Aeronautical Research in Ohio

Keynote Address
CUG 2003
May 13, 2003
Columbus, Ohio
Janet R. Daly Bednarek, Ph.D.
University of Dayton

Copyright© 2003, Janet R. Daly Bednarek. All Rights Reserved.

Aeronautical Research in Ohio

Just as in many ways Ohio can claim to be the birthplace of aviation, so it can also claim to be the birthplace of modern aeronautical engineering research, for not only did Wilbur and Orville Wright invent the airplane, they also invented modern aeronautical engineering research. And since the seminal work of the brothers from Dayton, the state of Ohio has been a location for a rich variety of important aeronautical research activities. A full accounting of the accomplishments and contributions of aeronautical research in Ohio would take longer than the time allotted. For that reason, I will focus on events at two important nodes of activity – Dayton and Cleveland. From the first work of the Wright Brothers at the turn of the twentieth century through World War II, Dayton held a position of prominence in the world of aeronautical research. What started in a bicycle shop soon spawned active research laboratories at first McCook Field and then at Wright Field. After World War II a second important center of aeronautical research appeared in Ohio. In 1941 the National Advisory Committee for Aeronautics (NACA) broke ground next to the Cleveland Municipal Airport for its new Aircraft Engine Research Laboratory (later known as the Lewis Laboratory and now the NASA Glenn Research Center). At first focused on research dealing with reciprocating engines, before the end of World War II this NACA laboratory soon shouldered much of the burden of helping the United States catch up to and then surpass the world in jet engine technology. As the space age dawned, the laboratory turned to research on rocket propulsion. At several points in the twentieth century, the Lewis Lab had some of the most advanced wind tunnels and computers at work in the world.

In addition to looking at aeronautical research activity at two locations in Ohio, I will also focus on basically three phases in the development of modern aeronautical research. Peter Jakab, an historian with the National Air and Space Museum in

Washington, D.C., has identified these three important phases in the history of aeronautical research. They are: the invention phase (the work of the Wright Brothers); the maturing of research and the creation of an interconnected industry, government and military research establishment (the inter-war period to present); and the computer revolution with the introduction of computational fluid dynamics (since late 1960s).[1] In all three phases, individuals and organizations in Ohio provided vital leadership.

The Wright Brothers and the Invention of Aeronautical Engineering Research

Most historians agree that the main reason the Wright Brothers succeeded in inventing the airplane when so many contemporaries failed is that they adopted a systematic engineering approach to the problem. While their work also involved a number of important conceptual breakthroughs, at the root laid an engineering methodology that provided the foundation for their work.

The Wrights began where most other engineers of their time would have begun – with a literature search. This allowed them the opportunity to familiarize themselves with this emerging field of research, absorb the useful ideas available, and avoid wrong turns down blind alleys. Following this initial step, the Wrights then adopted a number of approaches and applied many of their own skills to the problem. First of all, as several historians have noted, the Wrights recognized that the airplane was not a single technology, but a system of technologies (aerodynamics, control, structures, propulsion, etc.). Each area represented a research and design problem and each had to be solved before an airplane would fly. Continuity of design also marked the Wright brothers' approach. Their first gliders through their powered airplane all evolved from a single basic design. Each was tested thoroughly and lessons learned from one model were applied to the next. The Wrights also engaged in technology transfer. Most notably, much of the hardware on the Wright Flyers came from their bicycle shop including the sprocket-and-chain drive transmission system that connected the propellers to the engine crankshaft. Also, their experience with bicycles taught them that the bicycle was an inherently unstable machine, but one that could be controlled. This led the Wrights to think of the airplane as an unstable machine that could be controlled. With this concept in mind, the Wrights developed their three-axis control system. It was the control system, perfected on their 1902 glider that the Wrights patented. And they also had the skills necessary to move from conceptual models to functioning hardware. As Jakab described it, "They could visualize technological components, manipulate and refashion them in the mind's eye, and then transform them into a working mechanical device."[2]

In addition to this rather standard engineering methodology, one that could be applied to any area of engineering research, the Wrights also adopted two fundamental research tools that became central to aeronautical engineering practice and research – "the use of the wind tunnel in aerodynamic research and flight testing as a data-gathering and information feedback resource."[3]

First, the Wrights did not invent the wind tunnel. What they did, however, was to used a wind tunnel to gather "specific aerodynamic data" that they then "incorporated directly into the design" of their airplane. The Wrights began their research assuming that the published data on aerodynamics was correct. They designed their first two gliders using that data. After both gliders failed to perform as predicted, the Wrights began to suspect that the data, specifically the published coefficients of lift, were incorrect. They then determined to do their own research to gather aerodynamic data and chose the wind tunnel as their tool. Crude though it was, the six foot long and sixteen inches square tunnel provided them with the data they needed to recalculate the coefficients of lift to a very high degree of accuracy, even by more modern standards. They then applied what they learned in the wind tunnel to the design of their 1902 glider.

