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The Wright Brothers' Odyssey of Discovery
By J. A. Donoghue

When Orville Wright made the first flight of a powered airplane on Dec. 17, 1903, the world changed forever. The way people would view time, distance and each other would never be the same. The ability to fly widened and accelerated all activities on the planet, unfortunately including warfare. But more importantly, the explosion of travel and commerce made possible by an ever-expanding airline industry helped bring prosperity and peace to much of the world that embraced the change.

All of this was far from the minds of Wilbur and Orville Wright when they began their pursuit of flight. Disregarding the many decades of frustrated attempts to fly by hundreds of great intellects around the world, and small fortunes spent, the Wrights took up the chase merely for the fun of it, the intellectual challenge, rather than any grandiose belief that they would make history and change the world.

A naiveté marked their initial efforts; they simply didn't know what they were getting themselves into. The brothers wrote a few years after the fact, "We had taken up aeronautics merely as a sport. We reluctantly entered upon the scientific side of it. But we soon found the work so fascinating that we were drawn deeper and deeper into it."

Some of their most important work began in an offhand sort of way. Probably the most significant such development followed Wilbur's invitation to speak to a group of engineers. His intention to tell the group that two years of glider experiments led him to believe that the accepted calculations of lift were all wrong initiated months of increasingly sophisticated wind tunnel testing to support that assertion. The product of those tests formed the basis of the Wright Flyer aerodynamic design and all lift calculations for years to come, withstanding the test of time.

December 1902 : The Wrights had recently returned home from Kill Devil Hill near Kitty Hawk, N.C., after a highly successful series of more than 1,000 flights in their 1902 glider. Confident that they had solved the main problems of lift and control, the Wrights set out to build their powered aircraft, now known as the Wright Flyer, twice as large as the 1902 glider.

Orville Wright

To find a light engine of adequate power they sent specifications to a dozen automobile manufacturers. Most of the few who replied said they couldn't produce a single special engine; one said it had an engine but the brothers doubted its abilities. In December they decided to make their own engine, a four-cylinder, water-cooled gas engine capable of a sustained 12 hp. Meanwhile, the Wrights started to discuss what they had assumed would be the fairly simple matter of designing and making propellers.

And, finally aware of the importance of their innovations, they started to apply for patents.

January

It was only after the sport, the hobby, of flying began to take shape for the intellectually curious and industrious brothers Wilbur and Orville Wright did they start to look out from the depths of their intense concentration on solving the problems of controlled flight. Suddenly they realized they had progressed to the point that success not only was possible, but probable. Only then did they start to consider the commercial possibilities.

Their first fascination with flight came in the form of a childhood gift from their father, a helicopter-like toy, really a propeller on a stick powered by rubber bands that would climb vertically. The young Wright brothers made several larger versions of the toy but their results diminished as the size increased, and the

Wilbur Wright

effort was abandoned.

Coming of age in the waning days of the 19th century in Dayton, Ohio, the Wrights' thoughts were not primarily of flight, although Wilbur would spend hours watching birds in flight, especially soaring birds. They were more concerned with developing several business ventures, finally spinning off Orville's success as a bicycle racer to begin repairing and then manufacturing the new and wildly popular "safety" bicycle that made cycling practical and available to the masses, the bicycle form common to this day.

Wilbur also was athletic in his youth, but his life changed dramatically when, at the age of 19, he got smacked in the face with a bat during an ice-skating game. This started a four-year period of convalescence

1897 Wright Bicycle

that transitioned into being the primary caretaker for his fatally ill mother, Susan, until she died in 1889. This period ended his hopes of higher education.

Sometime during the mid-1890s, the brothers became aware of the work of German aviation pioneer Otto Lilienthal. Lilienthal's gliding experiments, mostly from a hill he had constructed near Berlin, brought him worldwide recognition. He began approaching the problem of flight from a scientific perspective, developing a table of lift values for certain wing curves at various angles of incidence—the angle of the relative wind hitting the leading edge of the wing.

Ironically, it was not Lilienthal's success that moved the Wrights to action but his ultimate failure. "In 1896 we read . . . of the experiments of Otto Lilienthal," wrote Orville. "His death a few months later while making a glide off a hill increased our interest in the subject, and we began looking for books pertaining to flight."

Lilienthal had another effect on the Wrights: He lamented that there was no safe place for him to experiment and suggested the best location for test flights would be over hills of sand. His dying words, "Sacrifices must be made," inspired the cautious incremental approach that characterized the Wrights' work.

January 1902: Wilbur and Orville had flown for three summers on Kill Devil Hill's sandy terrain and were moving ahead with designing their Wright Flyer for their assault on powered flight. In January they used their homemade wind tunnel to test various shapes for the uprights between the wings, finding that rectangular uprights with rounded edges produced less drag than the teardrop shape favored by the conventional wisdom of the day. They decided they would keep the 1902 glider's skids for landing gear but would extend them forward and add bracing to account for the heavier weight of the Flyer and its engine.

Meanwhile, the Wrights abandoned their search for a usable propeller design theory, realizing that in the whole 100 years of marine use propellers had been created solely by the "cut and try" method. Acknowledging that they had to do it themselves, they started by analyzing the thrust from a 28-in. fan driven by a one-cylinder shop motor.

February

Control was key to flight; this seemed obvious to the Wright Brothers, who considered it odd that previous attempts at control had been relatively shallow. Both Otto Lilienthal and Englishman Percy Pilcher used the shifting weight of the pilot. Lilienthal paid the ultimate price for the limitations of that technique in 1896, while Pilcher died in 1899 when his glider's rain-soaked tail failed while being towed aloft, a lesson in structural strength not lost on the Wrights.

