National Aeronautics and Space Administration

NASA eClips™

Educator Guide

NASA'S REAL WORLD

BALLOON AERODYNAMICS CHALLENGE 1 AND 2

https://nasaeclips.arc.nasa.gov/

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Partner

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NASA eClips™ **Balloon Aerodynamics Challenge 1 and 2**

EDUCATOR GUIDE

THE REAL WORLD MATHEMATICS

Grade Level:
6-8

Subjects:
Physical Science

Teacher Prep Time:
30 minutes

Prerequisite Skills:
Students need an understanding of density prior to beginning this challenge.

Lesson Duration:
one and one half 50-minute classes for Challenge 1; an additional 50-minute class to complete Challenge 2.

National Standards:

Next Generation Science Standards (NGSS)

Physical Science

- Motion and Stability: Forces and Interactions
- Structure and Properties of Matter

Science and Engineering Practices

- Asking questions (for science) and defining problems (for engineering)
- Constructing explanations (for science) and designing solutions (for engineering)

International Technology and Engineering Educator Association (ITEEA)
Design

- Students will develop an understanding of the attributes of design.
- Students will develop an understanding of engineering design.
- Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

Instructional Objectives

Students will:

- work through the eight steps of the Design Process to complete a team challenge;
- demonstrate the concepts of lift, drag and thrust as examples of force and motion;
- demonstrate the concepts of buoyancy and density; and
- demonstrate an understanding of the two quantities (direction and magnitude) associated with every force (advanced students).

Lesson Overview:

Students think and act like scientists and engineers as they follow the eight steps of the Design Process to successfully complete a team challenge. In the Explore section, students design, measure, build, test, and re-design a neutrally buoyant helium balloon. In the Explain section, students demonstrate how different forces affect motion. In the Extend section, students apply what they have learned about balloons and density to design a series of balloons that float at different heights. Advanced classes or students also attach sensors to the balloons to gather environmental data. Students compare what they observe with a NASA eClips™ video segment to learn more about forces and motion in a near zero gravity environment and how these forces act similarly or differently than they do in Earth's gravity.

Icons flag two areas of interest or opportunities for teachers.

- **Technology Icon** highlights opportunities to use technology to enhance the lesson.
- **Resources Icon** relates this lesson to other NASA educator resources that may supplement or extend the lesson.

Materials List:

Per student

Secondary Engineering Design Packet available at:

https://nasaeclips.arc.nasa.gov/resources/download/45

Per group of 4

- 1 Mylar™ helium-filled balloon (available at craft and grocery stores)
- 1 watch, clock or stopwatch
- 50 paperclips, grains of uncooked rice, seed beads (small beads available at a craft store), or other objects of a similar mass
- 1 paper cup for carrying ballast
- Temperature or other sensors
- 3 yards of ribbon or thin string

Note: several meters of space inside or outside the school building are needed to space balloons and collect data.

NASA's Scientific Ballooning Program

Large unmanned helium balloons provide NASA with an inexpensive means to place payloads into a space environment. The unique capabilities of this program are crucial for the development of new technologies and payloads for NASA's space flight missions. Many important scientific observations in fields such as hard x-ray/gamma-ray and infra-red astronomy, cosmic rays and atmospheric studies have been made from balloons. The newly developed capability focused on thin-film high altitude balloons for higher altitude flights and super pressure balloons for long duration ballooning has greatly expanded the opportunities for scientific studies from balloons.

On January 7, 2009 three long duration, sub-orbital flights were launched and operated in Antarctica during the current Southern Hemisphere summer, reaching a milestone of 20 years of scientific ballooning in the region. This accomplishment was a result of a partnership between the National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) with NSF providing communication and logistics and NASA providing the satellite communication link.

These balloon flights carried the balloons and their instruments to the edge of space to investigate the nature of ultra-high-energy cosmic rays and search for anti-matter, in air currents that circle Antarctica. Unique atmosphere circulation over Antarctica during the austral summer allows scientists to launch balloons from a site near McMurdo Station and recover them from very nearly the same spot weeks later.

Antarctic flights are of a long duration because of the polar vortex, a persistent, large, low-pressure system that exists because there is very little atmosphere or temperature change. Constant daylight in Antarctic means no day-to-night temperature fluctuations on the balloon, which helps the balloon stay at a nearly constant altitude for a long time. Since the beginning of the collaboration between NSF and NASA in 1989, one or two flights per year have been achieved.

