Smithsonian
National Air and Space Museum

How Things *Fly*

How can an airplane fly upside down?

Here's an uplifting explanation. A wing is shaped and tilted so air moves faster over the wing than under it. This creates an upward force called lift. A wing will produce lift even while flying upside down, as long as the wing's front edge is tilted far enough above its rear edge.

Why don't blimps float up into space?

A blimp will take you pretty far up, but not above the atmosphere. The reason is buoyancy, the upward force of the air. Buoyancy is created by the difference in air pressure between the bottom and top of the blimp. It decreases the higher you go. The blimp stops rising when its buoyancy equals its weight.

If Air has so much pressure, Why don't I feel all that force?

Air is stuff. It has mass. This means air has weight. It presses against you with a force of nearly 15 pounds per square inch (about 1 kilogram per square centimeter). You don't feel it because the air and fluid pressure within your body balances the air pressure around you.

OVERVIEW

Flight—the dream of centuries—is a staple of modern life. For more than 100 years, we have been defying gravity. Our ability to lift off the ground, take flight, and control the movement of aircraft is the result of putting our knowledge of the principles of science to work. With this poster, you can help your students think about how humans have achieved flight.

Using this poster, students can explore the fundamental physics of flight. Poster activities explore how air pressure changes with velocity. Simple hands-on activities bring Bernoulli's principle to life. A blackline master for paper airplanes lets each student explore how an aircraft's weight distribution affects its stability.

Poster activities assume that students are generally familiar with gases, including the properties of air. Activities are designed for upper elementary and middle school students, but older students may benefit from them as well.

OBJECTIVES

★ Students will be able to describe how the pressure of a gas changes as the gas's velocity changes.

★ Students will be able to describe how Bernoulli's principle enables airplanes to fly.

★ Students will be able to show how an airplane's weight distribution affects its stability.

EDUCATION STANDARDS ADDRESSED IN THESE ACTIVITIES

National Science Education Standards

Science as Inquiry

★ Abilities necessary to do scientific inquiry

Physical Science

★ Properties and changes of properties in matter

Science and Technology

★ Understanding about science and technology

HOW TO USE THIS POSTER

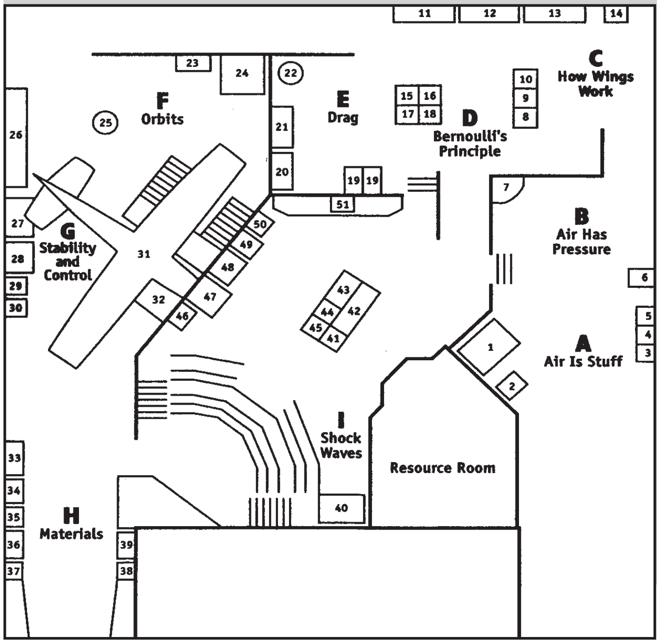
This poster is designed to be a flexible teaching tool. Students can do poster activities before or after visiting the National Air and Space Museum. More important, you can use this poster to help plan your visit to the *How Things Fly* gallery.

To get the most from poster activities, students should be familiar with the properties of air and air pressure. You can use the poster's cover questions to introduce or review these concepts.

