

TEACHER'S GUIDE 4-8



# LEGENDS OF FLIGHT

FOR RELEASE IN **2D** AND **3D**

## LEGENDS OF FLIGHT 3D

*Legends of Flight* is an inspiring and exciting documentary for IMAX® and other Giant Screen theaters featuring milestone 20th century aircraft, including the Stearman wooden biplane, Constellation, Harrier Jump Jet and Schleicher glider. Discover the design challenges, financial risks and the many lessons learned from a century of aviation trial and error, bringing us to the dawn of a new era of revolutionary aircraft—Boeing’s 787 Dreamliner and the Airbus A380. Witness the construction and final assembly of the 787, and join 787 Chief Pilot Mike Carriker as he puts the new airliner through its rigorous test flights.

Throughout the history of flight, inventors and engineers have worked to mimic the properties and techniques that enable winged creatures to fly nearly effortlessly. The leading-edge aviation innovators in *Legends of Flight* 3D are keen examples, applying composite materials and variable wings to better achieve bird-like strength, weight and flight agility. To illustrate these innovations in a way that comes to life for young people and adults, filmmaker Stephen Low uses SANDDE [Stereoscopic Animation Drawing Device] animation technology as a perfect tool to bring the organic nature of flight alive in 3D for giant screen audiences. (This film also plays in 2D.)

### EDUCATIONAL MATERIALS FOR THIS FILM

Educational materials for this film have been made possible by the generosity of The Boeing Company. These materials have been designed to complement the film and make learning about principles of flight and aviation fun and interesting.

The Boeing Company is the world’s leading aerospace company and the largest manufacturer of commercial jetliners and military aircraft combined. Additionally, Boeing designs and manufactures rotorcraft, electronic and defense systems, missiles, satellites, launch vehicles and advanced information and communication systems. As a major service provider to NASA, Boeing operates the Space Shuttle and International Space Station. The company also provides numerous military and commercial airline support services. Boeing has customers in more than 90 countries around the world and is one of the largest U.S. exporters in terms of sales. Headquartered in Chicago, Boeing employs more than 158,000 people across the United States and in 70 countries. This represents one of the most diverse, talented and innovative workforces anywhere.

For additional information about the film and for additional educational resources, visit [www.legendsofflightfilm.com](http://www.legendsofflightfilm.com)

## CREDITS

The *Legends of Flight Teacher’s Guide* was developed by Kristen Clapper Bergsman and Matthew Merritt for Pacific Science Center, under the direction of project manager Heather Gibbons.

All materials produced for the film, *Legends of Flight*. Reviewed for The Boeing Company by Scott Lefeber.

Layout, design, and illustrations by Clayton DeFrate.

Editing by Sally Armbrecht.

Special thanks to Ryan Bergsman; James Seferis, Ph.D and David Bowes of GloCal Network Corporation.

Prototyping thanks to the students of Siri Haugen and Lynn McCabe, Madrona K-8 (Edmonds, WA); Sylvie Davidson, Zeta Strickland, and Pacific Science Center.

### LEGENDS OF FLIGHT

Directed by Stephen Low

Produced by Stephen Low and Pietro L. Serapiglia

Executive produced by Bob Kresser and Jan Baird

In Association with the Smithsonian

National Air and Space Museum

## SUGGESTED TEACHER RESOURCES

### Legends of Flight Film

<http://www.legendsofflightfilm.com>

### Your Own Flight: Forces of Flight

<http://www.fi.edu/flights/own2/forces.html>

### What Makes an Airplane Fly?

<http://www.allstar.fiu.edu/aero/ftmidfly.htm>

### NASA: Four Forces on an Airplane

<http://www.grc.nasa.gov/WWW/K-12/airplane/forces.html>

### Boeing Education: Four Forces of Flight

<http://www.boeing.com/companyoffices/aboutus/community/fof.html>

## TABLE OF CONTENTS

- 3 **GRAVITY**  
Investigation #1: Heavy vs. Light
- 6 **LIFT**  
Investigation #2a: Defying Gravity  
Investigation #2b: Lift it Down
- 8 **DRAG**  
Investigation #3a: Drag Kites  
Investigation #3b: Testing Drag—Paper Drop
- 10 **THRUST**  
Investigation #4: Balloon Thruster Challenge
- 12 **AIRPLANE DESIGN**  
Investigation #5: Spotlight—Lunch
- 14 **INTERNATIONAL TEAMWORK**  
Investigation #6: A Sum of Parts
- 18 **MATERIAL SCIENCE: COMPOSITES**  
Investigation #7: Composite Weave Lab
- 20 **AVIATION CAREERS**  
Investigation #8: Gizmo Factory

## NATIONAL SCIENCE EDUCATION STANDARDS FOR GRADES 4-8

### Science as Inquiry:

All students should develop abilities necessary to do scientific inquiry.

### Physical Science:

All students should develop an understanding of motions and forces.

### Physical Science:

All students should develop an understanding of transfer of energy.

### Science and Technology:

All students should develop abilities of technological design.

### Science in Personal and Social Perspectives:

All students should develop an understanding of science and technology in society.

### History and Nature of Science:

All students should develop an understanding of science as a human endeavor, the nature of science, and history of science.

## GLOSSARY

**Airfoil:** A specially designed fin that provides lift when a current of air passes over it. Bird wings and most airplane wings are airfoils.

**Air pressure:** The force exerted by air molecules, measured over a given area of surface.

**Bernoulli's Principle:** Developed by Swiss mathematician Daniel Bernoulli, this principle states that the pressure of a flowing fluid or gas decreases as the velocity increases and increases as the velocity decreases.

**Composite:** A new material made by combining two or more ingredient materials, each with its own distinct physical or chemical properties. When combined, the features of each ingredient are shared and the composite benefits beyond the individual parts. In a composite, there must be a reinforce-

ment ingredient, which provides the structure, and a matrix ingredient, which is the binding agent.

**Drag:** The force that opposes thrust. Drag is a result of the displacement of air when an object moves through air. Drag must be overcome in order for an airplane (or anything else, for that matter) to move forward through a gas or liquid. Other terms for drag are wind resistance and friction.

**Force:** A measurable push or pull in a certain direction.

**Gravity:** The force exerted by massive objects on other massive objects over a distance. The closer the objects are to each other, the stronger the force of attraction becomes.

**Lift:** The force that makes an airplane wing or helicopter rotor rise and helps the aircraft escape the pull of the earth

(gravity). Lift is a result of differences in air pressure, as is explained by Bernoulli's Principle, and equal and opposite forces, as explained by Newton's laws.

**Light-emitting diode (LED):** An electronic semiconductor device that emits light when an electric current passes through it. Light-emitting diodes are considerably more efficient than incandescent bulbs, and rarely burn out.

**Newton:** A unit used to measure force. One Newton equals 102 grams (3.60 oz), the approximate weight of one apple.

**Thrust:** The force that moves objects forward. Without thrust, we would never go anywhere. Thrust is also the opposite force to drag, which slows objects from moving forward.

**Velocity:** The rate of change of an object's position in space.

## BRINGING ME DOWN

When you jump, your legs push you into the air. What brings you back down?

In December 1903, Orville Wright flew his four-cylinder engine-powered Wright Flyer a mere 120 feet (36.58 m). What brought the airplane back to the ground?

About 400 years ago, Italian scientist Galileo Galilei watched four tiny dots in his telescope circle around Jupiter. What was keeping those moons traveling around the planet?

If you are thinking **gravity**, you are right! So how does gravity work? How do airplanes defy gravity and stay in the air?

Did you know that people were flying long before the Wright Brothers? On October 15, 1783 (220 years before the Wright Flyer), J.F. Pilatre de Rozier flew over eighty feet (24.38 m) into the sky above Paris, France. He then comfortably returned to the ground. How did he do it? He used a **force** that opposed gravity. Watch the smoke from a fire or the steam from a tea kettle and you will notice that heated air rises. De Rozier was able to heat the air inside a hot air balloon so that it became less dense

than the air outside and floated upward. But the Wrights used different forces to oppose gravity: **Lift** and **Thrust**!

Airplanes are much denser than air and unlike a hot air balloon, do not need heated air to fly. Instead, the forces of lift and thrust help an airplane to overcome the force of gravity. When an airplane engine is turned off and the plane is at rest, it is the force of gravity that keeps the airplane firmly on the ground. Gravity is the invisible force of attraction between any two objects. It is a force that depends on the size and distance of the two objects. An object with a very large mass, like a star or planet, exerts a very strong gravitational force on objects that are nearby and exerts a lesser force on objects that are farther away.

Seventy-five years after Galileo's discovery, the English physicist Sir Isaac Newton developed the three laws of motion. In his writings, Newton used the Latin word *gravitas* which would later be changed to the term gravity. He also developed a mathematical way to measure gravity called the law of universal gravitation.

