In the Cause of Flight

TECHNOLOGISTS OF AERONAUTICS AND ASTRONAUTICS

HOWARD S. WOLKO

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ABSTRACT

Wolko, Howard S. In the Cause of Flight: Technologists of Aeronautics and Astronautics. *Smithsonian Studies in Air and Space*, number 4, 121 pages, 1981.—Many of the individuals who made prominent contributions to the technology of flight have attracted little historical attention; yet their accomplishments served to stimulate progress in aerospace development. This work represents an effort to foster interest in flight technologists and their contributions to vehicle performance. Information scattered throughout the literature is assembled herein to provide students of flight history with a convenient source of biographical material on 129 technologists. The biographical sketches are arranged in chronological order of contribution following each topical discussion. The topics include bouyant flight; aerodynamics; air-breathing propulsion; materials, structures, and design; vertical flight; and rocketry and space flight.

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In the Cause of Flight

Howard S. Wolko

Introduction

Man's aspiration to fly can be traced to antiquity through early writings, conceptual sketches, and surviving accounts of tower jumpers; but such evidence merely serves to document the persistent dream of flight in a mechanically unenlightened era. Little to advance the cause of practical flight was accomplished by these activities. True flight, with power and control, proved to be an endeaver totally dependent on the emergence of engineering as a major creative force—an event that did not occur until the latter half of the 19th century. For this reason, it is appropriate to trace briefly the origins of contemporary engineering and the factors that influenced its growth in the years prior to flight demonstration.

Society has always been influenced by a technological age of sorts, but technology as practiced prior to the scientific revolution of the 17th century differed markedly in philosophy and substance from that which was to follow. The 17th century, more than any preceding it, was a time in which learned men questioned the established doctrines of reason and, finding them inadequate, began to search for more realistic means of describing observed phenomena. It was a time in which scientific curiosity rather than application was the prevailing motive power, but the cause at work was right for formulation of the prerequisites required for engineering accomplishment. During this period a number of great thinkers united to form academies of science, which provided an intellectural atmosphere and fostered exchange of information. These academies served to focus effort on transforming vague and often intractable concepts into idealized theories accessible to mathematical treatment. Academicians of the caliber of Blaise Pascal, Robert Hooke, Gottfried von Leibnitz, and Issac Newton, to mention just a few, composed theories that were instrumental in shaping the patterns of reason and understanding of physical phenomena that would guide future generations to superb technical achievements.

With few exceptions, engineers of the period were not involved with the mainstream of scientific activity. At the time, engineers were trained through apprenticeship to be skilled artisans engaged in military ventures related to roads, fortifications, and machines of war. Most had no college training and little exposure to the sciences. Theirs was an application-oriented occupation based principally on empirical rules-of-thumb developed from practical work experience and frequently without sound physical or mathematical justification. Engineering schools were nonexistent and field experience was often gained from prolonged assignments in the colonies.

France was the first to recognize the need to provide engineers with systematic training. As a major land power engaged in consolidation and defense of its colonial holdings, the French government founded the Corps des Ingenieurs du

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Genie Militaire (Corps of Military Engineers) in 1675 to provide the army with specialists in building fortifications. This was followed in 1720 with the Corps des Ingenieurs des Ponts et Chaussees (Corps of Engineers for Roads and Bridges) (Rae, 1967:328). Five years later these organizations were consolidated to form a Corps du Genie (Corps of Engineers), which required its members to have an elementary knowledge of mathematics, drafting, and the principles of fortification. In 1747, the first professional engineering college to offer civil as well as military engineering, the École des Ponts et Chaussees was founded as an offshoot of this corps. Two years later, a second engineering school at Mezieres was founded to train engineers for fortification work (Rae, 1967: 329).

While these schools represent a major step toward systematic training of engineers, their military ties continued the French practice of training engineers principally for government service. In addition, the teaching methods employed retained an air of apprentice training since engineers with field experience were used to explain to individual students how a given type of structure should be designed and constructed. Neither group lectures nor training in the physical sciences or mathematics, beyond geometry, were included in the course of instruction (Gilmor, 1971:9).

Throughout much of the 18th century, France was in a state of military and political unrest that finally erupted into the French Revolution of 1787. Starting with formation of L'Assemblee Nationale (National Assembly), the privileges of nobility were progressively eliminated as many institutions of the *ancien régime* were abolished or reorganized. Primarily of noble lineage, the students and professors at the engineering schools soon were regarded with suspicion and, in time, the schools were closed. But France was at war with the European coalition and desperately in need of engineers to build fortifications, roads, and bridges.

In 1794, a distinguished mathematician, Gaspard Monge persuaded the new government to organize a type of engineering school to replace all those of the *ancien régime*. Known as the École Polytechnique, the school was remarkably different from any of its predecessors (Timoschenko, 1953:67). Monge, who was given responsibility for organizing the school, was a fundamentalist who believed that students well versed in the sciences of mechanics, mathematics, physics, and chemistry would have little trouble acquiring the specialized knowledge required of engineering application. Accordingly, he organized a three-year program of study: the first two years were devoted entirely to the fundamental sciences, and engineering courses were reserved for the third year. Later, when the École des Ponts et Chaussees and the other schools were reopened with improved curricula, the École Polytechnique became a two-year school concentrating only on the fundamental sciences. Students interested in completing their engineering preparation could do so at one of the schools offering training in engineering applications (Timoschenko, 1953:68).

To implement his educational philosophies, Monge introduced the lecture system of teaching and recruited an outstanding faculty, which included, among others, such distinguished scientists as Lagrange, Fourier, and Poisson. Admission to the École Polytechnique was open to all candidates but controlled by competitive examination. The prestige associated with selection served to attract the most talented students in Paris, who sought exposure to the greatest mathematicians and scientists of the time.

During the 18th century, the scientific results of the preceding hundred years were closely scrutinized by continental mathematicians who sought to clarify concepts left lacking in sharp definition by Leibnitz and Newton. As the complementary disciplines of the calculus and mechanics were refined and united to provide a rational means for investigating physical problems, scientific methods were gradually brought into closer harmony with engineering needs. The success of the École Polytechnique and the superb quality of its graduates was a pivotal factor in raising the standards of engineering education on an international level. With the notable exception of Great Britain, all the principal countries of Europe modeled their methods of engineering education after those initiated in France (Timoschenko, 1953:70).

In Germany, the government sought to promote industry and rebuild its economic structure following the Napoleonic wars by founding several engineering schools. These schools were given the status of universities and held responsible for educating engineers to academic standards comparable with those of the recognized professions. While basically patterned along the lines of the École Polytechnique, German schools introduced some interesting variations that resulted in substantial differences in orientation, organizational structure, and administration. Organized around four year curricula designed to cover the full course of study, these schools concentrated on preparing engineers to meet the needs of industry rather than those of the military. The French practice of devoting the first two years of instruction to the fundamental sciences was retained, but students could complete their training in engineering without transferring to a satellite school. This permitted the schools to retain continuity and provided for better regulation of the balance between theory and application required of sound engineering preparation. Administratively, the new schools were conducted in accordance with the principles of academic freedom instead of the military regimen common to their French counterparts. Among other things, the canons of academic freedom permitted the students to elect some of their courses (Timoschenko, 1953:130).

Upon completion of their education, German engineers entered the ranks of industry. Here they were confronted with the practical considerations of engineering, which included the analysis and sizing of machine parts. It was soon discovered that the abstract mathematical treatment of mechanics popularized by the superb faculty of the École Polytechnique was ill-suited for use on such problems. To correct the situation, the German community of engineers mounted an effort to develop mechanics for engineering applications. This effort led to the introduction of a number of books emphasizing methodology and what became known as "engineering mechanics." Works such as Julius Weisbach's *Mechanics of Machinery and Engineering*, which was highly regarded in Europe and America (an English translation was published in 1848), typify the German effort to emphasize the utility of engineering mechanics in practical situations. Introduction of the German approach to mechanics permitted analysis to be presented in a way that could be understood by those unaccustomed to the concepts of higher mathematics, a factor which proved to be of immeasurable value in the development of self-educated engineers (Timoschenko, 1953:131).

As mentioned previously, engineering schools patterned after the École Polytechnique were established in most European countries during the first quarter of the 19th century. Great Britain, whose earlier success with industrialization resulted in the so-called Industrial Revolution, was the outstanding exception to this trend. Britain, with its established reputation as the world's most advanced industrial society, had little reason to question its traditional practice of preparing engineers through apprentice training, since technology was still largely a matter of innovation derived from experience and intuitive reasoning. Men familiar with industrial equipment and processes through such training were uniquely equipped to function in the prevailing technical environment without resort to mathematical analysis or scientific training (Rae, 1967:329).

Early in the 19th century, a number of British "mechanics institutes" were opened, but these schools were not comparable with the professional schools being developed on the continent. The "mechanics institutes" were little more than trade schools offering after hours courses for those interested in supplementing their apprentice training. Established British universities did not offer engineering until the 1840's and, even then, it was not regarded as an accepted academic discipline (Rae, 1967:329).

Although Great Britian was slow to appreciate the engineering advantages of systematic training in science and mathematics, its community of engineers was more conscious of their need for professional recognition than their continental counterparts. It appears that British engineers were the first to recognize the promise of technical affiliation and to organize voluntary societies to promote their professional identity. The Institute of Civil Engineers, with Thomas Telford as its first president, began to meet on a regular basis in 1820. Telford, a proven apprentice-trained engineer of Scottish lineage, stressed the importance of voluntary participation and initiated the practice of recording the substance of papers presented at the Society's weekly meetings. Chartered in response to a petition submitted to the attorney-general in 1828, this society became the first of its type to acquire the status and permanence of a fully recognized professional engineering society. Membership to the society was highly selective and kept so by requiring prospective members to present written evidence of both their practical and theoretical qualifications (Armytage, 1961:123).

As technological complexity increased and began to assume the dimensions of a creative force, a number of engineers limited their activities to particular concerns and formed additional technical societies to promote professional recognition of their engineering specialties. This first began in Great Britain through the efforts of George Stephenson, an eminent railway engineer, who was denied admission to membership in the Institute of Civil Engineers because he failed to submit evidence of his engineering qualifications. Stephenson and his followers considered this requirement a professional affront and resolved to establish an independent society to represent their specialized interests. The Institute of Mechanical Engineers, with George Stephenson as president, was founded in 1847 to promote improvement in the mechanical sciences. Formation of this society established the precedent for extending professional recognition to engineers engaged in a specialized branch of engineering. Other technical societies were organized in Great Britain during the latter half of the century as technology continued to develop along lines which emphasized the need for increased specialization in engineering (Armytage, 1961:131).

Although the national situation in America was far different from that in Europe, the early 19th century proved to be a crucial time for the development of engineering on both continents. In its broad outlines, the basic structuring of American engineering conformed to the emerging pattern in Europe, but the manner in which it was implemented combined the influence of French, German, and British experiences in a way uniquely fitted to meet immediate American needs. The result was an interesting variant which contained elements from each of the major European approaches to engineering preparation.

As a new nation engaged in expanding its frontiers beyond the Alleghenies, the United States began the 19th century with little industry and a critical shortage of capital, labor, and trained engineers. There were few major population centers, no engineering schools, and insufficient industrial shops to foster an apprenticeship system comparable to that in Great Britain. Under these conditions, men were measured, not by their ancestry, breeding, or education, but by their ability to get things done with limited manpower and funds. Such men, characterized in the 19th century as self-taught "Jacks-of-all-trades," were at a premium. To an extent this image was not overdrawn. America's engineering cadre was recruited from three principal sources at this time. Men from each of these sources went on to achieve distinction from engineering accomplishments that profoundly influenced the American patterns of industrial growth and westward expansion (Rae, 1967:330).

The first and most obvious source was Europe, where British apprentice-trained technologists held a commanding industrial edge. British-American relations, however, were abrasive to the extent that England had imposed stringent rules forbidding emigration of technically trained men. However, the engineering advantage of an undeveloped land, rich in natural resources, prevailed. Sizable numbers of trained European engineers, including a number from England, seized the opportunity to supervise the construction and operation of American canals, railroads, and other industrial pursuits. Many, such as German-born John A. Roebling, English-born Samuel Slater, and French-born Elouthere Irenee DuPont remained to occupy prominent positions in America's budding engineering community. This infusion of talent from each of Europe's dominant engineering powers led to a merging of ideologies which set the American pattern of engineering growth apart from that of its European originators (Rae, 1967:331).

The second source was the United States Military Academy at West Point. In 1802, Congress authorized the Corps of Engineers to train a limited number of cadets at West Point. The Academy was intended to be the country's first engineering school—a role not fulfilled until the superintendent's involvement with building harbor defenses was eliminated after the war of 1812. Reopened in 1813 with Sylvanus Thayer as superintendent and remodeled after the École Polytechnique, the Academy proceeded to fill a great national service by providing an urgently needed body of trained engineers. For over a decade the Academy was the only institution in the United States where academic preparation in engineering could be obtained. Rensselaer Polytechnic Institute, founded in Troy, New York, in 1824, became the country's first nonmilitary school to offer an engineering curriculum. Although the number of engineering graduates from R.P.I. remained small for some time, they were instrumental in establishing the country's railroad networks, which had a vital influence on America's westward expansion (Rae, 1967:332).

The third and by far the most common source of American engineers during the first half of the century was the self-educated, who frequently coupled their expertise with apprentice or on-the-job training. While such methods would be inadequate in today's technologically oriented society, they were remarkably successful in their time. In fact, some of America's greatest 19th-century engineers rose from the ranks of the self-educated to become leading figures in the engineering community. Octave Chanute, for instance, began his career as a chainman with a crew surveying the Hudson River Railroad and rose to the position of chief engineer of a number of western railroads. In addition, he was responsible for a number of major engineering endeavors, including the Missouri River bridge at St. Charles, the Kansas City bridge, and the Chicago stockyards, which was yet another fundamental factor in America's plans for westward expansion. Chanute later became a central figure in the American aeronautical community.

As technology continued to grow and become increasingly more complex, the existing methods of training engineers were inadequate to meet the needs of America's expanding economy. The requirement for formally educated engineers was most acute in the northeastern states, which had developed into a major industrial center. In response, a number of universities in the Northeast introduced engineering curricula. These universities included Harvard (1847), Yale (1850), the Polytechnic Institute of Brooklyn (1854), and Cooper Union (1859). To further stimulate engineering education, Congress passed the Morrill Land-Grant College Act of 1862. This act, granting land to the states for support of "colleges of agriculture and the mechanic arts" was eventually responsible for the founding of sixty-seven land-grant colleges geographically disbursed throughout the United States (Rae, 1967:332).

While this enormous growth of interest in engineering education was taking place, American engineers were attempting to acquire professional recognition by organizing technical societies similar to those in Great Britain. As in Great Britain, the American Society of Civil Engineers, founded in 1852, was the first of America's technical societies to gain recognition. This was followed in 1871 with the American Institute of Mining Engineers and the American Society of Mechanical Engineers founded in 1880 (Rae, 1967:333).

Engineers and Aeronautics

By the latter half of the 19th century, engineering had acquired the dimensions of a creative force with the capacity to shape the physical and economic growth of nations. In the process, engineers had gained confidence in their underlying philosophy of solving practical problems through application of a few well-understood principles. In fact, it was precisely because of this nature of their training and employment that engineers were so peculiarly suited for the study of aeronautics. Most were trained to apply a broad general knowledge to a variety of situations and consequently were accustomed to working on new problems, often in unrelated fields of endeavor (Crouch, 1979:7).

In England, a number of engineers had become sufficiently interested in aeronautics to found the Aeronautical Society of Great Britain in 1866. While the total membership of the Society was small, it consisted of some of the most successful engineers in Europe, who took an active part in directing the course of the organization. Their *Annual Report*, aimed at an audience of scientists and engineers, served the important function of bringing a professional approach to aeronautical studies. For years after publication of the first volume in 1868, the *Annual Report* was the principle English-language source for serious studies in aeronautics (Crouch, 1979:8).

As in Britain, respected members of the French and German engineering communities fostered professional interest in flight through publication of engineering journals. *L'Aeronaut*, which first appeared in Paris in 1869, and *Revue de L'Aeronautique*, which followed in 1888, were both published with this idea in mind. The first German aviation journal intended for a technical audience, *Zeitschrift fur Luftschiffahrt und Physik der Atmosphase*, did not appear until 1882, but articles on flight had appeared in other German engineering journals almost a decade earlier (Crouch, 1979:8).

Thus, by 1875, noted European engineers had openly expressed the opinion that flight was a practical problem to be solved by application of engineering means. It remained, however, for engineers to progress beyond theoretical studies through systematic experimentation to construction of operating flight vehicles. Francis Herbert Wenham, a founding member of the Aeronautical Society of Great Britain, was one of the first professional engineers to recognize the need for generating experimental data under controlled test conditions. His use of the wind tunnel for study of the lift characteristics of bird wings led to important discoveries later incorporated in construction of full scale vehicles. In many respects, Wenham was the prototype of a long line of experimentalists, including such influential figures as Alphonse Penaud, Hiram Maxim, Clement Ader, and others, who assembled the base of empirical evidence which culminated in the success of 1903 (Crouch, 1979:10).

Otto Lilienthal, a German engineer, had begun serious work on the problem of flight in 1879. In addition to conducting and publishing a classical series of studies on lift and air resistance, Lilienthal designed and built a series of successful monoplane and biplane gliders. As a pioneer in flight testing, Lilienthal completed over 2,000 flights prior to his death in 1896 in a gliding accident. Percy Sinclair Pilcher, a British engineer, continued in the Lilienthal tradition and like the German master also died in a glider crash (Crouch, 1979:13).

By 1898, European flight experimentation had suffered a number of serious setbacks. Lilienthal was dead and other experimentalists had either exhausted their funds or become discouraged. At about this time, aeronautical leadership shifted to the United States, where a unique community of experimentalists were working in the spirit of informed cooperation. Although not formally organized along lines of the European communities, there were definite lines of communication and participation at conferences and other activities.

Geographically disbursed centers of activity, located in Chicago, Washington, and Boston, were kept informed of each other's progress through Octave Chanute, who had developed an interest in aeronautics in 1872 as a result of its relation to the problems of air resistance in bridge design. By 1890, Chanute's publication activities and extensive correspondence with major aeronautical figures had led to his recognition as one of the world's best informed aeronautical authorities. His promotional efforts of aeronautics included organization in Chicago in 1893 of the International Conference on Aerial Navigation, in which a number of prominent American engineers enthusiastically participated. Too old for active participation in gliding experiments, Chanute remained influential by hiring a group of young engineers to produce vehicles of his design while pursuing their own aeronautical ideas. In 1896, the Chanute-sponsored glider trials held in Indiana were enthusiastically reported by the press to gain national recognition of America's involvement in aeronautical research (Crouch, 1979:15).

A second major aeronautical center developed in Washington, D.C., when Samuel Pierpont Langley became Secretary of the Smithsonian Institution and hired trained engineers to assist him with flight experiments involving both models and a full-scale vehicle. As one of the country's most distinguished scholars and Secretary of a revered institution, Langley's interest in flight and commitment to prove its feasibilty made the subject a matter of public interest. Langley's visibility and 1896 successes with steam powered models provided the reading public with convincing evidence that the airplane was indeed a real possibility. In a sense, Langley's successful flights with steam powered models proved his original thesis, but he was determined to press on toward the ultimate goal of manned, powered flight. With funding from the Army Board of Ordinance and Fortification, Langley continued his research, only to experience crushing defeat when his manned *Aerodrome* twice failed to fly in the fall of 1903 (Crouch, 1979:15).

While aeronautical research centers were developing in Chicago and Washington, a third one was being established in Boston. The central figure of this group was James Means, a retired shoe manufacturer, publisher of *The Aeronautical Annual*, and a personal friend of both Chanute and Langley. Means established the Boston Aeronautical Society to sponsor seminars, contests, and experiments. While this society also provided a means for disseminating aeronautical information, the main interest of the Boston center appears to have been directed more toward modeling and gliding experiments than toward powered, manned flight (Crouch, 1979:15).

Although lesser aeronautical groups were established in other regions of the country, their influence remained local and remote from the mainstream of American aeronautical activity in the closing years of the 19th century. The loosely organized community of American aeronautical enthusiasts had reached its high point in1896, the very year in which Wilber and Orville Wright began to take a serious interest in flight. Unlike most of the men involved with aeronautics, Wilber and Orville Wright were not trained engineers. Both however, had completed high school and had sufficient knowledge of mathematics and physics to understand the primitive analyses contained in contemporary aeronautical literature. Moreover, they had developed their manual skills through shop experience and were accustomed to solving mechanical problems (Crouch, 1979:19).

From the beginning, the Wrights approached flight in a more systematic way than others before them. Aware of their need for self-education, the Wrights embarked on a detailed study of the aeronautical literature. During this period, the Wrights read critically, forming the value judgments which enabled them to derive maximum benefit from the work of their predecessors. They also contacted the leaders of America's aeronautical communities and sought the advice of Langley and Chanute. Based on this research the Wrights devised a successful demonstration of powered flight in December of 1903. While their approach encompassed certain ideas from earlier researchers, their own talent and meticulous attention to experimental detail enabled them to far surpass their predecessors. Most importantly, the Wrights devised an intuitive solution to the basic problems of control which set their work apart from all prior efforts (Crouch, 1979:19).

The success of Wilbur and Orville Wright at Kitty Hawk was not the product of chance or luck, as some would believe. It was the culmination of two generations of engineering research in aeronautics. By accumulating experiences, by raising critical questions, by refining data, and analyzing failure, the Wrights came to realize that the central issue of flight concerned control—and the way to resolve it was research in the air. With penetrating clarity, Wilbur Wright compared their learn-by-doing approach with riding a fractious horse. "If you are looking for perfect safety," he stated, "you will do well to sit on a fence and watch the birds, but if you really wish to learn you must mount a machine and become acquainted with its tricks by actual trial" (McFarland, 1953:99).

In realizing what has been characterized as "one of civilization's greatest accomplishments," the Wrights personified the emergence of engineering as a major creative force.

Acknowledgments

Many of the individuals who made prominent contributions to the technology of flight have attracted little historical attention, although their accomplishments stimulated progress in aerospace development. Writers interested in biographical information on these technologists soon discover that such material is scattered throughout the literature and remains to be assembled in convenient form. This book is written to bring together as much of this material as is likely to prove useful. It is neither an encyclopedic treatment of vital contributions to flight technology nor a comprehensive source of those responsible for them. Instead, it represents a starting point, to be expanded upon as time and resources permit.

The 129 biographical sketches are arranged in a topical format. Each topic is introduced with an overview of events of technical interest. Biographies of principal contributors are arranged in the chronological order of their main contribution.

A task as elusive as identifying individuals responsible for specific developments in flight technology requires the assistance and cooperation of persons with specialized knowledge. The staff of the National Air and Space Museum, Smithsonian Institution, admirably fulfilled this function. I especially want to acknowledge my appreciation to Michael Collins and Melvin Zisfein, the former director and deputy director of the Museum, respectively. I also wish to express my gratitude to the following individuals for their assistance in the preparation of this work: Donald Lopez and Frederick C. Durant III were constant sources of encouragement. Dr. Richard Hallion, Dr. Thomas Crouch, and Dr. Roger Bilstein proved to be inexhaustible sources of suggestions and historical insights. Walter Boyne, Robert Meyer, Jay Spencer, and Frank Winter were welcome advisors with specialized knowledge of aeronautics and astronautics. Catherine Scott, Dominic Pisano, and Mimi Scharf of the museum's library assisted in locating biographical information on a number of technologists referenced in little-known reports and publications. Particular recognition is extended Lillian Kozloski for her patience in typing the manuscript.

I am also grateful for the cooperation and assistance of the American Institute for Aeronautics and Astronautics History Committee chaired by Dr. Eugene Emme. Finally, I take this opportunity to thank Professor Charles H. Gibbs-Smith, first occupant of the Lindbergh Chair of Aerospace History, who reviewed the manuscript at an early stage and suggested numerous additions and corrections.

Buoyant Flight

Observation of ordinary phenomena such as cloud formations or rising smoke most probably prompted early scholars to entertain the notion of floating through air. Early concepts were based largely on conjecture and erroneous conclusions on the nature of the atmosphere, which precluded a systematic approach to the problems of flight. This situation prevailed until it was discovered, early in the 17th century, that air has weight. Only then did attention turn toward finding a substance lighter than air and a suitable means for its containment.

The French author Savinien Cyrano de Bergerac was among the first to set upon the right track (Ege, 1974:6). In novels written around 1650, he described fictional journeys to the moon and sun made possible by a novel scheme consisting of bottles of dew attached to a belt. As the bottles were heated by the sun the wearer was floated skyward ostensibly by the sun's attraction for dew. Of course, de Bergerac's scheme was impractical and his reasoning suspect but his premise was correct: moist air is less dense than dry air and tends to rise. De Bergerac's scheme was based on a popular trick by which an eggshell reportedly can be made to momentarily levitate by adding a small amount of dew and placing the sealed shell in the hot sun (Hart, 1972:50, 51). In principle, as the shell heats, the dew vaporizes causing the shell to rise in bouyant flight.

Other concepts, dating to the 17th and early 18th centuries, were based on more conventional ideas and serve as indicators of the rate at which the fundamentals of bouyant flight were assimilated. In 1670 the Jesuit Father Francesco de Lana-Terzi proposed an ingenious design for a flight vehicle; it was to be supported by four large evacuated spheres made from very thin copper sheet. Each sphere was to be 25 feet (7.62 m) in diameter and was to be fabricated from 0.0044-inch (0.1118-mm) thick foil (Nayler and Ower, 1965:6). De Lana reasoned that by creating a vacuum in the spheres they could be made to weigh less than the air they displaced which would cause the vehicle to rise. (To the writer's knowledge de Lana's reasoning represents the first attempt to apply Archimede's buoyancy principle to lighter-than-air flight. Unfortunately his calculations may have been in error, since each sphere would weigh approximately 400 pounds and provide a much lower amount of buoyant lift.) Correct in principle, the scheme was impractical since de Lana neglected to account for the effect of atmospheric pressure, which would have collapsed the fragile spheres.

The first recorded successful demonstration of a lighter-than-air vehicle is attributed to another clergyman, Father Laurenco de Gusmão. This demonstration is reported to have taken place on 8 August 1709 in the presence of the royal court of Portugal. Gusmão's vehicle was a near-classic example of a hot air balloon. It consisted of a light wooden framework covered with a paper skin. Hot air, generated by a small fire contained in a basket suspended below the balloon, entered the balloon through an opening in its base. Later rumors suggest that Gusmão made a balloon ascension but there is no evidence to confirm this (Ege, 1974:7).

Balloons

During the 18th century much of the European scientific movement was motivated by the birth of interest in the physical sciences. Henry Cavendish, an English chemist, discovered hydrogen in 1766 and proved it was an element capable of quantity production. The discovery prompted other scientists to conduct experiments with hydrogen-filled soap bubbles in an attempt to determine the lifting power of the gas.

Apparently inspired by observation of cloud formations, the Montgolfier brothers, Joseph and Étienne, experimented unsuccessfully with steam-filled balloons. Abandoning their experiments with steam, they erroneously concluded, in 1782, that smoke was a mysterious gas caused by combustion and unwittingly introduced hot air into their ballooning experiments (Gibbs-Smith, 1970: 17). The unmanned balloon rose obligingly. Apparently unaware of Gusmão's earlier success, the Montgolfiers independently arrived at the same conclusion.

When news of the ascent reached Paris, it motivated J. A. C. Charles to begin development of a similar device. Charles, however, was unaware that the Montgolfiers had used hot air as the medium of displacement and decided to use hydrogen. From his experience as an experimentalist, Charles knew hydrogen could be produced from iron filings and sulfuric acid, but he was also aware that the subtle gas would escape through the balloon fabric. To prevent this, he contacted the Robert brothers, who had dissolved rubber in turpentine and covered the fabric with an impervious layer of the mixture. A small balloon was constructed and successfully launched from the Champ de Mars, Paris, on 17 August 1783.

After centuries of dreams and speculation, manned flight in a Montgolfier balloon occurred in Paris on 21 November 1783. On 1 December of the same year, also at Paris, a similar feat was accomplished in a hydrogen balloon that was significantly more advanced than its hot-air counterpart. Charles' hydrogen balloon incorporated nearly all the features of modern balloon design, including a valve line to permit the aeronaut to release gas and control the descent, an appendix to allow the expanded gas to escape and prevent rupture of the balloon, and a nacelle that consisted of a wicker basket suspended from a network of ropes covering the balloon. These features set the standards of construction until new materials made stratospheric balloons possible (Nayler and Ower, 1965:6).

