Name: _____ Date: _____

Smeaton's Number and the Wrights' Wind Tunnel

Reading level 13 · 1754 words

The 1901 Wright glider had been designed on paper to lift itself, at 100 pounds, plus a pilot of 150 pounds, in a 15 mile an hour wind with the wings tilted at 5 degrees to the air. In flight it could barely lift itself, and only at a much steeper tilt. NASA Glenn reports that it flew up to 300 feet in a single glide while producing only about one-third of the lift that its design equation had predicted. The brothers had followed the accepted method carefully, and the method had failed them. Before they could build anything better, they had to discover which number in it was wrong.

In NASA Glenn's version of the equation they used, lift equals k times velocity squared times wing area times a lift coefficient. Velocity is squared because faster air presses harder on a wing, so doubling the speed quadruples the push. The lift coefficient depended on the wing's shape and its tilt, and the brothers took it from tables published by Otto Lilienthal. The letter k is the Smeaton coefficient, named for the 18th-century engineer John Smeaton. It is the pressure force on a one-foot-square flat plate moving at one mile an hour. The accepted value was .005, although values quoted in that era ran from .0027 to .005.

There were two suspects, Lilienthal's tables and Smeaton's coefficient. On September 18, 1901, in Chicago, Wilbur gave a talk titled Some Aeronautical Experiments to the Western Society of Engineers, and he suggested that Lilienthal's lift and drag tables might be somewhat in error. Afterward the brothers ran a first test with a bicycle wheel laid on its side. A flat plate and a curved wing, set at five degrees as Lilienthal's table described, were mounted vertically on it. The wheel turned, which showed that drag was greater than lift. The device was too crude for precise measurements, so it could not say which number was at fault.

So in the fall of 1901 they built a wind tunnel from an old grinder and scraps of wood, with balances made from hacksaw blades and bits of wire. A tunnel lets the experimenter hold the wing still and move the air instead, and it allows small models to be compared quickly and under the same conditions. One balance measured the lift on a model and another measured its drag. Each model was tested at 45 different angles to the moving air. Readings were first written on scraps of wallpaper and later copied into notebooks, where the shapes could be compared side by side.

Reports differ on how many wing models the Wrights tested. The U.S. Centennial of Flight Commission says formal testing began on November 22, 1901, and covered 38 model airfoils, after about 200 shapes had been tried to check that the tunnel worked. The Wright Brothers Aeroplane Company's site says they tested over 200 miniature airfoils. NASA Glenn says over

fifty models. Reports also differ on how many were only trial shapes. NASA Glenn says the 1900 designs had used the .005 value. The Centennial of Flight account agrees with the brothers' site that each model was tested at 45 angles. All of them agree that the tunnel produced the numbers that the brothers trusted afterward.

By mid-December 1901 the result was clear. The tunnel pointed at Smeaton's coefficient as the main error. Wilbur's own value, .0033, came from the flight data of the 1901 season, and the modern accepted value is .00326. Because k multiplies everything else in the equation, the change from .005 to .0033 cuts the predicted lift by about a third. That alone explains only part of the shortfall. Wilbur's September talk had suggested that the published tables were in error, and the tunnel showed which part. The rest came from using Lilienthal's wing data for differently shaped wings, because the brothers had not corrected for the difference in aspect ratio, the ratio of a wing's span to its width.

Put simply, Lilienthal's numbers were right for his own wings, which had a rather short span and an elliptical outline. They were not right for the long, thin, rectangular wings the Wrights built. The tunnel also showed that a wing curved like a parabola, with its highest point about a quarter of the way back from the front edge, gave much more lift than Lilienthal's circular arc. The Centennial of Flight Commission says the brothers' tunnel figures differed from the published ones in every case, and that they chose to trust their own. In 1902 they designed the glider with them.

The 1902 glider had a 32-foot span, up from about 17 feet in 1900 and 22 feet in 1901, and it was designed with the brothers' own lift coefficients. The Park Service says it flew almost 1,000 times, with a best glide of 622 feet in 26 seconds. NASA Glenn calls it the first aircraft with active control on all three axes: roll, pitch and yaw. Between 1900 and 1905 the brothers designed and built three unpowered gliders and three powered aircraft. The Park Service says they were more than lucky mechanics and succeeded through study and scientific experiment. One site devoted to the brothers says the tunnel work gave them the lift knowledge they needed, which freed them to focus on control.

The specification Wilbur sent to ten engine makers in December 1902 was modest: a gasoline motor of no more than 180 pounds that produced at least 8 horsepower. Every reply was negative. Their shop mechanic, Charlie Taylor, machined the engine the brothers designed in six weeks. It had four horizontal cylinders, with a total volume of 201 cubic inches, and weighed about 200 pounds fully equipped. Reports give its power two ways. The Centennial of Flight Commission says about 16 horsepower at startup, falling to 12.5 in flight, and the National Air and Space Museum calls it a 12-horsepower engine. It had no throttle, so it always ran at full speed.

