Launching to the Moon

Submitted by: Ruth Coats, STEM
East Montgomery Elementary School, Clarksville, TN

Target Grade: 5th Grade STEM

Time Required: 180 minutes (4 Days)

Standards

Next Generation Science Standards (NGSS)

- 5-PS1-4. Conduct an investigation to determine whether the mixing of two or more substances results in new substances.
- 3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.
- 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Common Core State Standards English Language Arts

- CCSS.ELA-LITERACY.RF.5.4 Read with sufficient accuracy and fluency to support comprehension.
- CCSS.ELA-LITERACY.RF.5.4.A Read grade-level text with purpose and understanding.
- CCSS.ELA-LITERACY.RI.5.7 Draw on information from multiple print or digital sources, demonstrating the ability to locate an answer to a question quickly or to solve a problem efficiently.
- CCSS.ELA-LITERACY.SL.5.1 Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 5 topics and texts, building on others' ideas and expressing their own clearly.

Common Core State Standards Mathematics

- CCSS.MATH.CONTENT.5.NF.A.1 Add and subtract fractions with unlike denominators (including mixed numbers) by replacing given fractions with equivalent fractions in such a way as to produce an equivalent sum or difference of fractions with like denominators.
- CCSS.MATH.CONTENT.5.MD.B.2 Make a line plot to display a data set of measurements in fractions of a unit (1/2, 1/4, 1/8). Use operations on fractions for this grade to solve problems involving information presented in line plots.

Lesson Objectives

Students will:

- I can identify balanced and unbalanced forces and use them to predict the motion of an object.
- I can read a text in order to gather information needed to apply to a real-world situation.

- I can evaluate the results of mixing two substances together to identify whether a new substance is formed.
- I can test the effects of an unbalanced force and create a diagram to model the forces acting on an object.
- I can plan and carry out an investigation to determine the best ratio of water and Alka-Seltzer to launch a film canister rocket.
- I can calculate the average height of the launch of the rockets by estimating with fractional parts, adding fractions, and dividing fractions.
- I can design and create a prototype of a rocket that will launch as high and as close to vertical as possible.
- I can test a prototype and identify elements to be improved.
- I can create a line plot in order to display the data collected during an investigation.
- I can analyze the data on a line plot and solve related real-world problems.

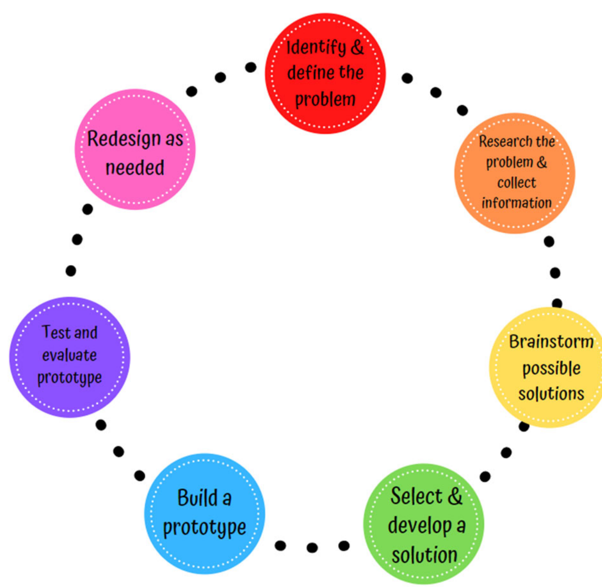
Central Focus

In this multi-day lesson, students will set out to design a rocket to help NASA get back to the moon by 2024. They will investigate the best rocket fuel for the highest launch of an Alka-Seltzer powered rocket and create an outer shell for the rocket to help it fly as straight as possible. The students will use makerspace supplies, computers, and a 3D printer (optional) in order to design and build their rocket. The students will gather and analyze data throughout the lessons and apply the data to improvements of their prototype. Student engagement is bound to *blast off* in this engaging, cross-curricular lesson!

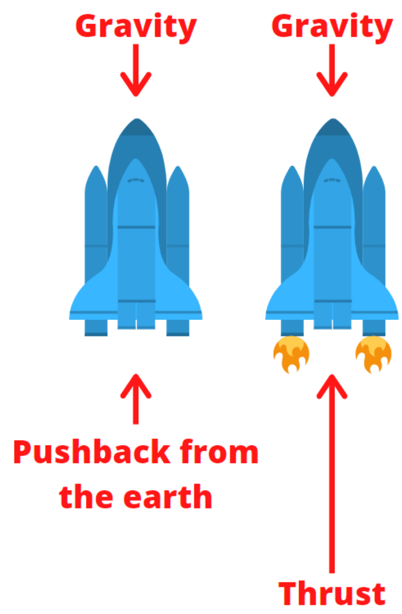
Key words: investigation, engineering design process, hands on, engineer

Background Information

Students should be aware of the engineering design cycle prior to this lesson. Students will identify the problem in this case and build a rocket that reaches optimum height. Students will then proceed through each step of the process: research the problem and collect information, brainstorm possible solutions, select and develop a solution, build a prototype, test and evaluate, and redesign.



In this lesson, students will be using Alka-Seltzer tablets in water to power their rockets. Alka-Seltzer tablets undergo a chemical reaction when placed in water. While the tablet is solid, the different components of the tablet (part acid and part base) are unable to interact. Once placed in water, the tablet begins to dissolve and the acid (citric acid) and base (bicarbonate) parts interact, releasing carbon dioxide bubbles. In this activity, the reaction will propel the rockets.



The image to the right demonstrates the forces acting on the rocket. This shows Newton's Second Law of motion, "for every action, there is an equal and opposite reaction." On the first rocket, the forces of gravity and pushback from the earth are balanced, causing no movement in to the rocket. The second rocket, however, has has the same amount of gravity pulling the rocket down, but it now has thrust overcoming the gravitational force, propelling the rocket.