These pioneering ascents marked the beginning of a romantic chapter in the history of flight. The appeal of ballooning rapidly attracted an enthusiastic following from scientists who viewed the balloon as a means for extending their knowledge of the atmosphere. More adventurous souls sought distance and altitude records, while those with a military bent viewed the balloon as a source of advantage. It did not take long, however, to discover the main disadvantage with ballooning. Once airborne in free flight, the balloon floated passively, with the wind in command of direction and destination. A dream had been partially fulfilled, but the price had been control. Serious enthusiasts recognized this flaw almost immediately and began to experiment with manually driven airscrews, oars, and even sails, but absence of a suitable engine was to remain a serious handicap to buoyant flight until the mid-19th century.

Airships

The first step toward ultimately transforming the balloon into an airship was made as early as 1784 (Nayler and Ower, 1965:15). In that year J.B.M. Meusnier, an officer in the French army, began design of an ellipsoidal-shaped balloon. Whether instinct or observation of some natural shape led Meusnier to conclude an elongated shape would have less drag is unknown, but his judgment was later confirmed by the low drag airship hulls of the 1930's. Meusnier's airship design showed considerable promise but was rendered impractical by the absence of a suitable engine. When calculations revealed that 80 men would be required to generate the speed necessary for control effectiveness, the growth in required size precluded success. Although his concept earned Meusnier a place in history as the one responsible for the practical airship form, the vehicle was never built.

Severely handicapped by the slow rate of development of the internal combustion engine, the airship nevertheless continued to be improved. By 1897, three basic structural types of airship had already been developed: non-rigid, semi-rigid, and rigid. The first two have much in common, whereas the rigid airship is in a class by itself.

In the non-rigid and semi-rigid airship, the shape of the envelope is maintained by keeping the internal gas pressure at a level slightly in excess of ambient pressure (Nayler and Ower, 1965:17). The excess internal pressure is determined from anticipated operating loads and must be sufficient to prevent excessive distortion or buckling due to either air loads caused by motion or forces resulting from externally carried loads. The semi-rigid airship is characterized by a keel, which extends along much of the length of the airship. The keel, of course, serves to stiffen the envelope and assists in carrying the applied loads. Both external and internal keels were used.

In the rigid airship, the shape of the envelope is maintained by an internal structural skeleton (Nayler and Ower, 1965:24). Composed principally of lightweight longitudinal members connected by ring-stiffeners or transverse wire bracing, the internal structure is designed to carry all externally applied loads. Rigid airships eventually came to be called Zeppelins, after Count Ferdinand von Zeppelin, who was almost entirely responsible for their development from 1898 until his death in 1917.

Historically, the technical development of the airship closely centers on the activities and contributions of three men: Alberto Santos-Dumont, Henri Julliot, and Ferdinand von Zeppelin.

Alberto Santos-Dumont, who later gained distinction as a pioneer in aircraft development, was unquestionably the most influential figure in the development of the non-rigid airship. During his brief enchantment with lighter-than-air flight, he built a total of fourteen airships. A colorful Brazilian who had relocated in Paris, Santos-Dumont did much to popularize the airship. On 13 November 1899, Santos-Dumont circled the Eiffel Tower in his highly successful No. 3 airship. Two years later, in October 1901, he won the Deutsch de la Meurthe prize offered for the first airship to fly a seven-mile course from St. Cloud around the Eiffel Tower and return in less than half an hour (Nayler and Ower, 1965:17).

While Santos-Dumont was popularizing the non-rigid airship, Henri Julliot, a French engineer, was working at the design of a much larger and more ambitious semi-rigid airship. Employed by the wealthy Lebaudy brothers, Julliot's first airship, the *Lebaudy*, was of an advanced design, which performed admirably (Nayler and Ower, 1965:18). Later responsible for design of a series of semi-rigid airships commissioned by various countries in Europe, Julliot significantly improved airship performance before immigrating to the United States.

Another colorful figure in the history of airship development, Count Ferdinand von Zeppelin pioneered development of the rigid airship. Recognizing the advantages of large airships, Zeppelin's first airship had a volume of nearly 400,000 cubic feet (11,200 cubic meters) (Nayler and Ower. 1965:24). First flown in 1900, the vessel was marginally satisfactory, but lacked structural stiffness. Convinced of the future of large rigid airships, Zeppelin founded his company at Friedrichshafen and proceeded to develop a long series of rigid airships. In spite of several early failures, he persevered and inaugurated regular passenger service with a fleet of four airships from 1910 to 1914.

Zeppelin's company flourished, gained a reputation as the leader in rigid airship manufacture and produced the great airships of the 1920's. A stable of talented engineers, including such notables as Ludwig Dürr and Karl Arnstein, were recruited. After Zeppelin's death in 1917, these engineers continued to develop rigid airships in the tradition established by Zeppelin at Friedrichshafen. Dürr was responsible for the design and construction of over 100 rigid airships, including the ill-fated *Hindenburg*, which burned at Lakehurst, New Jersey, after a trans-Atlantic flight.

Once regarded as a serious long-range competitor for the airplane, the airship declined in popularity as successive generations of aircraft were remarkably improved. Extremely vulnerable, the large airships of the 1930's experienced a series of disasters. One by one the leading countries in airship manufacture began to abandon the airship. After the loss of the *Akron* and the *Macon*, the United States withdrew from further airship development. Great Britain had already done so after losing the R-101. The tragic loss of the *Hindenburg* was the final blow. Since 1918, the history of rigid airships had been one long series of disasters. Even the non-rigids had ceased to serve a useful function although a few small non-rigids survive to serve a limited use in advertising.

Only the balloon remains to carry on the romantic traditions of man's earliest form of human flight. After creditable service as instruments of war and science, ballooning has once again appealed to the fancy of the sportsman. The recent revival in ballooning, with modern versions of the hot air balloon again attracting an enthusiastic following, has happily brought buoyant flight "full circle."

Biographic Sketches

Michel Joseph Montgolfier

1740–1810

Étienne Jacques Montgolfier

1745–1777

Invention of the practical hot air balloon

The Montgolfier brothers were two of sixteen children born of Pierre Montgolfier, a paper manufacturer near Annonay, France. Joseph was self-taught in mathematics and science, whereas Étienne was schooled in mathematics and architecture.

The precise reasons that prompted Joseph, who was the first to become interested in aeronautical matters, to become interested in lighter-than-air flight are not known, but his activities soon attracted his younger brother. Although popular accounts would have one believe the Montgolfiers' discovery of the hot air balloon was little more than a fortuitous accident, there is evidence that their approach was far more systematic, even though they lacked an appreciation for the lifting capability of hot air.

Familiar with Joseph Priestley's essay dealing with his observations of various gases, including hydrogen, the brothers experimented with small balloons filled with steam. They also appear to have experimented with other gases before becoming attracted to the possibility of trying a mysterious gas that they believed was produced by combustion and made visible in the form of rising smoke. While this conclusion was erroneous, they conducted an experiment with a small balloon filled with smoke from a mixture of burning straw and moist wool. When the balloon rose obediently, the Montgolfiers erroneously concluded its capacity for lift was derived from the smoke.

At the request of the French Académie des Sciences, the Montgolfiers made their first public demonstration with a small hot air balloon at Annonay on 4 June 1783. Manned flight in a Montgolfier balloon was made in the same year by J. F. Pilâtre de Rozier and the Marquis d'Arlandes on 21 November.

REFERENCES: *Dictionary of Scientific Biography*, Charles Scribners Sons, 1974; Lennart Ege, *Balloons and Airships*, Macmillan, 1974; J. L. Nayler and E. Ower, *Aviation: Its Technical Development*, Vision Press, 1965.

Jacques-Alexandre-Cesar Charles

1746–1823

Invention of the practical hydrogen balloon

Jacques-Alexandre-Cesar Charles was born in Beaugency, France, but little is known of his family or early life except that he received a liberal, nonscientific education. As a young man he moved to Paris where, after a period of employment with the bureau of finances, he acquired an interest in experimental physics.

The Montgolfiers' first public experiment with a hot air balloon took place at Annonay on 4 June 1783. This demonstration naturally attracted great attention and when news of the event reached Paris it motivated Charles to begin development of a similar device. It appears that Charles was not aware of the Montgolfiers' use of hot air as a source of lift and decided to use hydrogen. Realizing the importance of preventing hydrogen permeation he enlisted the aid of the Robert brothers, who had successfully dissolved rubber in turpentine, and developed a rubberized silk envelope to contain the gas. A small balloon was constructed and successfully launched from the Champ de Mars, Paris, on 17 August 1783. The first manned flight in a hydrogen balloon took place at Paris on 1 December 1783, with Charles and the elder Robert as passengers.

Charles developed nearly all the features of modern balloon design including the valve line that permits the aeronaut to control the release of gas for descent, the appendix that prevents rupture of the balloon sack due to gas expansion, and the nacelle that consists of a wicker basket suspended from a network of ropes covering the balloon.

REFERENCES: *Dictionary of Scientific Biography*, Charles Scribners Sons, 1974; Lennart Ege, *Balloons and Airships*, Macmillan, 1974; J. L. Nayler and E. Ower, *Aviation: Its Technical Development*, Vision Press, 1965.

Alberto Santos-Dumont

1873–1932

Pioneering work in air navigation and light general aviation aircraft

Alberto Santos-Dumont was born on Cabangu Farm at Rocha Dias village in the District of Joao Ayres in the State of Minas Gerais, Brazil. At the time of his birth his father, Henrique Dumont, was a railway construction engineer with the Dom Pedroll Railway (Brazilian Railway). His father later turned to agriculture, became a well-known farmer and the "coffee king" of his time.

At the age of 18, Santos-Dumont was sent to Paris, where he was tutored in physics, chemistry, electricity, and mechanics by a Frenchman, Mr. Garcia. While in Paris, he ordered from Maison Lachambre his first spherical balloon, *Brazil*. After competing successfully in his second balloon, *America*, he abandoned aerostation (i.e., free balloon flight) and devoted himself to solving the problem of steering a balloon. Developing the concept of the airship, he built the *Santos-Dumont No. 1*, a cigar-shaped hydrogen-filled balloon powered by a 3.5 horsepower engine. His No. 2 airship was destroyed in an accident on its maiden flight, but his No. 3 proved highly successful. On 13 November 1899 the No. 3 airship circled the Eiffel Tower, before proceeding to Bagatelle, where it landed without incident. The flight established the reality of air navigation.

Santos-Dumont continued with lighter-than-air flight for some time before turning to heavier-than-air flight. On 23 October 1906, unaware of the Wrights' success, he flew his *14-Bis*, an awkward box-kite canard biplane. It was the first flight in Europe in a powered heavier-than-air vehicle.

By 1909, Santos-Dumont had modified his design and introduced the *Demoiselle* (Dragonfly), the forerunner of today's light general aviation aircraft. He completed his last known flight as a pilot in November of the same year and abandoned aviation because of failing health. Disheartened by the use of aircraft for military purposes during World War I, he returned to Brazil in 1931. Further sickened by the bombing of his countrymen during the 1932 Brazilian Revolution, he committed suicide at the age of 59.

REFERENCES: Fernando Hippolyto Da Costa, *Alberto Santos-Dumont*, VARIG Maintenance Base, 1973; Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationary Office, 1970; J. L. Nayler and E. Ower, *Aviation: Its Technical Development*, Vision Press, 1965.

Henri Julliot

1856–1923

Notable contributions to the technology of non-rigid and semi-rigid airships

Henri Julliot was technical director of the sugar refineries belonging to the wealthy Lebaudy brothers, Pierre and Paul, when they commissioned him to design an airship. The *Lebaudy*, completed in 1902, was an advanced design of the semi-rigid type. When tested at Moisson on 13 November 1902, it proved to be superior to other airships. In 1905, the French government purchased the airship for army use. The success of the *Lebaudy* established Julliot as a capable airship designer who later built several airships for the French army, Russia, Germany, and Great Britain.

A graduate in mechanical engineering from the Central School of Engineers at Paris, Julliot was born at Fontainebleau, France. During the early years of World War I, Julliot was director of aeronautical work for France. In 1915, he emigrated to the United States where he was named general manager for the aircraft division of the Goodrich Company. While in this capacity, he designed and produced a variety of observation balloons and small non-rigid airships.

REFERENCES: Obituary, *New York Times*, 22 March 1923; Lennart Ege, *Balloons and Airships*, MacMillan, 1974.

Ferdinand von Zeppelin

1838–1917

Development of the rigid airship

Although the idea of the rigid airship did not originate with von Zeppelin, its development between 1898 and 1924 was so much the result of his work that the term "dirigible" became synonymous with his name. Descended from nobility, von Zeppelin was born in Konstanz on the Bodensee, Germany. After completing his studies at the Polytechnic School in Stuttgart, the University of Tübingen, and the Military School at Ludwigsburg, he joined the staff of the Quartermaster General of the Würtemburg army as a lieutenant in the Corps of Engineers. Rising to the rank of general, von Zeppelin retired from service in 1891 after a brilliant career during which he repeatedly distinguished himself as a combat soldier.

Having witnessed the military use of balloons while a volunteer with the Union Army during the American Civil War, von Zeppelin turned to the design of rigid airships after retirement. His first design of a dirigible was completed in 1894. Unable to convince the German government of the military potential of the rigid airship, von Zeppelin invested his own wealth to build the first Zeppelin, which flew successfully in 1900. Working with funds raised by public subscription, von Zeppelin so improved the performance of his third Zeppelin (completed in 1906) that the German government provided financial aid for further development.

The *Deutschland*, Zeppelin's ill-fated No. 7, is recognized as the first airship specifically equipped for passenger transport. As the first of the fleet of passenger airships run by the Deutsche Luftshiffahrt A.G., *Deutschland* crashed heavily only six days after her maiden flight. All thirty-three passengers were saved but the ship was seriously damaged and had to be dismantled. Undaunted by the disaster, the company operated regular passenger service with a fleet of four airships from 1910 to 1914. A total of more than 34,000 passengers were served by these airships, which featured comfortable accommodations for about twenty passengers with a buffet served aloft. The Zeppelin airliners marked the initial approach of comfort in air travel.

REFERENCES: Alfred Heim, "Ferdinand von Zeppelin," *Country Life*, 1937; J. L. Nayler and E. Ower, *Aviation: Its Technical Development*, Vision Press, 1965.

Ludwig Dürr

1878–1956

Significant contributions to the technology of rigid airships

Ludwig Dürr joined Count von Zeppelin's organization at Friedrichshafen in 1899, after completing a year of service with the navy at Wilhelmshaven. Born in Stuttgart, Germany, on 4 June 1878, Dürr completed Bürgerschule and Realschule and although he attended the Maschinenbauschule (engineering school) in Stuttgart he apparently did not graduate.

While with the Zeppelin organization, Dürr's grasp of theory and application earned the Count's respect. In 1902, while working on the LZ-2, he proposed use of triangular section girders in order to resist bending forces in all planes. Named technical director of the company in 1904, Dürr introduced basic technical innovations into rigid airship design.

Dürr was an able dirigible pilot and, beginning with the LZ-3, participated in flights of all airships made at Friedrichshafen. During his career with the Luftschiffbau Zeppelin GmbH, he was responsible for the design and construction of over 100 rigid airships, including the ill-fated

Hindenburg, which burned at Lakehurst, New Jersey.

REFERENCES: D. H. Robinson, *Giants in the Sky*, University of Washington Press, 1973; Obituary, *New York Times*, 3 January 1956; Duncker and Humbolt, *Neue Deutsche Biographie*, Berlin 1959; *Enciclopedia De Aviacion y Astronautica*, Edicion Garriga, volume 2, 1972.

Karl Arnstein

1887–1975

Development of principles fundamental to the stress analysis of rigid airship structures

During his career, Karl Arnstein earned a reputation as the world's most noted authority on airship structures. Born in Prague, Bohemia (now Czechoslovakia), he attended the University of Prague, graduating with the degree of Doctor of Technical Sciences in 1912. Appointed an assistant professor of bridge design at the University, he earned a reputation throughout Europe for his expert knowledge of stress analysis. Accepting an invitation to join the Luftschiffbau Zeppelin GmbH at Friedrichshafen, Germany, in 1914, he directed his attention to the stress analysis of rigid airship structures. Arnstein stayed with the Zeppelin company as chief engineer until 1924 when he came to the United States and joined the Goodyear-Zeppelin Corporation in Akron, Ohio, as technical director of aircraft construction.

In 1940, when the Goodyear-Zeppelin Corporation abandoned interest in airship construction and changed its name to the Goodyear Aircraft Company, Arnstein remained as vice-president and chief engineer.

Arnstein published numerous articles on the theory of structures (particularly on airships), and is credited with the design of over 70 military and commercial airships including the American airship *Los Angeles*. In addition to designing two military rigid airships of 6,500,000 cubic feet (182,000 cubic meters) capacity for the U.S. Navy, Arnstein directed design and construction of the *U.S.S. Akron* and *U.S.S. Macon*.

REFERENCES: *The Blue Book of Aviation*, The Hoagland Company, 1932; *Who's Who* (1942), The A. H. Marquis Company; Lennant Ege, *Balloons and Airships*, Macmillan, 1974.

Auguste Piccard

1884–1962

Development of the pressurized gondola used on stratospheric research

Auguste Piccard first attracted world-wide attention when, as a professor of physics at the Polytechnic Institute of Belgium, he invented a pressurized gondola for stratospheric research. The Piccard twins, Auguste and Jean Felix, were born to Jules and Hèléne Piccard in Basel, Switzerland, where their father was a professor of chemistry at the University of Basel. Both brothers had distinguished careers in aeronautics and shared similar interests through much of their lives. Reared in Basel, they attended the Obere Realschule and, upon graduation in 1902, attended the Swiss Institute of Technology in Zürich. Auguste earned his degree in mechanical engineering, whereas Jean took his in chemical engineering. The brothers then continued in graduate school and were awarded doctorates in natural science. Auguste remained at the Swiss Institute of Technology in Zürich until 1922 and then moved to Brussels as a professor of physics at the Polytechnic Institute of Brussels.

In 1931 and the following year, Piccard established two world altitude records in a balloon fitted with a stratospheric gondola that he had invented. The gondola, named *FNRS* for Fonds National de Recherche Scientifique, which financed it, was a spherical aluminum cabin with oxygen equipment and apparatus for making scientific observations at altitude. Piccard's flights proved it was possible to survive in the stratosphere.

In 1946 Piccard announced his plans to explore the ocean depths in a bathyscaphe designed on ballooning principles. He successfully accomplished his objectives in his bathyscaphe, which reached a depth of more than 10,000 feet (3000 m). He died in his home in Lausanne, Switzerland, on 24 March 1962.

REFERENCES: Anna Rothe, editor, *Current Biography*, The H. W. Wilson Company, 1947; Lennart Ege, *Balloons and Airships*, MacMillan, 1974.

Aerodynamics

In the popular mind the terms "science" and "technology" have acquired a vaguely synonymous meaning, yet the motives of science differ markedly from those of technology. The former is concerned with understanding man's environment, the latter with controlling it to achieve a specific objective. Throughout history there have been numerous occasions when this formal barrier of purpose has been crossed as scientists and technologists united in a common cause of accomplishment. Such is the case with aerodynamics.

When attempting to encapsulate the historical development of aerodynamics from its inception to its present posture as a recognized branch of mathematical physics, it is convenient to recognize three principle periods in which distinct changes in emphasis occurred. The earliest of these periods extends from Newton's publication of the first rational theory of air resistance in 1687, to international acceptance of the need for systematic research of flight-related problems in 1915. During much of this formative period, aerodynamics was mainly an empirical endeavor with little emphasis on rigorous mathematical development. As the advent of flight became apparent, the long reluctant forces of science mustered in a sincere commitment to the activity.

The period 1915 through 1935 was one of unprecedented cooperation between scientists and engineers. While scientists accepted study of incompressible flow phenomena (i.e., the movement of bodies through air at "low" speeds) as a topic for rigorous mathematical scrutiny, engineers addressed the problems of progressive refinement of aircraft. As low speed aerodynamics proved a subject amenable to mathematical description, the combined efforts of these two factions led to an impressive body of confirmed theory.

As aircraft performance steadily improved, the restriction of incompressible flow became increasingly unrealistic. During September and October of 1935, leading aerodynamicists from around the world gathered for the Volta Conference on High Speeds in Aviation. Held in Campidoglio, Italy, the conference stimulated subsequent research in high speed aerodynamics, a topic which identifies the main technological emphasis of the period initated in 1935.

The Formative Years, 1687–1915

In order to understand the historical development of aerodynamics and to appreciate the difficulties experienced by its pioneers, it is necessary to return to the era in which mechanics was founded. Long a topic for debate, the first rational theory of air resistance, derived from fundamental principles, is attributed to Isaac Newton (1642–1727), who published his conclusions in the classical treatise *Philosophae Naturalis Principia Mathematica* in 1687 (von Kármán, 1954:9). Introduced at a time when the calculus was in its infancy, Newton's formulation of mechanics did not gain immediate acceptance; consequently, early 18th century ballisticians continued to draw their conclusions from direct experiments. Their data on air resistance were acquired either by means of a whirling arm or by observation of falling bodies. None of this early work on air resistance was in any way motivated by the will to fly.

It appears that Sir George Cayley (1773–1857) was the first to appreciate the aeronautical significance of the ballisticians data. His vision and understanding of the principles of heavier-than-air flight, first published in a three-part paper in 1809–1810, greatly influenced early aerodynamic pursuits (Gibbs-Smith, 1970:21–30). There followed a series of influential, but premature, attempts to directly apply Cayley's insight to model and full scale flight vehicles. Unfortunately, ill-conceived configurations, coupled with structural or power plant deficiencies, resulted in a lengthy series of failures.

Invention of the wind tunnel, first introduced in Great Britain by Francis Herbert Wenham and John Browning in 1871, was a landmark in the cause to render aerodynamics amenable to systematic study (Gibbs-Smith, 1970:39). Vastly superior to the whirling arm, the wind tunnel was used to test a variety of shapes usually selected by intuition or observation of bird wing characteristics. In time, the superiority of the wind tunnel as an aerodynamic test device led to formation of the first laboratories devoted to the study of aerodynamic phenomena.

Not all aerodynamic investigations were conducted in ground test facilities. One of the most influential men in the history of aviation, Otto Lilienthal, introduced flight testing as a means of confirming empirically determined aerodynamic conclusions. After completing an extensive study on the aerodynamics of bird wings, particularly with regard to wing area and lift, Lilienthal began work on a series of gliders. Achieving success with his third vehicle, he continued to test his aerodynamic conclusions in gliding experiments until his tragic death in 1896 (Gibbs-Smith, 1970:72–80).

Lilienthal had approached flight in the spirit of a true airman. An appreciation of this spirit stimulated the Wright brothers to follow a similar course of action. When flight experiments failed to confirm their empirically determined expectations, they returned to the laboratory to conduct more tests and refine their aerodynamic data. In a remarkably short period the Wright's confirmed their beliefs, particularly with regard to the effectiveness of wing warp for roll control. The Wright brother's success in achieving manned flight in a controlled, powered, heavier-than-air vehicle must be attributed primarily to their meticulous experimentation and superb aeronautical judgment.

In common with most engineering subjects at the turn of the century, aerodynamics was largely an empirical venture. Judgment was guided and conclusions reached by interpretation of experimental data rather than predictive mathematical theories. As is so often the case with technology, practice preceded theory.

Coincident with the Wright's success, other aeronautical researchers were becoming convinced that the empirical approach to aerodynamics was a major fault, which could be corrected only through systematic research. This conviction was particularly prevalent in continental Europe where the traditions of engineering tended to favor the classical approach of predicting behavior through mathematical analysis. In 1904, Dimitri Riabouchinsky founded the Aerodynamic Institute at Koutchino, near Moscow, and immediately began construction of suitable test facilities. The following year, Alexandre Gustav Eiffel organized an aerodynamics laboratory in a suburb of Paris. Ludwig Prandtl, who had been actively engaged in aerodynamics research since accepting a chair at the University of Göttingen in 1904, opened an aerodynamics laboratory in the outskirts of town in 1908. The British government followed suit, in 1909, by forming an Advisory Committee for Aeronautics as a separate department of the National Physical Laboratory. By 1910, these laboratories, equipped with the most advanced wind tunnels of the time, were all engaged in systematic research of aerodynamic phenomena (Hallion, 1977:4).

European scientists were remarkably successful in their early attempts to compose mathematically tractable theories of lift and drag. The German mathematician Martin Wilhelm Kutta became interested in aerodynamic theory as a consequence of Lilienthal's gliding experiments. Kutta addressed the problem of why a curved surface produces a positive lift. At the insistence of his professor, S. Finsterwalder, Kutta published a paper on the subject in 1902 (Giacomelli and Pistollesi, 1963:348).

In Russia, Nikolai Zhukovski became interested in the same problem. Between 1902 and 1909, he developed the mathematical foundations for a theory of lift on a wing section in two dimensional flow. Both Kutta and Zhukovski independently had made the same fundamental assumption of smooth flow at the trailing edge. The assumption, now called the Kutta-Zhukovski condition, is the salient point in the theory of lift. With it, the whole problem of lift becomes purely a matter of mathematics (von Kármán, 1954:50–54).

In Germany, Ludwig Prandtl addressed the problem of frictional drag. In 1904, at the Third International Congress of Mathematicians held in Heidelberg, Prandtl showed that for a fluid of small viscosity, such as air, the effect of viscosity is limited to a thin layer adjacent to the surface, the so-called boundary layer. This insight permitted essential simplifications that made frictional drag accessible to mathematical analysis (von Kármán 1954:88).

Meanwhile George Hartley Bryan, a mathematics professor in England, published, in cooperation with W. S. Williams, an epoch making paper on the longitudinal stability of gliders. In the paper, Bryan introduced several completely new concepts including the equation governing stability. Too advanced for its time, the paper was not immediately accepted, but he persevered. Seven years later, in 1911, Bryan published his *Stability in Aviation*, a book regarded as a classic in aviation history.

While European scientists were successfully proving that aerodynamics was a subject amenable to mathematical treatment, little progress had been made in the United States. However, with the founding of the National Advisory Committee for Aeronautics (NACA) on 3 March 1915, America entered the arena of systematic aeronautical research. Founding of the NACA marks the advent of the second period of aerodynamic development.

The Years of Progressive Refinement, 1915–1935

During this 20-year period, aerodynamics was extensively developed and refined by the organized research establishments in Europe and the United States. Two factions, one motivated by the objectives of science and the other by the needs of technology, were particularly influential. Responsive to the scientific appeal of Ludwig Prandtl's mathematical idealization of incompressible flow phenomena, the continental mathematicians concentrated on developing the mathematical foundations of theoretical aerodynamics. Although solutions of idealized problems are of considerable value to those involved with applied research, they are seldom in a form usable by designers. In fact, a function of applied research is to convert results obtained from theoretical studies into a functional format. In the case of aerodynamics this function was admirably performed by the engineering staff of the NACA.

During World War I, however, systematic research was relegated to a position of minor importance, as those technically trained in aeronautics concentrated on the rudimentary improvements needed to meet the needs of war. When hostilities ended, aviation had reached an awkward adolescence. The airplane had proven its value as a combat weapon, but it had done so with an incomplete understanding of lift and drag. In prewar years, Kutta and Zhukovski had found that circulation was needed to eliminate flow anomalies in their two-dimensional theory of lift, while Prandtl's boundary layer theory had greatly simplifed calculation of drag on a wing of infinite span. As peace settled over Europe, development of the theory of circulatory motion and extension of Prandtl's boundary layer theory became particularly attractive problems for the mathematically inclined.

Unknown to investigators on the continent, Frederick W. Lanchester, a well-known British automative engineer, had composed a circulation theory of sustenation as early as 1894. Lanchester, who considered mathematics an unnecessary adornment, attempted to publish in 1897, but the reviewers did not comprehend his work and rejected the paper (Gibbs-Smith, 1970:70). His theory eventually appeared in two volumes, *Aerodonetics* (1908) and *Aerodynamics* (1907). Its significance, however, was obscured by the author's writing style and, for all practical purposes, went unnoticed until Ludwig Prandtl independently introduced a mathematical treatment of circulation (Gibbs-Smith, 1970:124). Prandtl's analysis systematized circulation theory by including several simplifying assumptions, such as the Kutta-Zhukovski condition (von Kármán, 1954:53). In time, the theory, which allowed assessment of the influence of wing geometry on performance, became known as the "Lanchester-Prandtl theory of wings."

