How does a parachute’s design affect the speed of descent and landing location of a model rocket?

Grade Band: Middle School • Discipline: PS, ETS • Time: Two 50-minute class periods

Lesson Level Performance Expectation

• Develop and test a parachute model to solve a problem and meet the criteria and constraints of the parachute design task.

• Use a model to show the cause-and-effect relationships between parachute deployment, parachute design, speed of descent, and the sum of forces acting on the rocket.

What Students Will Figure Out

• When the propellant is all burnt, gas particles stop leaving the rocket so there is no force on air particles being pushed out which means there is also no thrust. Gravity has stayed the same, so there is an unbalanced force in the opposite direction of how the rocket is moving. This results in a change in rocket motion (slows down, then stops, and then falls).

• When objects fall the motion is changing because it will keep falling faster until the force of gravity is the same as the force of air resistance/drag. When these forces are balanced, the object will continue to fall at a constant speed.
How does a parachute’s design affect the speed of descent and landing location of a model rocket?

- A parachute exerts a force in the opposite direction of gravity due to air resistance/drag. When the parachute opens, the rocket is moving fast through the air because it is falling, and the force of air resistance/drag is greater than that of gravity. The unbalanced force changes the motion of the rocket (slows down).
- The rocket slows to a point where the force of air resistance/drag is equal to the force of gravity. Since the forces are balanced the rocket continues to fall, but it falls at a slower speed that is constant (unchanging).
- How to develop a model to generate data for repeated testing and modification of a parachute to achieve an optimal design.

Lesson Snapshot

Middle school students, as scientists and engineers, investigate forces and motion to answer the following driving question: How does a parachute’s design affect the speed of descent and landing location of a model rocket? Students conduct tests and collect data to determine the effect a spill hole has on the time it takes for a parachute to land. Students share models and compare models with those of classmates to explain the full launch sequence of a model rocket in preparation for planning a safe launch in the next lesson.
How does a parachute’s design affect the speed of descent and landing location of a model rocket?

**Problem:**

*How can we design a parachute to ensure a safe landing 20–26 seconds after parachute ejection?*

<table>
<thead>
<tr>
<th>Science and Engineering Practices</th>
<th>Disciplinary Core Ideas</th>
<th>Crosscutting Concepts</th>
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<tbody>
<tr>
<td><strong>Defining Problems</strong></td>
<td><strong>PS2.A: Forces and Motion</strong></td>
<td><strong>Cause and Effect</strong></td>
</tr>
<tr>
<td>• Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions.</td>
<td>• 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-PS2-2)</td>
<td>• Cause and effect relationships may be used to predict phenomena in natural or designed systems.</td>
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<tr>
<td><strong>Developing and Using Models</strong></td>
<td><strong>ETS1.A: Defining and Delimiting Engineering Problems</strong></td>
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<td>• Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs.</td>
<td>• 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 is likely to limit possible solutions. (MS-ETS1-1) (secondary to MS-PS3-3)</td>
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This lesson could be one in a series of lessons building toward the following Performance Expectation(s):

**MS-ETS 1-1** 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.

**MS-ETS 1-4** 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.
How does a parachute’s design affect the speed of descent and landing location of a model rocket?

Materials

<table>
<thead>
<tr>
<th>Student Materials</th>
<th>Teacher Materials</th>
<th>Optional Teacher Resources</th>
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<tbody>
<tr>
<td>Per Student</td>
<td></td>
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<tr>
<td>• Parachute Testing Guide</td>
<td>• None</td>
<td>• Scientific American—Parachutes with Holes</td>
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<tr>
<td>• Safety Goggles</td>
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<td>• Tape</td>
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<td>• Scissors</td>
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<td>• Plastic Grocery Bag</td>
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<td>• Ruler</td>
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<td>• String/Dental Floss</td>
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<td>• Toothpick</td>
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<td>• Marker/Highlighter or Small Toy</td>
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<tr>
<td>• Student Unit Model Tracker</td>
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<td>Per Group</td>
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<td>• Stopwatch</td>
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<td>• Meter Sticks</td>
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<td>• Plastic Grocery Bag</td>
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Lesson Preparation

