

# What Physics Students Can Learn from the Wright Brothers

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The Wright brothers, Wilbur and Orville, are often depicted as lone geniuses, secretly assembling the first successful powered aircraft far from civilization at Kitty Hawk on the Outer Banks of North Carolina. There is a germ of truth in the popular story, but only a germ. The brothers succeeded while so many other experimenters failed not because they possessed superhuman intelligence, but rather because they approached the problem of powered flight as engineers, using a step-by-step methodology to tackle the many different challenges while at the same time carefully measuring and logging each test case. Still, this wasn't enough, and the brothers resorted to fundamental research in achieving their final breakthrough. Their approach to success remains a model of scientific research and applied technology, and is applicable today in the physics laboratory.

The Wrights began their quest for powered flight with homework. Wilbur acquired the latest articles and books on aeronautics, becoming familiar with the state-of-the-art. He identified the chief obstacles to success as being flight control and piloting skills. He learned that previous attempts to fly gliders all used weight shifting by the pilots to control aircraft. Wilbur realized that any flying machine sufficiently large to be powered would be far too massive to be controlled solely by pilots shifting their weight. As for piloting skill, recall that the brothers were bicycle mechanics and, in Orville's case, bicycle racers. Wilbur correctly realized that piloting an aircraft would take practice just like riding a bicycle takes practice. Interestingly, other experimenters of the time neglected this aspect altogether. Many assumed that a flying machine would be driven around the sky just like an automobile.<sup>1</sup>

Wilbur's idea for improved flight control came to him one day as he fiddled with a cardboard box from a bicycle inner tube. A customer in the Wright bicycle shop had just purchased the inner tube and as Wilbur toyed with the box, he theorized that if two wings in a biplane configuration could be slightly twisted, or warped, air flow at the wing tips would change, thus introducing a difference in the amount of lift on opposite ends of the wing. He imagined that if a wing could be made flexible, like the little cardboard box in his hand, he could build a flying machine that could be controlled without pilots needing to shift their weight.

Wilbur validated this idea with a small kite having a wingspan of about five feet. It was about this time that Orville signed on to the program and thereafter the creation of a flying machine was a true team effort. And the next step was something much larger than Wilbur's kite: a man-carrying glider, the construction of which would present a whole host of problems that would challenge their engineering expertise and even force them to engage in fundamental research. Wing warping would prove to be only the first step in a long road of invention.<sup>2</sup>

Immediately after the success of the little kite experiment,

Wilbur and Orville began designing their larger glider. To fly, and to carry a pilot, a glider needs wings, and the amount of lift provided by the wings must equal or exceed the weight of the aircraft plus the pilot. To calculate the wing surface area needed to achieve this amount of lift, the brothers used data from aerodynamic tables published in an 1889 book by a German experimenter, Otto Lilienthal.

The equation that the Wright brothers used to determine the amount of lift is rather simple, involving only four factors and multiplication:

$$\text{Lift in pounds} = k * S * V^2 * C_L \quad (1)$$

where:

$k$  = Smeaton's coefficient (in pounds/mph<sup>2</sup>/ft<sup>2</sup>)

$S$  = Surface area of the wing (in square feet)

$V^2$  = Wind velocity, squared (in mph)

$C_L$  = Coefficient of lift (dimensionless)

**Smeaton's coefficient** is a measure of the dynamic pressure of air, basically the density. You may think of this as the thickness of air. This measure was published in 1759 by John Smeaton, an English engineer seeking to improve the efficiency of windmills. He assigned a value of 0.005, which was good enough to design sails for windmills.

For the wing surface area, the Wrights estimated that about 205 square feet would work.

The velocity in this equation is simply the minimum amount of wind required to produce the desired lift. For their first glider, the Wrights planned to fly in a 15 mile per hour (MPH) wind. Since the velocity is squared in this calculation, this will be:  $15^2 = 225$ .

Finally, the **coefficient of lift** is a measure of lift to expect from a wing of a particular shape flying at a particular angle into the wind. The arch of a wing is called its **camber**. The arch need not be smooth with a peak in the middle. The peak, or **maximum camber**, can appear wherever the designer wishes to place it, usually toward the front of the wing. The Wrights used a coefficient of lift from Lilienthal's aerodynamic tables that had a value of 0.825.

Now we have enough information to solve the equation for the Wright brothers:

$$\text{Lift} = 0.005 * 205 * 225 * 0.825 = 190 \text{ pounds.}$$

The 190 pounds accounts for a glider of 50 pounds plus a pilot's weight of around 140 pounds and a wing of 205 square feet flying in a wind of 15 MPH.