On a Museum visit, students who have learned about air and air pressure (including Bernoulli's principle) will be challenged further by the interactive exhibits in the *How Things Fly* gallery. Or you can visit the gallery to introduce your students to air, air pressure, and the basics of flight. The gallery devices that reinforce concepts on this poster are listed below, along with suggested questions and comments to help students focus.

Even if you do not plan to visit the Museum, you can use this poster to introduce students to the basic physics of flight. Students can complete the poster activities in the classroom by working individually or in groups. Activities also work well as teacher demonstrations.

FIGURE 1



HOW THE GALLERY IS ORGANIZED

How Things Fly is an interactive gallery with more than 50 hands-on devices to explore the principles of flight. Devices are grouped by subject area (see map, figure 1). Planning a field trip to the gallery? If possible, make an advance visit. Touring the gallery ahead of time will help you plan, so your students can make the most of their visit.

Devices are numbered to correspond with the gallery map. The following devices relate to the *How Things Fly* teaching poster activities:

Area A. Air is Stuff

2. Stack of Bricks (Air has weight)
3. Rods to Lift (Air pressure changes with altitude)
4. Evacuated Tube (How does air affect things that move through it?)

Area B. Air Has Pressure

5. Out-Muscle Air Pressure (Can you?)
7. Barometer on Slide (Measure air pressure at different altitudes)

Area C. How Wings Work

8. Venturi Tube—Water (What happens to constricted fluids?)
9. Venturi Tube—Air (What happens to constricted air?)
10. Dynamic Pressure (What's the difference between static and dynamic pressure?)
11. Wing Tip Vortices (What happens to air at wing tips?)
12. Smoke Tunnel (See how air behaves around air foils)
13. Wind Tunnel (Measure air pressure at different points on an airfoil)
14. Water Wings (Why does a wing have a rounded front?)
19. How Wings Work (Computer simulations)

Area D. Bernoulli's Principle

15. Levitator Plate (Why doesn't the plate fall?)
16. Beach Ball (What keeps the ball up?)
17. Wing and Scale (Measure the effect of Bernoulli's principle on an airplane wing)
18. Baseballs and Blower (Why don't the balls blow apart?)

Area G. Stability and Control

28. Gyro Chair (Conservation of angular momentum)
29. Stability Rod (Why is the rod so hard to balance?)
30. Reaction Time Ruler (What's your reaction time?)
31. Cessna Airplane (What do the controls do?)
32. Cessna Model (Same plane, but smaller and "flyable")

BACKGROUND INFORMATION

To understand how airplanes fly, students need to know about **gravity** and **lift**. Gravity—the force that holds everything to the surface of the Earth—affects everything that flies. Properties of air help produce lift—an essential force of flight that acts in opposition to gravity.

Airplanes use the force of lift—which results from differences in air pressure—to overcome gravity. How does an airplane weighing many tons fly? The simple answer: The airplane's wings create enough lift to support its own weight.

The activities on this poster explore lift and how airplane wings are designed to put Bernoulli's principle to work.

Air, Air Everywhere

Air is pushy stuff. In fact, air is pushing us all the time from every direction. It presses against us with a force of nearly 15 pounds per square inch (about 1 kilogram per square centimeter.) This constant push of air is called air pressure. (Exhibits in gallery areas A and B let students get a "feel" for air pressure and its effects.) We don't feel air pressure, because the air and fluid inside our bodies balance the air pressure around us.

What's a Bernoulli?

Eighteenth-century Swiss mathematician Daniel Bernoulli discovered an important principle. Bernoulli found that when a fluid (such as moving air) changes speed, its pressure also changes. Airplane wings are specially designed to take advantage of this.

Wings are designed so the air moving over the top of the wing is forced to speed up more than the air moving below the wing. Why does the air speed up? An airplane's wing is an obstacle to the oncoming air. As the air meets the wing, its path narrows. But the amount of air moving past remains the same. Think of water moving past rocks in a creek. The rocks are an obstacle that narrows the path of the flowing water. But the amount of water that must pass by remains the same. The flowing water speeds up as its path narrows around the rocks.

