BOEING

Forces of Flight

Teachers Handbook
Grades 5–8

Introduction

One of the first questions people ask about flight is, “When did people first think of flying?” We don’t know exactly, but hieroglyphs from ancient Egypt show that thousands of years ago, people dreamed of flying and made up stories about flight. The ancient Greeks told the story of Icarus, who flew too close to the Sun and crashed into the ocean. And several hundred years ago, the Chinese used kites to move people and supplies up steep cliffs.

More recent history also abounds with examples of our fascination with the idea of flight. In the late 1600s, the artist and scientist Leonardo da Vinci designed (but never operated) the world’s first helicopter. In 1783, the Montgolfier brothers publicly demonstrated a hot-air balloon: They flew a sheep, a duck, and a cockerel over Paris. In the late 1800s, Otto Lilienthal flew gliders in Germany, helping to popularize gliding as a sport.

The first controlled flight occurred in 1903, when two adventurous brothers, Orville and Wilbur Wright, made their historic flight at Kitty Hawk, North Carolina. On that first flight, they flew just 120 feet – less than the wingspan of a Boeing 747 – and they stayed in the air just 12 seconds. With that short flight, they changed the face of the 20th century.

To make that flight, the Wright brothers built on the knowledge of those who had studied the forces of flight before them. But what interested them in flight in the first place? Apparently, their passion was sparked by experiments with paper helicopters in grade school. The simple helicopters were made from cork, cardboard, and a rubber band, but the experiments made an impression on the young Wright brothers. We include equally simple experiments on each poster, which we hope will help students understand the forces of flight.

The most important thing to keep in mind is that the four forces that influence flight – gravity, lift, drag, and thrust–are balanced against one another. Gravity is the force that attracts all objects to each other. Lift is the force that allows an object to counteract gravity. Drag is the force of resistance caused by air pressure that slows an airplane’s flight. Thrust is the force that creates an airplane’s forward motion.

Introductory Discussion Topic

A good way to emphasize the importance of flight is to consider what has changed since people have begun to fly. Consider the case of Hawaii. In 1903, the year that the tourism bureau of Hawaii first began advertising, 2,000 tourists visited Hawaii. They arrived by steamship from San Francisco. The journey took four days. Thirty-three years later, in 1936, the Hawaii Clipper airplane carried the first airborne tourists – seven passengers – to Honolulu. The trip from San Francisco took a little more than 21 hours. By 1941, larger airplanes that could carry as many as 74 passengers made daily flights. Not quite 60 years later, in 2000, Hawaii had seven million visitors, nearly all of whom arrived by airplane. Today, a trip aboard a jet airplane from San Francisco to Honolulu takes less than six hours.

Hawaii provides a dramatic example of how air travel has changed the world. Can you think of other examples?

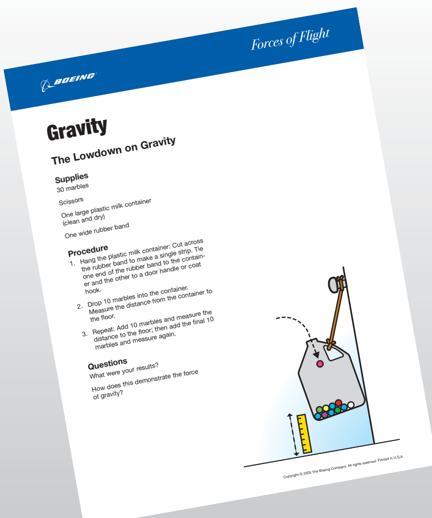
http://oahu.gohawaii.com/exec/107104/2543

http://www.hawaii.gov/dbedt/01vrr/index.html

Gravity

It is easy to think of gravity as negative, because we commonly associate it with being pulled down. However, it's important to note that gravity also holds Earth in orbit around the Sun, keeps us from being catapulted into space, and binds the atmosphere to the planet, allowing us to breathe. There is an up side to the downward pull, so to speak.

Experiments


Forces of Flight

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Gravity

The Lowdown on Gravity

Supplies
30 marbles

Scissors

One large plastic milk container (clean and dry)

One wide rubber band

Procedure
1. Hang the plastic milk container: Cut across the rubber band to make a single strip. Tie one end of the rubber band to the container and the other to a door handle or coat hook.
2. Drop 10 marbles into the container. Measure the distance from the container to the floor.
3. Repeat: Add 10 marbles and measure the distance to the floor; then add the final 10 marbles and measure again.

Questions
What were your results?

How does this demonstrate the force of gravity?

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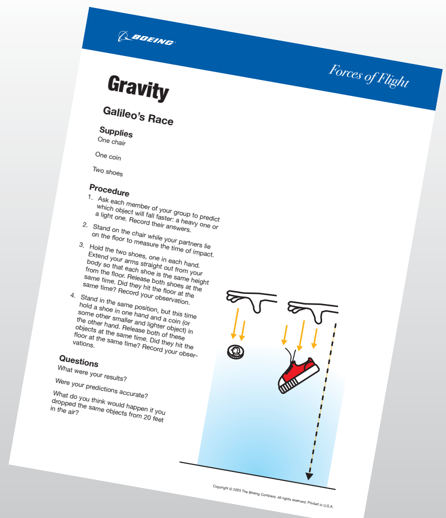
1. The Lowdown on Gravity is the simplest of all of the experiments suggested here, and most students will be able to guess the experiment's outcome in advance. However, this simple experiment provides the opportunity to talk about gravity (a word derived from the Latin word for weight) and how weight can affect our ability to fly. Try asking, "If something gets heavier, what happens to our ability to lift it?" Or, "Imagine a sparrow grabbing a bowling ball with its feet. Will the sparrow be able to fly with the ball?"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Forces of Flight

Gravity

Galileo's Race

Supplies
One chair

One coin

Two shoes

Procedure
1. Ask each member of your group to predict which object will fall faster: a heavy one or a light one. Record their answers.
2. Stand on the chair while your partners lie on the floor to measure the time of impact.
3. Hold the two shoes, one in each hand. Extend your arms straight out from your body so that each shoe is the same height from the floor. Release both shoes at the same time. Did they hit the floor at the same time? Record your observation.
4. Stand in the same position, but this time hold a shoe in one hand and a coin (or some other smaller and lighter object) in the other hand. Release both of these objects at the same time. Did they hit the floor at the same time? Record your observations.

