Program of the

# Thirteenth Annual Conference of the Cognitive Science Society

7-10 August 1991
Chicago, Illinois

LEA
1991
LAWRENCE ERLBAUM ASSOCIATES, PUBLISHERS
Hillsdale, New Jersey Hove and London

# The Invention of the Airplane

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**Abstract**

The invention of the airplane spans a period of 110 years from 1799 when Cayley first described the design of fixed-wing aircraft to 1909 when practical craft were flown at the Reims Air Show. At least 100 different designs were built and tested during this period, often at great expense, and occasionally at the cost of the pilot's life. With the exception of the Wright Brothers, progress was slow and sporadic. The Wrights needed only four years to develop their first airplane. Their efficiency is unique: No other inventor was able to duplicate the steady rapid progress of the Wright Brothers or duplicate their results until details of the Wright craft became available in 1906.

Numerous reasons have been advanced to explain this efficiency. Among these are the Wright Brothers' sense of materials, their focus on the control problem, the availability of gasoline engines, the synergy of the brothers in their work, and constraints imposed by limited funding. Although these factors are important, a crucial difference can be found in the manner in which the Wright Brothers and their contemporaries approached the task of invention. Most inventors spent their time constructing and testing complete craft; the Wright Brothers worked by isolating a problem, finding a system to test potential solutions, and integrating their solution back into an airplane design.

The problem-solving model of scientific discovery in turn explains why the Wright Brothers method was so efficient. The Wright Brothers were exploring a ***function space*** while their contemporaries were exploring a ***design space*** of aircraft. From the properties of the two spaces, it can be shown that search in the function space is far more efficient than search in the design space. Many of the same properties hold for the invention of other complex devices such as intelligent programs.

## Introduction

Sir George Cayley began the process of the invention of the airplane in 1799 with the publication of his paper *On Aerial Navigation*. This paper distinguished between the lifting and propulsion functions of bird wings and showed how these functions could be separated in a fixed-wing craft with propellers. One hundred and ten years later several practical craft were demonstrated at the Reims Air Show in France, completing the period of invention.

Figure 1 depicts the flight distances of 85 gliders and powered craft developed during this period, representing the vast majority of well-documented attempts to conquer the air. These attempts have been grouped into three categories: the Wright Brothers efforts, the efforts of other inventors from 1809 through 1905, and the efforts of other inventors from 1906 to 1909. Regression lines depicting progress over time are shown for each group: the long dashed line running across the figure represents early efforts by non-Wright inventors, the solid line rising sharply from 1900 represents the Wright Brothers, while bold line furthest right represents the efforts of other inventors from 1906 to 1909. In computing these regression lines unsuccessful craft that did not fly or were not tested have been excluded, as were 7 craft for which performance data was uncertain. Each point represents the maximum distance achieved by a particular design.

Trends in Figure 1 are obvious: for the most part, progress was slow and sporadic between 1809 and 1905. The Wright Brothers are a dramatic exception to this tendency. Their progress was rapid and steady. By 1905 they were making flights of 24 miles while their contemporaries were lucky to fly 300 feet. In 1906 the Wrights received a patent covering their control system, and details of the construction of their craft were widely published. Using this information, other inventors were able to copy the important features of the Wright craft and make rapid progress. By 1909 several were able to duplicate the Wright Brothers' success.