While scientists on the continent enthusiastically pursued fundamental aerodynamic research, their British counterparts refused to become involved. Organized under the protective umbrella of the National Physical Laboratory, the Advisory Committee for Aeronautics was so ineffective that aerodynamic research in Great Britain became highly disoriented in the postwar years. Aeronautical initiative in Great Britain shifted to the Royal Aircraft Establishment at Farnborough, where emphasis was given to practical problems in support of the Royal Aircraft Factory.

The number of fatalities resulting from loss of control caused by impending stall was a problem of paramount importance. Some, like Geoffrey T. R. Hill, a British engineer who flew as a test pilot during the First World War, were determined to design an aircraft that could not lose control due to pilot error. Hill's pterodactyl, an unconventional tailless aircraft with sharply swept wings, was designed for inherent stability (Gibbs-Smith, 1970:190). Other investigators sought to improve low-speed stability and control by more conventional means. Frederick Handley Page in Great Britain and Gustav Lachmann in Germany independently developed the slotted wing as a way to postpone stall by reducing the turbulence over the wing at high angles of attack. Like the flap, the slotted wing greatly increased lift at low speeds and virtually eliminated the stall-and-spin type of crash (Miller and Sawers, 1970:79–82).

Not all practical problems were related to flight safety. Throughout the twenties, aerodynamicists continued to be concerned with induced drag in their attempts to improve aircraft performance. Bennett Melville Jones, a professor at Cambridge University, exerted a great influence on aircraft design by considering an aircraft to be more than just the sum of its parts. In a classic paper, "The Streamline Airplane," published in 1929, Jones presented a comparative study of induced drag and theoretical drag determined by assuming ideal streamlining. The comparison provided designers with an idealized goal that served to indicate how much power was wasted in overcoming drag. Following publication, streamlining received considerable attention from aircraft designers (Miller and Sawers, 1970:60). A major fault with British aerodynamics was that it was heavily "pilot oriented" and too closely tied to development of particular aircraft to produce results of general value. Although badly needed, a systematic program in applied aerodynamics failed to materialize at either the National Physical Laboratory or the Royal Aircraft Establishment.

During the period in question, aerodynamic research in the United States was almost exclusively performed by, or in cooperation with, the NACA. When Congress had approved creation of the NACA on 3 March 1915, it contained the provision, "that it shall be the duty of the Advisory Committee for Aeronautics to supervise and direct the scientific problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions" (NACA, 1915:7). One interpretation of this provision is that of a no-nonsense directive to pursue an applied research activity!

President Woodrow Wilson named the 12-man Advisory Committee for Aeronautics on 2 April.

After the organizational formalities of the first meeting, the committee elected to survey current aeronautical research in the United States for the purpose of improving coordination of various governmental, academic, and private research efforts. Survey results were less than encouraging. Limited laboratory facilities capable of work in aeronautics were available, but few were actually engaged in aeronautical research. While academic institutions had mechanical laboratories, only two universities, the Massachusetts Institute of Technology and the University of Michigan, offered aeronautical courses or research (Hallion, 1977:24). To the committee, interest at most colleges was considered "more one of curiosity than that of considering the problem as a true engineering one, requiring development of engineering resources and, therefore, as not yet of sufficient importance to engage their serious attention" (NACA, 1915:13). Industry also proved disappointing. Manufacturers were reluctant to become involved with any activity that could cause radical changes in their product line.

Armed with a bleak appraisal that indicated the appalling state of American aeronautics, the committee moved to initiate corrective action at a rate consistent with available funding. A list of specific problems and most immediate needs was compiled for inclusion in the committee's first annual report to the President. In a concise description of the lead-off problem, the committee clearly established the tenor of future NACA research by noting: "The publication of many valuable treatises which have already been prepared is not sufficient, as many of these treatises are not in a form to be comprehended by designers and manufacturers who are otherwise fitted for practical accomplishments in aeronautical work." Distrust of mathematical theories was isolated as a major factor to be overcome before real progress could be expected (NACA, 1915:13).

No time was wasted in clarifying precisely what the NACA had in mind. Jerome Hunsaker, a brilliant engineer who later became chairman of the NACA, prepared the agency's first report, which convincingly presented research results in a way that could be readily understood. In his report, Hunsaker (1915) describes an experimental investigation of longitudinal stability conducted in a wind tunnel at MIT. Comparison of theory and experiment was accomplished by means of convenient graphs. Hunsaker's report was a model example of the format to be followed in subsequent NACA Technical Notes. It stressed applied research confirmed by experimental evidence that is presented so as to be useful to designers.

In its initial report to the President, the committee recommended gradual development of a well-equipped laboratory as an element essential to its work (NACA, 1915:8). First steps to acquire a suitable facility were taken in 1916 when Dr. Charles D. Walcott, Secretary of the Smithsonian Institution and chairman of the committee, approached Army and Navy authorities with a proposal for a joint Army-Navy-NACA experimental field and proving ground for aircraft. Walcott's reception is indicative of the cooperative spirit that prevailed among the agencies involved. The War Department agreed to purchase the real estate, since the Army had funds for that purpose. Part of the site was to be used by the Army for its aeronautical research studies, while separate allotments would be reserved for NACA and Navy use (Gray, 1948:13).

After evaluating numerous sites, a tract of land near Hampton, Virginia, was chosen as most appropriate to the needs of all involved. Following the Army's newly adopted policy of naming flying fields after Americans who had distinguished themselves in aeronautics, the location was designated Langley Field. Optimistically conceived, the well-laid plan for a joint military-civilian aeronautical research facility was not destined to survive. On 6 April 1917, the United States entered the European conflict with a declaration of war against Germany. The Army transferred its aeronautical experimental work to McCook Field in Ohio and made Langley Field an aviators' school. The Navy installed its test facilities at the Navy Yard in Washington, D.C. Only NACA proceeded with the original plan and started work on its laboratory the following year (Gray, 1948:14). By 1918, the first building was completed and emphasis shifted to construction of a wind tunnel. Construction of the five-foot tunnel, designed from studies of European facilities, was completed the following year but it did not become operational until 1920. With justifiable pride, NACA dedicated its first major research center, the Langley Memorial Aeronautical Laboratory, with appropriate ceremony in June 1920 (Gray, 1948:15).

Popular writers and historians have characterized American aviation in the postwar years as an era of wild speculation. An era made romantic by an overdrawn image of pilots as a fatalistic lot ready to risk life and limb in dilapidated crates. Much of what has been written accurately describes the conditions that prevailed during the early twenties when air regulation had not yet been enacted. The popular image, however, is not without fault. Its preoccupation with flight conditions and irresponsible promoters belies the true concerns of American aeronautics at that time. While the barnstorming circuit continued to attract skilled and unskilled pilots alike, government laboratories were quietly recruiting a cadre of engineers and technicians to work on fundamental technical problems (Hallion, 1977:4–5).

In anticipation of an operational facility, the NACA, in 1919 had asked George Lewis, a professor of mechanical engineering at Swarthmore College, to become its executive officer. Lewis, who had an uncanny ability to recognize latent talent, carefully picked for key positions men whose training and talents would be used to mutual advantage (Gray, 1948:45).

As Wind Tunnel No. 1 neared operational status, plans were finalized for its use in resolving critical aerodynamic problems. Principal among these was the need to establish a reliable means for predicting the performance of full-size aircraft from tests of wind tunnel models. NACA engineers knew that conclusions based on model test results did not apply to full-size aircraft, but they also knew that the controlled test conditions of a wind tunnel were essential for evaluating the influence of design changes on aerodynamic performance. When empirical correction factors developed for use with Tunnel No. 1 proved unreliable, the engineers decided to investigate alternate ways to obtain realistic results from model testing (Gray, 1948:34).

Max Munk, a German immigrant, had joined the research staff at Langley in 1921. Munk, who had studied under Prandtl and earned his doctorate from the University of Göttingen, was aware of European studies that proposed testing wind tunnel models in a fluid other than air. The fundamental idea of these studies was to test the models in accordance with the laws of dynamic similitude. In the case of fluids, the law of similarity is expressed in terms of a nondimensional parameter known as Reynolds number, normally written $\frac{\rho V L}{\mu}$, where ρ is the fluid density, V the flow velocity, μ the viscosity, and L is a representative length (usually the wing chord). To test the model at Reynolds numbers comparable to wthose encountered with a full-size vehicle, European scientists had proposed using carbon dioxide as the working fluid, because this gas has the lowest viscosity at any given pressure. The procedure, however, was considered impractical, because of the difficulty of handling large quantities of carbon dioxide, and had been abandoned. Munk reasoned that the same results could be obtained by compressing air to, say, 20 atmospheres while reducing the representative length to one-twentieth full size. Model test results obtained at 20 atmospheres should then compare with the results obtained from testing a full-size vehicle at normal atmospheric pressure (Gray, 1948:23).

The soundness of Munk's reasoning was proven in 1923, when the variable density tunnel went on line. It soon proved to be a highly superior test facility, which permitted lift and drag on wings to be evaluated under conditions closely corresponding to full scale flight. NACA's first substantial contributions to wing improvement resulted from tests conducted in the new facility (Gray, 1948:36).

American aeronautical research in the early 1920's was a curious parable of opposites. While aerodynamic research flourished at NACA's popularly called "Langley Labs," most academic institutions continued to regard aeronautics as a curiosity. By 1922, only five universities, Massachusetts Institute of Technology, University of Michigan, California Institute of Technology, University of Washington, and Stanford University, offered courses in aeronautics. Of these, only two, namely MIT and the University of Michigan, offered programs leading to an aeronautical degree (Hallion, 1977:27).

Although universities were reluctant to regard aeronautics as a serious endeavor, the NACA, as part of its responsibility, annually advised the President and the Congress of the need for a national aviation policy.

Recognizing that airfoil theory was in a fragmentary state, the NACA, in 1920, developed a uniform notation for describing the aerodynamic characteristics of airfoils. Initially, airfoil data from tests conducted in laboratories around the world were collected and disseminated in reports issued by the NACA. Each report ended with a series of summary graphs indicating relative performance with regard to particular criteria. Although testing under various flow conditions caused considerable scatter in the data points, the graphs were of great service to aircraft designers (Jones, 1977:1–11). Lacking an acceptable theory for predicting airfoil performance, NACA engineers decided to exploit the variable density tunnel and systematically determine the influence of airfoil shape on aerodynamic performance by a "trial and error" procedure. To accomplish this, an engineer would start with a given airfoil and arbitrarily modify one particular characteristic of its shape. After wind-tunnel evaluation of its response, the selected characteristic was further modified and the resulting shape again tested for comparative behavior. A tedious process at best, it never-the-less permitted each characteristic to be evaluated independently (Gray, 1948:99). By 1929, the NACA had published data on nearly 1000 different airfoil shapes.

Convinced that aeronautical research was being limited by existing wind tunnels, George Lewis boldly took the lead in planning and building facilities of unprecedented size and performance. When tunnels of conventional size proved inadequate for propeller research, Lewis proposed construction of a tunnel "large enough to take an actual fuselage with its engine installation and propeller of full size" (Gray, 1948:36). When completed in 1927, the tunnel was an awesome sight. Its throat measured 20 feet (6 meters) in diameter, but it solved the propeller problem and established the limiting speed of propeller operation. Known as the propeller research tunnel, its unique size made the tunnel an important facility for use on a number of critical problems.

One of these problems involved research on the aerodynamics of engine cooling. The first step toward improving the aerodynamics of engine cooling was taken as soon as the tunnel became operational. At the time, most American aircraft were equipped with air-cooled engines and it was common practice to ignore the drag resulting from exposed cylinders in order to promote adequate cooling. Fred Weick, a young engineer who had gained experience in propeller design while with the Bureau of Aeronautics, was placed in charge of the propeller research tunnel. When tests established that the drag from an exposed radial engine amounted to one-third that of the entire fuselage, Weick began an exhaustive series of tests, which finally led to the NACA cowling (Gray, 1948:37). The basic idea behind the cowling was to shape an engine enclosure such that drag would be reduced without undue compromise of engine cooling. When completed, the NACA cowling not only reduced drag, it promoted airflow and improved engine cooling.

By 1929, the status of aerodynamic research in the United States was far superior to that of any other nation. *Aircraft Engineering,* a British publication carried this tribute to the Langley engineers: "They were the first to establish, and indeed to visualize a variable-density tunnel; they have led again with the construction of the twenty-foot propeller research tunnel; and steps are now being taken to provide a 'full-scale' tunnel in which complete aeroplanes up to thirty-five-foot span can be tested. The present-day American position in all branches of aeronautical knowledge can, without doubt, be attributed mainly to this far-seeing policy and expenditure on up-to-date laboratory equipment" (Gray, 1948:16).

From the beginning the NACA was determined to concentrate on its advisory responsibilities and refrain from competition with industry. As military and civilian users pressed for improved performance, industry discussed its need with NACA engineers and found a receptive audience. As rapidly as new information was found and confirmed, it was disseminated to a broad spectrum of the American aeronautical community. Industry, the engineering profession, and military civilian agencies of the Federal government were kept informed of the latest findings in carefully edited Technical Notes. Aircraft design was steadily improved on an item by item basis as the information reported proved applicable to the needs of industry. By 1935, American aircraft were so superior that foreign countries were buying their transport planes from American manufacturers (Gray, 1948:16).

To aircraft designers the world over, the term "applied aerodynamics" had become synonymous with the results generated in a complex of specialized wind tunnels located at the Langley Labs. NACA's early recognition of the need to present research results in a useful form and its bold commitment to develop unprecedented facilities had been master strokes in the competition for aeronautical leadership. Aerodynamics entered the third period in its historical development with a proven portfolio of experimental and mathematical credentials.

The Years of Sonic Achievement, 1935–

In September and October 1935, distinguished aerodynamicists from the world's leading aeronautical powers assembled in Campidoglio, Italy, for what proved to be an influential conference on high-speed aerodynamics. Known as the Fifth Volta Congress on High Speeds in Aviation, the agenda was devoted to assessing the problems of supersonic flight. During the course of the meetings it became penetratingly clear that progress in supersonic aerodynamics was dependent on development of transonic and supersonic wind tunnels. Upon his return to the United States, Theodore von Kármán, the recognized dean of American aerodynamics, contacted responsible government sources to convey the pressing need for development of the necessary high-speed test facilities (Hallion, 1972:11).

While von Kármán's efforts met with comparative indifference, European scientists fared somewhat better. Jakob Ackeret, who was then Director of the Institute of Aerodynamics in Zürich, had earlier developed a continuous flow Mach 2 tunnel. As the world's first modern supersonic wind tunnel, Ackeret's facility was the prototype for a Mach 2.7 tunnel that was under construction at the Guidonia Laboratory. German engineers were also engaged in developing high-speed test facilities in support of their weapons development programs (Hallion, 1972:11).

By mid-1939, the European political situation was deteriorating rapidly. American concern over the build-up of European high-speed research facilities was approaching alarming proportions (Anderson, 1976:5). For years American leadership in commercial aviation had gone unchallenged, but high-speed research could give Europe the edge in the military sector. Army Air Corps Chief, Major General Henry H. "Hap" Arnold, established a special board to investigate military aircraft development. Ezra Kotcher, then a senior instructor at the Air Corps Engineering School at Wright Field, was asked to submit a report on future aeronautical research and development problems for review by the board. Submitted in August 1939, Kotcher's report was forwarded to Major General Arnold and the NACA (Hallion, 1972:12).

Kotcher's report stressed the importance of undertaking extensive research on transonic aerodynamics to study aircraft behavior at, or near, the speed of sound. Research in existing tunnels was limited to the subsonic or supersonic, because of the "choking phenomen." Kotcher advocated obtaining transonic data from a flight research program since no advance in wind-tunnel technology was apparent. Kotcher's call for a high-speed flight research program found a strong supporter in John Stack, a highly qualified engineer at NACA's Langley Laboratory. Intrigued with the idea of developing experimental aircraft for transonic research, Stack succeeded in convincing the NACA to establish a small group to study possible configurations (Hallion, 1972:15).

The thrust of American aviation was drastically altered with the outbreak of World War II on 1 September 1939. Further development of commercial aviation was greatly reduced as aircraft companies directed their efforts toward producing vehicles with the speeds, altitudes, and functions demanded of combat. For the NACA, the war meant a punishing workload. Long-range research plans were ruthlessly pruned to meet the short-term exigenices of military aircraft already in production (Anderson, 1976:7).

By 1943, compressibility problems had assumed critically important dimensions as operational squadrons began to experience losses when the effect was encountered in dives. The NACA's ground-based facilities on which the country had come to depend were still plagued with the choking phenomenon and were of no use for transonic testing. Aerodynamicists desperately sought alternate means for compiling usable data on compressibility. Robert Gilruth, a young engineer in the Flight Research Division, realized that when diving a P-51 at Mach 0.75 the accelerated airflow over the wing approached Mach 1.2. Perhaps flight research could provide the answer. Gilruth designed a small balance mechanism that could be fitted in the gun compartment of a P-51. It could be used to obtain data on test airfoils mounted vertically above the wing. While the test method had definite limitations and certainly lacked the controlled conditions of a wind tunnel, it did provide useful transonic data on airfoil shapes and the effects of aspect ratio, thickness, and section (Hallion, 1972:22).

While one faction of the NACA sought to provide data to solve the immediate needs, other factions of the agency and the military sought to develop separate transonic research aircraft projects. By the end of 1944, the military, the NACA, and the aircraft industry realized that designers needed more reliable information to overcome the effects of compressibility. Pending solution of the choking problem, the only solution was development of transonic research aircraft (Hallion, 1972:26).

On 10 March 1945, the Army Air Technical Services Command notified the NACA that it was awarding Bell Aircraft a contract for a transonic research aircraft. Within a month the Bureau of Aeronautics approved a Douglas proposal to develop the D-558 for similar purposes. Neither aircraft was completed in time to provide needed wartime data. Both aircraft, however, proved highly successful for investigation of transonic and supersonic flight. On 14 October 1947 Air Corps Captain Charles Yeager successfully flew the Bell X-1 faster than the speed of sound. Six years later on 20 November 1953, NACA's Scott Crossfield reached Mach 2 in the Douglas D-558-2 (Hallion, 1972:41–61).

While flight research aircraft painstakingly probed the flight envelope for transonic and supersonic flight, ground research teams struggled with the elusive problems of developing a transonic wind tunnel. By late 1950 John Stack and his team had found the key: "the slotted throat." Prior to this discovery, wind tunnels were of the closed throat type, which allowed shock waves from the test model to reflect off the tunnel walls. The reflection had caused the choking, which prevented accurate measurements at Mach numbers ranging from 0.75 to 1.3. The "slotted throat" eliminated this reflection and made the transonic tunnel a valuable research tool. Within a year, Richard Whitcomb, a brilliant aerodynamicist, had used the tunnel to verify his mathematical formulation of transonic area rule. Whitcomb's area rule amounts to a sensitive balancing of fuselage and wing volume, which minimizes drag at transonic speeds. Its application on postwar fighters resulted in operational military aircraft capable of supersonic flight (Anderson, 1976:11).

Robert T. Jones, who had developed into a gifted aerodynamicist and mathematician while with the NACA at Langley Field, mathematically discovered the drag-reducing faculty of swept wings. When wind tunnel tests confirmed his discovery, Jones was able to account for the subsonic behavior of sweptwings at supersonic speeds. In 1946, Jones was appointed senior staff scientist at the NACA Ames Research Center. While in this capacity, Jones extended Whitcomb's transonic area rule into the supersonic flight range. Jones' supersonic area rule makes it possible to minimize drag at any preselected supersonic Mach number.

With ground based facilities capable of providing reliable data over the full Mach number range of interest, NACA engineers and scientists systematically cleared away the vagaries of flight near, at, and beyond the speed of sound. Variable geometry configurations or "swing wings" are in the inventory. The supercritical wing, with its energy saving potential, is ready. The oblique wing is in advanced stages of development. Once thought to be beyond attainment, supersonic flight has been reduced to accepted routine. What lies beyond the years of sonic achievement is a matter for conjecture, but one point is clear: aerodynamics is no longer an empirical venture, it has become a fully matured science.

Biographic Sketches

Sir Isaac Newton

1642–1727

Formulation of the fundamental principles of mechanics which form the basis for modern aeronautical science

Unquestionably one of the greatest scientists of all time, Sir Isaac Newton was born prematurely to a mother widowed some three months prior to his birth. When his mother remarried, Newton was placed in the care of his aged maternal grandmother who raised him in his father's house in Woolsthorpe, near Grantham in Lincolnshire, England. He was admitted to Trinity College, Cambridge, in 1661, became Scholar in 1664 and Bachelor of Arts in 1665.

Although Newton's formulation of the fundamental principles of mechanics cannot be classified as flight technology, it did provide the basis for development of engineering and its subsequent application to flight. Announced in 1687, at a time in which scientific curiosity rather than application was the prevailing motivation to scientific inquiry, Newton's formulation embodied an approach to the subject of mechanics that was a marked departure from all earlier efforts. Introducing force as an undefined concept, Newton concentrated on characterizing its influence rather than attempting its definition. This identifying characteristic of his formulation had a powerful unifying influence on mechanics and its subsequent applications and expansion. For engineering applications, where velocities are small compared with the velocity of light, Newton's mechanics has yet to be disproved. It consequently survives as the basis of modern engineering science.

As the basis for most analyses, Newtonian mechanics has exerted an enormous influence on the entire movement in aeronautics and astronautics.

References: I. B. Cohen, "*Isaac Newton*" in *Dictionary of Scientific Biography*, volume 10, Charles Scribner's Sons, 1970; Theodore von Kármán, *Aerodynamics*, Cornell University Press, 1954.

Daniel Bernoulli

1700–1782

Formulation of the principles of hydrodynamics providing the basis for understanding lift

As the son of a distinguished mathematician, Daniel Bernoulli continued in the family tradition of scientific achievement. Born in Groningen, Netherlands, his imagination and fertile mind dealt with a wide and varied range of scientific interests. An able physicist and gifted mathematician, he was the first to link Newton's promising new formulation of mechanics with Leibnitz' ideas on the infinitesimal calculus. This union was later extended by others and finally emerged as the recognized hallmark of 20th-century technology.

Bernoulli's early accomplishments brought him considerable recognition in intellectual circles. In 1725 he accepted a chair at the St. Petersburg Academy, Russia, and began what many consider to be his most creative period. While at St. Petersburg, he outlined his famous book, *Hydrodynamica*, in which all propositions are derived from a single principle: conservation of energy. One of the most brilliant applications of this principle is found in Bernoulli's deduction of the celebrated theorem (Bernoulli's Theorem), which establishes that fluid pressure is inversely proportional to fluid velocity. This theorem eventually provided the connection between the lift of aircraft wings and the circulatory motion of the air around them. While Bernoulli's scientific interests were not motivated by an interest in flight, his theorem survives as a fundamental tenet of airfoil design.

REFERENCES: "Hans Straub," *Dictionary of Scientific Biography*, Charles Scribner's Sons, 1970; Stephen P. Timoschenko, *History of the Strength of Materials*. McGraw-Hill Book Co, 1953.

Sir George Cayley

1773–1857

Creative contributions to the empirical foundations of aerodynamics and the conceptual configuration of fixed wing aircraft

Destined to become regarded as the first to take a "serious step toward a successful airplane," Cayley was born on 27 December 1773. He lived and did most of his research at Brompton Hall, near Scarborough, England. Although not institutionally trained as a technologist, Cayley received his education in this area from two able tutors, George Walker and George Cadogen Morgan. In the course of his studies Cayley became familiar with the works of Newton and carefully read the publications of Robbins, Smeaton, and other 18th-century ballisticians. Cayley appreciated the aeronautical significance of their data on air resistance and applied it to the problem of flight.

In 1804 he began work on his famous paper, "Aerial Navigation," which was published in *Nicholsons' Journal* in 1809–1810. The three part paper presents Cayley's understanding of the principles of heavier-than-air flight. The work was a great advance over anything that had previously been written on the subject of aeronautics. In 1912, Orville Wright praised Cayley by stating:

> He knew more of the principles of aeronautics than any of his predecessors and as much as any that followed him up to the end of the nineteenth century. His published work is remarkedly free from error and was a most important contribution to the science.

Cayley's contributions to aeronautics were not confined to engineering speculation or abstract laboratory experiments. Convinced of the future of heavier-than-air vehicles, he built and flew model and manned gliders in an attempt to demonstrate their promise. His work on aerodynamics was widely read and directly inspired others to investigate the problems of flight.

REFERENCES: Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970; Charles H. Gibbs-Smith, *Sir George Cayley*, Her Majesty's Stationery Office, 1968; J. Lawrence Pritchard, "The Dawn of Aerodynamics," *Journal of the Royal Aeronautical Society*, volume 6 (March 1937).

Alphonse Pénaud

1850–1880

Creative contributions to the theory and practice of aircraft stability

Alphonse Pénaud was the son of a French admiral. Born in Paris, France, and equipped with an excellent engineering education, he was prevented from pursuing a naval career by a serious hip disease. Instead, he devoted himself entirely to aeronautics and contributed many fruitful suggestions and inventions. His "planophore" of 1871 marked a milestone in aviation history. A stable monoplane with tapered wings having tip dihedral and a diamond-shaped tailplane, also with dihedral tips, the "planophore" was propelled by a pusher propeller driven by a twisted band of rubber. Inherently stable with both lateral and longitudinal stability, the model was demonstrated in the Tuileries Gardens in Paris before the Société de Navigation Aérienne.

In 1876, Pénaud patented his design for a full-size amphibious tractor, two-seat monoplane, with many highly advanced features that were subsequently flight qualified. Lack of a suitable engine as well as financial backing prevented the design from materializing.

Poverty, ill-health, and public ridicule of his experimental efforts discouraged Pénaud to the extent that he committed suicide at the age of 30. His efforts proved to be one of the principal formative influences in aviation history.

REFERENCES: Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970.

William Henson

1812–1888

Engineering innovations which led to the propeller and double-surfaced cambered wings

Born 3 May 1812 in Nottingham, England, Henson was apprenticed to the lace manufacturing industry as a machinist. Although the motivating influence underlying his interest in flight is unknown, Henson's design of the aerial steam carriage, patented in 1843, proved to be one of the most outstanding and influential designs in early aviation history. The *Arial* was never built and the model of it would not fly, yet it was widely publicized and captured the imagination of flight enthusiasts the world over.

Examination of the superb patent drawings and design innovations establish Henson as an accomplished draftsman and contemporary engineer. His design was among the earliest in history to recommend use of an airscrew to obtain thrust. The outstanding design features of Henson's *Arial* included: (1) twin pusher airscrews powered by a single steam engine mounted in the fuselage; (2) wire braced monoplane configuration with vertical and horizontal stabilizers; (3) cambered wing surface formed from spars and shaped ribs; and (4) tricycle landing gear with tension braced wheels.

These innovations were skillfully combined to produce a design of such pleasing appearance and proportion that the *Arial* gained immediate popularity. A steam powered model was built but never performed as anticipated and reportedly collapsed upon release from its launch ramp. Its failure to fly appears to be attributable to deficiencies in the wing structure, which resulted in inadequate wing stiffness.

In 1848, shortly after the model's failures, Henson abandoned further interest in the field and emigrated to the United States.

REFERENCES: Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970; A. M. Ballantyne and J. L. Pritchard, "The Lives and Work of William Samuel Henson and John Stringfellow," *Journal of the Royal Aeronautical Society*, June 1956.

John Stringfellow

1799–1833

Influential research on steam-powered models including Henson's Arial

Born in Attercliffe, England, on 6 December 1799, Stringfellow served his engineering apprenticeship in the lace trade at Nottingham, but subsequently relocated in Chard. Excelling in the design and fabrication of steam engines, he collaborated with Henson to build a model of the *Arial* for test purposes. Henson attended mainly to construction of the air frame while Stringfellow took Henson's engine design, improved it substantially and produced an excellent little steam engine. The engine was installed in the unsuccessful model tested at Bala Down from 1845 to 1847.

When Henson abandoned aeronautics in 1848, Stringfellow continued to build and test models that retained the basic design innovations of the *Arial*. In the mid-1860's, as an engine manufacturer, he built a tri-plane model, which was exhibited at the Crystal Palace in 1868. Although it was unsuccessful, this and his other works were very influential in persuading Chanute—and through him the Wrights—to adopt a biplane configuration in their designs.

References: Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970; A. M. Ballantyne and J. L. Pritchard, "The Lives and Work of William Samuel Henson and John Stringfellow," *Journal of the Royal Aeronautical Society*, June 1956.

Francis Herbert Wenham

1824–1908

Aerodynamic contributions which mark the practical beginnings of wing-shape theory

One of the most influential figures in the pre-Wright era of aeronautics, Francis Herbert Wenham was born in Kensington, London. His father was an Army surgeon. Although not particularly adept in mathematics, the younger Wenham was endowed with a keen mechanical sense and the questioning interest of a practical engineer. Moreover, he became a first-rate mechanic capable of both designing and making what he wanted. At 17, he was apprenticed to a firm in Bristol where he completed training as a marine engineer.