Questions
What were your results?

Were your predictions accurate?

What do you think would happen if you dropped the same objects from 20 feet in the air?

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2. Galileo's Race is derived from a famous experiment that is often attributed to Galileo. However, according to many scholars, the attribution may be inaccurate. This experiment was performed by several people, but there's no documentation linking it to Galileo. Set up the experiment by asking, "Which do you think will fall faster? A heavy object or a light one?" This experiment shows that objects of different weights and sizes fall at the same rate.

Gravity (continued)


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Gravity

Newton's Ball Drop

Supplies

One large foam ball

30 feet of string

One marker

A stopwatch

Each group should have a teacher and three students: a timer, a measurer, and a recorder.

Procedure

1. Measure 5 feet of string and mark the 5-foot point with a black marker.
2. Your teacher stands on a chair, holds the ball 5 feet off the ground as measured by the string, and drops the ball.
3. Measure the amount of time it takes the ball to fall 5 feet. Record the number. Repeat two more times at 5 feet and record the numbers.
4. Repeat the experiment three times each at 10 feet up, 20 feet up, and 30 feet up, if possible. Your teacher can drop the ball from the gym bleachers, if necessary.
5. With your teacher's help, calculate the average time for the drop from each height and plot the averages on a graph of time versus distance. Draw a best-fit line to chart the effects of gravity.

Questions

What were your results?

What happened to the sponge's velocity as it fell from greater heights?

What results would you expect if you dropped the sponge from 100 feet, 500 feet, or 1,000 feet?

3. Newton's Ball Drop requires dropping an object from progressively greater heights and should be conducted with the supervision of an adult. It provides a good opportunity to show students how to create a graph and develop the ability to predict results from graphing. The experiment demonstrates that an object gathers speed as it falls; the greater the height from which it falls, the greater the object's acceleration.

Featured Scientists

Galileo Galilei (1564–1642)
An Italian astronomer, mathematician, and physicist, Galileo was one of a new breed of philosophers – today we call them scientists – who asked how things happened, rather than why they happened. Galileo conducted a series of experiments that led him to conclude that objects of different sizes and different weights fall at the same speed. He was also the first to use the telescope to observe the solar system. Ten years before he died, he published a work that supported Copernicus's theory that held that Earth was not the center of the universe, and that Earth rotates around the Sun. For his writings, Galileo was brought before the Inquisition in Rome, made to renounce his beliefs, and condemned for heresy.

http://www.pbs.org/wgbh/nova/galileo/

Sir Isaac Newton (1642–1727)
Newton, born in England the same year that Galileo died, is considered by many to be the most influential scientist who ever lived. His accomplishments in mathematics, optics, and physics laid the foundation for modern science and revolutionized the world. Newton built on Galileo's ideas, demonstrating that the laws of motion were the same in the "heavens" and on Earth. He defined the laws of motion and universal gravitation, which he used to predict precisely the motion of stars and the planets around the Sun. Newton's law of gravity is most famously associated with an apple falling from a tree and hitting him on the head. He reasoned that a force is required to change the speed of an object, and that gravity was the force that caused the apple to fall to the ground. (However, as best we can tell, that apple never hit him on the head. The story is probably a legend.)

The Law of Gravity

Newton realized *all* objects – not just Earth – exert the force of gravity upon each other, pulling them toward one another, and that the greater an object's mass, the greater the pull it exerts. After numerous scientific observations, Newton devised a mathematical formula to explain this **law of gravity**. It states: The force of gravity is proportional to the product of the two masses and inversely proportional to the square of the distance between their centers of mass.

Gravity (continued)

Put more simply: As objects get closer to each other, the force of their gravitational pull increases. As a result, as a small object is drawn toward a larger one (as the apple falls from the tree limb toward Earth), its speed also increases. This formula was the key to understanding how far planets are from one another and to beginning to understand the structure of the universe.

Newton's Laws of Motion

To understand how things fly, it helps to be acquainted with Newton's three laws of motion. To understand his laws, it also helps to know that two words – "velocity" and "acceleration" – are used differently than in common, everyday language.

1. **Newton's first law of motion** is also known as the law of inertia. It states: In the absence of force, a body at rest tends to remain at rest, and a body in motion tends to remain in motion, moving at a constant velocity (that is, moving at the same speed and in the same direction). In other words, all objects resist changes to their state of motion.

   (One cautionary note: The forces of friction are so common that it is extremely difficult to observe a moving object that is completely unaffected by any force whatsoever. Frictional forces always oppose motion, and sometimes they prevent it.)

   Let's say you're riding a bike. If the bike hits a curb or a large object in the road, the bike stops, but you continue to move and slide forward off the bike seat. Why? The wheel hitting the curb provided the force that changed the bike's state of motion. But there was no force to change your state of motion, and as a result, you slid off the seat.

2. Anytime an object changes velocity (that is, anytime it changes either its speed or its direction, or both) there must be an external force acting upon the object. The change in velocity is called acceleration, regardless of whether the object moves faster, or more slowly, or simply changes directions. **Newton's second law of motion** states that if an object accelerates (changes speed or direction, or both), the acceleration (the change that is produced) is proportional to the strength of the force. The law is expressed with this equation: Force = mass x acceleration.