It then performed as their new data had predicted. They went on to apply that same wind tunnel data to the design of their propellers and wing struts. The Wrights put the wind tunnel and its data at the heart of their endeavor, a place wind tunnel research still occupies today.[4]

Secondly, the Wrights conducted systematic flight testing. They subjected each of their craft to a "slow, systematic, incremental series of field trials, observing and recording performance characteristics, and feeding that information back into the design." This approach provided them with critical information. It also provided them with an important margin of safety as within the flight test process the Wrights learned to pilot their aircraft.[5]

In the decades that following their successful flights at Kitty Hawk, the use of wind tunnels and flight testing, introduced by the Wrights, gradually became fundamental elements of aeronautical engineering research, especially as the field matured in the years between the start of World War I and the conclusion of World War II.

The Maturation of Aeronautical Research: McCook and Wright Fields

In the United States, between 1914 and 1945 aeronautical engineering and research matured, developing the partnerships between government, industry and universities still so much a feature of research today. The creation of this research establishment included the Congressional authorization for the formation of the National Advisory Committee for Aeronautics (NACA) in 1915, the building of the Langley Memorial Aeronautical Laboratory in Hampton, Virginia, and the research programs established by the Guggenheim Fund for the Promotion of Aeronautics at such universities as MIT, Stanford and Cal Tech. It also included the US Army Air Service's Engineering Division Experiment Station at McCook Field in Dayton.[6] In the mid-1920s, the Army's air arm, now known as the Air Corps, moved its research station from McCook to nearby Wright Field.

Following US entry into World War I and the Congressional call for 22,625 aircraft (backed by a $640 million appropriation – the largest appropriation for a single purpose in US history at that point), the Army established a "temporary" research installation for Army Air Service engineers at North Field in Dayton. Later renamed McCook Field in honor of a local family of Civil War heroes, this temporary facility grew to 69 buildings and 2300 personnel by the time of the armistice in November 1918.[7]

Despite its initial temporary status, McCook Field soon boosted of some of the best aeronautical research facilities in the country. It had a sod airfield with a 1,000-foot long, 100-foot wide macadam and cinder runway. Its buildings housed a 14-inch and a 5-foot wind tunnel. Its engine torque stands and propeller whirl rigs were among the most powerful in the world. Using this and other equipment, the engineers and test pilots at McCook laid the groundwork for aeronautical research in the Army. They "investigated aerodynamic phenomena, propulsion technologies, and structural attributes of aircraft, often inventing or refining analytical methods as they went." The engineers at McCook also developed the first reliable methods of static and impact testing. For static testing, for example, they loaded aircraft wings with bags of shot or lead bars to simulate the stresses encountered in flight. Other accomplishments included: improvements to existing liquid-cooled engines; refining superchargers; and, perhaps most importantly, aiding the development of air-cooled radial engines. Engineers also developed new protective paints and fabrics, as well as new fuels and specialized materials for aviation use. While the operations at McCook Field eventually convinced the Army that building whole airplanes in-house was not economical, the work done there laid the foundation for a strong policy of cooperation between the military and private industry aimed at encouraging the growth of the aviation industry in America. Aeronautical research at McCook expanded rapidly during the war and the immediate post-war period, so much so that even as early as 1922 the Army began looking for an alternative, larger location.[8]

Business leaders in Dayton, including John H. Patterson and his son, Frederick, from the National Cash Register Company, determined that Army aeronautical research had to stay in the Dayton area. To that end, they spearheaded a campaign to raise the funds necessary to purchase a large parcel of land just outside the city to present to the Army as a new location for the activities at McCook Field. Founded in 1922, the Dayton Air Service Committee raised over $425,000. With that money they purchased 4520 acres of land east of Dayton. Included in the purchase was the land that had been used as the Air Service's Wilbur Wright Field (a training base) during World War I and the Fairfield Intermediate Depot. In 1924, the Dayton Air Service Committee "sold" the land to the government for $2 and the following year Congress began appropriating the funds necessary to move the facilities at McCook Field to the new Wright Field.[9]