A man of many dimensions, Wenham made notable contributions in such diverse fields as steam engines, optics, and photography before turning to aeronautics. As a founding member of the Aeronautical Society of Great Britain, he delivered the first lecture to the Society on 27 June 1866. Entitled "Aerial Locomotion," the paper was recognized immediately as a milestone in aeronautics.

An excellent shot, Wenham's prowess as an upland bird hunter provided numerous opportunities to study the structure of bird wings. Aware of Cayley's preference for cambered wings, Wenham drew attention to the fact that bird wings were cambered with a thicker section along the leading edge. He then proceeded to show that such wings derive most of their lift from the forward portion of the wing. These conclusions prompted him to advocate high aspect ratio wings.

Wenham conducted extensive studies of cambered wings and aspect ratio. Dissatisfied with test results acquired from whirling arm studies, he collaborated with John Browning to produce the world's first wind tunnel in 1871. Although understandably primitive, it represents a great improvement in aerodynamic test facilities. Active in the field until his death, Wenham corresponded with Octave Chanute until 1908.

References: J. Lawrence Pitchard, "Francis Herbert Wenham, 1824–1908," *Journal of the Royal Aeronautical Society*, August 1958; Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970.

Horatio Phillips

1845–1924

Experimental research on cambered two-surface wing sections which provided the foundations for airfoil design

Horatio Phillips, the son of a sporting-gun maker was born in Streatham, a suburb of London. An able experimentalist with a deep interest in aeronautics, he closely followed the wind tunnel and whirling arm research conducted under the auspices of the Aeronautical Society. Dissatisfied with the experimental results, Phillips decided to build his own tunnel to test flat plates and airfoils based on sections of a bird's wing. In an attempt to circumvent the unsteady flow in a fan-driven wind tunnel, Phillips introduced the steam injector as a method of wind tunnel drive. This remarkable innovation anticipates the injector drives presently used in many supersonic wind tunnels.

Based on data obtained in his tunnel, Phillips took out his first, and most influential, patent in 1884 and his second in 1891. His data on double-surface airfoil sections proved conclusively that on a thick cambered wing, curved more on the upper surface than on the lower, the greater part of the lift generated is due to reduced pressure above the airfoil section. His results were widely studied by aeronautical enthusiasts throughout the world and exerted a powerful influence on the cause for heavier-than-air flight.

REFERENCES: Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970; S. Lawrence Pritchard, "The Dawn of Aerodynamics," *Journal of the Royal Aeronautical Society*, volume 61 (March 1957).

Octave Chanute

1832–1910

Central role as a disseminator of aeronautical information on a world-wide scale

Considered an elder statesman among aeronautical enthusiasts, Octave Chanute was universally regarded as the world's most knowledgeable flight proponent at the turn of the century. Born in Paris, France, he came to America in 1838 when his father accepted a position as vice-president of Jefferson College (now Loyola University) in New Orleans. Displaying an early flair for mathematics and physical science, Chanute served his apprenticeship as a civil engineer. He subsequently entered and won design competitions for a number of major bridges and architectural projects.

One of the most active and successful civil engineers in America, Chanute became interested in aviation about 1875, when he first began to apply his professional knowledge of stress analysis and structures to problems in aerodynamics. By 1890 he had written extensively on the subject of flight and had published numerous articles in the *Railroad and Engineering Journal* under the title "Progress in Flying Machines." Reprinted as a book in 1894, these articles encapsulate the state of contemporary aeronautical history and theory. They represent a serious attempt to assess past and current achievements in aeronautics.

For many years Chanute functioned as the central disseminator of aeronautical developments around the world. Frequently offering encouragement and direct financial assistance to gifted aeronautical experimenters, he strongly advised them of their need to gain flight experience in gliders. With the aid of several younger disciples, Chanute designed gliders and evolved a biplane version that was more advanced, stable, and easier to handle than the best of Lilienthal's.

While Chanute's technical contributions to the Wright airplane were limited, his constant interest, encouragement, and advice to them were certainly an important factor to their final success.

REFERENCE: Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970.

Otto Lilienthal

1848–1896

Pioneering glider experiments which laid the foundations for the design of the first successful flight vehicles

One of the greatest men in the history of flight, Otto Lilienthal was born in the village of Anklam in Pomerania. He received an excellent education in mechanical engineering at the Berlin Technical Academy before entering the German army to serve in the Franco-Prussian War. Demobilized in 1871, Lilienthal began serious research in aeronautics with a series of experiments designed to establish the physical principles of bird flight as the foundation for design of flight vehicles. The test results, which included important studies of the lift created by a curved surface, were published in 1889 in *Der Vogelflug als Grundlage der Fliegekunst* (Birdflight as the Basis of Aviation). Considered the most important book on aeronautics published in the 19th century, it influenced the Wright brothers and other flight enthusiasts.

In 1891, Lilienthal began work on a series of gliders to demonstrate the practical applicability of his research. After two failures, he achieved success with the third vehicle, a hang glider in which the pilot hung by his arms and relied on shifting his body weight as the primary system of control. Between 1891 and 1896, Lilienthal constructed a total of eighteen glider types and completed 2000 glides.

On Sunday, 9 August 1896, Lilienthal was flying one of his standard monoplane gliders when a sudden gust caused him to lose control and stall. Unable to recover, the glider crashed, breaking his back. Lilienthal died of his injury in a Berlin hospital the following day.

REFERENCE: Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970.

Samuel Pierpont Langley

1834–1906

Construction and flight testing of large, powered, inherently stable model aircraft

A prominent experimentalist and administrator, Langley was born at Roxbury, a suburb of Boston, Massachusetts, and apprenticed in architecture and civil engineering. Abandoning interest in these areas of specialization, he turned to astronomy and astrophysics. From 1887 until his death he served as Secretary of the Smithsonian Institution. His interest in mechanical flight was aroused by a paper read at the Buffalo meeting of the American Association for the Advancement of Science.

In 1891, he published his report "Experiments in Aerodynamics," in which he described his experimental research conducted to determine the possibility of heavier-than-air flight. Two years later he again published on aerodynamics, and in 1896 he demonstrated over the Potomac River sustained flight with a steam-engine driven model aircraft. Invited by the War Department to build a manned vehicle, he accepted a $50,000 contract in 1898. The full size *Aerodrome* was completed in 1903. Intended to be catapulted from a houseboat, the *Aerodrome* crashed on both of its tests. It is not known whether the vehicle fouled the launching catapult or failed because of structural weakness. As a consequence, Langley came under attack by several Congressmen and the Press, and abandoned all further work in aviation.

REFERENCES: J. Gordon, Vaeth, *Langley: Man of Science and Flight*, Ronald Press Co., New York, 1966; Charles G. Abbott, "Samuel Pierpont Langley," *Smithsonian Miscellaneous Collection*, volume 92, number 3281 (August 22, 1934); Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970.

Wilbur Wright

1867–1912

Orville Wright

1871–1948

Pioneering research culminating with invention of the practical airplane

The Wright brothers were the sons of Milton Wright, a bishop of the Church of the United Brethen. Wilbur was born in Millville, Indiana. Two years later the Wright family moved to Dayton, Ohio, where Orville was born. Although both brothers completed high school courses, neither graduated. In 1893 they opened a shop for the sale, repair, and manufacture of bicycles.

Their active interest in aeronautical problems dates to the death of Otto Lilienthal, the German engineer who advocated actual flying experiments as the way to accomplish practical flight. An avid reader, Wilbur wrote to the Smithsonian Institution in 1899 for a bibliography of source material on flight. Among the materials recommended were Lilienthal's *The Problem of Flying and Practical Experiments in Soaring* (1893) and *Progress in Flying Machines* (1894) by Octave Chanute. Orville was soon as enthusiastic as his brother and they began to develop their engineering talents.

By 1900 they had completed their first man-carrying glider and tested it at Kitty Hawk, North Carolina. The disappointing results caused them to question the validity of available data. They returned to Dayton, determined to resolve the problem with the gliders poor lift characteristics. They built a small wind tunnel and conducted exhaustive experiments on wing surfaces of various configurations. When completed they had learned how to compile reliable data from which to design a flight worthy vehicle. They returned to Kitty Hawk in 1902 with a highly successful glider built from their own calculations. There, they made numerous controlled glides while becoming experienced pilots.

Only the problems of fitting a suitable engine and questions relating to the propeller remained to bar the route to powered flight. Failing to find a satisfactory automotive engine, the Wrights designed and built their own 12 horsepower, water-cooled engine. They also conducted research on propellers and developed a satisfactory one to surmount their last major obstacle. These improvements were incorporated in design of the 1903 *Flyer*. Alternating as pilots, the Wrights made the first powered flights in history on 17 December 1903 at Kitty Hawk.

REFERENCES: *Dictionary of Scientific Biography*, Charles Scribner's Sons, 1976; Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970.

Dimitri Pavlovitch Riabouchinsky

1882–1962

Notable achievements in the formative years of aerodynamics

Born in Moscow on 18 October 1882, Dimitri Pavlovitch Riabouchinsky was the son of a wealthy merchant. He attended the Academy of Commercial Sciences in Moscow for a year before transferring to the University of Heidelberg in 1901. From 1908 to 1912 he attended the University of Moscow and later was a private docent with the University. In 1904, Riabouchinsky founded the Aerodynamic Institute on his father's estate at Koutchino near Moscow, where he served as its director from its inception until he left Russia for Paris in 1918.

Riabouchinsky's Institute was favorably received in Russian scientific circles, which enabled him to attract a talented research staff and conduct important wind tunnel research at the Institute. When the Revolution of 1917 occurred, he nationalized the Institute and placed it under control of a committee in order to protect it from destruction and insure the position of the staff.

In 1922, he was awarded a Doctor of Science in Mathematics from the University of Paris; and in 1929, when the fluid mechanics laboratories at the University of Paris were founded, he was appointed their associate director. He simultaneously held the position of professor of theoretical mechanics in the Russian Superior Technical School in France.

Riabouchinsky's research activities in aerodynamics were exceptionally diverse and he published extensively. Under his direction, the Institute at Koutchino took an active and important part in the develpment of some of the fundamental theories of fluid motion.

REFERENCES: *Handwörterbuch fur Mathematic, Astronomie, Physik etc.* J. C. Poggendorff, Verlagchemie, GmbH Berlin 1938; D. P. Riabouchinsky, "Thirty Years of Research in Fluid Mechanics," *Journal of the Royal Aeronautical Society* (London), volume 34, 1935; D. P. Riabouchinsky, "Twenty-Five Years More of Theoretical and Experimental Research in Fluid Mechanics," *Journal of the Royal Aeronautical Society* (London), volume 66, 1962.

Alexandre Gustave Eiffel

1832–1923

Early establishment of a scientifically managed aeronautical research laboratory

Undoubtedly best known for his architectural achievements, Gustav Eiffel also made fundamental contributions to early aeronautics in his laboratory at Auteil, France. Born in Dijon, he studied at the École Polytechnique and the École Centrale in Paris. Intensely interested in innovative structures and with the effects of wind loading on plane surfaces, he experimented with air resistance on bodies of various shapes by dropping them from measured heights of the Eiffel Tower. He later established sound engineering principles on which to design a wind tunnel. Such a tunnel was built in his laboratory.

Eiffel conducted classical tests on a number of aircraft models and components which laid the foundation for future work. His tunnel was the first of what was later termed the "open-jet" type. The principal characteristic of Eiffel's tunnel was that it permitted models to be tested in a free jet of air that is not constrained by solid walls or boundaries. This type of tunnel has many advantages and was subsequently used widely. He published his results in three books published in 1907, 1910, and 1914.

REFERENCES: J. L. Naylor and E. Ower, *Aviation: Its Technical Development*, Vision Press, 1965; *The McGraw-Hill Encyclopedia of World Biography*, volume 3, 1973.

Frederick William Lanchester

1868–1946

Contributions to the fundamental theory of aerodynamics

The son of a noted architect, Frederick William Lanchester was born at Lewisham, England. He studied at the Royal College of Science from 1886 to 1889 but did not graduate. His engineering training was gained by attending evening engineering lectures and workshops at the Finsbury Technical College.

Well known as an automobile engineer, Lanchester expressed an early interest in aeronautics when he read his paper, "The Soaring of Birds and the Possibilities of Mechanical Flight" to the Birmingham Natural History and Philosophical Society in 1894. This paper reportedly contained the fundamentals of circulation theory of sustentation, but it was not printed and Lanchester did not preserve a copy. In the succeeding two years he expanded the paper and submitted it to the Physical Society of London in 1897. This paper embodied the circulation theory and was of profound importance to aeronautics. However, the Society rejected the paper for publication. Lanchester's theory eventually received full publication in 1907 in the first of a two volume treatise *Aerial Flight.* Complex in its presentation, the theory was not well received until the German engineer Ludwig Prandtl, who had been independently working along similar lines, clarified Lanchester's intent. The circulation theory of wings is today referred to as the "Lanchester-Prandtl Theory."

Among the several awards received for his work, Lanchester was awarded the Daniel Guggenheim Medal on 16 September 1931 on the occasion of the reading of the Wilbur Wright Memorial Lecture before the Royal Aeronautical Society in London.

REFERENCES: Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970; *The Guggenheim Medalists*, The Guggenheim Medal Board of Award, 1963.

Ludwig Prandtl

1875–1953

Creative work in the science of aerodynamics

As the founder of boundary layer theory and the progenitor of the German school of aerodynamics, Ludwig Prandtl was instrumental in establishing aerodynamics as a recognized scientific discipline. For over half a century, he and his students made Göttingen University a leading center for research on fluid mechanics. Among other things, Prandtl was the creator of modern concepts of wing theory, boundary layer mechanics, and turbulence.

The only surviving child of a surveying and engineering professor at the agricultrural college at Weihenstephan, Germany, Prandtl was born in nearby Freising. He studied mechanical engineering at the Technische Hochschule at Munich and earned his doctorate from the University of Munich with a dissertation on lateral instability of beams in bending. Upon graduation, he went to work in the Maschinenfabrik Augsburg-Nürnberg. In the course of attempting to redesign an installation for removing shavings by suction, Prandtl recognized some basic weaknesses in the structure of fluid mechanics. Accepting a professorship at the Hannover Technishe Hochshule in 1901, he concentrated on analyzing pipe flows and in 1904 published his celebrated paper on the flow of fluids with small viscosity. In the same year he accepted a chair at the University of

Göttingen where he undertook the direction of the Institute for Technical Physics.

The new environment at Göttingen permitted Prandtl to devote himself to purely scientific work and he soon acquired the assistance of doctoral candidates who did their work with him. Many of these students became leading authorities in the emerging science of aerodynamics.

REFERENCES: *The Guggenheim Medalists*, The Guggenheim Medal Board of Award, 1963; Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970; Theodore von Kármán, *Aerodynamics*, Cornell University Press, 1954; *Dictionary of Scientific Biography*, Charles Scribner's Sons, 1970.

Henri Farman

1874–1958

Maurice Farman

1877–1964

Early use of the aileron and development of practical aviation in Europe

Although generally regarded as Frenchmen, the Farman brothers were born in Paris of British parents, while their father was a correspondent of *The Standard* and *The Tribune*. Encouraged to take part in athletics, Henri and Maurice formed a cycling team while art students at the Paris School of Fine Arts and for a time were amateur champions of France. After winning national recognition as cyclists, the Brothers entered the automobile business and excelled at auto racing.

The Farman business was a flourishing success when, in 1907, Henri became enthusiastic about the prospects of flight. He left the automobile business, placed an order with Gabriel Voisin for a biplane and taught himself to fly. After winning the Deutsch-Archdeacon prize, he opened a flying school at Mourmelon and later began to build his own aircraft, the *Henri Farman III*. In a short time, Maurice also became enthusiastic about flying and started a rival aviation business. The two brothers finally united their companies to form the Farman Aviation Works, which grew to be one of the most successful manufacturers of aircraft in Europe. The later success of the company was largely due to a biplane design developed by Maurice in 1910. Henri and Maurice went on to develop and produce many land planes and seaplanes, including multi-engine aircraft designed specifically for commercial passenger transportation.

The Farman Aviation Works was subsequently nationalized in 1936 and was closed in 1937. Both Henri and Maurice continued their automotive activities but greatly reduced their involvement with aviation.

REFERENCES: Anonymous, Henri Farman–An Appreciation, *Flight*, 1958; Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationary Office, London, 1970; Raymond J. Johnson, editor, *Above and Beyond*, New Horizons Publishers, Inc., 1968.

Albert F. Zahm

1862–1954

Pioneering research on the aerodynamic resistance of shapes

The son of Jacob Zahm, a logger who had emigrated to the United States from Olsberg, in Alsace, Albert F. Zahm was born in New Lexington, Ohio. In 1878 he entered Notre Dame University, where he developed an interest in mathematics and the physical sciences. Zahm received his Bachlor of Arts degree in 1883 and his Masters of Science degree in 1890, before entering Cornell's Sibley College where he was awarded a second master's degree. At the Johns Hopkins University, Zahm earned his doctorate in physics in 1898 with a dissertation related to the physics of flight.

As an undergraduate Zahm built a number of model airplanes and several full scale vehicles. While he was in graduate school at Notre Dame, he chose to devote his talents to the scientific investigation of aerodynamics, and designed and built a primitive wind tunnel. He later built an aerodynamic laboratory while a professor of physical science at Catholic University. Equipped with a large wind tunnel, Zahm conducted methodical research on the aerodynamic resistance of various shapes.

Zahm exerted a strong influence on the growth of early aviation and was recognized as a leading authority in the United States. In 1912, he proposed formation of an aeronautical laboratory endowed by the government and jointly directed by a committee of scientists, military representatives and civilians. Continuing to champion this cause he toured Europe with Jerome Hunsaker in 1913 to assess European aeronautical research facilities. His report influenced Charles D. Walcott, then Secretary of the Smithsonian Institution, to take an active role in the formation of a national laboratory. The formation of the National Advisory Committee for Aeronautics in 1915 is directly attributed to Walcott's involvement as a consequence of Zahm's report.

REFERENCES: Biography, in A. F. Zahm Papers, University of Notre Dame Archives, South Bend, Indiana.

Max Munk

1890–

Significant contributions to aerodynamic theory

Born in Hamburg, Germany, on 22 October 1890, Max Munk earned his Doctor of Engineering degree from the Technical University, Hannover, and his Doctorate from the University of Göttingen in 1916. Emigrating to the United States in 1921, he joined the research staff of the NACA's newly formed Langley Memorial Aeronautical Laboratory. At about the time of his arrival, engineers at Langley were engaged in collecting and disseminating data on the aerodynamic characteristics of airfoils and had expressed concern with the unsatisfactory results obtained from attempts to apply wind tunnel data to full-scale aircraft. Munk suggested scaling in accordance with Reynold's number and proposed construction of a variable-density wind tunnel. When the variable-density tunnel became operational in 1923, the soundness of Munk's reasoning was verified. The tunnel eliminated the difficulties with earlier wind-tunnel testing and permitted small models to be tested at full-scale values of Reynold's number.

Continuing interest in airfoil theory, Munk introduced a significant advance in his thin-airfoil theory. While existing theories were dependent on highly complex applications of conformal mapping, Munk introduced a linearization that permitted calculation of the desired characteristics in terms of easily identified shape parameters. He then introduced his theory for the air forces on an airship. The linearizations introduced in these theories proved extremely useful when airfoil theory was extended to sonic and supersonic flight speeds.

Munk's work during this period was accorded special recognition by the chairman of the NACA in a report entitled "Resumé of the Advances in Theoretical Aerodynamics Made by Max M. Munk."

Leaving NACA in 1926, Munk returned to academic life at Catholic University in Washington, D.C. While with the University, Munk remained active in theoretical aerodynamics and published extensively on the subject.

REFERENCES: *Who's Who in Aviation, 1942–43*, Ziff-Davis Publishing Company, 1942; R. T. Jones, "Recollections from an Earlier Period in American Aeronautics," *Annual Review of Fluid Mechanics*, 1977; George W. Gray, *Frontiers of Flight*, Alfred A. Knopf, 1948.

John William Dunne

1875–1949

Notable contributions resulting in inherently stable aircraft

The son of a distinguished general, John William Dunne has been described as a wiry, resilient man of high intelligence and sensitivity. A keen chess player who acquired the nickname "Professor" as a boy, he was born in Kildare, Ireland, and educated in private schools.

Dunne's serious involvement in aeronautics dates to his tenure as a lieutenant in the Wiltshire Regiment when he was on sick leave from the Boer War because of enteric fever. He started to experiment with models and when in 1902 he met H. G. Wells, a noted writer of science fiction, he was encouraged to experiment further. By the time he had recovered and was due to return to South Africa, he had started design of an ambitious flight vehicle. In 1903, illness again caused his return to England and left him with heart trouble. He set to work to learn aerodynamics and soon was making models to test his theories on aircraft stability. In 1905, Dunne was introduced to an officer of the Royal Engineers, Colonel John Capper, then superintendent of the British army's balloon factory at South Farnborough. Dunne was attached to the balloon factory in 1906 and placed in charge of the design, construction, and testing of the first Bristol military aeroplane. Considered highly secret, Dunne's tests with model gliders and a man-carrying glider, the *Dunne D.I.*, were conducted under strict security measures.

When the army decided to discontinue research on stable aircraft, Dunne severed connections with the balloon factory and joined the Blair Atholl Aeroplane Syndicate, a small company formed to finance his experiments. Initial success with an inherently stable aircraft was realized in 1910. Dunne continued to experiment with his tailless configurations, inspired by the Zanonia seed, until ill health forced him to abandon aeronautics in 1914.

Dunne's inherently stable aircraft were the precursors of all subsequent tailless aircraft.

REFERENCES: Constance Babington-Smith, *Testing Time*, Chapter 1, Harper and Brothers, 1961; Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationary Office, London, 1970; P. B. Walker, *Early Aviation at Farnborough: The History of the Royal Aircraft Establishment*, Macdonald and Co., London, 1971.

George Hartley Bryan

1864–1928

Notable achievement in formulating the theory of aircraft stability

The only child of Robert Purdie Bryan of Clare College, George Hartley Bryan was born at Cambridge, England. Raised by his mother and grandmother after losing his father at a very early age, Bryan spent much of his early life in Italy, France, and Germany. Educated at Peterhouse College, Cambridge University, Bryan earned the degree of Doctor of Science in 1885 and was fifth wrangler in the Mathematical Tripos of 1886. He was a fellow of Peterhouse from 1889 until 1895, when he was awarded the chair of professor of pure and applied mathematics in the University College of North Wales, Bangor. He held the chair until his retirement in 1926.

Developing an early interest in aviation, Bryan published, in collaboration with W. S. Williams, an epoch making paper on the longitudinal stability of gliders in 1904. In the paper, he introduced the concept of resistance derivatives, deduced the equation governing stability, and applied Routh's discriminant to obtain the conditions of stability. Too advanced for its time, the paper gained little approval. Bryan persevered, however, and seven years later published his "*Stability in Aviation*," a book regarded as a classic in aviation history. When practical methods were found to experimentally evaluate the resistance derivatives, Bryan's theory became an integral part of aircraft design.

Bryan continued to work on the rigid dynamics of aircraft and inspired the research of many investigators. He received many awards before retiring to a villa near Bordighera, Italy, in 1926.

REFERENCES: Article by S. Brodetsky, *Nature*, 1 December 1928; A.E.H. Love, Obituary, *The Journal of the London Mathematical Society*, July 1929.

Geoffrey T. R. Hill

1895–1956

Significant achievement in development of swept wing tailless aircraft and inherently stable, stall-proof aircraft

A strong proponent of safe aircraft with a deep concern with stall phenomena, Geoffrey Hill served aeronautics in a number of capacities. During his professional career he occupied positions of engineer, designer, test pilot, and professor. The son of a noted professor of the University of London, Hill demonstrated an early interest in aviation. While still in their teens, he and his brother built and flew a full-scale glider.

Hill attended University College, London, and earned his degree in 1914. Upon graduation he entered the Royal Aircraft Factory as a graduate apprentice, remaining there until 1916 when he obtained a commission in the Royal Flying Corps. Injured in an aircraft accident while serving in France, he returned to flight status in 1918 as a test pilot at Farnborough. Later he became chief test pilot at Handley Page Ltd. where he shared in the early development of the Handley Page slat. By 1924 he designed, built, and flew the *Hill Pterodactyl Mark 1*. Joining the staff of Westland Aircraft Works, Hill designed several further types of pterodactyls, of which three were built.

Appointed to the Kennedy Chair of Mechanical Engineering at University College, London, Hill gained a reputation as an inspiring educator. During World War II, Hill was in charge of the Air Defense Research Department at the Royal Aircraft Establishment at Exeter, and in 1942 became scientific liaison officer between the British and Canadian governments. After the war, he was engaged as a consultant to Short Brothers at Rochester and to General Aircraft at Feltham, England. As aircraft speeds increased and aeroelastic effects became more pronounced, Hill developed the "aero-isoclinic" wing as a means of overcoming the effects that arise from operation in proximity to the control reversal speed. The concept was tried and proven on the *Sherpa*, but was never adopted for an operational aircraft.

Hill died during Christmas week on his farm near Londonderry.

REFERENCES: D. Kieth Lucas, Obiturary, *The Journal of the Royal Society*, volume 60 (March 1956); G. T. R. Hill, *Enciclopedia De Aviacion y Astronautica*, Edicion Garriga 1972; Charles Gibbs-Smith, *Aviation*, Her Majesty's Stationary Office, London, 1970.

Bennett Melville Jones

1887–

Notable achievement in aerodynamic theory particularly with regard to streamlining

When Bennett Melville Jones' publication "The Streamline Aeroplane" appeared in 1929 it exerted a lasting influence on subsequent aircraft. In this paper, Jones compared the skin friction drag of a number of aircraft with the theoretical drag determined by assuming ideal streamlining. The comparison provided designers with an idealized goal and indicated how much power was being wasted to overcome drag.

Jones was born in Birkenhead, England, on 28 January 1887. His father, Benedict Jones, was a barrister-at-law. Jones was educated at Birkenhead School and Emmanuel College, Cambridge. After completing the Mechanical Science Tripos in 1909 he was employed in aeronautical research at the National Physical Laboratory, Cambridge. In 1913, he joined W. Armstrong Whitworth and Company, joining the Royal Aircraft Establishment the following year.

During World War I, Jones qualified as a pilot and served as an observer with No. 48 Squadron, Royal Air Force. After a stint with the Technical Department of the air Ministry in 1918, he became the Francis Mond Professor of Aeronautical Engineering at Cambridge University, a chair he held from 1919 to 1959. Jones served with the Ministry of Aircraft Production from 1939 to 1945 and was chairman of the Aeronautical Research Council from 1943 until 1947.

Jones authored numerous papers and reports on aerodynamics. He was knighted in 1942 for his work in aeronautics and service to England.

REFERENCES: R. Miller and D. Sawers, *Technical Development of Modern Aviation*, Praeger Publishers, 1970; *Who's Who*, The Macmillan Company, 1960; *Who's Who in World Aviation*, American Aviation Publications, Inc., 1955.

Martin Wilhelm Kutta

1867–1944

Early contributions to aerodynamic theory particularly with regard to the theory of lift

Inspired by the experimental inquiries of Otto Lilienthal, Martin Wilhelm Kutta conducted a mathematical analysis of the lift on a wing section obtained from the surface of a circular cylinder. At the insistence of his teacher, S. Finsterwalder, he published his results in a note entitled "Auftriebskräfte in Strömenden Flüssigkeiten" which appeared in 1902. The fundamental assumption underlying Kutta's analysis was later independently put forward by Nikolai Zhukovski. Now commonly called the Kutta-Zhukovski condition, it is the salient point in the theory of lift. By means of this analysis the entire problem of lift is made amenable to mathematical investigation.

Born in Pitschen, Oberschlesian, Germany, Kutta obtained his doctorate from the University of Munich in 1900. He held the position of professor of applied mathematics at several technical academies and universities in Germany. In 1911, he was named a full professor at the Technische Hochschule, Stuttgart, a position he held until 1935.

Kutta's papers on aerodynamics and the theory of lift had a great influence on the growth of the subject during its formative years.

REFERENCES: William F. Durand, *Aerodynamic Theory*, Dover Publication, 1963; J. C. Poggendorff, *Handwörterbuch der exacten Wissenschaften*, volume 5, Leipzig, 1926; F. Pfeiffer Nachrichton, *Zeitschrift für Angewant Mathmatik und Physik*, volume 17, number 6 (December 1937).