For more information on the NASA Scientific Ballooning Program, visit *https://www.nasa.gov/scientificballoons/overview*

FORCES AND MOTION

When a helium balloon is floating and moving through the air, there are four forces that act on it called aerodynamic forces. The basic aerodynamic forces are lift, drag, thrust and weight.

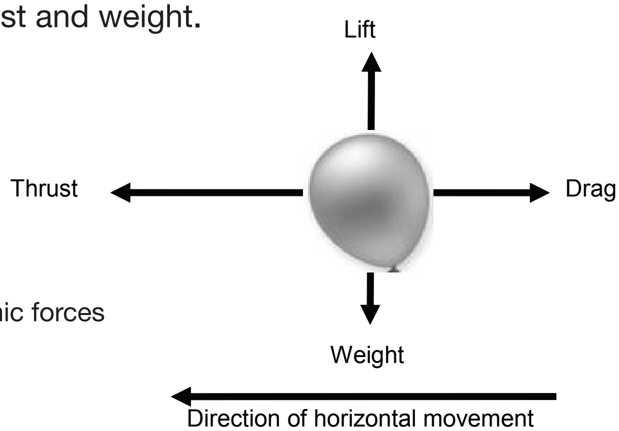


Figure 1. Aerodynamic forces

Weight is the force generated by the gravitational attraction of the Earth on an object. For a floating balloon, weight is a force which is always directed towards the center of the Earth. The magnitude of this force depends on the mass of the balloon and its payload (instruments and containers).

For the balloon to float a force must be generated to overcome weight. This force is called lift. Lift is caused by the buoyancy of the balloon. Buoyancy is an upward force caused by a difference in density between two fluids. In the case of a balloon, the two fluids are air and helium. Since helium is much less dense than air, a given volume of helium is less dense than the same volume of air. The heavier air exerts an upward force on the balloon causing it to rise.

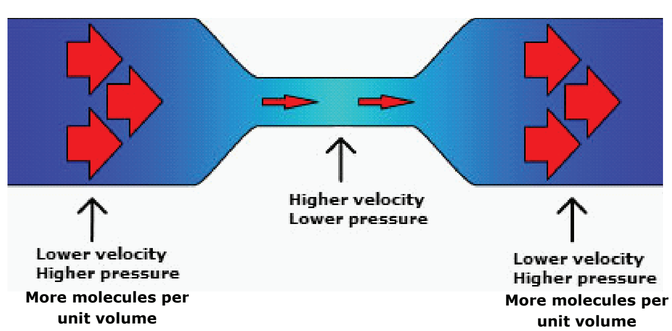
Once the balloon is floating, it is moved horizontally by the force of thrust. For a balloon, thrust is supplied by blowing wind. As the moving air strikes the surface of the balloon, it propels the balloon forward. As the balloon moves forward, the still air directly in front of the balloon pushes against the balloon and resists the movement of the balloon. The resistant force is called drag. In order for the balloon to move forward, the force of thrust must be greater than the force of drag.

DEFINITIONS

acceleration - Acceleration is the rate of change in velocity when an object speeds up, slows down, or changes direction over time. You are accelerating while driving on merge lanes when entering highways. When the car is speeding up, you can feel forces pushing you back into the seat, and if the driver hits the brakes, you'll feel a force pushing you to the front of the car. You can also feel forces pulling you toward the outside of the curves in a road. In each of these cases you're experiencing acceleration.

ballast – Material inside a vehicle that gives it additional mass for stability or other purposes. This material gives the vehicle more weight, a force pulling down toward the center of the Earth. Ballast is sometimes designed to be disposable.

Bernoulli's Principle - Bernoulli's principle states that as the velocity of a fluid increases, the pressure exerted by that fluid decreases. This can best be demonstrated by Figure 2 and the NASA eClips™ video.



buoyancy – Buoyancy is an upward force on an object in a fluid, e.g., when you float in a pool or the ocean or a balloon floats in air.

density – Density is the measure of the amount of matter contained in a certain volume. Example: A red clay brick is much more dense (has more mass per unit volume) than a Styrofoam brick of similar volume.

drag – Drag is the resistance on an object to movement through a fluid. It is a force that slows an object down. For example, swimmers and submarines experience drag as they move through water and birds and aircraft experience drag as they move through air.

fluid – A fluid is a substance that can flow, such as a gas or a liquid (examples of fluids: air, water, and oil).

force – A force is a push or pull. Forces have directions and quantities. They are represented in diagrams with arrows. See Figure 1.

