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# Riding the Crest: A History of Michigan's Aerospace Engineering Department

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**In 2014, the University of Michigan celebrated the 100th anniversary of the first formally organized academic program in aeronautical engineering in the world. Since 1914, the University has offered a degree program in a field that was to become one of the most important technological developments in the 20th century: the airplane, and later the space vehicle. Michigan's aeronautical engineering program was the first of its kind. Moreover, throughout its history, it rode the crest of major advancements in aeronautical and space technology. Because of its relevance and importance to all members of the aerospace community today, we tell its story here.**



## Introduction

THE story begins more than 100 years ago when, in 1896, a strange-looking batwing flying machine with a man hanging under it (Fig. 1) could be observed gliding for short distances over the Scottish countryside. The man was Percy Pilcher, an Assistant Lecturer in Naval Architecture and Marine Engineering at the University of Glasgow. Pilcher built and flew the first successful hang gliders in Britain, following the earlier pioneering work of Otto Lilienthal in Germany. Before his untimely death in 1899 while flying one of his gliders, Pilcher had become recognized as Britain's most distinguished contemporary pioneer in practical aviation ([1] pp. 19–20).

Observing Pilcher's success was Herbert Sadler, a teaching colleague of Pilcher at Glasgow. Sadler himself came from a family with some aeronautical interests and accomplishments. His great granduncle, James Sadler (1751–1828) of Oxford, was England's first balloonist, making his first flight on 5 May 1785, from Moulsey Hurst ([2] p. 54); tragically, much later, James's son was killed when he fell from a balloon in 1825. Herbert Sadler came to the University of Michigan in the fall of 1900 as Head of the newly established Department of Naval Architecture and Marine Engineering; two years after arriving at Michigan, he received his D.Sc. degree from Glasgow University. Among his early accomplishments at Michigan was the organization of the University's Aero Club, and in 1914 he helped to establish the first formal course in aeronautical engineering. Hence, through Herbert Sadler, the genealogy of aeronautical engineering at Michigan reaches all the way back to the pioneering hang gliders designed and flown by Percy Pilcher in Scotland.

On 17 December 1903, the Wright brothers accomplished the first successful sustained flight of a powered, heavier-than-air, controlled, piloted airplane (Fig. 2). The advent of the airplane, and later the space vehicle, proved to be one of the three most important technological advances of the 20th century, with the other two being the electronic revolution and the development of atomic energy. Their success, however, was not immediately publicized or accepted. With the dramatic first public flights by Wilbur Wright at Le Mans, France, in 1908, the airplane came into its own. The Wright brothers were the first true aeronautical engineers, and aeronautical engineering as an academic discipline was not far behind. The first course in aeronautics was offered by Professor Lucien Marchis at the University of Paris in 1909; indeed, his notes were published in 1912, some of the first text material in the field [3]. One of Marchis's students at that time was Felix Pawlowski, a young Polish student whose interest in aeronautics was galvanized by seeing several of Wilbur's flights. While doing graduate work in mechanical engineering, the motivated Pawlowski studied aeronautics under Marchis and, in 1910, taught himself to fly in the then popular Bleriot monoplane (Fig. 3).

With his certificat d'etude from the University of Paris, Pawlowski came to the United States in 1911 to pursue his interest in aeronautical engineering. Finding no employment at the Wright Company in Dayton, Pawlowski then applied for a professorship at 18 colleges and universities. The University of Michigan was one of only a few to reply and was the only institution to actually offer him a position. At the encouragement of Sadler, Dean Mortimer Coley offered Pawlowski an appointment as Teaching Assistant in Mechanical Engineering at the annual salary of $800, along with a promise that he would be permitted to teach a future course in aeronautical engineering [4].

Interest in aeronautics at the University of Michigan was stimulated in 1913 by a series of lectures given by Pawlowski and his teacher Lucien Marchis. Marchis came to the campus at Ann Arbor from Paris, and true to the science-based engineering found in European universities, gave lectures on the practical application of physics to various engineering problems, including aeronautics. In the words of Thomas Adamson, Professor Emeritus of Aerospace Engineering at Michigan, writing about Marchis' lectures, "the appearance of a world-famous authority on an American campus strengthened the increasing academic respectability of aeronautical engineering in this country" ([5] pp. 44–58).

We note that the principal players in aeronautics at Michigan in these very early years (Sadler, Pawlowski, and Marchis) were educated in Europe. They brought with them a certain fundamental science background that was a positive influence in engineering education in America, which at that time was steeped in practical, empirical engineering. Theodore von Kármán, arguably the most famous aerodynamicist in the first half of the 20th century, tells of his first visit to the United States in 1926, during which he visited a number of American Universities. At that time, von Kármán was a Professor at Aachen University in Germany and was actively being courted by Robert Millikan, President of the California Institute of Technology, to join Caltech in the building of its aeronautics education and research program. Two of the institutions visited by von Kármán were the University of Michigan and New York University. About these, he remarked:

> "I was struck with the dominance of Europeans. At Michigan the professor of aeronautics was a man of Polish origin named Pavlowski [sic], who was trained in Paris. The head of N.Y.U.'s aeronautics department was Alexander Klemin, an immigrant from London's East End, trained in England. Both these men made very important contributions to the education of young American aeronautical engineers" ([6] p. 127).

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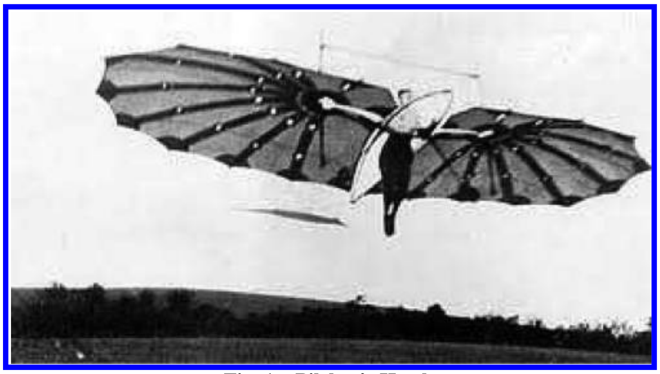

Fig. 1 Pilcher's Hawk.

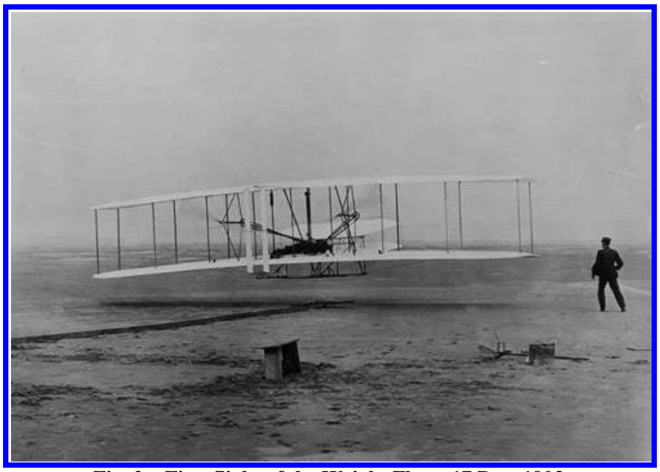

Fig. 2 First flight of the Wright Flyer, 17 Dec. 1903.

Fig. 3 Bleriot XI.

It was not until the early 1950s that the aeronautical engineering programs in most American universities adopted more of an engineering science flavor akin to the early European engineering education. The University of Michigan's aeronautical engineering program benefited from this tradition from its very beginning.

In the book *The Airplane: A History of Its Technology* [7], the technical development of the airplane is divided into three historical eras: 1) the strut-and-wire biplane, 2) the mature propeller-driven airplane, and 3) the jet-propelled airplane. In this paper, we will show how the growth and evolution of the aeronautical engineering program at the University of Michigan closely parallels the historical development of the airplane as detailed in this book.

## The Era of the Strut-and-Wire Biplane

This era begins with the Wright Flyer in 1903 and carries through to approximately 1930. It is characterized by seat-of-the pants flying and design techniques. It is the era of the "vegetable airplane" constructed from wood and fabric. Almost all designs had two wings, one above the other, mainly due to structural considerations. Having



Fig. 4 Curtiss Jenny.

two wings essentially distributed the aerodynamic lift and drag loads over two smaller wings. This biplane configuration persisted in airplane design into the early 1930s. A typical airplane from this era was the Curtiss JN-4D Jenny (Fig. 4). It was America's main technological contribution to World War I. (Even at that, Glenn Curtiss commissioned the Englishman B. Douglas Thomas, previously with Sopwith, to design the Jenny.) The JN-4D served mainly as a trainer and was not used in combat.

