



**Educational
Services**



Looking at Airplanes

TO EXPLORE THE SCIENCE OF FLIGHT



Smithsonian
National Air and Space Museum

Exhibits and Public Services Department
Public Services Division

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Looking at Airplanes

*Welcome to the
National Air and Space Museum*

HOW TO USE THIS GUIDE

This guide is for visitors to use before or after they have visited the *How Things Fly* gallery. You will compare wings, engines, streamlining, and controls on seven airplanes in the Museum. Through your observations you will discover how airplanes fly and how the science of flight makes these and other aircraft look the way they do.

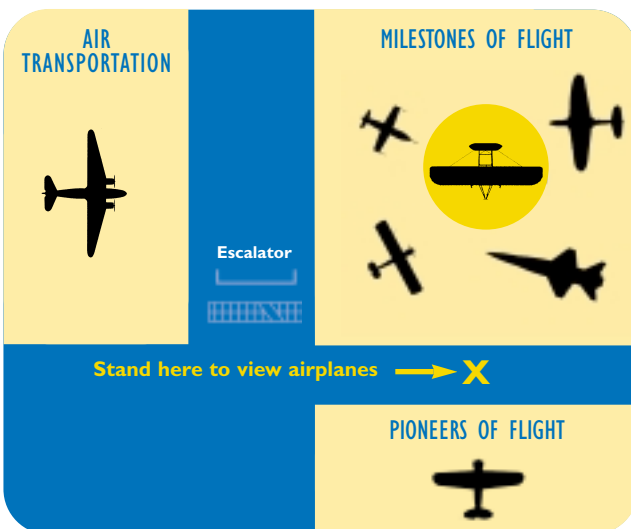
The map below will appear throughout the booklet. Each of the seven airplanes will be highlighted as you move from one to the next. The orange timeline along the top right of each page places each of the airplanes in history.

GETTING STARTED

Take one of the escalators from the main first-floor lobby to the **second floor balcony**, overlooking the *Milestones of Flight* gallery.

To begin, position yourself in the middle of the balcony so you are facing the Wright Flyer (highlighted below).

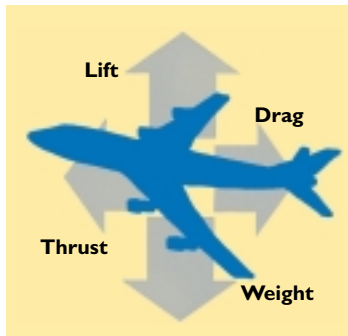
All seven aircraft explored in this booklet can be seen from this general area.



SAMPLE LOCATOR MAP

that orients visitors to the galleries containing the seven airplanes.

Quick Reference to How Airplanes Fly

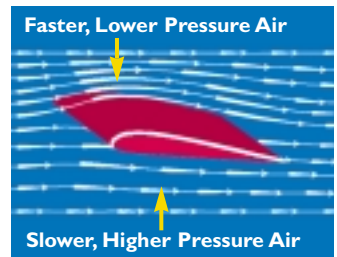


FORCES OF FLIGHT

Four forces affect things that fly: **weight**, **lift**, **thrust**, and **drag**. When an airplane flies, the wing is designed to provide enough **lift** for the airplane's **weight**. The engine provides enough thrust to overcome **drag** and move the airplane forward. The forces are interconnected, so a change in one affects the others. For example, increasing the weight increases the amount of lift needed. A larger wing provides more lift, but that in turn increases how much drag must be overcome, and that increases the thrust required to maintain speed.

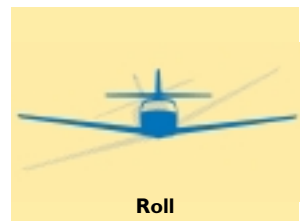
HOW WINGS LIFT

Air flowing over the top surface of a curved wing flows faster and has lower pressure than the less obstructed air flowing beneath the wing. The pressure differences between the top and bottom surfaces push the wing up, lifting the airplane. Increasing the curvature of a wing or expanding the surface area increases its lifting ability.