At about the same time, Congress passed the Air Corps Act of 1926. Under the provisions of this act, the newly established Air Corps created its Material Division. This new organization was responsible for all aviation engineering and research as well as the procurement, supply and issue of Air Corps aircraft and material. Proponents of the Air Corps Act offered a number of reasons for supporting Army aeronautical research. First, it would provide the Army with state-of –the-art aircraft in peacetime, thus better preparing the Air Corps for any eventual war. Second, they believed that such research, and the technological advances that would come with it, would further encourage the public's interest in flight. And the infant aviation industry also believed that increased research activity would benefit not just the military, but industry as well. Private industry would gain contracts to develop many of the new technologies emerging out of Army research. These new technologies included the earth inductor compass, high-altitude cameras and film, and aerial torpedoes.[10] While the relationship between the military and industry was not without its points of friction, its closeness clearly indicated the anticipated, if not necessary, interrelationship between the two.

It has been argued that both the organizational structure and the physical layout of Wright Field anticipated the "weapons system" approach of coordinated research that emerged after World War II. Concern for efficiency and coordination guided the design of many buildings at the field, in particular that of the Main Laboratory Building which housed the Experimental Engineering Section. This building had 150,000 square feet of uninterrupted floor space and provided "physical proximity and thus easy communication between all the different groups working within."[11] Those groups included the five branches of the Engineering section – Aircraft, Power Plant, Equipment, Materials, and Armament. A document from 1928 specifically noted, "the fact that they are under one roof, in one room, affords splendid coordination and promotes efficiency of operation to a degree that would be impossible under other conditions."[12] Such communication was crucial as changes in one area could affect all the others. For example, a stronger engine might necessitate a larger or more durable propeller; an engineer-propeller combination aimed at maximizing thrust might also produce vibrations that would, in turn, necessitate a stronger fuselage. Within the Aircraft Branch of the Engineering Division, engineers examined all the different technologies that comprised the contemporary military aircraft. While each technology (propellers, structural elements, engines) eventually had their own facilities beyond the Main Laboratory Building and organized their own research, nonetheless at Wright Field they operated in an atmosphere of close coordination.[13]

Further evidence of a more integrated approach to research is found in the Physiological Research Laboratory that opened at Wright Field in 1935. The Material

Division viewed the pilot as much a "researchable" component as any other part of an aircraft. This also, it has been argued, demonstrated the atmosphere of open inquiry at Wright Field where "virtually any aspect of aviation that could be identified was worthy of careful scientific attention."[14]

Flight testing also remained a part of the aeronautical research scene in Dayton. Following in the tradition of the Wright brothers, pilots from McCook field conducted flight tests both at McCook Field and nearby Wilbur Wright Field during World War I. They flew American, allied and captured enemy aircraft. They set a number of altitude, speed and endurance records. And in doing so, they pioneered American flight test methods and research.

One of the most important early test pilots in Dayton was James Harold "Jimmy" Doolittle. Doolittle came to Dayton to attend the Air Service's Engineering School at McCook Field. He graduated in 1923. The following year, returning from MIT, where he was pursuing a master's degree in aeronautical science, Dootlittle conducted a series of flight acceleration tests in a Fokker W-7 at McCook. The results of these tests taught the aeronautical research world much on why wings failed in flight. They also formed the basis for his master's thesis, "Wing Loads as Determined by the Accelerometer," and earned Doolittle a Distinguished Flying Cross (his second) in 1929. Doolittle went on to earn one of the first doctorates in aeronautical sciences.[15]

Flight testing continued after the McCook facilities moved to nearby Wright Field. There the Air Corps test pilots engaged in extensive flight testing as aircraft design and manufacture moved from wood to metal and from biplane to monoplane models. They tested both military and commercial aircraft – attack, pursuit, bomber, trainer, transport, and amphibious aircraft all benefited from the work of test pilots and engineers at Wright Field.