Materials

Day 1

- Main Article
  - Struggling Readers and English Language Learners: "What is a rocket?" K-4 Article
  - On-Target and Advanced Readers: "What is a rocket?" 5-8 Article
- Optional Article: "How Rockets Work"
- K-W-L Chart
- Teacher computer/projector OR individual student computers
- Rocket Launch Video: http://www.viewpure.com/lS9XcEEek48
- 3-2-1 Exit Ticket

Day 2

- Meter stick
- Painters tape/masking tape
- White bulletin board paper
- Black marker
- Film canisters (3 per group)
- Water
- Alka-Seltzer tablets (broken into fourths)
- Recording device (iPad, camera, computer, etc.)
- Safety glasses
- Graduated cylinder

Day 3

- Makerspace materials such as:
  - Cardboard

- Tape
- Playdough
- Toothpicks
- Paper
- hot glue gun
- hot glue

- Optional Materials:
  - 3D printer
  - Filament
  - Computers for designing
  - Tinkercad file: https://www.tinkercad.com/things/inhDluKIOGJ

Day 4

- Whiteboard
- Dry erase markers
- Bulletin board paper
- Markers
- Launching to the Moon Challenge Line Plot student worksheet

Instruction

Day 1

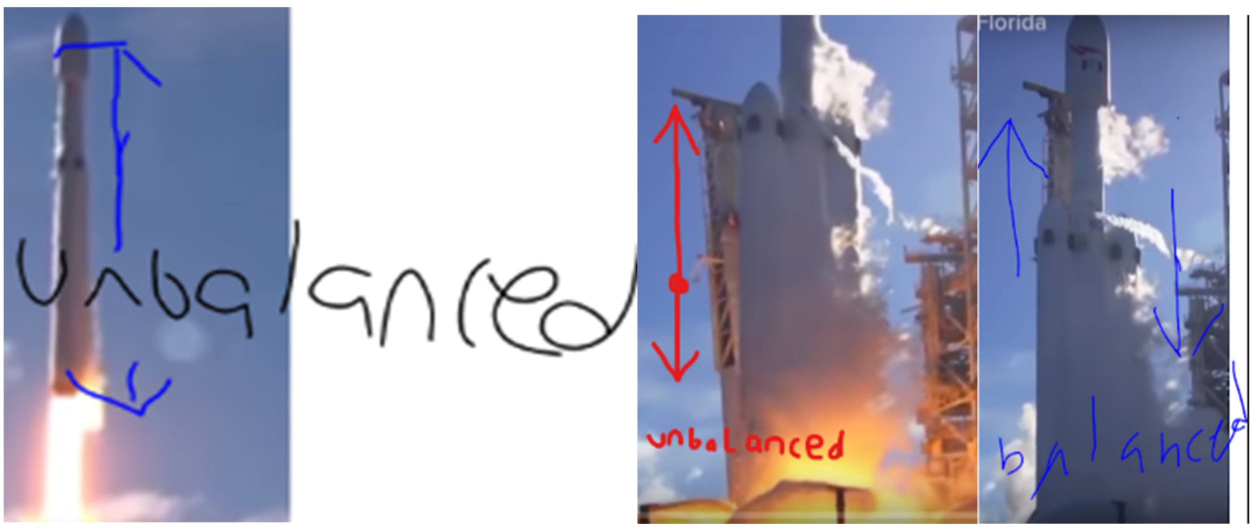
Introduction:

- The teacher will introduce the scenario: *NASA is planning to have people back on the moon by the year 2024. Your mission is to help NASA to develop the best rocket fuel to launch the rocket to escape the Earth's atmosphere and gravitational pull. The success of your mission will be measured by the height of the launch and how close to vertical the rocket launches.*

Procedure:

- The teacher will help the students build background knowledge about rockets through differentiated reading. Depending on the composition of the class, the teacher may have students complete the reading independently or collaboratively with a partner or small group.
  Struggling Readers and English Language Learners: "What is a rocket?" K-4 Article
  On-Target and Advanced Readers: "What is a rocket?" 5-8 Article
- The teacher will provide two focus questions before reading:
  1. What are rockets?
  2. How do rockets move?
- Before, during, and after reading the article above, the teacher and students will complete the K-W-L graphic organizer to organize the students' thoughts. Before the students read, they should write what they would like to know about rockets under "Know". While students are reading, they should write what they wonder about rockets in "Wonder". After students have finished reading, they should write notes about what they have learned from the article under "Learned".
- The students will share out with their table groups what they learned about rockets. Each table group will share out at least one item from each category of the graphic organizer.

- *Optional:* The teacher may choose to use the additional background information article "How Rockets Work." The teacher may choose to use this for teacher background information or for additional student information.
- After reading the article and completing the chart, the students will be asked to identify basic forces acting on the rocket and identify when the forces are balanced and unbalanced. The teacher will show a rocket launch video.
- At several places during the video, the teacher will pause the video and discuss forces acting on the rocket focusing on thrust (upward force) and gravity (pulling towards Earth's core).
- The teacher and students can draw diagrams to represent the forces and identify whether the forces are balanced or unbalanced.
- Alternatively, the students could watch their video on their own computer and screen capture 2-3 different images. Then, they could draw arrows to represent the forces and label them as balanced or unbalanced. (Sample student work is shown below.)



Closure:
- After reading the article and watching the rocket launch video, the students will reflect on the important information that they will apply to their STEM challenge using the 3-2-1 Exit Ticket.
- Students will write three facts about rockets that can help with their design, two questions they still have, and one new idea.

Day 2

Introduction:
- The teacher and students will discuss the previous day's lesson and the forces that act on rockets during a rocket launch.
- The teacher will show the rocket launch video that the students watched the previous day in order to review the forces acting on the rocket.
- The teacher will pause the video several times and the students will identify the forces.
- The teacher and students will focus on the role of thrust and gravity on the launch of the rocket.

Procedure:

- The students will develop and carry out an investigation to determine the correct amount of water to fuel the rocket with ¼ tablet of Alka-Seltzer.
- The students will need to identify the independent variable (the amount of water) and dependent variable (height of the launch) in their investigation.
- The students will write their procedures and create a data chart to collect their data.
- If students need more support, the teacher can guide the class to design the procedures together. The teacher needs to ensure that the students only change one variable (the amount of water) throughout the entire investigation. Depending on the students' experience collecting the data, the teacher may choose for students to create their own chart or provide a chart for the students to use.
- *Differentiation Opportunity for Struggling Students:* The teacher can provide fill in the blank procedures in which the students are completing a partially completed set of procedures. The teacher may provide a premade data chart if needed for the students to use.
- *Differentiation Opportunity for High Achieving Students:* Design two separate investigations, only changing one variable for each investigation. The students will then test a "rocket fuel" with the ideal amount of water and Alka-Seltzer.
  - Investigation 1: Independent variable is the amount of water. All other factors are controlled.
  - Investigation 2: Independent variable is the amount of Alka-Seltzer. All other variables are controlled.