Wilbur Wright in late May 1899 wrote to the Smithsonian Institution in Washington asking for information on human flight. A Smithsonian official responded with reports and recommendations to read Octave Chanute's "Progress in Flying Machines" from 1894 and copies of the "Aeronautical Annuals." The Wrights chose to follow the efforts of gliders like Lilienthal rather than the money-heavy efforts to go directly to powered flight such as that of Hiram Maxim in the UK and Clement Ader in France.

Lilienthal

From his observations of bird flight Wilbur believed the study of "straight-winged" soaring birds to be the most useful. He saw that small changes in the attitude of the wings caused one wing to rise and the other to drop, creating a turning motion. Initially the Wrights considered reproducing this action by changing the incidence of an entire wing through a series of gears but realized the structure would be either too heavy or too weak.

But one day while holding an open-ended rectangular cardboard box in both hands while talking to a bicycle customer, Wilbur was absently twisting it lengthwise when he realized that while the front and back of the box remained parallel and retained its structural strength, the top and bottom assumed a helicoidal twist. This was exactly the kind of shape a biplane wing would need to increase lift on one side and decrease lift on the other, making the aircraft rotate around its longitudinal axis into a turn-producing bank. Although Orville later said the Wrights already had been considering just such an approach to lateral control, the example of the box gave them a method to achieve the mechanical implementation of the technique.

Thus was born wing warping, the Wrights' initial invention—and the source of their most fruitful patents—which evolved into the aileron. A 5-ft.-wide biplane kite was constructed to test wing warping and flown by Wilbur just once in the summer of 1899, with a crowd of boys looking on, to prove the theory.

February 1903: The building of the Wright Flyer for the assault on powered flight moved ahead, the aircraft taking up a good part of the bicycle shop. The engine, designed and built in collaboration with machinist Charlie Taylor, ran for the first time. On the second test run, their father wrote, "the boys broke their little gas motor" when leaking gas wrecked the bearing lubrication, cracking the cast aluminum engine body. A second casting took two months to arrive.

Meanwhile, the Wrights' work on propeller theory had become a distilled version of their invention process—"envision, debate and create." They would begin the discussion after dinner, their voices growing louder and louder until they

lapsed into stony silence on either side of the fireplace. Then another attribute of their debates appeared: "After long arguments we often found ourselves in the ludicrous position of each having been converted to the other's side, with no more agreement than when the discussion began."

They did agree that a rotating propeller should be considered as a wing moving through the air at varying speeds and angles, a devilish problem, but 100 years ago this month they began working on a design for an 8-ft. propeller.

March

Although roll control through wing warping is one of the most famous inventions of the Wright Brothers, also vitally important but largely unheralded was their pioneering understanding and taming of center of pressure travel on a curved surface—in other words, a wing.

Center of pressure is the point where the forces of lift balance on a surface. Take a flat surface—a board, for example—and stand it upright, the broad side facing a wind. When wind blows against it, the center of pressure is in the middle of the impacted surface. When the top of the board is rotated toward the source of the wind, the center of pressure moves forward until, when the edge of the board is presented to the wind, the center of pressure has moved all the way to the leading edge and all lift is in the opposite direction.

Conventional wisdom at the dawn of the 20th century said a curved surface would perform in a similar manner. In fact, the center of pressure does start to travel forward as the angle of the surface to the wind decreases—but only up to a certain point. After that point, the center of pressure retreats rapidly toward the rear of the surface.

If an aircraft is designed so that the center of gravity is naturally at the center of lift, as was the practice of so many before the Wrights, the sudden reversal of travel will cause a loss of control and often, as in Lilienthal's case, a fatal accident.

The 1901 glider proved to be a huge disappointment despite a number of "improvements" from the 1900 version. The Wrights developed a series of tests at Kill Devil Hill to prove that when they went to a more deeply curved wing to follow Lilienthal, they were exacerbating the tendency for lift to move to the rear at shallow angles of attack. Only the "happy accident of design" of placing the elevator forward of the center of gravity allowed them to mush the aircraft relatively softly into the sand when control was lost instead of suffering the spin/crash disasters that took such a deadly toll of other inventors and novice pilots.

The Wright Flyer Motor

March 1903: The Wrights finally had a handle on their propeller design, having gone back to wind tunnel testing and their lift tables to construct props capable of 66% efficiency. Orville was ecstatic. "We had been unable to find anything of value in any of the works to which we had access, so we worked out a theory on our own on the subject, and soon discovered, as we usually do, that all propellers built heretofore are all *wrong*, then built a pair of propellers 8-1/8 ft. in diameter which are all *right*! Isn't it astonishing that all these secrets have been preserved for so many years just so that we could discover them!!"

Also in March, busy building their Flyer and installing the counter-rotating propeller drives, the Wrights received a request from Capt. Ferdinand Feber, a French artillery officer and erstwhile flyer, requesting that they build and sell him a copy of their successful 1902 glider. Wilbur wrote that the earliest they could do that would be the following winter.

April

Chanute

One man's name keeps popping up in the story of the Wright Brothers' invention of the airplane—Octave Chanute. The French-born civil engineer's only direct contribution to the Wright Flyer was a modified truss structure, derived from Chanute's basic bridge design, that the Wrights used as the basis for their strong but light wing bracing. In an airplane that was nothing but flying surfaces, this was the aircraft's structural foundation.