   Even in simple, everyday events, the external force is not always obvious. Suppose you're standing still, and then you begin to walk. What was the external force that caused you to accelerate? Here's a clue: it's very difficult to start walking if you're wearing new, smooth-bottomed shoes and standing on slick ice.

3. **Newton's third law of motion** is also known as the law of action and reaction. It states: For every action there is an equal and opposite reaction.

   The principle is demonstrated by what happens if you step off a boat onto the shore: As you step toward land, the boat tends to move in the opposite direction, away from shore.

Lift

Lift is a difficult concept. There are two key elements that must be understood.

- Air is a fluid. When most of us think of "fluid," we think of liquids, but a fluid can be either a liquid *or* a gas. To understand how wings work, it might be helpful to think of how fins work in the water.
- Wings are shaped in special ways – called *airfoils* – to create maximum lift. Airfoils create lift in two ways.
    1. Airfoils are designed so that the airflow over the top surface is faster than beneath the bottom surface. Lift is generated because air that moves quickly (over the top of the wing) creates less pressure than air that moves more slowly (under the wing). Result: The air pressure pushing up on the wing is greater than the air pressure pushing down on the wing, creating lift. Bernoulli's principle describes this kind of lift.
    2. Airfoils are angled (called the angle of attack) to divert air downward, which pushes the plane upward. This is the second and more powerful kind of lift, and it is described by Newton's third law of motion, which states that for each action, there is an equal and opposite reaction.

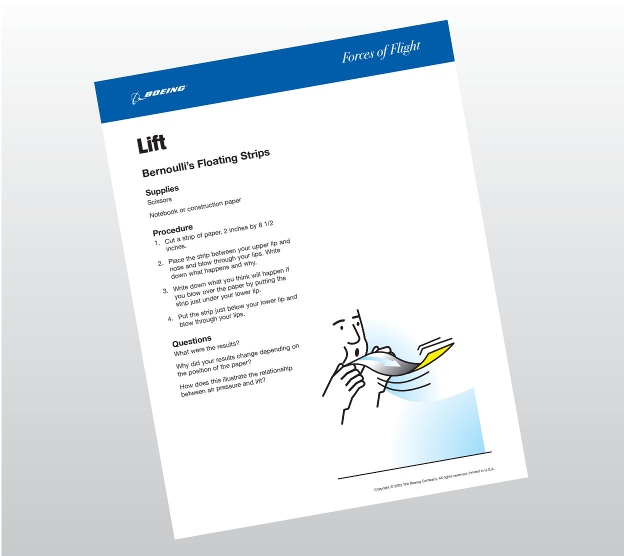
You can test the principle behind the angle of attack. (For safety's sake, do this experiment from a car that is moving slowly. Pick a road on which there is no other traffic and where no signs or tree limbs protrude into the roadway.) Put your hand out the car window with your palm facing downward. Next, turn your hand so that the front – your hand's *leading edge* – is tilted slightly upward. You'll feel your hand being pushed up by the flow of air against it.

If you look at a wing from the side, you can see an airfoil. The shape allows the wing to produce the greatest possible amount of lift with the least possible wind resistance, or drag. Wing designers use different airfoil shapes for different types of airplanes. Some airfoils are curved on top and flat on bottom; others are curved on both top and bottom. Some are very thin, and some are thicker.

In the early days of powered flight, airfoils were curved on top and flat on the bottom (as in the following experiment 3, called *Wing Thing*). As engines have become more powerful and planes much faster, the shape of airfoils (wings) has changed to maximize lift, but the principle remains the same.

Experiments

1. Bernoulli's Floating Strips is a very basic experiment that never ceases to amaze students. It shows how lift works and demonstrates the counterintuitive principle of how fast-moving air lifts a wing. Another way to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Lift

Bernoulli's Floating Strips

Supplies
Scissors
Notebook or construction paper

Procedure
1. Cut a strip of paper, 2 inches by 8 1/2 inches.
2. Place the strip between your upper lip and nose and blow through your lips. Write down what happens and why.
3. Write down what you think will happen if you blow over the paper by putting the strip just under your lower lip.
4. Put the strip just below your lower lip and blow through your lips.

Questions
What were the results?
Why did your results change depending on the position of the paper?
How does this illustrate the relationship between air pressure and lift?

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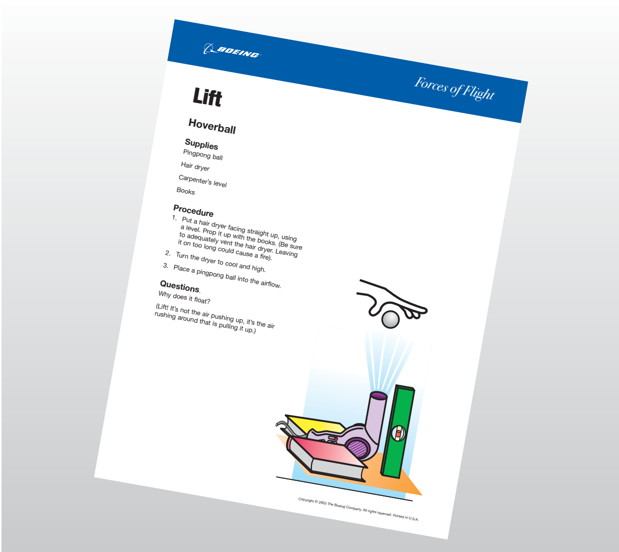
Lift (continued)

demonstrate this principle is to inflate two balloons, tie them so they hang at equal heights about an inch apart, and blow between them.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Lift

Hoverball

Supplies
Pingpong ball
Hair dryer
Carpenter's level
Books

Procedure
1. Put a hair dryer facing straight up, using a level. Prop it up with the books. (Be sure to adequately vent the hair dryer. Leaving it on too long could cause a fire).
2. Turn the dryer to cool and high.
3. Place a pingpong ball into the airflow.

