THE FORTY-SIXTH HARMON MEMORIAL LECTURE IN MILITARY HISTORY

The Wright Brothers and the Birth of the Air Age

Tom D. Crouch

United States Air Force Academy
2003

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The oldest and most prestigious lecture series at the Air Force Academy, the Harmon Memorial Lectures in Military History originated with Lieutenant General Hubert R. Harmon, the Academy's first superintendent (1954-1956) and a serious student of military history. General Harmon believed that history should play a vital role in the new Air Force Academy curriculum. Meeting with the History Department on one occasion, he described General George S. Patton, Jr.'s visit to the West Point library before departing for the North African campaign. In a flurry of activity Patton and the librarians combed the West Point holdings for historical works that might be useful to him in the coming months. Impressed by Patton's regard for history and personally convinced of history's great value, General Harmon believed that cadets should study the subject during each of their four years at the Academy.

General Harmon fell ill with cancer soon after launching the Air Force Academy at Lowry Air Force Base in Denver in 1954. He died in February 1957. He had completed a monumental task over the preceding decade as the chief planner for the new service academy and as its first superintendent. Because of his leadership and the tensions of the cold war, Congress strongly supported the development of a first-rate school and allotted generous appropriations to build and staff the institution.

The Academy's leadership felt greatly indebted to General Harmon and sought to honor his accomplishments in some way. The Department of History considered launching a lecture series to commemorate his efforts, and in 1959 the Harmon Memorial Lecture Series in Military History was born.

The Harmon Lecture series supports two goals: to encourage the interest in contemporary military history and to stimulate in cadets a lifelong interest in the study of the history of the military profession. The lectures are published and distributed to interested individuals and organizations throughout the world and many are used in courses at the Academy. In this way, we continue to honor the memory of General Harmon, who during his lifetime developed a keen interest in military history and greatly contributed to establishing the United States Air Force Academy.

LIEUTENANT GENERAL HUBERT REILLY HARMON

Lieutenant General Hubert R. Harmon was one of several distinguished Army officers to come from the Harmon family. His father graduated from the United States Military Academy in 1880 and later served as Commandant of Cadets at the Pennsylvania Military Academy. Two older brothers, Kenneth and Millard, were members of the West Point class of 1910 and 1912, respectively. The former served as Chief of the San Francisco Ordnance District during World War II; the latter reached flag rank and was lost over the Pacific during World War II while serving as Commander of the Pacific Area Army Air Forces. Hubert Harmon, born on April 3, 1882, in Chester, Pennsylvania, followed in their footsteps and graduated from the United States Military Academy in 1915. Dwight D. Eisenhower also graduated in this class, and nearly forty years later the two worked together to create the new United States Air Force Academy.

Harmon left West Point with a commission in the Coast Artillery Corps, but he was able to enter the new Army air branch the following year. He won his pilot's wings in 1917 at the Army flying school in San Diego. After several training assignments, he went to France in September 1918 as a pursuit pilot. Between World Wars I and II, Harmon, who was a Major during most of this time, was among that small group of Army air officers who urged Americans to develop a modern, strong air arm.

At the outbreak of World War II, Brigadier General Hubert Harmon was commanding the Gulf Coast Training Center at Randolph Field, Texas. In late 1942 he became a Major General and head of the 6th Air Force in the Caribbean. The following year General Harmon was appointed Deputy Commander for Air in the South Pacific under General Douglas MacArthur, and in January 1944 he assumed command of the 13th Air Force fighting in that theater. After the war General Harmon held several top positions with the Air Force and was promoted to Lieutenant General in 1948.

In December 1949 the Air Force established the Office of Special Assistant for Air Force Academy Matters and appointed General Harmon its head. For more than four years Harmon directed all efforts at securing legislative approval for a U.S. Air Force Academy, planned its building and operation, and served on two commissions that finally selected Colorado Springs, Colorado, as the site for the new institution. On August 14, 1954, he was appointed first Superintendent of the Air Force Academy.

Upon General Harmon's retirement on July 31, 1956, the Secretary of the Air Force presented him with his third Distinguished Service Medal for his work in planning and launching the new service academy and setting its high standards. In a moving, informal talk to the cadets before leaving the Academy, General Harmon told the young airmen that the most important requirements for success in their military careers are integrity and loyalty to subordinates and superiors. "Take your duties seriously, but not yourself," he told the cadets.

General Harmon passed away on February 22, 1957, just a few months before his son Kendrick graduated from West Point. The general's ashes were interred at the Air Force Academy's cemetery on September 2, 1958. On May 31, 1959, the Academy's new administration building was named Harmon Hall in his memory.

TOM D. CROUCH

Tom D. Crouch is Senior Curator of the Division of Aeronautics at the National Air and Space Museum. Throughout his career, Dr. Crouch has played a major role in planning museum exhibitions. He was involved in planning exhibitions for the Neil Armstrong Museum, Wapakoneta, Ohio; the Ohio Historical Center, Columbus, Ohio; and both the National Air and Space Museum and the National Museum of American History. He is the author or editor of a number of books and many articles for both popular magazines and scholarly journals. Most of his work has been on aspects of the history of flight technology, including *The Bishop's Boys: A Life of Wilbur and Orville Wright*, 1989; *Eagle Aloft: Two Centuries of the Balloon in America*, 1983; *A Dream of Wings: Americans and the Airplane, 1875-1905*, 1981; *The National Aeronautics and Space Administration*, 1987; *Apollo: Ten Years Since Tranquility Base*, 1979; *Charles Lindbergh: An American Life*, 1977; and *The Giant Leap: Ohio Aerospace Events and Personalities, 1815-1969*, 1971. He has won a number of major writing awards, including the history book prizes offered by both the American Institute of Aeronautics and Astronautics and the Aviation/Space Writers Association. He received a l989 Christopher Award, a literary prize recognizing "significant artistic achievement in support of the highest values of the human spirit," for *The Bishop's Boys* and was awarded the Smithsonian Distinguished Lecturer Award for 2002. He holds a bachelors degree from Ohio University, a masters degree from Miami University, and a Ph.D. from the Ohio State University, all in history. In addition, he holds the honorary degree of Doctor of Humane Letters, conferred in June 2001 by the Wright State University. In the fall of 2000, President Clinton appointed Doctor Crouch to the Chairmanship of the First Flight Centennial Federal Advisory Board, an organization created to advise the Centennial of Flight Commission on activities planned to commemorate the 100th anniversary of powered flight.