inertia – Inertia is the tendency of an object to continue doing what it is doing, either moving or resting, unless acted on by an outside force. The inertia of an object is related to its mass (the greater the mass, the greater the inertia).

lift – An upward force that opposes the downward pull of gravity. This is the force that allows a bird to fly.

magnitude – Magnitude is the size (or amount or quantity) of a measurement or object.

net force – The net force is the total of all of the forces acting on an object. These forces are vectors, which means they have direction as well as magnitude.

pressure – Pressure is the force per unit area. Even though you can't feel it, air has pressure. Air molecules move continuously. The more times they bump into each other or a surface, the greater the pressure. Air pressure is increased by:

1. increasing the number of molecules in the same amount of space (volume);
2. increasing the temperature (it makes the air molecules move faster); or
3. decreasing the volume.

speed – Speed is the rate of change in position per unit of time (in other words distance per unit time). For example, a common highway speed limit is 89 kilometers per hour (55 miles per hour).

thrust – Thrust is a force that propels an object. Thrust must be greater than drag for an object to move forward.

vector – A vector is a variable (something that can change/vary) that is composed of both an amount and a direction. An example of a vector is velocity. What makes velocity different than speed is the direction of travel. Wind velocity is a way vectors are used in everyday life. When the weather report states the wind is 40 kilometers per hour (25 miles per hour) out of the west, the wind's velocity, not speed, is what is being reported.

weight – Weight is the force of gravity on an object. Here on Earth, it means how hard the Earth pulls down on objects. Because the Moon is smaller than the Earth, the Moon wouldn't pull down on an object as hard and it would weigh a lot less there. However, since the object would still be made up of the same number and type of particles, its mass and density would be the same on the Earth and on the Moon.

Engineering Design Lesson Development

ENGAGE - Engineering Design Process and Balloon Challenge Introduction (10 minutes)

Explain that students will be working in teams of FOUR to solve a design problem. Show students the graphic of the engineering design process found on page 1 of the *Secondary Engineering Design Packet*. Introduce the steps the students will be using to solve their balloon challenge.

1. Identify the problem.
2. Identify criteria and constraints.
3. Brainstorm possible solutions.
4. Select a design.
5. Build a model or prototype.
6. Test and evaluate the model.
7. Refine the design.
8. Share the design.

1. Introduce students to the challenge, have them read page 2 of the Design Packet, and then break the students into groups of four.
   Instrumentation Balloon Challenge 1: Modify a helium-filled balloon to make it neutrally buoyant.
   Inform students that their challenge is to:
   Design a system to establish helium balloons floating at different altitudes in the classroom (or field if outdoors).
2. In their groups, have students discuss what they need to know to complete this challenge. Explain that they are continuing to **identify the problem** and addressing its criteria and constraints. Ask students to define the terms **criteria and constraints**, then have the students list questions so that they will know the criteria and constraints for the present challenge.
   a. *Criteria – Criteria are conditions that must be met to solve the problem.*

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   b. Constraints – Constraints are anything that might limit a solution, such as cost, availability of materials, and safety.

3. Ask students to create a list of questions relating to the problem. The research will be done for homework or in the next class. Some questions students might ask include:
   a. Why does a helium balloon float?
   The helium inside the balloon has mass and takes up space. The helium inside the balloon is less dense than the air surrounding the balloon, which also has mass, and takes up space. The air has a larger mass per given volume. Most of air consists of Nitrogen, N2, molecular weight of 28 amu, and Oxygen, O2, molecular weight of 32 amu. Helium gas, He, has a molecular weight of 4 amu.
   b. What does it mean for the balloon to be "neutrally buoyant?"
   To create a neutrally buoyant balloon, the balloon's forces of lift and weight must be balanced. A neutrally buoyant balloon doesn't rise or fall (if the atmosphere is still and stable) – it stays in place, floating at one level.
   c. What materials are available?
   The teacher may choose to limit resources.
      1. Paperclips, grains of rice, or seed beads allow for balancing the balloons very inexpensively.
      2. Each group should have access to the same materials.
      3. Provide paper cups that may be cut and tied to the balloons to hold materials that adjust balloon mass.
4. Have students establish rules BEFORE beginning the challenge. Some suggested rules might be:
   a. The balloons must float at 0.5 m intervals of height. Each team will be assigned a specific height.
   b. Students must work as teams to complete the challenge. Teams of four are suggested.
   c. Identify any other rules deemed necessary.
5. Team roles may include:
   Project Engineer (PE)
   - Checks the team's work.
   - Asks the instructor questions.
   - Leads team discussions.
   - Is in charge of safety.

