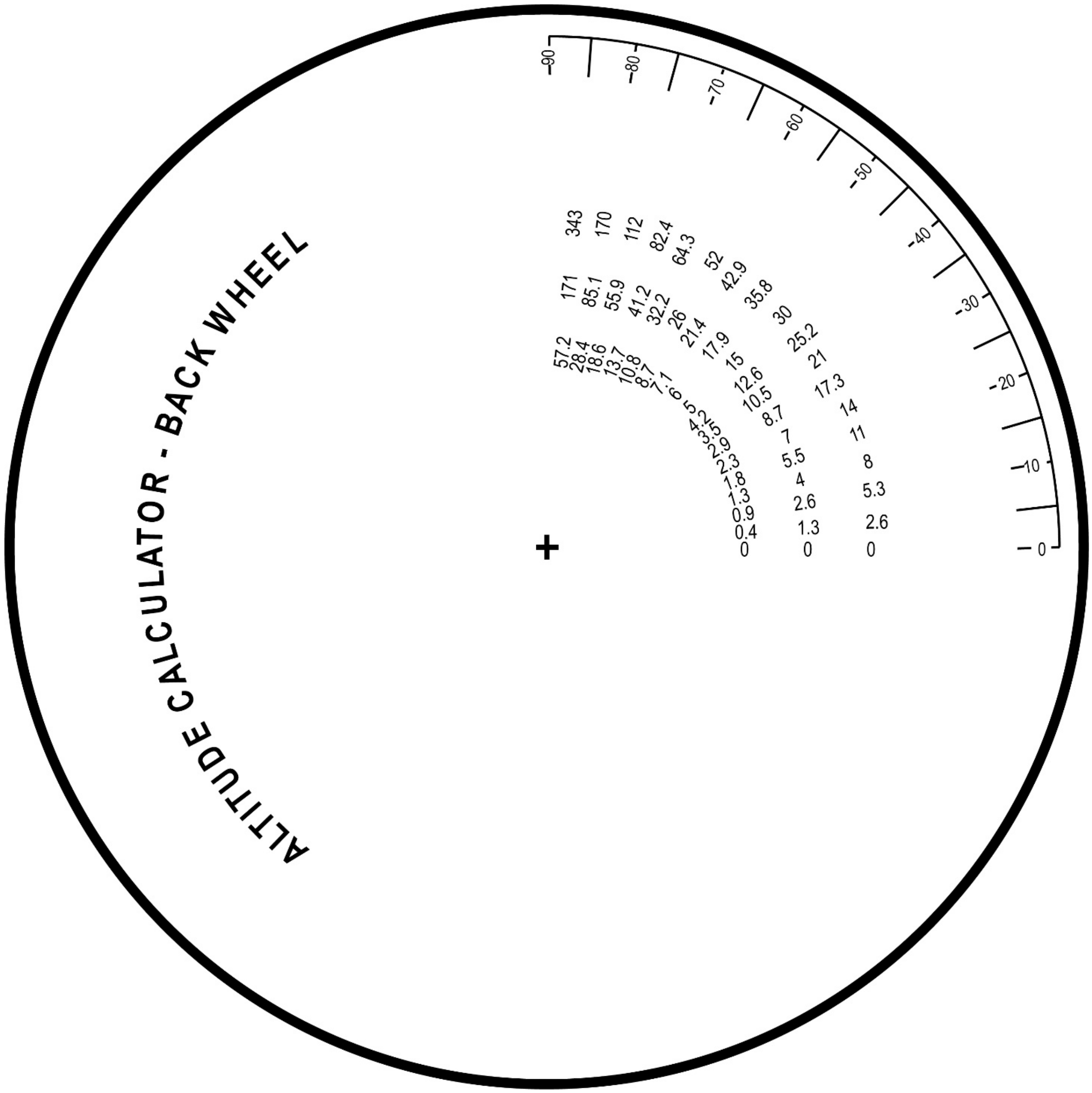
Altitude Tracker Template



Altitude Calculator Template—Front



Altitude Calculator Template—Back



Tangent Table

Degree	Tan	Degree	Tan	Degree	Tan
0	0.0000				
1	0.0174	31	0.6008	61	1.8040
2	0.0349	32	0.6248	62	1.8807
3	0.0524	33	0.6494	63	1.9626
4	0.0699	34	0.6745	64	2.0603
5	0.0874	35	0.7002	65	2.1445
6	0.1051	36	0.7265	66	2.2460
7	0.1227	37	0.7535	67	2.3558
8	0.1405	38	0.7812	68	2.4750
9	0.1583	39	0.8097	69	2.6050
10	0.1763	40	0.8390	70	2.7474
11	0.1943	41	0.8692	71	2.9042
12	0.2125	42	0.9004	72	3.0776
13	0.2308	43	0.9325	73	3.2708
14	0.2493	44	0.9656	74	3.4874
15	0.2679	45	1.0000	75	3.7320
16	0.2867	46	1.0355	76	4.0107
17	0.3057	47	1.0723	77	4.3314
18	0.3249	48	1.1106	78	4.7046
19	0.3443	49	1.1503	79	5.1445
20	0.3639	50	1.1917	80	5.6712
21	0.3838	51	1.2348	81	6.3137
22	0.4040	52	1.2799	82	7.1153
23	0.4244	53	1.3270	83	8.1443
24	0.4452	54	1.3763	84	9.5143
25	0.4663	55	1.4281	85	11.4300
26	0.4877	56	1.4825	86	14.3006
27	0.5095	57	1.5398	87	19.0811
28	0.5317	58	1.6003	88	28.6362
29	0.5543	59	1.6642	89	57.2899
30	0.5773	60	1.7320	90	------------

Activity Two: Track the Altitude of a Rocket

Student Handout

Your Challenge

Construct and use an altitude tracker and altitude calculator to estimate the height of a rocket at apogee (the highest point of the trajectory of the rocket).