The Wright Brothers and the Birth of the Air Age

What an appropriate moment to hold a symposium on the Winged Crusade! The Twentieth Century is over. We won the Cold War, and it is a safe bet that everyone in this room appreciates the role that air power played in bringing that about. It seems doubly appropriate in this year, when America commands the sky as no other nation ever has, that we should also be celebrating the centennial of powered, controlled, heavier-than-air flight, an American achievement that shaped the course of the century. Is that a coincidence? Is there something in our national character, our spirit, that specially suits Americans for aerospace achievement?

It is a tempting notion. Wilbur and Orville Wright were certainly the quintessential middle class Americans. Their story seems to exemplify our national strengths and values. They were the boys next door who made good through hard work, common sense, perseverance, and native ingenuity. In fact, however, it is more useful to see the Wrights as especially talented members of an international aeronautical community. They began their own work on a foundation laid by their European predecessors. Initially, their achievement had a far greater impact in Europe than in America.

Octave Chanute, a Chicago-based civil engineer who was the Wright brothers closest confidant in aeronautics, had begun to create an informal international community of flight researchers in the early 1880s. Having surveyed the history of the subject, he launched a vast correspondence with aeronautical experimenters scattered around the globe. He identified flight enthusiasts, gathered information from them, offered encouragement, spread news of what was going on elsewhere, and provided occasional financial support. Chanute wrote an authoritative book, Progress in Flying Machines (1894), published articles on flight technology in popular magazines and professional journals, lectured widely, and organized sessions of aeronautical papers for leading engineering and scientific societies.

Chanute attracted a new generation of enthusiasts into the field. The most notable of these was Samuel Pierpont Langley, who, as Secretary of the Smithsonian Institution after 1887, was effectively the unofficial chief scientist of the United States. In the spring of 1896, Langley and his team launched a steam-powered model aircraft with a fifteen-foot wingspan. The craft remained in the air for one minute and twenty seconds, climbing to an altitude of 70 feet and covering a distance of three-quarters of a mile.

In May, 1900, Chanute received a letter from yet another newcomer. Wilbur Wright, a thirty-three year old bicycle maker from Dayton, Ohio, admitted to being "…afflicted with the belief that flight is possible to man."[1] It was the first of hundreds of letters and telegrams that would pass between the two men over the next decade. Chanute would become the best friend and closest confidant that Wilbur and Orville Wright had in aeronautics. His work would also provide them with their basic approach to an aircraft structure. His most

[1] Wilbur Wright to Octave Chanute, May 13, 1900, Marvin W. McFarland, ed., The Papers of Wilbur and Orville Wright (New York: McGraw-Hill Company, 1953), 15.

significant contribution to their success, however, was to introduce the Wrights to the technical details of Otto Lilienthal's work.

Lilienthal provided the essential starting point for Wilbur and Orville Wright. They had followed his work in newspapers and magazines for almost a decade before their own entry into the field. Their decision to undertake experiments with manned gliders was certainly inspired by his example. He provided the coefficients for lift and drag, and the algebraic equations that would enable them to use such information to calculate the amount of wing area required to lift a glider and pilot into the air at a given airspeed. Without Lilienthal it is difficult to imagine how or where they would have begun.

All of this is to underscore the fact that aeronautical research in the early 20th century was an international enterprise. The achievement of Wilbur and Orville Wright was not dependent on the fact that they were quintessentially American. Had they been born with the same talents under similar circumstances in France, England or Germany, they might still have been the inventors of the airplane. In spite of increasing activity in the U.S., the airplane could as easily have been invented in Europe.

Why Wilbur and Orville? How were these two bicycle makers from Dayton, Ohio, able to succeed where so many others had failed? In part, it was a result of their upbringing and character. They had grown up in an extraordinarily tight knit family, where children were encouraged to explore, experiment, and think for themselves. Their mother, the daughter of a carriage maker, was well educated and good with her hands. Their father, a clergyman whose career was punctuated by a long series of disputes with fellow church leaders, taught his children to have the courage of their convictions and to put their trust and faith in family. Neither Wilbur nor Orville ever married, nor did either of them ever find a better friend than his brother. They knew, understood and trusted one another. Together as the Wright brothers, the whole was much greater than the sum of the parts.

The Wrights obviously brought special gifts and insights to the process of invention. Had you lived next to them on the West Side of Dayton, Ohio, in the year 1899, you would have regarded them as the most ordinary of men – friendly small businessmen, honest as the day is long, devoted to their family. But you never would have guessed that these two brothers were going to solve the great technical problem of the age, and change the course of history in the process. There were clues, however, for those who knew where to look. The airplane was not their first invention. They had designed and built printing presses and self-oiling wheel hubs for the bicycles that they manufactured. In both cases, they had approached the problems of design from their own unique and unexpected angle, producing a device that sometimes puzzled knowledgeable professionals. "Well, it works," remarked a visiting printer who inspected a press that the Wright brothers had constructed, "but I certainly don't see how it does the work."[2]

Wilbur Wright, in his early thirties, was running two small businesses with this younger brother, and living in his father's house. "I entirely agree that the boys of the

[2] Charles J. Bauer, "Ed Sines: Pal of the Wrights," Popular Aviation (June 1938), 40.

Wright family are all lacking in determination and push," he admitted to his sister-in-law. "None of us has as yet made particular use of the talent in which he excels other men, that is why our success has been very moderate."[3] Determined to break that mold, he wrote to the Smithsonian on May 30, 1899, announcing his interest in aeronautics and asking for advice on useful readings in the field. Over the next eight weeks, Wilbur and his brother Orville laid a firm foundation for their future, identifying a few kernels of useful information in the work of their predecessors, and carefully analyzing the problem. It was clear to them that an airplane would be a complex machine composed of three systems. It would have to have wings to lift it into the air, a propulsion system to move it forward, and a means of controlling it in the air.

Lilienthal had built wings capable of carrying him through the air on 2000 flights between 1890 and 1896. Langley's model wings seemed to have worked quite well. The Wright decided that they were safe in combining their own common sense with Lilienthal's data and his approach to calculating the required wing area. They would be flying gliders, so propulsion would not be an immediate problem. In any case, automobile builders were developing ever lighter and more powerful engines. If and when the time came for a power plant, the technology would be available. That left the problem of control. "When this one feature has been worked out the age of flight will have arrived," Wilbur explained, "for all other difficulties are of minor importance."[4]

Aerodynamic control was the element of the total problem that had received the least attention. Model builders like Samuel Langley had to design inherent stability into their craft, employing wing dihedral and a horizontal tail set at a slightly negative angle to keep the model moving forward in a straight line. As a result, they learned nothing about flight control. Most glider builders had relied on weight shifting control, moving their legs and lower torso in an effort to keep the center of gravity of the machine on top of the center of pressure of the wing. It was a dangerous technique that limited the size of the machine and the extent of control that a pilot could maintain. It had killed both Lilienthal and the English experimenter Percy Pilcher, who died in an 1899 glider crash. The Wright brothers were determined to develop a mechanical system that would enable the pilot, with a few simple movements, to maintain absolute control over an aircraft at all times.