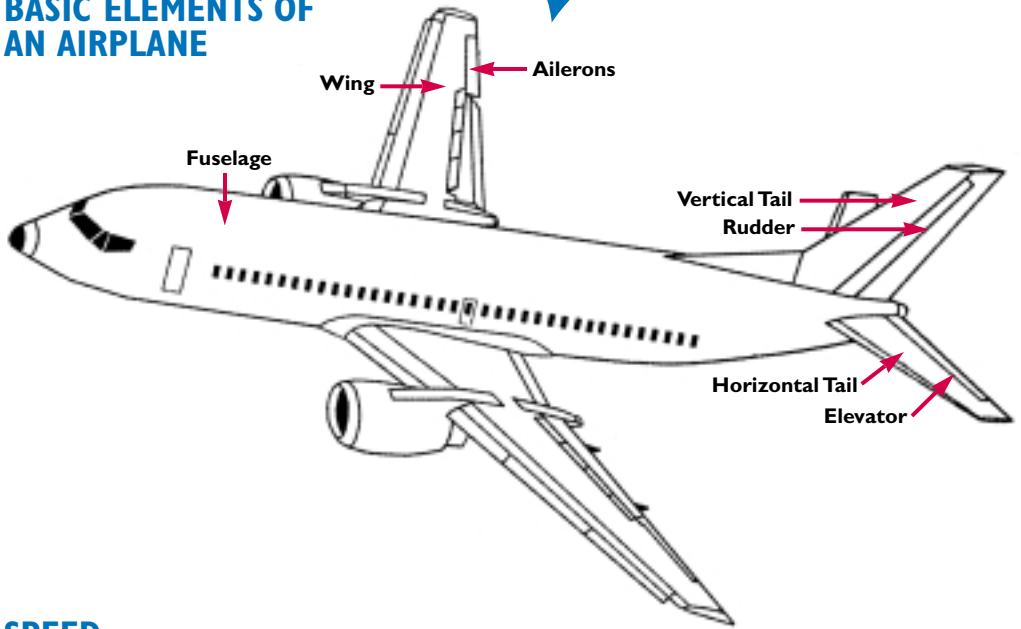


CONTROLLING AN AIRPLANE IN THREE AXES

Elevators are the movable surface on an airplane that control the airplane's nose in an up and down or **pitch** axis. **Rudders** are used to control the airplane's nose in a left to right or **yaw** axis. **Ailerons** (pronounced ay-Lër-ahns) are used to control the airplane's movement in a **roll** axis—moving one wing higher than the other.



BASIC ELEMENTS OF AN AIRPLANE

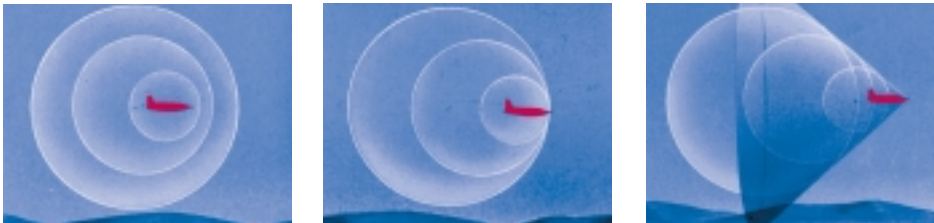


SPEED

Increasing the speed of an airplane increases the lift its wing provides. At slow speeds, airplane wings need more surface area and a thicker curved cross section to provide enough lift. At faster speeds, airplane wings need less surface area, so they can be smaller and still provide enough lift.

Increasing an airplane's speed also increases drag or resistance to oncoming air. The overall performance of faster airplanes is improved with streamlining, which helps reduce drag.

THE SOUND BARRIER



As an airplane moves through the air, it makes pressure waves that radiate from it at the speed of sound, about 1,120 kilometers (700 miles) per hour. When an airplane travels at the speed of sound (Mach 1), it catches up with its own pressure waves, which bunch together into a shock wave. When an airplane travels faster than Mach 1, it flies ahead of its pressure waves, creating an oblique shock wave at its nose.

Let's Explore the Basic Principles of Flight

COMPARE the large surface area of the Flyer's two wings with other airplanes in the gallery.

Why such big wings? (After all, they don't have as much weight to lift as the other airplanes.) The Flyer is lighter, but it is also much slower. A slow airplane needs more surface area on its wings to provide enough lift. That's why the bicyclist-powered *Gossamer Condor* above you has such long wings.

FIND the engine, drive chains, and propellers that move the Flyer forward.

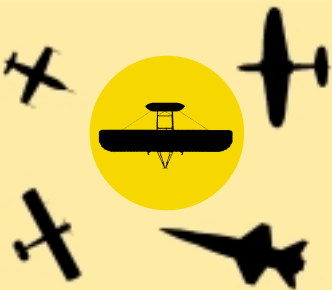
The 12-horsepower engine is just to the right of the pilot. The engine drives the two propellers in the rear of the airplane with chains and sprockets. The propellers generate thrust, which pushes the airplane forward. The Flyer's airspeed was around 48 kilometers (30 miles) per hour.

FIND the movable surfaces that control the airplane.

- ✦ The elevator, located in front of the airplane, controls the up-and-down movement, called **pitch**.
- ✦ The **rudder**, located in the rear, controls the side-to-side movement, called **yaw**.
- ✦ The **wing tips twist** in opposite directions, causing one wing to dip lower than the other and the airplane to rotate, a movement called **roll**.

The Wright brothers realized the need to control an airplane in three dimensions or "axes," and they were the first to figure out how to do it.