## LEGENDS OF FLIGHT



*Sir Isaac Newton 1643-1727*

In the famous story, Sir Isaac Newton watched an apple fall from a tree and was inspired to investigate the force that pulls objects to the ground and holds the Moon in its orbit.

### Newton's Laws of Motion

1. Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it.
2. The relationship between an object's mass ( $m$ ), its acceleration ( $a$ ), and the applied force ( $F$ ) is  $F=ma$ . Acceleration and force are vectors. In this law, the direction of the force vector is the same as the direction of the acceleration vector.
3. For every action there is an equal and opposite reaction.

### CHECK IT OUT!

As a way to recognize Newton for all his work, the science community named the unit for measuring force after him!

An apple falls to the earth with the force of about one **Newton**.



This little girl has around 500 Newtons of gravitational force trying to hold her to the ground.



The force of gravity on the 1936 Stearman wooden biplane is about 8,943 Newtons.



Imagine the force of nearly 2.2 million Newtons on this Boeing 787-8!



**INVESTIGATION #1**  
**HEAVY VERSUS LIGHT:**  
**WHAT WOULD WIN IN A RACE**  
**TO THE GROUND?**

Students drop objects of different masses from the same height to explore the equation  $F=ma$ . Which one wins in a race to the ground?

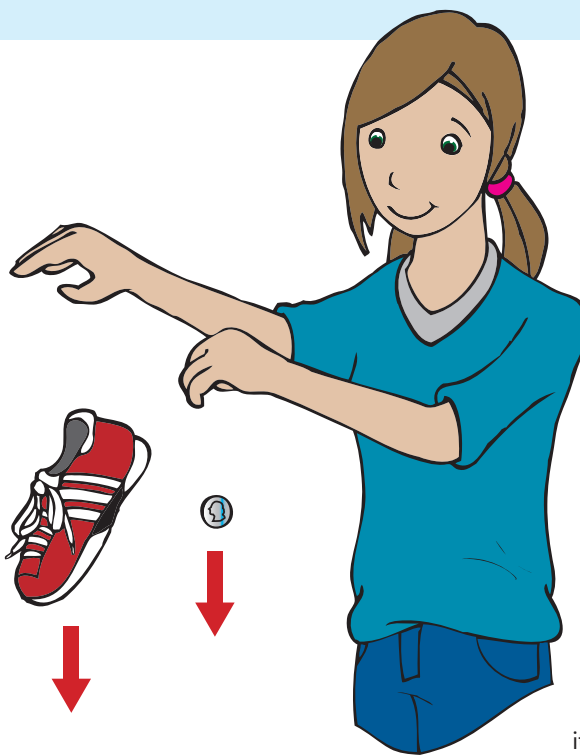
**Materials:** (per team of 3–5 student)

- 1 Chair
- 1 Coin
- 1 Basketball
- 1 Shoe
- 1 Sheet of poster paper folded into thirds to create three horizontal sections
- Markers

**Time:** 20 to 30 minutes

**Procedure:**

1. Working in teams of three to five, one team member at a time will drop two of the three items (coin, basketball, and shoe) from the same height while standing on a chair. The bottom of each item should be dropped from about the same height. The other team members will attempt to determine which object hits the floor first. A tie is a possible outcome for a drop.
2. Next, predict possible outcomes for the investigation and discuss your reasoning for these predictions. Record your predictions and supportive reasoning on the top section of the poster paper, using words, pictures, and diagrams.
3. Next, on the middle section of the poster paper construct a data table in order to record the results of multiple trials of each of the three drops.
4. One at a time, each team member should perform each of the three drops while the other team members watch and record the results, providing three to five sets of data for each type of drop.
5. Summarize your data and record your analyses on the bottom section of the poster paper.



(A QuickTime video of this demonstration can be viewed at <http://www.hq.nasa.gov/alsj/a15/a15v.1672206.mov>).

While objects fall at the same rate of acceleration, many people hold the misconception that lighter items fall more slowly than heavier items. This misconception is reinforced by the fact that many light items have more surface area and do not move through air as easily. The surface area to mass ratio, along with the orientation of the object as

it falls, are what determine how quickly or slowly an object will fall. An object moving through a gas or liquid experiences a force on its surface that is in the opposite direction to its motion. If there is more surface area perpendicular to the direction of the fall, there is more force pushing against the falling object and it is slowed down. The less mass the object has compared to that surface area, the more it is slowed. Air resistance, or drag, keeps items with more surface area to mass—like a feather—from falling as fast as items with less surface area to mass—like a hammer.

**Assessment:**

- Are students able to communicate, by writing or drawing, the effect of gravity on the falling objects?
- How confident are the students in their results? If they were able to videotape each drop and watch it slowed down, might their results change?

6. Then revisit the top section of your poster paper to critique their predictions and update your reasoning.
7. Finally, share their poster with the class.

**Results:**

All three items will hit the floor at the same time, which may be counter intuitive for many students. This investigation helps illuminate the equation  $F=ma$  by demonstrating that the acceleration rate ( $a$ ) of a falling object is a constant. The variable in the equation is the mass ( $m$ ) of the object, which is used to calculate the force of gravity ( $F$ ). The greater the mass of an object, the greater the force of gravity pulls on that object. The acceleration of the object is the same regardless of the object's mass.

**Why?**

Galileo discovered that due to gravity, freely falling objects fall at the same rate of acceleration, regardless of their mass. Astronauts on the 1971 Apollo 15 mission to the Moon were able to confirm Galileo's findings. An astronaut stood on the Moon's surface and dropped a feather and a hammer. Because there is no air on the Moon to create drag on falling objects, both objects slowly dropped and landed at the same time.

# RAISING THE SPIRIT OF ST. LOUIS

## LEGENDS OF FLIGHT



**Daniel Bernoulli 1700-1782**

Daniel Bernoulli was a Swiss mathematician born right around the time Newton was perfecting his laws of motion. Bernoulli proved that the pressure of a flowing fluid or gas decreases as its velocity increases. Today, we call this concept Bernoulli's Principle. **Bernoulli's Principle** is one explanation of how lift is created by an airplane wing.

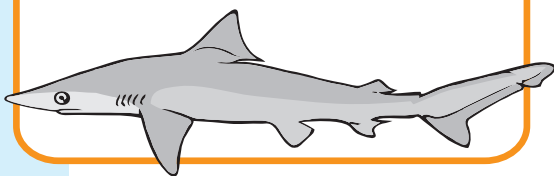


### CHECK IT OUT!

Early aircraft had airfoils that were inspired by the wings of birds and fins of sharks.

The profile of the albatross' wing shows the familiar shape of an airfoil. The bird can use its muscles to adjust the angle of its wings, either increasing or decreasing the amount of lift that it wants. Even the most modern airplanes are not able to do that...yet.

The powerful swing of a shark's rear caudal fin propels the shark forward through the water. To keep its head from dropping, the shark's wing-like pectoral fin generates lift and keeps the shark's body on a horizontal plane.



**Lift** is the force that opposes gravity. Flight is possible only when the force of lift is strong enough to overcome the downward force of gravity. Lift is created with moving air and an **airfoil**.

Most airplanes have wings that are shaped like an airfoil, which has a curved top surface and a flat bottom surface. Scientists have two explanations of how lift is created by an airfoil.

One explanation is that the curved top surface of the airfoil causes the air traveling above the wing to take a longer path. The longer path means the air above the airfoil must travel faster than the air below it. Faster moving air is lower in pressure than slower moving air. The slower moving air, with greater pressure, pushes the underside of the airfoil up into the faster air flow. According to **Bernoulli's Principle**, the differences in **air pressure** between the bottom and top of the wing pushes the wing up. When the force of lift is greater than the force of gravity on that object, then that object takes flight.

A compatible explanation is that as air moves over and underneath the airfoil, it is directed downward by the trailing edge of the wing. This is called a downwash. Newton's laws state that there must be an equal and opposite reaction to the downward force of the air, which forces the wing upward, and creates lift.

Imagine keeping a balloon off the ground by squirting it with a squirt gun. When the water bounces off the bottom of the balloon (action), the balloon goes higher (reaction). If you want the balloon to stay up, you must constantly squirt it. You are creating lift with your squirts of water by forcing a collision between the water and the balloon. A plane's engine moves it forward, causing a collision between the wing and the air. This collision, combined with the shape of the airfoil, creates downwash. The equal and opposite force from the downwash creates upward lift on the wing.

### INVESTIGATION #2a DEFYING GRAVITY

Students conduct a series of investigations to understand how Bernoulli's Principle explains how lift is created. Students learn how to use lift to keep a ball "magically" floating in an inverted funnel.