Once designed, the Wrights fabricated the parts and shipped the kit to the Outer Banks of North Carolina, where the U. S. Weather Bureau had assured them of plenty of wind. Completed and ready to fly, this 1900 glider had a wingspan

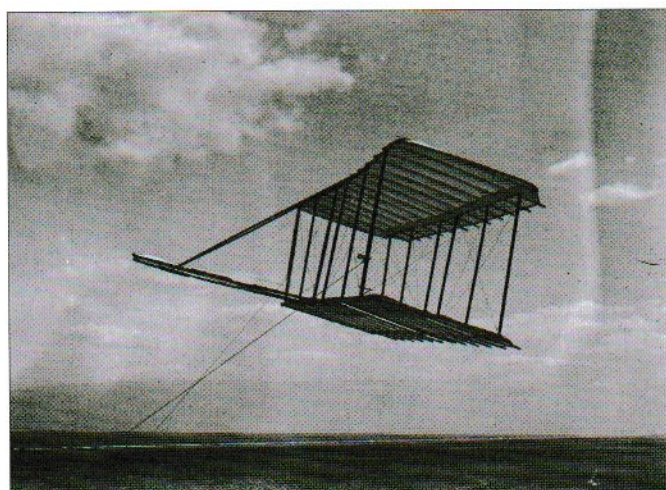


Fig. 1. The 1900 glider being flown as a kite, unmanned. This glider validated the wing warping technique to achieve longitudinal, or roll control, of the aircraft. Although the Wright brothers designed the glider using the best aerodynamic data available of the time, it failed to deliver the amount of lift expected. Even though lift was deficient, the 1900 glider confirmed the brothers' belief that much practice was needed to successfully control the glider in flight. (Library of Congress)

of 17.5 feet, chord or wing width of 5 feet, and it weighed 50 pounds. On the eve of testing, Wilbur was still hopeful, believing that practice was the most important part of their testing program. As he wrote to his father on September 23, "My idea is merely to experiment and practice with a view to solving the problem of equilibrium. I have plans which I hope to find much in advance of the methods tried by previous experimenters. When once a machine is under proper control under all conditions, the motor problem will be quickly solved."<sup>3</sup>

The first glider tests were unmanned. Then Wilbur slipped into the pilot position and attempted his first flight. He soared to an altitude of around 15 feet, but the glider bobbed up and down seemingly out of control. Wilbur's inexperience as a pilot was evident. After that somewhat frightening experience, the brothers resumed unmanned testing. That first short manned flight still produced worthwhile data. It revealed a problem: a stiff breeze of at least 25 MPH was needed to support the glider plus pilot. This was a much higher wind velocity than the brothers expected from their calculations. The glider lacked sufficient lift (Fig. 1).

During the unmanned tests, the Wright brothers made careful measurements of the wind speed, lift, and drag, and they loaded the glider with different weights, all to understand different aspects of flight. Drag was measured using a spring scale ordinarily used to weigh fish! They measured wind speed with a handheld anemometer borrowed from the Kitty Hawk weather station. By knowing the speed of the wind, and the weight of the glider along with its wing surface area, the Wrights could load it down with different known weights of chain to learn how the performance of the glider changed in these different conditions. Even when flown as a kite, they determined through careful measurement that a wind velocity of 22 MPH was necessary just to support the glider itself.

After further unmanned testing, Wilbur mustered the courage to again try a piloted flight. Wing warping was dis-

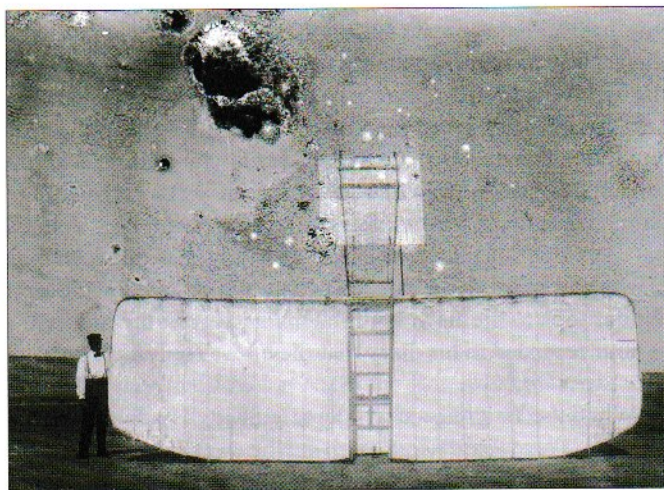


Fig. 2. In this image from a damaged glass negative, Orville is seen standing next to the 1901 glider. The Wright brothers made the wings noticeably wider than those of the previous year's glider, attempting to increase lift. The 1901 glider, like the 1900 glider, was designed using faulty aerodynamic data. The failure of the 1901 glider to perform as expected motivated the brothers to undertake fundamental research using a wind tunnel together with very sensitive and accurate force balances. The front of the aircraft is at the top in this photograph. (Library of Congress)

