



LEGENDS OF FLIGHT

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

NOTES:

WHAT IS GRAVITY?

The downward force on an airplane is caused by gravity. Gravity is the force that pulls objects down toward the ground, and keeps us and everything else on earth from floating away into space.

Gravity is a force of attraction between any two objects. All objects experience gravity and have an attraction to all other objects. Gravity makes an object that has a large mass feel heavy. This is because the effect of gravity pulls on objects with large masses with more force than it pulls on objects that have small masses.

Flight is possible only when the force of gravity is overcome by the force of lift. Heavy objects need more lift than lighter objects if they are going to be able to fly.

WHAT IS LIFT?

The upward force on an airplane is called lift. Flight is possible only when the force of lift is strong enough to overcome the downward force of gravity.

Most airplanes have wings that are shaped like an airfoil. An airfoil 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. When the force of lift is greater than the force of gravity on that object, then that object takes flight. This concept is known as Bernoulli's Principle.

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.

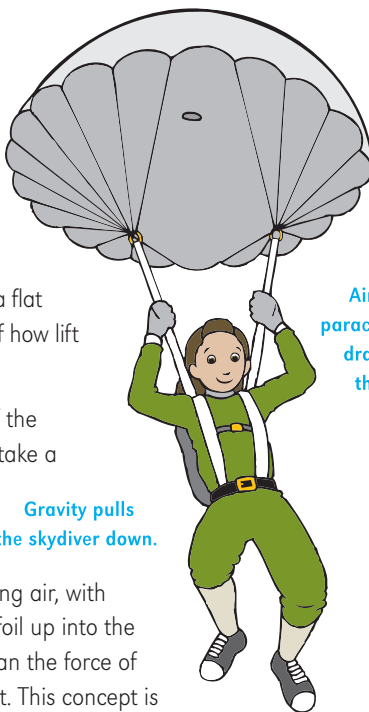
Imagine keeping a balloon off the ground by squirting it with a squirt gun. When the water bounces off the bottom of the balloon (action), the balloon goes higher (reaction). If you want the balloon to stay up, you must constantly squirt it. You are creating lift with your squirts of water by forcing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

DID YOU KNOW?

Gravity causes the tides!

Gravity is the force that keeps the moon in orbit around earth. But did you know the moon pulls on the earth too? The closer two objects are, the more pulling force they have on each other.

The earth has solid land and liquid oceans. Whatever portion of the earth is closest to the moon is most strongly affected by the moon's gravity. The water there rises in a bulge, causing the sea to rise in a high tide. In order for there to be a high tide somewhere on earth, there must be a low tide somewhere else. The relationship between gravity and tides is fascinating. To learn more, find a book or website about the tides.



Gravity pulls the skydiver down.

What would happen if the parachute did not fill with air?

Air fills the parachute, increasing drag and slowing the skydiver's fall.

WHAT IS DRAG?

Drag is the force that slows down an airplane. If you have ever held your hand outside the window of a moving car and felt the air pushing against your hand, you have experienced drag.

When an airplane moves through the air, drag is created when the airplane moves the air in front of it. The air then fills in the empty space left behind the airplane, which causes the air to pull—or slow—the airplane. In order for an airplane to fly, the force of thrust must overcome the drag. When speed is important, engineers try to design planes that have less drag.

A skydiver relies on drag to fill her parachute, which increases the air resistance and slows her fall. Drag is also important for controlling the direction of flight.

Airflow is faster over the upper surface and decreases pressure.



Airflow is slower over the lower surface and increases pressure.

