THE FOUR FORCES OF FLIGHT

An aircraft in straight and level flight is acted upon by four forces: lift, gravity, thrust, and drag. The opposing forces balance each other; lift equals gravity and thrust equals drag. Any inequality between thrust and drag, while maintaining straight and level flight, will result in acceleration and deceleration until the two forces become balanced.

Drag: The air resistance that tends to slow the forward movement of an airplane.

Gravity: The force that pulls all objects towards the earth.

Lift: The upward force that is created by the movement of air above and below a wing. Air flows faster above the wing and slower below the wing, creating a difference in pressure that tends to keep an airplane flying.

Thrust: The force that moves a plane forward through the air. Thrust is created by a propeller or a jet engine.

Try out the following activities to explore the Four Forces of Flight for yourself!

Adapted from: https://www.wai.org/education/resources/hands-aviation-education-materials#
Foamy Flyer

Problem
Does the amount of thrust affect the Foamy Flyer’s flight?

Materials
- Foam tray or plate
- Scissors
- Tape
- Large paper clip
- Rubber band
- Non-bendable straw
- Ruler
- Tape Measure (for testing)

Background
Thrust is the force that moves a plane through the air. Because airplanes fly in a three-dimensional environment, the following terms refer to the various directions an airplane can move:
- **Pitch**: to move the nose of the airplane up or down
- **Roll**: to tilt one wing up and the other wing down
- **Yaw**: to point the nose of the airplane left or right while remaining level with the ground
- **Bank**: to tilt the airplane inward while making a turn

Airplanes, including even the Foamy Flyer, use a variety of “control surfaces” to change the speed and direction in which they fly. These control surfaces include:
- **Ailerons**: movable sections, hinged on the rear edge of the wing near the wingtip, that cause the airplane to roll
- **Flaps**: movable sections, hinged on the rear of the wing, which can be lowered to increase lift and drag during takeoff or landing.
- **Stabilizer**: the vertical stabilizer is the upright portion of the airplane tail, while the horizontal stabilizer is the small wing usually located on the back of the airplane.

Procedure
1. Fold down the top three centimeters of the straw and insert the rubber band into the fold.
2. Fold the straw over the rubber band and secure the end with masking tape. This creates the launcher for your flyer.
3. Cut a triangle out of the foam tray from the flat inverted side. A good size to start with is 13 cm x 13 cm x 13 cm (an equilateral triangle).
4. Tape the paper clip to the top of the foam wings. Then, tape the wings to the top of the launcher so that it extends slightly over the tip (see Figure 3).
5. Hook the rubber band around the tip of your thumb and pull back on the opposite end of the flyer (see Figure 4). Release the straw and the flyer will fly forward. Make sure you release the rubber band too!
6. Make a designated launch area.
7. Launch your flyer using two different amounts of thrust.
   a. First, pull the nose of the flyer halfway to your elbow and let it fly.
   b. Next, pull the nose of the flyer all the way to your elbow and let it fly.
8. Observe the differences in your flyer’s flight and distance using different amounts of thrust. Record your observations in your data table (see Sample Data Chart: Foamy Flyer Tests below).

**Data**
- Before testing, create a data table to record flight data for your Foamy Flier.
  o Record the test number, amount of thrust, and distance of flight.
  o Leave space to make any other observations about the flight.
- Draw a diagram of your flyer.
  o Include dimensions of your wings.
  o Label how thrust affected the flight of your flyer.

**Sample Data Chart: Foamy Flyer Tests**

<table>
<thead>
<tr>
<th>Test #</th>
<th>Amount of Thrust</th>
<th>Distance of Flight</th>
<th>Modifications</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Troubleshooting and Safety Tips**
- Launching the Foamy Fliers can be done inside or outside.
  o If launching inside, make sure you have a long space (at least 10 feet).
- DO NOT launch your foamy flyer at a person.
- Save the unused parts of the foam tray for the extension activities.

