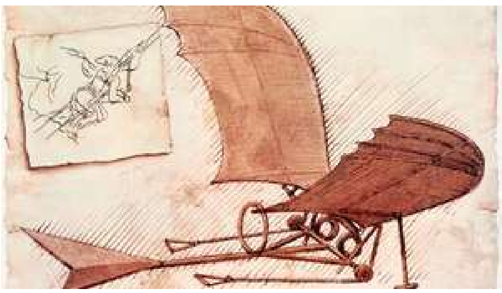
history of flight

history of flight, development of heavier-than-air flying machines. Important landmarks and events along the way to the invention of the airplane include an understanding of the dynamic reaction of lifting surfaces (or wings), building absolutely reliable engines that produced sufficient power to propel an airframe, and solving the problem of flight control in three dimensions. Once the Wright brothers demonstrated that the basic technical problems had been overcome at the start of the 20th century, military and civil aviation developed quickly.



Leonardo da Vinci's flying machine
In about 1490 Leonardo da Vinci drew plans for a flying machine.
SuperStock

Wright flyer, 1905
The Wright brothers' first practical flying machine, with Orville Wright at the controls, passing over Huffman Prairie, near Dayton, Ohio, October 4, 1905.
Library of Congress, Washington, D.C. (digital file no. 00658u)

This article tells the story of the invention of the airplane and the development of civil aviation from piston-engine airplanes to jets. For a history of military aviation, *see* military aircraft; for lighter-than-air flight, *see* airship. *See* airplane for a full treatment of the principles of aircraft flight and operations, aircraft configurations, and aircraft materials and construction. For a comparison of select pioneer aircraft, *see below*.

The invention of the airplane

On the evening of Sept. 18, 1901, Wilbur Wright, a 33-year-old businessman from Dayton, Ohio, addressed a distinguished group of Chicago engineers on the subject of "Some Aeronautical Experiments" that he had conducted with his brother Orville Wright over the previous two years. "The difficulties which obstruct the pathway to success in flying machine construction," he noted, "are of three general classes."

1. Those which relate to the construction of the sustaining wings.
2. Those which relate to the generation and application of the power required to drive the machine through the air.

3. Those relating to the balancing and steering of the machine after it is actually in flight.

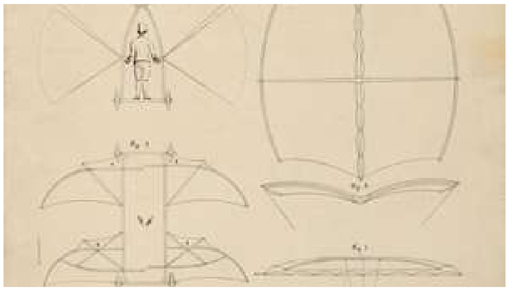
This clear analysis—the clearest possible statement of the problem of heavier-than-air flight—became the basis for the Wright brothers' work over the next half decade. What was known at that time in each of these three critical areas and what additional research was required are considered below.

Construction of the sustaining wings: the problem of lift

The dream of human flight must have begun with observation of birds soaring through the sky. For millennia, however, progress was retarded by attempts to design aircraft that emulated the beating of a bird's wings. The generations of experimenters and dreamers who focused their attention on ornithopters—machines in which flapping wings generated both lift and propulsion—contributed nothing substantial to the final solution of the problems blocking the route to mechanical flight.

Thus, the story of the invention of the airplane begins in the 16th, 17th, and 18th centuries, with the first serious research into aerodynamics—the study of the forces operating on a solid body (for instance, a wing when it is immersed in a stream of air). Leonardo da Vinci and Galileo Galilei in Italy, Christiaan Huygens in the Netherlands, and Isaac Newton in England all contributed to an understanding of the relationship between resistance (drag) and such factors as the surface area of an object exposed to the stream and the density of a fluid. Swiss mathematicians Daniel Bernoulli and Leonhard Euler and British engineer John Smeaton explained the relationship between pressure and velocity and provided information that enabled a later generation of engineers to calculate aerodynamic forces.