MILESTONES OF FLIGHT

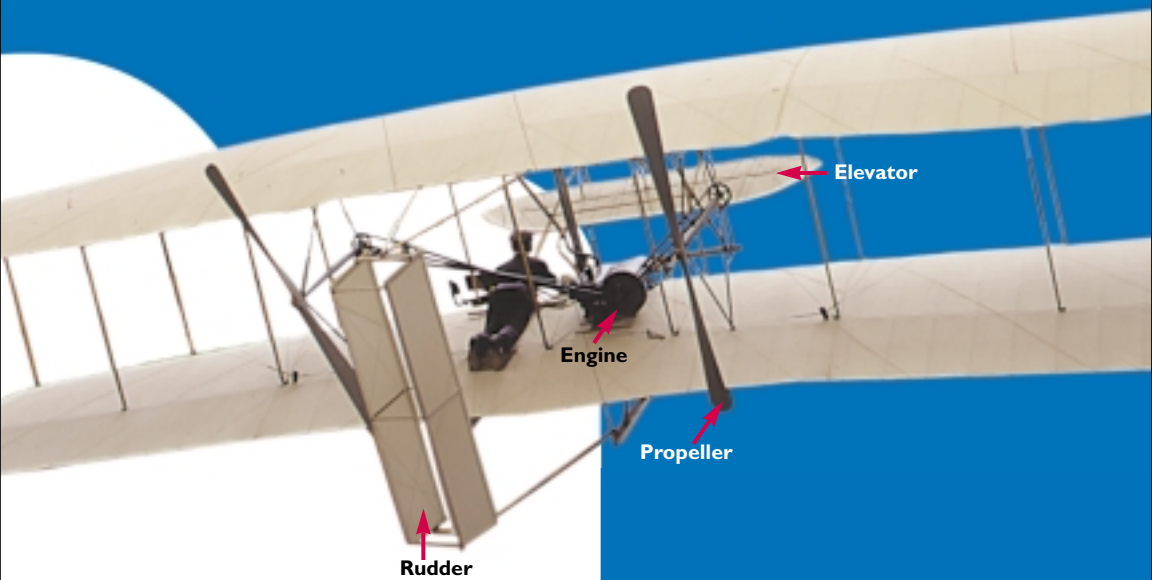


You can view this airplane from this location on the second floor.

X ← Stand here to view airplane

PIONEERS OF FLIGHT





THINK further.

- ★ In how many dimensions or axes can a car be controlled? (one—**yaw**)
- ★ How about a bicycle? (two—**yaw** and **roll**)

TRY this: Show how a pilot turns an airplane.

Stretch out your arms and “fly” in a circle. Did you fly with one “wing” lower than the other and your nose pointed up? That is how an airplane turns. Pilots *bank* it, yawing toward one side, rolling one wing lower than the other, and then raising the pitch of the nose so the airplane stays level. Moving into a turn, the pilot controls an airplane in three axes at once.

FIND the controls the pilot uses.

The pilot activated the elevator by moving the stick located just to his left. He operated the rudder and twisted the wings simultaneously by using his hips to move the cradle that he was lying in from side to side.

1903 Wright Flyer



The 1903 Wright Flyer made its inaugural flight on December 17, 1903, near Kitty

Hawk, North Carolina. The flight was a turning point in human history, the moment when a pilot-controlled, powered airplane took to the sky for the first time.

The 1903 flight was not simply about being the first. With this airplane Orville and Wilbur Wright demonstrated the basic solutions for powered, controlled flight. Today, a Boeing 747 flies by the same principles as the 1903 Flyer: Wings lift the airplane’s weight, engines thrust the airplane forward, and movable surfaces control the airplane in three-dimensional space.

A Wing That Lifts More Than 2 Tons

NOTICE the primary fuel tanks—the large gray area of the fuselage in front of the door.

Charles Lindbergh and the Ryan engineers had a dilemma: where to store the 1,710 liters (450 gallons) of fuel needed for the ocean crossing. Even though it meant the loss of his front window, Lindbergh decided it was safest to position the engine and fuel next to each other and for him to sit behind them. To look forward, Lindbergh turned the airplane and looked out



the side window or used the periscope. (It is visible near the window on the other side.)

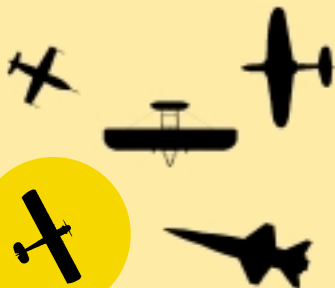
LOOK at the *Spirit's* wing tip.

That thickly curved top and flat underside provide lift at the *Spirit's* relatively slow speed of 137 to 171 kilometers (86 to 107 miles) per hour. This speed and wing shape were typical of the time period. The wing is often called a “high-lift wing.” With its large fuel load, however, the *Spirit* needed extra lift, so the wing was made 3 meters (10 feet) longer than other Ryan models of the time.