The University of Michigan's aeronautical engineering program began during the early part of this era. In 1914, Dean Cooley followed through with his promise to Pawlowski and approved the introduction into the curriculum of the first credit courses in aeronautical engineering. The first of these, Theory of Aviation, was taught by Pawlowski and covered the basic principles of aerodynamics and flight mechanics as they were understood at that time. This course served as a prerequisite for the next courses, which were listed and described in the University Catalog for 1915–1916 with Herbert Sadler as an additional instructor. The new curriculum, the first in America, was so important that it was published in the periodical *Aerial Age*, with this description ([5] p. 46):

> "The faculty of the College of Engineering of the University of Michigan is developing the course in aeronautics which they offer and it is to be their endeavor to make it as comprehensive as possible. It is expected that the students will gain much information and also practical experience in connection with the work done at the Packard Motor Car Company of Detroit. (Author's note: Due to the anticipated participation of the United States in World War I, the automobile industry was already gearing up to produce airplanes and aeronautical motors.) The aim of the course is to teach the theory of aeroplanes and to enable students to secure positions in manufacturing plants".

Other aeronautical courses listed at the same time were Theory and Design of Propellers, Airplane Design, Design of Aeronautical Motors, Theory and Design of Balloons and Dirigibles, Theory and Design of Kites, Design of Aerodromes and Hangars, and Advanced Stability. Several other courses in advanced reading, design, and research were listed. All totaled, the new program consisted of 14 courses, a noble endeavor with two primary faculty members to teach them. They represented the first formal program in the United States leading to a bachelor's degree in aeronautical engineering. The new degree program was housed in the newly renamed Department of Naval Architecture, Marine Engineering, and Aeronautics, where Sadler continued as Department Head. (Aeronautical engineering did not become a separate department at Michigan until 1930.)

By comparison, at the same time, aeronautics was becoming an academic subject at the Massachusetts Institute of Technology (MIT). Jerome Hunsaker and Edward Warner at MIT, two engineers who later were to play strong roles in the advancement of aeronautics in the United States, helped to develop an aeronautics graduate program in MIT's Department of Naval Architecture. The first graduate course, offered in 1914, was entitled "Aeronautics for Naval Constructors". The first undergraduate course in aeronautical engineering at MIT dates from 1926, with aeronautical engineering becoming a separate department in 1939.

In the decade after the end of World War I, the technological advancement of the airplane was slowed by the ready availability of surplus aircraft from the war and the consequent dampening effect on the aircraft industry. There was little incentive to spend the time and money to produce new, advanced airplanes. New technology was, however, being developed in two important government laboratories, the NACA Langley Aeronautical Laboratory in Hampton, Virginia, and the U.S. Army's McCook Field in Dayton, Ohio. The Curtiss P-6E Hawk fighter of 1931 (Fig. 5) is a good example of the state-of-the-art of airplane design at the end of the strut-and-wire era, reflecting gradual improvements in aerodynamic streamlining and the development of more powerful engines.

The aeronautical engineering curriculum and faculty at Michigan kept pace with the advances in airplane technology. In 1922, another faculty member was added: Ed Stalker, who received his bachelor's degree in aeronautical engineering from Michigan in 1919 and his master's degree in 1923. In 1922, more emphasis was placed in the curriculum on airplane performance, with each student making a complete analysis of the performance of a given airplane as well as a determination of its stability.

Two early graduates of this curriculum went on to very distinguished careers in NACA and NASA. Smith J. DeFrance in 1922 and Floyd L. Thompson in 1926 joined the NACA Langley Memorial Laboratory in Hampton, Virginia, immediately after graduating with their bachelor's degrees in Aeronautical Engineering from Michigan. Both spent their entire careers with NACA and NASA. "Smitty" DeFrance designed the historic Full Scale Tunnel at Langley and, in 1940, moved to the then new NACA Ames Laboratory at Moffett Field, California, to be its Director until his retirement in 1965. Floyd Thompson remained at Langley, becoming its Director in 1960 until his retirement in 1968. In 1974, Thompson was awarded the prestigious Guggenheim Medal for a lifetime of achievement in aeronautics. Both DeFrance and Thompson left their individual marks on NACA and NASA, and indirectly, so did the early Aeronautical Engineering curriculum and faculty at the University of Michigan.

In the early 1920s, important advancements in the theory of aerodynamics in Europe became known in the United States. In 1926, Michigan added a new course, Mathematical Theory of Wing Profiles, which included recent advances in the circulation theory of lift by Kutta, Joukowsky, and von Mises. Then, in 1927, two dramatic events occurred that would change the world of aviation and the world of aerodynamics. First, Charles Lindbergh flew solo across the Atlantic Ocean in the Spirit of St. Louis, massively increasing the public's interest and confidence in aviation. Michigan instantly seized on this interest by adding a new course entitled Air Transportation, dealing with the engineering and economic aspects. Second, the seminal contributions made earlier by Ludwig Prandtl in Germany on the circulation theory of lift applied to airfoils and wings were made available in the English language by the famous British aerodynamicist Hermann Glauert in his book *The Elements of Aerofoil and Airscrew Theory* [8], which became widely available in 1926–1927. The curriculum at Michigan almost instantly reflected these modern developments. In 1927, the Theory of Aviation course included a "general discussion of modern aerodynamical theories of lift and drag", and a new course, Mathematical Theory of Aerofoils, was added that covered, among other topics, "the Prandtl theory of the induced drag". The aeronautical engineering students at Michigan were studying the very latest state of the art almost as soon as it became available. This was most likely due to the European roots of Sadler and Pawlowski, who were in tune with developments in England and Germany. In 1928, the curriculum reflected another important addition, prompted by the growing appreciation by the faculty of the need to expand the role of aeronautical research in the program. For the first time in the university catalog, five courses were listed as "primarily for graduates", with a heavy emphasis on advanced design and research. Although the program had awarded 18 master's degrees and one Ph.D. by 1929, it was poised for a major thrust into graduate education and research.


**Fig. 5 Curtiss P-6E.**

Another important addition to the aeronautical engineering program at Michigan took the form of the construction of a large subsonic wind tunnel on campus. In 1924, Felix Pawlowski traveled to Europe on a fact-finding mission concerning the latest aerodynamic advances and wind tunnels. Upon returning, he designed a wind tunnel for the University; the octagonal test section was 8 ft across and was open to the atmosphere. The flow velocity in the test section could reach 250 mph. The tunnel was literally integrated into the construction of the new East Engineering Building on campus. Construction began in late 1924 and was completed in 1926 with the help of $28,000 from the Daniel Guggenheim Fund for the Promotion of Aeronautics. It is no accident that, in the 1927 course catalog, a new item was added to the material taught in the Theory of Aviation course: the results of wind-tunnel experiments. This tunnel was to serve the department well. It was not the first wind tunnel in an American university, but it came online at a time when wind tunnels began to serve a more important role in the advancement of the airplane. During the era of the strut-and-wire biplane, most airplane designers considered the data from existing wind tunnels to be unreliable. The tunnels were generally small, and the data obtained with the correspondingly small models in these tunnels suffered from scale effects that were not well understood. (The reluctance of some aeronautical engineers to use wind tunnels for airplane design persisted well into the 1930s. The famous British Spitfire of World War II was designed by R. J. Mitchell without a shred of wind-tunnel data.) This situation changed in the late 1920s when larger, more technically advanced wind tunnels became available in Europe and in the United States. Indeed, the NACA Langley Memorial Laboratory led the way in America with its Variable Density Tunnel, pressurized to 20 atm in the test section to simulate realistic Reynolds numbers, and the Full Scale Tunnel (designed by Michigan graduate DeFrance as noted earlier) with a 30 by 60 ft test section that accommodated full-size airplanes. By the end of the 1920s, wind-tunnel data was becoming more reliable, and airplane designers felt more comfortable in using tunnels to help fine-tune their designs. It was in this atmosphere that the Michigan tunnel became active. (Indeed, this tunnel was later used by Lockheed and a new student named Kelly Johnson in precisely this mode.)

In 1927, Elsie MacGill [9], the first Canadian woman to graduate in electrical engineering, would arrive to enroll in the new and expanded aeronautical engineering graduate program at the University of Michigan. She was to become one of the most distinguished graduates of this program, but one whose story is not widely known. Because of this, some elaboration is given here.

