Lesson 6: Heavier than Air—Rockets

This lesson teaches students how forces act differently on rockets and planes. Students will work in teams to design, build, and test rockets. Students will be introduced to an overview of rocket mechanics, learn where the center of mass of their rocket lies, and discover how it can be changed. Team collaboration is a key aspect of this lesson; be intentional and strategic when creating groups. Utilize project roles from the last session if you think they will help students stay on task. If you do use project roles it may be helpful to rotate positions so everyone has a chance to launch the rocket.

Learning Objectives

Students will

- Be able to explain the forces that propel a rocket and articulate how design affects these forces
- Learn what the center of mass of an object is and potential ways that it can be shifted
- Be able to describe the similarities and differences between airplane and rocket flight
- Gain an elementary understanding of the complexities of rocket propulsion

Materials

See detailed materials below. We recommend that you purchase or build a rocket launcher with a safety release cord of at least 15 feet. Anyone who participates in the included experiments does so at their own risk. Always exercise extreme caution and get additional support from teachers for group management during rocket launches.

Time

2 hours

WELCOME AND CHECK-IN (10 MINUTES)

Welcome students to the classroom and ask a check-in question. Today's lesson focuses on rockets and flight, so a good introductory question will get students thinking about the subject matter. Some example questions are

- What do you know about rockets?
- What forces do you think act on a rocket?
- How could you test your guesses?

PART I: WHAT IS A ROCKET? (20 MINUTES)

A rocket is a large, cylinder-shaped object that moves very quickly by forcing out burning gases. Rockets are used for space travel or as weapons.

You should display a diagram of a rocket or draw an elementary one for students to see. The diagram does not need to be intricate but does need to provide brief descriptions of the elementary components, including the nose cone and fins.

Rockets are different from planes and have different trajectories. Rockets are the oldest form of self-contained vehicles in existence. Early rockets were in use more than 2,000 years ago. However they were not originally used for human travel.

Forces on a Rocket Versus an Airplane

This is a good opportunity to test knowledge and retention from previous lessons. You can either draw or print diagrams of a plane and a rocket. If possible, display the images side by side and ask students which direction each force acts upon an airplane. Then ask them the same questions for a rocket.

If students need reminders of the forces, you can draw directional arrows in the motion of the force being applied. Students should be able to identify and explain the different roles that thrust, lift, drag, and gravity have on airplanes.

Notice which forces acting upon rockets are different.

Rockets are a great example of what law?

They're an example of Newton's third law of motion.

If the group needs a reminder you can reference a previous image and walk through the forces acting on the rocket, thrusting it out of the atmosphere. You want students to be able to identify the action and matched reaction on the rocket. If you have access to video, show students a rocket launching out of Earth's atmosphere. Students should understand the massive force that is necessary to propel a heavy item against gravity and into space.

The amount of thrust (force) produced by a rocket engine will be determined by the mass of rocket fuel that is burned and how fast the gas escapes the rocket. The reaction, or motion, of the rocket is equal to (and in the opposite direction of) the action, or thrust, from the engine.

Launching People

Here you have the option of showing a time line of human space exploration or a video of some of the first human rocket launches into space and footage from recent launches to compare innovations in technology. Students should identify what similarities and differences they notice between apparatuses.

Even though rockets have been around for quite some time, we haven't been using rockets to launch people into space for very long.

How does Newton's third law apply to rocket engine thrust?

Return to your elementary diagram of a rocket to have students identify the action and reaction during a rocket launch.

Rocket Engines

Here you will want to show the girls the internal structure of the combustion chambers of a solid and liquid rocket. Point out each respective part as you discuss it.

There are two main categories of rocket engines: solid rockets and liquid rockets. In a rocket engine, fuel and a source of oxygen, called an oxidizer, are mixed and exploded in a combustion chamber. The combustion produces hot exhaust, which is passed through a nozzle to accelerate the flow and produce thrust.

An example of a solid rocket is a firecracker or the solid rocket boosters on the sides of the fuel tank for the space shuttle. Basically, they are lit and just burn until all of the fuel is gone. There is no way to control them except by layering different fuels in the tube.

The three main engines on the space shuttle are liquid rockets. They have valves that control the flow of the fuel, like gas pedals on a car. It is possible to decrease and increase the thrust of shuttle engines. They are the most powerful single engines ever made.

Drawing similarities between exercises that students complete and real-world engineering tasks will help students visualize themselves in STEM professions. For example, consider illustrating the similarities between the rocket that students will build and rockets that are launched into outer space.

PART II: LAUNCH A BOTTLE ROCKET (60–90 MINUTES)

Have you ever launched a bottle rocket? It's not quite as complicated as a solid or liquid rocket, but it is just as fun! There will be no combustion in the rockets that you build. In order to increase the pressure on the inside you will partially fill the rocket with water, plug it up, and force air in using a bicycle pump.

Group students differently than in the past. Be intentional about pairings based on the dynamics of your cohort. If you have a smaller class, you can have students work in pairs. If you have a large class, consider creating groups of four and utilizing project roles.

Materials

You'll need the materials below for each group.

