The Wright Brothers as Design Engineers

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Abstract

The first successful flight of an engine powered aircraft took place at Kitty Hawk, NC almost one hundred years ago, on December 17, 1903. This flight was a result of the pioneering work of the Wright brothers, Orville and Wilbur. Although they barely completed high school, these brothers from Dayton, OH, have demonstrated that they can truly be considered design engineers. They proceeded through a rational engineering design process by a) studying the existing literature on flight, b) designing, building and testing of kites and tethered gliders, c) building their own wind-tunnel and testing various airfoils, d) flying their self-designed glider for many hours to get flight experience and finally, over a period of less than one year, e) they designed and built an engine, propellers and a successful aircraft, the Wright Flyer. Here, their design process procedures will be reviewed as an example for our students.

Introduction

At the time the Wright brothers began their quest, many people were attempting to build a powered "flying machine". The Wrights succeeded while others failed as a result of their brilliance as engineers and because they approached the problem of powered flight in a highly rational way. Here their approach will be described as an example of rational engineering design.

Two memorable unsuccessful attempts by others will be described briefly before examining the Wright approach. In these cases, the lack of success can be attributed to failure of the use of a rational design process.

The first example is an aircraft built by Maxim (1894 - five years before the Wrights started their design process). He gathered pertinent information, but failed in the conceptualization phase: Instead of testing parts of his design in stages, he spent a great deal of money to immediately build his final aircraft (Fig. 1). It weighed four tons, was powered by a 180 hp steam engine and actually lifted off the ground a few feet, flying several hundred feet until it crashed. After

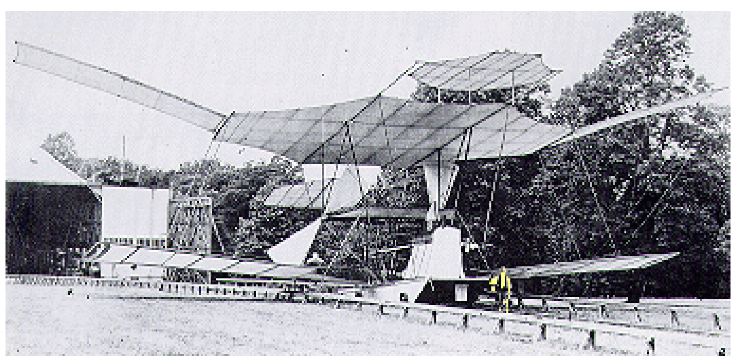

Fig. 1. The first powered aircraft, built by Maxim in 1894 was steam powered and weighed 4 tons. For scale, notice the man (colored yellow). The aircraft actually flew a few feet off the ground for a distance of several hundred feet and then crashed.

that, Maxim lost his interest in flight, but he wasn't hurting for funds as a result of his earlier invention - the machine gun. So Maxim can actually be considered the first person to build a power driven aircraft.

The second unsuccessful design is by Phillips (1904, a year after the Wrights first successful powered flight). It is assumed that he reasoned that since two wings give more lift than one, three will give more than two, etc. Phillips carried this sequence out to the limit (Fig. 2).

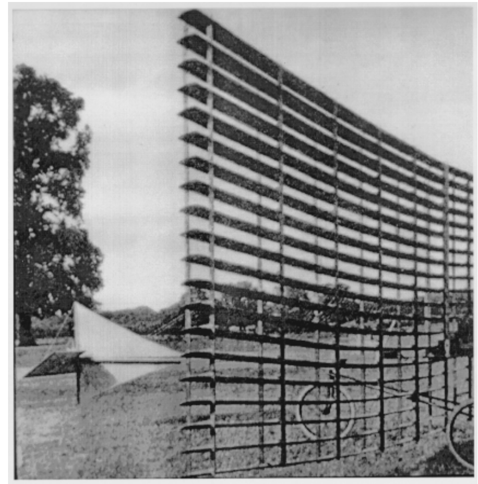
Fig. 2 Phillips (1904) multiplane tested the limit of the sequence that if two wings give more lift than one, three will give more than two, ...