Ask, Imagine, and Plan

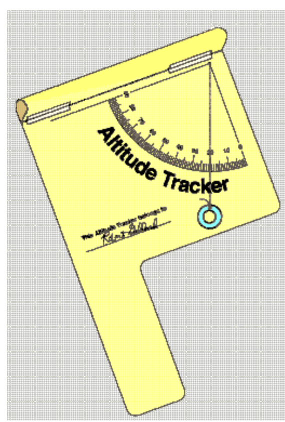
- At what angle should you launch your rocket for maximum altitude?
- What would happen if you changed the launch angle?
- Besides launch angle, what other factors will impact the trajectory of your rocket?
- What are some possible sources of error in this activity and how can your team mitigate them?
- Discuss the best location for a tracking station to determine the altitude of your rocket. Depending upon the expected altitude of the rocket, the tracking station could be 5, 15, or 30 m away. What is the maximum altitude that can be measured with the altitude tracker at each of the three tracking station locations (5, 15, and 30 m)? What distance will your team select for your tracking station and why?

Create

Construct both the altitude tracker and the altitude calculator using the following instructions. (Some of these steps may have already been completed by your teacher.)

Constructing the Altitude Tracker

1. Glue the altitude tracker template onto a piece of cardboard. Do not glue the portion of the tracker above the dashed line.
2. Cut out the template and cardboard along the outside edges.
3. Roll the part of the template not glued to the cardboard (shaded portion) around a milkshake straw and tape it along the top edge of the altitude tracker as a scope or sighting tube.
4. Punch a tiny hole in the apex of the protractor quadrant (the point at the upper right-hand corner).
5. Slip a thread or lightweight string through the hole. Knot the thread or string and tape it on the backside.
6. Complete the tracker by hanging a small washer from the other end of the thread as shown in the illustration.



Constructing the Altitude Calculator

1. Carefully cut out the front and back templates for the altitude calculator.
2. Join the two templates together where the center marks are located. Use a brass paper fastener to hold the pieces together. The pieces should rotate smoothly.

Test

Using the Altitude Tracker

1. Create a data table like the one that follows here on your sheet of paper.

Fun Fact

Hot gases exit the nozzle of the RS–25 engine at 13 times the speed of sound, or fast enough to travel from Los Angeles to New York in 15 minutes!

Learn more: https://www.youtube.com/watch?v=kJo157o_qaw

Career Corner

Mechanical engineers design, develop, build, and test mechanical devices, including tools, engines, and machines. NASA's SLS rocket needs mechanical engineers to work on the many different components of the rocket. One of the components designed by NASA engineers is used to steer the rocket. This part moves the nozzle of the rocket engine to point the SLS in the right direction.

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

Trial	Baseline distance, m	Angle of elevation, deg	Altitude using altitude calculator, m	Tangent of the angle	Altitude using tangent table, m
1					
2					
3					
4					
5					
6					
7					
8					

2. Select a tracking station location a short distance away from the rocket launchsite to measure the maximum height of the rocket using the altitude tracker. In your data table, record the baseline distance from the tracking station to the launch pad for each trial.
3. As the rocket launches, the person doing the tracking will hold the tracker at eye level and tilt the tracker upward, following the trajectory with the sighting tube. Stop and hold the tracker steady when the rocket reaches apogee, its highest point before falling back to Earth. Have another team member read the angle the thread or string makes with the quadrant protractor and record the angle of elevation for each trial in the data table.
4. Use the altitude calculator and/or tangent table to determine the altitude of the rocket in meters.

Using the Altitude Calculator

1. Rotate the inner wheel of the calculator so that the nose of the rocket pointer is aimed at the angle measured with the altitude tracker for each trial.
2. Read the altitude of the rocket by looking in the appropriate window associated with the baseline distance from the tracking station to the launch pad. The altitude the rocket reached will be in the window beneath the markings for 5, 15, or 30 m.
3. To achieve a more accurate measure of altitude, add the height from the ground to the eye level of the person holding the tracker.
4. If the angle falls between two degree marks, average the altitude numbers above and below those marks.

Using the Tangent Table

1. Identify the tangent of each launch angle using the tangent table and record it in your data table.
2. Multiply the tangent of the angle with the baseline distance to determine the altitude of the rocket for each trial.

Share

- Compare the values of the altitude of the rocket for each trial using the altitude calculator versus the tangent table. Were there any differences? Why or why not?
- What factors affected your team's ability to determine the rocket's altitude? How might you adjust this experiment to get more accurate results?

Activity Three: Build a Multistage Balloon Rocket

Educator Notes

Challenge

Students will work together as a team to design and build multistage balloon-powered rockets to demonstrate how rockets can achieve greater distances using the technology of staging.

Suggested Time

120 minutes

Learning Objectives

Students will

- Apply the steps of the engineering design process to successfully complete a team challenge.
- Design and build their own multistage rocket and successfully launch it across the classroom.
- Improve their rockets based upon the results of the experiment.
- Demonstrate an understanding of Newton's laws of motion and their application in rocket launches.