Parachute Prototype Testing

1. Gather the materials needed for the imagine activity with enough supplies for each group, and identify a place where students can safely drop their parachutes from.
2. It is highly recommended that you create and test your own parachute. This will allow you to resolve any difficulties that may arise and will allow you to have a 3-D model for students to reference.
Experience the Problem

What Students Are Doing

In this section, students rewatch videos of a successful rocket landing and a video in which a parachute does not open. Students consider the unbalanced forces acting on the model rocket during its descent and the effect of an open parachute on the speed and location of a rocket’s landing.

Teacher Guidance

1. Project the Flight Sequence Diagram and place the Driving Question Board (DQB) in a place where all students can see it.
   Ask students to summarize which stages of the flight sequence and questions they have figured out and what questions remain. Ask students if they have any new questions.

Listen For

- We had a lot of questions about the parachute on the DQB.

2. Tell students to investigate these questions about parachutes. They will begin by rewatching two of the videos from Lesson
   Replay video of rocket landing safely: Green Eggs Full Flight From Ground video.
   Replay video of the rocket launch in which nose cone does not eject, and parachute does not open: Model Rocket Crashes, Close Calls, and CATOs [17:44–19:03]

3. Ask students to return to their Unit Model Tracker and discuss new ideas with a partner.
   Remind students that we have already learned about different forces that can explain the rocket launch, and we’ve used arrows on our model to show that when the forces are not balanced, the motion of the rocket changes. Ask students to use what they have learned so far about forces to explain Steps 4–6 of the flight sequence. Why does the rocket stop at its peak altitude, then fall back to the ground? In addition, how could we use force arrows to represent what is occurring with the parachute? After students spend time in the “alone zone,” prompt them to compare their models with a partner.

Suggested Prompts

Provide time for pairs to start discussions on their own, and only use these prompts if pairs are having difficulty engaging in cause-and-effect thinking.

- When our rocket launched, it went from not moving to moving. Were the forces balanced or not? How did we represent that on our previous models?
- Ask students to review what they learned in lessons 2–4. What force is thrust a reaction to? Does the engine continue to burn indefinitely? What happens with the force arrows when the engine is no longer burning?
- What do you think happens right here at the top—when the rocket stops moving up and right before it starts moving down to the ground? How would you represent that using force arrows?
- Look at step 3 in the flight sequence. What forces are acting on the rocket as it coasts, yet continues to climb?
- Think about the difference between the rockets with and without a parachute. Which rocket came back down faster? Why? How would you describe the effect of a parachute on the rocket’s descent?
- Do you think the parachute is exerting a force on the model rocket? In what direction?
  - How big do you think the arrow is?
  - Do you think the parachute arrow is bigger or smaller than the gravity arrow? Why do you think this?
Ideas that may be represented on the student models

- There should be a point at the top of the diagram where the rocket is coasting and there is no force arrow representing thrust.
- The rocket stops moving straight up because the propellant stops burning, so there are not as many gases flowing out from the back of the rocket (force decreases). So the opposite force (thrust) up also decreases until it is absent.
- The force of gravity acting on the rocket always stays the same. Since the thrust force is absent, the forces are now unbalanced in the other direction, and gravity slows the rocket until it reaches peak altitude, then starts to pull the rocket down.
- Rockets without parachutes come down faster, so students should infer that the parachute exerts a force in the opposite direction as gravity. This slows down the rocket. The arrow should be larger than the gravity arrow because the rocket is down to the ground.

4. Point out that many students identified that a parachute slows down the descent or landing of the rocket, so it must be exerting a force on the rocket.

Ask students to look at the place on their models that shows the forces involved as the parachute works to slow the descent of the rocket. Then acknowledge that many students agree that the parachute provides a force on the rocket in the opposite direction of gravity. Say, “That makes sense: We need an opposing force because we could clearly see that the parachute slows down the rocket.” Then ask, “Where is that force coming from?” As you facilitate this discussion, include student ideas and ask students how the ideas might be represented on our class model.