Example Investigation Procedures: (Safety glasses should be worn)

1. Prepare the wall behind the launch site by marking each meter with painters tape or masking tape.
2. Fill the film canister A with 10 mL of water, film canister B with 15 mL of water, and film canister C with 20 mL of water. Measurements should be made with a graduated cylinder. All water should be room temperature.
3. Prepare to record the launch with an iPad or other device.
4. Start recording. Drop ¼ tablet of Alka-Seltzer in canister A. Put the lid on tight. Turn it over on the launch site.
5. Watch the video to determine the height of the launch and record the data in the chart. Estimate the height to the nearest ¼ meter.
6. Repeat steps 4 and 5 with canisters B and C.
7. Repeat steps 2-6 until 3 trials have been completed.
8. Calculate the average height of each canister.

Film Canister	Trial 1 (height in meters)	Trial 2 (height in meters)	Trial 3 (height in meters)	Average Height (meters)
A--10 mL				
B--15 mL				
C--20 mL				

- Teacher Setup for the Investigation: The teacher will need to mark meters vertically along the wall.
  - Option 1: Use painters tape or masking tape to mark each meter.
  - Option 2: On long bulletin board paper, mark each meter and hang the paper on the wall.
- Using the procedures previously established, the students will conduct the investigation to collect data about the best rocket fuel for their rocket.
- The students will record each launch so they can view it in order to determine the height of their rocket. The students would repeat the trial 3 times with each amount of water and calculate the average of each launch.
- After the launches, the teacher and students will compare the forces acting on their rockets to the video watched in the previous lesson. The teacher and students will discuss the forces acting on the Alka-Seltzer rockets before and during the launch.
- The students will draw a diagram to show the forces acting on the rocket and identifying them as balanced or unbalanced. Example:

Before Launch — (Balanced, no movement)

During Launch — (Unbalanced, accelerating upwards)

- After the forces are identified, the teacher and students will discuss these questions which build on previously established knowledge about matter: What caused the thrust (upwards force) in our rocket launch? Was a new material formed during the course of our rocket launch?
- The teacher allow students time to think, pair, share, and then will guide the discussion to lead the students to the conclusion that the force of thrust was caused by a build-up of gas released when the Alka-Seltzer and water combined. As the pressure builds, the cap of the film canister can no longer remain attached to the rest of the canister and the pressure is released as it pops open. The force of this reaction sends the rest of the canister upwards. Evidence that a new material is formed is the formation of bubbles (which is an observable effect of a gas being released) and a solid and liquid that combine to create a gas.

Closure:

- After investigating, students will write a “Claim, Evidence, Reasoning” statement about their investigation. Students will need to refer to the data they collected to explain the best ratio of water to Alka-Seltzer in order to create the best rocket fuel.
- *Claim, Evidence, Reasoning Statement example:*
  - 10 mL of water combined with ¼ tablet of Alka-Seltzer will create the best rocket fuel. According to my investigation, the rockets that launched with 10 mL averaged 2 ½ meters high. The rockets that launched with 15 mL averaged 1 ¾ meters high. The rockets that launched with 20 mL averaged 1 meter high. The rockets launched with 10 mL of rocket fuel launched an average of 1 ½ meters higher than the rockets with 20 mL of water and ¾ meters higher than the rockets with 15 mL of water.
  - *Differentiation for struggling learners and English language learners: The teacher will provide a fill-in-the-blank version of a claim, evidence, reasoning statement. The students will complete*

the statement with their own data. The level of support can be adjusted by changing how much is provided for the student.

- Example: __ mL of water combined with ¼ tablet of Alka-Seltzer will create the best rocket fuel. According to my investigation, the rockets launched with __ mL averaged ___ meters high. The rockets launched with __ mL averaged __ meters high. The rockets launched with __ mL averaged __ meter high. The rockets launched with __ mL of rocket fuel launched an average of __ meters higher than the rockets with __ mL of water and __ meters higher than the rockets with __ mL of water.

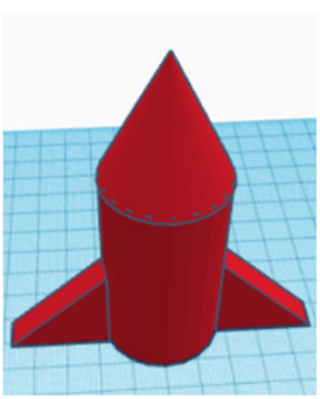
Day 3

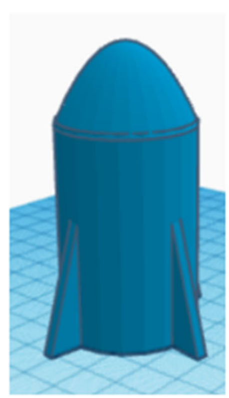
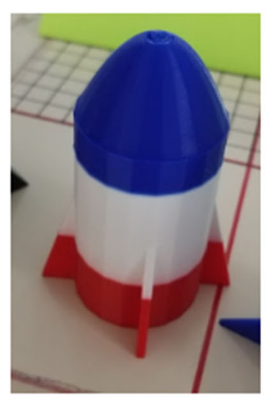
Introduction:

- The teacher and students will review the original task, focusing on the part involving launching the rocket as close to vertical as possible. *NASA is planning to have people back on the moon by the year 2024. Your mission is to help NASA to develop the best rocket fuel to launch the rocket to escape the Earth's atmosphere and gravitational pull. The success of your mission will be measured by the height of the launch and how close to vertical the rocket launches.*
- The teacher and students will discuss previously learned information about the forces involved in rocket launches. The teacher may refer back to Day 1 when the students began to build background knowledge about rockets. Today, students will adapt the film canister to launch in a more vertical path.

Procedures:

- Working in groups, students will create a detailed plan, including the needed materials, amount of materials, and a diagram of their ideas. The students will be encouraged to follow their plan as closely as possible, but will be given the opportunity to make improvements to their plan as needed throughout the process.
- Rocket Design Option 1: Students will use Makerspace supplies such as cardboard, tape, paper, toothpicks, etc. to adapt the film canister to become a rocket that flies as straight as possible. Students can add a nose cone, fins, or a combination to their rocket.
- Rocket Design Option 2: Students will design in 3D using www.tinkercad.com. For students new to 3D design, the students can start with [this file]() that has the correct diameter. Students will need instruction on how to change the height, add wings and a nose cone (if they choose to have one), and move the 3D objects vertically. Students will need to be shown how to change the work plane in order to attach the parts of the rocket. Examples of student designs and the printed product:



- After designing, creating and/or printing the rocket, the students can test the ability of the rocket to launch as high and as straight as possible using the optimal rocket fuel as determined by the investigation previously conducted. Using the same meter marks, use a straight, vertical line to assess how straight the rocket is able to launch.
- *Optional*: To embed math and technology skills, take a screen capture of the rocket at the highest point of the launch. Use a tool such as Windows Ink Workspace Snip and Sketch to overlay a protractor and measure the angle of the rocket compared to the vertical line.