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. • 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.	*Disciplinary Core Ideas (continued)* – 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: Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy and matter flows within systems. • Energy and Matter: Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior. • 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. • Planning and Carrying Out Investigations: Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters. • Construct Explanations and Design Solutions

Technology (ISTE)	
Standards for Students • Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions. – 5c: Students break problems into component parts, extract key information, and develop descriptive models to understand complex systems or facilitate problem solving. • 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)* – 4a: Students know and use a deliberate design process for generating ideas, testing theories, creating innovative artifacts, or solving authentic problems. – 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)	
Content Standards by Domain • CCSS.MATH.CONTENT.6.SP.B.5: Summarize numerical data sets in relation to their context, such as by: – CCSS.MATH.CONTENT.6.SP.B.5.A: Reporting the number of observations. – CCSS.MATH.CONTENT.6.SP.B.5.B: Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.	*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. • 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.
- Print copies of the Student Handout for each team.
- If presenting videos or web-based resources, test the links and the classroom technology ahead of time.
- Prepare the classroom by setting up "launch pads" consisting of fishing line running across the classroom parallel to the floor but high enough so students are able to walk underneath them or near the walls. If you set up two launch pads side by side, students can launch simultaneously to race their rockets across the classroom.

Materials

☐ Foam coffee cups
☐ Fishing line or smooth string
☐ Long balloons (5- by 25-in. balloons work best)
☐ Straight drinking straws
☐ Scissors
☐ Copies of Student Handout and blank paper
☐ Masking tape
☐ Balloon hand pumps (optional)
☐ Wooden spring-type clothespins or large binder clips
☐ Paper/pencil for brainstorming

Introduce the Challenge

- Provide context for this activity using the Introduction and Background information in this guide. Discuss how NASA uses rocket stages for deep space exploration.
- Explain the role of engineers in designing technology to solve problems. Share the NASA video Intro to Engineering and introduce the engineering design process.
- Introduce any new terminology (e.g., first stage, second stage, and thrust).
- Distribute the Student Handout and blank paper and explain the challenge and constraints.

Design Constraints

1. Each team will receive the same materials to construct a multistage balloon-powered rocket that can travel across the classroom along fishing line.
2. The balloon rocket must be securely attached to straws on the fishing line to provide guidance, navigation, and flight control during the launch.

Demonstration

Use the following instructions to demonstrate how to set up a two-stage rocket using two balloons and a foam cup.

1. Thread the fishing line through the two straws. Stretch the fishing line snugly across a room and secure its ends. Make sure the line is just high enough for people to pass safely underneath or near a wall to avoid people walking into it.
2. Cut the coffee cup in half so that the lip of the cup forms a continuous ring.
3. Stretch the balloons by pre-inflating them. Inflate the first balloon about three-quarters full of air and squeeze its nozzle tight. Pull the nozzle through the ring. Twist the nozzle and

Share With Students

Brain Booster

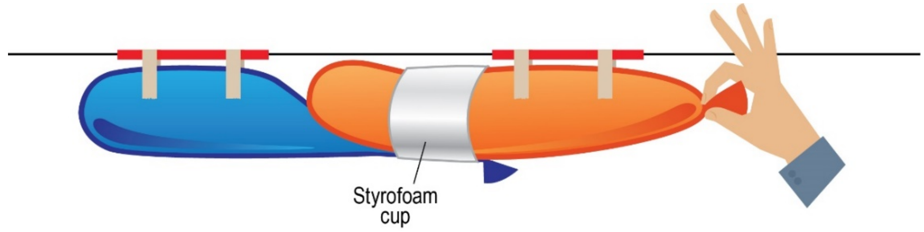
Johann Schmidlap was a German fireworks maker and rocket pioneer. He invented the step rocket, a multistaged transport system for lifting fireworks to higher altitudes. A large skyrocket (first stage) carried a smaller skyrocket (second stage). When the large rocket burned out, the smaller one continued to a higher altitude before showering the sky with glowing cinders. Schmidlap's idea is basic to all of today's multistage rockets that travel to space.

Learn more: https://www.grc.nasa.gov/www/k-12/TRC/Rockets/history_of_rockets.html

On Location

As NASA's mission and requirements have evolved, the Marshall Space Flight Center in Huntsville, Alabama, has evolved to support them. Marshall has developed world-class capabilities in areas such as propulsion, materials, space environments, avionics, advanced manufacturing, life support, testing, and systems integration.

Learn more: https://www.nasa.gov/centers/marshall/home/index.html



hold it shut with a clothespin or binder clip. Inflate the second balloon. While doing so, make sure the front end of the second balloon extends through the ring a short distance. As the second balloon inflates, it will press against the nozzle of the first balloon and take over the clip's job of holding it shut. It may take a bit of practice to achieve this. Clip the nozzle of the second balloon shut also.

4. Take the balloons to one end of the fishing line and tape each balloon to a straw with masking tape. The length of the balloons should be parallel to the fishing line, allowing the thrust to propel the balloons along the string.
5. Remove the clip from the first balloon and untwist the nozzle. Remove the clip from the nozzle of the second balloon as well, but continue holding it shut with your fingers.
6. Conduct a launch countdown. As you release the balloon you are holding, the escaping gas will propel both balloons along the fishing line. As the balloon you released expels air, it will separate from and release the nozzle of the other balloon, which will then provide thrust to continue to propel the balloon rocket across the string.

Facilitate the Challenge

Ask, Imagine, and Plan

Engage the students with the following discussion questions:

- What is the benefit of a multistage rocket?
- What factors could slow your rocket down as it moves across the string?
- What problems do you anticipate encountering?

Create, Test, and Improve

- Each team will build multistage rockets using only the materials supplied.
- Each team will test their design and make observations for systematic improvements to their rockets throughout the activity.