Toward the end of World War II, Colonel Ernest K. Warburton, a test pilot from Wright Field, visited the British Royal Air Force's Empire Test Pilot School. When he returned to Dayton, he determined to establish a Flight Test Training Unit, following a formal curriculum based on the British model. While his actions were important, the crucial breakthroughs came with the arrival of then Colonel Albert Boyd, known as the "father of modern flight test." He arrived at Wright Field in 1945 and immediately established exacting standards for experimental test pilots." Boyd wanted pilots who were highly skilled in the air, but also had the talents of an engineer. What began at Dayton, Ohio, though, as the Air Material Command Experimental Test Pilot School soon began moving operations to Muroc Air Force Base, California. In 1949, Muroc changed its name to Edwards AFB and the test pilot school – soon renamed the Air Research and Development Command Experimental Test Pilot School – finished its move to Edwards in 1951.[16]

While research and flight testing remained important in Dayton through World War II and to the present, other centers of activity emerged in the state. These new centers, especially the one constructed in Cleveland, continued the maturation of aeronautical research and the building of partnerships between government, industry and universities.

The Role of Lewis Laboratory

In the 1930s the NACA began to lobby Congress for funds to create a new Aircraft Engine Research Laboratory. Congress had created the NACA in 1915 in response to the fact that after leading the world in aviation research in the early years of the twentieth century, after 1910 aviation in the United States had rapidly fallen behind developments in Europe. The NACA, with its research facility in Virginia, succeeded in once again making the United States a leader in aeronautical research by the early 1930s.

However, that lead was again slipping away by the middle of that decade, especially in the area of propulsion. In particular, well-trained German scientists and engineers were at work, steadily improving the quality of both air-cooled and liquid-cooled engines. By the late 1930s, German aircraft with advanced liquid-cooled engines were capable of speeds of over 400 miles per hour. At that time warnings about the advances made by Germans in engine technology reached officials in Washington from numerous sources. Charles Lindbergh, for example, returned from his trip to Germany and immediately reported to General Henry "Hap" Arnold, soon to become the chief of the Air Corps. Following that meeting, Lindbergh agreed to chair a Special Committee on Aeronautical Research Facilities. He was convinced that the United States had to create an engine research laboratory focused on the development of liquid-cooled engines. In addition to Lindbergh, the periodical *Science* also called for such a facility, pointing to "the superiority of foreign liquid-cooled engines."[17]

Even before Congress authorized the money, the NACA began planning for a new engine laboratory. George Mead, designer of Pratt & Whitney's Wasp and Hornet engines, headed the NACA's Power Plants Committee. In late 1939, Mead created a Special Committee on New Engine Research Facilities to develop the design for the proposed new facility. Among the first decisions made, the new laboratory would focus its research on both liquid- and air-cooled engines. The committee also decided that the new facility should include a wind tunnel for the altitude testing of aircraft engines. At the time, only three such tunnels existed in the United States, and none could test engines at the altitudes being reached by the new European engines. In testimony before Congress, George Lewis, the NACA engineer who would go on to direct the new laboratory, emphasized the limited amount of fundamental engine research being conducted in the United States. He stated in no uncertain terms in his congressional testimony that the new laboratory would engage in important fundamental research. Finally, following the fall of France in June 1940, Congress appropriated the funds for the new facility.[18]

Just as planning for the new facility predated the Congressional authorization of funds, so too did efforts to bring it to Cleveland, Ohio. Leading the charge was Frederick C. Crawford, president of Thompson Products, a manufacturer of automotive and aircraft engine parts. He and Clifford Gildersleeve of the Cleveland Chamber of Commerce began an intense lobbying campaign at the first rumors of the possibility of a new laboratory. They felt that such a laboratory could make Cleveland, hard-hit in the Depression decade, an attractive site for the industrial growth they anticipated with war preparedness in the late 1930s. Also, the city of Cleveland had a long history of actively supporting aviation, having long-sponsored the National Air Races at it municipal airport.