It took the Wright brothers five iterations of the design process to get to the first successful power aircraft. Each iteration, which took about a year, brought them closer to their final success. The iterations started with a kite and progressed to gliders. These gliders were successively improved until they could build their famous powered aircraft. Each iteration also allowed the Wrights to gain valuable experience in learning how to fly.

Orville and Wilbur Wright were designers and manufacturers of bicycles, which were very popular at that time. Their formal education had ended with high school. Having become bored with bicycles, they seriously started to work on the 'flying machine' project in 1899.

Iteration 1 (summer '99)

Once having decided to start this project, the Wrights wrote the Smithsonian Institute (May 30 '99) requesting published papers and a list of important references. From these works they learned what approaches were unsuccessful and some of the challenges which lay ahead. After only two months of having received this material, they had defined the design problem. Their basic requirements for an aircraft were: a) wing-like structures to lift (or support) the aircraft, b) a means of propulsion (propeller and engine), and c) a method of control and balance. Control and balance were recognized to be major problems and so they concentrated their effort on these aspects. Because an aircraft can fly in three orthogonal directions and also rotate in three orthogonal directions, learning how to fly is much more complicated than driving an automobile which translates and rotates each in one orthogonal direction.   They therefore concentrated their design effort on balance and control. Very few of their predecessors gave much attention to this area. In fact, although several replicas of the Wright's first power aircraft have been built, it appears that no one else has succeeded in flying them!

How did they manage to focus upon the essential problem of flight so quickly? Both their brilliance and their good working relationship helped. In trying to reason out a problem, the two brothers would debate it thoroughly, then each would reverse his position and debate it once again. The control problem was solved mainly by what the Wrights called 'warping', the twisting of the wings about their axis. The effect is similar to what is accomplished by ailerons, the flaps at the trailing edge of modern aircraft wings. The source of their idea for control is unclear - perhaps it was from observation of bird flight.

The Wright brothers did not then immediately proceed to build a powered aircraft and attempt to fly it as their contemporaries did. In the summer of the same year they wrote the Smithsonian, they built a small tethered aircraft, essentially a kite of 5 ft wingspan, to test their control system (Fig.3). This represents another important demonstration of the application of a rational design process - the testing of warping. The kite design was based partially on a known biplane configuration. The test was successful; wing warping gave them excellent control of the kite. This design of the kite involved decisions on the airfoil shape, the wing size and the elevator (small wings in front of main wings which are now part of the tail of an aircraft).

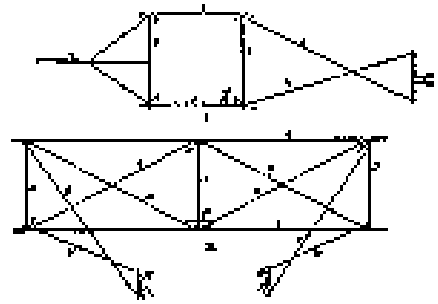

Fig. 3 Sketch of the Wright brothers' 1899 kite. The top sketch is the side view of the kite with the warping control cables at the right. The lower sketch is a front view of the kite also showing the warping control cables.

Iteration 2 (summer '00)

The next step was again not to build a full-scale powered aircraft but to build and test a full-sized glider - one which could carry a person. Their design was tested summer of '00. (All of their tests were performed in the summer because they had to support themselves by repairing and building bicycles during the winters.) As a demonstration of their attention to detail in the rational design process, it is remarkable that they wrote the US Weather Bureau to find an ideal place for their testing. They needed sand for soft landings, strong and constant winds and privacy. Privacy was of concern to them since they were in competition with others. Kitty Hawk, North Carolina was their choice. They lived in a tent with wind-blown sand and a terrible mosquito problem. The tested glider was a 17 ft wingspan biplane, weighing 50 lb (Fig 4). Most of their flights were tethered and controlled by strings from the ground. They found it difficult to simultaneously control its fore-and-aft balance (pitch) and its lateral (roll) stability. Towards the end of the first summer at Kitty Hawk, they had their first successful manned gliding flight (300-400 ft). For this and subsequent glider flights, the aircraft was launched by a brother and an assistant who lifted the aircraft by the wing tips and ran with it until it lifted on its own. Although they failed to get extensive flight experience, they demonstrated that many of their design concepts and assumptions were sound. They also learned that the drag