George Cayley, an English baronet, bridged the gap between physical theory, engineering research, and the age-old dream of flight. He gathered critical aerodynamic data of value in the design of winged aircraft, using instruments developed in the 18th century for research into ballistics. Cayley was also a pioneer of aircraft design, explaining that a successful flying machine would have separate systems for lift, propulsion, and control. While he did produce designs for ornithopters, he was the first experimenter to focus on fixed-wing aircraft.



George Cayley's glider, 1853
English aeronautic pioneer George Cayley established the modern notion of a fixed-wing aircraft in 1799, and he designed a glider (shown in the drawing) that was safely flown by his reluctant servant in 1853 in the first recorded successful manned flight.
Library of Congress, Washington, D.C. (neg. no. LC-DIG-ppmsca-02521)

Cayley found the secrets of lift in the shape of a bird's wing, surmising that an arched, or cambered, wing would produce greater lift than a flat wing because of lower pressure on top of the curved surface (*see* Bernoulli's theorem). His observations of birds in flight led him to recognize the superiority of relatively long and narrow (in modern terminology, high-aspect-ratio) wings for soaring. As a practical matter, however, he designed biplane and multiplane wings (the first of their kind) as a means of providing maximum surface area in a strong and easily braced structure.

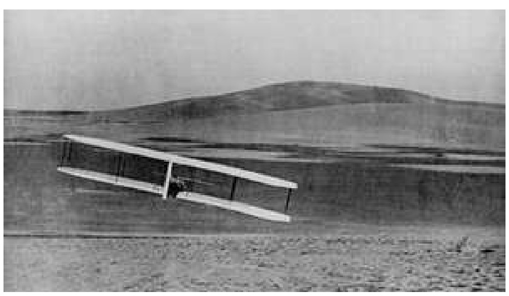
Addressing the first meeting of the Aeronautical Society of Great Britain in 1866, Francis H. Wenham provided a concise and forceful restatement of Cayley's most important ideas regarding wings. Five years later, in cooperation with John Browning, Wenham built the first wind tunnel, a device that would have a profound effect on the study of wings and the development of improved airfoils. Horatio Phillips, a fellow member of the Aeronautical Society, developed an even more effective wind tunnel design, and he patented (1884) a two-surface, cambered-airfoil design that provided the foundation for most subsequent work in the field.

Beginning in the 1870s, Otto Lilienthal, a German mechanical engineer, undertook the most important studies of wing design since the time of Cayley. His detailed measurements of the forces operating on a cambered wing at various angles of attack provided precise bits of data employed by later experimenters—including, in the United States, the engineer Octave Chanute and the Wright brothers—to calculate the performance of their own wings. Having published the results of his research, Lilienthal designed, built, and flew a series of monoplane and biplane gliders, completing as many as 2,000 flights between 1890 and the time of his fatal glider crash in August 1896.

Lilienthal glider
German aviation pioneer Otto Lilienthal piloting one of his gliders, c. 1895.
Library of Congress, Washington, D.C. (digital id. ppmsca 02545)

At the outset of their own aeronautical experiments, the Wright brothers carefully studied the work of their predecessors and decided that there was little need for them to focus on wing design. “Men already know how to construct wings…,” Wilbur explained in 1901, “which when driven through the air at sufficient speed will not only sustain themselves but also that of the engine, and of the engineer as well.”

Two years of experimenting with gliders, however, demonstrated the need to pay considerably more attention to wing design. Beginning in November 1901, the Wright brothers used a wind tunnel of their own design to gather information that enabled them to calculate the values of lift and drag for an entire series of airfoils at various angles of attack and to measure the performance of wings with differing aspect ratios, tip shapes, and other design features. That information culminated in the Wright glider of 1902, a breakthrough machine whose wing design enabled the Wright brothers to take the final steps to the invention of the airplane.