Cleveland had lost out to Sunnyvale, California, when Congress authorized the construction of what became the Ames Aeronautical Research Laboratory. When Congress authorized the second new laboratory, however, Cleveland came forward with the offer of nearly 200 acres near its municipal airport (available for $1 per acre) and the promise to raise $550,000 locally for the new facility. Despite stiff competition from a number of other cities, including both Dayton and Cincinnati, Cleveland won the prize. Construction began in the winter of 1941.[19]

Note that in all the discussions of the new aeronautical engine research laboratory, attention focused on air-cooled and liquid-cooled engines. Very few researchers in the United States were thinking of jet propulsion. Most all the engineers concerned with propulsion at the NACA in the late 1930s reflected what was in many ways the conventional thinking on the future of propulsion technology – that better aircraft engines would result from small improvements of the components of the piston or reciprocating engine. The new laboratory, it was assumed, would take this conventional, incremental approach to the reciprocating engine. There was no sense that it would research unconventional or radically new means of aircraft propulsion. Meanwhile, in England and in German, two researchers who had gone beyond conventional thinking and had determined that "the combination of compressor and turbine was uniquely suited as a power plant for flight," Frank Whittle (England) and Hans von Ohain (Germany) developed the world's first jet engines.[20]

Though NACA engineer Eastman Jacobs did conduct some early jet engine research, as the US military became aware of the new technology, General Arnold decided to turn to private industry (the General Electric Company) to develop the country's first jet engine, based on the Whittle design. Arnold was quite disappointed when he discovered just how little research had been done on jet propulsion in the United States prior to World War II. Although he placed much of the blame on the engine manufacturers, he also blamed the NACA and, in many ways, lost confidence in its ability to do additional research in that area. Therefore, during the war, the new NACA laboratory in Cleveland focused almost exclusively on problems associated with piston engines.[21]

Once the war was over, however, the engineers at the propulsion laboratory (renamed Lewis Laboratory in 1948 in honor of its first director) eagerly embraced the opportunity to do research in jet propulsion. While they did not completely abandon research on piston engines, the laboratory's leaders proposed that they reduce research on piston engines from 95 percent of the effort to only 5 percent. In place of piston engine research, the laboratory's engineers would begin fundamental research in such categories as compressor, turbine, combustion, fuels, materials, lubrication, supersonics, and nuclear and unconventional engines. From that point forward, the laboratory aimed at being on the frontiers of propulsion research.

Reflecting the new emphasis on jet propulsion, the laboratory created four new research divisions: Fuels and Thermodynamics, Engine Performance and Materials, Compressor and Turbine, and Wind Tunnels and Flight. Among these, the Compressor and Turbine Division soon "became the premier division of the laboratory, claiming the largest number of staff and the highest output of research papers."[22]

The Lewis Lab also began research in supersonics. To pursue this area of inquiry, the NACA engineers built two tunnels, "an 18-inch x 18-inch square tunnel and a 20-inch diameter round tunnel, both capable of speeds up to about Mach 2." And the lab did not ignore rocket propulsion. Before World War II, Cleveland had a group of enthusiastic amateurs interested enough in rocketry to form the Cleveland Rocket Society. Though this group had vanished by World War II, reports of V-2 rockets in 1944 awakened a strong interest among laboratory personnel. In June 1945, the small rocket group submitted a report that called for investigating turbojets, ramjets, and rockets as potential power plants for guided missiles. Among all those involved in propulsion research at Cleveland was a sense that they needed "to catch up and not ever fall behind again in advanced propulsion."[23]

In addition to propulsion research, in the post-war period engineers at Lewis also engaged in operations research – research involving when to certify an airplane for take-off and landing. Among the most important research of this type conducted at Cleveland was icing research. Icing is a "silent enemy" of flight. "Ice adds weight and impairs the aerodynamic efficiency of an airplane, often leading, in severe conditions, to a crash." Even before the war was over, engineers at Cleveland designed and built an icing tunnel. In addition to the research conducted with the icing tunnel, laboratory engineers worked in cooperation with the Air Force to conduct icing flight tests. In 1948, for example, test pilots “logged a total of 249 icing encounters” over the Great Lakes. The data generated by the Lewis icing experiments “became the basis for the design criteria for federal requirements for aircraft icing protection adopted by the Civil Aeronautics Administration in the mid-1950s.”[24]

As the NACA gave way to NASA in the late 1950s, rocket research grew in importance. Lewis completed construction of its Rocket Engine Test Facility in 1957. Lewis played an especially prominent role in the development of liquid hydrogen fuel. Lewis researchers had experimented with a small liquid hydrogen fueled rocket in the 1950s and in 1954 had developed “the nation’s first regeneratively cooled liquid hydrogen-liquid fluorine rocket with 5000 pounds of thrust.” This evolved in the Centaur rocket, which became the upper stage for both Atlas and Titan rockets and helped launch a number of important unmanned space probes. Moreover, in 1959, Lewis researchers, based on the work they done, convinced Werner von Braun that the upper stages of his proposed Saturn rocket had to use liquid hydrogen as fuel.[25]

Space flight vehicle research soon became the “glamour” program at Lewis Lab. With the end of the Apollo program, though, Lewis had to once again redefine its research agenda. Since the 1970s Lewis (now the NASA Glenn Research Center) has conducted research in such areas as jet aircraft noise suppression, alternative energy sources, and, hearkening to its past, turboprop propulsion.