After a false start or two, the brothers came up with the notion of inducing a twist across the entire wing, increasing the angle of attack, and lift, on one side of the machine, and reducing the angle, and the lift, on the other. By manipulating the geometry of the wing in this fashion, they would control the movement of the center of pressure with regard to the center of gravity, maintaining precise control of the entire machine.

In addition, they were decided on a specific structural design – a biplane configuration in which the two wings were linked through a system of struts and wires in a

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[3] Wilbur Wright to Lulu Billheimer Wright, June 18, 1901, in box 7, Papers of Wilbur and Orville Wright, Manuscript Division, Library of Congress.

[4] Wilbur Wright, "Some Aeronautical Experiments," Journal of the Western Society of Engineers (December 1901).

standard engineering truss. In this manner, the relatively frail single wings were transformed into a very strong-trussed beam structure. The basic idea was inspired by a well-engineered trussed biplane glider developed by Octave Chanute and his associates in 1896. The Wright brothers added their own brilliant twist to the design, however. Like the Chanute original, they would rigidly brace their biplane along the leading and trailing edges. They would not truss the ends, however. Rather, the wires that would warp, or twist, the wings would be a closed loop, maintaining the strength of the beam across the ends, while at the same time allowing for wing warping. It was brilliant, elegant engineering.

The creation of a system to provide effective lateral control is an example of the extent to which Wilbur and Orville Wright were able to think in non-traditional ways. They had the ability to visualize a machine that had yet to be built, and to imagine how it would behave with forces operating on it. It was only one of a series of gifts that enabled them to succeed where so many others had failed.

They had an intuitive grasp of a process that would enable them to move forward toward a full solution to the manifold problems of flight. It was something more sophisticated than the notion of design, test, and incorporate the lessons learned in the next design. Had their approach been that simple, they would not have been able to isolate and study problems in a specific system. Rather, the brothers were able to test specific aspects of their craft. With some notable exceptions, they were careful to incorporate changes in a new design so that the impact of a single alteration could be evaluated.

Wilbur tested the basic wing warping system with a kite built and flown in Dayton in the summer of 1899. Having satisfied themselves that their system of lateral control would work, the next step was to design and build a full scale machine. Using Lilienthal's table of lift and drag coefficients they calculated the wing area required to lift the estimated weight of the glider and a pilot in a wind of given velocity. The calculations indicated that the craft would either have to have enormous wings or be flown in a considerable headwind. Correspondence with the U.S. Weather Service regarding average wind speeds across the U.S. led to the selection of Kitty Hawk, NC, as the site for a "scientific vacation," during which they could test their new craft.

When testing began, it was immediately apparent that the craft was generating far less lift than their calculations had predicted. True to their method, the brothers tied off the flight control system to simplify matters and focus on the central problem at hand. The Wrights devised a means of precisely measuring the forces acting on their machine when being flown as a kite. They attached a grocer's scale to the kite line, which provided a measure of the total force operating on the machine. They measured the angle of attack at which the kite was flying, and determined the wind speed with an anemometer. With that information in hand, and some simple trigonometry, they could calculate the actual lift and "drift," or drag generated by craft.

Their next machine, the 1901 glider was both the least satisfactory and most instructive of their aircraft. They made the mistake of introducing too many variables. Unsure as to the source of the aerodynamic problems encountered in 1900, they increased the wing area of their 1901 glider from 165 feet to 290 square feet, adopted a much lower aspect ratio, and introduced a radically different airfoil. While the larger wing area allowed the Wrights to make repeated glides, the aircraft was still delivering 20% less lift than the calculations predicted. Because of the multiple changes in wing design, the brothers had no way of isolating the problem, or understanding the impact of any one of the variables.

Worse, now that the Wrights were spending more time in the air, they discovered serious and unexpected control problems. When the pilot warped the wings to increase the lift on one side of the machine, that wing would often slow and drop, rather than rising, sending the aircraft into an incipient spin. The Wrights reasoned that addition of a rudder would balance the increased drag on a positively warped wing and allow effective lateral control. When incorporated into the design of the 1902 glider, the rudder was originally fixed. It was almost immediately made moveable, however, and linked to the wing warping system to increase its effectiveness in countering adverse yaw and allowing for smooth and controlled banks and turns.

At the end of the 1901 season at the Kill Devil Hills, Chanute assured the Wrights that they had moved far beyond all previous experimenters. Indeed, the Wrights were pleased to have spent some time in the air, to have discovered the problem of adverse yaw, and to have come up with a tentative solution that they could test on their next machine. At the same time, they knew that the continuing gap between their calculations and the actual performance of their first two gliders was evidence of a serious underlying problem. While they had not suffered any serious injuries in 1901, the fate of Lilienthal and Pilcher was never far from their minds. "When we left Kitty Hawk at the end of 1901," Wilbur later recalled, "we doubted that we would ever resume our experiments."[5]

Instead, they did a courageous thing, discarding all of the Lilienthal data on which they had based their performance calculations. It was the great turning point in their story. Had they suspected that there were problems with the inherited information at the outset, they might never have begun. They would not have had a firm starting point. Now they set out to gather their own data. They employed a simple airfoil device mounted over the handlebars of a bicycle to confirm that the existing data was flawed. The next step was to build a wind tunnel.

Francis Herbert Wenham had built the first such aerodynamic testing device in the 1870s with a grant from the Aeronautical Society of Great Britain. If the Wrights did not invent the wind tunnel, they were certainly the first to produce useful balances, the delicate instruments placed in the air stream inside the tunnel to measure the minute forces playing across the miniature wings being tested. Small enough to fit in a shoebox, constructed of old hacksaw blades and bicycle spoke wire, the two balances – one to measure lift, the other resistance – were brilliantly conceived mechanical analogs of the algebraic equations that the brothers were using to calculate performance. There is no clearer example of Wilbur and

[5] Wilbur Wright, "Brief and Digest of the Evidence for the Complainant…." The Wright Co. vs. the Herring Curtiss Company and Glenn H. Curtiss in Equity, National Archive.