Nikolai Yegorovitch Zhukovski

1847–1921

Important contributions to the science of aerodynamics

Nikolai Yegorovitch Zhukovski (Joukovsky) did much to place Russian aviation on a firm scientific basis. Born in the village of Orekhovo in central Russia on 5 January 1847, he was the son of an engineer. Sent to highschool in Moscow, he excelled scholastically and upon completion entered Moscow University, where he specialized in mathematics. After graduation he taught physics at a secondary school in Moscow. Two years later he became professor of mathematics at the Moscow Higher Technical School (Vyssheye Teknicheskoye Uchilishche, abbreviated MVTU). He also taught mechanics at the Academy of Commercial Sciences, Russia. Zhukovski received a Doctorate of Applied Mathematics in 1882. Appointed professor of mechanics at Moscow University in 1886, he simultaneously held a comparable position at the MVTU.

Taking an interest in aeronautics, Zhukovski began to scientifically investigate the theory of flight. In 1902, he directed construction of the first wind tunnel in Russia in the laboratory of the MVTU. This facility was subsequently expanded into an aerodynamics laboratory where his lectures on aviation theory complemented experimental work on the wind tunnel. With the outbreak of World War I, he used the facility as a school for instruction of military pilots in aviation and aerodynamics. Later, he founded The Central Institute for Aerodynamics (TsAGI).

Perhaps best known for his theorem, shared with Kutta, which proved applicable to any airfoil section, Zhukovski published extensively. His work directly influenced the early growth of aviation in Russia and brought him many of his country's highest honors.

REFERENCE: H. J. Nowarra and C. R. Dural, *Russian Civil and Military Aircraft, 1884–1969*, Fountain Press Ltd., 1970.

Jerome Clark Hunsaker

1886–

Notable contributions to aerodynamics, aircraft design, and rigid airships

A brilliant engineer with a remarkable record of aeronautical accomplishment, Jerome Clark Hunsaker was a leading figure during the formative years of U.S. aviation. The son of Walter and Alma Hunsaker, he was born in Creston, Iowa, and educated in the public schools of Saginaw and Detroit, Michigan, before attending the United States Naval Academy. Graduating in 1908 at the head of his class, Hunsaker subsequently attended the Massachusetts Institute of Technology (MIT) where he earned his masters degree and later his doctorate.

Hunsaker's career in aeronautics began when he and his wife translated the pioneering work of Alexandre Eiffel on wind tunnel testing of aircraft. Invited to visit Eiffel's laboratory, he went to Paris in 1913 and worked with Eiffel's assistants on wind tunnel testing. While in Europe Hunsaker visited the leading aerodynamics laboratories with Albert Zahm before returning. Upon his return in 1911, he prepared a series of comprehensive reports on the European laboratories for the U.S. Navy Department and inaugurated wind tunnel research at MIT to determine data for rational aircraft design.

Recalled to Washington during World War I, Hunsaker was placed in charge of the Aircraft Division of the Bureau of Construction and Repair, which was responsible for design, construction, and procurement of all naval aircraft. He was given two engineering projects of particular interest in 1918. The first was for the design and construction of a Zeppelin and the second, to design and build a flying boat capable of crossing the Atlantic.

The flying boat project resulted in the historic NC-4, the first aircraft to cross the Atlantic, while the Zeppelin project led to the *Shenandoah*, the first Zeppelin to use helium as a lifting gas.

In 1921, Hunsaker was transferred to the Bureau of Aeronautics where his duties remained as before. While working in this capacity, he contributed much to the development of naval aircraft. Detailed as assistant naval air attache at London, Paris, Rome, and Berlin in 1923, Hunsaker continued to serve until he resigned from the Navy in 1926. He then joined the research staff at the Bell Telephone Laboratories, where he was in charge of wire and communication services for commercial aviation. He became a vice-president of the Goodyear Tire and Rubber Company in 1928 and remained with the company until completion of the *Akron* and *Macon* airships. He then returned to MIT as head of the departments of Mechanical Engineering and Aeronautical Engineering.

In 1941 he was elected chairman of the National Advisory Committee for Aeronautics, and was reelected annually for a period of sixteen years.

REFERENCES: *The Guggenheim Medalists*, The Guggenheim Medal Board of Award, 1963; *Pioneering in Aeronautics*, The Guggenheim Medal Board of Award, 1952.

Hermann Glauert

1892–1934

Aerodynamic contributions to airfoil and airscrew theory and aircraft stability and control

Hermann Glauert had earned an international reputation as an authority on airscrews, and on the aerodynamics of gyroplanes when he was killed in a blasting accident on Fleet Common. Born in Sheffield, England, he was educated at the King Edward VII School and attended Trinity College, Cambridge, where he took a first class in the Mathematical Tripos and was awarded the Ryson Medal for Astronomy.

Glauert joined the staff of the Royal Aircraft Establishment in 1916. As a Fellow of the Royal Society and a Fellow of Trinity College, he was one of the principle workers at the Air Ministry. He was the author of *Elements of the Aerofoil and Airscrew Theory* and published many papers on aerodynamics. Although primarily a mathematician, Glauert had a deep appreciation of the value of practice as a check on theory, and his opinons were highly regarded by practical men and theorists alike. At the time of his death he headed the Aerodynamics Department of the Royal Aircraft Establishment at Farnborough.

REFERENCES: Obituaries, *New York Times*, 6 August 1934; *The Aeroplane*, 8 August 1934; *Journal of the Royal Aeronautical Society* (London), 1934.

Virginius Clark

1886–1948

Significant contributions in airfoil theory and wooden aircraft construction

Virginius Clark was a leading figure in the formative years of U.S. aviation. The son of Henry and Sarah Clark, Virginius was born in Uniontown, Pennsylvania. He distinguished himself at the Naval Academy, graduating in 1907, and learned to fly at San Diego while still with the Navy. He transferred to the Aviation Section of the Signal Corps and was sent to the Massachusetts Institute of Technology for graduate work.

After leaving M.I.T., Clark served as an officer in charge of the Experimental and Repair Department of the U.S. Army Air Station in San Diego. His unique qualifications as a regular officer, pilot, engineer, and flying unit commander lead to his appointment, in 1917, as a military member of the newly formed NACA. This service further enhanced his qualifications for selection to go to Europe in 1917 as a member of the U.S. Aeronautic Mission. This experience enabled him to act as an advisor on the types of aircraft to be produced and to initiate design projects of his own.

Clark served in many capacities during this period, first in Washington and later at McCook Field which he commanded at one time and where he rose to the rank of colonel. As an engineer and pilot he designed a number of competition winning aircraft, but he is perhaps best known for his development of the Clark airfoil series, which culminated in the Clark "Y" airfoil, a high lift low drag section. The Clark "Y" airfoil was used for several decades on a wide variety of U.S. and foreign aircraft.

Clark left the service to enter industry and served in executive engineering positions with the Dayton Wright Company, Consolidated Aircraft Corporation, and others, before forming the Clark Aircraft Corporation. He invented the duramold construction method which used formed, plastic-impregnated wooden shells for aircraft structures. The duramold process was successfully applied on several aircraft, ranging from small personal planes to the huge Hughes HK-1 flying boat. At the time of his death, Clark was working for Hughes.

REFERENCES: Walter Boyne, National Air and Space Museum, Smithsonian Institution, Washington, D.C.; *Who's Who in American Aeronautics*, Floyd Clymer Publishers, 1925.

John K. Northrop

1895–

Significant achievement in streamlining and flying wing technology

John K. Northrop was the chief proponent of flying wing design in the United States. Born in Newark, New Jersey, Northrop was nine years old when his family relocated in Santa Barbara, California. Deeply interested in mechanics, he curtailed his formal education to work as a garage mechanic, carpenter, and draftsman before going to work in 1916 with the Loughead brothers, who were building flying boats. Except for a period with the Army Signal Corps, Northrop stayed with the Lougheads until 1923, when he joined the Douglas Aircraft Company. He remained with Douglas working as draftsman, designer, and project engineer until forming the Lockheed Aircraft Company in 1927. It was while he was with Lockheed that he designed the famous Lockheed *Vega*, an aircraft whose design was considered far ahead of its time.

Northrop began his research on flying wing aircraft in 1928 in an effort to reduce drag to a minimum. Forming a small engineering group known as the Avion Company, he built and test-flew a semi-flying wing, which made numerous test flights until the Depression caused further research with it to be abandoned. The pressure of designing and building conventional aircraft prevented complete concentration on flying wing aircraft, but in 1939 Northrop began engineering tests of a new flying wing design. Known as the NIM "Jup," the vehicle was flight-tested at Muroc Dry Lake in 1940 and made over 200 flights.

Encouraged by the Air Force to investigate the applicability of flying wing aircraft for bombardment, Northrop built four N9M flying wing aircraft in 1942. These aircraft were used to prove the flight characteristics of flying wing aircraft and indoctrinate pilots in their use.

Northrop designed a number of flying wing aircraft including the XB-35, which was the first in a series of large flying wing bombers, and the jet powered YB-49, the only true large flying wing. The last Northrop-designed flying wing to be built before his retirement was the X-4, a miniature flying wing laboratory intended to explore all wing configurations at sonic speed ranges.

In addition to designing flying wings, Northrop also introduced a type of wing construction known as "multiweb construction" which was widely used by the industry.

REFERENCE: E. T. Maloney, *Northrop Flying Wings*, World War II publications, 1975.

Ernst Mach

1838–1916

Pioneering studies in airflow and its behavior at sonic speeds

Born in Turas, Moravia (Austria), Mach was the son of a school teacher, who relocated in Vienna while Ernst was still a baby. He obtained his doctorate in physics from the University of Vienna in 1860 and taught mathematics at Graz University. Later he headed the departments of physics at the universities of Prague and Vienna.

The author of numerous technical books dealing with physics and philosophy, Mach was the first to take note of the change in airflow over a moving object as it reaches the speed of sound. Although his experimental work in ballistics was not widely known until aircraft approached the speed of sound, Mach's writings and teachings were widely disseminated. The term "Mach number" came into universal use in 1947 when Captain Charles Yeager exceeded the speed of sound in the Bell X-1. Mach number is the ratio of the velocity of a body in a gas to the speed of sound in the gas under given conditions of temperature. It has been called the most important concept of speed in compressible fluid theory, because it provides a convenient index to the compressibility of a fluid at any given speed.

Mach retired in 1901, after suffering a stroke, but remained active in his field until his death at Vaterstetten, near Haar, Germany.

REFERENCE: *Dictionary of Scientific Biography*, Charles Scribners' Sons, 1970.

Osborne Reynolds

1842–1912

Fundamental studies on the transition from laminar to turbulent flow

Osborne Reynolds was born into an Anglican clerical family in Belfast, Ireland. Educated at Dedham Grammar School and then privately, he apprenticed in mechanical engineering before going to Cambridge and eventually pursuing a career in civil engineering. A brilliant student, he graduated from Cambridge in 1867 as seventh Wrangler and received a fellowship at Queens College. He contributed significantly to a variety of engineering subjects during his tenure as an engineering professor at Owens College, Manchester.

Initially interested in electricity and magnetism, his attention turned to fluid mechanics after 1873. His experimental investigation of flow stability in pipes and channels is described in a paper published in the *Philosophical Transactions for the Royal Society of London* in 1883. In this work Reynolds shows that transition from laminar to turbulent flow is dependent on the ratio of inertia to viscous forces, a ratio now known as the Reynolds' number. This ratio is particularly important in aerodynamics and wind tunnel testing, because it allows results to be generalized and correlated with relative ease.

Introduced in 1883 during a series of experiments on flow in tubes, the nondimensional parameter (i.e., Reynolds' number) was not immediately recognized as a fundamental similarity law. Neither Reynolds nor other scientists who followed him gave a specific name to the parameter until 1908 when the physicist Arnold Sommerfeld (1868–1952) named it in honor of Reynolds. It has since come into general use in those sciences which have to do with fluid flow.

REFERENCES: *Dictionary of Scientific Biography*, Charles Scribners' Sons, 1970; Theodore von Kármán, *Aerodynamics*, Cornell University Press, 1954.

Frederick Handley Page

1885–1962

Introduction of the slotted wing and the laminar flow wing

A life long advocate of the safe, economical, and comfortable airplane, Frederick Handley Page was one of the most remarkable personalities in British aviation. Genial, outspoken, and a shrewd businessman, his voracious appetite for reading and flawless memory served him well in the cause of aviation. Born in Cheltenham, England, he enrolled at Finsbury Technical College at the age of seventeen. At Finsbury he studied electrical engineering and so distinguished himself that he became chief designer of a British electrical manufacturing company at 21 and was offered a position with Westinghouse. He was primarily interested in aeronautics, however, and in 1909 founded Handley Page Ltd. at Cricklewood, England.

"H. P.," as he is most frequently referred to, pioneered in the development of large aircraft. During World War I he produced the 0/400 bomber and by 1918 had developed the V/1500 four-engine bomber for the purpose of bombing Berlin. The V/1500 was not ready for use until just before the armistice. Handley Page bombers, particularly the *Hampton* and *Halifax*, also saw considerable service during World War II. In all, the company produced 63 different types of aircraft.

Handley Page and his staff contributed to aviation the invention of the slotted wing, which greatly improved aircraft safety. Under license the slot was fitted on civil and military aircraft over most of the world. In his latter years, Handley Page championed the laminar flow wing, which was developed to reduce the cost of flying while improving safety.

Throughout most of his years, Handley Page took an active part in institutions connected with British aviation. A great educationist, he also fostered the importance of technical education and training. His service in England on the Board of Governor's of Imperial College and the College of Aeronautics contributed much to their financial and technnical stability.

REFERENCE: "An Appreciation by J. Lawrence Pritchard," *Journal of the Royal Society*, December 1962.

Gustav Lachmann

1896–

Notable contributions to the development of high lift devices

Born in Dresden, Germany, on 2 March 1896, Gustav Lachmann served as a lieutenant in the Imperial German Army assigned to the Hessian Life Dragoon Regiment 24 before being trained as a pilot. Lachmann's interest in high lift devices may be traced to an accident he experienced as a pilot during the First World War. He conceived of the slotted wing as a means for generating lift while hospitalized with severe injuries sustained when his plane stalled and crashed in 1917. After conducting smoke tests on a model, he applied for a patent in February 1918, but the application was rejected on the grounds that it would destroy lift.

After the war he studied engineering at Technische Hochschule, Darmstadt, and received his doctorate from the University of Göttingen. When a 1920 article in a British journal described the Handley Page slotted wing and indicated a 60 percent increase in lift, Lachmann again applied for a patent. The patent was awarded after he persuaded Ludwig Prandtl to conduct wind tunnel tests that showed the slotted wing to increase lift by 63 percent. He pooled his patent rights with Handley Page in 1921.

In 1924 he was a designer with the Franz Schneider Aircraft Works in Berlin. The following year he became chief designer at the Albatross Aircraft Works in Berlin but left to become technical advisor to the Ishikawajima Aircraft Works in Tokyo in 1926. He remained in this capacity until joining Handley Page Ltd. in 1929. While at Handley Page Ltd., Lachmann served as director for scientific research.

The slotted wing was crucial in the development of the flap and was one of the most significant improvements to aircraft safety.

REFERENCES: *Who's Who in World Aviation*, American Aviation Publishers, Inc., 1955; R. Miller and D. Sawers, *The Technical Development of Modern Aviation*, Praeger Publishers, 1970; R. P. Hallion, *Legacy of Flight*, University of Washington Press, 1977.

George William Lewis

1882–1948

Direction of aeronautical research at the NACA during the formative years

George William Lewis was endowed with a talent for leadership, which admirably suited him to lead American aeronautical research from 1919 to 1947. During this critical period, military and commercial aircraft came into their own. Born in Ithaca, New York, he attended Scranton High School before attending Cornell University. Graduating from Cornell in 1908 as a mechanical engineer, Lewis remained in the capacity of instructor and graduate student to earn his masters degree in 1910. He then joined the faculty of Swarthmore College, and in 1917 he became engineer-in-charge of Clarke Thompson Research of Philadelphia.

Lewis joined the National Advisory Committee for Aeronautics (NACA) at Langley Field in 1919 as a power plane engineer and was appointed executive officer in November of that year. In 1924 the appointment was changed to director of research. He served in this capacity until his retirement. During his tenure as research director, NACA flourished and became a research giant responsible for scientific and technical contributions of incalculable value to the United States and to the world in general. Lewis pioneered in the design, construction, and use of variable density, full scale, refrigerated, free flight, gust and high speed tunnels.

Under Lewis' direction the NACA decentralized from its location at Langley Field and established comparable centers at Moffet Field, near Palo Alto, California, and Cleveland, Ohio. The research center at Cleveland was later given the name "Lewis Flight Propulsion Laboratory" in recognition of the part which he had played in its design and construction.

A special feature of each of these laboratories is its Flight Research Division. Lewis held it as a cardinal principle that laboratory results must be proven in the air before being turned over to the military or the industry. Related to this requirement is the attention given to the development of special instrumentation required to record observations made while in flight. This special activity has led the world in aeronautical research and may be traced directly to Lewis.

A true architect of flight technology, Lewis was tireless in his pursuit of aeronautical progress until, his health impaired, he was relieved of his task as director of research to become a consultant to NACA in 1947.

REFERENCES: William F. Durand, *Biographical Memoir of George William Lewis*, National Academy of Sciences, Washington, D.C., 1949; Obituary, *Aviation Week*, 19 July, 1948; George W. Gray, *Frontiers of Flight*, Alfred A. Knopf, 1948; *The Guggenheim Medalists*, The Guggenheim Medal Board of Award, 1964.

Jakob Ackeret

1898–

Pioneering research in supersonic aerodynamics

Jakob Ackeret's two dimensional theory for prediction of the lift and drag on a wing moving at supersonic speeds proved to be fundamental to the body of theory assembled in support of high speed flight. Ackeret, who introduced the term "Mach number" to denote the ratio between the velocity of motion and the velocity of sound was born in Zürich, Switzerland, on 17 March 1898. He earned his engineering diploma in mechanical engineering and his Doctor of Science degree from the Zürich Federal Institute of Technology. Ackeret also took postgraduate work at the University of Göttingen under the direction of the founder of modern aerodynamics Ludwig Prandtl. While at Göttingen he was a department head at the Kaiser Wilhelm Institute.

Returning to Switzerland in 1928, he was appointed chief engineer with Escher Wyss Ltd., Zürich. Four years later Ackeret returned to academic life as professor and director of the Institute of Aerodynamics, Swiss Federal Institute of Technology, Zürich.

After returning to Zürich, Ackeret designed and had constructed the world's first modern supersonic wind tunnel. A continuous-flow return-circuit wind tunnel with a Delaval nozzle, it was capable of reaching Mach 2. A description of the wind tunnel was published in 1935. Ackeret received many awards and honors for his research in high speed aerodynamics.

REFERENCES: *Who's Who in Switzerland 70/71,* Nagel, Geneva, 1971; Theodore von Kármán, *Aerodynamics*, Cornell University Press, 1954; Hugh Dryden, "Supersonic Travel within the Last Two Hundred Years," *The Scientific Monthly*, May 1954.

Eastman Jacobs

1902–

Aerodynamic improvement of airfoils and notable contributions to air flow visualization

A native of Greeley, Colorado, Eastman Jacobs lived there until graduating from high school. He then attended the University of California at Berkeley, graduating with honors in 1924 with the degree of Bachelor of Science. Upon graduation he joined the engineering staff of the Pacific Telephone and Telegraph Company before becoming a research engineer with the National Advisory Committee for Aeronautics at Langley Field in 1925.

Jacob's research activities were largely concerned with studies made in the variable-density wind tunnel at Langley Field. As a group leader he worked on the problem of reducing airfoil drag by delaying the boundary layer transition from laminar to turbulent flow. Recalling an earlier observation by Prandtl, Jacobs conceived the idea of designing an airfoil to provide progressively falling pressure across the chord. Prandtl had shown that such a condition would prevent instability of the laminar flow. This concept changed the approach to airfoil design and led to development of the low drag wing. As a consequence of Jacob's contribution, the performance of aircraft with regard to both speed and carrying capacity was greatly improved and many military and commercial aircraft adopted the wing sections he designed.

In 1937 Jacobs received the Sylvanus Albert Reed award for the outstanding contribution to aeronautical science during the year. The award cited Jacobs for his work on the aerodynamic improvement of airfoils. He also contributed significantly to the design of special research equipment including high-speed wind tunnels and smoke-flow tunnels for flow visualization.

REFERENCES: George W. Gray, *Frontiers of Flight*, Alfred A. Knopf, 1948; Eastman Jacobs, manuscript in the Biographical Files, National Air and Space Museum, Smithsonian Institution, Washington, D.C.

Hugh Latimer Dryden

1898–1965

Fundamental contributions to supersonic flight and outstanding leadership in aerospace research

An architect of international space cooperation, Hugh Latimer Dryden stood at the forefront of research in aeronautics and astronautics for almost half a century. A native of Pocomoke City, Maryland, he earned his way through the Johns Hopkins University. A brilliant student, he graduated in 1917 with highest honors and earned his doctorate in physics before he was 21. Upon graduation he was named chief of the Aerondynamics Section of the Bureau of Standards. Dryden immediately embarked on a series of pioneering research projects in high speed phenomena, which won him international recognition as a scientist. Within four years he made some of the earliest recorded studies of airflow around wing sections at speeds near or above the speed of sound. His career at the National Bureau of Standards was characterized by important research in turbulence and boundary layer control.

Named assistant director of the Bureau in 1946, he was promoted to associate director in the same year. He left the Bureau of Standards the following year to become director of aeronautical research of the National Advisory Committee for Aeronautics. In 1949 his responsibilities were again increased as he become director of NACA, the highest career position in the agency. In 1954 he headed the NACA, which was formed to supervise development of an airplane to explore the problems of space and high speed flight. The X-15 developed for the task proved to be an extremely useful research tool, providing data at speeds in excess of six times the speed of sound and an altitude of nearly seventy miles.

On 8 August 1958, Dryden was named deputy administrator of the newly formed NASA and was a dominant figure in Project *Mercury.* Later he took a prominent part in the planning for *Gemini* and *Apollo* and in the decision to mount a lunar exploration mission.

A recipient of numerous awards, he had devoted over 45 years of his life to Federal service at the time of his death.

REFERENCE: *The Guggenheim Medalists*, The Guggenheim Medal Board of Award, 1963; Obituary, *Astronautica Acta*, volume 12, no. 2, 1966; Official NASA Biography.

Theodore von Kármán

1881–1963

Pioneering achievements in the development of high-speed aerodynamics and its application to supersonic flight

Revered as one of the world's leading aerodynamicists, Theodore von Kármán greatly influenced the development of high-speed aircraft in the United States. His investigations dealing with aerodynamic phenomena became the accepted theory of supersonic drag and charted the way for supersonic flight and guided missiles.

Theodore von Kármán was born in Budapest, Hungary, the son of Professor Maurice and Helene von Kármán. His father, an eminent teacher and philosopher at the University of Budapest, guided von Kármán's interests toward science and technology from the beginning. He graduated as a mechanical engineer with highest honors from the Budapest Royal Technical University in 1902. Returning to the University as an assistant professor after a year of military service, he left in 1904 to join the Ganz Company, manufacturers of machinery.

Resuming his technical studies, he enrolled as an advanced student at the University of Göttingen in Berlin in 1906. Awarded his doctorate in 1908, he remained on as an associate professor until 1912 when he accepted a position as director of the Aeronautics Institute and professor of aeronautics and mechanics at the University of Aachen. When his work was interrupted by World War I, he served with the Austro-Hungarian Aviation Corps. In the postwar years he returned to the University of Aachen and under his guidance the Aeronautics Institute became one of Europe's leading aeronautical research centers.

In 1926 the Guggenheim Fund for the Promotion of Aeronautics brought von Kármán to the United States to lecture and assist in organizing the Guggenheim Aeronautical Laboratories at California Institute of Technology (GALCIT). He returned in 1928 as research associate at Caltech and in 1930 became director of GALCIT.

With the outbreak of World War II, von Kármán reoriented his research activities toward military objectives and undertook leadership of the Army Air Force jet propulsion and rocket motor program at Caltech. His ideas and achievements were instrumental in development of the Bell X-1, which became the first supersonic aircraft. He subsequently was a founder of the Aerojet

Engineering Corporation, which became a major producer of guided missiles.

Signally honored for his many contributions to applied mathematics, mechanics, and physics, von Kármán served in a variety of high-level positions. World renowned as a scientist of towering stature, he died on 7 May 1963 at Aachen.

REFERENCES: *Current Biography*, The H. W. Wilson Company, 1955; *The Guggenheim Medalists*, The Guggenheim Medal Board of Award, 1963.

Henri Coanda

1885–1972

Aerodynamic research resulting in the phenomenon known as the "Coanda effect"

A resident of Paris for much of his life, Coanda was born in Bucharest, the son of Constantine Coanda, president of the Romanian Council of Ministers. An intensely serious scholar, Henri was a graduate of the military school of Jassy when he enrolled in the Technische Hochschule of Charlottenburg in Berlin. In 1906 he entered the University of Liege and the École Superieur d'Eléctricité de Montefiore in Belgium. He was a member of the first graduating class of the École Superieur de l'Aeronautique.

Coanda's interest in aeronautics dates to conversations with Gabriel Voisin and Louis Blériot during a railway trip in 1906. During 1909–1910 Coanda designed and built his first airplane, a turbo-air compressor powered vehicle. In 1912 he was appointed chief engineer of the Bristol Aeroplane Company. With the outbreak of World War I, Coanda returned to France and served with the 22nd Artillery Regiment before being assigned to the Delauney-Belleville factory, which was engaged in aircraft production.

In 1933 he exhibited a small model of a saucer-shaped plane, which raised itself vertically, and in 1937 demonstrated the principle known as the "Coanda effect," an aerodynamic phenomenon producing lift by deflection of jet blasts.

Honored at a luncheon of the Wings Club in New York, Coanda was introduced as "the man who symbolizes the past, present, and future of aviation development." A prolific inventor, Coanda received many honors and was granted a number of patents which deal with various applications of the "Coanda effect" to airplane, automobile, and boat construction.

REFERENCE: *Current Biography*, The H. W. Wilson Company, 1956.

Alexander Lippisch

1894–1976

Pioneering use of the delta wing

Although his ideas were sometimes ridiculed and often shunned, only to gain prominence later, Alexander Lippisch's zeal for innovation in aviation never diminished. Born in Munich, Bavaria, Lippisch was educated at the Technische Hochschule Berlin and received his doctorate from the University of Heidelberg at the age of 50. His first contact with flight occurred in Berlin on the occasion of Orville Wright's 1909 flying demonstration. After World War I, when gliding dominated Germany's aeronautical activities, Lippisch entered the field of aviation by designing several gliders and initiating fundamental studies on delta wing aircraft. His *Delta I* glider, built in 1930, was converted into a powered plane and demonstrated to the public in 1931. Ignoring the prejudice of aerodynamicists against the new concept, Lippisch further developed the type and later designed the first high-speed rocket-powered aircraft, the ME 163.

Having subjected an even more radical design to tests in a supersonic wind tunnel, Lippisch conceived the idea for a supersonic aircraft in his P13 design, a low-aspect-ratio Delta type. A glider version, designed to test low-speed performance was still under construction when it fell into the hands of American occupation forces. This model together with Lippisch's research results were given to U.S. Air Intelligence after his escape from the occupation of Vienna by the Russians. Full-scale testing of the glider at NACA and further wind tunnel testing of the delta wing showed the superiority of this type for high-speed aircraft.

After escaping from Vienna, Lippisch came to the United States where he served as a consultant to the U.S. Air Force at Wright Field and the Naval Air Materiel Center at Philadelphia. He subsequently joined the Collins Radio Company in Cedar Rapids as head of aeronautical research. While at Collins, Lippisch worked on the development of vertical take-off and landing aircraft and the airfoil, a radical flying boat, designed to exploit surface effects.

REFERENCES: Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970; Obituary, *New York Times*, 13 February 1976.

Ezra Kotcher

1903–

Administrative and technical accomplishments resulting in significant advances in high-speed performance

Known as the man responsible for re-establishing and organizing the Air Force Institute of Technology, Ezra Kotcher was known throughout the Air Force as an educator, scientist, and leader with exceptional foresight and flexibility. A native of New York City and a graduate of the University of California with a Bachelor of Science degree in aeronautical engineering, he acquired his Master of Science degree in aeronautical engineering from the University of Michigan in 1938. Kotcher first became associated with the Air Force in 1928, when he was assigned to the Engineering Division at Wright Field. His potential as a teacher was soon recognized and he was assigned to the Air Corps Engineering School as an instructor in mathematics. By 1941 he had risen to the rank of senior professor. When the activities of the School were temporarily halted with the advent of World War II, Kotcher was called into active service with the rank of lieutenant colonel. Following his release from active duty in 1946, he returned to Wright Field as director of the newly formed Air Force Institute of Technology. In 1951 he was again recalled to active duty and assigned as technical executive to the Aeronautics Division, Wright Air Development Center. Released in 1953 with the rank of colonel he remained with the Aeronautics Division as technical director. At the time of his retirement he held the position of technical director, Directorate of Advanced Systems Technology, Wright Air Development Division.