Can I Measure the Pull of Gravity? BUILD A NEWTON SCALE

Materials (per group of 2–3 students)

- 1 Half-pint milk carton, empty and partially open at top
- 1 Rubber band
- 1 Paper clip, large
- 1 24" (0.61 m) strip of masking tape
- 1 Pencil
- 1 Felt tip pen
- 1 Hole punch
- 1 Measuring cup with a mark for either ½ cup, 4 oz. or 118 ml.
- Water
- Tub for catching spills

Time: 30 minutes

Set Up

1. Punch a hole in the sturdy top of the milk carton.
2. Fold the rubber band in half around the pencil, so that the pencil is at the crease and the ends of the rubber band dangle on either side. Pull one end of the dangling rubber band through the loop of the other end, attaching it to the center of the pencil.
4. Take a paper clip and unfold the center bend of the paper clip 180°. You will create a shape that has a hook at the top and bottom.
5. Hook one end of the paper clip through the milk carton hole. Hook the other end of the paper clip through the rubber band loop attached to the pencil.
6. Place the eraser-end of the pencil on the tabletop almost all the way to

where the rubber band is attached. Securely hold the eraser-end of the pencil so that the sharpened-end of the pencil sticks out several inches past the edge of the tabletop. The milk carton should freely hang from the pencil.

Do This!

1. For this activity, work in small groups of 2-3 students per group.
2. Stick a 24" (0.61 m) long strip of masking tape down the leg of a table or desk.
3. Hang your empty Newton Scale from the table as described above. Make a horizontal mark on the masking tape where the bottom of the milk carton hangs. Write a "0" next to this mark.
4. Make a prediction of how the milk carton will move when it is filled with water. Will it move lower or higher from the zero mark?
5. Place the tub below the Newton Scale to catch any spills. Fill the measuring cup with water to slightly less than the mark.
6. Carefully pour the water from the measuring cup into the milk carton. Hang the Newton Scale as before and mark the tape where the bottom of the milk carton hangs. Write a "1" next to this mark. The distance between the "0" and "1" marks shows you the amount of pull of one Newton.
7. Predict what will happen when the milk carton is filled with more water or with other materials. Draw a mark and label it with a number for each material that you test. Try it!

NOTE: The scale will only be able to determine if materials are greater or less than one Newton. Due to the changing resistance in the rubber band, two Newtons will not necessarily be twice as far from the zero point as the second mark. Filling the milk carton with 0.42 pints of water can produce a two Newton mark on the tape.

Think About It!

Imagine the force of gravity on a Boeing 787 airplane. A fully loaded 787-8 is approximately 219,539 kg. This is equal to 927,942 half-pint milk cartons filled up with water! The force of gravity on this plane pulls at about 2.2 million Newtons. How far would a super strong rubber band stretch with a Boeing 787-8 hanging from it?

Why?

The force applied to an object causes the object to change position. A force can push or pull. Gravitational force is measured in Newtons, and always pulls down toward the center of the earth. Gravity pulls more on objects that have more mass.

In this investigation, you observed the amount of gravitational force created by one Newton (The gravitational force pulls 0.21 pints of water with a force of one Newton). Using one Newton as a standard, you can explore other materials and measure the amount of gravitational force pulling upon them.

How Does Thrust Work? PUSH ME? PUSH YOU BACK

Materials (per pair, this works best with students of similar weight)

- 2 Scooter boards borrowed from gym class (skateboards or office chairs can be substituted)
- Poster paper, folded in half
- Pencil

Time: 15 minutes

Prepare

Explain to the students what will happen in this experiment – each member of the student pair will sit completely on his/her scooter board. Only one student of the pair will push the other student firmly with his or her arms. Both riders need to try to keep their entire bodies on the scooter and off the floor.

Do This!

1. On the top half of the poster paper, draw a sketch of the two scooters with their riders. Using arrows and words, predict what will happen to BOTH riders after the push.
2. Run the experiment as described. Try to push your partner's scooter board instead of her body if she can't stay balanced on the scooter board.
3. On the bottom half of the poster paper, draw the two scooters and riders. Using arrows and words, describe what actually happened after the push.
4. Run more trials and observe the results.

Think About It!

- What happened to the rider who was pushed? Did this surprise you?
- What happened to the rider who did the pushing? Did this surprise you?
- How does the movement of the scooter riders simulate how an airplane engine moves an airplane forward?

Why?