#### Materials: (per pair of students)

- 2 Drinking straws
- 1 Small funnel
- 1 Ping pong ball with a smooth surface
- 2 Antiseptic alcohol wipes
- 1 Sheet of poster paper
- Markers
- 1 Copy of *Lift: Raising the Spirit of St. Louis* background reading (page 6)
- 1 Flat table top

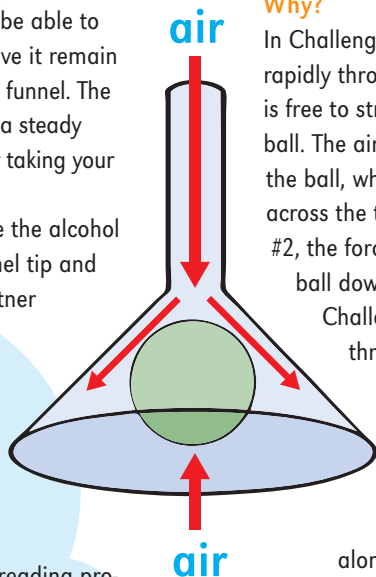
**Time:** 30 to 40 minutes

#### Procedure:

1. In pairs, collect your materials and read *Lift: Raising the Spirit of St. Louis* background reading.
2. **Challenge #1:** Use the straw to blow the ball so that it rolls from one side of the table to the other.
3. **Challenge #2:** Stand and hold the ball in the large end of the funnel and point the large end of the funnel down. Students let the ball go to confirm that the ball will fall to the ground due to the pull of gravity.
4. **Challenge #3:** Repeat Challenge #2, but this time blow a steady stream of air through the small end of the

funnel while holding the ball in place with a finger. Release the ball, but continue blowing through the funnel. The result may last only a second or two, but you should be able to release the ball and have it remain in the large end of the funnel. The trick is to keep blowing a steady stream of air even after taking your finger off the ball.

5. Make sure that you use the alcohol wipes to clean the funnel tip and let dry before your partner tries the activity.
6. On your poster paper, record your explanations of what happened to the ball in each of the three challenges. Using the background reading provided, determine why the ball stayed in place in Challenge #3.



**Results:**  
In Challenge #3, the ball will remain floating inside the funnel.

**Why?**  
In Challenge #1, the air moves rapidly through the straw and is free to strike the side of the ball. The air applies a force onto the ball, which moves the ball across the table. In Challenge #2, the force of gravity pulls the ball down to the ground. In Challenge #3, the air moves through the neck of the funnel. When the air encounters the ball, it accelerates as it moves through the constriction alongside the ball. Bernoulli's Principle tells us that air pressure is lower in fast-moving air,

like the air moving alongside the ball. Bernoulli's Principle also tells us that air pressure is greater in slow-moving, like the slow-moving air below the ball. The higher pressure air exerts an upward force on the ball, just as the slow-moving air under an airfoil exerts an upward force on a wing. The result is lift.

- Assessment:**  
Students should be able to:
- Explain why the ball moves along the table as a result of the blowing force in Challenge #1.
  - Explain why the ball falls to the ground in Challenge #2.
  - Explain why the ball stays in place as a result of the lift created in Challenge #3.

## INVESTIGATION #2b

### LIFT IT DOWN

Students use Bernoulli's Principle in a surprising investigation where a piece of paper moves downward when air is blown underneath it.

- Materials:** (per pair of students)
- 2 Textbooks of equal thickness
  - 1 Ruler
  - 1 Sheet of notebook paper
  - 2 Drinking straws
  - 1 Sheet of poster paper folded in half to create two horizontal sections
  - Markers

**Time:** 10 to 15 minutes

**Procedure:**

1. Each pair sets up the investigation by placing the two textbooks on a table top, about 5" (12.7 cm) apart. Next, lay the notebook paper on the books, spanning the space between them like a bridge. The sheet should lay nearly straight across the gap. If not, move the books closer together.

2. Predict what will happen when they use the drinking straw to blow air under the paper and record this prediction on the top section of the poster paper. Include a drawing and description with your prediction.
3. Take turns placing the straw just underneath one side of the paper, and blowing a strong, steady stream of air through the straw. Observe what happens to the sheet of paper.
4. Return to your poster and record your observations and results on the bottom section of the poster paper, including a labeled diagram that shows air pressure.
5. It is important to note that the high pressure above the paper that pushes it down is the opposite of an airplane wing, where the high pressure below the wing pushes it up.

**Results:**  
The sheet of paper will be pushed down into the gap between the books.

**Why?**  
Bernoulli's Principle tells us that the air pressure is lower in fast-moving air, while the air pressure is higher in slow-moving air. Blowing fast-moving air through the straw creates lower air pressure underneath the paper while the still air above the paper has high air pressure. This pushes the paper downward. The result is that an apparently stable sheet of paper is downward by the relationship between the zones of high and low air pressure. The principle of lift actually moves the paper downward.

**Assessment:**  
Are students able to use the principles of lift to communicate, by writing or drawing, the resulting forces on the poster paper?

## EVER GET THE FEELING THAT SOMETHING IS HOLDING YOU BACK?

**Drag** is the force of resistance caused by air on anything trying to move through it. If you have ever held your hand out the window of a moving car and felt the air pushing against it, you have experienced drag.

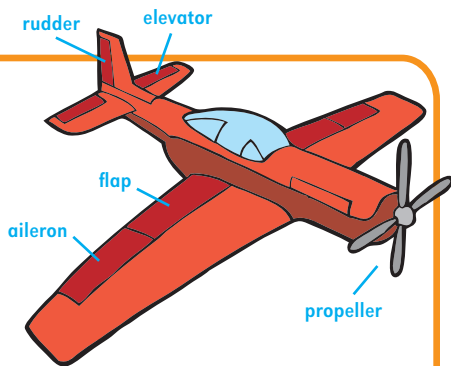
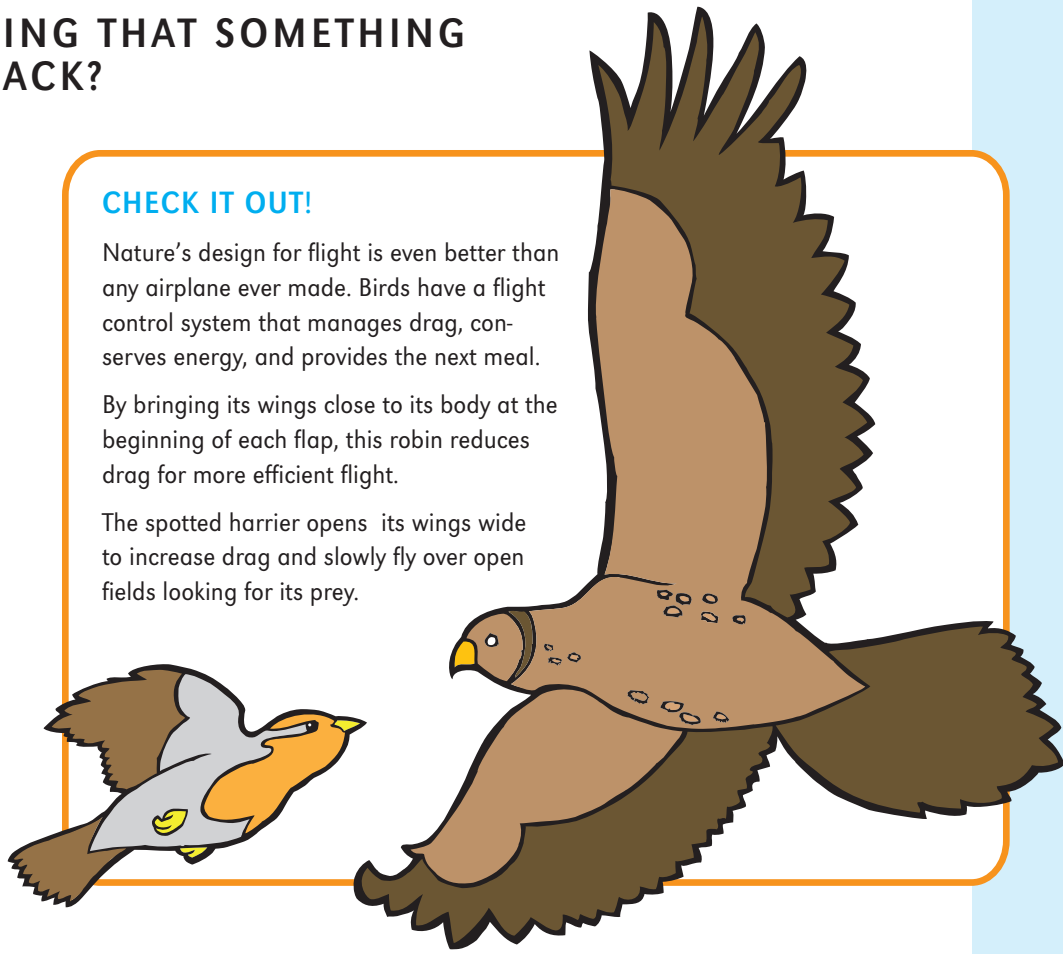
For airplane makers, drag requires serious consideration. At high speeds, drag can be strong enough to tear an airplane apart. Drag slows the aircraft down, making flights longer and even more expensive. Large engines are required to overcome the force of drag and propel the aircraft forward. These heavy engines need strong structural supports throughout the aircraft and require huge amounts of costly fuel. If it sounds like drag is nothing but bad, consider this: without drag, controlling an airplane would not be possible.