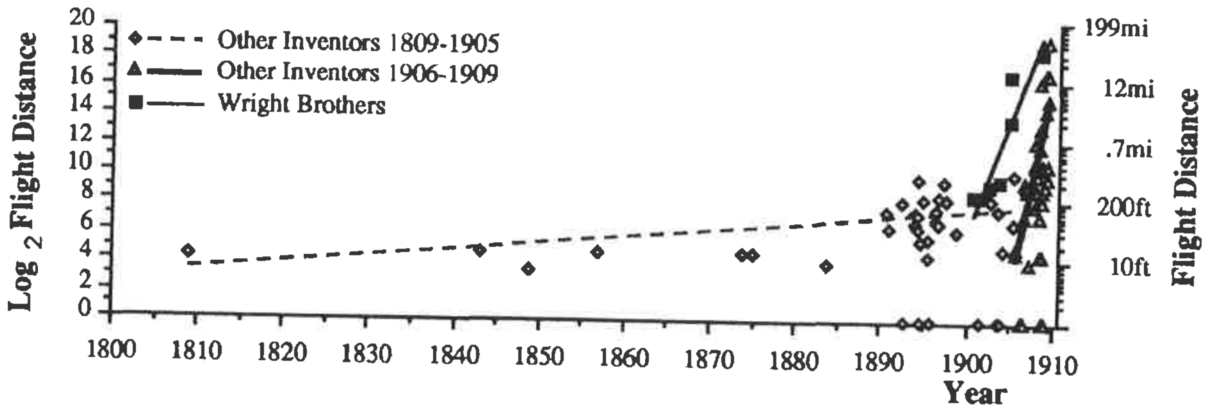


**Figure 1**
**Flight Attempts 1809 - 1909**[1]

## On the efficiency of the invention process

The issue we wish to address is: What made the Wright Brothers so efficient in their invention? This question has been discussed by historians and biographers, and many others as well. As with many other questions, the answer is not simple: Doubtless many factors contributed to the efficiency of the Wright Brothers. Yet many factors that contributed to their efficiency were held in common with other inventors. Our purpose is not to develop a comprehensive list of contributing factors, but to identify what set the Wright Brothers apart from their contemporaries.

Many historians, biographers, and others have suggested reasons for the Wright Brothers' efficiency. Two reasons are frequently suggested by people unfamiliar with the details of the invention of the airplane: the synergy provided by working together as a team and the constraints imposed by limited funding. Doubtless both factors contributed to the Wright Brothers' success, but these are far from unique factors. Many inventors worked in teams: Samuel Langley and Charles Manley, Gabriel and Charles Voisin, Otto and Gustav Lilienthal. Blériot assembled a large and talented team headed by Peyret. Indeed, working in teams was almost a necessity given the task of constructing a person-carrying craft. Along the same lines, we find most of the inventors struggling with limited resources: the Voisin brothers, Herring, even Blériot. None of the serious accounts of the invention of the airplane focuses on these as pivotal factors for the Wright Brothers' success.

Charles Gibbs-Smith, one of the foremost authorities on the history of the invention of the airplane, advances a different reason for the Wright Brothers' efficiency. He divided inventors into two camps: *chauffeurs of the air* and *airmen* (Gibbs-Smith, 1966). A characteristic of the chauffeur approach was the belief that an airplane would be similar to a car. Given sufficient power, a plane could be 'driven' into the air much as a car drives along a freeway. In the chauffeur mentality, muscle substituted for aerodynamics and control. This group focussed their efforts toward the development of large power plants. Sir Hiram Maxim, the inventor of the machine gun, illustrates the chauffeur mentality. Squandering £20,000 of his own funds, Sir Hiram constructed a four-ton steam-powered behemoth in 1894. The wingspread was over a hundred feet. Eighteen-foot propellers drew the unwieldy craft down an 1,800 foot track. On its first test, the plane struggled two feet into the air, broke a guard rail on the track, and was shut down, never to be tested again.

Airmen focussed their attention on the problems of flight with less regard to the development of powered craft. Airmen often built and tested gliders in an attempt to master the art of flight. The Wright Brothers clearly fall into the airmen category. They developed three gliders from 1900 to 1902 before attempting to construct an airplane. Gibbs-Smith's distinction is a useful one: we now recognize the importance of aerodynamics and control in airplane flight. Airmen have an obvious advantage over chauffeurs of the air in developing airworthy craft. Unfortunately, once again we find that this distinction does not differentiate the Wright Brothers from all other inventors. Lilienthal, Pilcher, Chanute, and Herring were airmen, sharing this advantage with the Wright Brothers.

[1] This figure was compiled using the following sources: Crouch (1982, 1989a, 1989b), Dollfus & Bouché (1980), Howard (1987), Jarrett (1987), Magoun & Hodgins (1931), Gibbs-Smith (1966), McFarland (1953), and Schwipps (1979). Models developed during the period are not shown due to the difficulty in equating their performance with larger-scale craft. The figure is not comprehensive: as many as 25 additional attempts are mentioned in Gibbs-Smith (1966) without sufficient detail for inclusion in the table. Few of these craft would have flown as far as 50 feet.

Gibbs-Smith also draws attention to the Wright Brothers' concern with active control instead of passive inherent-stability. Here we find one factor that distinguishes the Wright Brothers from their contemporaries. Even when details of the Wright system of control became available, few appreciated the importance of this contribution to the development of practical craft. Significantly, the Wright Brother's close friend Octave Chanute, who witnessed the success of the Wright gliders and flyers, was unable to appreciate the importance of an active system of control.