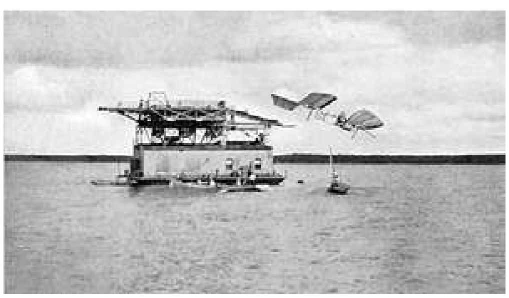
Wright glider
Wilbur Wright executes a banking turn to the right in the Wright brothers' first fully controllable glider, at the Kill Devil Hills, North Carolina, October 24, 1902.
Wright State University, Archives & Special Collections

The generation and application of power: the problem of propulsion

At the beginning of the 19th century, sustained powered heavier-than-air flight remained an impossibility because of the lack of suitable power plants. The level of technology that would permit even limited powered flight lay over a century in the future. Clockwork mechanisms and other sorts of spring-powered systems were clearly unsuitable for human flight. While electricity powered several airships during the last quarter of the century, the poor power-to-weight ratio of such systems made it difficult to imagine an electrically propelled airplane.

The aeronautical potential of propulsion systems ranging from hot-air engines to gunpowder to compressed air and even to carbonic-acid power plants was discussed during the course of the century. The Australian Lawrence Hargrave, in particular, experimented with compressed-gas propulsion systems. Nevertheless, steam and internal-combustion engines quickly emerged as the choice of most serious experimenters. As early as 1829, F.D. Artingstall constructed a full-scale steam-powered ornithoptor, the wings of which were smashed in operation just before the boiler exploded. A lightweight steam engine developed by the English pioneer Frederick Stringfellow in 1868 to power a triplane model aircraft survives in the collection of the Smithsonian Institution, Washington, D.C.

Russian Alexandr Mozhaysky (1884), Englishman Hiram Maxim (1894), and Frenchman Clément Ader (1890; *see* Ader Éole and Ader Avion) each jumped full-scale steam-powered machines off the ground for short distances, although none of these craft was capable of sustained or controlled flight. In the United States, Samuel Pierpont Langley achieved the first sustained flights in 1896 when he launched two of his relatively large steam-powered model aircraft (*see* Langley aerodrome No. 5) on aerial journeys of up to three-quarters of a mile (1.2 km) over the Potomac River.



Langley aerodrome of 1903

The unsuccessful launch of Samuel Pierpont Langley's full-sized manned aerodrome from a houseboat on the Potomac River, Oct. 7, 1903. The pilot, Charles Matthews Manly, is just visible behind the forward pair of wings.

United States Air Force

As the end of the 19th century approached, the internal-combustion engine emerged as an even more promising aeronautical power plant. The process had begun in 1860, when Étienne Lenoir of Belgium built the first internal-combustion engine, fueled with illuminating gas. In Germany, Nikolaus A. Otto took the next step in 1876, producing a four-stroke engine burning liquid fuel. German engineer Gottlieb Daimler pioneered the development of lightweight high-speed gasoline engines, one of which he mounted on a bicycle in 1885. German engineer Karl Benz produced the first true automobile the following year, a sturdy tricycle with seating for the operator and a passenger. In 1888 Daimler persuaded Karl Woelfert, a Lutheran minister who longed to fly, to equip an experimental airship with a single-cylinder gasoline engine that developed all of eight horsepower. The initial test was marginally successful, although the open-flame ignition system presented an obvious danger to a hydrogen-filled airship. In fact, Woelfert perished when an internal-combustion engine finally did set a much larger airship on fire in 1897.

At the beginning of their career in aeronautics, the Wright brothers recognized that automotive enthusiasts were producing ever lighter and more powerful internal-combustion engines. The brothers assumed that if their gliding experiments progressed to the point where they required a power plant, it would not be difficult to buy or build a gasoline engine for their aircraft.