Chanute was a flying pioneer himself, having conducted glider trials from sand dunes along the Lake Michigan shore and at Kill Devil Hill along side the Wrights, but his discoveries were more of the "what to avoid" nature. Beyond the wing structure, though, Chanute was a catalyst that transformed and redirected the Wrights' path of discovery at numerous critical steps along the way.

Their first meeting was through a survey of aeronautical writings that Chanute gathered and republished, recommended to the Wrights by the Smithsonian Institution, part of their introduction to the science of flight. Chanute made himself an international clearinghouse of information on aviation research. He often encouraged and advised the Wrights and in turn received frequent letters about their progress. He made a number of visits to the Wrights' camp at Kill Devil Hill, where he photographed the Wright work while testing his own designs.

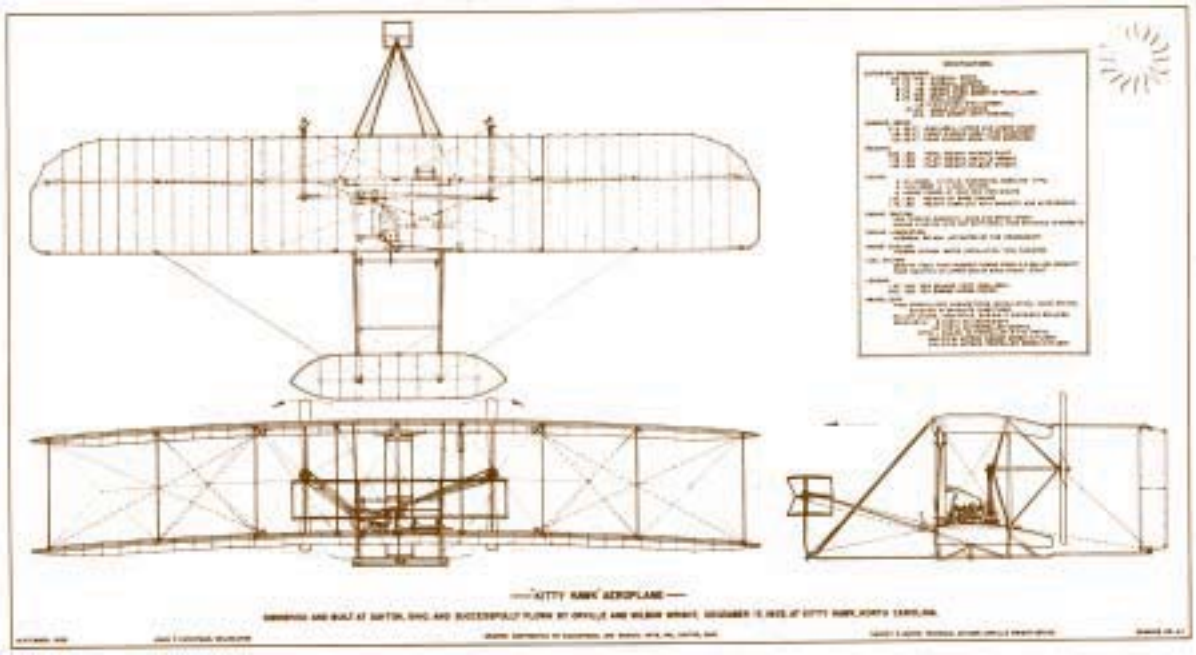
However, in disseminating news about Wright developments, including in early 1903 the basics of their three-axis control system, Chanute advanced the cause of aviation while creating a legal problem for the brothers' later battle for patents.

He also introduced them to a flying enthusiast who was a great help—George Spratt—and another who was a nuisance—Augustus Herring. After the Wrights' early gliding success, Chanute invited Wilbur to speak at an engineers' meeting that led the brothers into wind tunnel tests that

corrected historical errors and allowed them to build effective wings and propellers.

Although Chanute offered financial help, the Wrights never accepted for fear of future entanglements over ownership of the technology they invented. The Wright project truly was run on a very tight budget: The cost of the Flyer, including multiple trips to and from Kitty Hawk, was less than $1,000. The brothers were proud their launching track cost $4; they had heard that the launching mechanism for Samuel Langley's Aerodrome cost $50,000, weighed 15 tons, and it failed.

April 1903: the Flyer had been under construction for three months, its components fairly filling the Dayton bicycle shop. Milton, son of Wright brother Lorin, played beneath the developing wing sections. Knowing that their powerplant was weak for the weight it was going to pull, the Wrights worked to reduce drag as much as possible.



While based on the successful 1902 glider, the Flyer was much larger, with a wingspan of 40 ft. 4 in. and a chord of 6 ft. 6 in., giving a total wing area of more than 500 sq. ft. The center section was stiffened with additional bracing to account for the weight of the engine, and the right wing was made 4 in. longer than the left to compensate for the extra weight of the engine on that side of the aircraft. The wings were designed to droop slightly to minimize the effects of gusting crosswinds.

May

Learning the art of flying was high on the Wright Brothers' list of priorities. The importance placed on developing piloting skills was not unique to the Wrights, but it was unusual among their pioneering contemporaries. Indeed, the bulk of airplane design efforts before the Wrights had foundered on the rocky shores of a search for a design with inherent stability that would minimize the need for pilot input.

However, one of the Wrights' major breakthroughs that distinguished their efforts from most others and paved the road to success was their decision to reject natural stability in favor of control effectiveness. This course led directly to the idea that if a pilot was to have full control over the airplane, he'd better know how to use it.

Indeed, the competitive Langley Aerodrome had no lateral control and no skill was though necessary since it was planned simply to flop into the Potomac River at the end of its flight. Its pilot, Charles Manly, had no training, although in the end that is not why the Aerodrome failed.