Yet the Wright Brothers' concern with active control does not explain all of the efficiency of their invention process. Indeed the control problem was largely solved by the Wrights in 1899 when they constructed a 5' biplane kite to demonstrate the efficacy of wing-warping as a method of lateral control. This kite also had an elevator for horizontal control. During the next two years the Wrights spent little time on this problem; the controls for wing-warping were tied off in most of the trials of the 1900 and 1901 gliders. The 1901 glider had a nearly-complete control system, yet Wilbur was so dismayed by the performance of the craft that he told Orville on the trip back from Kitty Hawk that man would not fly within their lifetime (Crouch, 1989a). In addition to working out the control problem, the Wrights revised lift tables of the day, determined efficient and stable shapes for wings, developed the modern theory of propeller function, and tested wing spars for drag. These developments were not motivated by a concern for active control, yet all were necessary for the first powered flight.

Biographers often mention the Wright Brothers' skill in the construction of lightweight craft. They were good with their hands and knew how to develop strong lightweight structures. In contrast, Samuel Langley would create engineering blueprints of craft, then turn the designs over to workmen for construction. The resulting products were often weak and unstable. Once again this factor is not unique to the Wright Brothers. Lilienthal, Chanute, and Herring were all accomplished at the construction of lightweight, strong craft. Lilienthal and Chanute both had engineering backgrounds. Chanute introduced to the field the biplane design strengthened by the Pratt truss used in bridge construction. This design was used by the Wright Brothers in all their early craft.

Without a doubt all of these factors contributed to the Wright Brothers' efficiency and ultimate success. Yet with the exception of their focus on active control, none of the factors is unique to the Wright Brothers, and so cannot explain their advantage over contemporary competitors. Part of their success derives from their focus on active control, yet this factor is too specific to explain all of the Wrights' success. Of course, success may derive from a subtle synergy of several factors working together, rather than being the product of a single factor. Rather than pursue this line, I will discuss one final factor mentioned by historians: the method used by the Wright Brothers. Although many give the Wrights credit for their method of invention, few comprehensive accounts have been provided that describe the nature of their method, and document why it was so different from their contemporaries.

## Methods of invention

Consider first the style of invention prevalent at the time. A would-be inventor would design and construct a new glider or plane. The craft usually embodied some novel feature that the inventor hoped would enable the craft to succeed where others had failed. The craft would be taken out to the field and tested. In many cases modifications or adjustments would be made to the craft, while at other times the craft would be quickly destroyed in an accident. Eventually the inventor would tire of the design; sometimes he would return to the drawing board to try again, sometimes he would give up in discouragement. Central to this approach is a concern with the performance of a working craft. Inventors measured their success in how high and far the craft flew, how long it remained in the air, and so on. Usually the results were not impressive: only 4 non-Wright craft out of 39 tested up to 1906 broke the 300' barrier, flying further than the length of a football field. Those who went back to the drawing board attempted to utilize their performance data to improve the design of a newer model, although many simply abandoned one ill-considered design in favor of another equally-poor choice.

This approach is termed ***design-space*** search for the prominence given to the design, construction, and testing of complete crafts. The inventor has available a number of different features that may be included in a design, including the number of wings, their shape and placement, the position of the rudder and elevator, propulsion systems, and so on. An inventor might explore a monoplane, biplane, or triplane design. Multiple wings could be arranged in a vertical, staggered, or tandem configuration. The rudder and elevator could be integrated in one unit or divided into two. Wings and tails could be mounted on springs, and so on. To construct a craft, the inventor has to make a decision about each of these factors, which are largely independent of one another. Table 1 shows some of the many features that were manipulated to create different designs for aircraft. Even though the list is far from comprehensive, at least 12,960,000 designs can be realized through different decisions about craft design. The task of the inventor is to determine a configuration of airplane components that leads to a working craft.

Octave Chanute developed an interesting craft in 1896 that illustrates the design-space approach. His glider had six pairs of wings that could be independently placed on the fuselage. The first configuration tested had all six pairs mounted in the front. This configuration was top-heavy. The number of wing pairs was reduced from six to four. Then it was tested with two pairs in front and four in the rear. The wings were shifted about mercilessly; finally the arrangement was fixed with five pairs in front and one pair at the rear. In this configuration it flew a distance of 82 feet. Later an umberella-like appendage, called an aerocurve, was added above the wings. The modified craft made a flight of 188 feet. In designing a glider with

## Table 1: Design space of gliders

| Characteristics of craft | Variants explored by early researchers |
|---|---|
| Number of wings | 1 - 80 |
| Wing configuration | monoplane, biplane, triplane |
| Wing placement | stacked, tandem, staggered |
| Wing angle | anhedral, flat wing, dihedral |
| Camber of wings | 1/20, 1/15, 1/12, 1/8, 1/6 |
| Wingspan | 6' to 104' |
| Chord | 3' to 10' |
| Shape of wings | bird-like, rectangular, bat-like, insect-like |
| Tail placement | forward (canard), rear, mid |

80*3*3*3*5*20*5*4*3 = 12,960,000 different designs

movable wings, Chanute was attempting to expedite the search through the space of glider designs: with a single craft he was able to explore a number of different designs.Even still, the different configurations that were tested represent only a fraction of the possible configurations shown in Table 1.