**Reflection Questions**
- Does the amount of thrust affect the Foamy Flyer’s flight? How?
- What did you observe when using different amounts of thrust to launch your Foamy Flyer?
- Did the Foamy Flyer fly differently after modifications were made to the ailerons, flaps, stabilizers, or rudder? How?
- What other factors affect how your flyer flew?
- Why was your flyer successful or unsuccessful?
- How does the thrust of the Foamy Flyer compare to the thrust of a real airplane?

**Activity Extensions**
- Cut wing flaps and ailerons into the back of the foam wings.
- Change the weight of the flyer by adding weight behind the wings with tape or paper clips.
- Use the leftover foam plate parts to add stabilizers and rudders to your flyer.
- Try different sizes or types of triangles for your foam wings.
**Vocabulary**

- **Thrust:** the forward force developed in a jet engine as a reaction to the high-velocity rearward ejection of exhaust gases
- **Lift:** the aerodynamic force that tends to keep an aircraft in the air
- **Gravity:** the force that pulls all objects towards the earth
- **Drag:** the air resistance encountered as an aircraft tries to move forward
- **Wings:** the large airfoils that extend out from either side of the middle on an airplane’s fuselage to provide the lift needed to fly
- **Nose:** the front portion of the aircraft
- **Fuselage:** the body of an airplane to which the wing, tail and landing gear are attached
- **Ailerons:** movable aircraft control surfaces located near the end of the wing which are used to make an aircraft bank or roll
- **Flaps:** devices located on the trailing or rearward portion of the wing that can be extended to increase lift and drag, especially during takeoff or landing
- **Pitch:** term used to describe the three-dimensional movement of an aircraft. Pitch is the rotation of an airplane around its lateral axis.
- **Roll:** term used to describe the three-dimensional movement of an aircraft. Roll is the motion of an aircraft around its longitudinal axis.
- **Yaw:** term used to describe the three-dimensional movement of an aircraft. Yaw is the movement of an airplane around its vertical axis.
- **Bank:** to tilt an aircraft laterally and inwardly during forward flight

**Resources**

Adapted from: [https://www.wai.org/sites/default/files/assets/EducationKit/1%20fourforces%20thrust.pdf](https://www.wai.org/sites/default/files/assets/EducationKit/1%20fourforces%20thrust.pdf)

**Internet**

- [https://howthingsfly.si.edu/](https://howthingsfly.si.edu/)
Paratroopers Away

Problem
How does a parachute create drag for a falling object?

Materials
- Plastic grocery bag (with handles)
- Clothespin, binder clip, or large paper clip

Background
Drag is the force that acts against the forward movement of an airplane and slows it down. All moving objects experience drag.

Procedure
1. Bring the handles of the grocery bag together and secure with a clothespin.
2. First, drop the parachute from a chair-standing height. With the grocery bag first crumpled up, observe the descent of the clothespin.
   a. Note: make sure the clothespin drops first.
3. Next, open up the parachute fully and drop it from the same height. Observe the descent of the clothespin.
4. Experiment with the two different ways of dropping the clothespin.
5. Record your observations (see Sample Data Chart: Paratroopers Away Tests below).

Challenge: Create a parachute that lands accurately on a bullseye target.

Data
- Before testing, create a data table to record test data for your paratrooper.
  o Record the starting height, starting position of your parachute (closed or open), and the weight you use (clothespin, binder clip, etc.).
  o Leave space to make any other observations about the tests.
- Draw a diagram and label the two parachute drops.
  o Closed chute
  o Open chute

<table>
<thead>
<tr>
<th>Sample Data Chart: Paratroopers Away Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test #</strong></td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
</tbody>
</table>

Troubleshooting and Safety Tips
- Testing the parachute can be done inside or outside.
  o If testing outside, be careful of wind that might blow your parachute away.
- DO NOT drop your paratrooper on anyone.