The Wrights' efforts to learn the art of piloting started with flying their gliders as kites, tied down in a high wind, the controls manipulated by cords from the ground. When they invented the movable rudder on the 1902 glider to perfect their three-axis control system, they flew the glider hundreds of times to refine their technique. Wilbur wrote in late 1902 of the experience: "Into the last 10 days of practice we crowded more glides than in all the weeks preceding. In two days we made about 250. This practice enabled us to very greatly increase our skill in the management of the machine."

By the time of the first powered flights, the Wrights had accumulated much more time flying gliders than anyone in the world, and had flown further and remained aloft longer, but they remained cautious. Writing about a conversation with supporter Octave Chanute, Orville said, "He doesn't seem to think our machines are so much superior as the manner in which we handle them. We are of just the reverse opinion."

The brothers incorporated two design features that allowed them to achieve the required skills. The "happy accident of design", placing the elevator in front of the wing that minimized the disastrous consequence of a stall allowed the Wrights to crash gently many times without killing themselves. The second was the purposeful decision to interconnect the new movable rudder with the wing-warping cables to reduce pilot workload.

The dedication with which the Wrights developed their piloting skills seems in direct conflict with the numerous changes they made in how their controls actually worked. In building the 1902 glider, for example, they reversed the functioning of the elevator control from the 1901 glider, a change that resulted in at least one glider-damaging prang. The controls were changed at least seven times by the time the Flyer took off in 1903, and changes continued in further developments.

May 1903: the building of the Flyer

continued, although it was never to be assembled fully until arriving at Kitty Hawk. The difficult propellers finally were taking shape and the drive chains for the contra-rotating props, versions of automobile transmission chains, were being custom-made by the Diamond Chain Co. of Indianapolis.

June

The Wright Brothers' 1903 trip to Kitty Hawk was relatively uneventful, their experience smoothing the way. Their first trip, however, was an arduous ordeal for Wilbur, who went with the 1900 glider several weeks before Orville.

In that time the barrier islands of the Outer Banks of North Carolina were difficult to reach. A boat sailed from Elizabeth City, the closest rail line, just once a week. Wilbur missed that and chartered another boat for the 40-mi. trip, and found it leaky and so foul he refused to eat during the weather-battered two-day trip. Tolerating primitive living conditions that first year, the Wrights slept in a tent that frequently was blown down by the Outer Banks' high winds. The Wrights ruefully realized that the high average winds that brought them to Kitty Hawk were often the result of one day of no wind and another of 40 knot gales.

The glider the brothers assembled and flew at Kitty Hawk already incorporated their wing warping for lateral control and front "rudder," or elevator, for pitch control. They started by flying it as a kite on ropes in the stiff wind, taking turns in the aircraft flying it in place with the glider still roped down. Sometimes they controlled the glider with cables from the ground, weighting it down with chains.

Their first discovery was that the dihedral they built into the wings—following popular belief that dihedral added stability—actually made the craft more difficult to control in crosswinds. They eliminated the dihedral and continued.

Next they discovered that the angle of incidence, or angle of attack, needed for flight was much larger than they expected based on the Lilienthal lift tables. The wings were not producing the expected lift, the Wrights' first hint that the tables might be flawed.

They altered the glider in numerous ways during these "flights." They even moved the elevator to the rear of the wing and found it much more stable. However, they returned it to the leading position "because it absolutely prevented a nose dive such as that in which Lilienthal and many others had met their deaths," Orville wrote years later.

The Wrights spent only one day free-flying the 1900 glider in the six weeks they were in North Carolina, the testing cut short by storms that wrecked the craft and a need to get home to tend to business. But that one full day of gliding from Kill Devil Hill, a large sand dune next to their camp site several miles from Kitty Hawk, and the success they had with their control systems, encouraged them. The glider had flown, and the controls worked.

They turned the glider over to the Tate family, who had helped them. Mrs. Tate used the sateen wing covering to make dresses for her little girls. The Wrights returned to Dayton to build a better glider for the next year's testing.

*June 1903: A*ssembly of the Flyer was going so well that Orville took the time to write a long letter—Wilbur was the usual

1901 Glider

1900 Glider Flown as a kite

writer of the pair—to supporter George Spratt. He described how concerned the brothers had been about building such a large aircraft. "We are greatly increasing the size of the front rudder so as to have an abundance of control," Wilbur wrote. In fact, the new elevator was far too effective, its size, along with an unfortunate positioning of the hinge, contributing to the aircraft's extreme sensitivity in the pitch axis.

Manufacture of the troublesome propellers finally was completed and stronger valve springs boosted their engine's output to 16 hp, Orville wrote. He thought they might depart for Kitty Hawk in August, but that was not to be.

July

Flush with the thrill of success with the 1900 glider, their first attempt to build a flying machine, Orville and Wilbur Wright returned to their Dayton home eager to build a bigger, better glider in which they could do some serious flying. They got far less than they expected. The 1901 glider's performance was a huge disappointment, creating a crisis of confidence for the pair. However, in a key period in the development of the airplane, the determined Wrights worked through the crisis, along the way ending any reliance on the rest of the world's knowledge of flying. They found themselves so far ahead of the pack that there was nothing to refer to but their own considerable powers of observation and invention.

The 1900 glider confirmed the effectiveness of their wing-warping control and front elevator, as far as they could tell, but clearly the new aircraft would have to be

bigger to sustain a man for extended flights. The new glider had a wingspan of 22 ft. with a chord of 7 ft., compared to the 17.5-ft. span of the 1900 glider. The total lifting area exceeded 300 sq. ft. compared to 165 sq. ft. in the 1900 version.