They were essentially correct. Having flown their successful glider of 1902, the Wright brothers were confident that their wings would lift the weight of a powered flying machine and that they could control such a craft in the air. Moreover, three years of experience with gliders, and the information gathered with their wind tunnel, enabled them to calculate the precise amount of power required for sustained flight. Unable to interest an experienced manufacturer in producing an engine meeting their relatively narrow power-for-weight specifications, the brothers designed and built their own power plant.

Charles Taylor, a machinist whom the brothers employed in their bicycle shop, produced a four-cylinder engine with a cast aluminum block that produced roughly 12.5 horsepower at a total weight of some 200 pounds (90 kg), including fuel and coolant. It was by no means the most advanced or efficient aeronautical power plant in the world. Langley, who was also building a full-scale powered flying machine, spent thousands of dollars to produce a five-cylinder radial engine with a total weight equal to that of the Wright engine but developing 52.4 horsepower. Langley produced an engine far superior to that of the Wright brothers—and an airplane, the aerodrome No. 6, that failed to fly when tested in 1903. The Wright brothers, on the other hand, developed an engine that produced exactly the power required to propel their flyer of 1903—the world’s first airplane to demonstrate sustained flight.

The design of the propellers for the 1903 airplane represented a much more difficult task, and a much greater technical achievement, than the development of the engine. The propellers not

first flight by Orville Wright, December 17, 1903

Orville Wright beginning the first successful controlled flight in history, at Kill Devil Hills, North Carolina, December 17, 1903.

Library of Congress, Washington, D.C. (reproduction no. LC-USZ62-6166A)

only had to be efficient but had to produce a calculated amount of thrust when operated at a particular speed by the engine. It is important to recognize, however, that once powered flight had been achieved, the development of more powerful and efficient engines became an essential element in the drive to improve aircraft performance.

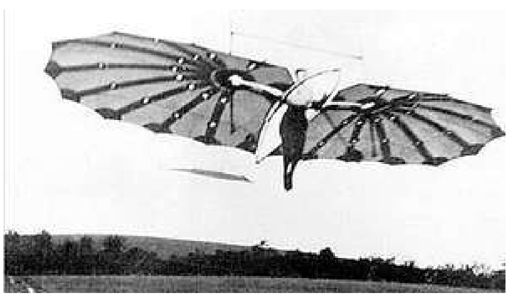
Balancing and steering the machine: the problem of control

Having decided that the design of wings and the development of a power plant were fairly well in hand, the Wright brothers focused on the element of control. Other experimenters had given some thought to the subject. Cayley was the first to use an elevator for control in pitch (directing the nose up and down). Throughout the second half of the 19th century, airships had used rudders for yaw control (directing the nose to the right and left).

It was far more difficult to conceive of a way to control an aircraft in roll (that is, balancing the wingtips or banking the aircraft). Moreover, most experimenters were convinced that the operator of a flying machine would find it difficult or impossible to exercise full control over a machine that was free to operate in all three axes of motion at once. As a result, far more thought had been given to the means of achieving automatic or inherent stability than to active control systems.

Cayley, for example, suggested dihedral wings (wingtips angled up from the midpoint of the wing) as a means of achieving a measure of stability in roll; he also recommended the use of a pendulum to control pitch. French aviation pioneer Alphonse Penaud was the first to produce an inherently stable aircraft, the Planophore (1871), which featured a pusher propeller powered by twisted rubber strands. The hand-launched model featured dihedral wings for stability in roll and a horizontal surface set at a slight negative angle with regard to the wings to provide stability in pitch. With the addition of a vertical surface for stability in yaw, this was the approach taken by virtually all experimenters with model aircraft, including Langley.

Model builders were forced to employ automatic stability, but those experimenters who built and flew gliders had to develop active flight controls. Virtually all of the pre-Wright brothers glider pilots, including Lilienthal, used hang-gliding techniques, in which the pilot shifted his weight in order to alter the position of the centre of gravity of the machine with regard to the centre of pressure. Weight shifting was dangerous and limiting, however. If simple movements of the operator's body were to have a significant impact on the motion of the machine, the wing area had to be reasonably small. This limited the amount of lift that could be generated. Moreover, it was by no means difficult for such an aircraft to reach a stall or some other uncontrolled position from which weight shifting could not effect a recovery—as demonstrated by the deaths of Lilienthal (1896) and the English experimenter Percy Pilcher (1899) in glider crashes.