Questions.
Why does it float?
(Lift! It's not the air pushing up, it's the air rushing around that is pulling it up.)

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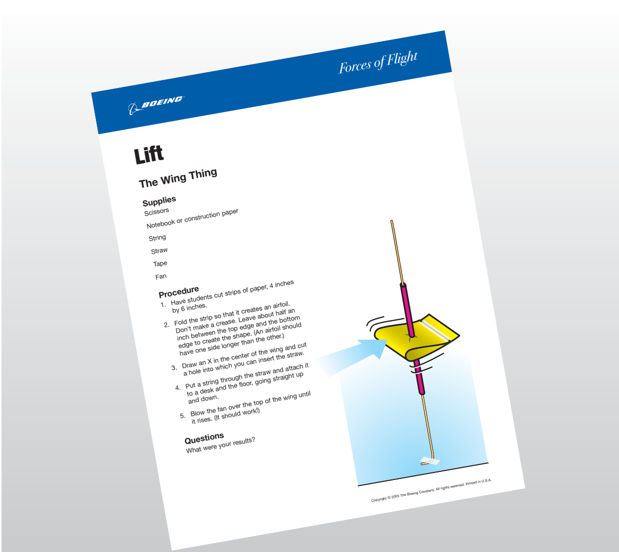
2. Hoverball tests students' understanding of the concept of lift. Ask students why the ball does not fly away or fall. (Tip: The ball is pulled up by the faster-flowing air, not supported on the column of air.) This experiment also works with a balloon and a standard box fan.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Lift

The Wing Thing

Supplies
Scissors
Notebook or construction paper
String
Straw
Tape
Fan

Procedure
1. Have students cut strips of paper, 4 inches by 6 inches.
2. Fold the strip so that it creates an airfoil. Don't make a crease. Leave about half an inch between the top edge and the bottom edge to create the shape. (An airfoil should have one side longer than the other.)
3. Draw an X in the center of the wing and cut a hole into which you can insert the straw.
4. Put a string through the straw and attach it to a desk and the floor, going straight up and down.
5. Blow the fan over the top of the wing until it rises. (It should work!)

Questions
What were your results?

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3. The Wing Thing is an experiment in which students build a simplified airfoil. This is a difficult experiment. (The trick is in getting the shape of the airfoil just right, so don't be disappointed if students have trouble.) The airfoil should travel up the string, but often it does not move smoothly.

Featured Scientists

Daniel Bernoulli (1700–1782)
Bernoulli, a Swiss mathematician and scientist, discovered that as the velocity of a fluid increases, its pressure decreases. That principle – the Bernoulli principle – is the basis for the airfoil shape of an airplane's wing. The difference in pressure above and below the airfoil (or wing) creates lift.

Otto Lilienthal (1848–1896)
Lilienthal was a German civil engineer whose work inspired Orville and Wilbur Wright. Lilienthal conducted a systematic series of experiments and made major developments in the glider based on his observations of birds. He designed, built, and flew many gliders, including two biplanes, which marked a turning point in the history of aviation. In his gliders – the equivalent of modern hang gliders – the pilot was suspended by the arms. Lilienthal went on more than 2,500 glides, some of which were longer than 1,000 feet. After he died in a glider crash, his brother Gustav carried on his experiments.

Drag

Once we understand that air is a fluid, the concept of drag becomes fairly easy to understand. Drag can be useful in a parachute, but most of the time, drag is something engineers try to reduce.

There are two main kinds of drag: *friction drag* and *form drag*.

Friction drag – also known as **surface drag** – is the resistance that comes from rough or protruding surfaces. Imagine the hull of a boat. Over time, tiny sea animals called barnacles can form groupings, or colonies, on the boat. As barnacles collect, they increase resistance and slow a boat's progress in the water. That is why barnacles are scraped off boats' hulls.

Form drag is all about shape. Certain shapes produce more drag than others. Sports cars have low, sleek shapes to minimize resistance. In contrast, delivery trucks aren't meant to go very fast, and so it doesn't matter that their boxy shapes produce a lot of drag. As our manufacturing abilities have improved and our understanding of form drag has become more sophisticated, we have made significant changes in the way we build cars and planes. Look at the visible changes in the posters. Notice how the planes on the posters become more streamlined over time. The changes in shape have been made to minimize drag.

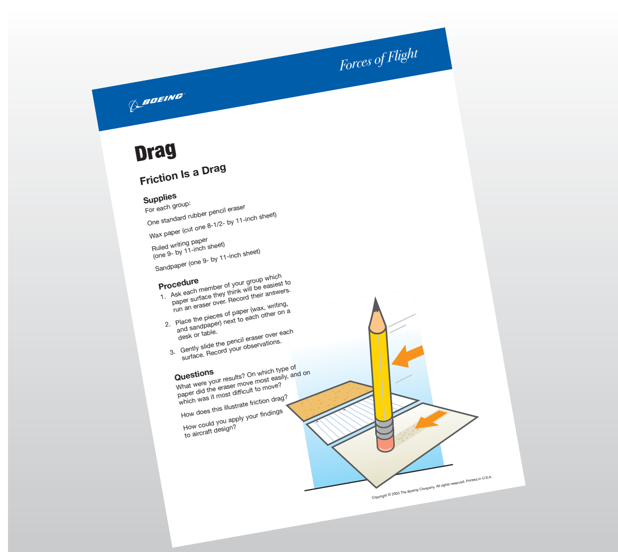
When you throw a baseball, it flies through the air, eventually slows down, curves towards Earth, and hits the ground. Why? Two forces are acting on it. Friction drag – or surface drag – acts on the ball, slowing its speed. Earth's gravity also acts on the ball, pulling it downward.