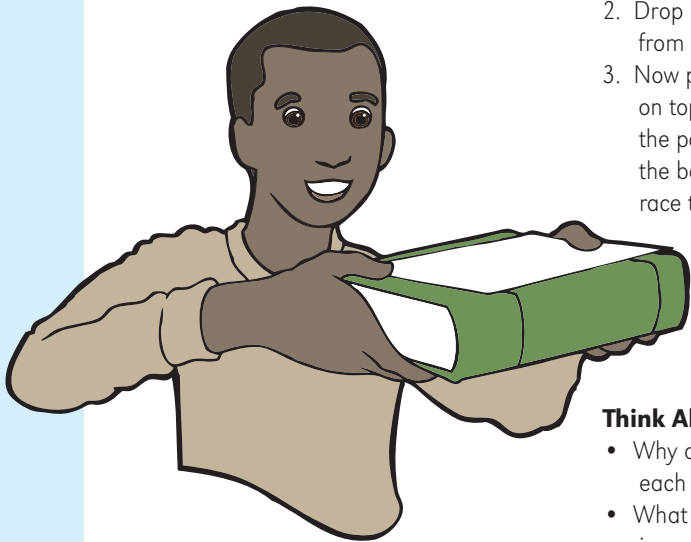
Newton's Third Law states that every action has an equal and opposite reaction. Young children love the idea of thrust – a kick of a soccer ball or the roar of a rocket launch. One of the most difficult concepts linked to thrust is that the force of movement in one direction is equal to the force pushing back.

Can Air Slow a Fall? DRAG RACING

Materials (per person)

- 1 Sheet of paper
- 1 Hardback book larger than the paper

Time: 15 minutes



Do This!

1. Hold the sheet of paper in one hand and the book in the other at the same height. Predict which one will win in a race to the ground.
2. Drop both objects at the same time from approximately shoulder height.
3. Now place the sheet of paper directly on top of the book without any part of the paper hanging beyond the edge of the book. Predict which one will win in a race to the ground.
4. Hold the paper onto the book with your thumbs and drop both the book and the paper at the same time from the same height as before.

Think About It!

- Why does the paper fall differently in each drop?
- What forces are acting upon the paper in each drop?
- Air resistance acts on airplanes and sheets of paper alike. What is the difference between a falling piece of paper and an airplane?

Why?

When an object moves through air, drag is caused by air resistance. Air resistance is the result of collisions of the object's leading surface with air molecules. The actual amount of air resistance encountered by the object is mostly dependent upon the area of the leading edge of the falling object. The book and the notebook paper experience nearly the same amount of air resistance because their leading edges are approximately the same area, but air resistance has little effect on the book, because the force of gravity is much greater than the opposing force of drag. When the paper falls on top of the book, the leading edge of the paper is shielded by the book, minimizing the effect of air resistance.

Can a Breath Lift Water? STRAW FOUNTAIN

Materials (per person)

- 1 Disposable plastic drinking cup, filled $\frac{3}{4}$ full with water
- Masking tape, 1-2" (3-5 cm) wide
- 2 Drinking straws
- Scissors
- Towels for clean up
- 11" x 17" (28x43cm) sheet of black construction paper
- Tub for preparing materials and catching spills

Time: 20 minutes

Set Up

1. Fill the drinking cup $\frac{3}{4}$ full of water.
2. Place a single strip of masking tape over the top of the drinking cup.
3. Make a small tear (smaller than the diameter of the straw) in the center of the tape with the scissors. Push Straw A through the hole so that it stands up on its own near the center of the cup, but does not touch the bottom of the cup. Trim Straw A so that it is about $\frac{1}{2}$ cm. taller than the cup.

Do This!