Orville's ability to move from the abstract to the concrete, from a mathematical formulation to a brilliantly conceived machine that would provide the precise bit of data required.

Lilienthal had tested on a singly airfoil shape. In less than a month during the fall of 1901, the Wrights gathered data on the lift and resistance of over forty airfoils through an entire range of angles of attack. In addition, they conducted wind tunnel experiments to determine the best aspect ratio for a wing, the efficiency of various wingtip shapes, and the aerodynamic effect of changing the gap between the wings of a biplane. No longer dependant on borrowed data, the brothers could now move forward with confidence. It was the great turning point.

The 1902 Wright glider was the result of two years of experience in the field, and a few short weeks of pioneering research with the wind tunnel. Unlike its predecessors, the new glider performed exactly as calculations predicted. The addition of a moveable rudder resolved the control problems of 1901. After three years of effort, the Wrights had achieved their initial goal – to produce a heavier-than-air flying machine operating under the complete control of the pilot. Wilbur and Orville completed perhaps 1000 glides with the machine between September 20 and October 24, 1902, and continued to fly the glider the following year, while they were assembling and testing their 1903 powered machine.

The Wrights did not patent a powered flying machine. They patented their 1902 glider, reasoning that three axis flight control was a patentable system. No one, they were confident, would be able to fly without drawing on ideas covered by their patent. Their all-important aerodynamic data, which could not be patented, would be kept secret and made available to manufacturers who purchased the right to use their patent.

If Wilbur and Orville had overestimated the reliability of the aerodynamic data gathered by their predecessors, they had also underestimated the difficulties that they would face in the area of propulsion. The engine was not the problem. When a preliminary contract failed to turn up a manufacturer willing to build a power plant to their specifications, they decided to design and build it themselves. Charles Taylor, the machinist whom they employed at the bike shop, produced an engine that did the job. It was not a particularly powerful engine. The key was that fact that the brothers could calculate the power required to fly, and estimate a maximum weight for the engine. Once they had a power plant that met their specifications, they were satisfied. Any attempt to improve the engine beyond what was required, they realized would represent over engineering, and a waste of time and effort.

The Wrights had not anticipated difficulties with propeller design. Their original assumption that they could borrow a design approach from marine propellers proved incorrect, however. In order to produce propellers whose thrust could be accurately calculated, the Wrights developed a theoretical approach to propeller design that began with a recognition that a propeller was a rotary wing, in which the lift was vectored as thrust. The brothers were familiar with the work of the physicist/engineer W.J.M. Rankine, and used a form of what engineers call blade element theory to design their propellers. Recent wind tunnel tests revealed that first generation Wright propellers are almost 80% efficient. That is to say, the propellers transform 80% of the engine horsepower delivered to them into thrust.

A modern wooden propeller for a light airplane is usually only 85% efficient. No other experimenters of the era came even close to the efficiency achieved by the Wright propellers. That is what kind of engineers they were.[6]

This year we celebrate the centennial of the four powered, sustained and controlled flights that the Wright brothers made from the sand flats at the base of the Kill Devil Hills, four miles south of Kitty Hawk, NC, between 10:35 AM and noon on December 17, 1903. Of course that was not the end of the process of invention. On the best of those four flights, Wilbur Wright flew 852 feet over the sand in 59 seconds. The brothers knew that, with practice and an opportunity to keep improving the elements of their machine, they could do much better.

The Wrights decided to continue their experiments at Huffman Prairie, a 100-acre pasture some eight miles east of Dayton. By working close to home, they could devote full time to their experiments while keeping an eye on their business and avoiding the expense of living away from home. They worked at Huffman Prairie for the next two years, designing and building a new airplane each year. Initially, they found that the absence of steady headwinds made it difficult to get into the air. In September 1904, they resolved this limitation by using a catapult system and began to make real progress. By the fall of 1905, they were covering distances of over twenty miles through the air, flying tight circles over their field for over half an hour at a time. They had transformed their marginal success of 1903 into the reality of a practical airplane.

The brothers were never happier than when they were wrestling with a difficult technical challenge. “Isn’t it wonderful,” Orville wrote to his friend George Spratt, “that all of these secrets have been preserved for so many years just so that we could discover them”[7] The process of invention that had begun with a wing-warping kite in the summer of 1899 was now complete, but the career of the Wright brothers was far from over.

The Wrights grounded themselves from 1905 until 1908, while they struggled to market their invention. By May of 1908, with signed agreements in hand for the sale of airplanes to both a French syndicate and the U.S. Army, the brothers equipped their 1905 airplane with upright seating for a pilot and passenger and a new upright control system, they returned to the Kill Devil Hills to brush up their flying skills with the new arrangement. Then Wilbur was off to France, where he made his first public flights at the Hunaudières racecourse, near Le Mans, on August 8, 1908. Orville followed this first flight to demonstrate their machine to the U.S. Army at Fort Myer, Virginia, on September 3, 1908. For five years, the brothers had been shadowy figures, their claims widely reported in aeronautical circles, and widely doubted. They swept all of the doubts away with these first public flights, and emerged as great public heroes on both sides of the Atlantic.

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[6] Robert L. Ash, Stanley J. Miley, Drew Landman and Kenneth Hyde, “Evolution of Wright Propellers Between 1903 and 1912,” American Institute of Aeronautics and Astronautics Paper #2001-0309; see also propeller information on the Wright Experience website: http://www.wrightexperience.com/pdfs/props.pdf

[7] Orville Wright to George Spratt, June 7, 10903, Marvin W. McFarland, ed., The Papers of Wilbur and Orville Wright (New York: McGraw-Hill, 1953), 313.

Of course, by 1908, the Wrights no longer had the sky to themselves. Alberto Santos-Dumont, a wealthy Brazilian living in Paris, had flown his airplane, *14-bis*, 722 feet through the air in 22.5 seconds on November 12, 1906. On October 26, 1907, Henri Farman piloted his *Voisin* aircraft through a full, remaining in the air for 74 seconds. It was the first time that anyone had matched the Wright brothers 1903 performance. In July 1908, just a month before Wilbur made his first flights in France, Farman remained in the air for twenty minutes, twenty-two seconds at Ghent, Belgium. There was fresh activity in America, as well. On July 4, 1908, Glenn Hammond Curtiss, from Hammondsport, NY, won the Scientific American Trophy for the first flight in the U.S. of more than one kilometer.