READ about how the *Spirit* lost weight.

Even with the extra lifting ability of the *Spirit's* wing, Lindbergh still had to justify every ounce of weight. One by one he eliminated pieces of equipment and supplies: his parachute, radio, a 1.35-kilogram

MILESTONES OF FLIGHT



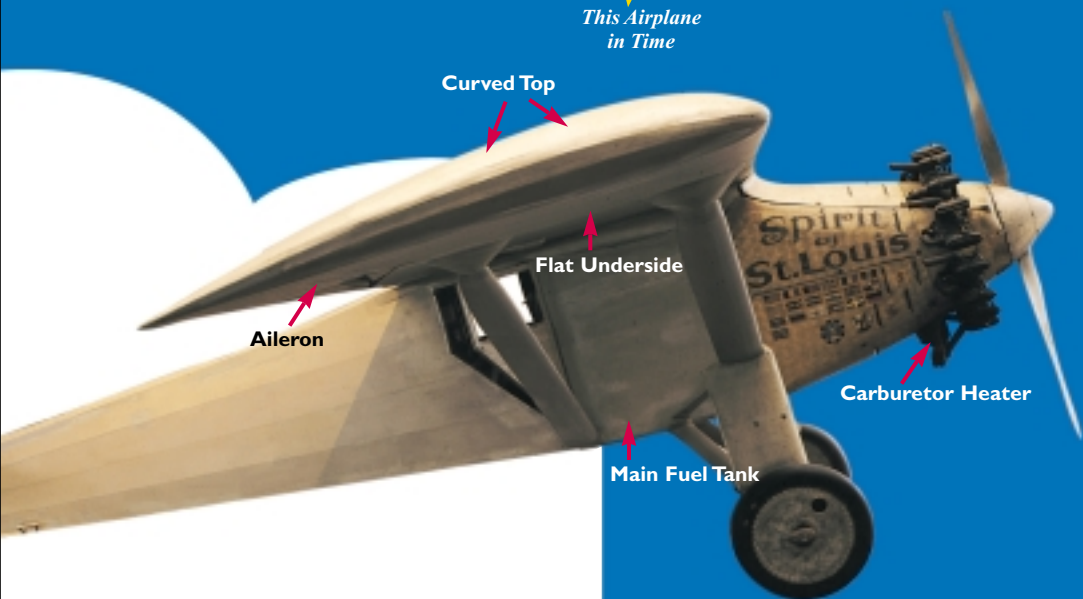
You can view this airplane from this location on the second floor.

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PIONEERS OF FLIGHT



This Airplane
in Time



(3-pound) carburetor heater, all food except five ham sandwiches and all but a small ration of water. He did change his mind on one item (and it wasn't the sandwiches!). He nearly had engine failure over the Rocky Mountains during an earlier transcontinental flight when his carburetor iced up. Begrudgingly, he had the carburetor heater reinstalled for the Paris flight. You can see it just behind the engine.

TEST YOURSELF!

FIND the *Spirit's* control surfaces and compare them with the *Flyer's*.

The **elevator** is part of the horizontal tail, and the **rudder** is part of the vertical tail. The “wing twisting” has been replaced by **ailerons** located on both sides of the wing's trailing edge.

Spirit of St. Louis



Charles Lindbergh left New York in the *Spirit of St. Louis* on May 20, 1927. He arrived in

Paris 33 hours, 30 minutes later. He was the first person to fly nonstop from New York to Paris.

When Lindbergh first contacted Ryan Airlines in early 1927 to purchase this airplane, he knew customized design features would be necessary for a 6,400-kilometer (4,000-mile) nonstop flight. He worked closely with the engineers at each step. They calculated that 1,710 liters (450 gallons) of fuel were needed, including emergency fuel for 800 extra kilometers (500 miles). Extra fuel tanks were added, and a wing was designed to provide enough lift for the additional 1,215 kilograms (2,700 pounds) of fuel.

Streamlining Pays Off

NOTICE the Vega's smooth, rounded fuselage.

The exterior skin is molded plywood glued to an internal frame. This construction strengthened the fuselage, because both the skin and the internal frame provided structural support. Compare the Vega's fuselage with the boxy shape of the *Spirit's*. Which looks more streamlined?

LOOK for other streamlining features on the Vega.

The Vega has a "cowling" or cover on the engine and "wheel pants" on the landing gear. These alone

added 32 kilometers (20 miles) per hour to the airplane's maximum speed. The Vega's wing—braced inside and stronger than the *Spirit's*—does not have external supports or "struts." And the Vega's rounded fuselage reduces wind resistance (drag) too.

THINK further: Why was streamlining important for the Vega?