   Developmental Engineer (DE)
   - Is in charge of getting the design completed.

- Leads construction.
- Makes the supply list.
- Approves the design after construction.

Facilities Engineer (FE)

- Collects the supplies and equipment.
- Directs cleanup.
- Returns supplies and equipment.
- Makes sure to use only what is needed.

Test Engineer (TE)

- Records all information.
- Makes sure written reports are completed.
- Fills out forms of any kind for the team.
- Makes team reports to the rest of the group.

6. Ask students to **Brainstorm possible solutions** to the Balloon Aerodynamics challenge. Students should complete the **identify the problem**, **criteria and constraints**, and **brainstorm** in the Design Packet (or in a science notebook). Encourage students to make drawings of their solutions.

EXPLORE

Select, Build, and Test a Balloon Aerodynamics Design (40 minutes)

1. Use the Design Packet to guide students through the next four steps of the design process.
   - **Select a design**
   - **Build a model or prototype**
   - **Test the model and evaluate**
   - **Refine the design**

EXPLAIN (35 minutes)

1. Ask students to share their solutions with one another, verifying that their balloons are neutrally buoyant.
2. Have students use/apply the related vocabulary as they describe their balloons.
3. (**TECHNOLOGY**) Show the NASA eClips™ video segment *Real World: Keeping the International Space Station in Orbit* (5:39) to the students. This segment can be found on the NASA eClips™ website: *https://nasaeclips.arc.nasa.gov/video/realworld/real-world-keeping-the-international-space-station-in-orbit-archived*
4. The video may be streamed or downloaded from the nasa.gov web site. A captioned version is also available at the nasa.gov site. This video may be streamed in high definition from the NASA eClips You Tube™ channel: *http://www.youtube.com/watch?v=NpHOlmNtFTQ*

(**TECHNOLOGY**) To illustrate to students the importance of neutral buoyancy, Show the NASA eClips™ video segment *Launchpad: Fluid Dynamics – What a Drag!* (7:13) to the students. This segment can be found on the NASA eClips™ page of the NASA web site:
https://nasaeclips.arc.nasa.gov/video/launchpad/launchpad-fluid-dynamics-what-a-drag
This video may be streamed in high definition from the NASA eClips You Tube™ channel:
http://www.youtube.com/watch?v=sQ-kEz9Im2U

4. In their science notebooks, ask students to reflect and sketch diagrams of forces affecting balloon flight. Share responses.
5. Ask students to research and discuss ways NASA uses balloons.
   (**RESOURCE**) For more information about how NASA uses balloons go to *nasa.gov/scientificballoons*
   (**RESOURCE**) For an example how NASA uses the concept of neutral buoyancy in astronaut training go to *https://www.nasa.gov/feature/building-on-a-mission-neutral-buoyancy-facilities-for-spacewalk-training*

EXTEND – Instrumentation Balloon Challenge 2: Data Collection
(50 minutes)
Groups of four students will again follow the design process to solve a second challenge.

1. Assign students an altitude for an environmental measurement. Have students obtain that length of string. Have student teams outfit their balloons with some type of data sensor and make their best guess at a density adjustment to float their balloon inside a room with a high ceiling (hallway or gym) or outside on a calm/windless day at their assigned altitude. Students should record all adjustments in their notebooks or design sheets.
2. If going outdoors have students do an instrumentation balloon data test in the classroom. Students should plan and practice to ensure balloons are NOT released. (Released, unretrieved helium balloons can be an aircraft and wildlife hazard and are considered litter/pollution).
3. Have each student group take their SECURELY TETHERED (with the premeasured string) instrumentation balloon outside. Have students let out the string to their assigned altitude and note if the balloon rises to the entire extension of the string.
4. Have students record their data measurements and enter their data in notebooks. Back in the class, the data should be put in a class table and graph.
5. Have students meet back in their groups to discuss their design adjustments

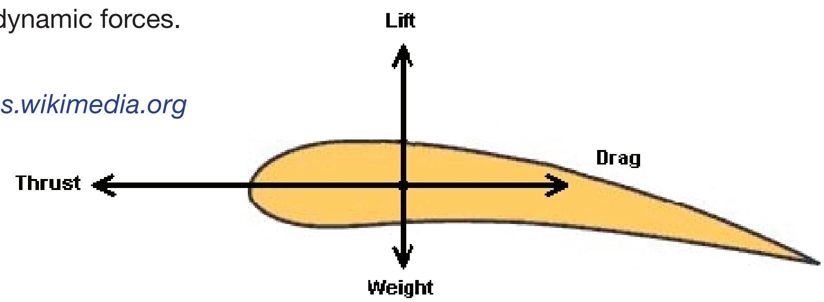
and whether changes are necessary. Each group should prepare a presentation of their design, the modifications they made, the data they obtained, and any additional modifications they would make if they had time for an additional instrumentation balloon trial.