In addition to working closely with industry, engineers at Lewis also built a strong relationship to nearby universities, especially the Case Institute of Technology (now Case-Western Reserve University). The relationship proved mutually beneficial. Lewis personnel gained access to the faculty, courses and degrees offered at Case. In turn, under the presidency of T. Keith Glennan, Case transformed from a small regional technical school to a major engineering institution with strong graduate programs; its graduates finding employment and its faculty finding research funding through Lewis Laboratory.[26]

In both Dayton and Cleveland, thus, aeronautical research witnessed the maturing and development of partnerships described by Jakab. It also experienced the "revolution" that came with increased computer power and the introduction of computational fluid dynamics.

The Computer Revolution in Aeronautical Research

During the early years at Lewis Laboratory, "computers" -- at that time largely women -- were employed through human resources. The analog machines available to aid research filled large rooms and engineers understood that it was best to finish programming their problems into the machine towards the end of the workday so that their programs could run all night long. In the morning, hopefully, they would have a solution.[27]

In the late 1960s and early 1970s the advent of higher power computers allowed aeronautical engineers to add another tool to aid them in their work – computational fluid dynamics. Before the age of the supercomputer, aeronautical researchers used wind tunnels and flight testing as well as theoretical fluid dynamics. Wind tunnels and flight testing came out of the strict engineering approach to aircraft design pioneered by the Wright brothers. Theoretical fluid dynamics, however, generally involved scientists, not engineers, and in the early twentieth century had little connection to the design of aircraft. Only in the 1920s and 1930s did these two communities – engineers and scientists – begin to merge and interact in meaningful ways.[28]

The introduction of computational fluid dynamics (CFD) offered engineers a new avenue of study. "CFD numerical experiments are done within the computer to simulate flow field configurations over a given surface and generate data that represents the character of this simulated flow." CFD allows an engineer to do in a computer what had been done in a wind tunnel, but also allows for "many more data points [and] a more complex set of variables." At first it seemed that CFD would make wind tunnels obsolete, but as some of the early enthusiasm wore off, a number of its limitations came to light.[29] As Peter Jakab summarized them:

> First, there is the danger of introducing numerical errors resulting from manipulating the relevant equations when setting up CFD programs. Even more problematic, engineers still have great difficulties in precisely defining the exact nature of certain aspects of a flow. Persistent inadequacies in modeling phenomena such as turbulence and drag have compromised CFD programs. . . . Further, despite the dramatic expansion of computer power and capability since the 1970s, computing requirements of CFD still pose limitations. It was only as recently as 1986 that for the first time the Navier-Stokes equations for a flow field over a complete airplane were solved in their entirety using CFD.[30]

By the 1990s, a certain consensus emerged among engineers on the value of CFD. They concluded that it existed as a complement to wind tunnel experiments and flight testing. As such, CFD has been clearly demonstrated "and the technique has become firmly entrenched in aerospace engineering practice." It is now the "third fundamental component of aerodynamic research along with wind tunnel" and flight test experiments, "and theoretical fluid dynamics."[31]

The engineers at Lewis Lab participated fully in this revolution in aeronautical engineering research. NASA completed construction of Lewis's Research Analysis Center in 1980. In the 1990s it housed the laboratory's major computers, including two Cray supercomputers, two powerful Amdahl mainframes, and a large variety of special computer systems. Among the many projects undertaken, researchers at Lewis used computer modeling and simulation to aid the development of the National Aerospace Plane (NSAP). Though the program was later cancelled, while it was in place during the

1990s, it posed a number of significant engineering challenges. For example, the NASP was designed to attain speeds far in excess of any wind tunnel's capacity. Computer modeling and simulation were vital to providing the needed high-speed test data.[32]