Pilcher Hawk
In 1896 English aviator Percy Sinclair Pilcher designed, built, and flew the Pilcher Hawk, a monoplane glider with birdlike wings.
Encyclopædia Britannica, Inc.

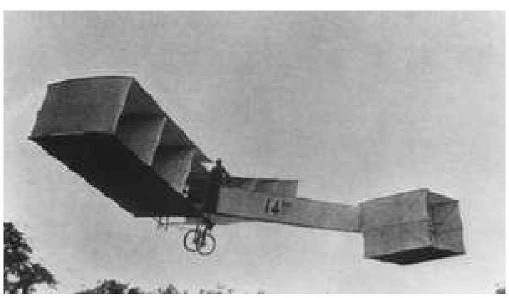
Determined to avoid those problems, the Wright brothers created a positive control system that enabled (indeed, required) the pilot to exercise absolute command over the motion of his machine in every axis and at every moment. Others had rejected that goal because they feared that pilots would be overwhelmed by the difficulty of controlling a machine moving in three dimensions. The Wright brothers, however, had recognized how easily and quickly a bicycle rider internalized the motions required to maintain balance and control, and they were certain that it would be the same with an airplane.

Recognizing the dangers inherent in attempting to rely on control of the centre of gravity, the Wright brothers devised a system to control the movement of the centre of pressure on the wing. They achieved this by enabling the pilot to induce a twist across the upper and lower wings in either direction, thus increasing the lift on one side and decreasing it on the other.

This technique, which they called "wing warping," solved the crucial problem of roll. Meanwhile, an elevator (a horizontal surface placed at the front of the aircraft) provided the means of pitch control. When the Wright brothers introduced a rudder to their design in 1902, this device was used to compensate for increased drag on the positively warped side of the aircraft. In 1905 they disconnected the rudder from the wing warping system, enabling the pilot to exercise independent control in yaw for the first time. The Wright flyer of 1905 is therefore considered to be the first fully controllable, practical airplane.

Other aviation pioneers

The work of the Wright brothers inspired an entire generation of flying-machine experimenters in Europe and the Americas. The Brazilian experimenter Alberto Santos-Dumont, for instance, made the first public flight in Europe in 1906 in his 14-*bis*. Frenchman Henri Farman made his first flight the following year in the Farman III, a machine built by Gabriel Voisin. Farman also completed the first European circular flight of at least 1 km (0.62 mile) early in 1908. On July 4, 1908, the American Glenn Hammond Curtiss, a leading member of the Aerial Experiment Association (AEA), organized by Alexander Graham Bell, won the Scientific American Trophy for a flight of 1 km in the AEA June Bug.

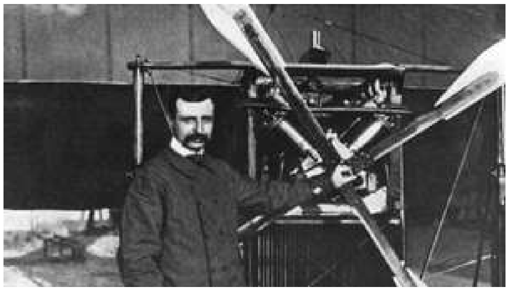


Santos-Dumont and his No. 14-*bis*

In 1906 Brazilian aviation pioneer Alberto Santos-Dumont made the first significant flights of a powered airplane in Europe with his No. 14-*bis*. *Encyclopædia Britannica, Inc.*

The Santos-Dumont, Voisin, and Curtiss machines were all canard (elevator on the nose) biplanes with pusher propellers that were clearly inspired by what the designers knew of the work of the Wright brothers.