EVALUATE (30 minutes)

1. Use the Evaluation Checklist in the Design Packet to evaluate student understanding of the engineering design process.
2. (**TECHNOLOGY**) Ask students to create a lesson on balloon aerodynamics based on the vocabulary words related to the design challenge(s). They should include images and illustrations of their balloon and the vector forces that affected them. Each term should be supported by one or more diagrams or short videos. Encourage students to find NASA or other videos to support their lessons. They should include the URL of the websites where the videos are housed as well as how long the videos are. Their lessons should also answer one or more of the following questions:
    a. What is density? Give some examples. (*Density is mass per unit volume. A small stone is more dense than a large beach ball, thus the stone will sink when thrown into water but the beach ball will float*).
    b. How can you change the density of a balloon? (*Add solid objects to the paper cup to give the balloon more "ballast," or let helium out of the balloon. Since helium is lighter than air, the less helium, the less the difference there is between the density of the balloon and the air*.)
    c. What could you do to a neutrally buoyant balloon or its surroundings to make it sink and rise? (*Add more ballast or let out helium to make it sink. Remove ballast or add more helium to make it rise*.)
    d. What is the fluid that holds the balloon up? (*Air*)
    e. When might you want an object to be neutrally buoyant in water? (*An underwater rover or a scuba diver need to be neutrally buoyant to accomplish tasks underwater*.)
    f. What can you say about the density of oil plumes that float beneath the surface of the ocean? (*If the oil plume isn't floating on the surface, it is less dense than the water at the ocean's surface. The density of ocean water increases as depth increases*.)
    g. How does a hot air balloon pilot make the balloon rise, descend or remain at a certain altitude? (*Heat is applied to make the air in the balloon warmer. Warmer air is less dense than cooler air. When the heat is turned off, the air cools, and the balloon will begin to sink. The pilot needs to balance heat with the surrounding air conditions to keep the balloon at one altitude*.)

h. How is the flight of a balloon different than that of an airplane? (*The movement of a balloon is more dependent upon the winds and current atmospheric conditions (rising thermals, etc.) due to its large surface area and round shape. Airplane wings are shaped to so that they produce lift and reduce drag. Airplanes are able to control their speed with engines generating thrust.*)

Figure 3. Aerodynamic forces.
Image Credit:
http://commons.wikimedia.org



i. In your science notebook or design log, add diagrams of the forces controlling balloon and airplane flight. (*See Figure 1 for forces controlling a balloon*.)

j. In your teams, brainstorm how learning about balloon and airplane flight can help NASA's space program. Include three of your best ideas here and share them with the class.

RESOURCES

For additional ideas about using balloons to gather data, go to NASA-Supported Sensor Aims to Improve Weather Data Collection:
https://www.nasa.gov/centers/armstrong/features/sensor-aims-to-improve-weather-data-collection.html

Learn how NASA Balloon Makes Record-breaking Flight flying around the South Pole. Visit:
https://www.nasa.gov/vision/universe/starsgalaxies/cream.html#:~:text=Flying%20near%20the%20edge%20of,orbits%20around%20the%20South%20Pole

Learn how hot air balloons work at this How Stuff Works website. Visit:
http://science.howstuffworks.com/transport/flight/modern/hot-air-balloon.htm

Learn how NASA's SuperTIGER Balloon studies cosmic particles. Visit:
https://www.nasa.gov/feature/goddard/2017/nasas-supertiger-balloon-flies-again-to-study-heavy-cosmic-particles

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The National Balloon Museum dedicates itself to providing the public with a comprehensive understanding of ballooning and its history with museum archives of more than 200 years of ballooning. It even has a section about women balloonists. See:
https://www.nationalballoonmuseum.com/women-balloonists/

The NASA-funded Florida International University's Aeronautics Learning Laboratory for Science, Technology, and Research (ALLSTAR Network) website is an excellent resource, with multiple levels of information on the forces effecting flight. See:
https://web.eng.fiu.edu/allstar/index.htm