Born in 1905, Elizabeth Muriel Gregory MacGill was always called Elsie. Her background had prepared her well to break new ground for women. Her mother and grandmother had led by example. Both had worked in the 19th century for women's suffrage. Her mother, Helen MacGill, was the first woman in the British Empire to receive degrees in music (Trinity College, Toronto) and the first woman in British Columbia to be a judge.

Elsie continued this tradition at Michigan, where she was the first and only female student in the aeronautical engineering department in 1927, and where she was awarded a graduate fellowship. Campus-wide, about one-quarter of the Michigan graduates were female.

MacGill was exposed to the latest work in aeronautics through Pawlowski and her work with Edward Stalker, especially his boundary-layer research. She was to cite both of them as important to her development ([9] pp. 68–69). They were impressed with her work. Pawlowski was proud of his student and through his travels in Europe was confident that she was on track to be the "first woman in the world to complete the academic and technical work necessary for qualifications as an aeronautical engineer". She certainly was the first in North America, and Pawlowski always maintained that, at the time of her graduation in 1929, "she was the only one in the world" ([9] p. 70). May of 1929 was to bring her one of her greatest personal tests when, just before graduation, she was stricken by a poliolike neurological disorder. The MSE was awarded to her at the age of 24 in her hospital room. She was originally told that she would never walk again; she did eventually become mobile, but would suffer from the effects for the rest of her life.

During the three years of recovery, she designed a seaplane to keep her mind occupied and turned to writing to help pay medical bills. In 1932, she was accepted into the Ph.D. program at MIT but was not granted a student assistantship. In 1934, approaching 30 and facing greater money problems, she took a job with Fairchild in Canada. As an Assistant Aeronautical Engineer, she began an active span of design, coordination, and accomplishment in aviation that brought her honors and fame. MacGill (Fig. 6) started work in the era of design revolution from strut-and-wire to all-metal planes. Early work at Fairchild included stress analysis and wind-tunnel tests and work on the Fairchild 71, which was intended to be the first all-metal plane designed and built in Canada. It was at Fairchild that she established her policy of always going on the flight tests of planes that she helped build. This earned her the immense respect of the test pilots. Her big disappointment was that she was never able to become a pilot herself.

By 1938, the world was beginning to face the potential of another war, and Canadian Car and Foundry (Can-Car) offered her the position of Chief Aeronautical Engineer as they began to prepare for a change to aircraft production. In 1938, she also became the first female member of the Engineering Institute of Canada. In January 1939, she was asked to design the Maple Leaf II, an all-Canadian biplane to be used as a trainer. She designed and built the prototype in eight months. Therefore, it was said that she may "rightly be considered to be the first woman to design, build and test her own airplane" ([9] p. 120). In 1940, she proposed to the Engineering Institute of Canada that, in evaluating aircraft designs, "Standardized Flight Test Reporting Forms" be used. She believed that the tests were as central to professional engineering and scientific undertaking as any other phase of the design and regarded test pilots as collaborators ([9] p. 129).

**Fig. 6 Elsie MacGill.**


**Fig. 7 Hawker Hurricane.**

In December 1938, Can-Car received from Britain an order for 40 Hurricanes, a new fighter designed by Hawker aviation (Fig. 7). The factory needed to be expanded; design plans, machine parts, supplies, coordination, and workers were all needed; and MacGill was central to the completion of what eventually became over 1400 planes. The Hurricanes produced in Canada were a major contribution to the war effort. She became internationally famous in 1940 when New York Times headlines read "Girl designs new trainers", and as the "Queen of the Hurricanes" she was featured in a comic book. She was described as "all feminine not severely mannish, liking afternoon teas, cooking and knitting" ([9] p. 158). She presented another paper in 1940, to the Engineering Institute of Canada, concerning methods of mass production (similar to automobiles) of aircraft to improve "costs and efficiency". Her papers were widely disseminated, and in 1940, Elsie MacGill was awarded the Engineering Institute of Canada's then highest award, the Gzowski gold medal, for outstanding contribution to engineering. Her important contribution to adapting the Hurricanes came with her methods to winterize them for use in Russia. She developed ways for Canadian planes to fight ice and adaptations for landing on snow. Her fundamental research took on new importance in the jet age when planes were flying at higher altitudes ([9] p. 170).

After 1943, she essentially ended her work in production but continued to contribute to aviation. She became a private consultant, again a first for Canada and possibly North America. When the International Civil Aviation Organization was formed (mid-1940s), MacGill was asked to serve on many committees, especially in the area of stress analysis. Her contributions to air safety and travel may be one of her greatest contribution to aviation through her work in these committees ([9] p. 219) and as an active public speaker for aviation. Increasingly in the 1950s, she became active in the Federation of Canadian Business and Professional Women's Clubs and, in 1963, became the National President. In 1953, the American Society of Women Engineers made her an honorary member and named her "Woman of the Year" for her meritorious contribution to aeronautical engineering. As her own experiences broadened, her active involvement with women's concerns increased. In her own career, she seemed not to have seen or felt the slights or limitations. As early as 1937, she protested that civil service listings of job openings were not open to women. The next postings were opened [9]. For the next 20+ years, many of her efforts were related to women's issues where she gained expanded influence, nationally and internationally. In 1967, she was appointed to the Royal Commission on the Status of Women, where she was "one of the most active and influential members" [9]. She received many honors and awards. In addition to ones mentioned earlier, a sampling includes induction into the Canada's Aviation Hall of Fame, Officer of the Order of Canada, the Amelia Earhart Medal from the Ninety-Nines, Queen's Jubilee Medal, and Honorary Doctorates from Toronto and other universities. MacGill was a member of the Royal Aeronautical Society, AIAA, National Research Council, Canadian Royal Commission on the Status of Women, and was serving on the Canadian Organizing Committee for the International Year of the Disabled in 1980, when she died on 4 November 1980 of pulmonary fibrosis at the age of 75.

In perspective, Elsie MacGill's distinguished career in aeronautical engineering can be traced back to her education at the University of Michigan. This woman, who was the first female aeronautical engineering graduate in what was then a "man's world", went on to distinguish both herself and the aeronautical engineering program at Michigan.

## The Era of the Mature Propeller-Driven Airplane

The book *The Airplane: A History of Its Technology* identifies this second era as covering roughly the time period from 1930 to 1947. This is the period of the first design revolution, where the technology and the visual appearance of the airplane changed dramatically, as reflected in the aesthetically beautiful Douglas DC-3, designed in 1933. In 1929, the famous British aeronautical engineer Sir B. Melvill Jones gave a seminal paper to the Royal Aeronautical Society in London simply entitled "The Streamlined Airplane" [10]. The paper was a clarion call for the aerodynamic advantage of streamlining. Jones presented results showing that the maximum speeds of existing airplanes could be increased by 50 to 100 mph just by eliminating the pressure drag due to flow separation (form drag) by complete streamlining. His results knocked the socks off the airplane designers in attendance; streamlining quickly became a much more important consideration than in the past.

Indeed, streamlining was just one of the important aspects of the design revolution that took place in the 1930s. The Douglas DC-3 (Fig. 8) is an excellent example of an airplane reflecting the design revolution. It is beautifully streamlined. The engines are wrapped in a cowling developed just a few years earlier by NACA; the NACA cowling dramatically reduced the form drag associated with the airflow through the otherwise exposed cylinder rows, for some airplanes by as much as 50%. The airplane had retractable landing gear, a variable-pitch propeller, and a very high-aspect-ratio wing (aspect ratio of 9.14) with a modern NACA airfoil shape (NACA 2215 at the root). It was a monoplane (single wing) as opposed to the prevailing biplane configurations, and the airplane was all metal in contrast to the older wood and fabric construction. These are all features of the design revolution in the 1930s.

Following suit, during this period, Aeronautical Engineering at the University of Michigan went through its own design revolution. The aeronautical engineering program became a separate department, with Professor Ed Stalker as the department head. In the 1930–1931 catalog, a comprehensive description of the overall mission of the department appeared for the first time:

> "The courses offered by the Department are arranged to cover the essentials of aerodynamics necessary for the proper understanding of the action of wings, propellers, and problems connected with stability and maneuvering; and form the basis for the application of such studies to the design, construction, and analysis of performance of all types of aircraft."


**Fig. 8 Douglas DC-3.**

The description went on to state:

> "From its inception the Department of Aeronautical Engineering has realized that the utilization of the air as a means of transportation, the settlement of problems confronting the designer, and the future development of this field must rest upon a thorough foundation of aerodynamic theory. As a preparation for this, and for design purposes, beside the usual mathematics, courses in theory of structures, mechanical engineering, including gas engine design and hydromechanics also are essential. In the design of aircraft, the student is given a chance to apply such studies, so as to obtain the best solution to any given set of conditions."