An important clue lies in the Vega's 450-horsepower engine. It was twice as powerful as the *Spirit's*, yet its maximum speed is only 96 kilometers (60 miles) per hour more than the *Spirit's*. Additional speed means an airplane can lift more weight, but extra speed also increases wind resistance, or drag. Increased drag slows the airplane down and uses up fuel. Think of athletes who wear streamlined clothing to reduce drag.

READ about a man ahead of his time.

Jack Northrop always had his sights set on the future. As he developed designs to solve problems for a wood-framed Vega, he was exploring techniques for building aluminum airplanes. Perhaps most

MILESTONES OF FLIGHT



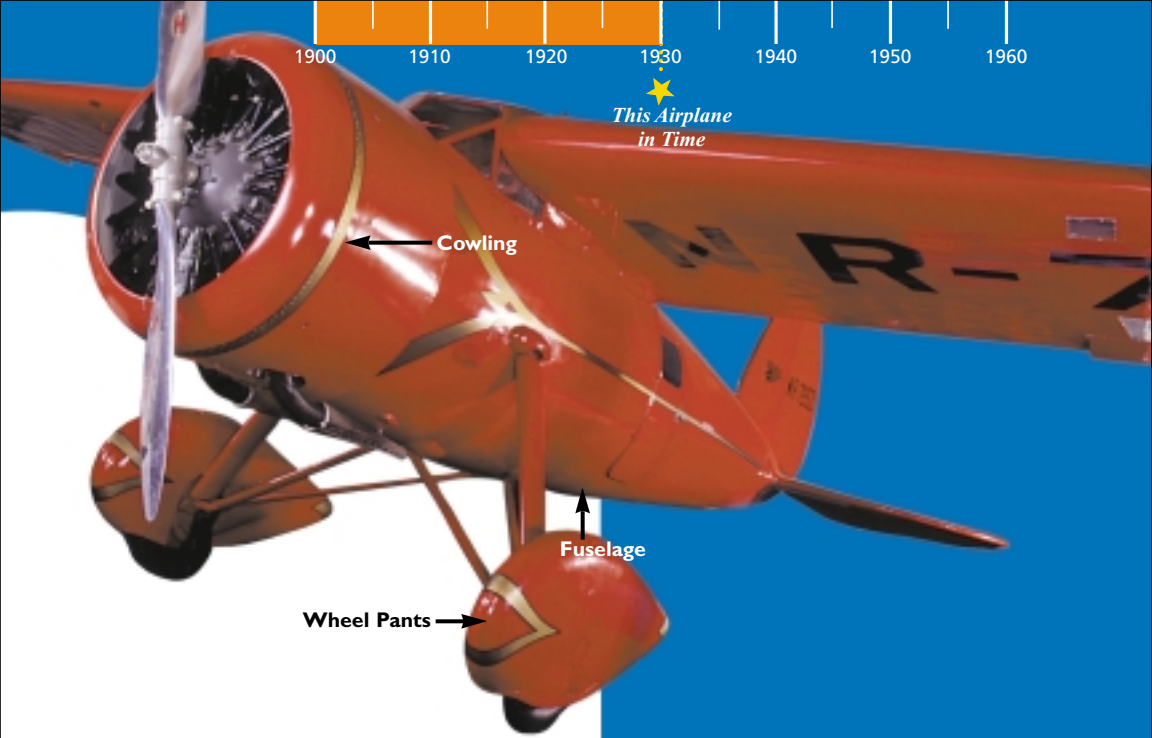
You can view this airplane from this location on the second floor.

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PIONEERS OF FLIGHT



*This Airplane
in Time*



revolutionary was his design in the late 1920s for a “flying wing.” Northrop presented his ideas to the U.S. Army Air Corps, but the airplane wasn’t developed because it had a seemingly unsolvable problem with pitch control. With



the advent of computer-controlled flight, the Air Force again became interested in his plans. Before he died in 1987, Northrop was invited to the unveiling of the B-2 stealth bomber—a “flying wing” based upon his designs. Pictured above is the Northrop NM-1 that was developed in 1940 and is in the Museum’s collection.

Lockheed Vega



Amelia Earhart owned this Vega between 1930 and 1933. She flew it solo across

the United States and then across the Atlantic. It is one of 130 that were built, establishing the Vega as one of the first commercial successes in aviation.

During the late 1920s and early ‘30s, Vegas had a reputation for being reliable and efficient. Adventurers used them to set speed and distance records and to explore the globe. Many transportation companies used them because the airplane could carry up to four passengers as well as heavy bulky cargo. Much of the Vega’s success is due to designer Jack Northrop. He devised construction techniques that strengthened the fuselage for carrying more weight and opened up its interior for better use of the space. He also streamlined the Vega, which contributed to its overall performance.

Why Does It Look Modern?

IDENTIFY the features that make this airplane look like modern passenger airplanes.