It is safe to say that none of those individuals would have flown had it not been for Wilbur and Orville Wright. The brothers were as important to this generation as Lilienthal had been to them. Now they were the starting point. They had met Glenn Curtiss, and answered his technical questions and those of his colleagues in the Aerial Experiment Association, a group organized by Alexander Graham Bell in 1907. In 1900 and 1901, the brothers had published three technical articles, complete with photos of their first two gliders.[8] Chanute had described their work to his wide circle of correspondents, and given a slide illustrated lecture on the subject to the members of the *Aero Club de France* in April 1903. The substance of the talk, and the illustrations, were published within the month.

Virtually all of the French aviators who took to the air in 1907-1908 had entered the field as a result of Chanute's lecture/article. Most of the new generation of French aeronautical pioneers began by building their own versions of a Wright glider. Santos-Dumont's *14-bis* and the early machines designed and built by the Voisin brothers and Henri Farman were braced biplanes with pusher propellers and an elevator located in front of the leading edge of the wing. That is not a natural configuration. The French used it because they knew that was what the Wrights had done. None of them understood or appreciated the Wright control system, but they knew what the Wright aircraft looked like, and they knew the Wrights had flown. Make no mistake; the subsequent history of aviation begins with the Wright brothers.

The Europeans who began running to catch up with the Wright brothers swept past them by 1909, and kept right on going. Having mastered flight control after Wilbur's first flights in France, they seized leadership in world aeronautics from the land where the airplane had been born. Louis Bleriot's flight across the English Channel on July 25, 1909, followed by the first great international aviation meet and competition held a month later (August 22-29) on the plain of Bethany, three miles north of the cathedral city of Reims, marked the beginning of European hegemony in the air. The six years remaining before the outbreak of war in August 1914 witnessed constant startling improvements in performance, almost all of them the work of Europeans.

New developments in engine technology were of central importance. By 1914, the four cylinder, 12.5 horsepower Wright engine of 1903 had given way to 100 hp eight

[8] For all of the Wright's published articles, see Peter Jakab and Rick Young, The Published Writings of Wilbur and Orville Wright (Washington, D.C.: Smithsonian Institution Press, 2000)

cylinder water-cooled in-lines and 90-140 hp rotaries like the *Gnôme*. Louis Bechereau had incorporated the monocoque structure, originally developed by the Swiss engineer Eugene Ruchonnet, in the design of the *Deperdussin* racing monoplanes. Hans Reissner experimented with corrugated aluminum wings, while Ponche and Primard produced the *Tubavion* monoplane, the first genuinely all-metal aircraft.

Henri Fabre made the first water take-off on 28 March 1910. The Russian Igor Sikorsky pioneered very large aircraft with his four engine *Bolshoi* of 1913. The following year, Glenn Hammond Curtiss produced a multi-engine flying boat intended to fly the Atlantic. The ocean would have to wait for another five years, but, by August 1914, the North American continent had been flown coast-to-coast, both ways, and both the Alps and the Mediterranean had been traversed by air.

On December 17, 1903, the world's first airplane had traveled a maximum distance of 852 feet in 59 seconds, reaching a speed of 30-35 m.p.h. and an altitude of 10-15 feet. Ten years later, only six years after the Wrights had first flown in public, the records had increased to a speed of 126.67 m.p.h. (Maurice Prevost in a *Deperdussin*); a distance of 634.35 miles over a closed circuit (A. Seguin in a *Farman*); and an altitude of 20,079 feet (G. Legagneux in a *Nieuport*).

The American Glenn Curtiss had won the first James Gordon Bennett race, staged as part of the Reims meet in 1909. By 1913, the U.S. could not field a competitor for the same race. "We could not send an American biplane or monoplane over," Alan Hawley, President of the Aero Club of America, explained, "because none of our machines are half speedy enough." The airplane, born in America, came of age in Europe.[9]

How did the nation that had given birth to the airplane fall so far behind so quickly? It has often been suggested that the series of patent suits brought by Wilbur and Orville Wright were to blame for the retarded growth of aeronautics in the United States. A careful analysis of the situation is an important first step in understanding the underlying economic and political forces that would drive flight technology for the rest of the century.

The American aviation industry got underway on March 3, 1909, when Glenn Curtiss and Augustus M. Herring incorporated the Curtiss-Herring Company. They quickly sold one airplane to the Aeronautic Society of New York and began entering prize competitions. The Wright Company was incorporated under the laws of the State of New York on November 22, 1909. Wilbur served as president of the firm, and Orville as vice president. The board of directors included August Belmont, Cornelius Vanderbilt, Robert Collier and other leading figures in American business and finance. Corporate offices were in New York, but the heart of the operation, the factory and flying school, were in Dayton, where the brothers could retain personal control.

[9] Henry Serrano Villard, Contact!: The Story of the Early Birds, Man's First Decade of Flight From Kitty Hawk to World War I (New York: Bonanza Books, 1968), 192.

The new factory began production in November 1910, turning out Wright Model B aircraft. Powered by a 40 horsepower engine, it was the first Wright production aircraft, and the first Wright machine mounted on wheels. When operating at full capacity, the workmen could push two airplanes a month out the factory door. The company produced 12 distinct aircraft designs between 1910 and 1915, when Orville Wright sold his interest in the firm. While precise figures are not available, the Model B and Model C, which sold to the U.S. Army, were produced in the largest numbers. Other models included the EX, which Calbreath Perry Rodgers flew from coast to coast in 1911; the Model R, designed for air racing; and the Model G flying boat.

Even before the founding of the company, the Wrights and their backers had recognized that the basic Wright patent, granted in 1906, was one of their most valuable assets. The era of the patent suits began August 18-19, 1909, when the Wrights filed a bill of complaint enjoining their principal American rival, Glenn H. Curtiss and the Herring-Curtiss Company, from the manufacture, sale or exhibition of airplanes that infringed on the Wright patent.

The patent litigation spread to Europe in 1910, when the Wright licensees, the *Compagnie Generale de Navigation Aerienne* (CGNA), brought suit against six rival aircraft manufacturers (Bleriot, Farman, Esnault-Pelterie, Clement-Bayard, Antoinette, and Santos-Dumont) for infringing on the Wright's French patents. The following year, a consortium of five German aircraft builders brought suit against the incorporators of the German Wright Company in an effort to overturn the Wright patents in that nation.

