NASA Engineering Design Challenge
Spacecraft Structures
Teacher Guide

Overview
Space Transportation
NASA engineers at Marshall Space Flight Center, along with their partners at other NASA centers, and in private industry, are designing and beginning to develop the next generation of spacecraft to transport cargo, equipment, and human explorers to space. This design challenge focuses on rockets, which will replace the Space Shuttle in the task of putting people, satellites, and scientific experiments into space.

Connect to Engineering and Science
The Engineering Design Challenges connect students with the work of NASA engineers by engaging them in similar design challenges of their own. With some simple and inexpensive materials, you, the teacher, can lead an exciting unit that focuses on a specific problem that NASA engineers must solve and the process they use to solve it. In the classroom, students design, build, test, and revise their own solutions to problems that share fundamental science and engineering issues with the challenges facing NASA engineers.

The Design Challenge
You will present students with a challenge: Build a model thrust structure that is as light as possible, yet, strong enough to withstand the load of a “launch to orbit” three times. As a means of getting your students excited about this lesson, show them the student videos and mission videos found only on the NASA Explorer Schools Virtual Campus at explorerschools.nasa.gov.

Students first determine the amount of force needed to launch a model rocket to 3.3 feet (1 meter), which represents low Earth orbit. Then they design, build, and test their own structure designs. They revise their designs over several design sessions, trying to maintain or increase the strength and reduce the weight of their structure. They document their designs with sketches and written descriptions. (Use Test Results Sheet and Design Specifications Sheet at end of this Teacher Guide.)

Time Required
The design challenge can be carried out in two 45-minute class periods, but you could easily extend it for twice that length of time.

Value to Students
These activities help students achieve national goals in science, math, and thinking skills. In the pilot testing of the design challenge, students embraced the design challenge with excitement. This activity will provide your students the opportunity to solve a challenge based on a real-world problem that is part of the space program and to use creativity, cleverness, and scientific knowledge in doing so. During these activities, students will have many opportunities to learn about forces, structures, and energy transfer. The culminating activity gives students an opportunity to develop their presentation and communication skills.
National Science Education Standards

Science as Inquiry
All students should develop abilities necessary to do scientific inquiry.

Fundamental Abilities and Concepts
- Students should develop general abilities, such as systematic observation, making accurate measurements, and identifying and controlling variables.
- Students should use appropriate tools and techniques, including mathematics, to gather, analyze, and interpret data.
- Students should base their explanation on what they observed, providing causes for effects and establishing relationships based on evidence.
- Students should think critically about evidence, deciding what evidence should be used, and accounting for anomalous data.
- Students should begin to state some explanations in terms of the relationship between two or more variables.
- Students should develop the ability to listen to and respect the explanations proposed by other students.
- Students should become competent at communicating experimental methods, following instructions, describing observations, summarizing the results of other groups, and telling other students about investigations and explanations.
- Students should use mathematics in all aspects of scientific inquiry.
- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigations.
- Scientific explanations emphasize evidence.
- Scientific investigations sometimes generate new procedures for investigation or develop new technologies to improve the collection of data.

Physical Science
All students should develop an understanding of motions and forces.

Fundamental Concepts and Principles, Grades 5-8
- An object that is not being subjected to a force will continue to move at a constant speed and in a straight line.
- If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.
- Energy is transferred in many ways.

Science and Technology
All students should develop abilities of technological design.

Fundamental Concepts and Principles
1. Design a solution or product
   a. Consider constraints
   b. Communicate ideas with drawings and simple models
2. Implement a design
   a. Organize materials
   b. Plan work
   c. Work as collaborative group
   d. Use suitable tools and techniques
   e. Use appropriate measurement methods
3. Evaluate the design
   a. Consider factors affecting acceptability and suitability
   b. Develop measures of quality
   c. Suggest improvements
   d. Try modifications
Communicate the process of design
Identify stages of problem identification, solution design, implementation, evaluation

The challenge satisfies the following criteria for suitable design tasks:
- Well defined, not confusing.
- Based on contexts immediately familiar to students.
- Has only a few well-defined ways to solve the problem.
- Involves only one or two scientific concepts.
- Involves construction that can be readily accomplished by students, not involve lengthy learning of new physical skills, and not require time-consuming preparation or assembly.