The new, large wind tunnel in the department was noted: "The wind tunnel offers facilities for experimental work in all problems relating to the subject, and is available for research work for advanced students."

Finally, reflecting the high professional reputation of Pawlowski, Stalker, and others now on the faculty of the department, and their resulting close connection with Government and Industry:

> "The Department is in constant touch with the Government and industrial concerns which demand well-trained men in this field. The development of this newest element, in which a large part of high speed transportation must inevitably be carried on in the future, will continue to call for numbers of properly trained engineers, both in the design and research fields."

(We note that the reference to the demand for "well-trained men in this field" reflects the male domination of engineering during this period.)

The environment for aeronautical research and education in the department at this time was among the best available in the country. This author wagers that, if there had been a U.S. News and World Report ranking in the 1930s, the undergraduate program in aeronautical engineering at Michigan would have been ranked number one. It was into this environment that a fresh new student by the name of Clarence "Kelly" Johnson appeared in 1929.

Kelly Johnson was born and raised in Michigan. He had a love of learning and spent considerable time in public libraries reading books, principally on aviation. He later wrote, "I decided by the time I was 12 years old that I would be an aircraft designer" ([11] p. 7). He followed this goal for the rest of his life, becoming arguably the most famous and productive airplane designer in the last half of the 20th century. From a family of moderate means, and because he was a citizen of Michigan, he naturally chose to attend the University of Michigan in Ann Arbor. This was one of those examples of serendipity that can sometimes be found in the history of technology: a very studious young person with a burning desire to be an aeronautical engineer enrolled in the country's leading undergraduate aeronautical engineering program that just happened to be at his state university, affordable, and figuratively just around the corner.

Johnson was taken under the wing of Ed Stalker, who had just become head of the newly established independent department. That year Stalker published a textbook entitled *Principles of Flight* [12], one of the few aeronautical engineering texts available at that time. There were a number of homework problems scattered throughout Stalker's book, and Johnson later took it upon himself while working as a student assistant for Stalker to work out each one in detail, with the thought of publishing them for general use. He was made to realize that "it would undermine the book and considerably diminish sales" ([11] p. 17).

In 1930, Johnson and the wind tunnel were mated when Stalker assigned Johnson to help with the test program. The work apparently went so well that some vacant time was available in the facility. In an entrepreneurial spirit, Johnson and his best friend and classmate Don Palmer asked Stalker for permission to rent this time to outside customers. Amazingly, Stalker agreed. Johnson wrote that, "for $35 a day, plus power charges, Don Palmer and I became part-time proprietors of the University of Michigan wind tunnel" ([11] p. 15). Johnson promptly lined up a drag-reduction test program with the Studebaker Motor Company for testing the Pierce Silver Arrow. As time went by, Johnson and Palmer demonstrated to Studebaker that the drag on the headlights on their cars was increasing the power required by 16% at 65 mph. This was the first of a string of dramatic wind-tunnel results that would later come from Johnson and the University's wind tunnel.

In 1931, a hardly noticeable but subtle change was made in the department's written descriptions. The word "aeroplane" was replaced by "airplane". In the early 1920s, NACA standardized the nomenclature for aeronautical usage in the United States. Among the standards adopted was the replacement of the European terms "aeroplane" and "aerofoil" with "airplane" and "airfoil". The faculty at Michigan, probably due to the European origin of Pawlowski and Sadler, persisted with the European usage for another decade. In this vein, we also note that, from the very beginning of the program at Michigan, several courses open only to graduates and seniors stated that the "knowledge of French and German is most desirable". This indicates the faculty's emphasis on the latest aeronautical research, most of which was coming from universities and laboratories in France and Germany and was available only in French and German publications.

The year 1931 saw a shift to modern aerodynamic theory in the classwork, even at the junior level, in the course Theory of Aviation. For graduates, Prandtl's boundary-layer theory, which revolutionized aerodynamic analysis, was taught in the Theoretical Aerodynamics course for the first time at Michigan, with the proviso that it would be discussed "when time permits". To make certain that "time permits", a new Advanced Theoretical Aerodynamics course was added to the curriculum in 1932, covering "a detailed discussion of the approximate theory of thin wings, followed by an exposition of the induced drag theory of monoplanes, biplanes, and multiplanes". The course also covered "more recent developments" in the flow of viscous fluids, namely boundary-layer theory.

In 1932, the course Helicopters and Autogiros was also added. Today, helicopters are a major research area at Michigan under the direction of Professor Peretz Friedmann, and the roots of this interest at Michigan reach all the way back to 1932, in the midst of the design revolution.

Also in 1932, steeped in the features of the design revolution taught at Michigan, Kelly Johnson graduated with his bachelor's degree in aeronautical engineering and set out to look for employment in the aeronautical industry in California. This was the period of the Great Depression, and few, if any, jobs were available. However, when Johnson interviewed with the Lockheed Aircraft Corporation, he was given some encouragement for future employment. Lockheed, just coming out of receivership, was being reorganized. The company had a new airplane design on the boards, a twin-engine transport that eventually was to become the very successful Lockheed Electra. Richard von Hake, who was about to become the production manager of the new company, was optimistic about Lockheed's future with this new airplane. He strongly recommended that Johnson return to the University of Michigan for a master's degree and then try again for a position with Lockheed.

Johnson did just that, returning to the Ann Arbor campus with his friend Don Palmer, and both started work on a master's degree in aeronautical engineering. Once again, Johnson was assigned to work in the Michigan wind tunnel, and this time it was very propitious. One of the companies contracting work in the tunnel was Lockheed with a model of their new Electra transport. Kelly Johnson participated in these tests and noticed some serious stability problems with the design. Being a student, however, he was not in a position to counter the conclusions by Ed Stalker that the test results were acceptable.

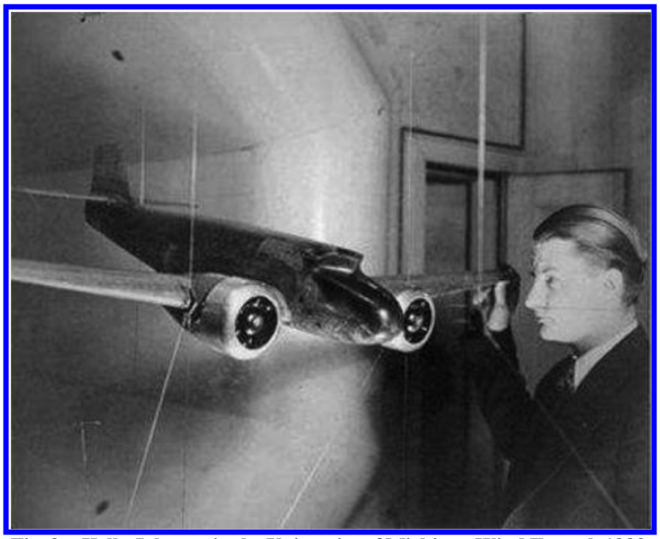

**Fig. 9 Kelly Johnson in the University of Michigan Wind Tunnel, 1933.**

Johnson graduated in 1933, and this time he was offered a position with Lockheed.

Within months of starting to work, Johnson was back on the road to Ann Arbor with a wind-tunnel model of the Electra in the back seat of his car. He had been able to convince Hall Hibbard, a well-known airplane designer and chief engineer at Lockheed, that the Electra design had a serious stability problem. This time, Johnson was back on campus as an engineer working for Lockheed, and he had complete control over the Lockheed Electra wind-tunnel tests (Fig. 9). The original Electra design incorporated a single vertical tail and had fillets at the wing–fuselage juncture, a new feature in airplane design that surfaced as part of the design revolution. After 72 runs in the Michigan wind tunnel, Johnson had solved the problem. When the single vertical tail was replaced by twin tails at each end of the horizontal stabilizer and the fillets were done away with, the model was stable. Johnson carried these results back to Lockheed, where the appropriate changes were made in the Electra design, and the airplane became a needed best seller for Lockheed. Kelly Johnson and the University of Michigan wind tunnel had saved the Lockheed Aircraft Corporation in the middle 1930s, perhaps one of the best testimonials to the importance of the Department of Aeronautical Engineering at Michigan during the period of the design revolution. After that, twin- and multiple-tailed designs became a signature feature of Lockheed airplanes, e.g., the P-38 Lightning (Fig. 10) and the triple-tail Constellation (Fig. 11), both designed by Kelly Johnson.