Reflection Questions
- How does a parachute create drag for a falling object?
- What were the differences they observed between the two drops?
- How does drag affect the flight of an airplane?
- Would increased weight require a larger parachute? Why?
### Activity Extensions
- Try different sized parachutes.
- Add different weights. Try adding more clothespins or using small toys.
- Drop the parachute from different heights, like from the top of the stairs or off a balcony. Just make sure no one is in the drop zone!

### Vocabulary
- **Drag**: the air resistance encountered as an aircraft tries to move forward.
- **Parachute**: a device that is attached to people or objects to make them fall slowly and safely when they are dropped from an aircraft. It consists of a large piece of thin cloth that opens out in the air.
- **Weight**: how heavy somebody/something is, which can be measured in, for example, kilograms or pounds.
- **Descent**: an action of coming or going down.
- **Streamline**: to give something a smooth, even shape so that it can move quickly and easily through air or water.
- **Observation**: the act of watching somebody/something carefully for a period of time, especially to learn something.
- **Paratrooper**: a soldier trained to jump from an airplane and be lowered slowly to the ground using a parachute.
- **Drag chute**: a parachute used to slow down an airplane or other object that travels through the air.

### Resources
**Adapted from**: https://www.wai.org/sites/default/files/assets/EducationKit/3%20fourforces%20drag.pdf

**Internet**
- [https://howthingsfly.si.edu/](https://howthingsfly.si.edu/)

**Videos**
- Playtime with Parachutes: Physics for Kids - [https://www.youtube.com/watch?v=Ab_g5sLoXoY](https://www.youtube.com/watch?v=Ab_g5sLoXoY)
- How to make a Parachute at home From plastic bag - [https://www.youtube.com/watch?v=uA_qzmaDF_8](https://www.youtube.com/watch?v=uA_qzmaDF_8)

**Definitions**
- [https://www.wai.org/sites/default/files/assets/EducationKit/3%20fourforces%20drag.pdf](https://www.wai.org/sites/default/files/assets/EducationKit/3%20fourforces%20drag.pdf)
- [https://www.wai.org/sites/default/files/assets/EducationKit/7%20aviation%20terms.pdf](https://www.wai.org/sites/default/files/assets/EducationKit/7%20aviation%20terms.pdf)
- [https://www.oxfordlearnersdictionaries.com/us/](https://www.oxfordlearnersdictionaries.com/us/)
Paper Airplanes

Problem
How does the design of the airplane affect the lift?

Materials
- Copy paper
- Paper Airplane Templates
- Stopwatch

Background
Lift is created by the shape of the wing, which makes the air pressure above the plane’s wing less than the pressure below. This causes the plane to lift forward. When the lift is greater than gravity, the plane goes up.

Procedure
1. Make the two different designs of airplanes. (See Paper Airplane Template #1 & #2)
2. Before testing your planes, think about which plane design will stay in the air longest.
   a. Record your hypothesis in your notebook.

Test your planes
3. The pilot will fly his or her design at the timer’s signal.
4. The timer starts when the pilot releases the plane and stops when the plane lands.
5. Record the time aloft (how long the plane stayed in the air) each trial. (see Sample Data Chart: Paper Airplane Tests below)
6. Repeat the test three to five times for each plane.

Challenge: Design a new airplane that will remain aloft the longest.

Data
- Calculate the average time aloft for each plane design.
  o Add up the times of all flights. Divide the total time aloft by the number of flights. This is the average.
- Create a graph from the data you recorded about your flight tests.
  o Do you see any patterns?

<table>
<thead>
<tr>
<th>Sample Data Chart: Paper Airplane Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Airplane Design #1</strong></td>
</tr>
<tr>
<td>Flight/Test #</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td><strong>Average Time Aloft</strong></td>
</tr>
</tbody>
</table>

Reflection Questions
- How does the design of the airplane affect the lift?
- What features of the plane keep it aloft the longest?
- What features of the plane prevent the plane from staying aloft?
- How does this activity show how a plane stays aloft?
Troubleshooting and Safety Tips

- Paper airplanes usually fly best when the folds are very tight.
- When you test your planes, try to find someone to help you time the flights.
- You can fly your paper airplanes inside or outside.
  - Inside: Make sure you have a large area, so you don’t hit the wall or ceiling.
  - Outside: Flying paper airplanes outside can be difficult if it is windy.