Kotcher's contributions and projects greatly influenced development of the first Air Force jet aircraft. He also supervised development of the first air-to-air refueling system for B-17 and B-24 aircraft and reconstructed the German V-1 buzz bombs for the Air Force. Kotcher had much to do with the successful development of the X-1, the first supersonic aircraft, and was later associated with problems concerning *Dyna Soar*, the B-70, and communications satellites.

The recipient of many honors and awards for his educational and aeronautical achievements, Kotcher retired from the Air Force in 1961, after thirty-two years of service.

REFERENCES: Anonymous, "Educator, Scientist, Leader," *Contact*, February 1961; Richard Hallion, *Supersonic Flight*, the Macmillan Company, 1972.

John Stack

1906–1976

Originating the research aircraft program and design of the transonic throat for high-speed wind tunnel testing

Internationally known and respected for research in high-speed aerodynamics and leadership in wind tunnel development, John Stack was born in Lowell, Massachusetts, where he attended public schools and Woods Business College. His undergraduate education was at Chaucy Hall School in Boston and the Massachusetts Institute of Technology. Upon graduation Stack joined the National Advisory Committee for Aeronautics as a junior aeronautical engineer in 1928, and a year later he designed the nation's first high-speed wind tunnel, which was used to develop airfoils.

Over the next decade, Stack became recognized as an authority in wind tunnel design, construction, and application. As chief of NACA's compressibility research division he guided much of the research in transonic speeds and conceived the research airplane as a tool of the scientist. Beginning with the X-1 and the D-558, the research airplane series paced progress in aeronautics and space flight, culminating in the X-15. Stack contributed to development of the variable-sweep wing presently in use on advanced military aircraft.

One of his outstanding achievements was his role in the design, construction, and application of a transonic throat in a wind tunnel test section. This accomplishment made it possible to study flow conditions over the full transonic speed range in a large tunnel. The development of this tunnel solved the problem of "choking" which had baffled aeronautical scientists for years.

While with NACA, Stack filled a number of key positions, successively becoming section head, division chief, and assistant director, before being appointed director of aeronautical research. He retired from Federal service in 1962 to become vice president of engineering with Republic Aviation Corporation. When that company was absorbed by the Fairchild Hiller Corporation in 1965, Stack was appointed its vice president of engineering.

Signally honored for his contributions to aeronautics, Stack died of head injuries sustained in a fall from his horse.

REFERENCES: Fairchild Hiller Official Biography; Obituary, *Fairchild News Release*, FI-9-215 (20 June 1972); Richard P. Hallion, *Supersonic Flight*, Macmillan Co., 1972.

Adolf Busemann

1901–

Pioneering research on high speed aerodynamics and gas dynamics

Recognized as the first to propose use of swept wings in the design of high-speed aircraft, Adolf Busemann was born in Luebeck, Germany. After completing high school in Luebeck, he attended the Technische Hochschule Braunschweig, graduating as an engineer in 1924. Awarded his doctorate in engineering from Braunschweig the following year, Busemann started his professional career at the Kaiser Wilhelm Institute (now the Max Planck Institute) in Göttingen. He later became chief engineer of the Institute. While at Göttingen he conducted theoretical and wind tunnel experimentation in the field of high-speed aerodynamics.

In 1913 Busemann began a four-year period as a lecturer in the Engine Laboratory of the Technische Hochschule, Dresden, but returned to Braunschweig in 1935. From his return until the Allied occupation ten years later, he served as chief of the Gas Dynamics Division of the Aeronautical Research Laboratory. Following a period as a research consultant in England during part of 1946 and 1947, Busemann accepted an invitation to continue his career as a research scientist in the United States and joined the NACA research staff of the Langley Research Center. At Langley, Busemann conducted original research on transonic and supersonic aerodynamics and served as a consultant on gas dynamics and related problems. He later became chairman of the advanced study committee of the Langley Research Center and supervised preparation of science lectures used in training astronauts for manned space flight.

REFERENCE: Official NASA Biography.

Richard T. Whitcomb

1921–

Innovative aerodynamic research leading to major advances in high-speed flight

Richard T. Whitcomb gained international recognition for his discovery of the transonic area-rule concept. Whitcomb's concept amounts to a revolutionary method of combining the aircraft's wings and body to reduce to a minimum an aircraft's interference drag in the transonic speed range. It has been adopted and applied by aircraft designers to increase by at least 25 percent the performance of supersonic jets without requiring additional engine power.

Born in Evanston, Illinois, his family moved to Worcester, Massachusetts, when he was a child. Whitcomb attended public schools in Worcester and, in 1939, entered Worcester Polytechnic Institute. He received his Bachelor of Science in mechanical engineering with high distinction in 1943 and accepted a position with the National Advisory Committee for Aeronautics at Langley Laboratories. During his career with NACA, Whitcomb has worked primarily on problems involved with supersonic flight.

More recently, Whitcomb invented NASA's supercritical wing, an innovation which may be more significant than the area-rule development. Flight tests of the supercritical wing were so successful that the concept is expected to form the basis for design of commercial transports in the 1980's. As a result of Whitcomb's research, commercial airlines will be enabled to fly faster and farther with substantial reductions in fuel consumption and direct operating costs.

His many awards include an honorary doctor of engineering from Worcester Polytechnic Institute.

REFERENCES: National Aeronautic Association Press Release, 4 June 1974; *Current Biography*, The H. W. Wilson Company, 1956.

Robert T. Jones

1910–

Significant achievements evidenced in formulation of the theory of swept wings and the supersonic area rule

Robert T. Jones, a brilliant aerodynamicist and mathematician with an earned reputation for original and perceptive research, did so without advantage of a complete formal education. Born in Macon, Missouri, he was in college for only two semesters. He then had a variety of jobs including a short stint with The Nicholas Beasely Airplane Company. When the Depression finished this venture, however, he found himself operating an elevator in Washington, D.C. On the recommendation of his Congressman, David John Lewis (Dem. Md.), Jones obtained a job with the National Advisory Committee for Aeronautics at Langley Field. At NACA, Jones had the opportunity to continue his studies by reading the literature and attending lectures.

Gifted with a remarkable ability to express a complex problem in understandable and useful terms, Jones was working on a stability problem of a proposed Army missile when he discovered the drag-reducing faculty of the swept wing. When wind tunnel tests confirmed his discovery, Jones was able to mathematically account for the subsonic behavior of swept wings at supersonic speeds.

Jones was appointed senior staff scientist at the NACA Ames Research Center in 1946. While in this capacity, he extended Whitcomb's transonic area rule, which enabled reduction of the transonic drag, into the supersonic region. Jones' supersonic area rule, which made it possible to minimize the drag of an airplane at any chosen supersonic speed, is recognized as a substantial contribution to aerodynamic theory. He also introduced the concept of the oblique wing, which showed considerable promise when tested on a remotely piloted vehicle at NASA Flight Research Center, California.

REFERENCES: E. P. Hartman, *Adventures in Research*, National Aeronautics and Space Administration, 1970; G. W. Gray, *Frontiers of Flight*, Alfred A. Knopf, Inc. 1948; Theodore von Kármán, *Aerodynamics*, Cornell University Press, 1954.

John V. Becker

1913–

Achievement in evolving the technology of supersonic and hypersonic flight

As chairman of the hypersonic research airplane study group, John V. Becker was instrumental in development of the X-15 hypersonic research airplane. Born in Albany, New York, Becker earned a Bachelor of Science degree from New York University in 1935 and a Master of Science degree in 1956. Joining the National Advisory Committee for Aeronautics research staff at Langley Field as a junior aeronautical engineer, he was appointed head of the 16-foot high-speed tunnel in 1943. Later he was named assistant chief of the Compressibility Research Division, and in 1955 became chief of the division, which was subsequently designated Supersonic Aerodynamics Division.

Becker was head of the then subsonic 16-foot tunnel when interest in research on transonic and supersonic flight led to the decision to develop the X-1 research airplane. Modifications to the tunnel upgraded its performance first to transonic and later to supersonic speeds. Expansion of the research airplane idea to include development of an entire family of specialized aircraft, designated the "X series," provided Becker with the opportunity to contribute significantly to the technology of supersonic flight.

At a 1954 meeting of the NACA interlaboratory research airplane projects panel, the members reached the conclusion that an entirely new research airplane was desirable. Langley Laboratory created a hypersonic research airplane study group and assigned Becker to chair it. The design produced by the study group closely resembled the X-15 configuration and featured many aspects of the later design, including use of Inconel X heat sink construction, similar weights, and specifications. The design study further recommended a cruciform tail configuration and a "wedge" vertical fin. Becker presented the panel's report to a joint NACA–Air Force–Navy panel and won endorsement. The endorsement ultimately led to development of the X-15.

In 1955 Becker was cited by New York University as one of its 100 outstanding graduates of the College of Engineering.

REFERENCES: Official NASA Biography; R. P. Hallion, *American Rocket Aircraft: Precursors to Manned Flight beyond the Atmosphere*, International Astronautical Federation, 1974.

H. Julian Allen

1910–1977

Significant achievements in solving the problems of aerodynamic heating and origination of the blunt body concept used on re-entry shapes

Endowed with a remarkable instinct for using approximations and reasonable assumptions to reduce extremely complex problems to a level amenable to solution, H. Julian Allen developed a variety of original and ingenious research techniques. A native of Maywood, Illinois, he graduated from Stanford University with a Bachelor of Arts degree in 1932 and acquired a Bachelor of Science in aeronautical engineering from the same institution in 1935. In 1936 he joined the research staff of the National Advisory Committee for Aeronautics at Langley Field and became a leading authority in aerodynamics and design of supersonic and hypersonic wind tunnels.

Equally comfortable with either experimental or theoretical research, Allen moved to NACA's newly formed Ames Research Center in 1940 as head of the Theoretical Aerodynamics Section. While at Ames he became involved with the problem of aerodynamic heating during ballistic re-entry and originated the blunt body concept for re-entry shapes. This led to use of the blunt body for every U.S. manned spacecraft. He was also the first to recognize that entry into planetary atmospheres, or returns to Earth, at faster than escape velocity requires modification of the blunt entry shape.

When Dr. Smith J. DeFrance, the founder and director of the Ames Research Center retired in 1965, H. Julian Allen was named his successor. The honor closely followed an earlier one in which Allen had been awarded NASA's highest scientific honor, the NASA Medal for Exceptional Scientific Achievement. Having laid much of the groundwork for spaceflight, he retired from NASA in 1969 at the age of 58.

REFERENCES: *NASA News Release* 68-183 (25 October 1968); E. P. Hartmann, *Adventures in Research*, National Aeronautics and Space Administration, 1970.

Air-Breathing Propulsion

More than any other single factor, engine performance set the pace for progress in aeronautics. In fact, it was the absence of a suitable engine that precluded the notion of powered flight in the pre-Wright era. Engine reliability, or rather a lack of it, later proved to be a principal deterrant in the development of commercial air transportation. Still later, when propeller limitations threatened to limit aircraft performance to subsonic speeds, the jet engine provided a way to eliminate the propeller and neatly sidestep the problem. There are countless other instances in the history of flight when engine performance was either the barrier or the key to aeronautical progress.

Predecessors of the Aircraft Engine

Steam Engines

The steam engine, which reigned supreme as the prime mover of 19th-century machinery, was the major predecessor of internal combustion engines. While steam engines were never serious contenders for a permanent role in aeronautics, they did attract the attention of early flight enthusiasts. A typical example is that of Henson and Stringfellow, who unsuccessfully tried to fly a steam-powered model in the late 1840's. In 1852, Henri Giffard built and successfully flew a steam-powered airship in which he attained a speed of some 5 mph. But steam engines were ill-suited to serve the needs of practical powered flight. Heavy, cumbersome, and too slow to be of direct service, the steam-engine none-the-less provided a century of experience, during which fabrication techniques were refined to the point where they could be easily converted to the manufacture of internal combustion engines.

In an excellent article (Bryant, 1967:648–664) on the origins of the internal combustion engine, Lynwood Bryant clearly establishes its relation with growth in the illuminating gas industry in Europe around the middle of the 19th century. According to Bryant, illuminating gas was a principal source of residential lighting and heating in the cities. This was made possible by a gas distribution network fed from a central generating station. This system provided incentive to develop the internal combustion engine, which served the same purposes as today's electric motor.

Étienne Lenoir, in 1860, produced the first illuminating gas engine to be sold in quantity, even though it was not a particularly good one. Clearly influenced by steam engine practice, it was big, heavy, inefficient, and rough running but it did prove illuminating gas could be used as an alternative to steam. Unlike steam, however, the use of gaseous fuels severely limited the notion of a portable engine driving a wheeled vehicle. The idea of using liquid fuels for this purpose was apparent, but the technology for vaporizing the fuel and mixing it in proper proportion with air simply did not exist for the fuels then available.

There is little doubt that the enormous growth of air breathing propulsion and its impact on aeronautics in this century is a consequence of the discovery of gasoline; yet the importance of fuel technology to aviation is seldom mentioned in historical accounts of flight. The first well specifically drilled for oil was brought in at Titusville, Pennsylvania, in 1859. Prior to the "Drake Well," petroleum in the form of asphaltic bitumen and mineral pitch had been collected from seepage sites and used for a variety of purposes (G.I.A., 1974:165). Although distillation techniques had been known and were used to obtain illuminants from the seepage residues, they had not been used for processing gasoline, possibly because the more volatile fractions of crude oil are soon lost upon exposure to the atmosphere.

Commercial production of gasoline was started within four years of drilling the "Drake Well," but it's origins and those responsible for its discovery remain unknown. Accepted sources (Williamson and Daum, 1959:234) contend that gasoline was discovered by Joshua Merrill who had earlier discovered "keroselene," a highly volatile derivative obtained from steam distillation of coal oil, when he applied the procedure to distill petroleum naptha. In 1863, Merrill began to commercially produce gasoline at the Downer plant in Boston. Originally introduced as an illuminant, gasoline was justifiably considered an extremely hazardous by-product requiring special care in packaging and shipping. A major amount of it was simply dumped to avoid the hazardous handling problem.

Automobile Engines

In 1876, Nikolaus August Otto introduced the earliest recognizable ancestor of today's air-breathing piston engines. Although the engine was fueled with illuminating gas and only developed around 3 horsepower at a weight of close to 2000 pounds per horsepower, it represented a major improvement in propulsion technology. During its development, Otto had prophetically combined three principle ideas: internal combustion, compression of the fuel before ignition, and the four-stroke cycle. The idea of combining the four-stroke cycle with pre-ignition compression of the fuel was the outstanding feature, which makes Otto's engine such a notable advance.

Otto's engine was a great commercial success and was soon being manufactured in a number of countries as competition offered similar engines to an expanding market. By 1880, improvements in engine performance had generated interest in adapting the engine for automotive use, but this proved to be a difficult and prolonged endeavor. For automotive use, the only practical route was to adapt the engine to liquid fuel, drastically reduce its weight and increase its running speed with an improved ignition system. Consequently, the critical components to be developed were the carburetor and the electric ignition.

During the last two decades of the 19th century the most significant progress in automobilism was accomplished in Germany. Gottlieb Daimler, who had gained experience with internal combustion engines while working as production manager on Otto's engine, left the firm in 1882, in order to devote his full attention to development of the automobile. An associate of long standing, Wilhelm Maybach, had followed Daimler to Otto's firm, and when Daimler left to form his own company, Maybach again joined him. A talented mechanic, Maybach attacked the problem of developing a carburetor that would operate satisfactorily under the fluctuating speeds and loads anticipated for an automobile. This proved to be an elusive endeavor, which was not solved satisfactorily until 1893, when Maybach introduced a fine jet which sprayed gasoline into the intake air. Maybach's discovery of the principle of modern carburetion was a crucial step in later development of the gasoline-fueled portable engine.

Daimler and Maybach had met with earlier success when, in 1883, they had produced a gasoline-fueled engine capable of around 900 rpm. Although this engine used a less satisfactory form of carburetion, it was equipped with a radically different type of ignition, which simply provided a steady hot spot in the combustion chamber and neatly avoided the problem of timing. Daimler's cars of the 1890's used this type of ignition.

Contemporary engine designers, such as Karl Benz, struggled with the difficulties of electric ignition, but, in the absence of a suitable magneto, generally had to resort to a low-voltage make-and-break system, which was more reliable at moderate speeds. A suitable electric ignition system was not developed until 1902, when Robert Bosch introduced a high tension magneto able to deliver a hot spark without any battery (Bryant, 1967:653). This type of electric ignition won quick acceptance and soon became the standard ignition for automotive use.

The intense interest in automobilism, which captured the fancy of European technologists in the last twenty years of the 19th century, was solely responsible for the progress made in developing light, fast, gasoline-fueled engines. From an inauspicious beginning in the 1880's as a one horsepower affair weighing some 200 pounds, the automobile engine emerged, in 1901, as a 35 horsepower package with its weight neatly trimmed to a respectable 14 pounds per horsepower. In this form, it powered a Daimler automobile to a speed of 53 miles per hour (Bryant, 1967:661).

The Aircraft Engine

Aeronautical application of the gasoline-fueled engine came soon after, but early aircraft engines were not direct transplants from the automotive field. Instead, they were fresh developments accomplished with technology borrowed from the proving ground of a racetrack. The Wright engine of 1903, and the remarkable Langley engine, completed late in 1901, and tested over the next three years, were the legitimate precursors of engines developed specifically for aeronautics (Taylor, 1971:1).

Designed and built by the Wright brothers with the assistance of their mechanic Charles E. Taylor, the 1903 Wright engine followed contemporary automotive practice, but was a comparatively crude affair. Orville Wright described the motor as follows:

> The motor used in the first flights at Kitty Hawk, N.C., on December 17, 1903, had [four] horizontal cylinders of 4-inch bore and 4-inch stroke. The ignition was by low-tension magneto with make-and-break spark. The boxes inclosing the intake and exhaust valves had neither water jackets nor radiating fins, so that after a few minutes of running time the valves and valve boxes became red hot There was no float-feed carburetor. The gasoline was fed to the motor by gravity in a constant stream and was vaporized by running over a large heated surface of the water jacket of the cylinders. Due to the preheating of the air by the waterjacket and the red-hot valves and boxes, the air was greatly expanded before entering the cylinders. As a result, in a few minutes' time, the power dropped to less than 75 percent of what it was on cranking the motor. [McFarland, 1953:1210]

Clearly a marginal engine, even by contemporary standards, it did manage to power the first aircraft and in so doing earned an honored place in history. Considering reliability to be more important than lightness, the Wrights later modified their basic engine design with improved cooling and accessories.

Considering the performance of contemporary engines at the turn of the 20th century, the 52-horsepower, 5-cylinder radial engine developed for Langley's aerodrome represents one of the most extraordinary engines of the period. Designed by Charles M. Manly, an engineering graduate of Cornell University, and Stephen Balzer, an automobile builder from New York City, the engine was a stationary radial design with a specific weight of 2.16 pounds per horsepower. In many respects, the Langley engine anticipated the highly successful radials, which came into wide use on commercial vehicles of the thirties.

Although German Technologists had pioneered development of gasoline-fueled automotive engines, they were strangely absorbed in adopting their engines for use on dirigibles and showed little interest in more conventional flight. The British were similarly slow to react to the cause of flight. Of all Europe's leading aeronautical powers, only France took an active role in developing aircraft engines. In 1906, Leon Levavasseur began to manufacture a 50 horsepower, 8 cylinder engine, which he called "Antoinette." These superb engines were to become important power plants for European aviation.

Antoinette engines were water-cooled V-type arrangements with machined-steel cylinders fitted with brass waterjackets and equipped with inlet port fuel injection. Together with the later engines of Glenn Curtiss in the United States, they pioneered use of liquid cooled V-engines in aeronautics (Taylor, 1971:19). Although Curtiss' earlier engines had been air cooled, in 1908 he developed a water-cooled engine similar to Levavasseur's.

By 1909, European designers could choose from among several different types of French aircraft engines. In addition to the water-cooled Antoinette, there was the 35-horsepower Renault air-cooled V-8 and the 24-horsepower Anzani, a 3-cylinder fan-type air-cooled engine selected by Blériot for his cross-channel flight.

The year of 1909 was also memorable for the appearance of the Gnome engine; a 50-horsepower 7-cylinder rotary engine. A masterpiece of engineering, the Gnome's smooth-running characteristics soon won the approval of European designers. Skillfully designed by Laurent Seguin, the Gnome rotary attained such popularity that the design was modified and produced by several other rotary engine manufacturers. Used extensively by both sides during World War I, rotary engines derived from the Gnome were manufactured in France by LeRhone and Clerget, in Germany by Oberürsel and Siemens, and in England by the Humber Company who released lighter and more efficient engines under the designations Bentley BR-1 and BR-2. The rotary engine reached its maximum development early in the war but became obsolescent by 1918, chiefly because of speed limitations due to centrifugal stress.

As aircraft performance improvements rendered rotary engines obsolete, the water-cooled V-type engine rose to the position of prominence. In the United States the Curtiss OX-5 continued to lead the field until 1917, when the Liberty and Hispano-Suiza engines were introduced to counter the German 6-cylinder Mercedes of 1915.

The 180-horsepower Mercedes engine was derived from an earlier 160-horsepower model, which introduced a new style in liquid-cooled cylinder design. That design influenced later British, French, and American designs until it finally yielded to cast aluminum en bloc construction (Taylor, 1971:30). The cylinders were machined from steel forgings with valve ports screwed and welded to the cylinder head. The whole assembly was then encased in welded sheet steel waterjackets. Among the engines built with Mercedes-type construction, an important one was the Liberty engine built in the United States. Surplus Liberty engines played an important role in the postwar growth of aviation in America and remained militarily important well into the thirties.

Undoubtedly the most technically significant aircraft engine to be developed during World War I was the Hispano-Suiza V-8, designed and built in Spain by a Swiss engineer Marc Birkigt. This engine was adopted for French Fighters in 1916 and used in the historic Spad VII and XIII. Birkigt's principal contribution to engine design was the en bloc construction, in which the cylinders were formed from an aluminum block casting with cored water passages. The success of this engine revolutionized design of liquid-cooled engines. Hispano Suiza engines were adapted to American manufacturing methods and produced in quantity by the Wright-Martin Aircraft Corporation, later renamed the Wright Aeronautical Corporation. The Hispano-Suiza engine was the prototype for subsequent development of liquid-cooled engines, such as the Kestral, Rolls-Royce Merlin, Allison V-1710, and the German Daimler-Benz and Junkers V-12.

Parallel development of air-cooled engines with steel lined aluminum cylinders was initiated prior to the end of World War I. At that time, the Royal Aircraft Factory assigned Professor A. H. Gibson and Sam D. Heron the task of developing more effective air-cooled cylinders. A comparable effort was started in the United States by Charles L. Lawrance who founded the Shinnecock Airplane Company in 1915 and started development of a 2-cyclinder air-cooled engine (Schlaifer and Heron, 1950:162).

After selling the rights to the 2-cylinder engine to the Army, Lawrance approached the Navy with a proposal for an upgraded version, which ultimately became the 3-cylinder model L of 1918. In the following year discussions with both the Army and Navy resulted in a contract that led to production of the 9-cylinder model J-1 engine. The popularity and success of the J-1 was a decisive factor in establishing the air-cooled engine in the United States.

In 1921, Sam Heron came to the United States and was employed by the Army at McCook Field, Ohio. A capable engineer with an extensive knowledge of air-cooled engine design, Heron was to assist in the development of large radial engines. Although perhaps best known for his work in developing the sodium-cooled valve, which solved a major problem in engine endurance, Heron made a number of fundamental contributions to air-cooled cylinder design.

Keenly aware of shipboard maintenance limitations, Navy engineers strongly favored the comparative simplicity of radial engines. Realizing that Lawrance's facilities were too small to be satisfactory for the major developmental effort it had in mind, the Navy tried to interest both the established aircraft engine companies, Wright and Curtiss, to begin development and production of air-cooled radial engines. Neither company was particularly interested in diverting its interest from liquid-cooled engines until the Navy informed Wright that it would no longer purchase 200-horsepower Wright Hispano engines. When this policy was enforced in 1922, the president of Wright, F. B. Rentschler yielded and, with the Navy's approval, purchased the Lawrance Corporation as the most expedient route to production of air-cooled engines (Schlaifer and Heron, 1950:174–175). Making Charles L. Lawrance vice president of Wright, the company began developments that led to the J-3 and J-4 air-cooled engines.

Becoming increasingly at odds with his directors, Rentschler resigned as president of Wright, in 1924. The following year, he attracted away from Wright Chief Engineer George J. Mead and the Assistant Engineer in Charge of Design A. V D. Willgoos and, encouraged by the Navy, founded a company within the Pratt and Whitney Aircraft complex to produce engines. With an engineering team used to working together, they succeeded in producing the highly successful Wasp engine in early 1926.

In the same year, at Wright, E. T. Jones, who had headed the power plant section at McCook Field was made chief engineer of Wright bringing Sam Heron with him. Heron's presence at Wright resulted in substantial improvements to the Whirlwind. With redesign of the whirlwind in progress, Jones, Heron, and Lawrance began design of a completely new engine, the R-1750 Cyclone, which passed a type-test at 500 horsepower, in 1927 (Schlaifer and Heron, 1950:192).

The basic feature of the Wasp and Cyclone engines, the 9-cylinder air-cooled radial engine, became the hallmark of "modern" radial engine design. Some additional improvements, notably forged and machined cylinder heads, automatically lubricated valve gearing, and the vibration-absorbing counterweight were introduced on later models, but the basic technology of air-cooled radial engine design and construction remained unchanged.

For commerical uses, the simplicity and ease of maintenance of the air-cooled radial engine made it the popular choice of designers. With few exceptions, commercial air transports throughout the world relied on this type of engine until the postwar advent of jet and turbine engines all but eliminated the commercial market for piston engines.

Exhaust Valves

Piston engine reliability and endurance proved to be particularly sensitive to exhaust valve performance. Located, of necessity, in the combustion chamber, poppet exhaust valves characteristically experience gas temperatures as hot as 3000°F, which must be dissipated through the small stem and seat areas. Technologists confronted with the task of improving engine endurance first attempted to solve the valve problem by using improved materials. By 1918 the ordinary steels used on early engine valves had been replaced by high-speed tungsten alloy tool steel. While certainly an improvement over the low carbon steels, it was soon found that tungsten alloy valves were susceptible to severe burning at the valve seat. Within a few years, tungsten alloy steels were replaced with high chromium steels further alloyed with one of several other elements such as nickel, cobalt, or silicon. Around 1934, further material improvement was realized by introducing stellite facings on both valve seats and seat inserts (Taylor, 1971:63).

When material substitutions alone proved to be an inadequate solution to the valve problem, engine designers attempted to enhance the transfer of heat along the valve stem by using hollow valves partially filled with liquid. Early attempts to use mercury-filled valves were unsuccessful since mercury will not wet steel, which is required for good heat transfer. Some success was achieved with mercury fillers after Midgeley and Kettering developed a method of coating the interior surface of the valve with a mercury wettable material (Taylor, 1971:64).

In 1919, Sam Heron, one of the pioneers of the liquid-filled valve concept, was working on valve coolants at McCook Field, when he decided to try a mixture of sodium and potassium nitrate. Achieving some success Heron continued to investigate the potential for sodium and by 1928 had adapted liquid sodium as the internal valve coolant. Heron's sodium-filled valve was a major contribution to engine technology and was later recognized as a milestone in the determined effort to improve engine reliability and endurance.

Superchargers

As air becomes increasingly less dense with altitude the power developed by an engine decreases until a level is reached where the power developed is just enough to sustain flight. To go higher or faster, more air is needed to support the combustion needed to develop more power. During World War I, the loss in engine power with altitude limited military aircraft to an absolute ceiling of around 20,000 feet (6.1 km). In 1914, a Swiss engineer, Alfred Boechi suggested use of a turbo supercharger, but, aside from some experimental models developed in France by Rateau, little serious technical work was done on supercharging until after the war. Both England and the United States started intensive development of aircraft superchargers in 1918.