Share

Engage the students with the following discussion questions:

- What problems did your team encounter? How did you solve these problems?
- What forces prevented the rocket from reaching its destination?
- What configuration of balloons was the most successful?
- How do the experiment results compare or contrast to what you know of modern rocketry?
- What was the most innovative solution in the class?

Extensions

- Encourage students to try other launch arrangements, such as side-by-side balloons, three-stage rockets, or multistage heavy lift (vertical) rockets. (Resource: Heavy Lifting Rocket Activity. https://www.nasa.gov/sites/default/files/atoms/files/sls_heavy_lifting_508.pdf)
- Brainstorm ideas for flying a two-stage balloon rocket without the fishing line as a guide. How could the balloons be modified to make this possible?

Reference

Modified from Balloon Staging: https://www.grc.nasa.gov/www/k-12/rocket/TRCRocket/balloon_staging.html

Additional Resources

- Rocket Science in 60 Seconds Video Series. https://www.nasa.gov/exploration/systems/sls/multimedia/rocket_science_in_60_seconds
- Digital Badging: Online NASA STEM Learning. https://www.txstate-epdc.net/digital-badging/

Activity Three: Build a Multistage Balloon Rocket

Student Handout

Your Challenge

Design and build a multistage balloon-powered rocket to demonstrate how rockets can achieve greater distances using the technology of staging.

Design Constraints

1. You are only allowed to use the supplies provided by your teacher.
2. Your balloon rocket must be securely attached to straws on the fishing line to provide guidance, navigation, and flight control during the launch.

Ask, Imagine, and Plan

Discuss ways to configure two or more balloons in stages to design a rocket with enough thrust to travel across the room.

- How many balloons will your team use?
- How and where will the balloons be attached to the straws?
- What problems do you anticipate encountering?
- Sketch and label your ideas and design on the paper provided by your teacher.

Create, Test, and Improve

1. Assemble your multistage rocket design and attach it to the straws on the fishing line.
2. On a sheet of paper, create a data table like the example below.
3. Launch your rocket and record the distance traveled in your data table.
4. Your team must conduct flight tests during construction and systematically improve the design after each test. Record observations during the flight tests that will help you modify your design.
5. Redesign your rocket and balloon configuration to improve the thrust of the rocket and increase the distance traveled.

Share

Write a summary of your launch vehicle using correct science and technology terms. Describe the improvements made to your vehicle after each test and the resulting change in the rocket's performance.

- What was the greatest challenge for your team today?
- What problems did your team encounter? How did you solve these problems?
- What forces prevented the rocket from reaching its destination?
- What configuration of balloons was the most successful?
- How do the experiment results compare or contrast with what you know of modern rocketry?

Flight Test	Distance Traveled
1	
2	
3	
4	
5	
6	
7	
8	

Fun Fact

The power generated by four RS–25 engines is equivalent to the output of 16 Hoover Dams!

Learn more:
https://www.youtube.com/watch?v=MLgYJh6OFbY&feature=youtu.be

Career Corner

Testing 1, 2, 3… Researchers use wind tunnels to learn more about how an aircraft will fly. Aerodynamic testing for the SLS is a critical component to mission success. Discover a career as a research engineer and test scale models of aircraft and spacecraft of the future.

Learn more:
https://www.youtube.com/watch?v=_ChkbjRQq28&list=PLBEXDPatoWBmX3yrpEObbUoNF5rbbNcgX&index=27

Activity Four: Optimize a Water Rocket Engine

Educator Notes

Challenge

Students will work together as a team to build an air-powered water rocket from a 2-liter soda bottle to find the optimal amount of water volume to air pressure for producing maximum thrust.

Suggested Time

120 minutes

Learning Objectives

Students will

- Construct flightworthy water rockets.
- Find the optimal amount of water to compressed air within their water rockets to reach maximum performance (altitude).
- Demonstrate an understanding of Newton's second and third laws of motion and how they apply to rocket launches.

Curriculum Connection

<table>
<tr><th colspan="2">Science and Engineering (NGSS)</th></tr>
<tr>
<td>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.
• 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-ETS1-2 Engineering Design: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.
– 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.
• 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.</td>
<td>Crosscutting Concepts (continued)
• System and System Models: Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy and matter flows within systems.
• Energy and Matter: Tracking energy and matter flows, into, out of, and within systems helps one understand their system's behavior.
• 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.
• Planning and Carrying Out Investigations: Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters.
• 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.
• Obtaining, Evaluating, and Communicating Information: Scientists and engineers must be able to communicate clearly and persuasively the ideas and methods they generate. Critiquing and communicating ideas individually and in groups is a critical professional activity.</td>
</tr>
<tr><th colspan="2">Technology (ISTE)</th></tr>
<tr>
<td>Standards for Students
• 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.</td>
<td>Standards for Students (continued)
– 7c: Students contribute constructively to project teams, assuming various roles and responsibilities to work effectively toward a common goal.</td>
</tr>
<tr><th colspan="2">Mathematics (CCSS)</th></tr>
<tr>
<td>Content Standards by Domain
• CCSS.MATH.CONTENT.6.SP.B.5: Summarize numerical data sets in relation to their context, such as by:
– CCSS.MATH.CONTENT.6.SP.B.5.A: Reporting the number of observations.
– CCSS.MATH.CONTENT.6.SP.B.5.B: Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.</td>
<td>Mathematical Practices
• CCSS.MATH.PRACTICE.MP1: Make sense of problems and persevere in solving them.
• CCSS.MATH.PRACTICE.MP3: Construct viable arguments and critique the reasoning of others.
• CCSS.MATH.PRACTICE.MP5: Use appropriate tools strategically.</td>
</tr>
</table>