Activity Extensions

- Add elevators to their planes and observe changes in flight.
  - To make elevators, fold up tips or sides of the wings.
- Add rudders by folding the base of the fuselage (body).
- Challenge: Design a new airplane that will remain aloft the longest.

Vocabulary

- **Lift**: the aerodynamic force that tends to keep an aircraft in the air
- **Descent**: an action of coming or going down
- **Ascent**: the act of climbing or moving up
- **Landing**: an act of bringing an aircraft or a spacecraft down to the ground after a journey
- **Aloft**: in the air
- **Design**: a drawing or plan from which something may be made
- **Fuselage**: the body of an airplane to which the wing, tail and landing gear are attached
- **Wing**: the large airfoils that extend out from either side of the middle on an airplane’s fuselage to provide the lift needed to fly
- **Nose**: the front portion of the aircraft
- **Elevators**: the control surface located on the horizontal tail of an aircraft that, when move by the pilot, makes the airplane climb or descend
- **Rudder**: the movable vertical portion of the tail (or empennage) that is used to control the yawing movement of an aircraft

Resources

Adapted from: [https://www.wai.org/sites/default/files/assets/EducationKit/4%20fourforces%20lift.pdf](https://www.wai.org/sites/default/files/assets/EducationKit/4%20fourforces%20lift.pdf)

Internet

- [https://howthingsfly.si.edu/](https://howthingsfly.si.edu/)

Videos

- How to Make a Paper Airplane - [https://www.youtube.com/watch?v=7KPaxKUDj6I](https://www.youtube.com/watch?v=7KPaxKUDj6I)
- How to fold the Classic Dart Paper Airplane - [https://www.youtube.com/watch?v=dCrzMJcVuyw](https://www.youtube.com/watch?v=dCrzMJcVuyw)
- Foldable Flight (channel with many paper airplane tutorials) - [https://www.youtube.com/channel/UC71_mrmoliZQgd0rfhShGfg/featured](https://www.youtube.com/channel/UC71_mrmoliZQgd0rfhShGfg/featured)
- How to Make a Paper Airplane (channel with many paper airplane tutorials) - [https://www.youtube.com/channel/UCeIKPXYHHUs4tq1WET8HiJg/videos](https://www.youtube.com/channel/UCeIKPXYHHUs4tq1WET8HiJg/videos)

Definitions

- [https://www.wai.org/sites/default/files/assets/EducationKit/7%20aviation%20terms.pdf](https://www.wai.org/sites/default/files/assets/EducationKit/7%20aviation%20terms.pdf)
- [https://www.oxfordlearnersdictionaries.com/us/](https://www.oxfordlearnersdictionaries.com/us/)
Paper Airplane Template 1
Classic Dart

1. Take an 8-1/2 x 11” sheet of paper, fold it in half lengthwise and open it flat again.

2. Fold the top two corners to the centerline.

3. In the same manner, fold the corners again to the centerline.

4. Fold back the sides along the original fold line, plain sides together. Fold down the sides half way down the wing.

5. Hold the plane underneath and launch with a hard, forward thrust.
Paper Airplane Template 2
Flying Wing

1. Fold an 8-1/2 x 11 piece of paper lengthwise and open it.

2. Fold the bottom edge to the middle crease. Fold it again making four thicknesses

3. Crease the folded part at its midpoint, causing a slight angle in the wing.

4. Hold at the back of the wing and launch with a gentle forward thrust.
Gravity Busters

Problem
How does lift work against gravity?

Materials
- Gravity Buster model
- Scissors
- Stapler or paper clips
- Stopwatch

Background
Gravity is the force pulling the plane down. When the gravity is stronger than the lift, the plane goes down. Helicopters are really airplanes with moving wings called rotors, which replace the fixed wings and propellers used on an airplane. A helicopter rises for the same reason an airplane flies: the movement of the air results in a pressure on the bottom of the rotor blades (wings) that is greater than the pressure on the top of the rotor blades (wings).