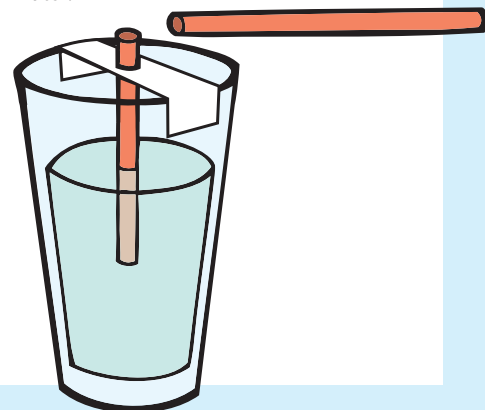
1. Place the cup of water at one end of the black paper.
2. Get out your chair and keel or crouch so that your head is level with the top of the cup. Hold Straw B perpendicular to the top of Straw A. Blow through Straw B so that the air moves perpendicularly across the top of Straw A. What happens?
3. Make small changes to the angle and the distance of Straw B as you blow. What changes?

Think About It!

- Why does the water move up and out of Straw A?
- Where is the air pressure changing in this investigation?
- Can you explain how a perfume sprayer works based on this demonstration?

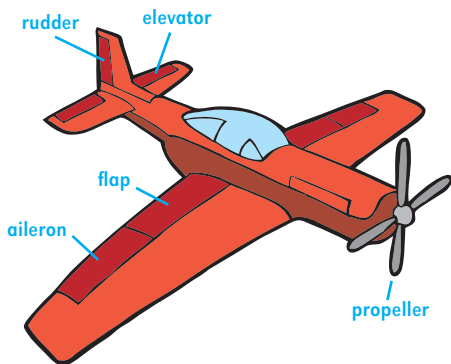
Why?

By blowing air across the top of Straw A, you are lowering the air pressure above Straw A. The still air inside Straw A moves upward into the space of lower air pressure above the straw. As the column of air in Straw A moves up, the air in the cup pushes down on the surface of the water around Straw A, pushing the water in Straw A up and out its top. When the water gets to the top of Straw A, it is blown out in a mist. The black paper is there to confirm the spray of water.



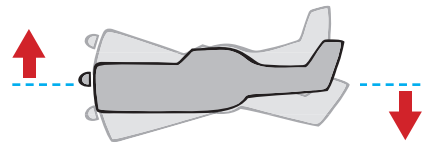
Flight School: How Do Pilots Control an Airplane?

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.



Pitch

Elevators make the nose of the airplane pitch up or down. The elevators are on the tail of the aircraft. 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.



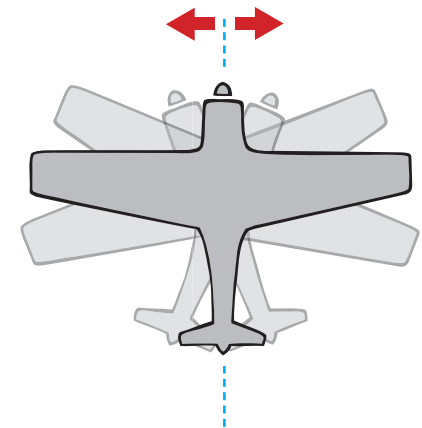
Roll

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



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 to 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.



WHAT IS THRUST?

The force that moves an airplane forward is called thrust. An airplane can fly only when the thrust is strong enough to overcome the drag on the plane.

An airplane's engines create thrust. Enough thrust must be made to move the plane fast enough to create lift with the wings. There are four main types of airplane thrusters: propellers, jet turbines, ramjets, and rockets. Birds, bats, and insects create thrust by flapping their wings.

Some airplanes do not have engines or their own source of thrust. These are called gliders. A glider needs specific environmental conditions in order to fly, such as an uplifting wind or a tow into the air from an airplane with an engine.

Airplane Propeller: The Twisted Wing

If you look closely at the shape of a propeller, it should look familiar. It is the shape of an airfoil, just like a wing! There is one difference between a wing and a propeller – the propeller is perpendicular to the ground. While a wing's airfoil creates lift to keep the airplane flying, the propeller's airfoils spin to create thrust and move the airplane forward.



Newton's Third Law of Motion

"All forces occur in pairs, and these two forces are equal in magnitude and opposite in direction."