- A 2-liter bottle
- 1 roll of tape (duct or packing)
- 4 manila envelopes
- 2–3 large cardboard boxes cut into 8 ½ " X 11" pieces
- 4–5 pieces of construction paper
- A small amount of clay to use on desks as a stabilizer during the construction process
- 1 pair of scissors
- Protective eyewear for each student

The groups will take turns using the following

- 1 bike pump
- 1 rocket launcher (we recommend that you purchase a rocket launcher with a safety valve and a distance trigger to allow for students to stand away from the launcher during this activity)

Tell students to think about what they already know about rockets. Aerospace engineers have to consider all of the potential factors that may affect a rocket during launch into or out of our atmosphere.

What do rockets look like? What are some characteristics that many of them have? How are Bernoulli's principle and Newton's third law going to affect the flight path of their rocket? What other forces should you consider when building your rockets?

Instructions

1. Tell students that they are going to work as teams to build a rocket. The goal is to have their rocket launch as high into the air as possible.
2. Give students 15–20 minutes to build their rockets using their construction materials. Make sure that everyone is included in the design and building process.
3. After the allotted time is up, instruct students to decide who will launch their rocket, who will pump the rocket up with air, and who will observe and draw a picture of the findings.
4. Tell one student from each group to fill up their rocket with water. Students can choose how much water they want to put in the bottle but should decide with their teammates. Ideally each group will have the opportunity to launch several times, each with a different amount of water in their rocket. Tell students to think strategically about how amount of water, air, and pressure will all affect the flight of their rocket.
5. Once students have filled their rockets, instruct them to sit in a line at least 30 feet from your rocket launcher.
6. Choose one group to launch first. A good incentive to get everyone's attention is to choose the quietest group.
7. Place the rocket on the launcher by turning the launcher upside down and fitting the gasket to the top of the 2-liter bottle.
8. The student who has been selected to pump the bicycle pump will now pump up the rocket, filling it with pressure. Keep in mind that about 70 psi of pressure will launch these rockets around 100 feet into the air. If your launcher does not have a safety valve to prevent the bottle from exploding, it is not recommend to launch rockets with more than 70 psi.
9. Once the student is done pumping, tell them to return to their group and have a seat. No one should be standing near the launcher before or during rocket flight.
10. Now instruct all students to quietly watch as the final step is completed. Having all students attentive will prevent anyone from inadvertently being hit by the bottle.
11. Tell the student who was deemed the rocket launcher to pull the release cord to launch the rocket. Make sure that this student is standing as far away as possible from the launcher. The cord should be at least 15 feet long and fully extended when the student pulls it.
12. One student should retrieve the rocket so teams can see how the impact affected their rocket and improve design if you have time for another launch.
13. Repeat steps 7–12 with the other groups while maintaining control of the class. Students may be very excited about this activity, especially if their rockets soar high in the air. But always put safety first.

For an added challenge, you can tell students to also construct parachutes to create soft landings for their rockets. Be sure to provide plastic bags and string for this modification. Ask students how the addition of parachutes will affect balloons as they launch. Students should explain that parachutes will create drag, which will affect the height and velocity of their rockets.

Back to Newton

For every action there is an equal but opposite reaction.

> When we pump air into the bottle, we will increase the pressure inside the bottle. The small opening at the bottom will allow fluid to escape in one direction, thus providing what?

Students should answer that it provides thrust downward, allowing the rocket to propel skyward.

Remind students that they will have the chance to improve the design of their rocket and launch again as long as everyone stays on task.

Things to Consider

Ask students reflective questions to see if they can guess what would help the flight of their rocket.

After some discussion you can give the students hints about how they can improve the design of their rockets to maximize velocity, height, and thrust.

The shape of your nose cone can minimize drag (air resistance) and provide stability and control (keep it pointing in the right direction without wobbling).

> As the rocket moves through the air, drag (friction between the surface of the rocket and air) will slow it down. So some of your team will need to concentrate on nose design. What do you know about the shape of airplane nose cones? How about rocket nose cones? How can this information help you redesign your rocket?

Fins provide stability during flight to allow the rocket to maintain its orientation and intended flight path.

> Remember, you are trying to keep your rocket in the air for as long as possible. So some of your team will need to think about fins.

You should also explain the rocket's performance and its relationship to the center of mass.

In order for a rocket to fly in a stable fashion, the center of mass of the rocket must be forward of the center of pressure. Give students the opportunity to see this in action by altering the weight of their nose cone. The easiest way to do this is to let students experiment with different materials to build the cone.

> The center of mass of an object is the point at which, if the object were standing on one point—like your finger, it would balance and not tip over (like a weather vane). The center of pressure is the average spot where pressure force applies. In this case, that's water pressure. Center of pressure is difficult to calculate precisely, but knowing that the center of mass has to be forward of the center of pressure, you can use trial and error to alter your rocket for the best performance. By adding weight to the nose cone, you can move the center of mass toward the nose.
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> To find the center of mass of a rigid object such as a water bottle rocket, balance the rocket on your finger so that the rocket is horizontal. The center of mass is the point directly above your finger.

The center of mass can be moved closer to the nose cone end of a rocket by adding some mass near the nose cone. This will increase stability. But if you add too much weight, your rocket will just tumble end over end.

Now you should give students more time to implement what they have learned about fins and the shape of the nose cone of their rockets. If you utilized project roles, instruct students to switch to a different role. Every group should have an illustration for this activity before the end of this session.

Guiding Discussion Questions

- What is similar between how planes fly and the rockets that you made today? What is different?
- If you were to conduct this experiment again, how would you design your rocket differently? Why?
- How could you have moved the center of mass for your rocket?
- Give two examples of how this experiment illustrates Newton's third law.