Closure:

- After testing the rocket at least 3 times, students will reflect on their launch and answer the questions below on a FlipGrid.
  1. How can the rocket fuel be improved to help the rocket launch higher?
  2. How can the rocket design be improved to help the rocket launch higher and straighter?
- After students reflect on their rocket fuel and design, they can improve as time allows. Students will record the testing of their improvement and determine the effectiveness of the improvements. Students will reflect and explain why they believe the improvements were successful or unsuccessful.

Day 4

Introduction:

- The teacher and students will discuss the rocket launch. The students will share out their favorite successes and discuss areas they identified for improvement.

Procedures:

- As a whole class, create a line plot to show the average height each rocket travelled (to the nearest ¼ meter).
- The teacher will have the students work in pairs or groups to answer the following questions. Each student will record the line plot on their own sheet using the "Launching to the Moon Challenge Line Plot" student worksheet.
  1. What is the total height our rockets traveled?
  2. What is the difference between the rocket which traveled the highest and the rocket which traveled the shortest distance?
  3. Compare and contrast the two rockets. What do we notice is similar? What do we notice that is different?
  4. How many rockets traveled higher than 1 ½ meters?
  5. How many rockets traveled 1 ½ meters or less?
  6. Imagine the rockets traveled the same total distance. Each rocket traveled the exact same distance as all the other rockets. How far did each rocket travel?

Closure:

- Students will reflect on what they have learned and their group's rocket. Students should consider the following questions:
  - How does the distance it launched compare to the other rockets in the class?
  - What do you notice is different about your rocket and the rocket that launched the farthest?

Assessment

Day 1

- The students will complete a KWL chart, identify forces in the rocket launch video, and complete the Exit Ticket to reflect on the lesson.

Day 2

- The students will demonstrate their understanding by sketching a force diagrams and the claim, evidence, reasoning statement.

Day 3

- The teacher will use observation to assess the students' mastery of the learning objectives and standards. The teacher can use the following simple rubric while observing.

	Developing	On Track	Mastered
Design and construction	The student's design lacks necessary elements to launch the rocket.	The student's design allows for proper launch of the rocket but may have parts that are lacking.	The student's design allows for proper launch of the rocket and includes essential elements.
Testing	The student tests the design but does not follow the procedures as planned.	The student conducts the tests as planned.	The student conducts the tests as planned and accurately records the data.
Identifying Improvement	The student does not identify areas for improvement or does not develop a plan to address it.	The student identifies at least one area of improvement and develops a plan to address it.	The student identifies multiple areas of improvement and develops a plan to address each one.

Day 4

- The students will analyze the data of the line plots, and the teacher will examine student work to determine the level of understanding for analyzing data with line plots.

July 13, 2011

What Is a Rocket?

This article is part of the NASA Knows! (Grades K-4) series.

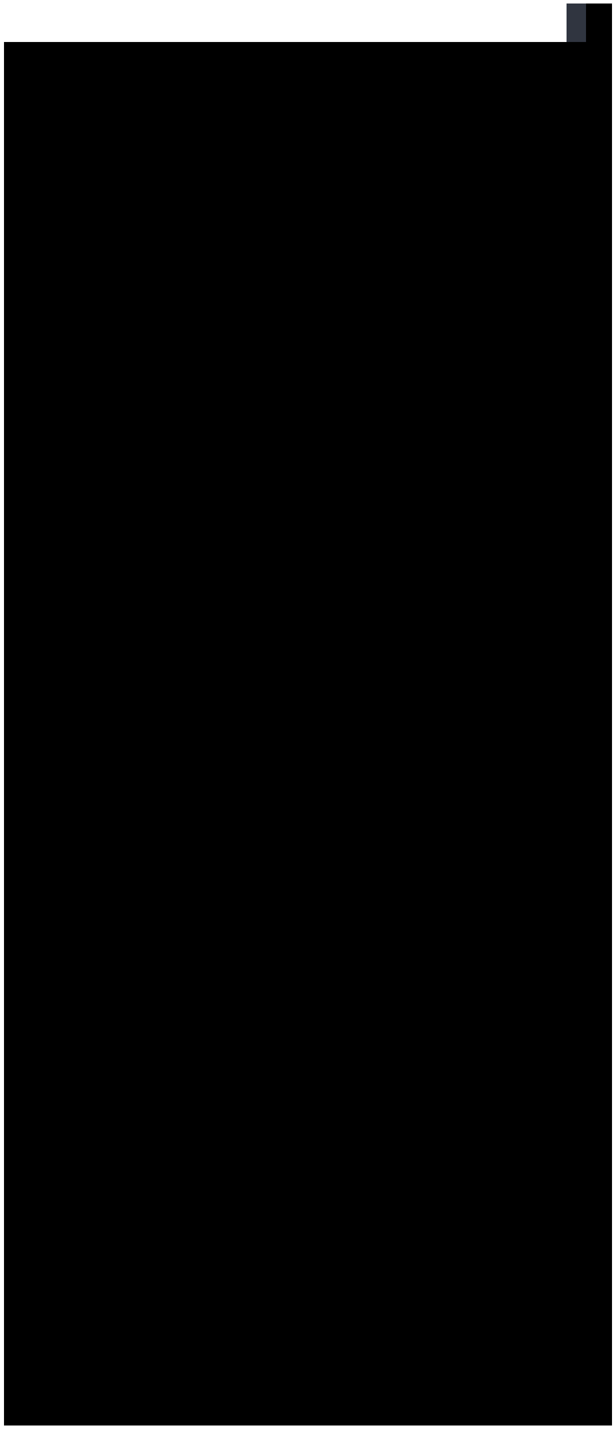
The word "rocket" can mean different things. Most people think of a tall, thin, round vehicle. They think of a rocket that launches into space. "Rocket" can mean a type of engine. The word also can mean a vehicle that uses that engine.

How Does a Rocket Engine Work?
Like most engines, rockets burn fuel. Most rocket engines turn the fuel into hot gas. The engine pushes the gas out its back. The gas makes the rocket move forward.

A rocket is different from a jet engine. A jet engine needs air to work. A rocket engine doesn't need air. It carries with it everything it needs. A rocket engine works in space, where there is no air.

There are two main types of rocket engines. Some rockets use liquid fuel. The main engines on the space shuttle orbiter use liquid fuel. The Russian Soyuz uses liquid fuels. Other rockets use solid fuels. On the side of the space shuttle are two white solid rocket boosters.

NASA's Saturn V rocket carried humans to the moon.
Credits: NASA



They use solid fuels. Fireworks and model rockets also fly using solid fuels.