In 1917, the NACA was confronted with the problem of maintaining, at high altitudes, the power of the Liberty engine. Sanford Moss, who had become interested in building a gas-driven turbo engine while a graduate student at Cornell University, was then working in the gas-turbine division of the General Electric Company and was directed to undertake the study and development of a turbo supercharger. The following year, the Engineering Division of the Army Air Service contracted for the work, with Moss in charge of development. Experimental models applied to a Liberty engine were tested at an altitude of 14,109 feet (4.3 km) on Pike's Peak in 1918. The tests proved conclusively that Moss' invention was a success, but it was too late to be used in the war (Durand, 1953:65–68).

The first flight test of Moss' invention was made at McCook Field the following year in a Le Père biplane equipped with a turbo supercharged Liberty engine. During the test, the aircraft attained a world's altitude record of 38,180 feet (11.6 km). Although interest waned in spite of a number of record-setting flights, Moss continued to refine his turbo supercharger in cooperation with the flight test section of the Army Air Corps. The turbo supercharger did not gain full acceptance until March 1939, when tests on a Boeing B-17 conclusively established its real value.

Categorized as an engine accessory item, aircraft supercharger development opened the way for efficient high altitude operation of air breathing engines. The Wright Turbo-Cyclone R-3350, introduced around 1946, is indicative of the sophisticated refinement realized in supercharger technology.

Carburetors and Fuel-Injection Systems

The subject of fuel metering is essentially a saga of the parallel efforts to develop efficient carburetors and fuel-injection systems. A comprehensive treatment of the subject, from which much of the following is derived, is contained in an excellent book by Robert Schlaifer and S. D. Heron (1950:509–544).

Fuel metering devices, such as carburetors and fuel-injection systems, are essential engine accessories generally developed by ancilliary firms working in cooperation with engine manufacturers and the military. Although serving a similar function, these two types of fuel metering devices operate in a distinctly different manner. With carburetors, fuel is metered, atomized, and mixed with incoming air to form a combustible mixture, which is then distributed to the cylinders by the intake manifold. With fuel-injection systems, the intake manifold only distributes air and relies on a fuel injector to meter and supply fuel to the appropriate cylinder (Schlaifer and Heron, 1950:509).

Although primitive fuel-injection systems were tried on aircraft engines before the First World War, the simpler and lighter carburetor continued to dominate the market for aircraft engines throughout the between-the-wars period. When World War I ended, the Zenith Carburetor Company was the major supplier of aircraft carburetors in the United States. Confronted with a failing market brought on by the use of less volatile fuels and an overabundance of surplus Liberty engines, the Zenith Company defaulted aircraft sales to the Stromberg Motor Services Company, which had no experience with aircraft needs but was a known supplier of automobile carburetors. Typical of contemporary fuel-metering technology, the Stromberg Company relied on a float to maintain constant fuel pressure (Schlaifer and Heron, 1950:54).

While funds for development of carburetor improvements were not readily available, Stromberg managed to introduce some notable refinements during the 1920's, which, among other things, allowed for satisfactory operation during short periods of inverted flight. Stromberg float-type carburetors, however, were incapable of automatically compensating for the variations in air density associated with changes in altitude. The basic inadequacies of the float-type carburetor came into prominence in the early 1930's when carburetor icing problems began to be a major source of concern. Float-governed carburetors attracted further criticism when the Navy, and later the Army, began to experience carburetion problems that caused aircraft fires during dive-bombing practice (Schlaifer and Heron, 1950:515).

M. E. Chandler, who had been in charge of Stromberg carburetor engineering, left the company in 1934 and, with backing from the Holley Carburetor Company, introduced production simplifications that resulted in a definite cost advantage. In an effort motivated both by an interest in solving float-related problems and developing a novel arrangement calculated to result in a sales advantage, Chandler replaced the float with a fuel control valve activated by pressure of the fuel on a diaphragm. During flight tests with Chandler's floatless carburetor, the Navy discovered that the carburetor was less susceptible to icing and adopted it for use on their Cyclone engines. In March 1937, Trans World Airlines, for similar reasons, made it the standard for airline Cyclones as well (Schlaifer and Heron, 1950:517–521).

In 1935, F. C. Mock replaced Chandler as head of Stromberg carburetor development and convinced management to support development of a competitive floatless carburetor. Mock's design was a bold departure from established carburetion principles in that it balanced both the fuel and air flow by the action of two opposing diaphragms. The new carburetor was put in production in 1938 and was such an overwhelming success it was adapted for use on all high-power engines produced by Pratt and Whitney and on the Wright Cyclones that powered B-17's (Schlaifer and Heron, 1950:521–524).

A competitive form of fuel metering, known as "fuel injection" was well known, at least in principle, long before the onset of the First World War. In fact, a primitive form of fuel injection had been used by the Wright brothers on their original engine; but the comparative lightness and simplicity of carburetors resulted in their selection as a standard aircraft engine accessory. No attempt at systematic development of aircraft fuel-injection systems was made in the United States until carburetion difficulties were encountered during dive bombing in the late 1920's. These difficulties caused the services to become interested in fuel injection as a possible cure.

M. G. Chandler (not to be confused with M. E. Chandler of the Stromberg Motor Services Company), who had earlier patented a fuel-injection system, was hired by the Marvel Carburetor Company in 1926 to oversee further development of his invention. In the following year, the Army ordered a Chandler injection system for a one-cylinder engine, which was tested at Wright Field in 1928. When the test showed Chandler's single-cylinder system to be competitive with contemporary float-type carburetors, the Army ordered an experimental injection system for a 9-cylinder air-cooled radial engine. The Marvel pump and distribution system performed quite satisfactorily, but it suffered from a design limitation that precluded its use on engines with more than 12 cylinders. Unfortunately a company dispute with the military over payment of development costs led to collapse of the Marvel Company in 1935 (Schlaifer and Heron, 1950:530–533).

After Marvel's collapse, interest in further development of fuel-injection systems was continued by the United American Bosch Corporation, with Army support, and the Eclipse Aviation Corporation, which pursued development with Navy support. By 1940, both of these companies had developed injection systems that had been reasonably well proven but had not been fully certified for military use. Impressed with the extensive use of fuel injection by the Germans, both services quickly increased their developmental activities to equip the R-3350 with fuel injection as soon as possible. When the Navy withdrew from further development of fuel injectors in 1942, the Army continued alone. Shortly thereafter the Bendix Products Division which had assumed responsibility for the Eclipse injector development, adopted the operational Bendix Stromberg pressure carburetor as a means to meter fuel to the injector pump. The innovation proved superior to any preceding performance by an injector system and was accepted for Army use and released for production in 1943 (Schlaifer and Heron, 1950:541–542).

The Bendix modified Eclipse injector system simplified the problem of fuel distribution and completely eliminated icing difficulties. However it increased the complexity of the fuel metering device, which required both a complete carburetor and an injector pump.

Variable Pitch Propellers

Although interest in a variable pitch propeller predates the advent of conventional flight, existing mechanisms were unsatisfactory until a practical model was introduced in the early 1930's. This model was the result of developmental efforts conducted in Britain, Canada, and the United States during the preceding decade (Miller and Sawers, 1970:73).

In Great Britain, the Air Ministry's request for designs prompted Professor Hele-Shaw, a recognized authority in hydraulic mechanisms, and his partner T. E. Beacham to adapt a hydraulic pump they had developed for other purposes to control the pitch of an aircraft propeller. While Hele-Shaw's interest in propeller design was in direct response to a request on the part of the government, the Air Ministry decided that a variable pitch propeller, which required its development to be conducted at private initiative, was not necessary.

A similar situation occurred with W. R. Turnbull who, in 1923, began work on an electrically operated pitch control mechanism under a grant from the Canadian National Research Council. As in Hele-Shaw's case, early work was financed by the government but the cost of later developments was principally supported by industry. Frank W. Caldwell, who designed the first variable pitch propeller to come into general use and probably contributed more to the development of variable pitch propeller technology than any other individual, chose to make its development a private endeavor rather than a venture dependent on military support. In contrast with both Hele-Shaw and Turnbull, who worked outside the industry, Caldwell was an aeronautics professional who had been in charge of propeller development for the Army. Convinced mechanical control devices would not work, Caldwell left government service to work out his ideas without interference. During the first half of 1929, he completed the design and applied for patents. In June of the year, he joined the Standard Steel Propeller Company in order to carry on with his work (Miller and Sawers, 1970:73).

Three months after Caldwell joined Standard, the company was bought by United Aircraft and merged with the Hamilton Propeller Company to form the Hamilton-Standard Division. In 1929, Boeing and Northrop, who were also members of United Aircraft were engaged in the design of all-metal monoplanes, which became the forerunners of the "modern" commercial air transport. The loss of performance of the fixed-pitch propellers prompted Caldwell to simplify his design and press for flight qualification, which was realized by the end of 1932 when his propellers were readied for production.

Boeing originally designed the 247 in 1932 with fixed-pitch propellers, but found its take-off performance from some of the higher airports in the Rocky Mountain region was inadequate. Caldwell was able to convince Boeing to test the aircraft with variable pitch propellers. The 247's performance was notably improved: Normal take-off run was reduced by 20 percent and its single engine ceiling was increased from 2,000 to 4,000 feet (600 to 1200 m) (Miller and Sawers, 1938:74). The success of Caldwell's propeller on the impressive 247 convinced American designers of the advantages of variable pitch propellers, which became standard on all subsequent commercial aircraft.

Development of a constant speed control mechanism for the propeller was completed by Hamilton Standard with help from the Woodward Governor Company and placed in production in late 1935. Three years later the propeller was further modified to permit feathering and, in 1945, was again improved to provide reversible pitch.

While Caldwell's propeller was hydraulically actuated, W. R. Turnbull decided in favor of an electrically operated pitch control. With funding from the Canadian National Research Council, Turnbull completed design in 1925 (Miller and Sawers, 1970:75). Tests in 1927, on a 130-horsepower engine showed his design to be fully reliable and convinced Curtiss-Wright to take an exclusive license on Turnbull's patents the following year. Curtiss promptly replaced the wooden blades used by Turnbull with forged aluminum, which had been developed by their propeller-making subsidiary, the Reed Propeller Company.

For reasons unknown, Curtiss proceeded more slowly than Hamilton-Standard and did not attract a production order until 1935, when the Navy ordered 50 propellers for the P2Y2 flying boats. By this time Hamilton-Standard had a substantial lead and was about ready to release its constant-speed variable pitch propeller. Of course, Curtiss had been working on an automatic constant-speed control since 1934 and so they immediately went into production for this type, producing the first ones in 1935. Curtiss electric propellers soon became a strong competitor to the Hamilton-Standard hydraulically actuated propeller (Miller and Sawers, 1970:76). Both were used extensively during World War II.

Turbojet Engines

Systematic research of turbojet engines intended for aeronautical use may be traced to Alan A. Griffith of the Royal Aircraft Establishment at Farnborough, England. In 1926, he delivered a classic paper in which he proposed development of a gas turbine engine to drive a propeller (Hallion, in litt. 1971). While at Farnborough, Griffith conducted wind tunnel tests on airfoil configurations representative of turbine and compressor wheels and, in 1929, tested a single stage compressor and a single stage turbine mounted on a common shaft. The engine achieved a remarkable 90-percent efficiency on both stages (Schlaifer and Heron, 1950:332). Evaluating Griffith's work, Britain's Aeronautical Research Committee recommended continued experimentation, but Griffith was soon transferred to an Air Ministry laboratory that had no facilities with which to pursue the work. In time, he returned to Farnborough, but the world-wide Depression had made research money scarce and Griffith's unconventional project was shelved. Although Griffith's work foreshadowed development of the turboprop engine, it was not so recognized at the time and no further research on gas turbine propulsion was conducted by the Royal Aircraft Establishment until 1936 (Schlaifer and Heron, 1950:333).

In contrast with Griffith's concept of using a gas turbine engine to drive a propeller, Flying Officer Frank Whittle became interested in the possibility of using the thrust from the jet exhaust of such an engine as a primary propulsive force. Granted a patent in 1930, Whittle, who was then only 23, requested the Air Ministry to support his intended design effort, but his proposal was rejected. While his concept was considered sound, at least in principle, the Air Ministry could see no military advantage at the then prevalent flight speeds and felt metallurgical limitations would preclude the possibility of success. Private industry was similarly disposed (Schlaifer and Heron, 1950:333–335).

Whittle persisted and, in 1935, gained sufficient technical and financial support to form Power Jets Ltd., a small turbojet development firm. In the following year, the company again approached the Air Ministry for financial support, but was again refused. Fortunately, Henry T. Tizard, the chairman of the Aeronautical Research Committee, stated that Whittle's engine proposals were completely sound, which convinced Whittle's backers to continue their financing (Schlaifer and Heron, 1950:341).

The WU, Whittle's first jet engine, was completed and ready for testing by April 1937. Strictly a bench test model with a compressor efficiency less than Whittle had predicted, the test results were sufficiently encouraging to gain the respect of the Directorate of Scientific Research. Spurred on by reports of gas turbine developments abroad, the Royal Aircraft Establishment resurrected Griffith's earlier concept and was authorized to begin design studies of a gas turbine engine to drive an aircraft propeller (Schlaifer and Heron, 1950:349).

Whittle continued to systematically develop the WU engine and, after a number of design modifications, produced, in 1938, a version that was used in combustion research for the next 2½ years. The Air Ministry, which had regarded gas turbine research to be only of theoretical interest, now became interested in the practical possibilities of jet propulsion. In 1939, it agreed to fund development of a Whittle engine (the W.1) for flight testing (Schlaifer and Heron, 1950:350). Later that year, after the invasion of Poland, the Air Ministry contracted with Power Jets Ltd. to build a second, more powerful engine, the W.2. They then authorized the Gloster Aircraft Company Ltd. early the next year to design a twin-engine fighter to be powered by two W.2 engines. This aircraft was produced in 1943 as the *Gloster Meteor Mark I*.

Other British engine firms, including Rolls Royce, Bristol, and de Havilland, soon began turbojet engine development programs. In 1942, development and production of a modified W.2 engine, the W.2B was transferred to Rolls Royce, and eventually emerged as the Rolls Royce Welland engine (Schlaifer and Heron, 1950:364).

In the mid-1930's, parallel turbojet developments were occurring in Germany where Hans von Ohain, a student at the University of Göttingen, patented a centrifugal-flow turbojet engine design (Schlaifer and Heron, 1950:377). In 1936, through the intercession of R. W. Pohl, Ohain's professor, the young engineer was hired by the Ernst Heinkel Flugzeugwerke, and put in charge of aircraft gas turbine development. Ohain's first engine, a ground test device, was tested in 1937 and attained a 550-pound thrust. Encouraged, Ohain and Ernst Heinkel decided to develop a flight test engine capable of about 1800-pounds thrust. The prototype flight engine was completed and bench tested in 1938. After extensive modifications to improve its thrust characteristics, the engine emerged in 1939 as the He S-3b, capable of 1100-pounds thrust (Schlaifer and Heron, 1950:378).

Concurrent with the turbojets development, Heinkel had privately developed a special test aircraft designated the He 178. On 27 August 1939, Erich Warsitz took off in the He 178 powered by the He S-3b to make the world's first jet-propelled flight.

Another German firm, Junkers Flugzeugwerke, was also interested in turbojet research (Schlaifer and Heron, 1950:379). Junkers turbojet research was directed by Herbert Wagner and Max Mueller who investigated both turboprops and turbojets. Unlike Whittle and Ohain's centrifugal designs, Mueller developed an axial flow design, the Junkers 006, which was tested in 1938 (Schlaifer and Heron, 1950:379). Mueller's engine is noted for its small diameter, low weight and straight-through axial compressor. By the end of 1941, German engine manufacturers clearly favored axial designs over centrifugal designs.

In 1943, with Germany reeling under round-the-clock bombardment and its fighters matched or exceeded in performance by Allied piston-powered aircraft, the decision was made to give production priority to turbojet fighters (Schlaifer and Heron, 1950:398). Accordingly, the superb Me 262, a twin-engine fighter superior to any other in the world, was placed in production in 1944.

Turbojet engine development in the United States clearly failed to gain any momentum comparable to that of Great Britain and Germany. Although some thought had been given to turbojet research in the 1920's and 1930's, serious developmental efforts were not initiated until 1939, some five years after Whittle and von Ohain had become convinced of its potential. In 1939, Vladimir H. Pavlecka of Northrop Aircraft proposed development of a turboprop engine (Schlaifer and Heron, 1950:446). After receiving the backing of John Northrop, the company's founder, a small design staff was assembled and directed to develop a suitable engine.

Around a year later, Nathan Price, an engineer with the Lockheed Aircraft Corporation, proposed development of a turbojet engine. Price had begun his research at the request of Lockheed officials who felt that conventional power plants were rapidly approaching the point of maximum exploitation. At this time, the applicability of turbojet aircraft was not generally accepted in the United States. In fact, the National Academy of Sciences, in a report released in January 1941, concluded that gas turbine aircraft engines were completely impractical (Schlaifer and Heron, 1950:443).

In the spring of 1941, General Henry H. Arnold, Chief of the Army Air Corps, visited Great Britain. While abroad, he learned of the Whittle engine and of the comparatively advanced status of British turbojet developments. Surprised to find turbojet engines already in the hardware stage, Arnold arranged for discussions between British and American representatives as a first step toward American manufacture of the Whittle engine. By September, arrangements had been made for General Electric to build the Whittle engine for an aircraft to be designed and constructed by Bell Aircraft Corporation. On 1 October 1941, a Whittle engine and drawings for the W.2B were flown to the United States (Schlaifer and Heron, 1950:461).

Upon receipt of the drawings, General Electric began development of an American version of the W.2B, completing the first test engine in March 1942. Test results revealed the need for design changes which resulted in the engine emerging as the I-A, capable of delivering 1300 pounds thrust. Two I-A's installed in the Bell designed XP-59A powered this aircraft on America's first jet powered flight (Schlaifer and Heron, 1950:462).

By mid-1943, the Army had approved development of the Lockheed L-100 engine, started earlier by Nathan Price, while the Navy contracted with Allis-Chalmers for production of the British-developed de Havilland H.1 Goblin turbojet. Interested in using the Goblin engine in combat aircraft, the Army then contracted with Lockheed to develop a suitable airframe. Designed by Clarence ("Kelly") L. Johnson, this aircraft emerged as the Lockheed XP80, which first flew on 8 January 1944.

When the war ended in 1945, Great Britain, Germany, and the United States had turbojet development programs underway. Only the United States had not completed turbojet aircraft in time to see combat service in the war. Firmly established as the power plant for post-war fighters, jet engines were later developed for commercial air transports, as well. Today jet engines are the predominant type used for military and commercial air transportation, relegating the piston engine to the service of general aviation.

Biographic Sketches

Nikolaus August Otto

1832 - 1891

Engineering innovations resulting in the internal combustion engine and the four-stroke cycle

The son of a farmer, Nikolaus Otto was born in Holzhausen on 14 June 1832. At 16, he left school and moved to Cologne to work for a merchant. In 1860, he read an enthusiastic account of an illuminating gas engine built by Étienne Lenoir. The following year, he had a small engine built and started experimenting with it in his spare time. Working as a solitary amateur inventor, Otto had exhausted his funds when he met Eugen Langen, an industrialist trained at Karlsruhe Polytechnic. The two men joined forces, determined to design an engine capable of competing with Lenoir's. After several lean development years they succeeded in producing a practical engine in 1867, the Otto and Langen, which could operate at 80 to 90 rpm, and won a gold medal in the Paris Exhibition of 1867.

Otto's engine of 1876, the so-called Silent Otto is the earliest recognizable ancestor of the automobile engine. It burned illuminating gas, developed about three horsepower at 180 rpm and weighed over one thousand pounds per horsepower. It was a far more successful engine than Lenoir's, which suffered from technical weaknesses due to its low compression.

In designing his engine, Otto had prophetically combined three principal ideas: internal combustion, compression before ignition, and the four-stroke cycle. Otto's idea of combining the four-stroke cycle with compression of the gas prior to ignition is the feature that makes this engine such a notable step forward. Otto's patent was invalidated in 1886 when competition convinced the authorities that Alphonse Beau de Rochas had earlier described the four-stroke cycle in an obscure pamphlet.

REFERENCES: Lynwood Bryant, "The Beginnings of the Internal Combustion Engine" *Technology and Western Civilization,* volume 1, Oxford University Press, 1967; *A Biographical Dictionary of Scientists,* Halstead Press, 1974; Lynwood Bryant, "The Silent Otto," *Technology and Culture,* volume 7, University of Chicago Press, 1966; *Encyclopaedia Britannica,* volume 16, William Benton, 1966.

Gottlieb Daimler

1834 - 1900

Development of the light-weight, high-speed gasoline engine

Gottlieb Daimler was an experienced professional intent on inventing a light-weight, high-speed engine to drive a road vehicle. Born in Schorndorff, near Stuttgart, he began his technical education as a gunsmith's apprentice in 1848. Daimler attended a technical school in Stuttgart and, after several years experience in a Strasbourg steam engineering works, completed his education as a mechanical engineer at the Stuttgart Polytechnic. After some ten years in heavy equipment engineering with Bruderhaus Maschinenfabrik as manager, he left to become director of Machinenbau Gesellshaft in Karlsruhe. Joining Gasmotorenfabrik Deutz as chief engineer in 1872, he became involved in perfecting the Otto engine. Daimler left Otto's firm in 1882 taking with him a talented mechanic, Wilhelm Maybach, and opened a factory in Stuttgart for the development of a light-weight portable engine in anticipation of automotive needs.

For automotive use, the internal combustion engine had to be adapted for use with liquid fuels, and the only liquid fuel that could be used was gasoline. The detailed work necessary to develop a reliable light-weight gasoline engine demanded, among other things, solution of problems involving carburetion, cooling, and ignition. By 1883, Daimler and Maybach had successfully resolved all of these problems and produced an engine capable of 600 to 900 rpm. The increase in engine performance was due mainly to a unique ignition system, which created a continuous hot-spot in the combustion chamber. Daimler's engine made the automobile engine a practical proposition and it was the automotive industry alone that brought gasoline-engine technology to a state in which it could be modified for flight application.

REFERENCES: *A Biographical Dictionary of Scientists,* Halstead Press, 1974; Lynwood Bryant, "The Beginnings of the Internal Combustion Engine," *Technology in Western Civilization,* volume I, Oxford University Press 1967; *Encyclopaedia Britannica,* volume 6, William Benton, 1966.

Karl Benz

1844–1929

Pioneering innovations in automotive engineering and internal combustion engines

Karl Benz' invention of the motorcar in 1885 precipitated a movement in automobilism that had a direct influence on the growth of aviation. An experienced engineer with an intense interest in developing a small, fast engine to power a road vehicle, Benz strongly advocated electric ignition as the means to controlling fluctuating speeds and loads. Although Benz was unsuccessful in achieving this objective, he contributed much to the development of internal combustion engines and their use as automotive power plants. His motorcar of 1885 created an immense interest in ground transportation, which resulted in a reservoir of trained mechanics who were later needed in the service of aeronautics.

The son of a railway mechanic, Benz was born in Karlsuhe, Germany, on 25 November 1844. Showing an early aptitude for machines, he studied mechanical engineering at Karlsruhe Lyzeum and Polytechnikum. After a short stint with industry, he established a machine-tool shop in Mannheim in 1871. In 1877 he began design and development of a two-stroke engine, which proved highly successful. When Nikolaus Otto's four-cycle patent was invalidated in 1886, Benz designed a four-cycle engine specifically for automotive use. His motorcar, which he drove around Mannheim later that year, had a gasoline engine, a water cooling system, a battery-buzzer ignition system, and a differential gear. By 1900 his company had become the largest automobile manufacturer in Europe. In 1903, Benz retired from management of his company, which later merged with the Daimler company to form Daimler-Benz A.G.

REFERENCES: *A Biographical Dictionary of Scientists,* Halstead Press, 1974; Lynwood Bryant, "The Beginnings of the Internal Combustion Engine," *Technology in Western Civilization,* volume 1, Oxford University Press, 1967; *Encyclopaedia Britannica,* volume 3, William Benton, 1966; *Encyclopedia Americana,* volume 3, Americana Corporation, 1976.

Wilhelm Maybach

1846–1929

Noted achievement in the design and manufacture of airship engines and improvements in the technology of internal combustion engines

William Maybach is best known in aeronautical circles for his engines used on the airships manufactured by the Zeppelin Company at Frederichshafen, Germany. He is less frequently cited for his improvements in carburetion, fuel injection, timing and gearing, which greatly influenced the technology of automobile and aircraft engines.

Born at Heilbronn, Würtemberg, Maybach was the son of a carpenter. When his father died, he was left in the care of an orphanage at age 10. A long lasting association with Gottlieb Daimler was formed when the two met while working for an engineering firm in Würtenberg. In 1869 he was employed as a draftsman by Daimler and followed him to the firm of Otto and Langen in 1872. When Daimler left to form his own company at Connstatt in 1882, Maybach again joined him in making high-speed engines. It was while with Daimler that Maybach invented the carbureter that made the automobile engine practical. In 1894 he became technical director of the firm.

Maybach designed the first Mercedes car and in 1907 left the Daimler company to set up a special factory at Friedrichshafen. Maybach's company manufactured the engines used by the Zeppelin Company. His engines were also used in Russian aircraft designed by Nikolai Polikarpov.

REFERENCES: *A Biographical Dictionary of Scientists,* Halstead Press, 1974; Lynwood Bryant, "The Beginnings of the Internal Combustion Engine," *Technology in Western Civilization,* volume 1, Oxford University Press, 1967.

Charles Matthew Manly

1876–1927

Design and development of a lightweight air-cooled radial engine specifically for aircraft

A talented mechanical engineer, Charles Matthew Manly was born in Staunton, Virginia. After a year at the University of Missouri, he entered Cornell University as a sophomore. Upon recommendation of the Dean of Engineering, he joined Langley to supervise construction of the *Aerodome* and was graduated in absentia.

Langley had originally contracted with Stephen Marius Balzer, a New York City automobile builder, for a 12 hp rotary engine, but when technical difficulties delayed delivery it was decided that Manly should join in the further development of the Balzer engine. After consulting European builders, Manly abandoned the rotary engine in favor of a stationary radial design; a choice which was quickly justified. Manly's engine weighed 135 lbs and developed 52 hp. This engine somewhat anticipated modern radial aircraft engines in its use of a master connecting rod, its cam and valve-gear arrangement, and its use of crankcase, cylinders, and parts machined to carefully controlled dimensions.

Although full credit for the engine cannot be attributed to Manly, it was his modification and development of Balzer's rotary engine as a stationary radial engine that proved of significance.

REFERENCES: Robert B. Meyer, Jr., editor, "Langley's Aero Engine of 1903," *Smithsonian Annals of Flight,* number 6 (1971); C. Fayette Taylor, "Aircraft Propulsion: A Review of the Evolution of Aircraft Piston Engines," *Smithsonian Annals of Flight,* volume 1, number 4 (1971); *Aerial Age Weekly,* 21 October 1918.

Laurent Seguin

1883–1944

Louis Seguin

1869–1918

Development of the first successful mass-produced rotary engines

Responsible for the first engine to represent a complete departure from accepted automobile practice, Laurent and Louis Seguin produced an engine of unrivaled low weight, a factor which made them a favorite of many aircraft designers. Louis Seguin, the elder brother, was born at Saint Pierre-La-Pelaud, Rhone, France, and graduated seventh in his class from the École Centrale. In 1895, Louis began manufacturing gasoline engines, turning to automobile engines in 1900 under the spur of long-distance automobile racing. Founding the Sociêté des Moteurs Gnome in 1905, he located his plant at Génévilliers. Laurent, his half brother and a brilliant designer, abandoned his studies at the École Centrale to join Louis in his new endeavor.

In 1907, amid the strongly awakening aviation activity in France, the two brothers decided to build an aircraft engine—the 50 horsepower Gnome rotary. The name "Gnome" was chosen to convey the idea of an engine busily at work, producing substantial power for its size. Choosing a rotary arrangement because of the prospect of achieving minimum weight, Laurent, the true inventor of the engine, also attempted to achieve adequate cooling without the complication of a water cooling system.

The skepticism surrounding the radical design quickly gave way to admiration when the engine proved capable of producing 50 horsepower at a surprisingly low weight of only 165 pounds. Featuring a short, hollow, single-throw crankshaft, which served as an inlet tube for a combustible mixture of gasoline and air, the engine achieved even combustion, which made for smooth running. Its main disadvantages were its relatively high consumption of fuel and castor oil, which was used for a lubricant, and the gyroscopic effect, which reduced maneuverability. In spite of these disadvantages many thousands of Gnome rotaries were built, especially during the early years of World War I when they powered many of the most famous aircraft of the war. By 1917 the Gnome engine had begun to yield to more conventional designs and it was soon obsolete.