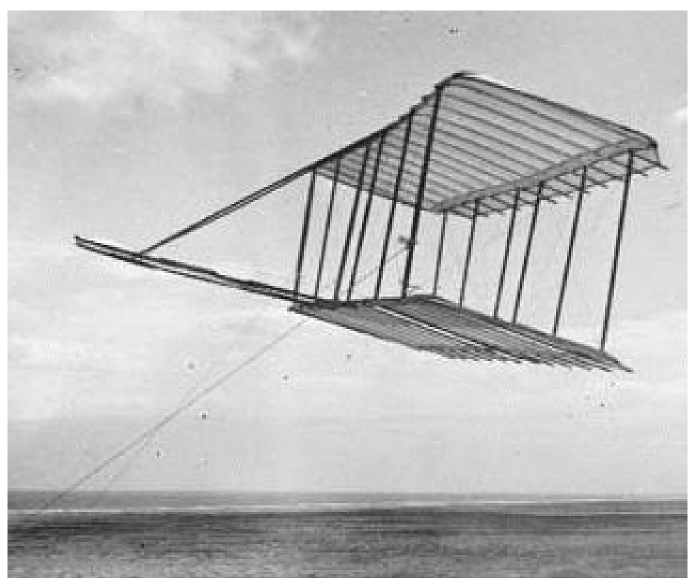

Fig. 4 The Wright brothers first glider, 17 ft wingspan, 50 lb. Notice the tethering strings.

and lift forces they measured were considerably different from those calculated from published data (by Lilienthal).

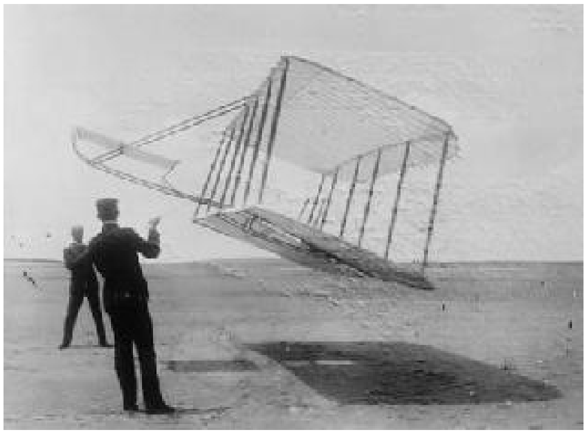

Fig. 5a. The 1901 glider, 22 ft wingspan, 7 ft chord, 98 lb being flown tethered.

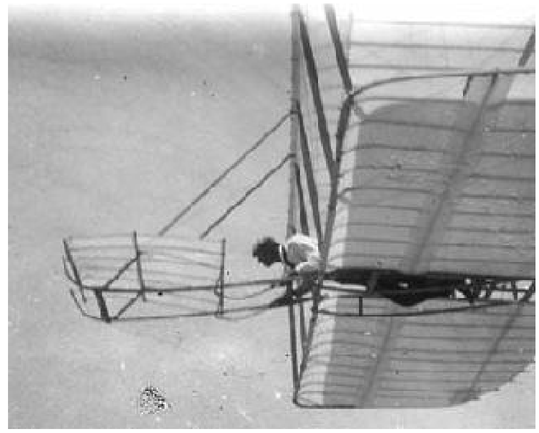

Fig. 5b. The 1901 glider flown by Wilbur Wright.

Iteration 3 (Summer of ‘01)

The objective of this iteration was still to get flight experience but first they had to increase the lift force. The Wrights conjectured that they were not getting the predicted values of lift because their wing configuration differed somewhat by the configuration in the published data. Therefore for their experiments in the summer of ‘01, they built a larger glider (22 ft wingspan, 7 ft chord, 98 lb - Fig 5) and constructed the wings so that their configuration (camber) could be altered in the field. In flying the glider, they still had serious lateral control difficulties and they still did not get the predicted lift and drag forces. They broke camp mid-August feeling so dejected that Wilbur was quoted as having said: “man would not fly for fifty years”. In September of ‘01 they were invited to lecture at the Western Society of Engineers in Chicago. The enthusiastic reception of their talk encouraged them to continue.