Why Does a Rocket Work?
In space, an engine has nothing to push against. So how do rockets move there? Rockets work by a scientific rule called Newton's third law of motion. English scientist Sir Isaac Newton listed three Laws of Motion. He did this more than 300 years ago. His third law says that for every action, there is an equal and opposite reaction. The rocket pushes on its exhaust. The exhaust pushes the rocket, too. The rocket pushes the exhaust backward. The exhaust makes the rocket move forward.

This rule can be seen on Earth. Imagine a person standing on a skateboard. Imagine that person throwing a bowling ball. The ball will go forward. The person on the skateboard will move, too. The person will move backward. Because the person is heavier, the bowling ball will move farther.

When Were Rockets Invented?
The first rockets we know about were used in China in the 1200s. These solid rockets were used for fireworks. Armies also used them in wars. In the next 700 years, people made bigger and better solid rockets. Many of these were used for wars too. In 1969, the United States launched the first men to land on the moon using a Saturn V rocket.

How Does NASA Use Rockets?
Early NASA missions used rockets built by the military. Alan Shepard was the first American in space. He flew on the U.S. Army's Redstone rocket. John Glenn was the first American in orbit. He flew on an Atlas rocket. NASA's Gemini missions used the Titan II rocket. The first rockets NASA built to launch astronauts were the Saturn I, the

Robert Goddard built the first liquid-fuel rocket.
Credits: NASA

The Falcon 9 rocket carries supplies to the space station.
Credits: NASA

Saturn IB and the Saturn V. These rockets were used for the Apollo missions. The Apollo missions sent men to the moon. A Saturn V also launched the Skylab space station. The space shuttle uses rocket engines.

NASA uses rockets to launch satellites. It also uses rockets to send probes to other worlds. These rockets include the Atlas V, the Delta II, the Pegasus and Taurus. NASA uses smaller "sounding rockets" for scientific research. These rockets go up and come back down. They do not fly into orbit.

How Will NASA Use Rockets in the Future?
New rockets are being developed today. They will launch astronauts on future missions.

The new rockets will not look like the space shuttle. These rockets will look more like earlier ones. They will be tall and round and thin. These rockets will take astronauts into space. They will take supplies to the International Space Station. NASA also is working on a powerful new rocket called a heavy lift vehicle. This rocket will be able to take big loads into space.

Together, these new rockets will make it possible to explore other worlds. Someday they may send humans to Mars.

Read What Is a Rocket? (Grades 5-8)

Return to NASA Knows! (Grades K-4)

Return to Students K-4

David Hitt/NASA Educational Technology Services

Last Updated: Aug. 7, 2017
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Sept. 21, 2010

What Is a Rocket?

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Illustration of Space Launch System in flight.
Credits: NASA/MSFC

When most people think of a rocket, they think of a tall round vehicle that flies into space. But the word "rocket" can mean two different things. The word can describe a type of engine. The word rocket also is used to talk about a vehicle that uses a rocket engine.

How Does a Rocket Engine Work?
Like many other engines, a rocket produces **thrust** by burning fuel. Most rocket engines turn the fuel into hot gas. Pushing the gas out of the back of the engine makes the rocket move forward.

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There are two main types of rocket engines. Some rockets use liquid fuel. The main engines on the space shuttle orbiter use liquid fuel. The Russian Soyuz uses liquid fuels. Other rockets use solid fuels. On the side of the space shuttle are two white solid rocket boosters. They use solid fuels. Fireworks and model rockets also fly using solid fuels.

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NASA's Saturn V rocket carried humans to the moon.
Credits: NASA

When Were Rockets Invented?
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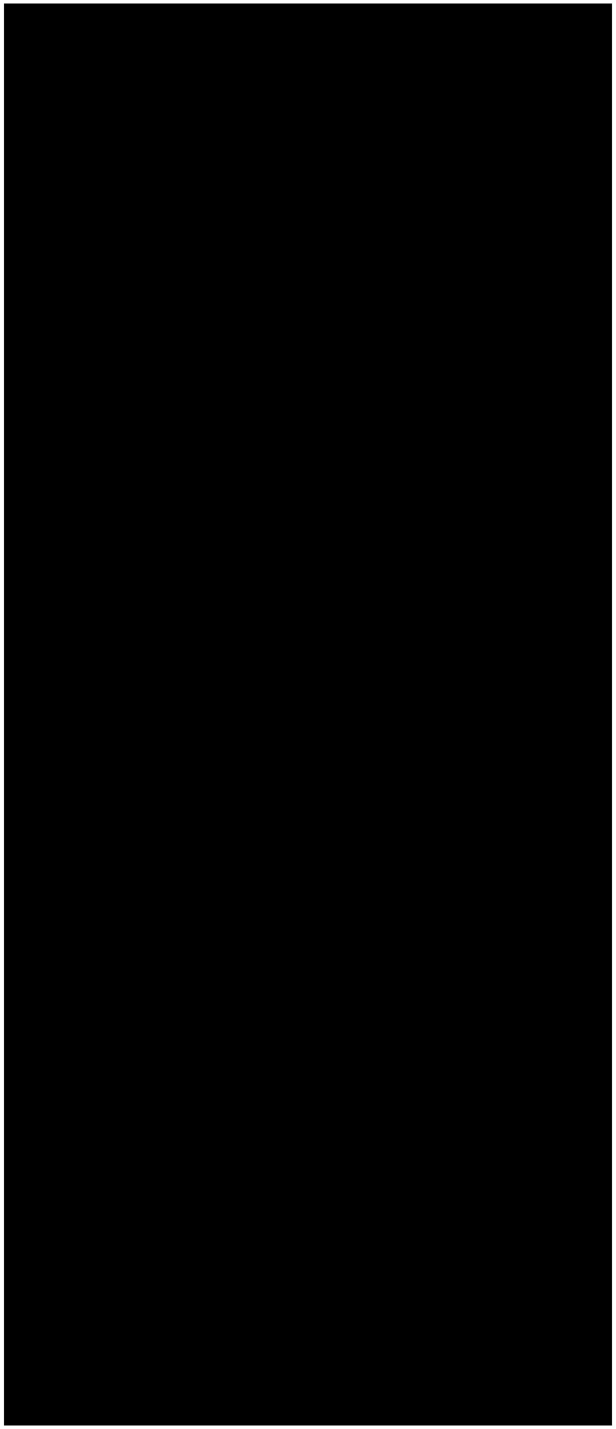
In 1903, a Russian teacher named Konstantin Tsiolkovsky wrote a paper describing the idea of liquid-fuel rockets. In 1926, American scientist Robert Goddard flew the first liquid-fuel rocket. German scientists led by Hermann Oberth improved liquid-fuel rockets. During World War II, Germany used rockets to bomb other countries. In 1957, the Soviet Union used a rocket to launch the first satellite. In 1961, Soviet cosmonaut Yuri Gagarin rode in a rocket to become the first person in space. In 1969, the United States launched the first men to land on the moon - Neil Armstrong and Buzz Aldrin - using a Saturn V rocket.