The patent suits proved to be difficult, expensive and time-consuming for all parties. In the end, they failed to produce a clear-cut resolution. In Germany, the courts invalidated the Wright patents, arguing that prior disclosure, the publication of information on the basic elements of the Wright airplane before the approval of their patent, had compromised their claims. The French suit, complicated by a very different legal system and the absence of spirited prosecution by the CGNA, was still not fully resolved when the Wright's French patents expired in 1917.

The situation in the U.S. was just as complex. As early as January 3, 1910, Judge John R. Hazel of the U.S. Circuit Court at Buffalo, NY, had issued an injunction prohibiting Glenn Curtiss from the manufacture or sale of aircraft. Curtiss posted a $10,000 bond and appealed the decision. He could legally continue flying until the appellate court reached a decision, but he took a terrible risk in doing so. If Judge Hazel's decision was upheld, Curtiss would have to negotiate a settlement with the Wrights covering all of the monies earned while the injunction was in effect. Curtiss moved forward with the prospect of financial ruin staring him in the face.

On January 13, 1914, the judge of the U.S. Circuit court of Appeals of New York ruled in favor of the Wrights. Rather than taking immediate financial vengeance against Curtiss, the leaders of the Wright Company, sensing the opportunity for monopolistic profits, announced the schedule of rates that they would charge anyone who wished to exhibit an airplane in the United States. Glenn Curtiss, represented by the best lawyers that money could buy, announced that he would immediately alter the control systems of his aircraft so that they no longer infringed on the Wright patent. Few knowledgeable individuals believed that was possible, but it was enough to muddy the waters and set the legal process in motion once again.

Ultimately, Orville did profit from the patent suits. He sold his interest in the company to a group of New York financiers in 1915 for an undisclosed sum said to have been in the neighborhood of $1.5 million. Certainly, it appeared that the patents might enable the firm to dominate the new industry. Orville sold out at the perfect moment, acquiring a personal fortune that would enable him to live comfortably for the rest of his life. Two years later, in 1917, industry leaders, with the support and advice of the federal government, brought the era of the patent trials to an end by purchasing the rights to all aeronautical patents and creating a pool of leading manufacturers who would share access to all patents.

Did the long battle over patents retard the growth of American aeronautics? Evidence to the contrary begins with the fact that the Wright Company was much more severely damaged by the patent suits than the Curtiss Aeroplane and Motor Company. Consider the matter of aircraft sales, the most basic measure of corporate success. Between 1909 and 1915 Wilbur and Orville Wright and the various Wright companies operating on the basis of their patents, sold a total of fourteen aircraft to the U.S. Army, their largest single customer.[10] Orville Wright estimated the total production of the Dayton factory between 1910 and 1915 at roughly 100 airplanes.

During the same period, the companies controlled by Glenn H. Curtiss sold a grand total of <u>232</u> aircraft to the U.S. Army. This number, representing 24 distinct designs, was almost half of the total number of aircraft purchased by the Army prior to U.S. entry into W.W. I, and nearly ten times the number of Wright aircraft purchased during this period.[11] In addition, sixteen of the first 27 aircraft purchased by the U.S. Navy were Curtiss machines. The Burgess Curtiss Company, unrelated to Glenn Curtiss, produced four of those original naval aircraft. The Wright brothers were in <u>third</u> place with the sale of only three machines to the Navy. After 1913, Curtiss sales to the Navy skyrocketed, while the Wright Company sales to the Navy were at an end. The precise figures for civil and foreign aircraft sales are not available, but Curtiss' success in marketing single and multi-engine flying boats to several Allied nations suggests that he was more successful in those categories as well.[12]

[10] James C. Fahey, <u>U.S. Army Aircraft (Heavier-Than-Air), 1908-1946</u> (New York: Ships and Aircraft, 1946), 6.

[11] Ibid.

[12] Precise statistics on early U.S. military aircraft purchases are difficult to find. The best sources include: Fahey, <u>U.S. Army Aircraft</u>; Robert B. Casari, <u>U.S. Army Serial Numbers and Orders, 1908-1922 Reconstructed</u> (Chillicothe, Ohio: Military Aircraft Publications, 1995; <u>United States Naval Aviation, 1910-1980</u> (Washington, D.C.: Naval Air Systems Command, NAVAIR 00-SOP-1), appendices 4 and 8; William T. Larkins, <u>U.S. Naval Aircraft, 1921-1941</u> (NY: Orion Books, 1988), 344-348.

Curtiss prospered during the patent suit era, while the Wrights suffered. At the end of the period, Glenn Curtiss was the most successful producer of aircraft in America. He was the principal supplier of training aircraft to the U.S. government, and the only American manufacturer producing combat aircraft of his own design for the Allies. The Wright brothers were out of the airplane business.

Why did the Wright Company suffer as a result of the patent suits? The reasons are not so difficult to understand. Wilbur and Orville Wright, the engineering geniuses at the heart of the firm, paid far more attention to winning victory in the patent suit than to the development of new and improved products. In truth, the brothers wanted most of all to be recognized as the true inventors of the airplane, and for the world to appreciate the magnitude of their accomplishment. Victory in the patent suits, and any money that resulted, would symbolize the realization of those goals. Glenn Curtiss, on the other hand, wanted nothing more than to develop, build and sell improved aircraft. He had bet that good lawyers would see him safely through the patent suits. While the patent suits may have frightened some embryonic U.S. aircraft firms, the fact that Curtiss won his bet suggests that the patent suits had at best a limited impact on the development of aviation in the United States.

If the patent suits do not explain the retarded growth of the industry in America, what forces were at work? Before the First World War, the pressure of competition was an important factor encouraging technical progress. Initially, there was little to differentiate the prizes and rewards available to aviators in Europe and America. That began to change by the summer of 1909, as the leading European powers sought to showcase the aeronautical achievements of their citizens. Having served as the site of repeated competitions, cities like Blackpool, Hendon, Reims, Milan, Vienna, and Berlin emerged as world aviation centers. Between May 1910 and October 1913, Johanisthal, the principle Berlin flying field, hosted a total of <u>seven</u> *Flugwoche* (flying weeks), offering a total of 312,900 *marks* in prize money. In addition, the field served as either the starting point or an important stop on a number of famous long-distance contests, including the Circuit of Germany (June 12-July 10, 1910); the Berlin to Vienna Race (June 9, 1912); and the Circuit of Berlin (August 31-September 1, 1912).[13]

The more strenuous competition and richer prizes available in Europe fueled technological change. In the U.S. the leading aviators were members two or three touring exhibition teams who earned salaries for performing aerial stunts to thrill crowds of paying customers. There were no better pilots in the world than men like Lincoln Beachey and Walter Brookins, but they did not face the constant pressure to fly higher, faster and farther against a wide range of competitors, week after week. More important, their technology was not tested either. The original configuration of the Wright airplane -- a pusher biplane with a canard elevator – remained the U.S. standard until 1911, when a series of accidents among military aviators led companies like Curtiss and Martin to switch to the tractor configuration.