abled, since the brothers now viewed that as a proven technology, allowing Wilbur to concentrate on pitch control. By the end of that test series, Wilbur had the glider well under control, making glides of 300 to 400 feet, lasting around 15 seconds each, and landing smoothly in the sand. By the time the Wrights departed Kitty Hawk on October 23, Wilbur had logged a total of two minutes of flight time.

Despite the successful glides, the machine of 1900 was flawed. The actual lift was only about half of what the Wrights expected it to be from their design calculations. Nevertheless, they had several reasons to be pleased. First, the wing warping by a pilot was confirmed as a workable method for longitudinal control. As you recall, the Wright brothers viewed wing warping as their main fundamental discovery for controlling an aircraft, a necessary innovation to ever build an aircraft sufficiently large to be powered. They had also polished their data-gathering techniques, a most essential aspect of any research program. Without good data, engineering becomes guesswork.

In terms of its aerodynamic qualities and controls, the 1900 glider was the most sophisticated and well-designed aircraft that had ever been built.<sup>4</sup> The Wright brothers' ability to understand a complex challenge as a collection of smaller challenges, and then work out good solutions to each of the individual problems in a step-by-step process, was key to their success in 1900, and would become even more so in the next two years. Finally, the 1900 flying season confirmed their intuition as bicycle riders that a great amount of practice was necessary to master a flying machine.

The solutions to the problems of 1900 seemed simple enough. Since the glider of 1900 lacked lift, and the Wright brothers reasoned this was due to having wings that were either too small or of the wrong shape, they designed a glider for 1901 with larger wings, and cleverly made the camber ad-

justable. With these changes they believed they could occupy themselves with learning to fly, which they still thought was the chief obstacle standing in the way of success (Fig. 2).

The glider design was complete by the middle of May 1901, and the finished pieces were shipped from their home in Dayton, OH, in July. It had a 22-foot wingspan with a seven-foot chord, resulting in a noticeably different appearance compared to the 1900 glider. The final assembly took place at Kitty Hawk, and the glider was ready to fly on July 27 when, indeed, Wilbur took to the air in it. Problems appeared immediately. Wilbur recorded in his diary that the lift was only 1/3 of what they expected.<sup>5</sup>

When the Wright brothers departed Kitty Hawk on August 20, 1901, they were discouraged, maybe even ready to give up. Many years later, Orville recalled that on their journey home to Dayton from Kitty Hawk, Wilbur had lamented, "Not within a thousand years would man ever fly."<sup>6</sup>

What then may have saved the day was an invitation for Wilbur to speak about their experiments at a meeting of the Western Society of Engineers.<sup>7</sup> Wilbur had only a few weeks to prepare his presentation and, more importantly, to get his thoughts in order: appreciate what he and Orville had accomplished and face up to the remaining challenges.

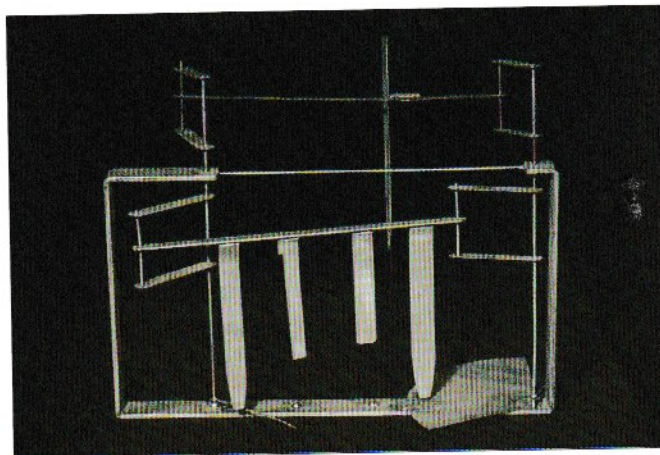
Wilbur was not a professional engineer, and he was nervous about speaking to a society of professionals. When his sister asked whether the talk would be "witty or scientific," Wilbur replied that it would be "pathetic." It was far from pathetic. It was a brilliant technical lecture on the state-of-the-art in flying machines.<sup>8</sup> Wilbur, speaking for both himself and Orville, had more experience than anyone on the planet. They had flown the largest gliders ever, over the longest distances ever.