For the most part, the Wright Brothers did not work this way. Rather than building whole craft, they explored problems related to flight in isolation. This style is apparent from the very beginning of their efforts. Recognizing the need for a method to control the lateral orientation of an airplane to prevent rolls, Wilbur realized that by twisting the wings of an airplane it could be turned into an 'animated windmill' to right itself. The brothers built a 5' biplane kite to test this method. Twisting the wings of the kite proved effective at controlling the lateral movement of the plane. This solution was embodied in every craft the Wright Brothers built through 1909, without significant change.

Having solved the problem of lateral control, the Wrights built and tested their first glider in 1900. Given the innovative nature of the new system for controlling lateral roll via warping the wings, it might be expected that much of the testing that year would center around the controls. Nothing could be further from the truth: the new glider for the most part was flown as an unmanned kite with the wing-warping controls tied off. Wilbur and Orville were confident in their solution to the control problem, and were far more concerned with the amount of lift generated by their glider. They obtained crude estimates of lift using wind-speed data provided by the nearby Kitty Hawk weather station and measuring the pull of the ballasted craft with a spring balance. The obtained lift was far below their expectations, although some of the problem arose because they were forced to substitute short spars in their original design, and the curvature of the wing did not match that used by Lilienthal in determining his tables of lift.

Unhappy with the compromised construction of their first craft, the Wrights built a second glider in 1901. This craft had adequate spars and wing curvature matching the semicircular camber favored by Lilienthal. Before returning to Kitty Hawk in 1901, the brothers realized they needed their own anemometer to obtain reliable measures of wind speed at the test site. Once again the craft was routinely tested as an unmanned kite. Using a spring balance and measurements of wind speed, the brothers quickly realized that the lift developed by their craft was below the expected value. Recognizing the futility of attempts to construct further gliders in an effort to solve the problem of lift, a discouraged Wilbur told his brother on the trip back from Kitty Hawk that man would not fly for fifty years.

Recognizing the limited success of the 1901 glider, an inventor adhering to design space search might have continued to construct and test new 'improved' versions of the craft. The Wrights never appear to have given a moment's thought to this idea. After returning to Dayton, the brothers soon realized they needed another approach to explore the problem of lift. They wanted a way to quickly explore a large set of wing designs, something impractical with full-scale craft. Between September and November of 1901 the brothers built three different instruments to measure lift. One was a simple balance wheel mounted on a bicycle, two others were wind tunnels. Using the third wind tunnel, they were able to measure the lift and drag of fifty different wing designs in three weeks, and found a wing design far more efficient than that used in their 1900 and 1901 gliders.

Armed with this newfound knowledge, the brothers built a third glider in 1902, returning to Kitty Hawk to test it late that year. Although Lilienthal had flown hang gliders that achieved equal distances, the 1902 glider was the first successful aircraft with three-axis control. It represented the solution to most of the fundamental problems of powered flight. From this success, the Wright Brothers turned to the task of developing a powered aircraft. Here they were faced with another problem: how to build effective propellers. In late 1902 and early 1903 the brothers developed the modern theory of the propeller as a moveable wing with forward lift, and returned to their wind tunnel to explore effective propeller shapes. This led to the development of their 1903 flyer, the first successful airplane.

The Wright Brother's method can be understood as a search through the *function space*. For a plane to fly, the wings must have sufficient lift, the power plant must generate sufficient thrust, and the operator must be able to control the orientation of the craft. Rather than exploring the design space for a configuration that met these functions, the Wrights tackled each problem independently, and found effective solutions for each problem. Each feature could be integrated back into the design of an aircraft. This led to a pattern of steady progress: with the exception of the 1901 glider, each craft flew further than its predecessor[2].

## The efficiency of different search methods

The efficiency of the Wright Brothers was a natural outcome of their method of invention. For many inventions, search in the function space is easier than search in the design space. This inherent efficiency stems from two factors: feedback in the function space is more direct than feedback in the design space, and the function space is smaller than the design space.