### CHECK IT OUT!

Nature's design for flight is even better than any airplane ever made. Birds have a flight control system that manages drag, conserves energy, and provides the next meal.

By bringing its wings close to its body at the beginning of each flap, this robin reduces drag for more efficient flight.

The spotted harrier opens its wings wide to increase drag and slowly fly over open fields looking for its prey.

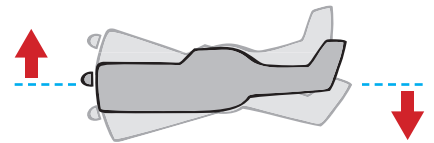


### CHECK IT OUT!

Drag is necessary for the pilot's controls to work properly. By increasing the drag on specific parts of the plane, small flaps called ailerons, elevators, and rudders make it possible for the pilot to control the flight of the airplane. No drag, no control!

#### Pitch

The elevators are on the tail of the aircraft. They make the nose of the airplane pitch up or down. If you raise the elevator, the tail drops down and the plane pitches up. If you lower the elevator, the tail comes up and the plane pitches down.



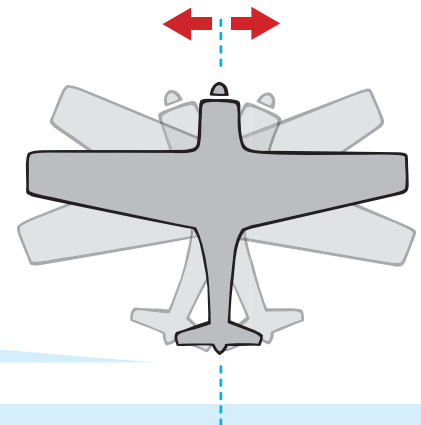
#### Roll

There is an aileron on the back edge of each wing. Ailerons make the plane roll side to side, which dips each wing up or down. By moving the ailerons in opposite directions, you can make the plane roll.



#### Yaw

The rudder makes the airplane yaw, which turns the nose of the airplane toward the right or left. If you move the rudder to the right, the plane yaws the right. If you move the rudder to the left, the plane yaws to the left. To make the plane turn, you must roll and yaw at the same time.





### INVESTIGATION #3a

#### DRAG KITES

Students compare the flight path of two paper kites to determine the impact of drag.

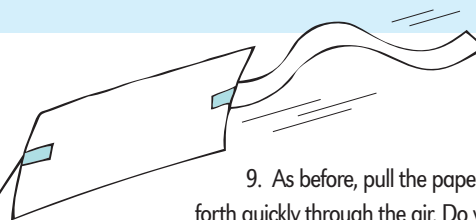
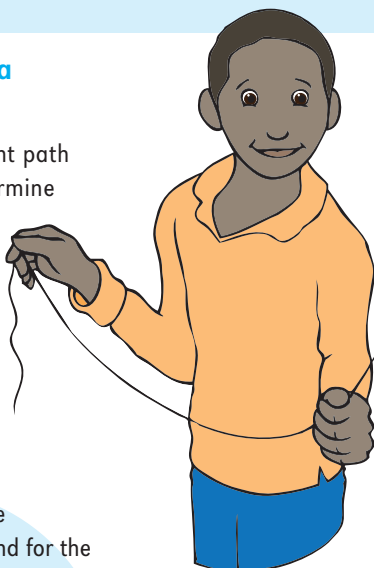
**Materials:** (per student)

- 1 Sheet of notebook paper for kites
- 1 Pair of scissors
- 1 Piece of string, 20" (50.8 cm) long
- 1 Ruler
- 1 Roll of cellophane tape
- 1 Piece of plain paper and for the data sheet
- 1 Pencil

**Time:** 20 to 30 minutes

**Procedure:**

1. Create a data sheet by folding the sheet of plain paper horizontally into four rows and label as follows: *Observation, Prediction, Results, and Explanation.*
2. Cut the notebook paper in half lengthwise to create a piece that measures 11" x 4.25" (27.9 x 10.8 cm).
3. Tape your piece of 20" (50.8 cm) long string to the short end of one of the strips of paper.
4. While standing, students hold the free end of the string and pull the paper back and forth quickly through the air.



5. Describe the movement of the paper on your data sheet in the section labeled *Observation.*
6. Cut a 2" (5.08 cm) wide strip of paper from the unused half of the notebook paper, creating a strip that measures 11" x 2" (27.9 x 5.08 cm).
7. Tape the 2" (5.08 cm) strip to the middle of the short end of the first strip of paper, creating a long tail. The entire assembly should be shaped like a long spatula.
8. Next, students predict how the movement of the original piece of paper will change when they pull it through the air with the "tail" they just added. Students should record their predictions in the *Prediction* section of their data sheet.

9. As before, pull the paper back and forth quickly through the air. Do you notice changes in the movement of the paper?
10. Record the changes in the *Results* section of their data sheet.
11. Formulate an explanation for the change in movement and record it in the *Explanation* section of your data sheet. Relating your *Drag Kite's* tail to the tail of a real kite or airplane may help.

**Results:**

The paper with the tail will move along a smoother and more regular path than the paper without the tail.

**Why?**

The wider paper in the first trial will flap and twist randomly, causing inconsistent changes in the airflow and air pressure across the paper. The addition of the narrower tail will help keep the angle of the leading edge of the wider paper more consistent, due to the drag pulling on the back of the wider piece. This pull will cause less flapping of the front of the wider piece, and will provide a smoother path for both pieces of paper to follow.

**Assessment:**

Are students able to reason and support their scientific ideas?

### INVESTIGATION #3b

#### TESTING DRAG: PAPER DROP

Students investigate the effects of drag on objects that have the same mass, but different surface area.

**Materials:** (per student)

- 2 Sheets of notebook paper

**Time:** 10 to 15 minutes

**Procedure:**

1. Examine the two identical pieces of paper and notice that the mass of each piece of paper is the same.
2. Crumple one piece of paper into a tight ball.

3. Find a partner and share your predictions of what you think will happen when the flat sheet and crumpled ball of paper are dropped from the same height, at the same time.
4. Hold the flat sheet of paper parallel to the ground. Drop the flat sheet and crumpled ball from the same height, at the same time.
5. Returning to your partner, share your observations and compare the results of the investigation to your predictions.

**Results:**

The crumpled ball of paper will hit the ground before the flat sheet of paper.

**Why?**

Air resistance, or drag, is slowing down both pieces of paper as they fall. However, drag is having a greater effect on the flat sheet of paper. The flat sheet of paper moves more air as it falls, causing it to fall more slowly.

**Assessment:**

Are students able to communicate, by writing or drawing, the different effects of drag on the pieces of paper?

## MOVING PLANES FORWARD FOR MORE THAN 100 YEARS

**Thrust** is the force that pushes an airplane forward and allows enough air to run above and below the wing in order to create lift. Developing thrust was the final hurdle for the early pioneers of flight in getting aircraft off the ground. Thrust is the force that opposes drag and can be achieved by either pulling or pushing the airplane in a forward direction.

Without an engine, airplanes are unable to produce their own thrust. Planes without engines are called gliders, sailplanes, or hang gliders. These engine-less planes are able to glide if there are special upward winds called thermals or if the plane gets a tow to a higher altitude by an engine-powered airplane.

Thrust can be produced in a number of ways. Birds, bats, and insects flap their wings and sharks swing their tails to create thrust. The four main ways modern airplanes produce thrust are propellers, rockets, jet turbine engines, and ramjet engines.

**Propeller:** A propeller is made of rotating blades, each one shaped like an airfoil. The rotating blades convert the engine's power into forward thrust. Propellers can push or pull the aircraft along, depending on how the blades are angled and which direction the propeller is turning.

**Rocket:** A rocket engine is the only engine type that does not require outside air to operate. Rocket engines burn a fuel to create thrust, pushing hot exhaust out a nozzle at the back of the engine. Rockets can even operate in space, where there is no air at all!

**Jet Turbine:** Jet turbine engines push air through the blades of a spinning turbine, which compresses the air. Fuel is then combined with the air and ignited. When the fuel burns, it rapidly expands from liquid to a gas and is forced out the rear of the engine. As the gas is forced out the back of the engine, the airplane is pushed forward.

**Ramjet:** A ramjet engine is similar to a jet turbine, except it has no moving parts. Ramjets only work after the aircraft is already moving quickly, so the aircraft initially needs another source of thrust. Once the aircraft is moving quickly, air is forced into the front opening of the engine at a high speed, which compresses the air. Inside the engine, fuel



### CHECK IT OUT!

Did you know the Wright Brothers were NOT the first people to fly? Orville Wright's 1903 flight was historic because it was the first engine-powered human flight. However, we have reports from China that as many as 2,500 years ago, people were using wind and wings to sail through the air! The glider or sailplane has been around for a long time. The pioneer of sailplanes may have been Lu Ban, a fifth-century B.C. Chinese philosopher.