Preparation Time

2 to 3 hours for setup, but several weeks for collecting bottles

- 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.
- Note: This activity requires a water rocket launcher. This apparatus can be built in a few hours using basic tools and materials found at most hardware stores. The Water Rocket Launcher Directions in NASA's Rockets Educator Guide include a detailed supply list and building instructions for a water rocket launch stand. Commercial launchers are also available from many science education supply companies.
- Tip: Each team will also need an empty 2-liter soda bottle to complete this activity and several spare bottles to replace any with damage. It is recommended that you begin collecting 2-liter soda bottles a few weeks before you plan to perform the activity.
- If using a glue gun, even with cool-melt glue, set up a station for the glue gun to supervise safety and oversee proper use.
- Precut the PVC pipe for the launch lugs (one per team; instructions follow here).
- Optional: Construct the assembly stands for each team.
- Review the Water Rocket Introduction below for additional context and ties to the curriculum.
- If presenting videos or web-based resources, test the links and the classroom technology ahead of time.

Water Rocket Introduction

A water rocket is a chamber, usually a 2-liter soda bottle, partially filled with water. Air is forced inside the bottle with a pump. When the rocket is released, the pressurized air forces water out of the nozzle (pour spout). The bottle launches itself in the opposite direction. The bottle usually has a nose cone to reduce drag and fins for stability. Water rockets are easily capable of 100-m-high flights, but advanced hobbyists have combined bottles to create staged rockets for flights over 300 m high.

Water bottle rockets are ideal for teaching Newton's laws of motion. The launch of the rocket easily demonstrates Newton's third law. Students can see the water shooting out of the nozzle (action) and see the rocket streak into the sky (reaction). Students will experiment with different pressure levels inside the chamber and different amounts of water. The rocket will not fly very high if it is filled only with air. The air will quickly rush out during the launch, but its mass is very low. Consequently, the thrust produced is also low (Newton's second law). When there is water in the bottle, the air must force the water out first before the air can leave the bottle. The water increases the mass expelled by the rocket, thereby increasing its thrust.

Like all rockets, the flight performance of water bottle rockets is strongly influenced by the rocket's design and the care taken in its construction. Beveling the leading and trailing edges of fins allows them to slice through the air more cleanly. Straight-mounted fins produce little friction or drag with the air. A small amount of ballast weight inside the nose cone helps to balance the rocket. This moves the center of mass of the rocket forward while still leaving a large fin surface area at the rear.

Share With Students

Brain Booster

If heat energy from the SLS's solid rocket boosters (SRBs) could be converted to electric power, two SRBs firing for 2 minutes would produce 2.3 million kWh of power, enough to supply power to over 92,000 homes for a full day.

Learn more:
https://www.nasa.gov/sites/default/files/atoms/files/sls_at_a_glance_10202015.pdf

On Location

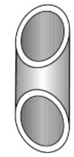
The 65-m- (212-ft-) tall core stage of the SLS will undergo testing on the B–2 test stand at NASA's Stennis Space Center near Bay St. Louis, Mississippi. The B–2 test stand is NASA's largest rocket engine test stand and was built in the 1960s to test the engines of the Saturn V, the first rocket to travel to the Moon. These "Green Run" tests ensure mission success by proving and certifying new hardware ready for flight.

Learn more:

https://www.nasa.gov/feature/new-video-highlights-stennis-space-center-preparations-for-nasa-space-launch-system-testing

https://www.youtube.com/watch?v=6rSsMtRyV70&feature=youtu.be

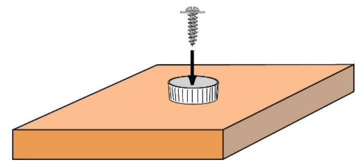
Launch Lug Construction



Launch lug with slanted cuts.

Precut the PVC segments using a saw or PVC cutter. The cuts can be slanted to make them more aerodynamic (see picture). The segments act as launch lugs to guide the rocket up the launch rod during the first moments of the rocket's skyward climb.

Assembly Stand Construction (Optional)

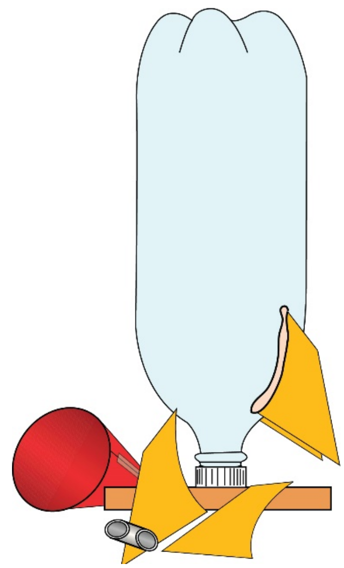


Make mounting stand by screwing the plastic bottle caps to the board. Use a washer for added strength.

Construct assembly stands out of small blocks of wood. Attach a bottle cap to the middle of each board with a small screw and a washer through the cap. When students begin constructing their rockets, they can screw the bottleneck into the cap, and the board below will hold the rocket upright for gluing. The blocks are also a convenient way of storing the rockets upright when not being worked on.