It has a large fuselage with windows, large wings, and large twin engines. The shape of the fuselage and other surfaces are streamlined. And it is made of aluminum!

THINK further: What's so great about aluminum?

It is stronger and lighter than wood. An aluminum airplane (unlike the mainly wood and fabric construction of the Flyer and the



Spirit and the wood construction of the Vega) could have a larger fuselage and larger wings and therefore could carry more weight.

NOTICE the rivets on the fuselage and the wings.

The aluminum skin was attached with rivets to an internal aluminum frame. Just like the Vega, the external skin and the internal frame both provide support and add to the airplane's strength.

TEST YOURSELF !

THINK about why the DC-3 looks the way it does?

- ✦ Why are the wings so large? They provide lift for the heavy cargo, passengers and fuel the DC-3 typically carried on long-distance flights.
- ✦ Why are all the surfaces rounded? The 1,200-horsepower engines provided a cruising speed from 248 to 304 kilometers (155 to 190 miles) per hour, so drag reduction was important. The DC-3 has a rounded fuselage, a smooth, curved area where the wing is attached to the

AIR TRANSPORTATION



Escalator



MILESTONES OF FLIGHT



X ← Stand here to view airplane

You can view this airplane from this location on the second floor.

PIONEERS OF FLIGHT



This Airplane
in Time



fuselage, cowlings surrounding the engines, and retractable landing gear.

- ★ Find the control surfaces used on the DC-3. The rudder, elevator, and ailerons are located similarly to the *Spirit* and the *Vega*. The ailerons extend across a large portion of the wing. This gives extra control in the roll axis.

IMAGINE taking a flight on the first DC-3.

It is June 1936. This first model is outfitted as a luxury sleeper. There are seven upper and seven lower berths. You board in New York at 6 p.m. with a friend, comfortable clothes, a toothbrush, and your favorite pillow. After dinner, you settle into your berth and close your eyes. Before you know it (unless you were awakened by the three or four refueling stops), it is 10 a.m., and you are landing in Los Angeles. How far can you travel today in 19 hours on a large jetliner?

Douglas DC-3



The DC-3 became a legend in its own time. The airplane's strength and reliable twin engines made it an industry favorite. By 1938 the DC-3 handled most of the nation's airline traffic and assured the commercial success of passenger service.

The DC-3, or "Gooney Bird" as it was affectionately nicknamed during World War II, typically carried up to 21 passengers. It was known for providing a smooth, quiet ride over long distances at an impressive speed of 288 kilometers (180 miles) per hour. Thousands of DC-3s were built, and the resulting growth in passenger travel created profits for the airlines for the first time. There are still 400 DC-3s in service today.

Jet Power!

FIND the engines on the XP-59A.

There aren't any propellers. A jet engine works on a different principle than a piston engine. A piston engine and propellers generate thrust by creating differences in air pressure around the propellers. A jet engine's burning fuel sends gases out the back of the engine with such force that the airplane is thrust forward. The same principle explains the movement of a balloon if it is filled with air and then let go. Try it when you get home!

SEE how a typical jet engine works.



Air is drawn into the front of the engine, compressed by spinning blades, and forced into a combustion chamber. In the chamber, the air mixes with fuel and ignites in a continuous burn. The gases blast out of the back of the engine with tremendous force. The equal and opposite reaction thrusts the airplane forward.

TEST YOURSELF!

COMPARE the wings of the *Spirit*, *Vega*, and *DC-3* with those of the *XP-59A*. Why does the *XP-59A* have a thinner wing?

A main benefit of the jet engine is increased speed. The *XP-59A*'s 560 kilometers (350 miles) per hour increased the lifting ability of the wing, so less wing area was

MILESTONES OF FLIGHT



You can view this airplane from this location on the second floor.

X ← Stand here to view airplane

PIONEERS OF FLIGHT





← Air Intake

needed. The increased speed also increased drag. A thinner wing helps reduce drag.

LEARN more.

Try to find the combustion chambers on the piston, jet, and rocket engines in the *How Things Fly* gallery.



The XP-59A was constructed in great secrecy. The United States was unaware that Germany had jet airplanes ready for combat, so elaborate precautions were taken to avoid spying. While the airplane was being tested in Muroc Dry Lake, California, officials disguised the XP-59A's jet technology by attaching a fake propeller to its nose.

Bell XP-59A Airacomet



The XP-59A is the direct ancestor of American jet-propelled airplanes. It was commissioned in 1941 by the Chief of the Army Air Forces. The airplane never entered combat, but it provided training for Army Air Forces personnel and valuable data for the development of higher-performance jet airplanes, including contemporary jetliners, which can carry 400 passengers at 800 kilometers (500 miles) per hour.

The “X” in its name means it is an experimental airplane. When the Army Air Forces ordered its development, there was hope that jet technology would evolve fast enough to support U.S. efforts in World War II. That did not happen. Even so, the XP-59A reveals basic features of a jet airplane.