To illustrate the role of feedback, we must recognize that inventors often use a hill-climbing strategy in their development process: they attempt to use the performance of an existing design to improve upon that design. Consider the problem of applying a hill-climbing strategy to make improvements to a glider or plane. When the current design is tested in the field, the performance of the craft is a function of a number of factors. Many factors are related to the design of the plane, such as the lift of the wings and the drag of the fuselage. Yet external factors play a role in overall performance as well. Is the air still or turbulent? Are updrafts or downdrafts present? Even the density of air and air temperature can have a measurable influence. The plane must be tested extensively to eliminate the influence of external factors. Even still, there is no simple way to attribute characteristics of flight performance to features of the design. Did the craft fly 80 feet because it was a biplane configuration or because it had a rear-mounted elevator? The global performance metrics give few clues to the individual contributions of the design features. Thus, even having an accurate picture of the performance of a craft in the field, it is difficult to develop an improved design. This can be seen in the many setbacks suffered by most inventors: it was not uncommon for a moderately-successful craft to be replaced by one that could not be flown.

Feedback in the function space is far more direct. When the Wright Brothers measured lift in their wind tunnel, they were obtaining direct evidence relevant to wing shape. From this information, they were quickly able to identify an efficient wing. Compared to the design space, feedback in function space is far more diagnostic, so that improvements are easier to discover.

The function space is a smaller space to search than the design space. This is evident when considering the small number of functions a plane must possess to fly: develop sufficient lift to overcome gravitational attraction, generate sufficient thrust to overcome drag, and control the plane in 3 axes. The vast array of contemporary aircraft illustrates that many different designs can execute the same basic functions, evidence that the design space is larger than the function space.

A curious aspect of function space search is that it often involves design-space search in a smaller design space. Consider for a moment the manner in which the Wright Brothers solved the problem of lift. In testing wing shapes, the Wright Brothers engaged in a search of a smaller design space. They had little theory of aerodynamics to guide their construction and testing of fifty wing shapes. The necessary mathematics and physics were not developed until after the airplane was a practical reality. Yet in investigating the design space of wing shapes, the Wrights did not have to concern themselves with other factors of glider design, such as fuselage shape, wing placement, and so on. The design space of wing shapes is a part of the larger design space of gliders and planes, because all wing shapes can be used in gliders or planes, yet gliders and planes involve other design decisions as well. By searching through the more restricted design space, the Wrights were quickly able to identify an efficient wing design, and preserve the efficiency of the function space approach in developing a working airplane.

Given the combination of direct feedback and a reduced search space, the method of investigating the functions of aircraft is far more efficient than constructing and testing full designs. Out of all factors contributing to the Wright Brothers' efficiency of invention, this factor is far more important than others that have been discussed. This method enabled the Wright Brothers to make sustained progress that eluded their contemporaries. How and why the Wrights happened upon this approach is not known, but the difference between Wilbur and Orville and their contemporaries is striking.

## Conclusion

This analysis is based upon the problem solving model of scientific discovery put forward by Herbert Simon (1973). Although invention of a complex device is not synonymous with the discovery of scientific laws, it shares an important component of creativity. The scientist or inventor is understood to be engaged in heuristic search. Drawing upon the general model of problem solving (Newell & Simon, 1972), we see that the Wright Brothers were searching through a different space than their contemporaries. Given the attributes of this search space, their search was inherently more efficient than other erstwhile inventors. As a result of this efficiency of

[2] The 1900 craft flew about 400' with assistance from the ground crew, who ran alongside and stabilized the craft in flight. The 1901 glider flew a distance of 389' in free flight.

method, the Wrights were quickly able to invent the airplane.

Not every invention has the properties of the airplane, and can be subjected to the same type of analysis. However, it is likely that the airplane is not an isolated case. Consider the development of complex intelligent systems, such as speech recognition programs. Inventors can focus their efforts on the construction and testing of complete systems and receive global performance feedback that is not very diagnostic, or they might focus their efforts on functions that must be carried out by the system, then develop and test modules that carry out each function. An advantage the Wright Brothers enjoyed was that the functional decomposition had already been provided by Cayley one hundred years before they began their research. Yet the efficiencies of the function-space method are so great that inventors might consider a program of determining the functional decomposition and working in the function space. Given the advantages of function-space search, this method is likely to be more effective than blind attempts to construct complex systems.

## Acknowledgements

The authors thank Lewis Harvey and Evelyn Ferstl for their assistance in translating German sources, and to the Undergraduate Research Opportunities Program for financial support. Additional funds were provided by the Department of Psychology and the Institute of Cognitive Science.

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