### LEGENDS OF FLIGHT



*Sir Frank Whittle 1907-1996  
Dr. Hans von Ohain 1911-1998  
Co-inventors of the jet turbine engine.*

Whittle, from England, was the first to register a patent for his jet turbine design in 1930. Von Ohain, from Germany, was granted his patent in 1936. Neither man knew of each other's work. Ohain worked with a German aircraft manufacturer to design the Heinkel He-178, the world's first jet turbine powered aircraft. The plane first flew in 1939. Two years later, the Pioneer airplane took its first flight powered by Whittle's W1 engine.

### GOING GREEN!

The Boeing 787 Dreamliner and the Airbus A380 both are built with super-efficient, gas-sipping jet turbine engines. Compared to similar aircraft, the 787 uses 20 percent less fuel and reduces emissions of both carbon dioxide and nitrogen oxides. The A380 uses seventeen percent less fuel per passenger seat. The 787 and A380 engines are also quieter, both inside and outside the planes. This greatly reduces these planes' noise footprints.

is injected, mixed with the compressed air, and ignited. As the fuel burns, the exhaust explodes out the nozzle at the rear of the engine, which creates thrust. Ramjet engines are usually lighter than jet turbine engines, which makes them ideal for supersonic flight. Ramjet engines are also used for missiles and some types of space craft.

**CHECK IT OUT!**

**Harrier Jump Jets**

These amazing aircraft are called V/STOL (Vertical/Short Take-Off and Landing) airplanes. They use jet turbine engines for forward thrust, just like a standard jet. But what makes these planes special is their ability to change the direction of their jet nozzles. When they land and take off, their jets can be pointed straight down, allowing the jump jet to lift straight off from the ground. Harriers can even hover like a hummingbird.



**INVESTIGATION #4**

**BALLOON THRUSTER CHALLENGE**

Students are challenged to design a balloon thruster that can travel a certain distance in the shortest amount of time.

**Materials:** (per team of 4–5 students)

- 10 Drinking straws
- 1 Pair of scissors
- 1 or more 12 ft. (3.66 m) lengths of string, floss, ribbon, and/or fishing line
- 5 Balloons (different sizes and shapes)
- 2 Chairs the same size
- 1 Roll of cellophane tape
- 1 Sheet of poster paper
- Markers
- 1 Stop watch or clock with second hand
- 1 Tape measure

**Time:** 30 to 40 minutes

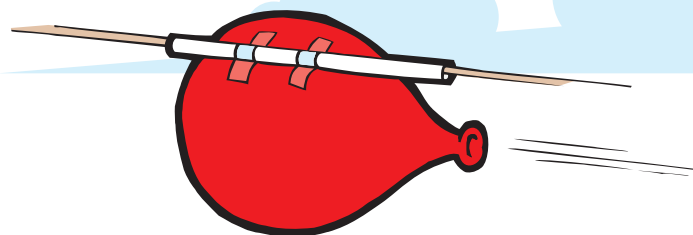
**Procedure:**

**The Challenge**

Find the combination of balloon shape, string type, and straw length that moves the balloon thruster from one chair to the other in the shortest amount of time.

**Plan and Predict**

1. In a team of three to five, fold the poster paper into three columns and label the columns: Plan, Predictions and Results.
2. Review the *Design Set-Up* section for the background you need to plan your design and make your predictions.
3. Develop a plan to meet the challenge and predict your results. Record your plan and predictions in the columns on the poster and provide explanations for your reasoning.



**Test**

4. Once planning is complete, test your design.
  - Inflate the balloon and hold the neck of the balloon closed.
  - Slide the *Balloon Thruster* so that it is pushed against the “start” chair.
  - Release the neck of the balloon and time how long it takes for it to reach the other chair.
5. Make adjustments or improvements to your design, as needed, using the extra materials. Record all of your adjustments on your poster paper.
6. Test your improved design and make improvements until you are satisfied.
7. Share your poster with the entire class before running the final trials.

**Final Trials**

8. Run the final trials as either a race between all teams at the same time using multiple tracks, or as time trials where everyone watches while each team runs their best-tested design.

**Design Parameters**

These are the guidelines for designing your investigation:

- Set two chairs 10 feet apart with the backs facing each other.
- Thread the straw onto whatever stringing material you chose for your track (string, floss, ribbon, or fishing line).
- Tie or tape your track to the back of the chairs in order to create a level track for the balloon thruster.
- Tape the balloon to the straw.

**Results:**

The results will depend on the teams’ unique designs.

**Why?**

Newton’s Third Law of Motion states that for every action, there must be an equal and opposite reaction. In this scenario, the *action* is when the opened balloon pushes the air out the back of the balloon. The *reaction* is when the air pushes the balloon forward, which creates thrust and moves the balloon along the track.

**Assessment:**

Are students able to provide an explanation for why one design was faster than the others? Encourage students to use data evidence to support their reasoning.

## ENLIGHTENING AIR TRAVEL

What colors and patterns are most restful to weary travelers? What shapes and lighting will make passengers feel most comfortable? These questions and many others were examined by the interior designers who designed the cabin of the new Boeing 787 Dreamliner and the Airbus A380.

Boeing worked with an interior design firm called Teague to help them design the interior spaces of the 787 Dreamliner. The company's CEO, John Barratt, describes how Boeing and Teague approached the design of the new aircraft:

*"Passenger well-being, on both an emotional and physical level, relies heavily on collaborative and research-orientated design practices. In designing the highly-anticipated 787 Dreamliner, Teague and Boeing employed a variety of design research techniques to determine the needs and desires of commercial travelers the world over. Defining and responding to the collective needs and desires of air travelers fueled the design process, permitting new, unconventional ideas to flourish and succeed in an industry renowned for strict standards. The results surpassed expectations."*

Soft, relaxing, roomy, and comfortable are not normal ways of describing the flying experience. Yet when passengers board the 787 Dreamliner, these are some of the words Boeing hopes passengers will use to describe their flying experience aboard the



aircraft. Years of research and passenger input have gone into making the Dreamliner "a dream come true" for passengers. From bigger overhead bins and larger windows to improved air quality, every passenger is promised a unique and top-notch flying experience.

At the heart of this experience is the airplane's interior lighting. The goal of the designers was to use a combination of lofty arches and a "sky effect" to give the passengers a sense of spaciousness. The "sky effect" makes the ceiling of the airplane look like a blue sky. This is achieved by shining a series of **light-emitting diodes (LEDs)** onto the curved interior surfaces of the airplane.

### WHAT IS A LIGHT-EMITTING DIODE?

A light-emitting diode or LED is a new lighting device that has a number of advantages for airplane interiors over standard incandescent and fluorescent lights.



1. LEDs produce more light than incandescent bulbs. Advantage: When needed, the inside of the airplane can be brighter than ever before.
2. LEDs can shine a single color light. Advantage: The inside of the airplane can change color depending on what effect is desired. Would you like sunset or sunrise?
3. LEDs are difficult to damage. Advantage: Lights will not need to be replaced as frequently.
4. LEDs have an extremely long life span. Advantage: LEDs burn longer, are more efficient, and are better for the environment.

5. LEDs can be very small and work very well when dimming is needed. Advantage: Lights can be placed in tight areas and can dim or brighten quickly.

Lighting effects do not begin and end in the entry hall of the Dreamliner. LED lighting throughout the cabin gives the flight attendants the ability to change day to night, and then back to day with a simple touch of the controls. With their ability to dim, LED lighting can even be programmed to simulate dusk and dawn, so passengers will begin to sense the time to sleep or wake up without sudden changes in light. The ability to mimic natural day cycles will help reduce jet lag for passengers flying on long-haul flights.

Passengers will notice that the windows are noticeably larger and do not have shades. With a simple touch of a control pad near the window, passengers will be able to progressively dim their windows.

Experts have thought about every moment during a flight and how lighting can help enhance the experience. They even thought about how lighting affects food! Have a look at Investigation #5 to explore how lighting can affect the appearance and appeal of food.

### GOING GREEN!

The Boeing 787 Dreamliner and the Airbus A380 both were designed to minimize their impact on the environment. Both aircraft use efficient LED lights throughout their cabins. LEDs last about three times longer than fluorescent tubes and more than 40 times longer than incandescent bulbs.



## INVESTIGATION #5

### SPOTLIGHT: LUNCH

Can the interior lighting of an airplane affect the mood of the passengers on the plane? Students will examine the effects of colored lenses on food items.