Importantly, the Wrights relied on Otto Lilienthal's air pressure tables to increase the curvature, or camber, of the wings, although the one disappointment of the 1900 glider was its failure to perform as those tables had predicted. An innovation on the new glider, much heavier than the first, was a pair of skids to use as a landing gear, replacing the pilot's legs in that role.

Returning to Kitty Hawk, the brothers, besieged this year by black clouds of mosquitoes, built a shed to house their machine and assembled it, this time with help from flying enthusiast George Spratt, recommended by their adviser, Octave Chanute, because Spratt had some medical training. Such training might not be needed by the Wrights, but Chanute thought it prudent to have it handy just in case.

From the earliest flights it became apparent that while the 1901 glider did fly better than its predecessor it did not perform nearly as well as it should have. In fact, it produced one-third the expected lift at any given angle of attack. Further, their pitch control produced unexpected results, the glider making a number of sudden dives into the sand.

Various tests and theorizing led the Wrights to the conclusion that their pitch control problem was caused by the center of pressure travel reversing at lower angles of attack, a previously unrecognized phenomenon. Realizing that the flatter wing of the 1900 glider had not had this problem, they modified the camber of the 1901 glider. It flew better, and glides of more than 300 ft. became common.

But now another problem raised its head: The more they flew and turned their aircraft, the more it seemed the glider, once in a turn, wanted to angle toward the high wing. They were in the process of discovering adverse yaw but were unable to define the problem completely until the following year. This, and the unexplained lift deficiency, left the brothers discouraged as they decamped for home. "When we looked at the time and money which we had expended and considered the progress made and the distance yet to go, we considered our experiments a failure," Wilbur would write several years later.

July 1903: The Wrights were in the final stages of building their Flyer. Wilbur had just given a guarded speech to an engineering society meeting on their gliding tests. When asked the best way to propel a powered machine, flapping wings or propeller, his reply clearly was meant to disguise his and Orville's plans: "I suspect that in efficiency they are not far from equal."

1902 Glider

August

Returning home from the crushing disappointment of the 1901 glider, the Wright Brothers launched themselves into quantifying exactly why that aircraft had failed to live up to their expectations. The result of these explorations was nothing less than the world's first true airplane, the 1902 glider, the first aircraft to have a fully realized three-axis control system that put the pilot in complete control of his craft. It didn't start out that way though.

The Wrights' first concern about the 1901 glider was why it had failed to perform the way lift tables said it should. They believed the existing tables were flawed, but it wasn't until Wilbur accepted an invitation to speak to the Western Society of Engineers that he decided to produce research to back up his beliefs. The brothers built a small wind tunnel for a single day of testing that affirmed their assumptions, and Wilbur said so in the speech.

Orville and Wilbur then built a larger wind tunnel in their bicycle shop to generate more precise lift data. The tests lasted a bit more than two months, with hundreds of airfoils being tested, the brothers rigorously eliminating outside variables, including not moving anything in their workshop.

By the time the necessities of business forced them to return their attention to bicycles they had developed rudimentary but correct lift tables that allowed them to produce wings that performed as expected. They shared their findings with others working in the field, including Octave Chanute.

Returning to Kitty Hawk the next August, they immediately repaired and enlarged their camp, tired of the rough living of previous visits. The glider they assembled looked very different from past efforts. The 1902 glider had a wingspan of 32 ft. compared to the 22-ft. span of the 1901 glider and the 17.5-ft. span of the 1900 glider. These new wings were an original Wright design. Learning from the wind tunnel tests about the benefits of a high aspect ratio—span compared to chord—span was now six times the chord instead of the 3:1 of the 1901 glider. This wing was less arched, with a 1:24 camber compared to the 1:12 camber on the 1901 glider. And, importantly, the high point of the wing arch was moved toward the rear to about 1/3 of the chord, a 20-in. shift.

Controls were changed as well, most notably moving the wing-warping function from a foot-operated mechanism to a cradle the pilot would lie in, shifting his hips from side to side. Further taxing their immature piloting skills was a decision to reverse the action of the elevator controls from the previous year.

One other change in the 1902 glider was the addition of a fixed vertical tail to counter the adverse yaw tendencies exhibited by the 1901 machine. Then, as now, the wingtip or aileron being deflected downward increases lift on that wing it also

Flyer and Shed at Kill Devil Hill

produces more drag, causing the aircraft to yaw away from the turn.

The new glider flew very well, and yet there were times when the craft in a bank would tend to slip sideways toward the low wing in an uncontrolled manner, often hitting the ground wingtip-first in a type of accident the brothers called "well digging." The Wrights had yet to solve fully the puzzle of adverse yaw.

July 1903: The Flyer was well in hand and plans were being made to return to Kitty Hawk. However, Wilbur had become concerned about an article that Chanute was about to publish describing their efforts, especially his description of their flight controls. He wrote to Chanute that he was disturbed that not only was the description incorrect but that publication of the actual details would make it difficult for the brothers to get patents in France and Germany. Chanute agreed to delete the passage.

September

After three weeks of flying the 1902 glider with wings of their own design and fixed twin vertical tails, the Wright Brothers were greatly pleased with the aircraft's gliding performance.

However, the occasional uncontrolled sideslip had them perplexed. Although infrequent, the slips would occur when the pilot warped the wings to start a turn. Before the turn actually started but after the aircraft had rotated around its longitudinal axis—the turn delayed by the fixed vertical tail—the glider would start sliding toward the low wing. Meanwhile, airflow would start striking the vertical tail on the side toward the low wing, forcing the low wing even lower. Attempting to stop the process by warping the wings to lift the low wing would produce more drag on that wing as lift increased, momentarily worsening the situation. By this time control would have been lost and the low wing would hit the sand and pivot around in a motion the brothers called "well digging."