Speed Faster Than Sound



NOTICE the sleek fuselage, skinny nose, and short, thin wings.

At the speed of sound, a second kind of drag—caused by shock waves—affects how the airplane must be designed. These are three major features on the Bell X-1 that help diffuse shock-wave drag.

FIND the engine: Do you see openings for drawing in air like a jet engine?

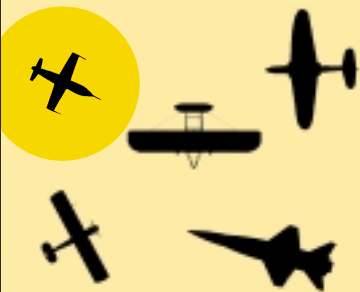
There are no openings for air. The Bell X-1 is powered by a rocket engine. Like a jet engine, a rocket engine burns a mixture of fuel and

oxygen. Unlike a jet, a rocket carries its own oxygen, usually in liquid form. The exhaust gases that rush out the back of the rocket exert pressure on the internal surfaces of the rocket engine, which pushes the rocket forward. It is easy to tell the difference between a jet and a rocket engine: a jet engine has an opening for air intake but a rocket engine does not.

SEPARATE the rockets from the jets.

From the middle of the second floor balcony, identify two other rocket-propelled airplanes and two jet airplanes. The rocket-driven airplanes, in addition to the Bell X-1, are the black North American X-15, hanging in the *Milestones of Flight* gallery, and the white Douglas D-558-2 Skyrocket, to the right of the X-15 and hanging above the escalator. The jet airplanes you can see are the XP-59A, which we've already discussed, and the Lockheed F-104A Starfighter, which is hanging to your left by the Planetarium.

MILESTONES OF FLIGHT



You can view this airplane from this location on the second floor.

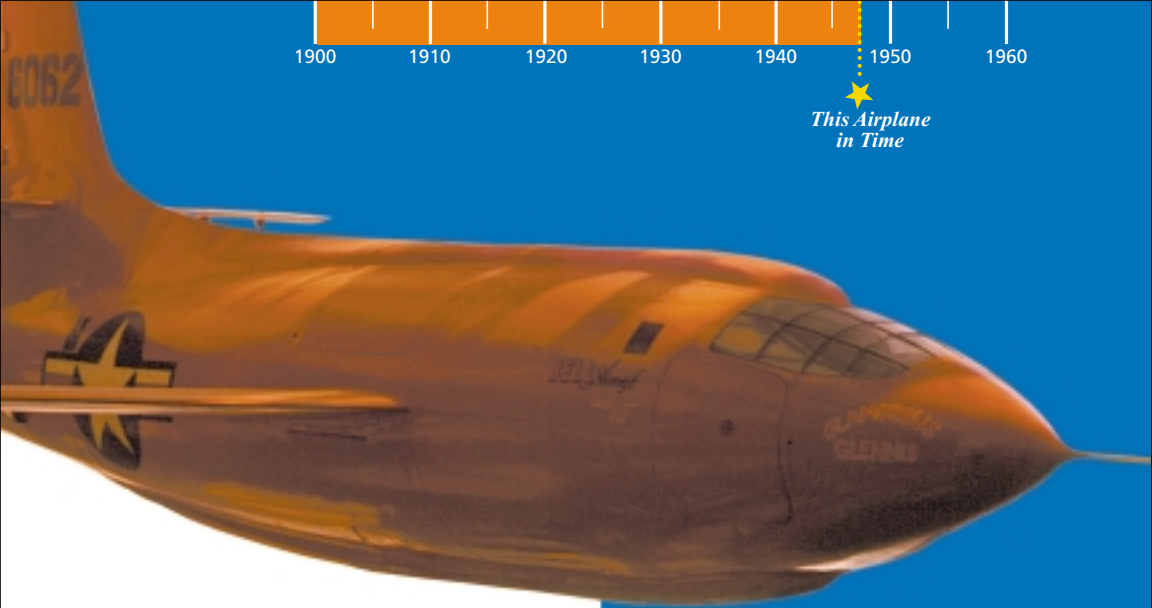
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PIONEERS OF FLIGHT



READ what the pilot said.

You can find the control surfaces for all three axes on the Bell X-1. But during the time Chuck Yeager was its test pilot, the engineers



were still uncertain about controlling the airplane at high speeds. They weren't sure what would happen to an airplane that attempted to go through shock waves. Some believed that

the whole airplane would vibrate and break apart from the pressure.

Others thought there was no "sound barrier." As Yeager approached the speed of sound, the airplane began to buffet, but once Yeager passed Mach 1, the airplane smoothed out. He remarked later, "Grandma could be sitting up there sipping lemonade."

TEST YOURSELF!