How Does NASA Use Rockets?
Early NASA missions used rockets built by the military. Alan Shepard became the first American in space flying on the U.S. Army's Redstone rocket. The Atlas **missile** was used to make John Glenn the first American to orbit Earth. NASA's Gemini missions used the Titan II missile to launch astronauts. The first rockets NASA built to launch astronauts were the Saturn I, the Saturn IB and the Saturn V. Apollo missions used these to send men to the moon. A Saturn V launched the Skylab space station. The space shuttle also uses rocket engines to carry



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How Will NASA Use Rockets in the Future?
New rockets are being developed today that will launch astronauts on future missions. Compared to the space shuttle, these rockets will look more like earlier rockets - tall and round and thin. These rockets will take astronauts and supplies to the International Space Station. NASA also is working on a powerful new rocket called a heavy lift vehicle. This rocket will be able to carry large amounts of equipment into space. Together, the heavy lift vehicle and other rockets will make it possible to explore other worlds and may someday send humans to Mars.

Words to Know

thrust: the forward or upward force produced by the engines of a plane or rocket.

missile: an object (such as a stone, arrow, artillery shell, bullet, or rocket) that is thrown, shot, or launched usually so as to strike something at a distance.

More About Rockets:
How Does This Work?
NASA Celebrating 90 Years: Robert Goddard's Rocket and the Launch of Spaceflight

Robert Goddard built the first liquid-fuel rocket.
Credits: NASA

The Falcon 9 rocket carries supplies to the space station.
Credits: NASA

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Return to Students 5-8

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How Rockets Work

Whether flying a small model rocket or launching a giant cargo rocket to Mars, the principles of how rockets work are exactly the same. Understanding and applying these principles means mission success.

In the early days of rocketry, the flight of a fire arrow or other rocket device was largely a matter of chance. It might fly; it might skitter about, shooting sparks and smoke; or it might explode. Through centuries of trial and error, rockets became more reliable. However, real advancements in rocketry depended upon a scientific and mathematical understanding of motion. That came in the seventeenth century with the works of scientists such as Galileo and Isaac Newton.

Galileo conducted a wide range of experiments involving motion. Through studies of inclined planes, Galileo concluded that moving objects did not need the continuous application of force (in the absence of friction and drag) to keep moving. Galileo discovered the principle of *inertia*, that all matter, because of its mass, resists changes in motion. The more mass, the more resistance.

Isaac Newton, born the year Galileo died, advanced Galileo's discoveries and those of others by proposing three basic laws of motion. These laws are the foundation of all rocket science. Understand the laws and you know just about everything you need to build successful rockets. Apply the laws and you become a "rocket scientist."

Newton's Laws of Motion

In his master work entitled *Philosophia Naturalis Principia Mathematica* (usually referred to as *Principia*), Isaac Newton stated his laws of motion. For the most part, the laws were known intuitively by rocketeers, but their statement in clear form elevated rocketry to a science. Practical application of Newton's laws makes the difference between failure and success. The laws relate force and direction to all forms of motion.

In simple language, Newton's Laws of Motion:

> **First Law**
> Objects at rest remain at rest and objects in motion remain in motion in a straight line unless acted upon by an unbalanced force.
>
> **Second Law**
> Force equals mass times acceleration (or f = ma).
>
> **Third Law**
> For every action there is an equal and opposite reaction.

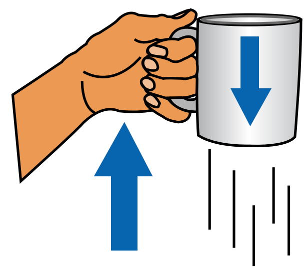
Before looking at each of these laws in detail, a few terms should be explained.

Rest and *Motion*, as they are used in the first law, can be confusing. Both terms are relative. They mean rest or motion in relation to surroundings. You are at rest when sitting in a chair. It doesn't matter if the chair is in the cabin of a jet plane on a cross-country flight. You are still considered to be at rest because the airplane cabin is moving along with you. If you get up from your seat on the airplane and walk down the aisle, you are in relative motion because you are changing your position inside the cabin.

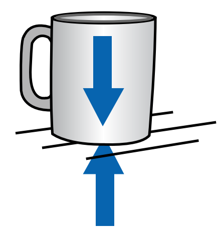
Force is a push or a pull exerted on an object. Force can be exerted in many ways, such as muscle power, movement of air, and electromagnetism, to name a few. In the case of rockets, force is usually exerted by burning rocket propellants that expand explosively.

Unbalanced Force refers to the sum total or net force exerted on an object. The forces on a coffee cup sitting on a desk, for example, are in balance. Gravity is exerting a downward force on the cup. At the same time, the structure of the desk exerts an upward force, preventing the cup from falling. The two forces are in balance.

Reach over and pick up the cup. In doing so, you unbalance the forces on the cup. The weight you feel is the force of gravity acting on the mass of the cup. To move the cup upward, you have to exert a force greater than the force of gravity. If you hold the cup steady, the force of gravity and the muscle force you are exerting are in balance.



Unbalanced force

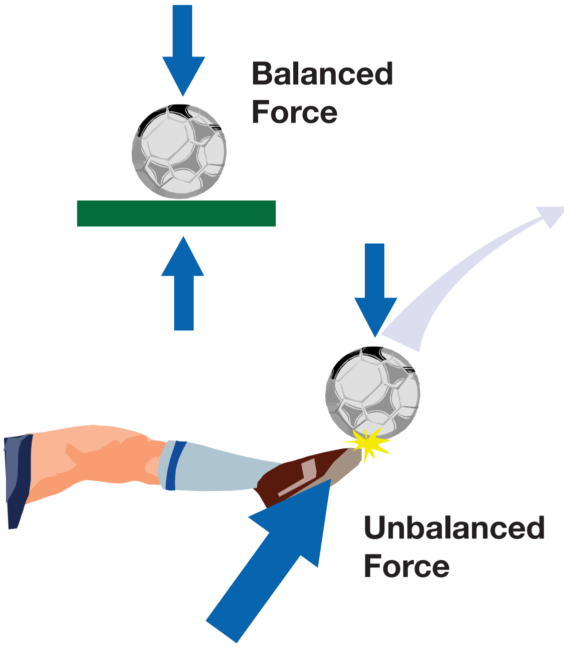


Balanced forces

Unbalanced force also refers to other motions. The forces on a soccer ball at rest on the playing field are balanced. Give the ball a good kick, and the forces become unbalanced. Gradually, air drag (a force) slows the ball, and gravity causes it to bounce on the field. When the ball stops bouncing and rolling, the forces are in balance again.