By early October they had been joined by their brother Lorin and frequent helper George Spratt and flew often, retiring to their enlarged hangar/shed at night to discuss aeronautical theory. On Oct. 2, after a lengthy discussion and too much late coffee, Orville stayed awake in bed. Tossing, he turned the sideslip problem over in his mind and it was there, he said, that the solution of a moveable rudder was born. If the vertical tail was movable, he thought, it could help to level the airplane at the start of a sideslip.

Orville presented this idea during breakfast the next morning. He and Wilbur discussed the concept and realized that a moveable rudder also would assist in initiating a turn and prevent the onset of the well-digging slip. Wilbur gave it a little more thought and added that since the pilot already was fully occupied and since the wing warping and rudder movement must occur at the same time, why not interconnect them to make the movement automatic?

The world's first aircraft with an effective three-axis control system was created in the following days when a single moveable vertical tail replaced the fixed twin unit. The Wrights had achieved their goal of building an inherently unstable aircraft that was fully controllable by the pilot, an accomplishment in direct opposition to many of the "informed" attempts of the day that favored inherent stability and minimal pilot input.

Now the aircraft could be flown into and out of difficult situations, even in crosswinds as high as 30 mph. The brothers flew hundreds of flights with this configuration of the 1902 glider, more than 250 flights in one two-day period. So well known locally was their flying that on Oct. 24 a coastal steamer came in close to shore to allow its passengers to watch. Four days later the Wrights packed for home, sorry to leave their very successful glider but in high spirits. Having solved the problems of lift and control, they were eager to return home to start the new project: An engine, propellers and a new airplane big enough for powered flight.

September, 1903: The Wrights' return to Kitty Hawk was behind schedule. The planned mid-August departure from Dayton slipped and it wasn't until Sept. 9 that the first shipment left. Wilbur and Orville finally departed on Sept. 23 and upon arrival in Elizabeth City, N.C., were horrified to learn that the freight depot through which the first part of their gear was to transit had burned to the ground the previous week. Happily, their cargo got out of town before the fire. They arrived at Kitty Hawk on Sept. 25 and prepared for the delivery of the Flyer.

October

"We had already before leaving Kitty Hawk [in 1902] about decided on many of the points of construction, but it takes considerable figuring to determine the proper sizes of the different parts so as to

Wright Wind Tunnel

maintain a high enough factor of safety in so large a machine." Wilbur's June 1903 letter to supporter George Spratt shows the Wrights' confidence in their accomplishments—they were ready to move on to adding power. But the power piece of the puzzle was not easily solved. First there was the question of obtaining a suitable engine, which they had to build themselves, and then propeller design and manufacture, where the Wrights once again rejected all previous practice to engineer their own props.

Finally, there was the problem of transfer of power. Orville wrote in late June, "We find it no easy matter to convey 16 horsepower from the motor to the two propellers." Whatever solution they came up with, it had to be light—the brothers had allowed about 200 lb. for the total propulsion system, and the engine, fuel and water system weighed roughly 180 lb.

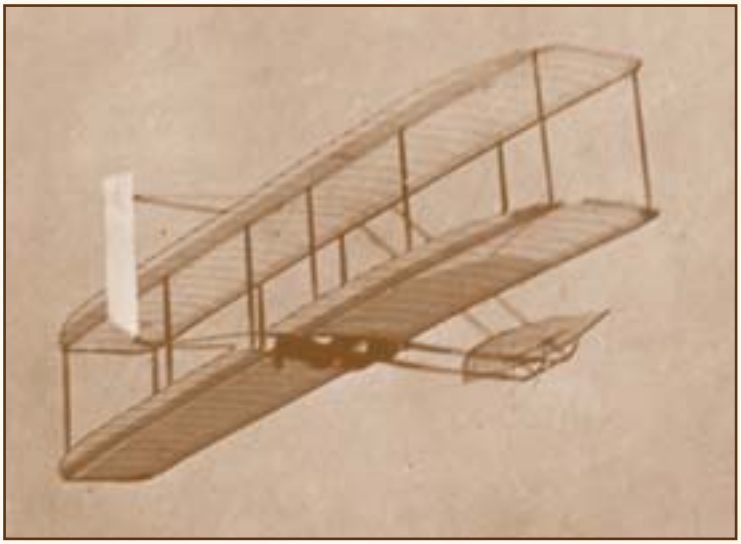
The Wrights decided that a pair of propellers would give them two advantages. One would be larger, slower-moving props that could be built with more twist, or bite, than a single prop. Second was the cancellation of the gyroscopic effect, or torque, of a single prop by having the two rotate in opposite directions.

While bicycle technology appears here and there in the Flyer, it is in the power transmission that it is most evident in the combination of sprockets and chains, although this also was common in automobiles of the day. This arrangement allowed the brothers to change gearing during testing by swapping sprockets to get the right combination of power and speed to their props. The custom-made chains were encased in metal tubes to reduce vibration and increase safety.

Meanwhile, word of the Wrights' success was getting out. Wilbur again spoke to an engineering group and Samuel Langley offered to pay their way to visit him in Washington at the Smithsonian Institution. They declined. They worked on a series of patent applications for their inventions in order to file them in early 1903.