[13] Ibid., 162.

The threat of war was an even more important factor. No one was certain what military utility the airplane might have. Faced with rising international tensions between 1900 and 1914, however, European leaders could ill-afford to allow a rival nation to forge ahead with the new technology. "With Russia and Austria-Hungary in their present troubled condition, and the German Emperor in a truculent mood," Wilbur Wright noted, "no government dare take the risk of waiting to develop practical flying machines…."[14]

As a result, European governments encouraged the development of a domestic aircraft industry through investment and subsidies.

The scale of European investment in flight technology is apparent in a table listing national spending for aeronautics prepared by U.S. Army officials in 1913.

Total Government Expenditureson Aviation, 1908-1913

(All figures in U.S. dollars, 1913)

Germany	$28,000,000
France	$22,000,000
Russia	$12,000,000
Italy	$8,000,000
Austria	$5,000,000
England	$3,000,000
Belgium	$2,000,000
Japan	$1,500,000
Chili	$700,000
Bulgaria	$600,000
Greece	$660,000
Spain	$550,000
Brazil	$500,000
United States	$435,000
Denmark	$300,000
Sweden	$250,000
China	$225,000
Roumania [sic]	$200,000
Holland	$150,000
Serbia	$125,000
Norway	$100,000
Turkey	$90,000
Mexico	$80,000
Argentina	$75,000
Cuba	$50,000
Montenegro	$40,000

(All figures are from: Aeronautics in the Army, Hearing before the Committee on Military Affairs, House of representatives, Sixty-Third Congress, First Session, USGPO, 1913)

[14] Fred C. Kelly, ed., Miracle at Kitty Hawk: The Letters of Wilbur and Orville Wright (NY: Farrar, Straus and Young, 1951), 170.

In addition to official appropriations, several leading aeronautical powers had also established national subscriptions that provided an additional $7,100,000 in financial support for their aeronautical industries. Once again, Germany led the way with $3,500,000 in private funds, followed by France ($2,500,000), Italy ($1,000,000), and Russia ($100,000). According to official U.S. government estimates, the nation's of the world had spent a total of $93,620,000 in public and private funds on aviation between 1908-1913.[15]

How was this money spent? England, France, Germany and Russia invested large sums on state-supported, well-equipped aeronautical research facilities. Patriotic philanthropists also contributed to the cause. In France, for example, industrialist Henri Deutsch de la Meurthe, Gustave Eiffell, and Basil Zaharoff pursued aerodynamic research, created aerodynamic institutes at French universities, and established endowed chairs in aeronautical engineering.[16]

In addition to government support for flight research, European nations nurtured aircraft manufacturers. The impact of this funding was dramatic. By 1914, the Farman company employed l,000 individuals in a series of plants scattered around Paris.[17] During the years 1909 to 1914, *Bleriot Aeronautique* produced 800 airplanes. The fact that two major firms, *Deperdussin* and *Nieuport*, prospered in spite of the early loss of very strong founders, is striking evidence of a growing industrial maturity. European governments at least occasionally targeted spending to support a troubled company. In April 1910, for example, when a flood devastated the *Voisin* factory, the French government ordered 35 aircraft from the firm in a successful effort to prevent a collapse.[18]

The European propulsion industry also prospered during the years leading up to the First World War. In 1913 alone, the 650-800 individuals employed at the Gnome factory at Gennevilliers, produced a total of 1,400 rotary engines. Renault, the second largest French producer of aircraft engines, provided fully one-third of the power plants purchased by the French military. The French aeronautical engine industry, the world leader by 1914, combined the use of the latest American machine tool technology with the older French tradition of handcrafted excellence in the metal trades.[19]

Without the incentive of war looming on the horizon, the United States did not even attempt to keep up. In 1910-1911, a period during which the U.S. Army took delivery of 14 airplanes, the French government ordered over 200 flying machines. In 1912, a committee

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[15] Aeronautics in the Army, Hearing before the Committee on Military Affairs, House of Representatives, Sixty-Third Congress, First Session, (US GPO, 1913).

[16] Walter T. Bonney, The Heritage of Kitty Hawk (New York: W.W. Norton, 1962), 155.

[17] L'Aerophile, no. 6 (15 March 1914), 124-127.

[18] Ibid., 16.

[19] John Morrow, The Great War in the Air: Military Aviation from 1909-1921 (Washington, D.C.: Smithsonian Institution, 1993), 33.

of wealthy French patriots raised four million *francs* to supplement the national budget for military aviation.[20] That year the U.S. Secretary of the Navy pointed out that that France had spent $7,400,000 on flight to date. Russia had spent $5,000,000; Germany $2,250,000, and Great Britain and Italy $2,100,000 each. Even Japan ($600,000) had out spent the U.S. ($140,000).[21] By 1913, fourteen nations -- including Belgium, Japan, Chili, Bulgaria, Greece, Spain and Brazil – were spending more on aviation than did the United States.

European nations recaptured the lead in flight technology, not because the Wright patent suits had retarded American development, but because European government investment had fueled the rapid development of aviation. The gap grew even wider as the pressure of war further accelerated developments in Europe. The result was, of course, that American airmen flew off to war in 1917 in aircraft that had been almost entirely designed and built, in Europe.

By that time, of course, the Wright brothers were no longer an active force in aeronautics. Wilbur had died of typhoid in 1912. The members of the family blamed it on the stresses and strains of the patent suits. Having sold the Wright Company in 1915, Orville allowed the Dayton-Wright Company to use his name, and served as a consulting engineer with the firm during World War I. He made his last flight as pilot in command on May 13, 1918. He would remain an honored figure, showered with honorary degrees and other awards and honored at scores of dinners and ceremonies for the rest of his life. The Wright achievement was commemorated by a great national monument dedicated in 1932, overlooking the spot where the brothers had made their first successful sustained and controlled powered flights. President Wilson appointed him to membership on the National Advisory Committee for Aeronautics in January 1918, a position he held until his death on January 30, 1948.