All students should develop understandings about science and technology.
- Difference between scientific inquiry and technological design.
- Technological designs have constraints.
- Technologies cost, carry risks, and provide benefits.
- Perfectly designed solutions do not exist; engineers build in back.

Implement a design systems.

Materials Needed

Materials for Spacecraft Structures (student designs):
- Craft sticks
- Dowels
- Glue guns and hot-melt glue
- Corrugated cardboard
- 35 mm film canisters
- Cardboard cutter

Materials for Launchpad:
- 1-liter soda bottles
- 2-liter soda bottles
- Meter stick
- 25 to 50 pounds of sand (11-23 kilograms)
- A sturdy cloth bag to hold the sand
- Ring stand
- Launch lever (constructed from 2x4 and hinge (see details below)
- Brass tubing
- Package tape (2-3 inches wide)
- 4-ounce paper cups
- Safety goggles

Build the Launchpad

Ring Stand (Launch Rod)
A ring stand of the type used in chemistry labs with a vertical rod 1/2 inch in diameter and approximately 3 feet (1 meter) tall. (This is taller than most.) The kind with a large heavy base is best.

You can use any straight metal rod 1/2 inch in diameter and 3 to 4 feet (0.9 to 1.2 meters) long if it can be attached to a suitable base. If you have a way to thread such a rod for several inches at one end, you can then attach it to a base with nuts and washers.

Weight for Dropping
A sturdy cloth bag about the size of a loaf of bread containing about 15 to 20 pounds (7 to 9 kilograms) of sand or fine gravel will work well. If you plan to do calculations using the mass of the dropped weight, 22 pounds (10
kilograms) provides a convenient figure. Lead shot makes an excellent filler for the drop weight. Sturdy sewing of the bag is important.

**Wooden 2 by 4**
1 piece 50 inches (1.3 meters) long (for the launch lever)
1 piece 4 inches (10 centimeters) long (for the mounting block)

**Plywood Base Board**
3/4 or 1/2 inch thick, 10 by 14 inches (25.4 by 35.6 centimeters). Any size from 8 by 12 inches (20 by 30.5 centimeters) to 12 by 16 inches (30.5 by 40.6 centimeters) is fine.

**Hinge**
You may use almost any kind of sturdy hinge that can be attached to the launch lever and the mounting block.

**One Piece Launch Stand**
If you mount the launch rod and the launch lever on the same base board they will stay correctly aligned.

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**Build the Rockets**

*As a means of getting your students excited about this lesson*, show them the student videos and mission videos found only on the NASA Explorer Schools Virtual Campus at explorerschools.nasa.gov.
**Materials Needed**

**Soda Bottles (and Caps)**
You will use the 1-liter size for most of the rockets, but it is good to have some 2-liter bottles on hand as well. The bottles that have a 5-lobe base are better for this activity than other kinds.

**Brass Launch Tubes**
Craft, art supply, and hobby stores sell brass tubing in sizes that just fit inside each other, so it is sometimes called “telescoping tubing.” It comes in 12-inch lengths. 9/16 inch outside diameter is just right to fit easily over the launch rod (the ring stand). You will need to cut the tube into 4-inch (10-centimeter) lengths, which you can do with a tubing cutter or a fine saw. You can also use PVC pipe with a similar diameter.

**Package Tape**
This is used to attach the launch tube to the soda bottle.

**Construction**

Fill the bottle with water and cap it tightly. Tape a 4-inch (10-centimeter) length of tube to the flat cylindrical part of the bottle. Be sure the tube is vertical.

![Spacecraft Structure](image-url)
**Introducing the Challenge and Getting Started**

To get your students excited about this lesson, show them the student videos found on the NASA Explorer Schools Virtual Campus website. This website also contains professional development videos and many more resources that will help you make this lesson a success in your classroom.