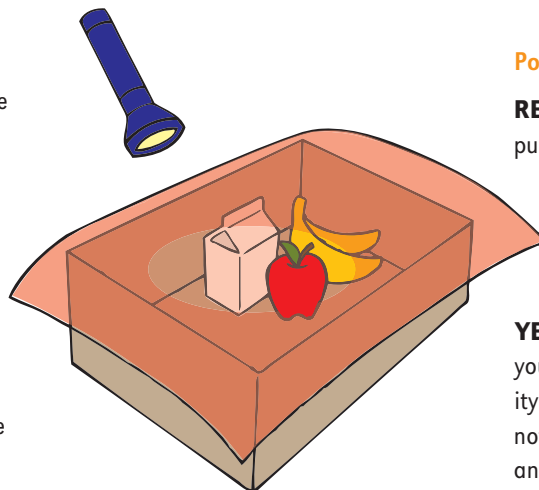
**Materials:** (per team of 4–5 students)

- 1 Small box or plastic tub, approximately 15" long, 10" wide, and 6" deep (38.1 x 25.4 x 15.2 cm)
- 5 Pieces of colored cellophane or plastic wrap (one of each color: red, yellow, blue, orange, and green) large enough to cover the top of the box or tub. (Available at gift wrapping or florist shops and at grocery stores.)
- 2 Food items, such as an apple or a piece of bread
- 1 Cup of milk in a transparent cup or glass
- 1 Flashlight
- Pencil and paper (one per student)

**Time:** 40 to 50 minutes

#### Procedure:

1. Working in teams of four to five, discuss how you think a color may be able to affect their moods. Read and discuss the background information.
2. In teams, you will get a chance to observe a variety of common foods through a series of colored lenses. Your role in this investigation is to be critical of details and to record a descriptive observation of how each lens affects your feelings about the food inside the observation box.
3. Each team member should create a data table on a sheet of paper. Include in the table space to record your predictions and observations about how color can affect your enjoyment of food. The lighting colors you will observe are natural, red, yellow, blue, orange, and green.
4. First, observe the food and drink items inside the observation box, under natural lighting conditions, by shining the flashlight onto the food items. Record your impressions of the food on your data table.



5. Cover the observation box with each colored "lens", one at a time, and shine the flashlight through it onto the food. Each student should record his or her reactions to each colored lens. What colors make the food look most appetizing? What colors make you feel hungry, alert, and ready to eat?
6. Once you have finished recording your data, discuss the *Post Activity Background Information* about how scientists view the physiological influences of color on people. Discuss whether you agree or disagree with the experts. Also, discuss why providing natural light is a challenge on an airplane.

#### Pre-Activity Background Information

Scientists have shown that colored lighting can affect people's moods, tiredness, and even appetite. The emotion triggered by a color depends on a person's nationality, past experiences, and, sometimes, personal preference. However, studies have shown that specific colors and color combinations can psychologically affect the majority of people, regardless of their culture or past.

#### Post-Activity Background Information

**RED** triggers a sense of power and impulsiveness, and increases one's appetite.

Be careful how you use red. It can also trigger anger, forcefulness, impatience, intimidation, conquest, violence, and revenge.

**YELLOW** has a stimulating impact on your memory. (Consider the popularity of the yellow notepads and Post-It® notes.) Yellow stimulates the intellect and promotes organization. It triggers joy, but when used in the wrong manner, or with the wrong combination of other colors, it can create feelings of criticism, laziness, and cynicism.

**BLUE** generates feelings of tranquility, love, acceptance, patience, understanding, and cooperation. If used inappropriately, its negative qualities are fear, coldness, passivity, and depression.

**ORANGE** triggers steadfastness, courage, confidence, friendliness, and cheerfulness. Its opposite effects are ignorance, inferiority, sluggishness, and superiority.

**GREEN** generates feelings of hope, growth, good health, freshness, soothing, sharing, and responsiveness. Its negative effects are envy, greed, constriction, guilt, jealousy, and disorder.

*From: Bloomsburg University, 2002.*

#### Assessment:

Ask each student to create a persuasive piece of writing directed toward a commercial airline executive:

Ms. Violet Black  
Vice-President of Passenger Relations  
Rainbow Airlines  
555 Green Avenue  
Bluebonnet, Oregon 99000

The short essay should convey the student's opinion about which color of light the airline should use in the airplane cabin while serving meals. Students should be sure to explain their reasoning by using evidence to support their choice of colors.

## ASSOCIÉ DU MONDE (“worldwide partner” in French)

In order to construct the Boeing 787 Dreamliner, Boeing employees traveled around the globe in search of partners. In the end, they formed the most far-reaching international development team in the history of commercial aviation.



Unlike the partnerships of the past, in which suppliers made parts and systems to fulfill a Boeing design, the new project asked a higher level of involvement and commitment from other companies. Boeing decided to share the responsibility for design and development, as well as manufacturing. This meant higher risks, because Boeing would need to entrust others with the work they only trusted themselves to do in the past. But it also guaranteed that in order to take part in the team, partners would need to be the very best in their field. In the end, partners in eleven different countries across four continents were selected to build parts and design systems that would all fit together into one airplane. The final assembly point was chosen—the Boeing Everett Plant in Washington, U.S.A.—and the challenge of figuring out how to transport all these separate parts to one place began.

### CHECK IT OUT!

Grab a calculator and try this: How far did all the Boeing 787 parts travel from the international partners in order to arrive at the final assembly plant in Everett, Washington, U.S.A.?

#### DISTANCE FROM EVERETT

Country	Language	In miles (mi.)	In kilometers (km)
Australia	English	7,908	12,727
Italy	Italian	5,627	9,056
South Korea	Korean	5,272	8,484
Germany	German	5,252	8,452
Japan	Japanese	4,769	7,675
United Kingdom	English	4,734	7,619
Sweden	Swedish	4,658	7,496
Canada	English & French	168	270
		<b>TOTAL:</b>	<b>TOTAL:</b>

### CHECK IT OUT!

The final assembly time for the Boeing 787 Dreamliner will be the fastest for widebody airplanes in commercial aviation history. The Boeing Company’s Everett Plant in the state of Washington is the final assembly facility for the 787 and the largest building (by volume) in the world. In 2011, an additional final assembly plant will be activated in South Carolina.

This short assembly time is only possible if the parts that arrive at the Boeing Everett Plant are ready for assembly. This meant that traditional forms of shipping needed to be rethought as well. The major structural components of the Dreamliner are built in Japan, Italy, Kansas, and South Carolina. Boeing had to design and build an airplane that could carry the major structure components of another airplane. The result is a flying flat-bed truck of sorts – the Dreamlifter. The Dreamlifter is a modified Boeing 747 that has a hump-shaped back, no passenger windows, and a tail that swings on a huge hinge to open the plane for cargo loading. The Dreamlifter is an engineering marvel, and its only job is to transport the parts for the Boeing 787.

**INVESTIGATION #6****TEAMWORK: A SUM OF PARTS**

What happens when people from around the globe work together to build and design a new airplane? Students find out in an international challenge, where they work as a team to solve a problem of global proportions.

**Materials:** (per station)

- A variety of building materials (i.e. newspaper, drinking straws, craft sticks, rubber bands, cloth strips, and construction paper)
- 1 Bottle of glue
- 1 Roll of cellophane tape
- 1 Stapler
- 1 Sheet of poster paper
- Markers
- 1 Station label

**Time:** 50 to 75 minutes

**Preparation:**

1. Set-up the classroom ahead of time by creating four stations around the classroom. Each station will need a table and chairs. Label each station with the name of one of the countries that is a major supplier for the Boeing 787 Dreamliner (United States, Canada, Japan, South Korea, Australia, Sweden, Germany, France, the UK, or Italy). For example, one station might be labeled as "Italian Manufacturing Station."
2. Evenly distribute the building materials among the four stations.
3. Also, set up one table in the center of the classroom with an additional roll of tape, stapler, and bottle of glue. Label this station as "Everett, WA Final Assembly Station."

**Procedure:**

1. Divide into four teams and take one of the country names and meet at your stations.
2. One representative (the Communications Officer) from each country team should come to the center of the room to get the team's mission: to design and build a section of an airplane. Each country team is assigned a different airplane part (body, wings, tail, or two engines). Each country team will have a short amount of time to plan and build its airplane part (two minutes of planning time and eight minutes of building time).
3. Return to your country teams and explain the challenge. Start the planning time. Be sure that the only discussion that occurs between your team and the other teams is through the Communications Officer. Otherwise, no talking or peeking at other teams. After two minutes have passed, you now have eight minutes to build your airplane parts.
4. When the eight minutes have elapsed, the Communications Officer from each country team goes to the "Everett, WA Final Assembly Station" with their team's airplane part. You will now try to assemble the airplane with tape, staples, or glue. The rest of the class observes silently.
5. After the representatives have tried to assemble the airplane, have an open discussion with the whole class. What are some suggestions for how you could improve the process next time in order to build a better airplane? Ideas will likely include the need for consistency in part size, materials, interface between connecting parts, and a uniform design. As you all share your suggestions, list the possible improvements on a sheet of poster paper or the classroom board.
6. Try the activity again, but this time apply your essential enhancements to the design and construction of their airplane parts. Run several trials of

this activity, allowing different team members to play the role of Communications Officer and provide more opportunities to refine the design and construction process.