Michigan's Department of Aeronautical Engineering continued to keep pace with the growing design revolution of the 1930s. The


**Fig. 10 Lockheed P-38.**

Fig. 11 Lockheed Constellation.

Theory of Aviation course emphasized the study of modern aircraft, and fundamental experimental data were given more attention. Airfoil and induced drag theory was given more importance. Of particular interest was the course on the Theory and Design of Propellers, which had been part of the curriculum from the beginning, but which in 1934 for the first time included variable-pitch and constant-speed propellers, major features of the design revolution. Also included in the curriculum was an expanded course in Experimental Aerodynamics, driven by the growing role and acceptance of wind-tunnel data in the airplane design process and the need for pure aerodynamic research. Kelly Johnson's success with the Electra model now became a feather in the department's cap and resulted in greater appreciation of its large wind-tunnel facility. In the Advanced Theoretical Aerodynamics course, much more time was spent on the modern boundary-layer theory and its application to aeronautics.

Although the 1930s saw the demise of the biplane and the rise of the monoplane in new airplane designs, there were still large numbers of biplanes flying. Seemingly an anachronism, biplane theory continued to be taught. The Advanced Theoretical Aerodynamics course took up the calculation of the induced drag for biplanes in detail. It was not until 1941, just before the United States entered World War II, that biplane considerations were dropped from the course of study.

Virtually all of the famous airplanes from World War II, such as the Curtiss P-40, Lockheed P-38, North American P-51, the British Spitfire, the German Me 109, the Japanese Zero, and the Boeing B-17, to name just a few, were designed at the height of the design revolution before the war started. The research and teaching program in aeronautical engineering at Michigan during the 1930s was equally advanced. As the speeds of these modern aircraft increased toward the speed of sound, the adverse and sometimes disastrous effects of compressibility became a serious problem in aerodynamics, propulsion, and stability and control. High-speed compressibility phenomena on airfoils and wings were studied by NACA beginning as early as 1918, but it took until the mid-1930s, right at the peak of the design revolution, before the actual physical nature causing these adverse compressibility effects was finally understood and action to deal with them could be taken. Students at Michigan benefitted from the advance knowledge of some of the faculty and were made aware of the effects of compressibility. Stalker's 1929 book had a brief discussion (about six pages) of the basic nature of compressible flow and how to make some simple calculations. The Lockheed P-38, designed by Kelly Johnson, was the first airplane to encounter severe compressibility problems, causing the airplane to become locked into a power dive from which the pilot could not recover. This "tuck-under" problem was Johnson's first major encounter with compressibility, and the early knowledge, no matter how fragmentary, of compressible flow that he obtained from Ed Stalker at Michigan was a start toward his understanding of what was happening. [Ultimately, NACA came up with a fix for the tuck-under problem ([1] pp. 642–643), although Kelly Johnson denied NACA's role and gave credit to himself and Lockheed ([11] p. 78).]

The study of compressible flow came to Michigan mainly in the form of Arnold Martin Kuethe, who joined the faculty in 1941. Kuethe had obtained his Ph.D. at the California Institute of Technology in 1933, the time when von Kármán was teaching advanced courses in aerodynamics, including compressibility, at Caltech. The first mention of compressibility in Michigan's course catalog was 1941 in regard to a new course entitled Mechanics of Fluid Resistance, where it was stated that "wave resistance and compressibility problems are discussed briefly". But 1941 was toward the end of the first design revolution. A second design revolution was about to begin, with the aeronautical engineering department at Michigan quickly responding.

## The Era of the Jet-Propelled Airplane

The morning of 8 January 1944 was unusually cold at Muroc Dry Lake in California. Painted a cold green and gray color and polished to a high gloss, a new airplane was positioned for takeoff. This airplane was different; it had no apparent means of propulsion: no propeller. Gathered around the airplane was a small group of U.S. Army Air Force personnel and an even smaller group of engineers and technicians from the Lockheed Burbank factory. Among those Lockheed engineers was Kelly Johnson, now the Chief Research Engineer for Lockheed. Milo Burcham, a test pilot for Lockheed, started the engine, but unlike all conventional aircraft at that time, there was no thundering roar from a piston engine — just a wailing scream from rotating machinery inside the fuselage. Burcham released the brakes, and slowly the sleek, streamlined airplane accelerated across the lakebed. At a speed of 110 mph, it left the ground and smoothly began to climb. Five minutes later, however, Burcham was back on the ground, with the landing gear having failed to retract. It was a minor problem, quickly fixed. By 10:00 a.m., the airplane was back in the air. The Lockheed engineers had affectionally named the airplane Lula-Bell, and quickly Lula-Bell and Burcham were out of sight. But not for long; suddenly Lula-Belle reappeared in front of the group, streaking by at low level and at full power with a speed of 475 mph. Burcham pulled up in a steep climb, made a series of rolls in both directions, and then landed. This was the first flight of America's first successful, soon to be mass produced, jet fighter, the Lockheed P-80, and it was designed in less than 143 days by Kelly Johnson. The Lula Belle now resides in the Jet Flight Gallery at the Smithsonian's National Air and Space Museum. The beautiful aerodynamic design of the P-80 (Fig. 12) attests to the education Johnson received while a student at Michigan, and the Department of Aeronautical Engineering can bask in the glory of this accomplishment, which might be considered part of the beginning of the era of the jet-propelled airplane.


Fig. 12 Lockheed P-80.

The invention of the jet engine took place in the middle 1930s independently in both Germany and England. Today, the German Hans von Ohain and the Englishman Frank Whittle share the credit equally for its invention. It was, however, 10 years later, in the middle 1940s, that knowledge of this revolutionary power plant became generally known. When the Lula Belle flew that January morning, the airplane and its engine were shrouded in secrecy. At that time, however, Germany had a combat jet fighter, the Me 262, already in action. The gas turbine jet engine had already prompted the second design revolution, that of the jet-propelled airplane.

The Aeronautical Engineering Program at Michigan had emphasized flight propulsion from its very beginning. In its first curriculum beginning in 1914, there was a course on the Design of Aeronautical Motors, and a companion course on the Theory and Design of Propellers. The Aeronautical Motors course was dropped from the curriculum in 1930, replaced by a Mechanical Engineering course on Internal Combustion Engines. Throughout the first design revolution, students in the Department of Aeronautical Engineering learned about internal combustion engines from the Mechanical Engineering Department. Considering the close relationship of the University with the massive automobile industry in nearby Detroit, this made sense. The department, however, in 1946 very quickly entered the second design revolution. In that year, the aeronautical engineering curriculum was revised, and two new courses were added, Aircraft Propulsion I and II. These courses were directly focused on jet propulsion, covering a “review of those phases of thermodynamics used in the analysis of compressible flow and propulsion systems”, and then analyzing the turbo jet, ram jet, and pulse jet engines. (Note that the German V-1 “buzz bomb” was powered by a pulse jet engine.) The second propulsion course continued with the “analysis of various propulsion systems, including ram jets and rocket motors, with special emphasis on the characteristics which govern the selection of a propulsion system for a specific installation”. This was 1946, and the Department of Aeronautical Engineering at Michigan was riding the crest of the second design revolution with an emphasis on jet propulsion!

At the same time, it was riding the crest with an emphasis on high-speed aerodynamics. In the same curriculum revision, two new graduate aerodynamics courses were added: Dynamics of Viscous Fluids and Dynamics of Compressible Fluids. The former was an in-depth presentation of modern laminar and turbulent boundary-layer theory and experiment as well as discussions of basic theories of turbulence. (Such discussions are still going on today.) The latter was an advanced study of the mechanics of high-speed flows, involving subsonic and supersonic flow through nozzles and diffusors; normal and oblique shock waves; effects of viscosity; flow past wedges, cones, and around corners; and transonic and supersonic airfoil theory. These courses were being taught in 1946, one year before Chuck Yeager and the Bell X-1 (Fig. 13) became the first pilot and airplane, respectively, to fly faster than sound, on 14 October 1947.

By 1947, the era of the jet-propelled airplane was in full swing. That same year, Michigan added a new course on Fan and Duct Systems, to augment the jet propulsion courses. Interestingly enough, the department held on to its long-standing course on propellers until 1954, when it was combined with the fans course and morphed into the course Advanced Theory of Propellers and Fans, beginning to relate to jet propulsion. (Today, Michigan, like most other universities, no longer teaches a separate course on propellers, although the majority of airplanes flying today are thousands of small general aviation propeller-driven airplanes.)