Whether it was Wilbur's presentation to the society, or just the passage of time, Wilbur and Orville determined to push on. To do that, they needed to perform fundamental research in the science of flight. Years later, after they had achieved success, Orville described their feelings at this time:

*The experiments of 1901 were far from encouraging.... We saw that the calculations upon which all flying-machines had been based were unreliable, and that all were simply groping in the dark. Having set out with absolute faith in the existing scientific data, we were driven to doubt one thing after another, till finally, after two years of experiment, we cast it all aside, and decided to rely entirely upon our own investigations. Truth and error were everywhere so intimately mixed as to be undistinguishable.<sup>9</sup>*

A week following Wilbur's talk to the Western Society of Engineers, the brothers tackled the problem of insufficient lift in both their 1900 and 1901 gliders.

What they did next was a *first* in the history of aviation. They built a wind tunnel in their bicycle shop in Dayton. The Wright brothers were not the first to build a wind tunnel, but they were the first to invent measurement devices of extreme



**Fig. 3.** A reconstruction of the lift balance used by the Wrights in their wind tunnel. The airfoil is the vertical component seen edge-on. Its lift is being compared to the wind resistance against the four flat plates in the lower portion of the device. The amount of deflection is read off of a scale and pointer in the lower right. Although this instrument made from hacksaw blades and bicycle spokes appears crude, it delivered results comparable in accuracy to modern low-speed wind tunnel instrumentation. (United States Air Force)

accuracy and use those devices to carefully measure a large number of airfoils or wing shapes<sup>10</sup> (Fig. 3). The wind tunnel was six feet long, 16 inches square, and powered by a two-blade fan running at around 4000 rotations per minute, giving a wind of 27 MPH.<sup>11</sup> It had a glass window where the brothers could observe the test and read off the values from their measuring instruments.

One instrument measured the lift of an airfoil. The other device measured the ratio of lift to drag, resulting in a *coefficient of drag*. These devices were so sensitive that, as Wilbur recorded:

*After we began to make our record measurements we allowed no large object in the room to be moved and no one except the observer was allowed to come near the apparatus, and he occupied exactly the same position beside the trough at each observation. We had found by previous experience that these precautions were necessary, as very little is required to deflect a tenth of a degree, which is enough to very seriously affect the results.<sup>12</sup>*

The instruments were so precise that even the circulation of the air in the bicycle shop had to be controlled to assure accurate results. How precise? It's not known exactly how many tests they ran. However, they logged results from 43 airfoil configurations out of probably hundreds of tests. Since the coefficient of lift differs with every angle of attack at which the airfoil meets the wind, they tested each airfoil in a range of 0°, that is, the airfoil slicing the wind like a knife, all the way to 45°. And they did this starting with increments of 2.5°, which is a change that's almost impossible to see with the naked eye. Altogether those 43 airfoils were measured for lift and drag at these angles of attack: 0°, 2.5°, 5°, 7.5°, 10°, 12.5°, 15°, 17.5°, 20°, 25°, 30°, 40°, and 45°.

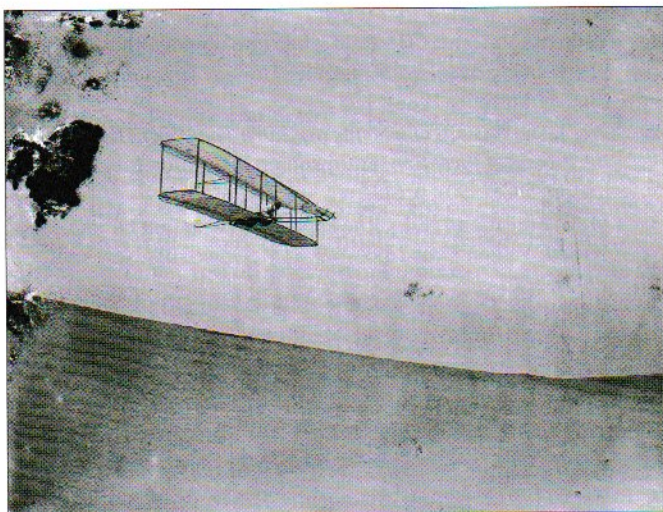


Fig. 4. In this image from a damaged glass negative, Wilbur pilots the 1902 glider, the first aircraft to have full three-axis control in pitch, roll, and yaw. The wings were designed using very accurate aerodynamic data obtained from careful testing in the brothers' wind tunnel and delivered the amount of lift expected from the design. (Library of Congress)