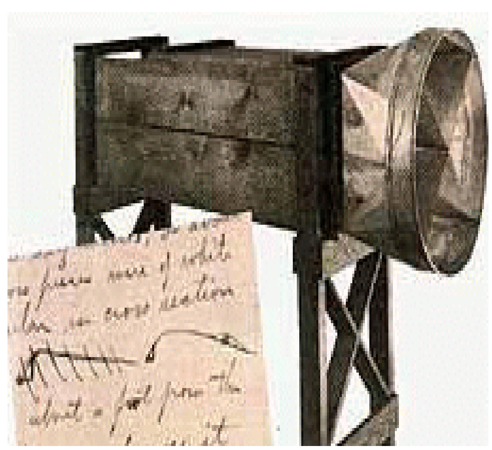

Fig. 6 The Wright brothers’ wind tunnel with a sketch of an airfoil profile.

Iteration 4 (Sept ‘01 to summer ‘02)

The Wrights decided to do their own wind tunnel measurements of lift and drag since their field work contradicted the published results by Lilienthal. Building a wind tunnel is not a trivial task, even for one as basic as the one theirs (Fig. 6). It took them over a month to get uniform air flow inside the wind tunnel. In addition they had to design a device to measure lift and drag forces. Finally, they tested more than 200 different airfoil shapes and compared their values with those measured in the field and with those found in the reference by Lilienthal.. They completed their measurements by December and concluded that the results of Lilienthal were erroneous.

A third, even larger glider (32 ft wingspan) was built which they flew during the summer of '02 (Fig. 7). It was so successful that Orville wrote that their wind tunnel data "would enable us to calculate in advance the performance of a machine". They made over 1000 perfect flights which allowed them to become highly skilled pilots. Their longest glide was 623 ft.

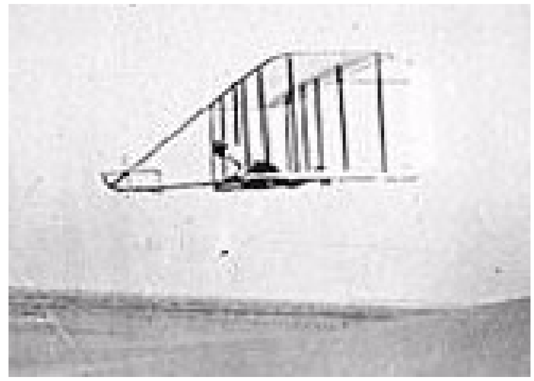

Fig. 7. The 1902 glider constructed after the Wrights wind tunnel tests - 32 ft wingspan

The control problem they had the previous summer (lateral control), had been solved using the rudder in the rear. A rudder works like a wing deflecting the airstream sideways resulting in a lateral force on the rudder.

Iteration 5 (fall '02 to fall '03)

The aircraft support structure phase of the design was completed so that the Wrights were ready for the design of the propulsion method, that is the engine and propeller design. There were dozens of gasoline engine manufacturers available. Out of the many manufacturers the Wrights wrote only ten replied and none of them could meet the Wrights' specifications for power and weight at a reasonable price. Thus, with the help of a mechanic, they designed and built their own engine. It was a crude device, but since it only had to run a short time there was no need for a radiator or water pump for cooling.

A literature search for propeller design information yielded only empirical results and, to quote Wilbur Wright, "the exact action of the screw-propeller, after a century of use, was still very obscure." They therefore spent some time working on the problem of propeller design and came to the conclusion that a propeller can be designed by treating the propeller blade as a rotating wing, using their own wind tunnel data. This contribution to applied fluid mechanics should be ranked as highly as their invention of the powered aircraft. The efficiency of their propellers was 70% while the best propellers of their time were only 50 % efficient. The Wrights decided upon using two counter-rotating propellers.

Their new engine powered aircraft (40 ft wingspan and a 6½ ft chord) was built and tested starting in the summer of '03. It took them several months to correct minor problems such as the loosening of transmission chains and cracked propeller shafts. Finally, on Dec. 17, 1903 when Wilbur was 36 years old and Orville was32, they had their first successful flights, the longest being 852 ft for 59 seconds (Fig. 8).