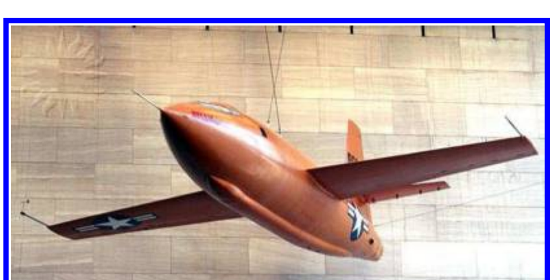

Fig. 13 Bell X-1 hanging at the Natoinal Air and Space Museum.

Fig. 14 Bell X-2.

The Bell X-1 flew beyond Mach 1 in 1947; the Bell X-1A exceeded Mach 2 in 1953; and the Bell X-2 (Fig. 14) exceeded Mach 3 in 1956, important stepping stones in the advancement of high-speed flight. The X-2, unlike the previous X-airplanes, had swept wings, and its aerodynamic design was very advanced for the age. The Chief Aerodynamicist for the X-2 was Richard A. Passman, who had three degrees from the University of Michigan: a bachelor’s degree in Aeronautical Engineering in 1944, a bachelor’s degree in Mathematics in 1946, and a master’s degree in Aeronautical Engineering in 1947. After graduation, Passman went to work for Bell Aircraft in Niagara, New York, where his knowledge and expertise in supersonic aerodynamics led to a very successful relationship with the company. Later, he moved to General Electric, where he became the General Manager for GE’s space activities. Today, Passman is retired but still very active as a research volunteer at the National Air and Space Museum of the Smithsonian, where he is doing research for a book on the X-15 hypersonic research airplane. He is an example of the many excellent graduates from Michigan who helped to spearhead the jet age at the beginning of the second design revolution.

In 1950, Arnold Kuethe, along with his colleague J. D. Schetzer, published a watershed modern textbook in aerodynamics, *Foundations of Aerodynamics* [13], which covered incompressible flow, compressible flow, and viscous flow in about equal treatments, and was widely used throughout academia. It is no surprise, then, that the Department of Aeronautical Engineering added a new required course, Fundamentals of Aerodynamics, in 1949, covering “a development of the fundamentals of aerodynamics which form the basis for the study of modern aircraft”.

In the middle 1950s, new supersonic airplanes were flying on a regular basis. An example is the Lockheed F-104 (Fig. 15), the first airplane to be designed for sustained cruise at Mach 2.

The F-104 was designed by Kelly Johnson and is again another fine example of an airplane design that can trace its intellectual roots back to the education received by Johnson at the University of


Fig. 15 F-104.

Michigan. At about this same time, in 1957, the department added a new course, Theory of Supersonic Wings and Bodies, directed toward the aerodynamic aspects of the design of supersonic aircraft and missiles. This is simply more evidence that the Aeronautical Engineering Department at Michigan was riding the crest of the second design revolution.

Felix Pawlowski, who had seen the program he started in 1914 grow to be one of the strongest aeronautical engineering programs in America, retired from Michigan in 1946 and moved to Pau, France, a small town near the Pyrenees. Pau holds a special place in the history of flight; in 1909, the Wright Brothers set up the world's first flying school there. Pawlowski was going back to his roots. He died in Pau in 1951. About Pawlowski's death, Tom Adamson much later wrote that "all who knew him experienced a great feeling of loss" ([5] p. 50).

Pawlowski, however, lived to see the beginning of the expansion of Michigan's aeronautical research facilities to the nearby Willow Run Airport. During World War II, the Ford Motor Company built and operated the largest production line for B-24 Liberator bombers at Willow Run. After the war, in 1947, the adjacent airport was sold to the University of Michigan for $1.00 with the provision that the university operate the airport as a research facility; in this way, the Michigan Aeronautical Research Center at Willow Run was founded. Immediately, a large supersonic wind tunnel was designed and built with U.S. Air Force funding. The blowdown facility had different nozzle blocks for Mach 1.4, 1.9, 2.8, and 3.8, and a test section 8 by 13 in. In 1947, this was one of the first and largest supersonic wind tunnels in a university, and it positioned the Aeronautical Engineering Department at Michigan to enter the second design revolution in a spectacular fashion. Much of the subsequent research was guided by Arnold Kuethe ([5] p. 55). It was at Willow Run in the early 1950s that Michigan played a leading role in the creation of the Bomarc guided-missile program. Indeed, guided missiles became a major focus at Willow Run with the Wizard Project sponsored by the U.S. Air Force. Also, tests of throttleable rocket engines and hypergolic propellants were carried out at that time. The creation of the Michigan Aeronautical Research Center at Willow Run in 1947 allowed large research facilities such as high-pressure wind tunnels and rocket engines to be operated a safe distance away from the main campus. This set a pattern for the building of similar off-campus aeronautical research complexes in other public universities, such as the University of Minnesota's Rosemount Laboratory in 1948 and Ohio State's Aeronautical Research Laboratory at the Don Scott Airfield in the early 1950s.

The early days of the second design revolution saw the major expansion of the profession of aeronautical engineering beyond airplanes into the design of missiles, rockets, pilotless aircraft, and for a while in the 1950s, the idea of nuclear-powered aircraft. This plunged aeronautical engineers more deeply into such areas as electronics, guidance and control, and overall systems considerations. Once again, Michigan's Department of Aeronautical Engineering rode the crest. In 1946, Professor Myron Nichols joined the faculty at Michigan and established two new research programs located at Willow Run. One of these involved the precursor of the computer revolution, namely the use of analog computers and differential analyzers. The other was a program to study the structure of the upper atmosphere and eventually led to the creation of the High Altitude Research Laboratory. Here, the Nike-Cajun sounding rocket was developed and found application worldwide. These activities prompted the U.S. Air Force to send a number of officers to Michigan for graduate studies to learn the emerging new technology of guided missiles. Upward of 50 officers per year were enrolled, and the program attracted new students from the U.S. Army and the Navy. Two new faculty members were hired to staff the new courses: Lawrence Rauch in 1949 and Robert Howe in 1950. Much later, Professor Emeritus Howe shared with us that

> "the importance of this program to the Aeronautical Engineering Department of the University of Michigan was dramatic. Not only did it increase the overall graduate enrollment in the department by a large factor, but it resulted in the inauguration of new courses in guidance and control of missiles, dynamics of linear and nonlinear systems, and random processes."

One of the arguments for carrying out research in a university is that new, modern ideas fostered by such research will flow into the teaching program; this was certainly exemplified by the changing curriculum at Michigan. For example, in 1950, a number of new courses were offered, such as Aircraft Servo-Control Systems, Nuclear Energy for Aircraft Propulsion, Fundamentals of Nuclear Engineering, and Fundamentals of Aeronautical Instruments and Research Techniques. In 1952, more courses were added: 1) Advanced Engineering Measurements (including transfer functions, impulse response characteristics of linear systems, synthesis and analysis by Fourier transform, power spectra, correlation functions of signal and noise, effects of nonlinear components, and modern information theory); 2) Control and Guidance of Pilotless Aircraft; 3) Telemetry and Remote Control of Aircraft; and 4) Theory of Nonlinear Oscillations. In 1953, five more courses were added: Engineering Applications of the Differential Analyzer, Advanced Feedback Control, Theory of Oscillations of Nonlinear Systems, Theory of Nonlinear System Response, and one with the curious name, Gyrokinetics, dealing with the theory and application of gyroscopes for control and guidance. Such advanced courses were not to be found in most other aeronautical engineering departments at that time; the University of Michigan was again riding the crest.

Elmer Gilbert, now a Professor Emeritus of Aerospace Engineering at Michigan, was a student in 1952, and he witnessed firsthand the impact of the new activities. In an interview with the author in 2012, Gilbert emphasized

> "the importance of Professors Myron H. Nichols and Lawrence L. Rauch, beginning in the late 1940s. Their activities included the setting up of the high altitude research lab and the guided-missile program of graduate studies for military officers. The guided-missile program led to the development of new courses in the system engineering area. This made the Department among the very first of aeronautical engineering departments to adopt such courses."

From this rose a new graduate level academic program in instrumentation engineering, which, during the period 1960–1968, evolved into the Information and Control Engineering Program. In a similar interview, Professor Emeritus Harris McClamroch told this author how the program cut across several departments in the College of Engineering and, in 1968, became an early interdisciplinary graduate program known as the Computer, Information and Control Engineering (CICE) Program, long before such interdisciplinary programs became popular in current-day engineering education. "CICE provided students with an integrated systems perspective that is now widely viewed as key to the development of many 21st century information technologies," McClamroch stated, "including those that are essential to the modern aerospace enterprise." CICE was dissolved in 1984 as a result of a reorganization in the college that resulted in the academic value of the program being distributed across several departments.