Materials

- ☐ Safety glasses
- ☐ 2-liter soda bottles with caps (one per team plus spare bottles)
- ☐ Foam food trays, posterboard, and/or cardboard
- ☐ Masking tape
- ☐ Clear tape or low-temperature glue gun with cool-melt glue
- ☐ 4 oz. of clay
- ☐ Sandpaper or emery boards
- ☐ String, such as kite string
- ☐ Art supplies
- ☐ Copies of Student Handout and blank paper
- ☐ Metric measuring cups (mL)
- ☐ Water
- ☐ Rocket launcher and bicycle pump or air compressor with regulator (see note in Preparation Time)
- ☐ Launch lugs: 1/2-in.-diameter PVC pipe cut into pieces 1 to 2 in. long. (One launch lug per team)
- ☐ Optional: Altitude tracker (from Activity Two)
- ☐ Optional: Assembly stand
    - ☐ Board measuring 4×4×1 in. (one per team)
    - ☐ Small screw and washer



The Assembly Stand supports the rocket while it is being constructed.

Introduce the Challenge

- Provide context for this activity using the Introduction and Background information in this guide and discuss how Newton's laws of motion apply to rocketry.
    - Optional: A balloon provides a simple example of how a rocket engine works. The air trapped inside the balloon pushes out the open end, causing the balloon to move forward. The force of the air escaping is the action; the movement of the balloon forward is the reaction.
    - Ask students to explain the phenomenon of the balloon rocket launch to assess prior knowledge and identify misconceptions.
    - Extend the concepts in the example of the balloon rocket to rockets for space travel. The combustion of fuel in a rocket engine produces great amounts of exhaust gas at high temperature and pressure. The hot exhaust passes through a nozzle, which accelerates the flow of gas. Thrust is produced according to Newton's third law of motion.
- 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., pressure, propulsion, and Newton's laws of motion).
- Distribute the Student Handout and blank paper and explain the challenge and constraints. Ask students to make a hypothesis before starting this investigation.

Safety

- Remind students of lab safety (e.g., wear eye protection and do not stand downrange during launch).
- Only use low-temperature glue guns or tape. High-temperature glue guns can melt and weaken the plastic bottles.
- Follow all safety instructions that accompany your water rocket launcher.
- Always wear eye protection when near the launch pad.
- Pump water rockets to a pressure no higher than 50 psi and NEVER allow a rocket to be pumped higher than 90 psi.
- Keep the launch area clear and do not stand over the launcher during pressurization and launch.
- Do not allow students to attempt to catch their falling rockets.

Design Constraints

1. Each team will receive the same materials to construct an air-powered water rocket.
2. Each team must attach a launch lug to the side of the rocket between two fins and midway up the body of the rocket.
3. After the rocket has been qualified for launch and certified flightworthy, the only variable that teams will change during testing is the volume of water added to the rocket.

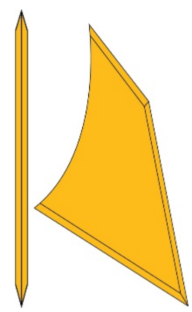
Facilitate the Challenge

Ask, Imagine, and Plan

Engage the students with the following discussion questions:

- What does it mean for a rocket engine to be efficient? What are the benefits of having an efficient engine?
- How do you think changing the amount of water and air inside the rocket will change its efficiency?
- When we test the water rockets, why do you think we keep the pressure constant for each launch?

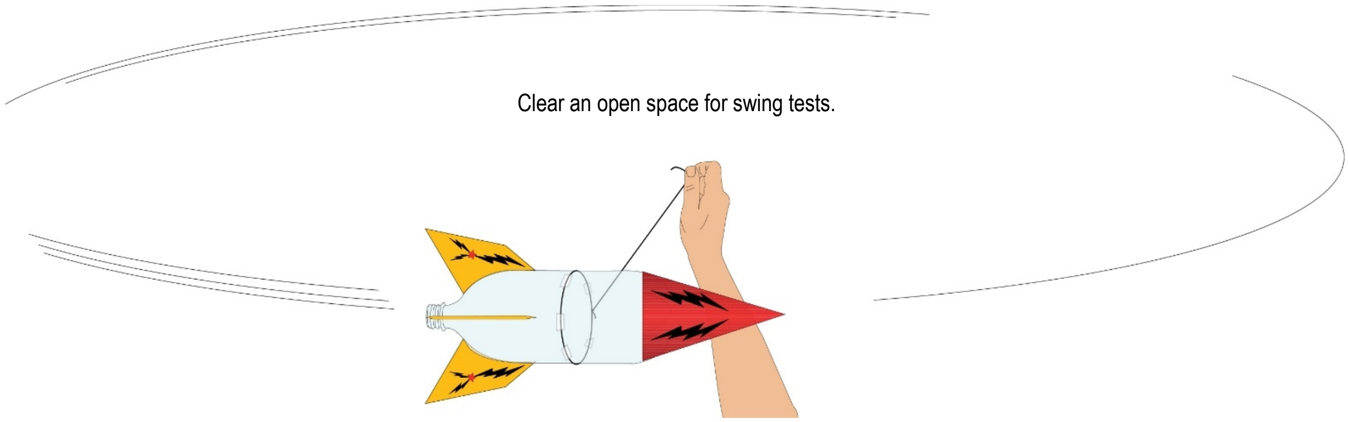
Create



- Describe how fins can be smoothed with sandpaper to slice through the air with little drag.
- Remind teams to add clay to the inside of their nose cones. Trim fin edges with sandpaper to give them knife-blade shapes to slice through the air.
- Have teams glue a launch lug to the side of their rocket. The launch lug should be glued midway up the body of the rocket and positioned midway between two fins.