Wind Tunnels

Wind tunnels simulate the conditions of an aircraft in flight by forcing a high-speed stream of air to flow past a model of an aircraft or part of an aircraft. The forces of lift and drag are measured. A common way to take those measurements is to track the tension changes in the wires that suspend the models in the air. Wind tunnels were originally invented because the mathematical calculations required to predict the behavior of air on a wing were too complicated to calculate and recalculate every time a design changed. However, as computer models have improved, wind tunnels are used less frequently.

Experiments

1. Friction Is a Drag is the simplest and most intuitive of these experiments, but it is important to understand the concept. While we may



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Drag

Friction Is a Drag

Supplies

For each group:

One standard rubber pencil eraser

Wax paper (cut one 8-1/2- by 11-inch sheet)

Ruled writing paper (one 9- by 11-inch sheet)

Sandpaper (one 9- by 11-inch sheet)

Procedure

1. Ask each member of your group which paper surface they think will be easiest to run an eraser over. Record their answers.
2. Place the pieces of paper (wax, writing, and sandpaper) next to each other on a desk or table.
3. Gently slide the pencil eraser over each surface. Record your observations.

Questions

What were your results? On which type of paper did the eraser move most easily, and on which was it most difficult to move?

How does this illustrate friction drag?

How could you apply your findings to aircraft design?

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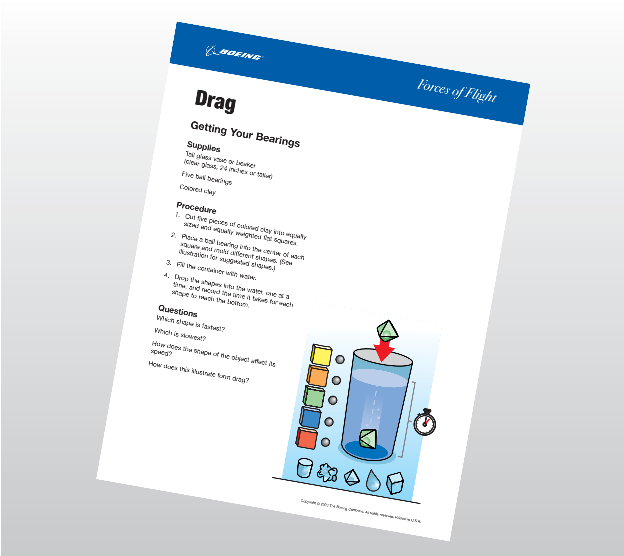
say, "Of course sandpaper has greater friction and slows the pencil," it's useful to link that understanding to the way that planes are built and to the evolution of creatures that fly or swim. The smooth surface of an airplane and the smooth skin of a shark both minimize friction drag.

Drag (continued)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Drag

Getting Your Bearings

Supplies

Tall glass vase or beaker (clear glass, 24 inches or taller)

Five ball bearings

Colored clay

Procedure

1. Cut five pieces of colored clay into equally sized and equally weighted flat squares.
2. Place a ball bearing into the center of each square and mold different shapes. (See illustration for suggested shapes.)
3. Fill the container with water.
4. Drop the shapes into the water, one at a time, and record the time it takes for each shape to reach the bottom.

Questions

Which shape is fastest?

Which is slowest?

How does the shape of the object affect its speed?

How does this illustrate form drag?

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2. Getting Your Bearings is an experiment in which students develop different shapes to maximize and minimize drag. Encourage them to do both. This is a good opportunity to time and graph the results of the experiments. Groups of students can compete to build the fastest and slowest shapes.


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Drag

Design Challenge

Procedure

Airplanes are designed to minimize drag. Identify four other objects that are designed to minimize drag.

Questions

What similarities do you see between these objects?

What differences?

Why do you think they are different?

1. Airplane
2.
3.
4.
5.

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3. Design Challenge is meant to encourage students to think about and compare various manmade and natural shapes for their drag profiles. This challenge is a fun way to make sure that students both understand and can apply this learning.

Featured Scientist

Ludwig Prandtl (1875–1953)
Prandtl, a German engineer, is sometimes referred to as the father of modern aerodynamics for his explanations of how moving fluids, such as air, affect objects. In the early 1900s, Prandtl developed a theory that explained friction (surface drag), which is created when a fluid passes over an object's surface. His theory explained how to reduce drag by streamlining moving bodies, such as streamlining the shape of airplane wings. Later, he helped explain how drag from an airplane's wing tips affects lift. In many areas of aerodynamics, his explanations and equations are still used today.

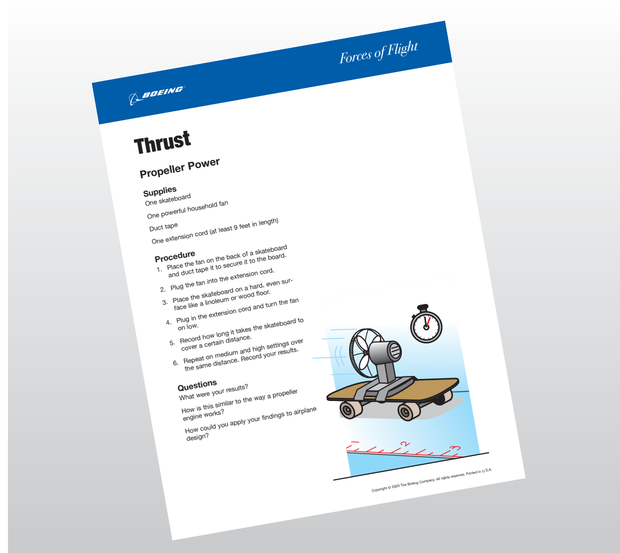
Thrust

Developing a means of thrust was the final hurdle in getting aircraft off the ground. Thrust is the force that opposes drag caused by air resistance. Thrust can either *pull* or *push* an airplane; either way, it gives an airplane forward motion. During takeoff, thrust must be greater than drag (and lift must be greater than weight) so that the airplane can become airborne. For landing, thrust must be less than drag (and lift must be less than weight).