THINK about the lift wings like these provide at slow speeds.

Not enough! The Bell X-1 landed at high speeds on a 4.8-kilometer (3-mile) runway. (It could take off under its own power, but was air launched to save fuel.)

Bell X-1



The Bell X-1 was modeled after a .50 caliber bullet. Engineers used that shape because

bullets were known to maintain stability at supersonic speeds. The success of the X-1 proved that airplanes could be designed for faster-than-sound flight. It also dispelled the notion of an actual physical barrier at the speed of sound. Streamlined design and a rocket engine were critical factors in reaching Mach 1.

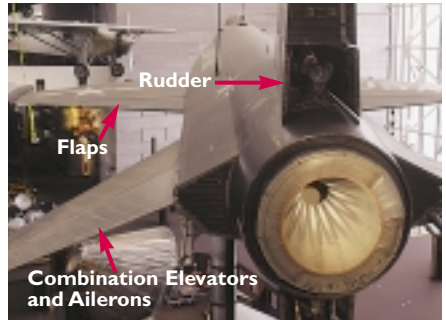
On October 14, 1947, Capt. Charles "Chuck" Yeager flew the Bell X-1 at an altitude of 13,106 meters (43,000 ft) at a speed of more than 1,120 kilometers (700 miles) per hour, faster than the speed of sound (Mach 1).

Rocket Thrusters

Dual Controls— for Air and Space

FIND the controls used in Earth's atmosphere.

The movable surfaces on the wings that look like ailerons are actually **flaps**, which provide additional lift as the airplane lands. What look to be elevators on the rear horizontal tail function as both **elevators** and **ailerons**. They can move up and down together to control pitch, or they can move in opposing directions to control the roll. The **rudder** on the vertical tail controls yaw.



THINK further: Why wouldn't these controls work in near-space?

These controls work by changing the pressure of the air that flows over the control surfaces of the airplane. There is no air above the Earth's atmosphere, and therefore no air pressure to change.

FIND the controls used in near-space.

Find the two holes on the side of the airplane's nose, the two on top, and the two on the wing. When you return to the first floor and look up at the X-15, you'll see another six—two under the nose and two each on the wing. Rocket thrusters control the airplane while it is high in the Earth's atmosphere. Gases blast from the holes with such force that they push the airplane in the opposite direction. (This is the same principle by which jet and rocket engines work).

MILESTONES OF FLIGHT



You can view this airplane from this location on the second floor.

X ← Stand here to view airplane

PIONEERS OF FLIGHT





MATCH the rocket thrusters with the three axes of control.

Twelve rocket thrusters control the airplane in three axes. Two on each side of the nose control yaw, two each on the top and bottom of the nose control pitch, and one each on the top and bottom of each wing control roll. Just over 50 years after the Wright brothers realized the need for control in three axes, their insight was applied to travel in space!

READ what the pilot said.

When X-15 test pilot Scott Crossfield was asked how he knew when it was time to use one set of controls rather than the other, he replied, “When one didn’t work, I simply used the other.”

TEST YOURSELF!

COMPARE the X-15 with the Bell X-1. Identify three key features on both airplanes that reduce shock-wave drag.

They have skinny noses; sleek, narrow fuselages; and short, thin wings.

North American X-15



The X-15 is a rocket-powered research airplane. It was built to fly in both air and space and to gather information for future space exploration. In 1959 the X-15 became the first winged aircraft to reach the fringes of Earth’s atmosphere, flying to an altitude over 107 kilometers (67 miles), and the first to attain speeds of Mach 4, 5, and 6—up to 7,200 kilometers (4,500 miles) per hour. That is fast enough to fly across the United States from coast to coast in 40 minutes!

Three X-15s flew 199 research missions. During the formative days of Project Mercury, America’s first attempt to put a person in orbit, NASA engineers gave serious consideration to building a larger version of the X-15 for the Mercury missions. But they determined that a blunt-body reentry vehicle, such as *Friendship 7*, exhibited in the *Milestones of Flight* gallery, better deflected the heat and buffeting from shock waves.



**Educational
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Flying Further

★ **FLIGHT** by Don Lopez

A richly illustrated and fun-to-read introduction to the history and science of flight. The perfect book for beginning aviation enthusiasts of all ages.

★ **“Bookmarks”** with recommended reading lists for families or preschoolers or budding curators are available in the *How Things Fly* gallery Resource Center. You can also preview recommended books while visiting the Center.

★ **Visit the National Air and Space Museum online at**

<http://www.nasm.si.edu>. To go directly to the *How Things Fly* gallery: <http://www.nasm.si.edu/GALLERIES/GALI09>

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Credits

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Cover photo Cessna 172, courtesy of the Cessna Aircraft Company. You can sit in the pilot's seat of a similar model, a Cessna 150, in the *How Things Fly* gallery.

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