Suggested Prompts

- The rocket is slowing down. Does that mean there is a change in its motion? What does that mean about forces acting on the rocket?
- Where on your rocket diagram can you identify changes in motion?
- This reminds me of the “mystery” force that pushed our rocket up. Do you think there are any ideas we used on the model that explained thrust that might help us think about this “parachute” force?
- Thinking about individual gas particles helped us explain thrust. Would it be helpful to think about the gas particles that air is made of to help explain this phenomenon as well? What is the air outside the rocket like?
- How can we represent the air particles outside of the rocket?
- If we draw the air molecules outside of the rocket, how would they be interacting?
- Are the air particles bumping against the rocket?
- What else would they bump against?
- Because of gravity, the rocket and parachute are falling through the air. How would that affect how the air particles would hit?
- As the rocket falls, before the parachute opens, it is moving faster and faster. How could we show that using the air particles?
- All along the open bottom of the parachute, you have lots of little arrows showing the force of each air particle hitting the parachute, with a force opposite to gravity. How could we simplify those arrows?
- Could we use this model to also help explain why the rockets with parachutes that didn’t open fell down faster compared to the rockets with parachutes that opened?
How does a parachute’s design affect the speed of descent and landing location of a model rocket?

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Sample Student Responses

- Yes, going slower is a change in motion, so unbalanced forces must be acting on the rocket.
- A change in motion happens when the rocket launches, when it accelerates, when it coasts to peak altitude, when it changes direction and starts to fall, when the parachute opens, and when the rocket hits the ground.
- The force that pushes the rocket up (thrust) was the equal and opposite force resulting from the force of gas particles getting pushed out of the engine.
- The air is made of lots of gas particles.
- We could show small circles with force arrows of different lengths, depending on the temperature of the air outside.
- The particles would be bumping into one another and other objects.
- Yes, they will hit the rocket.
- They would also hit the parachute.
- The rocket is falling through the particles, so they would all be hitting from the same direction.
- The faster the rocket falls, the air particles would hit with more force. We show more force with longer arrows.
- We could add all of the little arrows together and just show one big arrow.
- Yes! The parachute that isn’t open won’t be hitting as many air particles as it falls because it is smaller and there are less places for the air to hit, so the force of air resistance or drag would be less.

As you add the force arrow pushing the parachute (and rocket) in the opposite direction of gravity, you can tell students they just named another force. We call this force air resistance, or drag. Add this to the word wall, and allow the class to create a definition for drag based on what they just figured out together (the force that results from hitting air particles when something moves through air). The faster the object is moving, the greater the force.

Sample Class Consensus Models
If students struggle to think about how to represent the air particles as an object falls (and moves through them), use models like the examples provided below. Ask students to think about how you might represent objects on a road when a vehicle is driving by them. Think about showing relative motion. If something is moving through (or past) another thing faster, how might we show that? What if we threw a ball into the air? How could we show how fast it was moving at different points as it came back down?

5. **Ask students to make predictions about the movement of the parachute based on the force arrows placed on the diagrams.**

Until this point in the unit, we have been discussing how force changes the motion of an object. So far, the motion of the object we explained was always moving in the same direction as the force. In this case, the net force is changing the motion of the rocket by slowing it down, but the rocket is moving in a direction opposite that of the net force. This is an opportunity to address a common misconception that may have been forming. The direction of the net force does not always coincide with the direction the object is moving. Likewise, if the force arrows are balanced, it does not mean an object is not moving, but it does mean its motion is not changing.

Ask students to return to their model tracker to use what we just figured out to update the force arrows for each of the six steps of the flight sequence. Tell students to show whether forces are balanced or unbalanced at each step, and to describe how the motion of the rocket changes or does not change as a result. Encourage students to add a step between steps 4 and 5 to show what happens when the parachute first opens.