The first test run, on February 12, 1903, ended with an overheated engine that seized, and the brothers rebuilt it. By May it ran smoothly. The propellers raised a different problem,

because the brothers could find no published research on them. Their answer was to treat a propeller as a wing moving along a spiral course, so that the tunnel's lessons about lift and drag could be reused. Each of the two propellers was 8 and a half feet long, hand-carved from laminated spruce with a hatchet and a draw knife. Tests showed 66 percent efficiency: about two-thirds of the engine's work became thrust. That matched the formula's prediction to within 1 percent.

Nineteenth-century European propeller designs had reached 40 to 50 percent efficiency, according to the U.S. Centennial of Flight Commission. The Wrights' two propellers turned in opposite directions, driven by a crossed chain, and together gave about 90 pounds of thrust. The finished Flyer was a wooden frame covered in muslin with no sealant or paint, and it landed on skids instead of wheels. It had a wingspan of 40 feet 4 inches and a length of 21 feet 1 inch. It weighed 605 pounds empty, and its gross weight was listed as 750 pounds. The Smithsonian's museum calls the idea of a propeller as a rotary wing one of the most original aspects of the brothers' work.

The National Park Service lists the four flights of December 17, 1903. The first went 120 feet in 12 seconds, the second 175 feet in 12 seconds, the third 200 feet in 15 seconds, and the fourth 852 feet in 59 seconds. By this book's arithmetic, the average ground speeds were about 6.8, 9.9, 9.1 and 9.8 miles an hour. Soft sand ruled out wheels, so the Flyer was released from a 60-foot monorail once its engine was running. The parts had been shipped to Kitty Hawk because the machine was too large to assemble in Dayton, and on December 14 an unsuccessful attempt by Wilbur had damaged it slightly. Those ground speeds look slow, but they were measured against the sand, and the Flyer was flying into a strong wind.

How strong was the wind? The Kitty Hawk Weather Bureau instrument, 30 feet off the ground, recorded 27 miles an hour at 10 o'clock and 24 at noon, according to a statement the Wrights issued on January 5, 1904. Their own hand-held instrument, 4 feet up, read about 22 miles an hour for the first flight and 20.5 for the last. Orville's diary says 20 to 25. The readings matter because, as the equation shows, lift grows with the square of the air speed past the wings. The readings differ partly because the instruments sat at different heights. Orville's diary puts the speed at lift-off, as the machine left its truck on the fourth section of rail, at roughly 7 to 8 miles an hour. Through the air the Flyer moved at about 30 to 35 miles an hour, flying 8 to 10 feet up, a height the brothers chose for safety.

The records of that morning differ in small ways. Visitors to the memorial today find a boulder and numbered markers on the field that show where the four flights began and ended. The state of North Carolina's history page puts the first flight at about 10:53 a.m. and about 100 feet, while Orville's diary and the Smithsonian say about 10:35, and the Park Service says 120 feet. Orville's diary says the second flight was not measured and was about 175 feet, and the museum says the second and third were in the range of two hundred feet. The Wrights' own statement describes a launch run of about 40 feet along the track, against the Park Service's

60.

The longest flight of the day had ended when the machine pitched near a small hummock and hit the ground. After the four flights, a gust overturned the Flyer, and the National Air and Space Museum says it was severely damaged and never flew again. On October 5, 1905, with their third powered airplane, Wilbur flew for 39 minutes over a closed course, covering 24.5 miles, or 39.2 kilometers. The fourth flight of 1903 had covered 255.6 meters in 59 seconds. The 1905 flight averaged about 38 miles an hour over the ground, and the museum calls it spectacular. That is about 150 times as far as the fourth flight of 1903. Wilbur Wright died on May 30, 1912, and Orville Wright died on January 30, 1948.

Questions

1. What did the bicycle-wheel test suggest?

A. The wing was far too heavy to turn
B. The wheel was too small to spin
C. Drag was greater than lift

2. Which number did the tunnel results point to as the main error?

A. Smeaton's coefficient
B. The weight of the pilot
C. The length of the rail

3. Why did Lilienthal's figures not carry over to the Wrights' wings?

A. His tables were made up
B. Their wings were shaped differently
C. The air in North Carolina was thinner

4. The bicycle-wheel device was called crude. What does crude suggest about it?

A. Rough and imprecise
B. Very costly to build
C. Finished within one day

5. In the lift equation, what happens to lift if the air speed past the wing doubles and nothing else changes?

A. It stays about the same as before
B. It becomes four times larger
C. It doubles, and no more than that

Words to know

coefficient: multiplying number
drag: air resistance
efficiency: useful share

parabola: smooth curve
throttle: power control

Answer key: Smeaton's Number and the Wrights' Wind Tunnel

1. C. Drag was greater than lift
2. A. Smeaton's coefficient
3. B. Their wings were shaped differently
4. A. Rough and imprecise
5. B. It becomes four times larger