**Assessment:**

Are students able to:

- Relate to the construction of the Boeing 787 Dreamliner airplane and other modern airplanes?
- Describe how the actual construction of an airplane is even more complicated than what was experienced in this activity?

Students might mention differences in language, units of measurement, customs/shipping complications, levels of precision, cost, reliability, and access to resources.

**Variation:**

Build as many airplane parts as possible in twenty minutes. Bring all of their airplane parts to the center table. See how many complete planes can be assembled from the parts. Do some airplane parts take longer to build than others? How could you streamline the process to build more airplanes?

## COMPOSITES

### WHAT ARE COMPOSITE MATERIALS?

A composite is a combination of two or more different ingredients. When combined, the features of each ingredient are shared and the composite benefits beyond the individual parts. There are a variety of different types of composite materials. Composites found in the layers of plywood are called fiber reinforced polymers (FRP). Super strong composites may contain metal matrix composites (MMC). Composites designed to withstand heat may include glass reinforced plastics (GRP). There is a new type of cement that has ceramic matrix composites (CMC) as an ingredient. There are even OMCACs—organic matrix/ceramic aggregate composites. OMCACs can be found in nature, such as the shiny surface on some shells, which is called nacre or mother of pearl.

### HOW ARE CARBON FIBER COMPOSITES MANUFACTURED?

One process for creating carbon fiber composites is similar to the creation of acrylic fabrics. It all begins with extremely fine carbon filaments, which can be many times thinner than the diameter of a single human hair. The filaments are twisted into fibers called threads. These threads are then woven together and mixed with epoxy resin, which is basically a liquid resin that hardens with the help of high heat or special chemicals. This creates a material called a tape. The tape is wound on spindles which are placed on a machine called a prepregger. The prepregger is like a huge, mechanical loom that pulls tape from multiple spindles and weaves them together using a series of combs. The resulting woven mat is mixed with polymer epoxy resin, pressed in a mold, and cooked under high heat and high pressure in an industrial oven called an autoclave.

### WHY ARE COMPOSITE MATERIALS USED TO BUILD AIRPLANES?

Historically, most commercial aircraft have been made mostly from aluminum. The composite most used on the new Boeing 787 Dreamliner is carbon fiber reinforced polymer (CFRP) while the Airbus A380 uses CFRP and GLARE, an aluminum and fiberglass composite. The new CFRP material has replaced many of the aluminum structures on the Boeing 787 for the following reasons:

1. CFRP is lighter. The Dreamliner has some aluminum parts, but it is lighter than an all-aluminum airplane of the same size.
2. CFRP is stronger. In tests, CFRPs were pulled, twisted, torn, flattened, cracked, and punctured, and were proved to be as strong, if not stronger than the aluminum. This increased strength in the fuselage allows for the cabin to be pressurized at the equivalent of 6,000 ft. (1.83 km).
3. CFRP is more resistant to corrosion than aluminum. This allows for an increased level of humidity to be sustained in the passenger cabin. Pressurizing the cabin and humidifying the air helps air travelers to feel better and arrive at their destinations more refreshed and relaxed.
4. CFRP is more durable. Airplanes fly through a variety of difficult conditions that cause wear on aluminum parts. Extreme temperatures weaken the metal over time and the salty air above the oceans can create rust on metal surfaces. Composites will make airplanes more reliable and keep maintenance costs down.
5. CFRP is more resistant to high temperatures. Not only is CFRP stronger than aluminum at average temperatures, when the heat goes up, the difference in strength increases. As aluminum gets hotter, it becomes more malleable, which means that it can change shape.

This effect occurs to much lesser degree in composites.

6. CFRP can be molded into large pieces. Aluminum airplanes are made out of large pieces of aluminum that are held together with thousands of rivets. The seams and rivets on aluminum airplanes create drag. The Boeing 787 Dreamliner has nearly 50,000 fewer fasteners than on an aluminum airplane of the same size. With large composite pieces and fewer seams between parts, there are far fewer places for weak spots, adding to the overall safety of the airplane.

### WHERE ELSE ARE COMPOSITE MATERIALS FOUND?

If an item needs to be strong, flexible, and lightweight, composites are either being used, have been tried, or will be used soon. Graphite composites are found in golf club shafts and sail boat masts. Thermoplastic composites include bullet-proof vests and hockey sticks. Laminate composites are used for some types of countertops. A high-performance composite material called Mallite is used in the body of Formula 1 racing cars.



#### GOING GREEN!

Composites help create a more efficient airplane – less weight reduces the cost of taking off and landing, less fuel usage while flying, greater load capacity, and longer range. Since it is lighter than other aircraft its size, the Dreamliner will use 20 percent less fuel. This means fewer emissions and harmful impacts on the environment.



## INVESTIGATION #7 COMPOSITE WEAVE LAB

Students will model a carbon fiber composite by creating mats with different weave patterns. Then, students will design their own investigations to test the strength of the weaves.

**Materials:** (per team of 3–4 students)

- 4 Sheets of paper towel
- 1 Pair of scissors
- 100 Pennies (2 banker rolls)
- 1 Roll of cellophane tape
- Paper and pencil
- Ruler

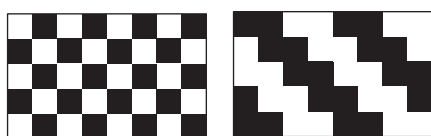
**Time:** 60 minutes

### Preparation:

1. If possible, try to obtain an object made from carbon fiber composite. Common items include: golf club shafts, tennis racquets, fly fishing rods, skis, snowboards, hockey sticks, bicycle frames, and bicycle helmets. In many instances, you will be able to see the carbon fiber weave in these items.

### Procedure:

2. Cut uniform strips from three of the paper towels. One paper towel will be left uncut for the experiment control. Strips that are 0.5" to 1" (1.3 to 2.5 cm) wide and 11" long will work well. It is important that the edges of the strips are as straight as possible, so you might want to use a ruler to measure the strip intervals and to draw straight lines before cutting.
3. You will be weaving the strips together to form two mats. For accurate testing, weaving must be as tight as possible. In your teams discuss possible weave patterns:
  - One over; one under
  - Two over; two under



4. Weave two mats. Use one of the example weave patterns for one mat, and design your own weave pattern for the second mat. Each weave mat should be at least six strips wide and long. Use tape to secure the edges of each weave mat. Tape should not be added to the mat anywhere except for the edges. Also, place tape along the edges of the uncut paper towel.
5. Once the weaving is complete, your team will need to design and conduct an investigation that will test the strength of your two weave mats and the uncut paper towel. Discuss in your team the different types of material strength, including:
  - **Tensile Strength:** *The maximum amount of loading that a material can handle before it fails. Some materials will stretch before breaking.*
  - **Shear Strength:** *The maximum amount of stress along a plane that a material can handle before it fails. An example of shear strength is tearing a piece of fabric into strips, or cutting a sheet of paper with scissors. Shear strength can be measured across the width, length, and diagonal of a material.*



6. In your team, design an investigation to test either tensile strength or shear strength. Plan out the investigation and record predictions on your piece of paper before conducting the investigation.
7. Discuss with your team what "failure" of the weave means. If coins slide through the weave, then this means that the tightness of the weave was too loose and could allow for air or water to penetrate the mat. If the mat

tears or breaks, then this means that the mat was not strong enough for its intended use. Some investigation ideas include:

- Hold the corners of the mat about 6" (15.24 cm) above to table top while placing coins onto the center.
  - Hold the corners of the mat a few inches from the floor and drop pennies from different heights onto the center of the mat. Try dropping a single penny from various heights or taping 2-3 pennies together to change the mass.
  - Try to rip the mats by tearing them along the length, along the width, and diagonally.
8. First, test the uncut paper towel (the control) and then test each of your woven mats (the variables).

### Why?

When designing a new airplane, aviation engineers need some materials that have strength and rigidity as well as some materials that have strength and flexibility. Weight is also always a critical factor, as aviation engineers want strong, but light, materials. The weave pattern of a carbon fiber composite, as well as the choice of resin, can create materials that meet the designers' specifications.

### Assessment:

Are students able to create investigations that include predictions and an explanation of their scientific reasoning behind those predictions? The investigation should also include accurate measurements, variables, data collection, data interpretation, the use of evidence to generate explanations, and a proposal of alternative explanations.

## A JOB THAT REALLY TAKE YOU PLACES

### FEATURED CAREERS IN THE AVIATION INDUSTRY

#### **DESIGNING AND BUILDING THE AIRCRAFT**

##### **AERONAUTICAL ENGINEER**

Aeronautical engineers plan the design and construction of airplanes. These engineers face many challenges, such as how to increase speed and fuel efficiency and how to decrease drag, turbulence, and noise. These engineers need a background in mathematics, physics, mechanics, and material sciences.