Take the soccer ball into deep space, far away from any star or other significant gravitational field, and give it a kick. The kick is an unbalanced force exerted on the ball that gets it moving. Once the ball is no longer in contact with the foot, the forces on the ball become balanced again, and the ball will travel in a straight line forever.

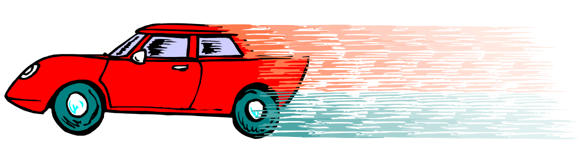
How can you tell if forces are balanced or unbalanced? If the soccer ball is at rest,

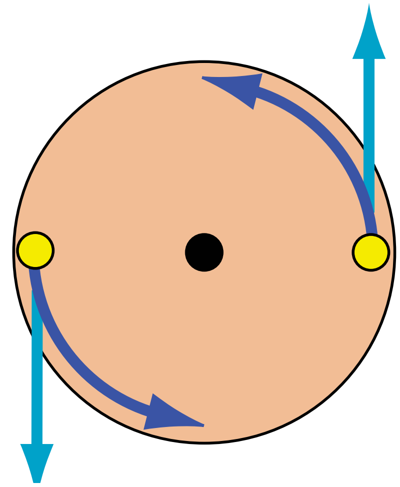


the forces are balanced. If the ball is moving at a constant speed and in a straight line, the forces are balanced. If the ball is accelerating or changing its direction, the forces are unbalanced.

Mass is the amount of matter contained in an object. The object does not have to be solid. It could be the amount of air contained in a balloon or the amount of water in a glass. The important thing about mass is that unless you alter it in some way, it remains the same whether the object is on Earth, in Earth orbit, or on the Moon. Mass just refers to the quantity of matter contained in the object. (Mass and weight are often confused. They are not the same thing. Weight is a force and is the product of mass times the acceleration of gravity.)

Acceleration relates to motion. It means a change in motion. Usually, change refers to increasing speed, like what occurs when you step on the accelerator pedal of a car. Acceleration also means changing direction.





Top view of two riders on a carousel. The carousel platform exerts unbalanced forces on the riders, preventing them from going in straight lines. Instead, the platform continually accelerates the riders in a counterclockwise direction.

This is what happens on a carousel. Even though the carousel is turning at a constant rate, the continual change in direction of the horses and riders (circular motion) is an acceleration.

Action is the result of a force. A cannon fires, and the cannon ball flies through the air. The movement of the cannon ball is an action. Release air from an inflated balloon. The air shoots out the nozzle. That is also an action. Step off a boat onto a pier. That, too, is an action.

Reaction is related to action. When the cannon fires, and the cannon ball flies through the air, the cannon itself recoils backward. That is a reaction. When the air rushes out of the balloon, the balloon shoots the other way, another reaction. Stepping off a boat onto to a pier causes a reaction. Unless the boat is held in some way, it moves in the opposite direction. (Note: The boat example is a great demonstration of the action/reaction principle, providing you are not the one stepping off the boat!)

Newton's First Law

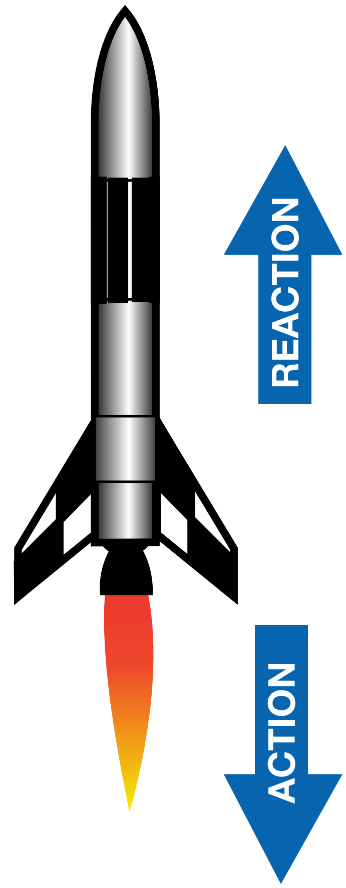
This law is sometimes referred to as Galileo's law of inertia because Galileo discovered the principle of inertia. This law simply points out that an object at rest, such as a rocket on a launch pad, needs the exertion of an unbalanced force to cause it to lift off. The amount of the thrust (force) produced by the rocket engines has to be greater than the force of gravity holding it down. As long as the thrust of the engines continues, the rocket accelerates. When the rocket runs out of propellant, the forces become unbalanced again. This time, gravity takes over and causes the rocket to fall back to Earth. Following its "landing," the rocket is at rest again, and the forces are in balance.

There is one very interesting part of this law that has enormous implications for spaceflight. When a rocket reaches space, atmospheric drag (friction) is greatly reduced or eliminated. Within the atmosphere, drag is an important unbalancing force. That force is virtually absent in space. A rocket traveling away from Earth at a speed greater than 11.186 kilometers per second (6.95 miles per second) or 40,270 kilometers per hour (25,023 mph) will eventually escape Earth's gravity. It will slow down, but Earth's gravity will never slow it down enough to cause it to fall back to Earth. Ultimately, the rocket (actually its payload) will travel to the stars. No additional rocket thrust will be needed. Its inertia will cause it to continue to travel outward. Four spacecraft are actually doing that as you read this. *Pioneers 10* and *11* and *Voyagers 1* and *2* are on journeys to the stars!

Newton's Third Law

(It is useful to jump to the third law and come back to the second law later.) This is the law of motion with which many people are familiar. It is the principle of action and reaction. In the case of rockets, the action is the force produced by the expulsion of gas, smoke, and flames from the nozzle end of a rocket engine. The reaction force propels the rocket in the opposite direction.

When a rocket lifts off, the combustion products from the burning propellants accelerate rapidly out of the engine. The rocket, on the other hand, slowly accelerates skyward. It would appear that something is wrong here if the action and reaction are supposed to be equal. They are equal, but the mass of the gas, smoke, and flames being propelled by the engine is much less than the mass of the rocket being propelled in the opposite direction. Even though the force is equal on both, the effects are different. Newton's first law, the law of inertia, explains why. The law states that it takes a force to change the motion of an object. The greater the mass, the greater the force required to move it.