**Suggested Prompts**

- Remember, we said that force changes the motion of an object. Did we say it necessarily changes the direction of motion? How else might we change the motion of something?
- If these arrows were the same size, it would mean drag and gravity are balanced. Does it mean the rocket stopped moving?
- Once the rocket lands, we must need another force that changes its motion from moving to not moving, correct? How could we show that?
- Can we use anything we learned so far to figure out how we could explain that force? If the rocket is pushing down on the ground, what must the ground be doing?
- Are there any other forces you think may be acting on the rocket over the course of this flight sequence that we haven’t considered?
Sample Student Responses
- The first example shows the arrow for gravity as larger than the arrow for drag, and the object is falling down.
- When the parachute opens, the arrow for drag is larger than the arrow for gravity.
- The larger arrow pointing up doesn’t mean the parachute is moving up; it means it is changing the motion by making it slow down.
- No, the balanced arrows just mean its motion is not changing. So the rocket is falling at the same speed.
- There must be another arrow pushing up on the rocket if we are changing its motion from moving to not moving.
- The ground is pushing back up on the rocket! That force makes the forces unbalanced and changes the rocket’s motion (it comes to a stop).

Sample Student Model Tracker Entry
Additional Guidance: Digging Deeper

During this discussion, some students may surface the idea that since there was air resistance when rockets fell down through the air, there would have to be air resistance when the rocket was launched and accelerated and when it climbed as well. If students identify this, ask the class if this is something they should add to the other steps of the flight sequence. When adding this force, it is important for students to realize that the overall balance of forces is still what determines how the rocket’s motion changes. You may choose to problematize this idea by asking if air is hitting the rocket on the way up as well as on the way down so students can bring this idea up. However, it is also acceptable to ignore the force of drag as the rocket ascends if it is appropriate in your context to move on without addressing this. The remainder of the unit will not be affected if students are not considering the force of drag over the entire flight sequence.

Investigate the Phenomenon

What Students Are Doing

Students will build and test parachutes as part of their research on the effect of a parachute spill hole on a rocket’s speed of descent and landing location.

Teacher Guidance

6. Define the problem.

Remind students that we now understand and can explain how a parachute works to slow down a rocket, then ask students to explain why (or if) it is necessary to have the rocket slow down before landing. Additionally, surface ideas about why descending too slowly could also pose issues.

Suggested Prompts

• What are the possible negative effects of a descent that is too fast?
• What are the possible negative effects of a descent that is too slow?
• Why do we not want the rocket to stay in the air too long? What could happen to the rocket?

Sample Student Responses

• If the rocket comes down too fast, it could break.
• If the rocket comes down too fast, it could leave a mark on the ground where it lands.
• If the rocket takes too long to come down, we could lose track of it and not know where it lands.
• The rocket could get pushed by the wind and land somewhere unsafe.
• If the rocket takes too long to come down, the wind could blow it away from us.
• Maybe there is an ideal landing window of time that we should be aiming for to make sure the rocket lands safely.

Point out that several students suggested that the ideal landing wouldn’t be too fast or too slow. Tell students that when they launch model rockets in the next lesson, they will be aiming for that ideal range: They will design a parachute that allows their rockets to land between 20–26 seconds after the parachute ejects. This time frame has been recommended based on previous tests with Estes model rockets.
7. **Tell students that to investigate how a parachute’s design affects the speed of descent and the landing location of a model rocket, they will run tests with parachute-like materials.**

Say, “For safety purposes and to protect the rockets so we can use them multiple times, let’s test some parachute-like materials so we can figure out how to avoid the negative outcomes you identified.”

8. **Introduce the rest of the Criteria and Constraints for the design on page one of the Parachute Testing Guide.**

Tell students that the criteria and constraints are for the model rocket they will launch in the next lesson, but they should consider them for their test parachute as well. Give students time to consider why these criteria and constraints will be important and to generate questions in the “alone zone” and with a partner. Ask pairs to share questions with the class.

Review the safety guidelines:

   a. Students will wear goggles when testing.
   b. Students will stand behind the line established by the teacher. Prototypes are only dropped after the teacher gives instructions.
   c. While a student is dropping the parachute, their partner is responsible for timing the duration of the flight.