By 1909 radical new monoplane designs had taken to the air, built and flown by men such as the French pioneers Robert Esnault-Pelterie and Louis Blériot, both of whom were involved in the development of the "stick-and-rudder" cockpit control system that would soon be adopted by other builders. Blériot brought the early experimental era of aviation to an end on July 25, 1909, when he flew his Type XI monoplane across the English Channel.



Louis Blériot and Type XI monoplane

Louis Blériot standing before his Type XI monoplane, which he flew across the English Channel on July 25, 1909.
Encyclopædia Britannica, Inc.

R.E.P. No. 2

French aviation pioneer Robert Esnault-Pelterie designed, built, and was the first to fly the R.E.P. No. 2, in 1908.
Library of Congress, Washington, D.C. (neg. no. LC-DIG-ggbain-04136)

The following five years, from Blériot's Channel flight to the beginning of World War I, were a period of spectacular growth and development in aviation. Concerned about the potential of military aviation, European leaders invested heavily in the new technology, spending large sums on research and development and working to establish and support the aircraft and engine industries in their own countries. (For an account of the aerial arms race, *see* military aircraft.) In addition to practical developments in the areas of propulsion and aircraft structural design, the foundations of modern aerodynamic theory were laid by scientists and academics such as Ludwig Prandtl of Germany. With the possible exception of flying boats (*see* Curtiss Model E flying boat), an area in which Curtiss continued to dominate, leadership in virtually every phase of aeronautics had passed by 1910 from the United States to Europe, where it would remain throughout World War I.

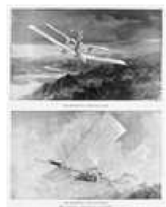
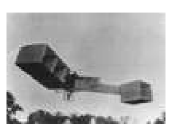
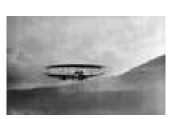
Tom D. Crouch

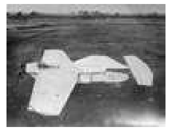
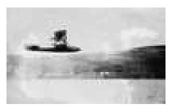
List of select pioneer aircraft

The table provides a comparison of select pioneer aircraft.

Pioneer aircraft

airplane	maiden flight		wingspan	length	weight
Ader Éole	1890		14 metres (45 feet 10 inches)	6.5 metres (21 feet 4 inches)	296 kg (653 pounds)

airplane	maiden flight		wingspan	length	weight
Lilienthal standard glider	1894		7.9 metres (26 feet)	4.19 metres (13 feet 1 inch)	
Chanute biplane glider	1896		4.9 metres (16 feet)	1.2 metres (4 feet)	14 kg (31 pounds)
Langley aerodrome No. 5	1896		4.3 metres (14 feet)	4.3 metres (14 feet)	11.8 kg (26 pounds)
Pilcher Hawk	1896		7.1 metres (23 feet 4 inches)	5.6 metres (18 feet 6 inches)	23 kg (50 pounds)
Ader Avion III	1897		17 metres (56 feet)		400 kg (882 pounds)
Wright flyer	1903		12.3 metres (40 feet 4 inches)	6.4 metres (21 feet 1 inch)	274 kg (605 pounds)
Santos-Dumont No. 14-bis	1906		12 metres (39 feet 4 inches)	10 metres (33 feet)	160 kg (350 pounds)
Voisin-Farman I	1907		10.2 metres (33 feet 6 inches)		520 kg (1,150 pounds)
June Bug	1908		12.9 metres (42 feet 6 inches)	8.4 metres (27 feet 6 inches)	

airplane	maiden flight		wingspan	length	weight
R.E.P. No. 2-bis	1908		9.6 metres (31 feet 6 inches)	8 metres (26 feet)	420 kg (925 pounds)
Bleriot XI	1909		8.52 metres (28 feet 6 inches)	7.63 metres (25 feet 6 inches)	326 kg (720 pounds)
Farman III	1909		10 metres (33 feet)	12 metres (39 feet 4 inches)	550 kg (1,213 pounds)
Curtiss Model E flying boat	1912		12.2 metres (40 feet)	7.9 metres (26 feet)	677 kg (1,490 pounds)

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