The whole Flyer never was assembled in Dayton—it was just too big. Completing what assembly they could, the Wrights crated and shipped their gear and left, arriving in Kitty Hawk on Sept. 25 to find that the worst winter in recent memory had ravaged their camp. Their 1902 glider was undamaged, however, and as they set about repairing and enlarging their buildings they flew the glider when winds were favorable, keeping their flying reflexes sharp. They apparently also were having lots of fun, trying to see how long they could soar in one place hovering balanced on the wind.

The Wrights were aware that Langley, with great financial backing, was trying to fly his Aerodrome off a houseboat in the Potomac River. Mistakenly assuming that his aircraft was viable, they considered themselves in a serious race and decided to go directly to powered flight with the Flyer instead of testing it as a glider first. Their new building largely finished, the brothers set about assembling the Flyer. Wilbur wrote to his sister Katherine, "The 'whopper flying machine' is coming on all right and probably will be done about Nov. 1st."



The 1902 Glider with three-axis control system in a coordinated turn

November

After the Wrights rebuilt and enlarged their camp at Kill Devil Hill they assembled the Flyer, a process that took three weeks. During that time they learned that Samuel Langley on Oct. 8 attempted to fly his Aerodrome only to have it flop into the Potomac River. "I see that Langley has had his fling and failed," Wilbur wrote to Octave Chanute. "It seems to be our turn to throw down now, and I wonder what our luck will be."

To others closer to the project the Wrights were more confident. "Flying machine market has been very unsteady the past two days," Orville wrote to Charles Taylor, the machinist who built their engine. "Opened yesterday morning at about 208 (100% means even chances of success) but by noon had dropped to 110….It gradually improved during the rest of yesterday and today and is now almost back to its old mark."

The weather had already grown cold and stormy, delaying their work, but in early November the Flyer was fully assembled. The first attempt to run the entire propulsion system ended badly, however, when an engine backfire lashed through the system, twisting a propeller shaft and tearing loose the supporting cross-arm. On Nov. 5 both shafts were sent back to the bicycle shop to be strengthened. "Will thought our best chance of doing the bird act would be to get home before Thanksgiving, but that now seems hopeless," Orville wrote from Kitty Hawk.

The improved shafts arrived on Nov. 20. After battling with sprockets loosening during test runs—solved by a liberal use of Arnstein's hard cement from the bicycle shop —they discovered that one of the new tubular shafts had cracked. Orville went home to make new shafts of solid tool steel. Both Wrights, however, were highly encouraged that thrust tests showed they had more than enough power to fly. Orville returned on Dec. 11, three days after Langley had tried to fly once again and failed in what turned out to be his last attempt. Three days later the Flyer and the Wrights were ready to go flying.

The brothers on Dec. 14th flipped a coin to see who would get the first try and Wilbur won. The wind was about 5 mph, Wilbur estimated. They had to lay their starting track slightly downhill, with a little crosswind. They started the engine and

Wilbur climbed on to the wing, slipping into the hip cradle that controlled the wing warping linked to the rudder, and grasped the elevator control lever in front of him. The Flyer's elevator had double surfaces, much more powerful than the 1902 glider's single elevator, and its hinge position was now in the center of the airfoil, which made the control surface want to deflect to full up or down when moved from a neutral position.

Orville released the restraining wire and Wilbur started down the track in good shape, the aircraft lifting off after about a 40-ft. roll. Then Wilbur, the first pilot of the first airplane, discovered his elevator's sensitivity when he over controlled it in an attempt to climb. The Flyer quickly ballooned 15 feet into the air with rapidly decaying airspeed. Wilbur dropped the nose some but kept it above the horizon, the aircraft sinking until it hit the sand, left wingtip first, slewing around to rest, cracking a skid and part of the elevator. "It was a nice, easy landing for the operator," Wilbur wrote that day. He had flown 105 ft., but neither Wright considered this a "flight."

"The machinery all worked in entirely satisfactory manner and seems reliable," Wilbur said. The power is ample, and but for the trifling error due to lack of experience with this machine and this method of starting, the machine would undoubtedly have flown beautifully. There is now no question of final success."

Wilbur nearly flies, Dec.14, 1903

December

Flight

Looking out of his window at the Kill Devil Hill life saving station on the morning of December 17, 1903, Captain S.J. Payne watched through binoculars as a flying machine, its noise muffled by the distance, rose into the air, its wings rocked by wind, flying straight ahead, finally landing with a light spray of sand. The impossible had been done; Payne was a distant witness to the Wright Brothers' conquest of powered flight.

The day had started poorly for flying. While the previous day's winds had been too calm for flight, this morning brought blustery winds to the flat sands below Kill Devil Hill, a cold air skimming standing pools of water with ice.

Wilbur and Orville Wright tried to wait out the 27 mph winds, but around 10 a.m. they decided the winds were as good as they were going to get that day and put out the signal—a cloth on their shed wall—for the men from the life saving station to come down to assist and to witness the event.

The aircraft was carried out. The 60-ft. track of 2X4s was laid down in a flat depression that several days earlier had held water. The aircraft was set on its launching dolly, which rolled down the track on trucks made of bicycle wheel hubs.

A camera was set up and Orville, the pilot of the first attempt of the day, briefed volunteer cameraman John Daniels when to take the picture, detailing with incredible accuracy exactly how high he would be at what position of the track.

Orville was the pilot this day because he had lost a flip of the coin with his brother three days before. Wilbur was the one to discover the new machine's handling qualities on that first flight attempt when the powerful and touchy elevator pushed him into a climb too steep to sustain flight, the airplane slightly damaged on touchdown.