Procedure
2. Test your Gravity Buster by standing on a chair and releasing it. It must be released from the same height each time.
3. Assign the following jobs for testing: Pilot, Timer, Recorder, Air-traffic controller (boss)
   a. The Pilot drops the Gravity Buster three times.
   b. The Timer will start at the release and stop at the landing.
   c. The Recorder records each trial time (see Sample Data Chart: Gravity Busters Trials below).
   d. The Air-traffic controller counts down to each drop.
4. Add one staple or paperclip to the bottom of the Gravity Buster and repeat step #5.
5. Add two additional staples or paperclips (three total) to the bottom of the Gravity Buster and repeat step #5.
6. Find the average descent time for each weight.
   a. Add the Descent Times of Trial 1, Trial 2, and Trial 3 for No Weight. Divide your answer by 3. This is the Average Time. Repeat for the other weights.
7. Create a graph of your results using the average times.

Data
- Before testing, create a data table to record test data for your Gravity Duster.
  - Record the descent time for each of the three weights you test.
  - Leave space to make any other observations about the tests.
- Find the average descent time for each weight.
  - Add the Descent Times of Trial 1, Trial 2, and Trial 3 for No Weight. Divide your answer by 3. This is the Average Time.
  - Repeat for the other weights.

Sample Data Chart: Gravity Busters Trials

<table>
<thead>
<tr>
<th>Weight Added</th>
<th>Descent Time (Seconds from release to landing)</th>
<th>Average Time (in seconds)</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Weight</td>
<td>Trial 1</td>
<td>Trial 2</td>
<td>Trial 3</td>
</tr>
<tr>
<td>1 Staple/Paperclip</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Staples/Paperclips</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Observations**

### Troubleshooting and Safety Tips

- Testing your Gravity Buster works best with 3-4 students or a student and an adult helper.
- Make sure you release your Gravity Buster from the same height for each test. If you change the height, you cannot accurately compare the descent times because your Gravity Buster will be traveling different distances.

### Reflection Questions

- How does lift work against gravity?
- Why did your group choose the winning Gravity Buster?
- How did the staples affect the Gravity Buster?
- How does this activity show how a helicopter stays in the air?
  - Answer: When lift is stronger than gravity, the craft stays up.

### Activity Extensions

- Construct Gravity Busters out of different materials and/or designs.
- Change the heights at which they are dropped.
- Add or remove weight.
- Challenge: Use all your knowledge to make the best Gravity Buster.

### Vocabulary

- **Gravity**: the force that pulls all objects towards the earth
- **Rotation**: the action of an object moving in a circle around a central fixed point
- **Rotary wing**: a long airfoil that rotates to provide the lift that supports a helicopter in the air
- **Weight**: how heavy somebody/something is, which can be measured in, for example, kilograms or pounds
- **Pull**: to take hold of something and use force in order to move it
- **Aloft**: in the air
- **Descent**: an action of coming or going down
- **Air-traffic controller**: a person on the ground who uses radar to track aircraft and radios to direct the movement of aircraft

### Resources

**Adapted from**: [https://www.wai.org/sites/default/files/assets/EducationKit/2%20fourforces%20gravity.pdf](https://www.wai.org/sites/default/files/assets/EducationKit/2%20fourforces%20gravity.pdf)

**Internet**

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- How to make a Parachute at home From plastic bag - [https://www.youtube.com/watch?v=uA_qzmaDF_8](https://www.youtube.com/watch?v=uA_qzmaDF_8)

**Definitions**

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- [https://www.oxfordlearnersdictionaries.com/us/](https://www.oxfordlearnersdictionaries.com/us/)
Gravity Buster Model

1. Cut along the solid lines.
2. Fold along the dashed lines.
3. Fold Flap A into the center. Then fold Flap B over Flap A.
4. Fold Blade 1 back and Blade 2 forward.