Test and Improve

- Conduct a preflight inspection before launch to ensure that the nose cone, launch lug, and rocket fins are securely attached.
- When the rocket construction is complete, teams must qualify their rockets for flight by conducting swing tests.
- Review launch procedures and safety with the teams. The instructions are outlined in NASA's Rockets Educator Guide.
- Set up a tracking station for measuring the altitudes achieved by the rockets. (See Activity Two, Track the Altitude of a Rocket.)
- Follow all safety procedures and instructions when launching rockets.
- Each team will launch their rocket several times. After each launch, the team will record the water volume, pressure, and altitude attained by their rocket in tables like the example shown on the Student Handout. Based on the altitude achieved by their rocket, the team will adjust the volume of water in their rocket (increase or decrease) in an attempt to reach a higher altitude. When they can no longer gain an increase in altitude by changing the volume of water in their rocket, they have found the optimum volume of water for their rocket engine and have optimized its efficiency.



Note: No matter how much water is in the bottle, increasing the pressure within the bottle will always produce more thrust. The challenge in this activity is to find the optimal amount of water volume to pressurized air within the bottle for maximum thrust, not merely to increase the pressure. To eliminate variables in the challenge, it is recommended to select a constant pressure (e.g., 40 or 50 psi) to pressurize the bottles for every launch.

Share

Engage the students with the following discussion questions:

- Did you try having your rocket nearly empty of water or nearly full of water for the launch? What was the result?
- What was the volume of water that your team found to be most efficient for your rocket? Was this the same or close to other teams? Why?
- If you were to increase the pressure in your rocket by 10 psi, do you think the volume of water you found would still be the most efficient? Why?

Extensions

- Challenge teams to think of a way to add a parachute to their rockets for soft landings. Plastic grocery bags or lightweight fabric scraps can be used to make parachutes, and strings can be used to attach them. The nose cone must remain in place until the rocket reaches the top of its flight, then it should open and release the parachute.
- Collect class data and graph water volume versus altitude. Repeat the experiment for a different air pressure. Look for a correlation.

Reference

Modified from Water Rocket Construction: https://www.nasa.gov/stem-ed-resources/water-rocket-construction.html

Additional Resources

- Rockets Educator Guide. https://www.nasa.gov/stem-ed-resources/rockets.html
- Digital Badging: Online NASA STEM Learning. https://www.txstate-epdc.net/digital-badging/

Activity Four: Optimize a Water Rocket Engine

Student Handout

Your Challenge

Build an air-powered water rocket from a 2-liter soda bottle to find the optimal amount of water volume to air pressure for producing maximum thrust.

Design Constraints

1. You are only allowed to use the supplies provided by your teacher.
2. You must attach a launch lug to the side of the rocket between two fins and midway up the body of the rocket.
3. After your rocket has been qualified for launch and certified flightworthy, the only variable that your team will change during testing is the volume of water added to the rocket.

Ask, Imagine, and Plan

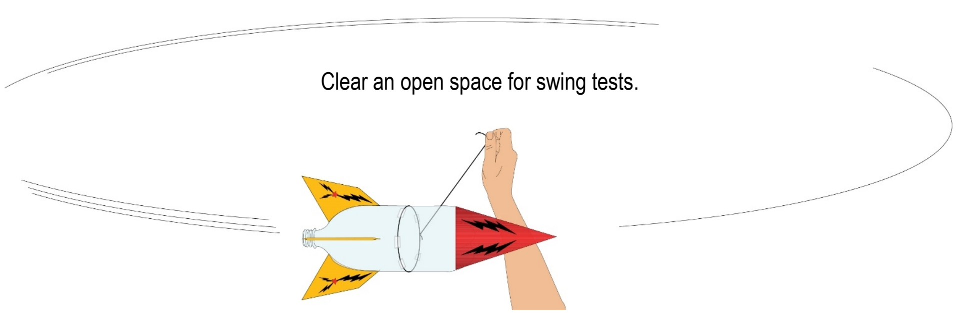
After receiving instructions from your teacher, ask any questions you may have about today's challenge and then sketch a diagram of the rocket you intend to build on the paper provided by your teacher.

Create

1. Using the provided materials, construct a nose cone and fins for your rocket.
2. Add mass to the nose of your rocket to improve stability.
3. Attach a launch lug to the side of the rocket body.

Test and Improve

1. Your teacher must conduct a preflight inspection of the nose cone, launch lug, and rocket fins to ensure they are secure. Qualify your rocket for launch by conducting a swing test.
2. **Swing Test:** Using several feet of string, tie the rocket around the middle so that it balances. Because of the nose cone weight, the balance point will be toward the nose. When the rocket hangs level, a small piece of tape should be temporarily fixed to the string and bottle to keep the string from slipping. The rocket is then swung in a circle. If the rocket tumbles while circling, it is not stable and needs more nose cone weight, bigger fins, or a combination of both. If the rocket circles with the nose always pointed forward, it is stable and ready for flight.



3. Once your rocket is ready for launch, your team will find the optimum volume of water to place in your rocket in order to maximize its performance as measured by its altitude.
4. Be sure to follow all safety instructions for launch as given by your teacher.
5. For each launch trial, you must keep track of the volume of water in your rocket (measured in mL). Your 2-liter rocket will hold a maximum of 2,000 mL of water.

Fun Fact

The RS–25 was the main engine of the space shuttle. If three RS–25 engines pumped water rather than fuel, they would drain a family-sized swimming pool in 25 seconds. The SLS rocket will use four RS–25s.