##### **CIVIL ENGINEER**

Civil engineers are responsible for the design and development of airports, including runways, parking lots, and roads. These engineers need a background in design, drafting, mathematics, physics, and project management.

##### **ELECTRICAL ENGINEER**

Electrical engineers build power systems that improve the airplane's performance. They must have a background in mathematics, physics, electrical drawing, computers, aircraft electrical systems, and project management.

##### **MECHANICAL ENGINEER**

Mechanical engineers design parts to help the airplane move and fly, such as the machinery in a plane's landing gear and flaps and the fuel pumps that deliver fuel to a plane. They solve mechanical problems such as how to design the landing gear to withstand the impact of the landing. These engineers need a background in mathematics, mechanics, thermodynamics, drafting, and design.

##### **INTERIOR DESIGNER**

Interior designers develop the "look" for the interior cabin of an aircraft. The designer will choose everything from carpet and seats to linens and silverware. The interior designer may also choose the seat and galley configurations.

#### **PSYCHOLOGIST**

A psychologist may be able to provide a window into the mind of passengers, crew, and mechanics. By understanding how these people use the aircraft, the airplane can be designed to accommodate their needs and desires.

#### **SCIENTIST**

The scientists are responsible for the research and development of new airplane technologies. They design and test new materials so that airplanes continue to improve.

#### **TECHNICIAN**

Technicians have a working understand of the airplane. They are the drafters, analysts, designers, and planners that help build and maintain the airplanes.

#### **MAINTAINING AND OPERATING THE AIRCRAFT**

##### **FLIGHT ATTENDANT**

Flight attendants spend more time with the passengers than any other airline employee. Their job is to be sure you get to your destination as safely and comfortably as possible.

##### **GROUND CREW**

There are a variety of jobs considered as part of the ground crew. Some include drivers, conveyors, and the flagger who helps the airplanes taxi to and from their gates. The ground crew helps flights begin and end as safely as possible.

##### **MAINTENANCE MECHANIC**

Maintenance mechanics have the important job of checking every airplane before take-off. They are capable of troubleshooting problems and performing emergency repairs.

##### **PILOT**

Pilots do much more than just fly—they are responsible for overseeing flight plans, airplane maintenance, and flight safety.

#### **SUPPORTING AIRPORT OPERATIONS**

##### **AIR TRAFFIC CONTROLLER**

Controllers are the specialists who work at the control center of the airport and provide pilots with instructions, air traffic clearance, and flight conditions.

##### **BAGGAGE HANDLER**

Handlers are the men and women who load and unload passenger bags and cargo. They are responsible for sorting bags and ensuring they are on the correct flight.

##### **METEOROLOGIST**

Meteorologists analyze weather data and prepare weather reports. They help plan safe flight routes to avoid poor flying conditions.

##### **SKYCAP**

Skycaps are dedicated to passenger service. They assist with luggage at the curb and answer questions about the workings of the airport.

##### **SECURITY**

Security at airports has become one of the most important jobs in the industry. These agents are highly trained and are dedicated to airport and passenger safety. Federal Air Marshalls are law enforcement officers who go undercover as passengers on airplanes.

##### **TICKET AGENT**

Ticket agents are usually the first person the passenger meets at the airport. They are concerned with customer service and helping passengers make their flights on time.

## INVESTIGATION #8

### GIZMO FACTORY Time: 60 minutes

In this challenge, each student works a specific job on an assembly line in a gizmo factory.

**Materials:** (per team of 5–7 students)

- 1 Pre-constructed “gizmo” model (see Preparation section)
- Assorted construction materials, such as craft sticks, straws, colored construction paper, cotton balls, tape, and scissors
- 1 Box in which gizmos can fit inside
- 1 Piece of chart paper
- Markers

#### Teacher Preparation:

1. Construct a unique gizmo for each team. Be sure to do this in secret, so that the students do not see the gizmo. A gizmo is a three-dimensional design of your own creation that does not resemble any usable item. It is a compilation of a variety of materials fashioned to form a random figure. Each gizmo uses the same number of construction materials (i.e. four craft sticks, one straw, two cotton balls, one red circle, one blue triangle, and two green rectangles cut from construction paper). However, each gizmo should be clearly distinct from the others.
2. Write the investigation rules on the classroom board:
  - RULE A:** Only the Scientist can see the gizmo.
  - RULE B:** The Manufacturer and the Engineer are not allowed to speak to each other.
  - RULE C:** The member of the Construction Team who receives the materials is not allowed to see the blueprint.
  - RULE D:** The Construction Team member with the blueprint can see what the other Construction Team member is doing but is not allowed to touch any of the materials.
  - RULE E:** The Supervisor is not allowed to see the gizmo, touch any materials, or touch the model gizmo.
3. Divide the class into teams of six. Ask each team to arrange their chairs in a row, school-bus style. Have the Scientist and the Engineer turn their chairs so that they are back-to-back. Label the students’

chairs with the different job titles to ensure proper arrangement of the assembly lines.

4. Place the four gizmos on a table, in a box with no lid, being sure that students cannot see them.

#### Teacher Procedure:

#### Job Assignments

1. Within each team, assign and discuss the responsibilities of each job:
  - **Scientist: The dreamer.** It is his/her responsibility to generate and communicate the idea of the gizmo. This person is not sure this idea will even work, but is willing to trust their vision and ingenuity.
  - **Engineer: The (wo)man with the plan.** The engineer listens to the scientist’s idea and makes it a reality. Engineers will design a blueprint from which every other step in the process is dependent.
  - **Manufacturer: Taking shape.** Manufacturers receive the blueprint and make important decisions on what materials can be used to construct the gizmo. They need to have the vision to imagine the final 3-dimensional product from the blueprint.
  - **Construction Team (two students):** The hard hat and the tool box. These two teammates will need to work together for a common goal. One will get the blueprint while the other will get the materials. It is only through their ability to communicate and construct that the gizmo can take shape.
  - **Supervisor: The boss.** This teammate is ultimately responsible for the final product. He/she will advise the team, but will be limited to advice only. The Supervisor can move freely up and down the assembly line.
2. Preview the construction process with the students and announce the goal of each team: To create a model gizmo that is as close to the original gizmo as possible.

#### Student Construction process

3. One by one, the Scientists go to the display table to view their team’s gizmo. Conduct this secretly so that each Scientist sees only her team’s gizmo, and does not see any of the other gizmos. Each

Scientist will need a few minutes to study the gizmo and memorize its unique features. Review **Rule A**.

4. Returning to the team, the Scientists must act as though the gizmo is his or her own beloved design. He/she describes the gizmo in detail to the Engineer. While this description is taking place, the Engineer creates a drawing of the model on the chart paper (referred to as the blueprint).
5. The Engineer passes the blueprint to the Manufacturer who uses it to help him/her compile the materials needed to build the model. The Manufacturer is the only one with access to all the materials. He/she must try to envision what the gizmo looks like without ever having seen it. He/she must also imagine which materials were used in its construction, and compile these materials for the next step. Review **Rule B**.
6. The Manufacturer then passes the blueprint to one Construction Team member and the materials to the other Construction Team member. Review **Rule C**.
7. The Construction Team begins to assemble the model gizmo. Review **Rule D**.
8. The Construction Team member with the blueprint must describe the blueprint and give advice by watching how the other Construction Team member is using the materials to put together the model gizmo.
9. The Supervisor, although not allowed to see the original gizmo, is allowed to offer advice at every other step in the process. He/she keeps the team on task and oversees the final step. Review **Rule E**.

#### Unveiling the Designs

10. When the construction process is complete, the Supervisors are allowed to take their model gizmos to the display table. Their goal is to select the original gizmo that was provided to their Scientist at the beginning of the construction process, thereby matching up the model gizmo they made with the original gizmo. The Scientist must not provide any help, since they are the only one who saw the team’s original gizmo.

# LEGENDS OF FLIGHT

SEE HOW THE AIRPLANES OF THE 20TH CENTURY HELPED INFLUENCE THE RADICAL NEW DESIGN OF 21ST CENTURY AIRCRAFT.

GO BEHIND THE SCENES TO OBSERVE HIGH TECH MANUFACTURERS AROUND THE WORLD USING MODERN TECHNOLOGY TO COORDINATE THE DESIGN AND CONSTRUCTION OF NEW AIRCRAFT.

FLY IN THE COCKPIT WITH 787 CHIEF PILOT, MIKE GARRIKER, AS HE TAKES THE NEW DREAMLINER ON ITS FIRST TEST FLIGHT.

FOR FILM INFORMATION PLEASE CONTACT

MARK KRESSER [MARK.KRESSER@X2COMMUNICATIONS.COM](mailto:MARK.KRESSER@X2COMMUNICATIONS.COM) (310) 563-2611 OR ED CAPELLE [EDWARDCAPELLE@COMCAST.NET](mailto:EDWARDCAPELLE@COMCAST.NET) (541) 345-8782