By then, the U.S. was the world's dominant airpower. The American aircraft industry had finally achieved parity with Europe during the years immediately following World War I. There things remained until the design revolution of the mid-1930s. The new generation of streamlined, all-metal aircraft that took to the air in those years were not the result of any one breakthrough. Rather, they were the end product of a wide range of innovations in structures, aerodynamics and propulsion that had occurred over a period of at least fifteen years.

The process of change began with the development of the first metal aircraft prior to WW I, continued with the introduction of duralumin, and culminated with the appearance of anti-corrosive coatings and new machine tools and production techniques. Variable speed and constant pitch propellers enabled the new aircraft to make full use of powerful radial engines shrouded in drag reducing cowlings. Stressed skin cantilevered wings, streamlining, the retractable landing gear and flush riveting reduced drag, while high lift devices enabled the new all-metal, high-performance monoplanes with their high wing loading to take-off

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[20] Ibid., 13. Professor Morrow provides the definitive account of the growth of the airframe and engine industry in the U.S. and Europe prior to and during WW I.

[21] Bonney, Heritage, 156.

and land safely. Each innovation had been significant in its own right. When engineers combined them to create a new generation of aircraft during the years 1933-1935, they added up to a revolution in aircraft design and performance.

It was an international revolution. Streamlining, monocoque construction, and other structural innovations appeared in France before 1914. Metallurgical developments, experience in metal aircraft design, and theoretical research in areas from aerodynamics to structures had flowed from Germany to other parts of Europe and America. English engineers took the early lead in radial engine design, and provided such key innovations as the sodium cooled valve and the first drag-reducing cowling. An English aircraft won the Guggenheim Fund Safe Airplane Prize by demonstrating the use of the slats and flaps that would enable larger, heavier aircraft to take-off and land safely.

While the impact of the design revolution was apparent in new aircraft produced in many nations, it was obvious that American industry was most successful at integrating new technologies into successful aircraft. New American airliners like the Douglas DC-3 set a world standard. The enormous industrial expansion of the U.S. aircraft industry during World War II completed the process begun in the 1930s.

America did not have a monopoly on good ideas or brilliant engineers. The European origins of the jet engine and the large ballistic missile were proof of that. The strength of the American economy, heavy post-war government spending on all aspects of the aerospace enterprise, a strong commercial airline system, a thriving military and civil space program and other factors insured that those ideas would find their fullest expression in the U.S. The success of the U.S. aerospace industry has been a major factor in our success as a nation since 1945. Through the end of the 1970s, U.S. manufacturers supplied perhaps 75% of the world's large commercial airliners. By the end of the century, as noted at the outset, the success of American air power enabled the nation to control the airspace over any potential battlefield.

As we look forward into the 21st century, problems cloud the horizon. American power inspires bitter opposition. Global competition challenges traditional American mastery of the market for large commercial aircraft. Analysts point out that our high tech work force is aging. And among the many things that we learned on September 11, 2001 was the relative ease with which adversaries who are weak in traditional military terms can turn the most sophisticated products of flight technology against us. The terrorist hijackers paid absolutely no attention to the good intentions of the men and women who design, build, and operate modern airliners. The words of historian Melvin Kranzberg ring truer than ever. "Technology is neither good, nor bad," he explained, "nor is it neutral."[22]

For better or worse, flight technology is ours to do with what we will. A thousand years from now, when our descendents look back on the 20th century, they will surely remember this as the time when human beings first took to the sky. Whatever its near-term consequences, flight has had a profound psychological impact on us.

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[22] Melvin Kranzberg, "Technology and History: 'Kranzberg's Laws,'" Technology and Culture 27 (1986): 544-560.

The Wright brothers launched a new era in history – the age of flight. The author of this paper works in a museum that is a shrine to the air age. In an average year, 9 million people will walk through the doors of the National Air and Space Museum (NASM) – 14 million in our best year. We welcome more visitors than the British Museum, the American Museum of Natural History, the Metropolitan, or the Louvre. It is the most visited museum in the world. When NASM opened to the public on July 1, 1976, the staff was confident of success, but no one expected the enormous number of visitors who arrived that first summer, or the wave of media enthusiasm that washed over the building. President Gerald Ford commented that the museum was "our bicentennial birthday present to ourselves." In fact, those of us who planned the museum could take only limited credit for its success.

The quality of the NASM collection is a far more important factor. What other museum in the world, covering any subject, can offer such riches? Visitors to the NASM can see the world's first airplane; the world's first military airplane; the first airplane to fly around the world; the *Spirit of St. Louis*; the Lockheed Vega that Amelia Earhart flew across the Atlantic; Wiley Post's *Winnie Mae*; Howard Hughes' classic H-1 racing aircraft; the B-29 *Enola Gay*; the Bell X-1 that Capt. Charles Yeager, he of the right stuff, first flew faster than sound; the world's fastest airplane; the first airplane to fly around the world non-stop and unrefueled; the first balloon to circumnavigate the globe; the first helicopter to fly around the world; the world's oldest liquid propellant rocket; the spacecraft that carried the first American into orbit; and the Apollo 11 Command Module, *Eagle*, that brought the first human beings to walk on the surface of another world home again. And that is only the tip of our iceberg.

But the core of the museum's appeal runs deeper even than the opportunity to see the actual aircraft and spacecraft in which intrepid men and women wrote the history of the 20th century in the sky. However one assesses the immediate consequences of aviation, flight remains one of the most stunning and magnificent of human achievements. People flock to the NASM from around the world because this is a museum that makes them feel proud to be human.

That is the legacy of Wilbur and Orville Wright. They were the inventors of the airplane in a much truer sense than Thomas Edison can be said to have invented the light bulb or Alexander Graham Bell the telephone. The Wrights chose the most difficult technical problem in sight. They analyzed the complex and confusing record of pervious experiments in the field, focusing their attention on flight control. Having selected a starting point, the brothers demonstrated their innate sense of a process of invention. They had to learn to fly gliders, risking life and limb, as part of that process. When their gliding experiments failed to provide necessary information, they developed a wind tunnel balance, an elegant engineering instrument that opened the way to success. In six short years, Wilbur and Orville Wright had produced an invention that would define the course of the 20th century.

The achievement of heavier-than-air flight involved nothing more nor less than the realization of the oldest and most potent of human symbols. To fly is to escape restraint, soar over obstacles, and achieve mastery and control of our fate. Suddenly, the old dream, which had become the very definition of the impossible, was a reality. If human beings could fly, what could they not accomplish? The invention of the airplane threw open the doors to unimagined possibility. That, it seems to me, is an achievement worth celebrating.

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