Conventional airplanes today use jet engines or propellers to generate thrust. Surprisingly, the engine that powered the Wright brothers' first flight at Kitty Hawk was very similar to the propeller engines that are used today. However, the Wright brothers' plane used a rear-mounted propeller system, which pushed the plane; most propeller airplanes today use a front-mounted propeller, which pulls the plane. The engine of the Wright brothers' plane was not very powerful, and to minimize weight, the plane did not carry much fuel.

Balancing power and efficiency – the two biggest factors that affected the Wright brothers' success – is still the main consideration in designing modern engines today.

Experiments



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Thrust

Propeller Power

Supplies

One skateboard

One powerful household fan

Duct tape

One extension cord (at least 9 feet in length)

Procedure

1. Place the fan on the back of a skateboard and duct tape it to secure it to the board.
2. Plug the fan into the extension cord.
3. Place the skateboard on a hard, even surface like a linoleum or wood floor.
4. Plug in the extension cord and turn the fan on low.
5. Record how long it takes the skateboard to cover a certain distance.
6. Repeat on medium and high settings over the same distance. Record your results.

Questions

What were your results?

How is this similar to the way a propeller engine works?

How could you apply your findings to airplane design?

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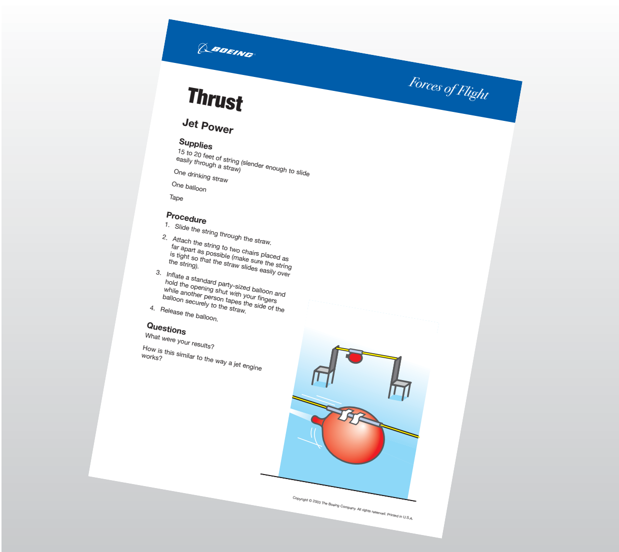
1. Propeller Power is often limited to recreating the pusher-style propeller used by the Wright brothers, rather than the pull-type propeller of most fans. However, if you have a fan with a reverse mode, you can create a pull-type propeller. Discuss with students what keeps the skateboard from flying away.

Thrust (continued)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Thrust

Jet Power

Supplies
15 to 20 feet of string (slender enough to slide easily through a straw)
One drinking straw
One balloon
Tape

Procedure
1. Slide the string through the straw.
2. Attach the string to two chairs placed as far apart as possible (make sure the string is tight so that the straw slides easily over the string).
3. Inflate a standard party-sized balloon and hold the opening shut with your fingers while another person tapes the side of the balloon securely to the straw.
4. Release the balloon.

Questions
What were your results?
How is this similar to the way a jet engine works?

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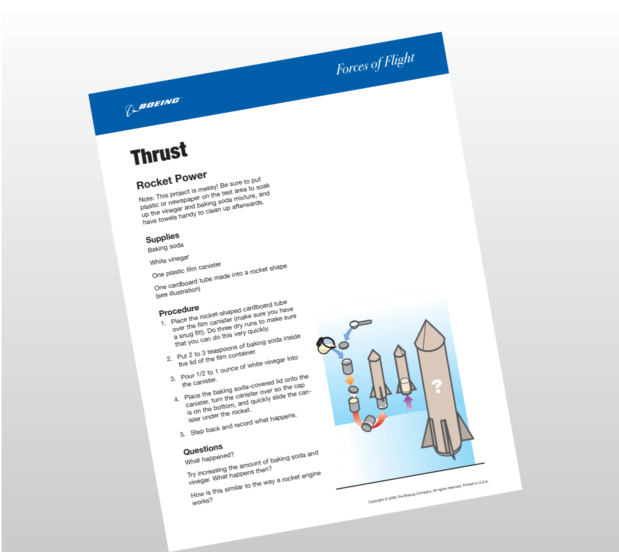
2. Jet Power simulates part of how a jet works, forcing air out a small opening to generate thrust. Obviously, there is no turbofan, but this simple experiment makes the point about the power of a jet. For fun, have students experiment with different types of balloons.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Thrust

Rocket Power

Note: This project is messy! Be sure to put plastic or newspaper on the test area to soak up the vinegar and baking soda mixture, and have towels handy to clean up afterwards.

Supplies
Baking soda
White vinegar
One plastic film canister
One cardboard tube made into a rocket shape (see illustration)

Procedure
1. Place the rocket-shaped cardboard tube over the film canister (make sure you have a snug fit!). Do three dry runs to make sure that you can do this very quickly.
2. Put 2 to 3 teaspoons of baking soda inside the lid of the film container.
3. Pour 1/2 to 1 ounce of white vinegar into the canister.
4. Place the baking soda–covered lid onto the canister, turn the canister over so the cap is on the bottom, and quickly slide the canister under the rocket.
5. Step back and record what happens.

Questions
What happened?
Try increasing the amount of baking soda and vinegar. What happens then?
How is this similar to the way a rocket engine works?