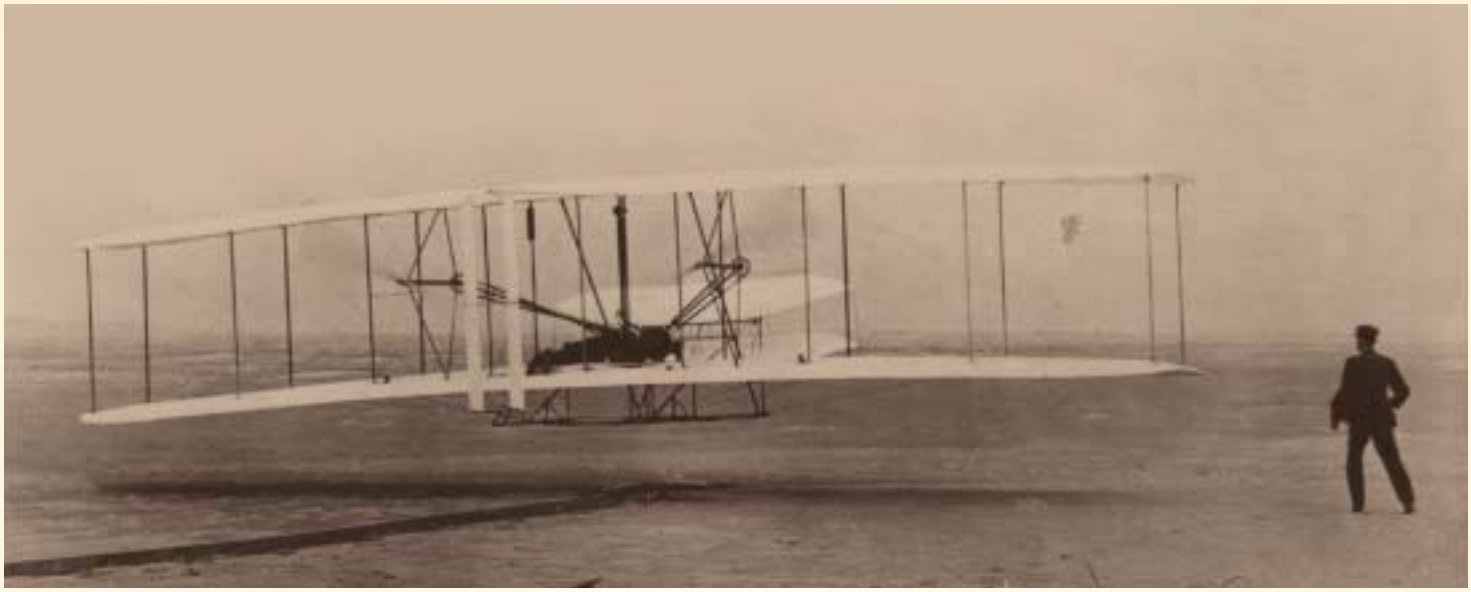
Stoic about the setback, the Wrights fixed the airplane and considered the event a modest success.

Now, on a frigid, windy day on the North Carolina coast, witnesses saw the brothers shake hands, pausing for a moment. Then Orville turned his cap around and settled on top of the wing. The engine had been started and allowed to warm for a minute or two when, with little ceremony, Orville started the takeoff, Wilbur running along side to steady the wing. Orville lifted off cleanly and successfully fought the sensitive elevator in the wind until 12 seconds into the flight, when the aircraft "darted" for the ground, and a safe landing. At 120 feet in distance, this flight was only 15 feet further than Wilbur had flown on the 14th. But this time Orville was in full control and stayed aloft more than 8 seconds longer fighting the wind. In still air he would have covered 540 feet. The Wrights had done it, and at that moment they were fully aware of the importance of their accomplishment.

They asked Daniels if he had taken the picture. Daniels, stunned by what he had just seen, could not say for sure. But he had, snapping what is now considered a perfect picture that forever captures that crystal moment with Wilbur by the wingtip and Orville off the ground in the Flyer. The Wrights didn't know they had a picture until they returned to Dayton and developed the plate.

Just as Orville had learned from Wilbur's experience three days before, Wilbur used what he had observed from Orville's flight and flew further on the next flight, as did Orville on the following effort. But on the fourth flight, all doubts of the ability of the machine, or the pilot, were erased when Wilbur flew for 59 seconds into the wind, covering 852 ft. until landing hard enough to damage the elevator.

Later, as the brothers and their assistants were discussing fixing the Flyer to attempt an even longer flight, a strong gust of wind turned over the Flyer and heavily damaged it. The Wrights packed up the



First Flight 1903

Flyer and shipped it home as they broke camp. The Flyer would never fly again, the Wrights moving on to improved models.

It has been pointed out that many of the elements of that day thought to be hostile for an attempted flight in fact greatly improved the Flyer's ability to take off. The following spring the Wrights began testing a new aircraft near their Dayton home only to discover that, at first, they couldn't get airborne. The low density altitude of that cold day at sea level on the Carolina coast, plus the strong wind, had facilitated their efforts.

In the end, the Wright's success seemed inevitable. Not only had they innovated a new control system, they also had discovered the true nature of lift and the movement of the center of pressure over a curved surface, and they had created a practical propulsion system. And last but certainly not least, they had taught themselves how to fly during the process of discovery. They had the correct mixture of talent, motivation and creativity, plus their incalculable advantage of working together as a true team, complimenting and improving on each other's genius.

The secret of flight clearly would have been discovered without the Wrights, but the Wrights gave the world a package of technology so completely and correctly conceived that further innovation from such a sure base was easy, setting off an exponential growth of aviation technology. The Wrights had opened the door to a new age.

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