In a letter to a fellow experimenter, Wilbur explained the need for making so many measurements with such slight changes: "We find that accurately measuring the lifts of different shaped surfaces at many angles brings out peculiarities in their actions which averaging widely discordant data and testing a few angles only would not indicate."<sup>13</sup> In one case, he wrote, "We have tested some very remarkable surfaces. For instance our #25 reaches its maximum lift at about  $7^\circ$  and then remains constant, within a range of less than 2 percent.... My brother thinks he can detect a rise of possibly one percent at about  $25^\circ$  but it's absolutely certain that the lift remains approximately the same from  $7^\circ$  to  $45^\circ$ ."<sup>14</sup>

This kind of experimentation has a name. It's called **parameter variation**, and it's a fundamental principle of engineering research. A parameter is simply the measure of something. It could be the shape, the size, the weight, or other aspects. For the Wright brothers, it was the shape of the airfoil and its angle of attack. The variation comes in making slight changes to only one aspect of the object. Then you test. Then you make another slight change. And test again. It is very important to change only one aspect or property of the device under test. If, for instance, you were to change both the weight and the shape, and your testing showed improvement, you couldn't be sure which change produced that improvement.

As you might imagine, parameter variation testing can be quite time consuming, maybe even tedious and boring, but this is also a chance for great discovery. Orville captured this excitement of discovery when he wrote: "Isn't it astonishing that all these secrets have been preserved for so many years just so that we could discover them!!"<sup>15</sup> By the end of November 1901, the Wright brothers possessed the most accurate and complete set of aerodynamic data in history.<sup>16</sup>

Using their airfoil data and an improved value for Smeaton's coefficient they determined experimentally, the Wright brothers constructed a glider for 1902 that was spec-

tacularly successful (Fig. 4). They not only solved the lift problem, but Orville also conceived the idea of a movable tail rudder, enabling true three-axis control in pitch, roll, and yaw.<sup>17</sup> Having full control of the aircraft, the Wright brothers now concentrated on flying; as Wilbur later explained to the Society of Western Engineers, "With this improvement our serious troubles ended and thereafter we devoted ourselves to the work of gaining skill by continued practice."<sup>18</sup> And practice they did. You can feel Orville's excitement as he related their experience to his sister:

*The past five days have been the most satisfactory for gliding that we have had. In two days we made over 250 glides.... We have gained considerable proficiency in the handling of the machine now, so that we are able to take it out in any kind of weather. Day before yesterday we had a wind of 16 meters per second or about 30 miles per hour, and glided in it without any trouble. That was the highest wind a gliding machine was ever in, so that we now hold all the records!*<sup>19</sup>

The longest glide lasted 26 seconds and covered 622.5 feet. In 1902, the Wright brothers came to Kitty Hawk to learn to fly. By the time they departed for home, both Wilbur and Orville each had logged more than an hour of flight time.<sup>20</sup> They were now pilots. And along the way, they invented the first modern airplane with three-axis control (which later served as the basis for their patent).

The Wright brothers still had the challenges of equipping their flying machine with an engine and designing propellers. They tackled these components with the same step-by-step methodology along with testing and measurement. But with the aerodynamic results from their wind tunnel, success was virtually assured, though just a matter of time.

While other experimenters used simple trial and error methods to build complete flying machines, the Wright brothers executed a well-planned engineering approach, identifying the many individual problems required for success, analyzing those issues, developing solutions, and measuring their results.<sup>21</sup> The problem for the Wright brothers was not *let's invent the airplane*; instead, it was *how do we solve each of these many little problems, that once all solved, may result in the invention of the airplane*. This is an important distinction and is why so many other inventors failed; it's also at the heart of thinking like an engineer. They were the first to view an airplane as a system of aerodynamics, structures, and controls.<sup>22</sup>

Together with their aerodynamic data, three-axis control, and propeller science, the Wrights defined the state-of-the-art in aerodynamics.<sup>23</sup> They were the first experimenters to both define advanced aerodynamic science and then build an aircraft to that standard. The brothers were also the last to do so. Once they showed the world that heavier-than-air flight was possible, the scientists and engineers with advanced academic training took up the challenge and made rapid advances in the science that other builders then used to construct ever more advanced flying machines.

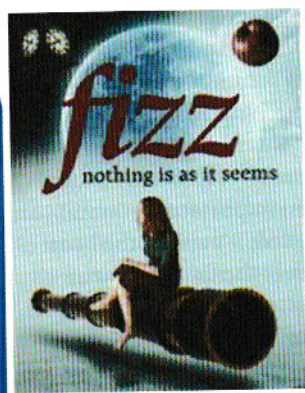
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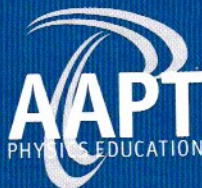
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