Air behaves the same way as it rushes over and under an airplane wing. The curved upper surface constricts the flow of air more than the flatter lower surface, causing the air above the wing to speed up more than the air below. And as Bernoulli discovered, when air speeds up, its pressure lowers. The faster the air speeds up, the lower its pressure becomes. So the faster moving air above has less pressure than the slower moving air below. The higher air pressure below pushes the wing up. (See gallery areas C, D, E on map.)

What's *not* going on

A common explanation of lift states that air moves faster over a wing's curved upper surface because it has farther to travel than air moving under the flatter lower surface. This explanation is wrong! It assumes that a volume of air separated by the wing's forward edge must meet again at the rear edge, but that doesn't necessarily occur.

Many factors affect lift

The size and shape of an airplane's wings, the angle at which the wings meet the oncoming air, the speed at which an airplane moves through the air, and even the density of the air all affect the amount of lift a wing creates.

How can an airplane fly upside down? Wing tilt is the trick. Tilting the upside-down wing upward forces the air traveling over the wing to speed up more than the air passing beneath the wing. The difference in air pressure results in lift.

ACTIVITIES

Activities on the following pages (4-6) enable students to discover for themselves how moving air creates changes in air pressure and how Bernoulli's principle is put to use in wing design. The results are often surprising!

BETWEEN THE BALLOONS

Blow up the balloons and tie each with a string. Hold the balloons a few inches apart by the strings. What do you think will happen if you blow between the balloons? Try it. What happens? What did you think would happen? How do you explain it?

What does this have to do with airplane flight?
When you blow between the balloons, you create a difference in air pressure. How does Bernoulli's principle help explain the result?

An airplane wing is designed to create the same sort of air pressure imbalance that pushes the balloons together. When you blow between the balloons, air moves past only one side of each balloon. In flight, air moves past both sides of a wing. To create a pressure difference, the wing is shaped and tilted to make air move faster over the top surface. The result: lower pressure above the wing and higher pressure below.

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BLOWING IN THE WIND

★ a piece of paper

Hold a piece of paper between your thumb and forefinger as shown. Now blow over the paper. What happens?
Can you figure out why the paper lifted as you blew? Remember: air can't suck anything up, but it can push. The paper is surrounded by air pressure. How did you change the air when you blew over the paper? Did you change the push of air above the paper or below?

How does this relate to airplane flight?
The higher air pressure below the paper pushes the paper up, just as higher air pressure under an airplane wing pushes the wing up.


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FOOL THE SPOOL

MATERIALS

- ★ a straight pin
- ★ a 3x5 card
- ★ a large spool

Hint: make sure the spool has only one main hole. If there are any other holes—even pin holes—tape them shut.

Stick a pin through the middle of a card from below. Place the spool over the pin. Hold the card and pin in place with one hand. Hold the spool with the other hand. Bring the spool up to your mouth and blow through the spool. As you blow, let go of the pin and card. What happens? What did you think would happen? How do you explain it?

Remember air is pushy stuff. It never pulls or sucks; it pushes. This push is called air pressure. When you blew the air, it had to move quickly between or around objects. As it sped up, it lost pressure. It stopped pushing as hard. As air squeezed between the spool and card, it moved faster. Its pressure dropped. But the air pressure below the card stayed the same. It pushed as hard as ever and held the card in place, even though you were blowing hard.

How does this relate to flight?

The difference in air pressure that held the card in place is the same effect that helps an airplane wing create lift. On a wing, the total force acting on both the upper and lower wing surfaces is what creates lift. The pressure on a moving wing varies from point to point, but the total force on the upper surface is less than the total force on the lower surface.

How does Bernoulli's principle help explain why the balloons, the paper, and the spool and paper all behaved the way they did?

HOW WINGS WORK

What is an airfoil?

Airfoil is the name for the special shape of airplane wings. Wings come in different shapes and sizes, but a wing's airfoil shape—like a teardrop on its side—is always designed to create lift.