A girl and a boy are standing on skateboards. When the girl pushes the boy, both skaters move away from each other with a force equal to that of the push.

A jet engine works using the same concept. The fuel burns and leaves the back of the engine with a huge force. The jet engine and everything connected to it move in the opposite direction with the same amount of force.

DID YOU KNOW?

December 17, 1903: Orville Wright flew the Wright Flyer into the history books. The longest of the three flights of the Wright Flyer was 196 feet (59.74 m). The Flyer gained an altitude of only about 10 feet (3.05 m) above the ground. The entire flight only lasted 21 seconds. The entire flight could have easily taken place inside the body of a Boeing 747 airplane.

CAREERS IN THE AVIATION INDUSTRY

There are many ways to become involved in the exciting aviation industry.

- Aerospace engineer
- Air Marshall
- Air Traffic Controller
- Baggage Handler
- Civil Engineer
- Electrical engineer
- Flight Attendant
- Ground Crew
- Interior Designer
- Maintenance Mechanic
- Mechanical engineer
- Meteorologist
- Pilot
- Psychologist
- Security Agent
- Systems Engineer
- Ticket Agent

SUGGESTED RESOURCES FOR TEACHERS

Legends of Flight Film
<http://www.legendsofflightfilm.com>

NASA: Four Forces on an Airplane
<http://www.grc.nasa.gov/WWW/K-12/airplane/forces.html>

The Boeing Company: Forces of Flight
<http://www.boeing.com/companyoffices/aboutus/community/fof.html>

NATIONAL SCIENCE EDUCATION STANDARDS FOR GRADES K-3

- **Science as Inquiry:** Students develop abilities necessary to conduct scientific inquiry.
- **Physical Science:** Students develop abilities to describe the position and motion of objects.
- **Earth and Space Science:** Students observe and describe objects in the sky.
- **Science and Technology:** Students develop an understanding about science and technology.

BIBLIOGRAPHY

Airbus. The A380: The Future of Flying. June 2008 <http://www.airbus.com/en/myairbus/airbusview/the_a380_the_future_of_flying.html>.

Arkell, Debbie. "Similarities Between 777, 787 Help Airlines, Passengers and Boeing." *Boeing Frontiers Magazine*. Vol. 4, Issue 5 (Sept. 2005). Nov. 2007 <http://www.boeing.com/news/frontiers/archive/2005/september/i_ca1.html>.

Cislunar Aerospace, Inc. *The K-8 Aeronautics Internet Textbook*. 2001. Nov. 2007 <<http://wings.avkids.com/>>.

Gates, Dominic. "Boeing Rolls out Dreamliner for the World." *Seattle Times*. July 9, 2007. June 2008 <http://seattletimes.nwsource.com/html/business/2003780816_787rollout09.html>.

German, Jennifer. "Configuration Innovation: 787 Dreamliner Gallery Lets Customers Easily Select Configurations." *Boeing Frontiers Magazine*. Vol. 5, Issue 9 (28 Feb. 2007): pp. 28-29. Nov. 2007 <http://www.boeing.com/news/frontiers/archive/2007/february/i_ca.html>. Path: Go (Con)figure; Full Story.

Morgan, Adam. "Wings Around the World." *Boeing Frontiers Magazine*. Vol. 4, Issue 10 (March 2006). Nov. 2007 <<http://www.boeing.com/news/frontiers/archive/2006/march/cover.html>>.

Norris, Guy, Geoffrey Thomas, Mark Wagner, and Christine Forbes Smith. *Boeing 787 Dreamliner - Flying Redefined*. Western Australia: Aerospace Technical Publications International Pty Ltd, 2005.

Sofge, Eric. "Boeing's 787 Dreamliner: How it Works." *Popular Mechanics*. Sept. 2006. Nov. 2007 <<http://www.popularmechanics.com/technology/transportation/3493516.html?nav=RSS20>>.

CREDITS

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LEGENDS OF FLIGHT

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In Association with the Smithsonian

National Air and Space Museum

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.

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