Computers also brought other changes to the world of aeronautical research and design. Computers using programs such as Computer-Assisted Design and Manufacturing (CADAM) now assist with the design and manufacture of prototypes for wind tunnel testing, making the work both faster and more accurate. In fact, according to a Lewis publication, by the 1990s Computer-Assisted Design (CAD) had "almost completely replaced the drawing table at Lewis." Models generated by CAD are sent to a computer-aided manufacturing (CAM) area, where a mold can be machined. The advantages of using CAD-CAM are many. "Engineers can test more designs before actually building the final product while eliminating the inaccuracies and lost time that go along with the paperwork. Because there are few inaccuracies, the quality of the finished product is better. Since fewer prototypes must be built and tested, the time it takes to get a design out of the idea phase and into production is shortened."[33]

Conclusion

Today, laboratories in Dayton and Cleveland continue to play important roles in aeronautical research. Not only do they continue their own research agendas, but NASA Glenn, the Air Force Research Laboratory (at WPAFB), and the University of Dayton's Research Institute are all members of the Ohio Aerospace Institute, a private, non-profit consortium of universities, industry and government focused on the creation, application, and commercialization of aerospace-related and other advanced technologies. In addition, the state of Ohio has taken steps to ensure that it will continue to play an important role in the world of aeronautical research. In 2001, Governor Taft announced the creation of the Ohio Aerospace and Defense Advisory Council. In establishing this new council, Taft recognized the importance of the aerospace industry in Ohio and declared his intention of promoting the future of aeronautical research in the state and at Wright Patterson AFB and the NASA Glenn Research Center in particular. So, what began in a bicycle shop in Dayton remains an important and vital activity in the state of Ohio.

---

[1] Peter L. Jakab, “The Wright Brothers and the Invention of Aeronautical Engineering,” in Jonathan Coopersmith and Roger Launius, eds., Taking Off: A Century of Manned Flight (Reston, VA: AIAA, 2003), pp. 7-8.

[2] Ibid., pp. 8-10.

[3] Ibid., p. 10.

[4] Ibid., pp. 10-12.

[5] Ibid., pp. 12-13.

[6] Ibid., pp. 13-14.

[7] Emma J. H. Dyson, Dean A. Herrin, and Amy E. Slaton, eds., The Engineering of Flight: Aeronautical Engineering Facilities of Area B, Wright-Patterson Air Force Base, Ohio (Washington, DC: U.S. Department of the Interior, National Park Service, Historic American Buildings Survey/Historic American Engineering Record, 1993), pp. 2-6;Aeronautical Systems Center History Office, Against the Wind: 90 Years of Flight Test in the Miami Valley (Washington, DC: Air Force Material Command, Aeronautical Systems Center, History Office, 1994), p. 4.

[8] Dyson, et. al., The Engineering of Flight, pp. 4-6.

[9] Ibid., pp. 7-8.

[10] Ibid., pp. 8-10.

[11] Ibid., pp. 13-14.

[12] Quoted in Ibid., p. 14.

[13] Ibid., p. 13-14.

[14] Ibid., p. 23.

[15] ASC History Office, Against the Wind,, pp. 10-11

[16] Ibid., pp. 22-23.

[17] Virginia P. Dawson, Engines and Innovation: Lewis Laboratory and American Propulsion Technology (Washington, DC: NASA Office of Management, Scientific and Technical Information Division, 1991), pp. 4-6.

[18] Ibid., pp. 6-10.

[19] Ibid., pp. 10-15.

[20] Ibid., pp. 41-58.

[21] Ibid.

[22] Ibid., pp. 69-72.

[23] Ibid., pp. 72-76.

---

[24] Ibid., pp. 109-117.

[25] Ibid., pp. 158-169.

[26] Ibid., pp. 93-97.

[27] For information on women "computers" and computing in the 1940s see Jennifer S. Light, "When Computers were Women," Technology and Culture, Vol. 40, no. 3 (July 1999): 455-483.

[28] Jakab, "Invention of Aeronautical Engineering," pp. 15-16.

[29] Ibid.

[30] Ibid., p. 17.

[31] Ibid.

[32] Computer Services Division, Computers in Aeronautics and Space Research at the Lewis Research Center (Cleveland, OH: NASA, Lewis Research Center, 1990), pp. 3, 10.

[33] Ibid., pp. 6-7.