The quest for speed and altitude marched on during the late 1950s. After the X-2 had achieved Mach 3, the next high-speed research airplane was the X-15 (Fig. 16), designed to penetrate the hypersonic regime above Mach 5. The world of advanced aerodynamics at that time became dominated by hypersonic flight, defined generically by flight above Mach 5. The first flight of the X-15 took place on 8 June 1959, piloted by Scott Crossfield. The first hypersonic flight of the X-15 was on 23 June 1961, when Captain Robert White took it to Mach 5.27. The highest Mach number achieved with the X-15 was Mach 6.7 with pilot Pete Knight on 3 October 1967. The University of Michigan's aeronautical engineering department once again rode the crest of this new field of hypersonics. In 1959, a new course, Aerodynamics of High Speed Flight, was added to the program, giving the students a "treatment of problems in the aerodynamics of


Fig. 16 X-15.

flight at supersonic and hypersonic velocities" and covering not only hypersonic aerodynamics but also the related areas of aerodynamic heating and real gas effects.

The X-15 was only the tip of the iceberg in hypersonic flight. The advent in the early 1950s of the intercontinental ballistic missile, with a payload that entered the Earth's atmosphere at Mach numbers around 24, greatly accelerated the importance of hypersonic aerodynamics. New problems arose. At these very high speeds, aerodynamic heating becomes extreme, and the flowfield temperatures are so high that the air becomes chemically reacting. The general interest in high-speed and high-temperature flows, not only for aerodynamics but for rocket propulsion as well, prompted two new courses at Michigan in 1954. One, simply entitled Gas Dynamics, covered "unsteady flow with heat addition, shock, detonation and deflagration waves, wave interaction, diffuser and nozzle flow, and applications to internal flow in engines". The other was a focused course on Combustion and Flame Propagation.

The program on high-temperature flows at Michigan was greatly enhanced with the creation of the Gas Dynamics Laboratory on the North Campus, an outgrowth of an earlier propulsion laboratory started by Professor Richard Morrison at the Willow Run facilities, and with the hiring of Professor Arthur Nicholls, who became the Director of the Gas Dynamics Laboratory. Professor Nichols was the first person to create a standing detonation wave in the laboratory, a significant contribution to the state of the art. The Gasdynamics Group was expanded between 1955 and 1961 by the hiring of two noted professors, Thomas Adamson from Caltech and Martin Sichel from Princeton, who taught courses in jet and rocket propulsion. Later, this group was further strengthened by James Driscoll from Princeton University and Gerard Faeth from Pennsylvania State University. Faeth went on to publish more than 500 papers in the fields of combustion, heat transfer, and gas dynamics. He was the first person in the department to become a member of the National Academy of Engineering. The department suffered a great loss when Faeth died suddenly on 24 January 2005. At the time, he was the Arthur B. Modine Distinguished University Professor of Aerospace Engineering.

The era of the jet-propelled airplane continues to the present day, and one of the most dramatic and modern intellectual developments during this period was the rise of computational fluid dynamics (CFD), which involves the numerical solution on powerful computers of the governing equations of fluid motion to obtain flowfield solution for problems that were impossible to solve in the past. For example, today CFD is used to obtain three-dimensional flowfields over complete airplanes at angle of attack and yaw. CFD is a sophisticated field, heavily based in the principles of applied mathematics. It is still new enough that centers of CFD activity exist in only a relatively small number of universities. Once again, the University of Michigan rode the crest. In 1986, the department hired one of the leaders in CFD research, Bram van Leer from the Netherlands, and in 1990 another leading figure, Phil Roe from England, was recruited. A third young faculty member, Ken Powell, was hired in 1987 directly after graduating from MIT. Thus, the Department of Aerospace Engineering created a center of excellence in CFD.

## The Space Age

The profession of aeronautical engineering was turned on its head in October 1957 with the launching of Sputnik, the first manmade artificial satellite, by the Soviet Union. The Space Age had begun. The era of the jet-propelled airplane was now overlapped by the era of the space vehicle, which greatly expanded our definition of the second design revolution. The motion of a vehicle in space, where the only "propulsive" mechanism is the force of gravity, is governed by the same physical laws as the motion of celestial bodies in the universe. To understand how a vehicle would "fly" in space, it was necessary to understand celestial mechanics, usually the purview of the Astronomy and Physics Departments. The design of space vehicles, however, was more closely aligned with the elements of the design of airplanes, and therefore education, design, and research on space vehicles most readily fit within the confines of aeronautical engineering. At Michigan, again riding the crest, some related material crept into the Mechanics of Flight course as early as 1954 with discussions of ballistics studies and trajectories in a vacuum and the atmosphere. These, however, were more motivated by the motion of ballistic missiles rather than spacecraft. Then, in 1959, the flood gates opened at Michigan. Added to the curriculum were two new courses, one on Rocket Propulsion, and one on Flight Mechanics of Space Vehicles. Professor Harm Buning, educated in the Netherlands, brought to Michigan new expertise in the motion of space vehicles, introducing studies in orbital mechanics not only to Michigan students but also to the first groups of astronauts at the NASA Johnson Space Center. Buning is shown in Fig. 17 teaching at the Johnson Space Center. To offer such advanced and topical material to students of aeronautical engineering at this early stage of the Space Age was truly at the forefront of engineering education. (This author was a junior in aeronautical engineering at the University of Florida in 1957; at the time of the launching of Sputnik, he was taking a pioneering course in space flight mechanics offered by Florida's Department of Aeronautical Engineering, created and taught by a Professor who had just moved to Florida from the University of Michigan.)

Again, we emphasize that, in 1957, the world of aerospace engineering was turned on its head, and responding to this sea change in the profession, in 1959, the department at Michigan changed its name; it was now the Department of Aeronautical and Astronautical Engineering, only to be changed again in 1965 to simply the


Fig. 17 Professor Harm Buning teaching at the Johnson Space center.

Department of Aerospace Engineering. Indeed, today the term aeronautical engineering is almost an anachronism, usually reserved exclusively to airplane design, and the whole profession has almost universally adopted the title Aerospace Engineering, inclusive of both airplanes and space vehicles.

However, in this sea of space activities, airplane design took on a particularly viable profile at Michigan in the form of extremely popular design courses taught by Edgar J. Lesher, who had obtained a B.A. in mathematics from the Ohio State University in 1937 and an M.S.E. from Michigan in 1940. Ed Lesher not only taught airplane design, he designed, built, and piloted several of his own designs: light pusher-prop aircraft that earned for him an international reputation. Tom Adamson described Lesher's airplanes and their contributions to the department and to the education of students as follows ([5] p. 52):

> "Although exploits in space were headline news in the 1960s, one of our faculty members did his bit to advance the art of airplane design. Professor Ed Lesher designed, built, and flew two of the pusher-prop designs for which he became internationally known. The first was built to prove the design feature, in particular the long shaft between the engine mounted immediately behind the pilot and the pusher propeller mounter at the rear of the fuselage. The dynamic problems conquered, Ed then built a smaller, lighter version conforming to the FAI class for aircraft with a total maximum weight of 500 kg. The Teal first flew in 1965 and by 1967 was beginning its series of record- breaking flights, the first three for speed in a closed circuit. Then, in 1970, Ed broke the previous record for distance in a closed circuit by 311 miles, roughly 25% longer than the record. Next, he broke two records for speed over a measured course. Finally, for his seventh record flight Ed set the record for distance in a straight line (1835.4 miles from St. Augustine, Florida to Goodyear, Arizona). One of the greatest demands for this flight was his diet; each pound he lost was a pound of fuel added! All in all, Professor Lesher was awarded four Bleriot medals by the FAI. It should be noted that the students in Ed's design class checked all numbers. They were aiding in the design of a real airplane and were very involved and interested in it. Not many of them realized how fortunate they were to be taught by a man who could design, build, and then fly an airplane, let alone one with such innovative and creative ideas in its design."

Ed Lesher's Teal is on permanent display at the Experimental Aircraft Association (EAA) Airventure Museum in Oshkosh, Wisconsin (Fig. 18). Lesher retired from the University of Michigan in 1985. He died in Ann Arbor in 1998.