9. **Organize students into groups and direct them to begin designing their parachute prototype following the directions on page 2 of the Parachute Prototype Testing Guide.**

Make clear to students that all groups will have the same designs for Design 1: a parachute that is the same size and shape and made of the same material.

10. **Direct students to run a test of Design 1 following the instructions on page 3 of the Parachute Testing Guide.**

11. **Ask students to consider how they could modify the parachute to decrease the amount of time it takes to land and affect where it lands.**

Tell students that they can’t change the material of the parachute or its overall size. What other changes could they make? To help students generate ideas, tell them that you have some pictures of parachutes for them to observe. Direct them to page 4 of the Parachute Testing Guide.

**Sample Student Ideas**

   - They could change the shape of the parachute.
   - They could cut holes into the parachute.
   - Both of the parachutes in the pictures have holes in them. The holes would create places on the parachute where air particles would not be pushing up. This might make the parachute come down faster.
   - Cutting holes in the parachute would make it weigh less, so the gravity arrow would be smaller. Maybe this would help it come down more slowly.

12. **Direct students to page 5 of the Parachute Testing Guide, and ask groups to discuss and make a prediction about the effect a hole in the parachute will have on the descent of the model rocket.**

Lead a whole-class discussion with one group representing each prediction (faster, slower, no effect) to share their ideas. Encourage students to ask one another questions about their predictions. If they need help getting started, students can use the prompts below.
How does a parachute’s design affect the speed of descent and landing location of a model rocket?

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Suggested Prompts

• What evidence did you use to make your prediction?
• I agree with ________, based on [piece of evidence]; it seems like the hole in the parachute will make the descent happen ________.
• I disagree with ________, based on [piece of evidence]; it seems like the hole in the parachute will make the descent happen ________.

Ask the class if any of the explanations provided by other groups changed their minds. Provide an opportunity for students to revise their predictions, if needed.

13. Direct students to page 6 of the Parachute Testing Guide, and tell them to follow the steps from the Modifications section through the Reflect and Apply section on page 9.

Tell students that they should be prepared to discuss their groups’ data and ideas about their parachute modifications. After all students have finished their testing analysis and their reflection, lead the class in a discussion of their results. On a board or chart paper, create a T-chart like the one below. Ask groups to put a tally mark or adhesive note below the effect they observed.

Effect of the Spill Hole We Observed

<table>
<thead>
<tr>
<th>The spill hole made the parachute descend quicker.</th>
<th>The spill hole made the parachute descend slower.</th>
<th>The spill hole did not affect the rate of the parachute’s descent.</th>
</tr>
</thead>
</table>

Ask for volunteers to explain the effect of the spill hole on the parachute’s descent time.

Listen For

• The spill hole made it go down faster because not as many air particles were exerting a force on the parachute, which was opposing the force of gravity.
• The spill hole made the parachute land faster because the force of drag will be lower. Since drag slows down the rocket when the parachute opens, having a smaller force will slow it down less.
Explain the Phenomenon

What Students Are Doing
In this section, students use the class consensus model to support a claim about the relative descent time of parachutes of different structures.

Teacher Guidance

14. Students work individually as they use the Class Consensus Model to explain why modifying the parachute changes the amount of time it takes the rocket to land.
   Tell students they will take some time to demonstrate their understanding of these results. Direct them to the space provided on the last page of the Parachute Testing Guide, and ask them to explain these results using the ideas they learned about how forces are acting on the rocket and parachute. Have the Class Consensus Model in a place where all students are able to see it, and tell students they may use that model or any of the models they have developed in their model tracker to help them develop their response. Tell them they may create a model to show how the forces are acting on the objects, but they must also use words to describe what they are showing.

Return to the Driving Question Board. Use the model to confirm that students have answered their questions about all of the phases of the flight sequence, and they showed they could use the information they know to make some predictions about how rocket motion will change when one part of the system is changed.
   Ask students if they think their models can also be used to help us think about all of the factors we need to consider before we launch a model rocket safely. Affirm students who point out that they could test this by preparing to launch their own rockets.