The Wrights built their second improved airplane and tested it in 1904. Its longest flight was 2.8 miles for over 5 minutes. Their first truly practical flying machine was completed in 1905, their third powered aircraft.

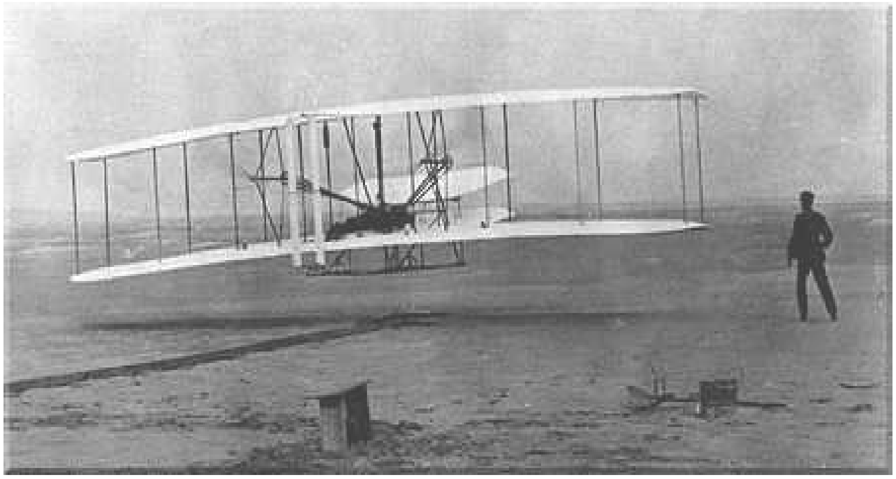

Fig. 8. “First Flight” on December 17, 1903. 40 ft wingspan, 6½ ft. chord.

The Final Step, communication of the design

The Wright brothers failed miserably with this final step of the design process. When they proposed to sell their aircraft and design to the U. S. government, they offered no proof that their aircraft could fly. No photos nor letters from eye witnesses were provided. Since the government offices had received many such proposals, they did not treat the Wright brothers’ letter with the respect it required. The British were more positive but nothing came of it. It would have taken only one flight in public with the press reporting on it to get the government to move, but the Wright brothers were too proud for that. In addition, they were concerned that others would try to steal aspects of their design. They would not allow even a potential buyer to even see the machine before a contract had been signed. It took many years and lawsuits before they were able to sell their design. By that time they had strong competitors.

“How did these two men, essentially alone, accomplish so quickly, and with such sophistication, what had eluded a great many others for so long? ..., the Wright brothers were the inventors of the airplane because they approached the problem with an effective methodology that was undergirded by a number of innate talents and personality traits that were especially conducive to technical creativity.”   (Jakab page 217)

Summary of the Main Design Steps

‘99
• gathering of information: contacted Smithsonian
• definition/analysis of problem: decided to concentrate on control (solution by warping)
• evaluation: small scale test of solution using a tethered aircraft (kite) which proved warping successful
‘00
• analysis/design: assumed data in literature were correct, designed and built full-scale glider
• evaluation: tests on a tethered gilder followed by free flight. They had control problems and

found that drag/lift forces were different from what was expected. Many design concepts were verified.

'01

• analysis/design: an improved glider was designed and built

• evaluation: test of improved glider was disappointing. They still could not get predicted lift/drag forces and had control difficulties: "man would not fly for fifty years"

'02

• analysis/experiment: built wind tunnel and tested many airfoils; literature data were found to be erroneous

• analysis/design: redesigned glider using wind tunnel test results

• evaluation: tests on redesigned glider very successful, obtained the fight experience needed

'03

• analysis/design: design/built engine powered aircraft

- designed and built own engine
- developed method of analysis of propellers and built propellers
- success, Dec 17.

'04 +

• communication of design: poor, they tried to sell their design without showing it to prospective customers.

Bibliography

The material for this article was extracted from lecture notes on the Wright brothers which have been presented locally from time-to-time. These notes were, in turn, extracted from the references given below. As a result of this procedure, there may be unattributed quotes in this article. Also, it is believed that the photographs presented are within the public domain.

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