My history colleagues tell me that events that occurred within the past 50 years are usually too new for any fundamental historical evaluation or judgments. The modern Department of Aerospace Engineering at Michigan fits that category. In this paper, I have concentrated on presenting an almost philosophical history of the department, showing how the education and research in the department closely followed the historical evolution of the technology of the airplane. The historical evolution of the technology of the space vehicle is beyond the scope of this paper. Space vehicles are multifaceted, and their technology cuts across many disciplines, such as aerospace, mechanical, and electrical engineering, physics, chemistry, and astrophysics. What is the standard configuration for a space vehicle? There is no concrete answer; every new space vehicle is different. To write the history of Michigan's Aerospace Engineering Department following the history of the technology of the space vehicle during the Space Age is simply beyond the scope and length of this paper. However, a few major aspects of the department history during this period will be mentioned here.

One major aspect was made clear during interviews with a number of professors emeriti in 2012, namely the number of graduates who went on to distinguish themselves as astronauts. For example, Col. Ed White performed the first walk in space in 1965 during the flight of Gemini 4, which was commanded by Col. Jim McDivitt. Both were graduates of the Aerospace Engineering Department at Michigan and returned to the campus to receive honorary doctorates in astronautical science. McDivitt went on to command Apollo 9, a 10-day mission that included the first flight of the Lunar module. All three astronauts on the Apollo 15 moon mission were University of Michigan alumni: Dave Scott, Jim Irwin, and Al Worden. They all received honorary doctorates in astronautical science from Michigan. Professor Emeritus Robert Howe relates that "both U of M aero students and faculty were thrilled to engage in personal discussions with the astronauts about what the mission was like". We also note that the pilot of Skylab 3 in 1973 was U.S. Marine Col. Jack Lousma, who received his bachelor's degree in Aeronautical Engineering at Michigan. Those graduates who went on to become astronauts performed an expanded service to the profession; rather than being designers of space vehicles, they flew the vehicles much in the same vein as the test pilots who flew the pioneering X-airplanes in the 1950s, constituting the "right stuff".

Having the right laboratory facilities for carrying out state-of-the-art research has been a hallmark of the Aerospace Engineering Department, and it is especially true for space research. The Bendix Corporation in Ann Arbor built one of the largest vacuum chambers in the country; testing for the Apollo Lunar Surface Experiments Package program was carried out in this facility during the 1960s, in conjunction with the University of Michigan. When the company left Ann Arbor, the vacuum chamber was mothballed until it was taken over by the University. Alec Gallimore from Princeton was hired in 1992 to refurbish the chamber for use in advanced propulsion research. A schematic of the Large Vacuum Test Facility (LVTF) is shown in Fig. 19.

Another space activity in the Department is the Michigan Exploration Laboratory, a core part of which is the development of novel flight vehicles and missions in space. "We fly what we build,


**Fig. 18 The Teal at the EAA Musuem.**

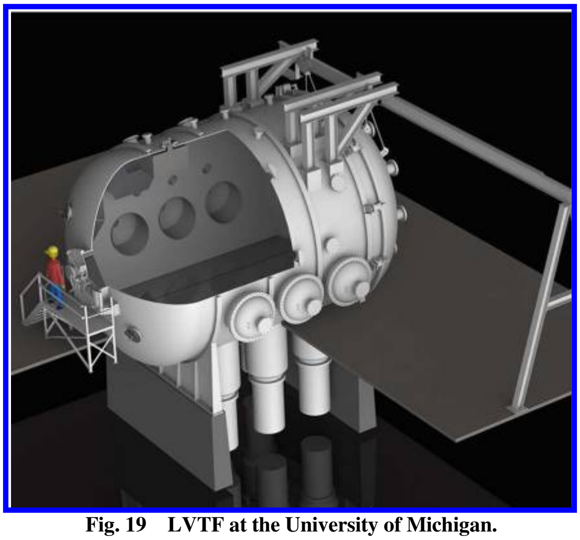

**Fig. 19 LVTF at the University of Michigan.**

and build what we research" is the laboratory's motto. An example is the Radio Explorer mission, which marks the National Science Foundation's first grant of a small satellite program to a University and greatly raised the profile of the use of small satellites for real science missions.

## The François-Xavier Bagnound Foundation

One graduate and his parents stand out in a different way from most. In 1982, François-Xavier Bagnoud, a student from Switzerland, graduated from the Department of Aerospace Engineering at the University of Michigan. He returned to Switzerland to work with his father at Air Glaciers, the largest private Alpine rescue and mountain flying company in the country. Within three years he had become an accomplished pilot in both airplanes and helicopters. Far too prematurely, he was killed in a helicopter crash in Mali, West Africa, in 1986. To commemorate Bagnoud, his close friends and his parents, Countess Albina du Boisrouvray and Bruno Bagnoud, formed the François-Xavier Bagnoud Foundation. The Foundation has been instrumental in philanthropic aid for worthy causes all over the globe, especially those involving sick children. Also, in memory of his great interest in and fond memories of the Department of Aerospace Engineering at the University of Michigan, the Association provided major funding for several initiatives. The François-Xavier Building (FXB), the Maya Lin "Wave Field" landscape sculpture next to the building, endowment for graduate fellowships, the François-Xavier Bagnoud endowed professorship (held by Peretz Friedmann), and the FXB Center for Rotary and Fixed Wing Air Vehicle Design are just part of François' legacy in Michigan's Aerospace Department. Bagnaud made no secret of his intense satisfaction with his education at Michigan, and thanks to the François-Xavier Bagnaud Foundation, there stands today the beautiful François-Xavier Bagnoud Building on the campus of Michigan, which exclusively houses the Department of Aerospace Engineering and its offices, classrooms, and laboratories. I have visited the Bagnoud building a number of times, and I can support the description by Tom Adamson that "it is truly one of the outstanding educational facilities in the country" ([5] p. 52).

## Conclusions

There are four major reasons for the success of the department over the past 100 years. First, starting with Herbert Sadler and Felix Pawlowski, the University of Michigan has always had the uncanny ability to hire the right faculty at the right time, thus riding the crest of the technology. Second, as was brought home to us in interviews with a number of professor emeriti, the faculty have, for the most part, enjoyed over the years strong support, intellectual and otherwise, from the institution itself. Third, the faculty has consistently put emphasis on educating students; in our interviews with the professors emeriti, their concern and focus on the education and welfare of their students was obvious. Finally, we have the students themselves, who have brought to the department over the past 100 years quality and enthusiasm, ready to be molded by the faculty and the overall Michigan experience. In this vein, we have mentioned names of graduates such as Smith DeFrance, Floyd Thompson, Kelly Johnson, and Richard Passman, who went on to bring the department great professional standing. Indeed, the department has benefitted greatly from all its alumni who actively support the program. In 2014, the Department of Aerospace Engineering is still riding the crest. In the most recent ranking by U.S. News and World Report, the department is number two in the country, a great testimonial to everything discussed in this paper and more.

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## References

[1] Anderson, J. D., Jr., *Introduction to Flight*, 7th ed., McGraw–Hill, New York, 2012.
[2] Hallion, R. P., *Legacy of Flight*, Univ. of Washington Press, Seattle, WA, 1977.
[3] Marchis, L., *Cours d'Aeronautique*, Dunof & Pinat, Paris, 1912.
[4] Weeks, R. P., "The First Fifty Years," Dept. of Aeronautical and Astronautical Engineering, Univ. of Michigan, Ann Arbor, MI, 1964.
[5] Adamson, T. C., "Aeronautical and Aerospace Engineering at the University of Michigan," *Aerospace Engineering Education During the First Century*, AIAA, Reston, VA, 2004.
[6] von Kármán, T., and Lee, E., *The Wind and Beyond*, Little, Brown and Co., Boston, 1967.
[7] Anderson, J. D., Jr., *The Airplane: A History of Its Technology*, AIAA, Reston, VA, 2002.
[8] Glauert, H., *The Elements of Aerofoil and Airscrew Theory*, Cambridge Univ. Press, Cambridge, England, U.K., 1926.
[9] Bourgeois-Doyle, R. I., *Her Daughter the Engineer. The Life of Elsie Gregory MacGill*, National Research Council, Ottawa, Canada, 2008.
[10] Jones, B. M., "The Streamline Airplane," *Aeronautical Journal*, Vol. 33, No. 221, 1929, pp. 358–385.
[11] Johnson, C. L., and Smith, M., *Kelly: More Than My Share of It All*, Smithsonian Inst. Press, Washington, D.C., 1985.
[12] Stalker, E., *Principles of Flight*, Ronald Press, New York, 1929.
[13] Kuethe, A. E., and Schetzer, J. D., *Foundations of Aerodynamics*, Wiley, New York, 1950.

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