An airplane wing is designed so air flows faster over the wing than it does beneath the wing.

Copy and distribute figure 2 to your students. Have them draw arrows to show how air moves past an airplane wing. Think about Bernoulli's principle. What does it tell you about how air will move over the airfoil shape?

FIGURE 2

EXTENSION IDEA

Have your students locate (or draw) an image of an "Indy race car" that has airfoils on the front and rear. Ask the students to place arrows by the airfoils to indicate the way air flows.

How does this increase traction?

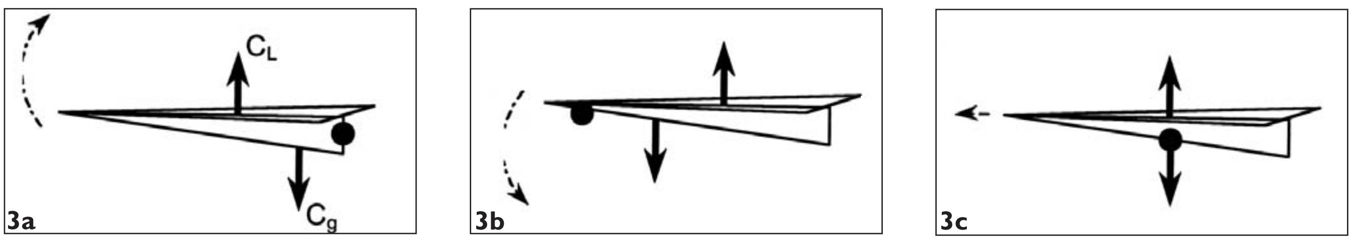
STABILITY AND CONTROL

Most airplanes have a long, tube-shaped body with wings sticking out on either side. It is important to balance the lift the wings provide with the distribution of the airplane's weight (the force of gravity). Otherwise the airplane will be unstable! Use the blackline master to make your own paper airplanes. Students can experiment with their airplanes to learn firsthand about stability and control.

To fold your airplane:

1. Make folds in order from 1 to 4
2. Fold away on the solid black lines.
3. Fold in on the dotted lines.
4. Bend up the triangular wings so they are horizontal.
5. Gently bend up the rear corners of the wings.
6. Try a test flight. What happens?
7. Put three papers clips on the back of your airplane as shown.
8. Fly your airplane again. What happens?
9. Move the paper clips to the front of your airplane as shown. Try another test flight. What's the difference?

FIGURE 3



How do you think you can stabilize your airplane?

Stability refers to an airplane's tendency to right itself after its balance is disturbed. Two important factors affecting stability are:

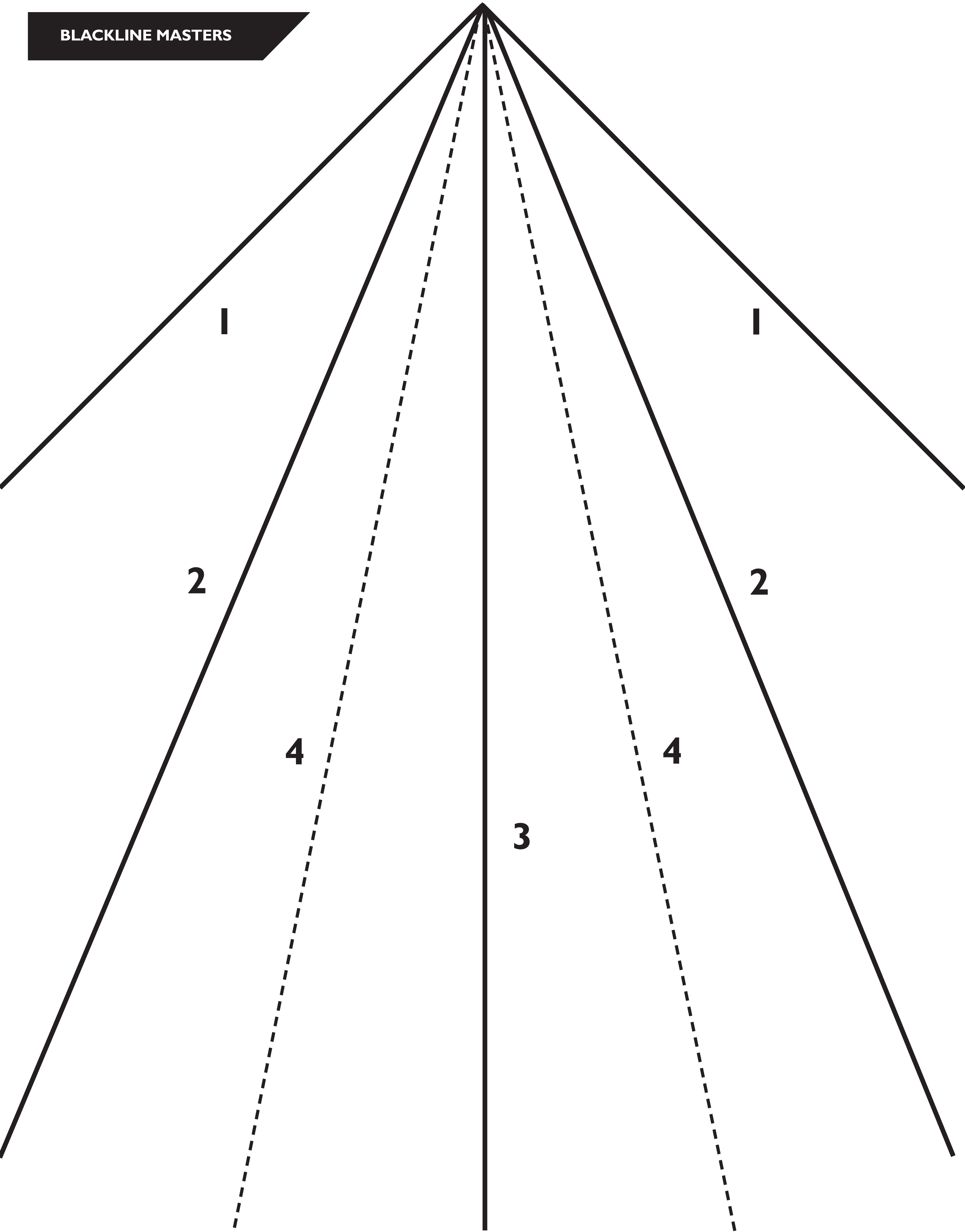
★ **Center of lift** (C_L)—the point where all the lifting force is centered.

★ **Center of gravity** (C_g)—the "balancing point" of an airplane. There is just as much mass ahead of this point as there is behind it. If you put your finger here, the paper airplane will balance.

What happened when you put all the paper clips on the back of the airplane? Where was the center of gravity located? What was the result? **(figure 3a)**

What happened when you moved the paper clips to the front? Where was the center of gravity? **(figure 3b)**

To stabilize your airplane, where should you put the paper clips? If the center of gravity and the center of lift are at the same point, they balance each other. **(figure 3c)** Suppose some wind lifts the front of the plane? Then the center of lift shifts rearward, behind the center of gravity, which brings the front of the airplane back down! (See gallery area G.)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VISITING THE NATIONAL AIR AND SPACE MUSEUM

On the National Mall in Washington, D.C., the Smithsonian's National Air and Space Museum maintains the largest collection of historic aircraft and spacecraft in the world. The Museum is open from 10:00 a.m. to 5:30 p.m. daily.

Guided tours and science demonstrations are available free of charge for school groups. Advanced registration is required.

For more information on school programs or to schedule a tour, request a *School Programs Guide* from the Museum's Reservation Office at (202) 357-1400, or visit the Museum's web site at ***http://www.nasm.edu/.*** Navigate to Educational Services and select "Planning a Visit."

On the Web

For more information about *How Things Fly,* visit the Museum's web site at ***http://www.nasm.edu/galleries/gal109.***

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