Newton's Second Law

The second law relates force, acceleration, and mass. The law is often written as the equation:

$$f = ma$$

The force or thrust produced by a rocket engine is directly proportional to the mass of the gas and particles produced by burning rocket propellant times the acceleration of those combustion products out the back of the engine. This law only applies to what is actually traveling out of the engine at the moment and not the mass of the rocket propellant contained in the rocket that will be consumed later.

The implication of this law for rocketry is that the more propellant (m) you consume at any moment and the greater the acceleration (a) of the combustion products out of the nozzle, the greater the thrust (f).

A Taste of Real Rocket Science

Naturally, launching rockets into space is more complicated than Newton's laws of motion imply. Designing rockets that can actually lift off Earth and reach orbital velocities or interplanetary space is an extremely complicated process. Newton's laws are the beginning, but many other things come into play. For example, air pressure plays an important role while the rocket is still in the atmosphere. The internal pressure produced by burning rocket propellants inside the rocket engine combustion chamber has to be greater than the outside pressure to escape through the engine nozzle. In a sense, the outside air is like a cork in the engine. It takes some of the pressure generated inside the engine just to exceed the ambient outside pressure. Consequently, the velocity of combustion products passing through the opening or throat of the nozzle is reduced. The good news is that as the rocket climbs into space, the ambient pressure becomes less and less as the atmosphere thins and the engine thrust increases.

Another important factor is the changing mass of the rocket. As the rocket is gaining thrust as it accelerates upward due to outside pressure changes, it is also getting a boost due to its changing mass. Every bit of rocket propellant burned has mass. As the combustion products are ejected by the engine, the total mass of the vehicle lessens. As it does its inertia, or resistance to change in motion, becomes less. As a result, upward acceleration of the rocket increases.

In practical terms, Newton's second law can be rewritten as this:

$$f = m_{exit}V_{exit} + (p_{exit} - p_{ambient})A_{exit}$$

("A" refers to the area of the engine throat.)

When the rocket reaches space, and the exit pressure minus the ambient pressure becomes zero, the equation becomes:

$$f = m_{exit}V_{exit}$$

In real rocket science, many other things also come into play.

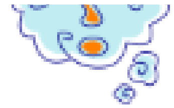
- Even with a low acceleration, the rocket will gain speed over time because acceleration accumulates.

- Not all rocket propellants are alike. Some produce much greater thrust than others because of their burning rate and mass. It would seem obvious that rocket scientists would always choose the more energetic propellants. Not so. Each choice a rocket scientist makes comes with a cost. Liquid hydrogen and liquid oxygen are very energetic when burned, but they both have to be kept chilled to very low temperatures. Furthermore, their mass is low, and very big tanks are needed to contain enough propellant to do the job.

In Conclusion...

Newton's laws of motion explain just about everything you need to know to become a rocket scientist. However, knowing the laws is not enough. You have to know how to apply them, such as:

- How can you create enough thrust to exceed the weight of the rocket?
- What structural materials and propellant combinations should you use?
- How big will the rocket have to be?
- How can you make the rocket go where you want it to?
- How can you bring it back to Earth safely?



Date ______________________________

Title: ____ Topic ________________

Know	Wonder	Learned
Before you read, write what you think you know about the topic.	Before or as you read, write what you wonder or want to know about the topic.	While reading or after you finish, take notes about what you learned.

Name ______________ Date _____________

Exit Ticket

3 Facts about rockets that will help me with my design	1. 2. 3.
2 Questions I still have about designing my rocket	1. 2.
1 New idea I have from reading the article	1.

Name ______________________________ Date _______________________

Launching to the Moon Challenge Line Plot

Directions: Construct a line plot using the data from the class below. Be sure to include a title and label the axis.

____

X=________________

____

Directions: Use the data on the line plot to answer the following questions.

1. What is the total height our rockets traveled?
2. What is the difference between the rocket which traveled the highest and the rocket which traveled the shortest distance?
3. Compare and contrast the two rockets. What do we notice is similar? What do we notice that is different?
4. How many rockets traveled higher than 1 ½ meters?
5. How many rockets traveled 1 ½ meters or less?
6. Imagine the rockets traveled the same total distance. Each rocket traveled the exact same distance as all the other rockets. How far did each rocket travel?

Name ________________________________ Date ______________________________

Launching to the Moon Science Assessment

Directions: Select the best answer for each of the questions below.

1. Four students were noticing that a new substance is formed when AlkaSeltzer and water are combined. Which student gives the best explanation about how they know a new substance is formed?
    a. Jenny says, "when the rocket launches in the air, a trail of water is left behind. That is evidence that a new substance was formed."
    b. David says, "when the water and AlkaSeltzer combine, the amount of water increases which causes the rockets to launch. The extra water is evidence of a new substance."
    c. Jamal says, "when the water and AlkaSeltzer combine, bubbles are created which releases a gas. Since a solid and liquid were combined, the gas must be a new substance."
    d. Naliyah says, "when the rocket launches in the air, the sound it makes is evidence of a new substance being formed."

2. When a rocket launches, the force of thrust helps it lift off. Which of the following is a true statement about the force of thrust?
    a. Thrust has to be greater than gravity in order for the rocket to lift off.
    b. Thrust has to be weaker than gravity in order for the rocket to lift off.
    c. Thrust is a magnetic force that is opposite gravity.
    d. Thrust is the only force acting on the rocket.

3. During which of the following times would the forces acting on a rocket be balanced?
    a. When the rocket is accelerating upwards and has almost escaped Earth's gravitational pull
    b. When the rocket is midway through its ascent and is still accelerating
    c. When the rocket is descending and reentering the Earth's atmosphere
    d. When the rocket is on the launch pad before lift off.

Directions: Complete each question below.

4. Draw a diagram that shows the forces acting on a rocket just after it launches. Label the diagram as balanced or unbalanced.

5. Draw a diagram that shows the forces acting on a rocket just before it launches. Label the diagram as balanced or unbalanced.

6. In your own words, explain how the amount of water impacts the power of the rocket. How does the rocket change when more water is added? How does it change when less water is added?

Directions: Read each statement. Determine whether the statement is true or false. Write your answer in the blank.

7. ___________ Balanced forces occur when the forces are equal and opposite. (T)

8. ___________ One type of evidence that a new substance is formed is bubbling. (T)

9. ___________ Unbalanced forces cause a change in direction but not speed. (F)

10. ___________ Objects at rest have no forces acting upon them. (F)