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3. Rocket Power is a fun, messy experiment that captures some of the drama of a rocket blasting off. (Tip: Make sure to get the cap on very quickly.) Encourage students to measure, graph, and compare the results of several trials.

Featured Scientists

Wilbur Wright (1867–1912)
Orville Wright (1871–1948)
The Wright brothers were bicycle mechanics from Dayton, Ohio, and self-taught engineers who had always loved to tinker with mechanical things. In 1896, they took an interest in flying, which at the time meant hang gliding. They learned about flight by watching buzzards and reading books on aeronautics (the mechanics of flight). Unfortunately, many of the books contained faulty information, which meant the Wrights learned mostly by trial and error. In 1899, four years before they made history at Kitty Hawk, North Carolina, the brothers built their first scaled-down flying machine – a pilotless "kite" made of wood, wire, and cloth with a five-foot wingspan. Eventually, the brothers amassed more information on wing design than anyone before them, compiling tables of computations that are still valid today. With the knowledge gained from their studies, they developed the 1903 Flyer, a gasoline-powered machine of spruce, ash, and muslin. In 1908, Wilbur, the older brother, took their equipment to France, where he stunned the European aviation community with the technology. Soon after, the brothers contracted with the U.S. government for the first military airplane. They remained active in aviation for the rest of their lives.

http://www.pbs.org/wgbh/nova/wright/

Thrust (continued)

Dr. Hans von Ohain (1911–1998)
Sir Frank Whittle (1907–1996)
Hans von Ohain, from Germany, and Sir Frank Whittle, from England, are recognized as the co-inventors of the jet engine, although neither knew of the other's work. Whittle registered his patent for the turbojet engine in 1930, and Ohain was granted a patent for his in 1936. However, Ohain's jet flew first, in 1939. Whittle flew his jet two years later, in 1941.

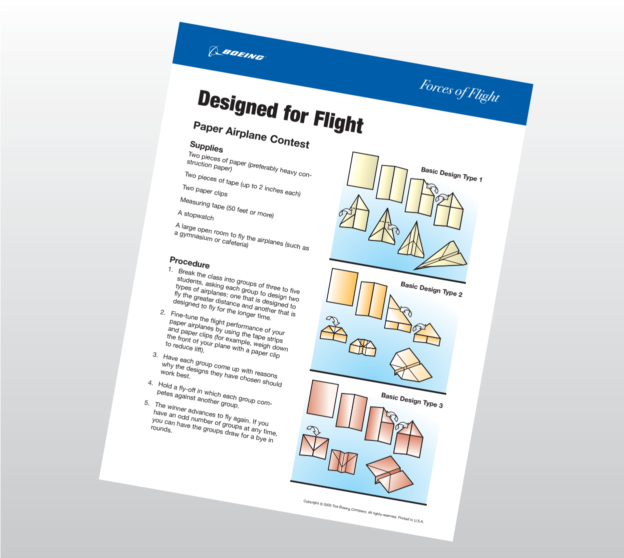
Inventor of the Rocket Engine–unknown
Solid-fuel rocket engines – the first engines ever built – were invented in China in 1232, about 800 years ago. Since then, they have been used widely in a variety of ways.

Robert Hutchings Goddard (1882–1945)
Goddard, an American physicist, is considered the father of the rocket age, and spent his life demonstrating the fundamental principles of rocket propulsion. He envisioned the exploration of space and, in a report published in 1920, he outlined the possibility of a rocket reaching the Moon, a proposal that drew ridicule when the press publicized the report. In 1926, he launched the first rocket powered by liquid fuel.

Designing for Flight

The final poster in the series shows the various movable surfaces on a variety of vehicles: a commercial aircraft (a Boeing 777), a military jet (an F/A-18 Hornet), and a Delta rocket. Each is designed to achieve a specific objective, which students should be able to figure out by studying how each is designed

Experiments


BOEING

Forces of Flight

Designed for Flight

Paper Airplane Contest

Supplies

Two pieces of paper (preferably heavy construction paper)

Two pieces of tape (up to 2 inches each)

Two paper clips

Measuring tape (50 feet or more)

A stopwatch

A large open room to fly the airplanes (such as a gymnasium or cafeteria)

Procedure

1. Break the class into groups of three to five students, asking each group to design two types of airplanes: one that is designed to fly the greater distance and another that is designed to fly for the longer time.
2. Fine-tune the flight performance of your paper airplanes by using the tape strips and paper clips (for example, weigh down the front of your plane with a paper clip to reduce lift).
3. Have each group come up with reasons why the designs they have chosen should work best.
4. Hold a fly-off in which each group competes against another group.
5. The winner advances to fly again. If you have an odd number of groups at any time, you can have the groups draw for a bye in rounds.

Basic Design Type 1

Basic Design Type 2

Basic Design Type 3

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Paper Airplane Contest is meant to encourage students to synthesize what they have learned. As the students choose designs, it may be helpful to remind them of the four forces – gravity, lift, drag, and thrust – and ask questions such as, "How do you think this design will be affected by drag?" Ask students what it means when the nose turns up (too much lift), or when the plane flutters out of control (too much drag). Help students achieve greater flight distance from their paper airplanes by adding weight to some of the designs

Tips for Poster 6 Questions

Commercial Aircraft

- *What features allow large airplanes to move heavy payloads over long distances?* They have big wings for lots of lift and big engines to produce lots of thrust.
- *What would happen if the wings were shorter?* There would be less lift, so the airplane would have trouble flying or would be unable to carry as many passengers or as much cargo.
- *What would happen if the wings were longer?* The airplane would fly more slowly, because drag would be increased.
- *What enables such a large airplane to stay aloft?* The engines are powerful enough to move the plane forward at the speed necessary to produce lift, and the size and shape of the wings provide lift to keep it aloft.