**Spacecraft Thrust Structures**

Every pound that is carried to space requires fuel to do so, regardless of whether that pound is cargo, crew, fuel, or part of the spacecraft itself. The more the vehicle and fuel weigh, the fewer passengers and smaller payload the vehicle can carry. Designers try to keep all the parts of the vehicle, including the skeleton (or structure), as light as possible. To design a lightweight structure is very difficult, because it must be strong enough to withstand the tremendous thrust (or force) of the engines during liftoff. Throughout the history of space vehicles, engineers have used various strategies for the structure. (Students can calculate the “payload” to total weight ratios for (a) the family car and (b) a student riding a bicycle.)

In order to make the spacecraft as light as possible, NASA engineers are constructing them of lightweight, strong materials, such as Al-Li 2195, an aluminum-lithium alloy, which is less dense and stiffer than pure aluminum. NASA engineers also design structures that use as little material as possible to achieve the strength and rigidity they need. So, for example, they make use of a network of hollow tubular struts (called a truss) rather than use more compact, but heavier solid beams.
The Challenge

- Build the lightest weight thrust structure that will withstand the force of launch to orbit at least three times.
- Launch to orbit = propelling a 1-liter bottle of water to the height of approximately 3 feet (1 meter) into the air.

Design Constraints

- Use only the specified materials.
- The thrust structure must be taller than 2 inches (5 centimeters) and must allow space in the center for fuel lines and valves represented by a 35mm-film canister without its lid.

Explain to students that during the following three class sessions, they will design a thrust structure, launch it, record the results, and then try to improve on the design by making it lighter and stronger. They will get at least four chances to improve on the design. Show students your heavy design, and tell them that you are sure they can do better!

Culminating Activity

Explain that each team will construct a "storyboard" or poster that will tell the story of the development of their thrust structure. Using the storyboard, each team will then make a presentation to the class explaining the evolution of their design.

The storyboard should contain at least three of the team’s recording sheets. If possible, students should attach three of the actual tested models. The poster should show the evolution of the team’s design from its initial to intermediate and final design stages. Essentially, it should “tell the story” of the design process and explain how and why the design changed. It should conclude with a concise statement of “what we learned.”

In addition to completing the recording sheets, direct students to keep running notes, diagrams, questions, research findings, data, etc., in a journal or log. These journals will provide an excellent resource for documenting their experience when they need to make their storyboard.

Determine the “Engine Thrust”

Explain to students that their first task will be to determine the necessary thrust to propel the bottle rocket “to orbit.” They will determine a drop height for the sandbag so that the rocket just flies off the ring stand. Discuss with students why you do not want it to fly too far off the launch rod. (That would be subjecting the structure to more force than necessary and overshooting “orbit.”)

Questions

Ask students: How much mass are we launching to orbit? (2.2 pounds or a 1 kilogram bag of sand) What is the source of the propulsive force? (22 pounds or a 10 kilogram bag of sand) What forces are acting on the bag of sand when it is suspended in the air before the drop? (Gravity and the student’s muscles) What forces are acting on the bag when it is released? (Gravity) Trace where the force goes. (Down on one side, up from the other end of the lever) Optional: Discuss why it is important for the lever to be stiff rather than flexible.

Introduce the Materials

Explain to students that they must build a thrust structure using the craft sticks and hot melt glue. The structure should be attached at the top to a square of cardboard on which the bottle will sit. The structure is NOT attached to cardboard at the bottom.

Review Safety Issues

Point out to students that the tip of the glue gun and the metal strip at the front of the glue pot are hot and should be avoided. Review the procedure for burns. Remind students to wear safety goggles when launching their model.
Introduce the Recording Sheets
Introduce the “Design Specifications” and “Test Results” sheets at the back of the Teacher Guide. One way is to make a transparency of each sheet and project it on the overhead. Tell students that these are where they will record all the details of their designs and the results of their testing. Explain that engineers need to keep careful records. Ask students why record keeping is so important. Discuss each part of the “Design Specifications” and the “Test Results” sheets. Make sure students understand that one sheet shows their model before testing and that the other shows it after testing.