Learn more:
https://www.youtube.com/watch?v=XP1CQtV8Qk8

Career Corner

The lead systems engineer works with other engineers and analysts to ensure the SLS meets the unique requirements and constraints for each Artemis mission. Systems engineering is both an art and a science. The systems engineer is like the conductor of an orchestra, who knows what the music should sound like (the look and function of a design) and has the skills to lead a team in achieving the desired sound (meeting the system requirements).

Learn more:
https://www.youtube.com/watch?v=VfmHda5e4Il&feature=youtu.be

6. Your teacher will provide the required air pressure (measured in pounds per square inch, or psi), and this will remain constant for all of your launches.
7. You will need to adjust the volume of water for each launch in order to determine the optimum water volume.
8. You will launch a maximum of five times.
9. Create a table like the example that follows here and record your data.

Trial	Volume of water in rocket, mL	Pressure, psi	Altitude, m
1			
2			
3			
4			
5			

Share

- Did you try having your rocket nearly empty of water or nearly full of water for the launch? What was the result?
- What was the volume of water that your team found to be most efficient for your rocket? Was this the same or close to other teams? Why?
- If you were to increase or decrease the air pressure in your rocket by 10 psi, do you think the volume of water you found would still be the most efficient? Why?

Appendix: STEM Standards and Practices

Next Generation Science Standards (NGSS)

https://www.nextgenscience.org/

Alignment of Activities With NGSS Disciplinary Core Ideas				
Motion and Stability (MS) Standard	**Design a Foam Rocket With Stabilizing Fins**	**Track the Altitude of a Rocket**	**Build a Multistage Balloon Rocket**	**Optimize a Water Rocket Engine**
Forces and Interactions				
MS-PS2-2	✓		✓	✓
Engineering Design				
MS-ETS1-1	✓		✓	✓
MS-ETS1-2				✓
MS-ETS1-3	✓		✓	✓
MS-ETS1-4	✓		✓	✓

Alignment of Activities With NGSS Crosscutting Concepts				
Concept	**Design a Foam Rocket With Stabilizing Fins**	**Track the Altitude of a Rocket**	**Build a Multistage Balloon Rocket**	**Optimize a Water Rocket Engine**
Patterns				
Cause and Effect	✓		✓	✓
Scale, Proportion, and Quantity				
System and System Models	✓		✓	✓
Energy and Matter			✓	✓
Structure and Function	✓			
Stability and Change				
Interdependence of Science, Engineering, and Technology	✓	✓	✓	✓
Influence of Engineering, Technology, and Science on Society and the Natural World				

NGSS Science and Engineering Practices

https://ngss.nsta.org/PracticesFull.aspx

Alignment of Activities With NGSS Science and Engineering Practices				
Practice	**Design a Foam Rocket With Stabilizing Fins**	**Track the Altitude of a Rocket**	**Build a Multistage Balloon Rocket**	**Optimize a Water Rocket Engine**
Asking Questions and Defining Problems	✓		✓	✓
Developing and Using Models	✓		✓	✓
Planning and Carrying Out Investigations			✓	✓
Analyzing and Interpreting Data	✓	✓		✓
Using Mathematics and Computational Thinking	✓	✓	✓	✓
Constructing Explanations and Designing Solutions	✓		✓	✓
Engaging in Argument From Evidence				
Obtaining, Evaluating, and Communicating Information		✓		✓

International Society for Technology in Education (ISTE) Standards for Students

https://www.iste.org/standards/for-students

Alignment of Activities With ISTE Standards for Students				
Standard	**Design a Foam Rocket With Stabilizing Fins**	**Track the Altitude of a Rocket**	**Build a Multistage Balloon Rocket**	**Optimize a Water Rocket Engine**
Knowledge Constructor				
3d	✓	✓		✓
Innovative Designer				
4a			✓	
4c	✓		✓	
4d				
Computational Thinker				
5c		✓	✓	
Global Collaborator				
7c	✓	✓	✓	✓

Common Core State Standards (CCSS) for Mathematics

http://www.corestandards.org/Math/

Alignment of Activities With CCSS Grade Level Content Standards by Domain				
Standard	**Design a Foam Rocket With Stabilizing Fins**	**Track the Altitude of a Rocket**	**Build a Multistage Balloon Rocket**	**Optimize a Water Rocket Engine**
6th Grade				
CCSS.MATH.CONTENT.6.NS.B.3		✓		
CCSS.MATH.CONTENT.6.SP.B.5			✓	✓
7th Grade				
CCSS.MATH.CONTENT.7.NS.A.2		✓	✓	
CCSS.MATH.CONTENT.7.NS.A.3		✓	✓	

Alignment of Activities With CCSS Standards for Mathematical Practice				
Practice	**Design a Foam Rocket With Stabilizing Fins**	**Track the Altitude of a Rocket**	**Build a Multistage Balloon Rocket**	**Optimize a Water Rocket Engine**
CCSS.MATH.PRACTICE.MP1	✓		✓	✓
CCSS.MATH.PRACTICE.MP2				
CCSS.MATH.PRACTICE.MP3	✓		✓	✓
CCSS.MATH.PRACTICE.MP4		✓		
CCSS.MATH.PRACTICE.MP5	✓	✓	✓	✓
CCSS.MATH.PRACTICE.MP6		✓		
CCSS.MATH.PRACTICE.MP7				
CCSS.MATH.PRACTICE.MP8				

Back cover: Illustration depicting NASA's Space Launch System (SLS) in the Block 1 cargo configuration as it leaves Earth. The solid rocket boosters produce 75 percent of the thrust to launch the vehicle and then separate from the SLS rocket after being expended. (NASA)

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