Military Jet

- *What design features enable the F/A-18 Hornet to fly fast and turn quickly?* It has big engines for speed, short wings to minimize drag, and twin stabilizers for extra control.
- *How would performance be affected if the nose were rounder, like the nose of a commercial airplane?* It would increase drag and make the jet fly more slowly.
- *How would performance be affected if the wings were longer?* It would create more drag and force the plane to fly more slowly and turn less quickly.
- *Why does this jet have two vertical stabilizers?* It provides additional control.

Designing for Flight (continued)

Rocket

- *What design features are suited to an expendable rocket, which is designed to cover long distances, reach a target location accurately, but not return to Earth?* The rocket is mostly engine – providing lots of thrust – and is stabilized by the attached boosters.
- *Why doesn't a rocket have wings?* At such high speeds, wings would provide too much drag.
- *How is a rocket equipped to leave Earth's gravity?* It has lots of thrust and a very low drag profile (no wings, for instance).
- *In what way is an expendable vehicle more useful for this mission than one that returns to Earth?* It's easier to design and operate because there is no concern about landing; the only concerns are launching and target accuracy.

Additional Resources

Books

Ames, Lee J. *Draw 50 Airplanes, Aircraft and Spacecraft.* 1987.

Anderson, Margaret J. *Isaac Newton: The Greatest Scientist of All Time (Great Minds of Science).* 2001.

Blackburn, K. and Lammers, J. *Kids' Paper Airplane Book.* 1996.

Courtenay-Thompson, Fiona (ed.). *Eyewitness Visual Dictionaries: The Visual Dictionary of Flight.* 1993.

Crouch, Tom. *The Bishop's Boys: A Life of Wilbur and Orville Wright.* 1990.

Eden, Maxwell. *The Magnificent Book of Kites: Explorations in Design, Construction, Enjoyment & Flight.* 2000.

Freedman, Russell. *The Wright Brothers: How They Invented the Airplane.* 1991.

Hightower, Paul W. *Galileo: Astronomer and Physicist (Great Minds of Science).* 1997.

Laux, Keith R. *The World's Greatest Paper Airplane and Toy Book.* 1987.

Macaulay, David. *The New Way Things Work.* 1998.

Nahum, Andrew. *Eyewitness: Flying Machine.* 2000.

Zaunders, Bo. *Feathers, Flaps, and Flops: Fabulous Early Fliers.* 2001.

Web Sites

K-8 Aeronautics Internet Textbook:
http://wings.avkids.com/

How Jetliners Fly, Boeing Commercial Airplanes:
http://www.boeing.com/commercial/safety/flash.html

How Things Fly Exhibit, National Air and Space Museum, Smithsonian Institution:
http://www.nasm.edu/galleries/gal109/NEWHTF/HTF030.HTM

How Things Fly, NASA:
http://www.aero.hq.nasa.gov/edu/

Science Fun with Airplanes: The Ohio State University Extension/4H:
http://www.ag.ohio-state.edu/~flight/

Your Own Flight: Forces of Flight, Franklin Institute Science Museum:
http://www.fi.edu/flights/own2/forces.html

PBS American Experience WayBack: Flight:
http://www.pbs.org/wgbh/amex/kids/flight/index.html

Glossary

The science of flight uses special terminology to identify important concepts. It may be helpful to refer to the definitions when learning about flight.

aerodynamic: Having a shape that allows for lift and smooth airflow.

air: A mixture of gases that surrounds Earth; this mixture is made up of molecules that take up space and have weight.

airflow: The motion of air molecules as they flow around an object, such as a wing.

airfoil: An object with a special shape designed to produce lift when it moves through the air.

air pressure: The force created by air pushing on a surface.

angle of attack: The angle of a wing to the oncoming airflow.

camber: The curve of an airfoil.

drag: The force that resists the motion of the aircraft through the air.

force: A measurable push or pull in a certain direction.

gravity: The force of attraction between two objects.

laminar flow: The smooth flow of fluid around an object.

launch angle: The angle at which an airplane takes off most efficiently.

leading edge: The front edge of an airfoil.

lift: Upward force produced by air passing over and under the wing of an airplane.

stall: A breakdown of the airflow over a wing, which suddenly reduces lift.

stall angle: The angle at which the wing meets the oncoming airflow and the wing stops generating lift.

thrust: A force created by the engines that pushes an aircraft through the air.

trailing edge: The back edge of an airfoil.

turbulent flow: Airflow around an object that does not flow in a smooth stream but swirls about.

weight: The force with which a body is attracted toward Earth or a celestial body by gravitation. Produced by gravity acting upon an object.

Standards

National Science Education Standards

Grades 5-6-7-8

Science as Inquiry	
Levels 5-8	
Abilities necessary to do scientific inquiry	**A**
Understanding scientific inquiry	**A**

Physical Science	
Levels 5-8	
Motion and forces	**B**

Earth and Space Science	
Levels 5-8	
The structure of Earth's system	**D**
Earth in the solar system	**D**

Science and Technology	
Levels 5-8	
Abilities of technological design	**E**
Understanding science and technology	**E**

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The Boeing Company
Philip M. Condit, chairman and chief executive officer

Community and Education Relations
Antoinette M. Bailey, vice president

Sponsorship and Brand Management
Fritz Johnston, director

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Writing and Editing
Paul Brase (copy editor)
Carrie Howard (posters, web site)
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Scott Nelson

Educational Review
Mike Lach, director of science, Office of Mathematics and Science, CPS
Nijole R. Mackevicius, family program coordinator, Office of Mathematics and Science, CPS
Michelle Schneider, science teacher, George B. Armstrong Elementary School, CPS
Marc Siciliano, science director, Young Women's Leadership Charter School, CPS
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