Remind students to keep track of their designs by numbering their recording sheets. Remind them that they will use their recording sheets to construct a storyboard at the end of the challenge. Explain to students the importance of a detailed sketch of their design. Their goal in sketching should be that someone looking only at the sketch could reconstruct their design. You may wish to show a completed recording sheet as a sample.

Explain the Test Procedure
- When their design is completed, the team completes a recording sheet and brings the model and the recording sheet to the teacher.
- The teacher checks the recording sheet for completeness and accuracy.
- The teacher checks that the model has conformed to all design constraints.
- Before their model is tested, each team must do a brief oral presentation (for the entire class) in which they describe the key features of the design.
- During the testing, the team should carefully observe and record the performance of their design.

Students Design and Build their Models
Allow 10–15 minutes for this first design and build. Establish a cut-off time when you will begin testing. Teams that do not have designs ready to test by the cut-off time must wait until the next round of testing.

Example of a structure design

Approving Models for Testing
- Model uses only allowable materials.
- Model is at least 2 inches (5 centimeters) tall.
- A 35mm film canister (without lid) fits entirely inside the thrust structure.
- The model has a team name or identifying mark on it.
- The recording sheet is completely filled out, including a satisfactory sketch.
If the model is approved, place it on the testing station table. You might call this “being on deck.”

Test the Models
Begin testing when most of the teams’ designs have been approved. Have students stop working and gather around the launch station.

Older students may be able to continue working while other teams have their models tested. For this arrangement to work, you will need to locate the launch station in a central location where students can view it from their work areas.

Before launching, have a member of each team stand and hold up the model or show it around to all other students. The representative should explain:
- Key features of the design.
• Why those features were used.
• Where the idea came from (a previous design, another team's design, another type of structure, etc.).

Assign a student to record the results of each test either on a chart on the chalkboard or on a large sheet of paper.

With no repairs allowed between launches, test each team’s model three times in succession. If you have more time, you may wish to increase the number of launches per model. Inspect the model after each launch. Students should make notes about which structural members failed or are in danger of failing.

A failed launch occurs when the rocket does not make it into orbit. A failed launch also occurs when the design no longer meets the design constraints, that is, it is less than 2 inches (5 centimeters) high or a film canister no longer fits inside. (Important: Do not leave the film canister in the model when launching.)

**Discuss the Results of Testing**

The post-test discussion is critical to expanding students’ learning beyond the design and construction techniques and connecting their design work with the science concepts underlying their work.

Encourage students to hold the model and use it to illustrate their point when they talk about a particular design feature.

For each model, you should pose the same guiding question:

• “How did this structure transmit the force of launch from the lever to the bottle?”

Record (or have a student record) the most successful design features on a transparency or on a wall chart. This list should be expanded and revised throughout the activity as the students collectively discover which designs are strong and lightweight.

If any of the columns in the structure have buckled, help students think about how to strengthen the posts, for example, through bracing.

**Design, Build, Test, and Discuss Results**

Continue to add successful design features to the list you started, on a transparency or chart paper, in the previous session. Continue to ask students how the thrust is transferred from the lever to the bottle and to have students trace the load paths on paper or directly on the model.

Allow students approximately 15 minutes to design, build, and complete a recording sheet for each model.

*Remember to register with NES*, or your students’ entries will be ineligible for the contest. Go to explroerschools.nasa.gov where you will find complete registration instructions.
Test Results Sheet

Date: __________________ Class: __________________ Team: __________________

Designer Names: ________________________________________________________

After testing, sketch your model below. Show failure points if any:

<table>
<thead>
<tr>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
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</tbody>
</table>

Record the test results

Describe the results of the testing. Explain which features seemed effective and which did not.

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Design Specifications Sheet

Date: ____________________ Class: ____________________ Team: ____________________

Designer Names: ________________________________________________________________

Sketch your design below. Identify materials used. Show glue points.

Describe the key features of your design:

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