REFERENCES: Lauren S. McCready, *The Invention and Development of the Gnome Rotary Engine,* Masters thesis, Polytechnic Institute of Brooklyn, June 1973; Tre Tryckare, *The Lore of Flight,* Cagner and Co., 1970; C. Fayette Tayler, "Aircraft Propulsion: A Review of the Evolution of Aircraft Piston Engines," Smithsonian Annals of Flight, volume 1, number 4 (1971).

Marc Birkigt

1878–1952

Notable achievements in developing the technology of light-weight liquid-cooled engines

Marc Birkigt's cast aluminum Hispano-Suiza V-8 engine is often regarded as the most outstanding aircraft engine of World War I. The Geneva-born Birkigt was educated at the École Technicum and began his engineering career as a designer of mining machinery. Relocating in Spain he turned to design of luxury automobiles, which were produced at his Hispano-Suiza factory in Barcelona. By 1913, Birkigt's fine automobiles had established themselves among the leading luxury cars of the period. His second Hispano-Suiza plant had been opened in Paris to produce beautiful "enbloc" form engines, in which the cylinders were bored from a single cast iron block.

With the outbreak of World War I, Birkigt turned over his Paris factory to the French Gnome company. Birkigt returned to Barcelona where, in 1914, he conceived the "Monobloc" aero engine, an ingenious engine fashioned from cast aluminum and fitted with forged steel cylinder liners. The cooling water was channeled through ports in the block, positioned so that the cooling water never touched the steel cylinder liners directly. The type of construction that became known by the term "dry liner" represented a bold departure from traditional engine construction practice. When tested in 1915, the engine's superb performance convinced the French government to officially adopt the Hispano-Suiza aero engine. The engine soon became so significant it was produced by fourteen firms in France alone.

Although a number of variants were produced, dry liner cooling became more critical when the bore and stroke were increased in an attempt to realize higher horsepower. A marked reduction in reliability coupled with the postwar decline in development eventually resulted in its abandonment.

REFERENCES: Thomas G. Foxworth, *The Speed Seekers,* Doubleday; C. Fayette Taylor, "Aircraft Propulsion: A Review of the Evolution of Aircraft Piston Engines," *Smithsonian Annals of Flight,* volume 1, number 4 (1971).

Sam D. Heron

1891–1963

Significant achievements in developing the technology which made high-power piston engines practical

Sam D. Heron's monumental contributions to the development of high-powered piston engines, as well as aircraft fuels and lubricants, were largely responsible for the rate at which manned flight developed in the period prior to jets. The son of an actor, Heron was born in Newcastle-on-Tyne, England, on 18 May 1891. His mother died during his infancy and his education was dispersed among Alleyns School, London University night school, and Durham University night school; he did not, however, obtain a degree. While attending night school he completed his apprenticeship as a mechanic and foundryman at Thames Ironworks Shipbuilding and Engineering Company.

Known for his independent nature, Heron experienced frequent changes in employment. During the period he worked at Rolls-Royce, Napier, and Siddeley aircraft engine companies. While at Farnborough during World War I, he was involved in the design and development of the first successful aluminum air-cooled cylinders at the Royal Aircraft Factory.

In 1921 he brought his extensive knowledge of air-cooled engine design and construction practice to the United States, where he was employed at McCook Field, Ohio. His association with the military (1921–1926 and 1928–1933) greatly contributed to the rapid development of the air-cooled aircraft engine. During 1926 and 1927 he was involved in development of the Wright Whirlwind engine while employed by the Wright Aeronautical Corporation. Although perhaps best known for his work on the sodium-cooled valve, which solved a major problem in engine endurance, Heron was an acknowledged authority on metallurgy and heat treating, application of hard-facing materials to exhaust valves, valve seat inserts, valve cooling, cylinder design, and engine lubricants and fuels. He was responsible for preparation of the first specifications for gasoline that included octane number and a champion of 100 octane fuel for aircraft use.

In 1934 he was appointed director of aeronautical research at the Ethyl Corporation. Except for a leave of absence to the U.S. Government in 1940, he remained in this position until his retirement in 1946.

References: S. D. Heron, *History of the Aircraft Piston Engine,* Ethyl Corporation, 1961; C. Fayette Taylor, "Aircraft Propulsion: A Review of the Evolution of Aircraft Piston Engines," *Smithsonian Annals of Flight,* volume 1, number 4 (1971); Robert Schlaifer and S. D. Heron, *Development of Aircraft Engines and Fuels,* Harvard University Press, 1950.

Charles Lanier Lawrance

1882–1950

Engineering contributions in support of air-cooled, radial engine development

Charles Lanier Lawrance's air-cooled radial engines proved so reliable, they were chosen by pioneer fliers for use on transoceanic flights. They also were used to establish records of national and international interest. Born in Lenox, Massachusetts, he attended Groton School and was graduated from Yale in 1905 with a Bachelor of Arts degree. He also earned a Diplôme École des Beaux Arts after studying architecture in Paris for three years. While in Paris he began development of a water-cooled aircraft engine with aluminum cylinders. With the outbreak of war, he returned to the United States to continue work on the engine.

In 1915 Lawrance and four associates formed the Shinnecock Airplane Company with the intent of developing a light private plane powered by a two-cylinder air-cooled engine designed by Lawrance. A 1917 decision to separate the company's air frame activities from its engine activities led to founding of the Lawrance Aero-Engine Corporation. Discussions between Lawrance and both the Army and Navy were begun in 1919 and resulted in production of the nine-cylinder J-1 engine. This engine proved quite popular and its success proved decisive in establishing the air-cooled engine in the United States.

In 1923 the Lawrance Aero-Engine Corporation was purchased by Wright Aeronautical under pressure from the Navy, which encouraged development of the air-cooled engine. In 1924 the model J-4 was brought out and given the name by which it has been popularly known ever since: the Whirlwind.

Lawrance was president of the Wright Aeronautical Corporation from 1924 to 1929 when he became vice-president of the Curtiss-Wright Corporation. In 1930 he organized and headed the Lawrance Engineering and Research Corporation in Linden, New Jersey.

Lawrance's name was closely associated with Charles Lindbergh, Richard Byrd, Clarence Chamberlin, Amelia Earhart, and others who depended on his engines in their record setting flights.

References: Robert Schlaifer and S. D. Heron, *Development of Aircraft Engines and Fuels,* Harvard University Press, 1950; C. Fayette Taylor, "Aircraft Propulsion: A Review of the Evolution of Aircraft Piston Engines," *Smithsonian Annals of Flight,* volume 1, number 4 (1971).

Frank W. Caldwell

1889–1974

Increasing aircraft performance through development of controllable and constant speed propellers

Born at Lookout Mountain, Tennessee, Frank Caldwell studied at the University of Virginia for a year before attending the Massachusetts Institute of Technology where he earned a Bachelor of Science in mechanical engineering. Employed as a process engineer with the Cahill Iron Works in Chattanooga, he left, in 1916, to join the Propeller Department of Curtiss Aeroplane Company in Buffalo. Caldwell was well aware of the aerodynamic advantages of the variable pitch propeller and was in charge of propeller development for the Army when the Hart-Eustis mechanically actuated design was tested. His experience with the Hart-Eustis design convinced Caldwell that mechanical control would not work.

Choosing to make development of the variable pitch propeller a private venture, Caldwell left Government service to develop his ideas for hydraulic control of pitch. Although he did not make a complete variable pitch propeller at the time he filed for patents, he had built and tested propellers with his basic hub design. After filing his patents, Caldwell joined the Stand Steel Propeller Company, which later became the Hamilton-Standard Division of United Aircraft. He built the first propeller in 1929–30 and tested it on a 150 horsepower engine. Caldwell had intended to make his propeller fully automatic so that the pilot need only control engine speed, but the urgent need for variable pitch control caused him to adopt a simpler two-position control for take-off and landing. By the end of 1932, Caldwell's propellers had been built and flown successfully. The improvement in performance of the Boeing 247 convinced designers of the advantages of pitch control.

In 1935 Caldwell received the Sylvanus Albert Reed Award for his work with variable pitch and constant speed propellers.

References: R. Miller and D. Sawers, *The Technical Development of Modern Aviation,* Praeger Publishers, Inc. 1970; C. Fayette Taylor, "Aircraft Propulsion: A Review of the Evolution of Aircraft Piston Engines," *Smithsonian Annals of Flight,* volume 1, number 4 (1971).

Sanford Moss

1872–1949

Development of the turbo-supercharger

To operate an internal combustion engine efficiently at altitude it is necessary to provide sufficient air to keep the fuel-air mixture in the correct proportion. Sanford Moss, the man responsible for this idea, had the tenacity to pursue his conviction when others said it couldn't be done. Born in San Francisco and educated in mechanical engineering at the University of California, Moss earned his doctorate at Cornell University in 1903. While studying at Cornell, he became intensely interested in the gas turbine and conducted hundreds of experiments. Upon graduation he joined the General Electric Company as a research engineer and continued to pursue his idea.

When the First World War started, Moss was one of the top authorities on the subject of gas turbines. As the need for aircraft to perform at altitude became pressing, the Government asked Moss to investigate the problem of superchargers for airplanes. Working tirelessly, he constructed a wooden model that showed clearly the principles he had in mind. Moss took the model to McCook Field, Dayton, Ohio, the engineering and research center of the Air Service, where it was enthusiastically received. Moss worked long and hard until he had the first turbo-supercharger completed. He returned with it to McCook Field and obtained permission to conduct official tests. The initial tests with a working turbo-supercharger mounted on a Liberty engine were conducted early in September 1918 at an altitude of 14,109 feet (4200 m) on Pikes Peak. The tests proved conclusively that Moss' invention was a success but it was too late to be used in the war.

Almost shelved by the postwar doldrums in aeronautics, interest in the turbo-supercharger was kept alive by the flight test section of the Air Corps. Due to interest by this group, Moss was able to continue his research. The first flight test of a supercharged engine was made by Major R. W. Schroeder who attained a world's altitude record of 38,180 feet in a Le Pere biplane equipped with a turbo-supercharged Liberty engine. Although interest waned in spite of a number of record setting flights, Moss continued to progressively refine his invention. The turbo-supercharger did not gain full acceptance until March 1939 when tests on a Boeing B-17 proved its full value.

Sanford Moss was awarded the Collier Trophy in 1940 for his work in developing the turbo-supercharger.

REFERENCE: D. J. Ingalls, *They Tamed the Sky,* D. Appleton-Century Company, Inc., 1947.

Sir Frank Whittle

1907–

Invention of the turbojet engine

One of the earliest and foremost developers of turbojet engines, Frank Whittle was a career officer in the Royal Air Force and a gifted mechanical engineer. A brilliant student, he was born in Coventry, England, and entered Leamington College at the age of eleven. He became an apprentice in the Royal Air Force at sixteen. Upon completion of his three-year apprenticeship, he became a cadet at the Royal Air Force College, which combined flight training with emphasis on scientific and engineering subjects. In his senior thesis, he discussed the possibilities of gas turbines and rockets as powerplants for aircraft. Graduating second in his class in 1928, he was posted with a fighter squadron stationed at Hornsby. In January of 1930 Whittle filed for his patent. Whittle completed the two-year engineering course at the Officers Engineering School in eighteen months and was sent to Cambridge for advanced study. He earned his Bachelor of Science from Cambridge in 1936.

Borrowing funds, he had an experimental engine built, but it was badly damaged during tests. Modifying the engine to incorporate multiple combustion chambers, he finally realized the design speed of 1600 rpm. With support from the British Air Ministry, arrangements were made for him to continue work on his engine. He started to work on an improved form with two units designated the W-1 and the W-1-X being built. At the same time Gloster Aircraft Company undertook design and construction of an airframe. The W-1-X was used for the test installation in May 1941, but it was subsequently replaced with the W-1 for a complete series of tests.

The W-1-X was later sent to the United States to become the basis for American development of the turbojet. Whittle came to the United States during 1942 to assist General Electric in development and production of his engine. He has been intimately associated with further improvements in jet engines and aircraft and has received many well-deserved honors, including knighthood, for his efforts.

REFERENCES: Grover Heiman, *Jet Pioneer,* Duell, Sloan, and Pearce, 1963; Robert Schlaifer and S. D. Heron, *Development of Aircraft Engines and Fuels,* Harvard University Press, 1950; *The Guggenheim Medalists,* The Guggenheim Board of Award, 1964.

Hans von Ohain

1911–

Invention of the centrifugal flow turbojet engine

Born in Dessau, Germany, Hans von Ohain had a compelling interest in science, and, much to his father's disappointment, complete lack of interest in a military career. Resigned to this fact, his father sent him to the University of Göttingen where he studied physics. A brilliant student and diligent worker, von Ohain completed the normal seven years of study in four, earning his doctorate in 1934. Intensely interested in developing the idea of jet propulsion for use on high-speed aircraft, he had already submitted for a patent when his professor recommended him to Ernst Heinkel who owned the Heinkel Flugzeugwerke GmbH in Rostow. Given complete freedom to develop his engine, von Ohain produced a test engine to demonstrate the fundamental soundness of the principles involved.

Continuing to work on his designs, he produced a vastly improved engine with liquid fuel injection, obtaining some eleven hundred pounds of thrust in 1939. Heinkel, elated with the performance of the engine, laid immediate plans to build a stronger engine for flight test and mate it to a specially designed airplane. He put construction of the He 178 on a crash basis and von Ohain and his team rushed the flight engine to completion. The engine was installed in the He 178 and the world's first turbojet powered flight was made by this combination on 27 August 1939.

Von Ohain then abandoned the centrifugal compressor concept for an axial compressor concept. It was this axial compressor engine, to which von Ohain contributed greatly, that powered the first operational jet fighter, the twin engine Me 262 fighter.

REFERENCES: Grover Heiman, *Jet Pioneers,* Duell, Sloan, and Pearch, 1963; Robert Schlaifer and S. D. Heron, *Development of Aircraft Engines and Fuels,* Harvard University Press, 1950.

René Lorin

1877–1933

Early development of the ramjet

Descended from French nobility, René Lorin was born in Paris on 24 May 1877. He studied at the Lycée Henri IV and graduated from L'École Centrale in 1901. Lorin entered the French army as an artillery officer. In 1907, he published his first article on direct reaction propulsion in *L'Aérophile.* This article was followed by others which continued until the start of World War I. During the war he specialized in transportation as officer in command of a mechanized courier service.

Although Lorin's engine, which represents an early form of the ramjet, was out of the main stream of contemporary aeronautics and was not practical at the speeds attainable at the time, it was to influence later generations of designers. His proposed design suggested use of two engines mounted on either side of the fuselage. It also featured a hinged mount to permit directional control of the jets for vertical takeoff and transition to horizontal flight. He later developed his idea into a ramjet powered flying bomb but failed to gain support from the French military authorities.

Lorin's engine concept was later adapted by René-Henri Leduc, who used a Lorin-type engine on the Leduc 0.10, and the Leduc 0.21 and 0.22. The first of these vehicles, the 0.10, was launched from a carrier over Toulouse in April 1949, sixteen years after Lorin's death. Although unorthodox in appearance it was highly successful, attaining a speed of 422 mph on half power. It later reached 500 mph on half power at an altitude of 36,100 feet (10,800 m).

Development of the Leduc vehicles ceased in 1957 when official support was withdrawn, but their performance substantiated Lorin's early concept.

REFERENCES: Anonymous, "René Lorin," *L'Aérophile,* March 1933; Charles Gibbs-Smith, *Aviation,* Her Majesty's Stationery Office, London, 1970; M. Taylor and J. Taylor, *Janes Pocketbook of Research and Experimental Aircraft,* Collier Books, 1976.

Alan Arnold Griffith

1893–1963

Significant achievements in aircraft propulsion systems and VTOL aircraft

Generally regarded as quiet and reserved, Alan Arnold Griffith was an acknowledged authority on gas turbine engines. Born in London, England, he attended the University of Liverpool, graduating in 1915. Upon graduation Griffith joined the Royal Aircraft Factory at Farnborough and later transferred to the physics department at the university, where he worked with the noted experimentalist Geoffrey I. Taylor on solution of torsion problems by use of the soap film analogy. While at the university he developed the Griffith theory of crack propagation, which is a basis for modern work in fracture mechanics.

In 1926, he delivered a classic paper entitled "An Aerodynamic Theory of Turbine Design," in which he proposed a gas turbine engine based on an axial-type of compressor. The axial-type jet propulsion engine later replaced the simpler centrifugal compressor engine developed in 1928.

In 1939 Griffith joined Rolls-Royce Ltd. as chief scientist and promptly started work on multistage axial compressors and turbines combined on the contraflow principle. Griffith continued his studies of contraflow applications until 1945, when he began to develop the principles underlying the Rolls-Royce Avon engine. He later proposed use of the bypass principle, which resulted in the Conway engine. In 1941 he addressed the problem of vertical take-off, which materialized in the Rolls-Royce Flying Bedstead. Following the success of the Bedstead tests, Rolls-Royce began design of their first lightweight lift engine, which was designated "RB108." Several were installed in Short SCI aircraft, which became the first VTOL aircraft to employ Griffith's lift and control ideas. The Short aircraft were successfully demonstrated in 1960, just prior to Griffith's retirement.

REFERENCES: Donald Eyre, "Dr. A. A. Griffith, CBE, FRS," *Journal of the Royal Aeronautical Society,* June 1966; Raymond J. Johnson, editor, *Above and Beyond,* New Horizons Publishers, 1968.

René-Henri Leduc

1898–1968

Development and application of the ramjet

Destined to devote a major part of his career to development of an athoyd or ramjet powerplant for aircraft, René-Henri Leduc was born at Saint Germain-les-Corbeil, France. He began his career as an apprentice in a garage in Corbeil and later became an official with the Factories and Foundries of Chantemarle in Essones. Serving with the army when France entered World War I, Leduc was sent to a school at Fontainebleau, where he graduated first in his class. Discharged in 1920, he continued his studies at the École Supérieure d'Électricité. After a short period with a cellulose factory in Tirol, Leduc joined the Breguet Company in 1924.

While with the Breguet Company, Leduc became involved with development of ramjet engines and in 1934 built one for test purposes. In 1936 he designed an aircraft to use his engines. Assigned a staff of designers, he began development of the Leduc 0.10. Interrupted by World War II and the occupation, during which the vehicle was disassembled and hidden, Leduc abandoned developmental work until after the war. He then resumed work on the 0.10. The first powered flight of the Leduc 0.10 was made on 21 April 1949 at Toulouse, France. Air-launched from a Languedoc-161 carrier aircraft, the Leduc flew for 12 minutes and reached a speed of 450 mph on only half power.

Leduc continued development of ramjet powered aircraft producing the Leduc 0.1 and 0.22. The 0.21's proved completely successful and were used to flight-test components for the 0.22 Mach 2 interceptor. When official support of the aircraft was withdrawn in 1957 due to insufficient funds, further development work was abandoned.

REFERENCES: *Enciclopedia De Aviation y Astronautica,* Edicions Garriga, volume 5, 1972; M. Taylor and J. Taylor, *Janes Pocket Book of Research and Experimental Aircraft,* Collier Books, 1976.

Flight Structures

Today's popular image of an airplane is that of a low-wing monoplane with internally braced cantilever wings and, except for some vehicles in the private sector, all-metal, flush riveted construction. The configuration and characteristics embodied in this image are now so casually accepted, few people realize their emergence as the structural standards of aeronautics required some 40 years of intense development. During much of this period, structural design was based more on intuition and empirical rules than sound principles for efficient use of materials. As aviation progressed beyond the realm of the individual pioneer inventor and attracted the attention of trained engineers, the companion sciences of elastic theory, strength of materials, and structural mechanics were extended to encompass the problems of flight structures. The guidance derived from this body of theory resulted in impressive improvements in performance and established the subject of airframe structures as a recognized engineering specialty.

Materials, Structures, and Design

Pioneer flight enthusiasts were often gifted amateurs and sportsmen more enamored of engines than the supporting structure, about which they knew little. From the beginning, they were conscious of the need for a lightweight structure, but very few of them had the theoretical preparation to understand the problem of airframe design. The problem is one of strength in relation to weight. In this problem, the object is to reduce weight, not increase strength. For a given aircraft, strength enters the problem as a value fixed by consideration of the most critical load the vehicle is likely to experience. Once fixed, the value of strength must be maintained if a safe structure is to result.

Weight enters the problem in a more influential way. A structure is usually regarded as an assemblage of solid components arranged to sustain load and provide shape. Its weight depends on only two factors: the material of construction and the way in which the material is disposed. Consequently, while airframe design entails material selection, the primary concern of the designer is to determine the disposition of material that results in the structure of least weight. One of the great problems of aeronautical engineering became that of selecting the best materials and determining the best way to use them.

It is doubtful if an awareness of the way in which weight and strength enter into the airframe design process would have made much difference to those who pioneered flight. Would-be flying machine builders regarded the structure as a minor problem, easily solved with available materials and trial-and-error procedures. Of the conventional materials available for construction of bridges and other stationary structures, only steel and select varieties of timber were considered suitable for flight. Familiarity with wood made it the natural choice of pioneer inventors, since it was readily available and inexpensive, required few specialized tools and could be easily worked by those with limited construction skills.

Wooden trusses joined together to form a framework were considered to provide the easiest and most satisfactory solution to the structural problems of early aircraft. This form of construction permitted a stiff, lightweight structure to be fabricated from simple two force members that could be easily replaced if damaged. Reliable methods for analysis and design of beams and trusses had been available for decades (Timoschenko, 1953:190–197), but most experimenters neglected theory in favor of intuition. In a brief description of early design procedure, Arthur W. Judge, an associate fellow of The Aeronautical Society wrote: "In the earlier type of aeroplane body it was the usual practice to obtain the sizes of the different members by trial and error methods, or to make chance shots at the dimensions, and to trust to luck whether the resulting body has any margin of safety or not" (Judge, 1917: 156).

With such a haphazard approach, it is not surprising that early aircraft experienced a high incidence of accidents due to structural causes. Around 1911, a number of writers, including Claude Graham-White, 1910 winner of the Gordon-Bennett International Aviation Cup, began to publish testimony and descriptive analyses resulting from aircraft accident investigations (Graham-White and Harper, 1911:104). The evidence clearly identified structural failure as the principal contributor to early flight accidents. A later note on aircraft fatalities and their causes that appeared in the July 1911 issue of *The Aeronautical Journal* (Anonymous, 1911:125) listed the fatalities that had occurred during the first six months of the year. The preface to the note begins: "At the moment of writing thirty fatal accidents have occurred this year, causing death to thirty pilots and four passengers. In every case, except one where reliable news is available, the accident has been due to one of three causes, inexperience, recklessness or faulty construction of the machine."

After citing the unfortunate circumstances of the exception, the preface to the note continues: "Faulty construction is the most fertile source of accidents, and always will be until constructors put first-class engineering knowledge into their work. An airplane, to use a well-known advertising phrase, must be built like a gun: it must be the best work designed by competent engineers to ample factors of safety" (Anonymous, 1911:125).

At the time this anonymously written note appeared, airframe constructors believed they were already designing to a "factor of safety" of 6; a value that exceeds the standard for many buildings. Unfortunately, this mistaken impression resulted from a misunderstanding of the term "factor of safety" that was not corrected until around 1920. The confusion with such a fundamental concept can be attributed to the fact that the term had acquired a significance in aeronautics that changed its conventional meaning. Loads on an airplane were inexactly known, so amateur builders somewhat arbitrarily took the "factor of safety" to be the ratio of the breaking strength of the structure to the load it sustains under steady, horizontal flight in still air (more correctly called, "load factor"). This is quite different from the correct engineering definition and can be misleading.

As an expression familiar to every engineer responsible for design of a stationary structure, the true factor of safety is the ratio of the breaking strength of the structure to the worst load it is ever likely to sustain. If, for instance, experience indicates that the worst winter storms in a given area leave a maximum of 10 pounds of snow on every square foot of roof, then the strength of all members that support the roof may be calculated as though the load was 50 pounds per square foot instead of 10. The true factor of safety will then be 5 (Warner, 1923:1–6).

By 1911, it had become apparent that aircraft structural design was a matter requiring the careful attention of competent engineers. To offset the absence of collected data and design methods, a number of engineers simply recommended using a factor of safety (actually a load factor) of 15 (Judge, 1917:56). Others, like Louis Bechereau, a gifted French-educated engineer, sought improved structural behavior by less conventional means. In late 1911, Bechereau adopted the ideas of the Swedish engineer Ruchonnet and produced the first of the Deperdussin racing monoplanes. Bechereau's Deperdussin was a beautifully streamlined, externally braced, mid-wing monoplane, with a monocoque fuselage of molded plywood. In contrast with contemporary aircraft structures, which used the skin merely as a covering and relied on trusses and frames to carry the primary loads, monocoque construction derived its strength solely from the load-carrying capacity of the skin. Effectively a precursor of stressed-skin construction, introduction of monocoque, and later semi-monocoque, construction marks a milestone in the evolution of light structures. Its use on the Deperdussin brilliantly forecast a future trend toward extensive use of shell structure in aeronautics.

Although Bechereau's handsome racers were highly successful, monocoque construction was not extensively adopted. The main reason was that the Deperdussin's fuselage was made from three layers of tulip wood reinforced with intermediate layers of fabric—an approach which proved to be expensive and difficult to fabricate without highly skilled workmen. Since most aircraft of the period were built on what, at best, can be described as a limited production basis, contemporary designers continued to rely on conventional truss and frame construction.

By the beginning of the "war to end all wars," European engineers were considering replacing wooden truss members with tubular steel members; but uncertainties with weld integrity and distortion due to heat shrinkage caused them to question the air-worthiness of welded structure. With few exceptions, wood remained the principal material of construction throughout the war, chiefly because the demand was immediate and there was little sympathy for introducing unproven innovations that might seriously disrupt production.

Positive steps toward extensive use of metal construction first occurred in Germany when Hugo Junkers boldly challenged the unquestioned merit of thin wing forms and introduced the J.1 in 1915. Motivated by interest in reducing drag, Junkers' J.1 was an all-metal, mid-wing monoplane with thick internally braced cantilever wings. The aircraft, which was capable of speeds in excess of 100 mph, had a smooth iron skin stiffened by a second layer of corrugated sheet metal welded to its inner side (Junkers, 1923:406).

Keenly aware of the structural implications of his innovations, Junkers extensively tested each new idea in the laboratory before committing it to fabrication. Tests on various wing arrangements led him (Junkers 1923:428) to conclude that "the theoretically best design appeared to be the system of the so-called supporting cover, that is, all tensile, compressive and shear forces are taken up by the wing cover." The importance of Junker's work lay in the skillful way in which he combined the ingredients of thick cantilever wings with metal stressed skin construction to achieve superior structural behavior. Some fifteen years were required before these ideas emerged as the standards of aircraft structures.

Unfortunately, German authorities were skeptical of such a radical departure from the more traditional wood and fabric biplanes and, ignoring the J.1's respectable performance, criticized the iron structure as impractically heavy. Undaunted, Junkers continued to champion the cause of metal construction and, in 1917, produced both the J.2 and the remarkable J.4, an all-metal armored ground attack aircraft. He then produced the first low-wing cantilever monoplane fighters. Charles Gibbs-Smith, the distinguished aviation historian commented (1970:178) on the significance of this approach:

> One of Junker's main reasons for adopting the low wing position was to minimize injury to the crew in a crash, as the wings would be the first to hit the ground and thus absorb a large part of the initial shock. When retractable landing gear became practicable, the low position was to prove ideal in its allowance of short, and hence light, under carriages.

Although Junker's advanced thinking was to exert a lasting influence on later aircraft structures, it was not immediately appreciated by his contemporaries, who preferred to remain with the fabric-covered biplane and who tended to substitute tubular steel members for wooden ones. This comparatively reticent approach was adopted by Reinhold Platz, who had joined Anthony Fokker's company as a welder, but later designed the historic Fokker D-VII fighter, which saw extensive service during World War I. Platz successfully developed the technique for welding steel tubing and pioneered construction of fabric-covered welded tube structure when he used it for the fuselage of the D-VII in order to decrease production time. Recognized as the finest all-round fighter of the war, Platz designed the D-VII with thick section, semi-cantilever wings. The wings were unique in that they were built with wooden box spars and plywood ribs arranged to divide the wing into a series of cells, each capable of resisting torsion (Weyl, 1965:214).

The trend toward increased use of metal in aircraft construction did not begin with a conscious effort to take advantage of the superior structural properties of metals. Commenting on the future of metal construction John D. North (1923:3), a noted British authority of the time, wrote:

> Of the three separate metal aeroplane movements in Great Britain, Germany and France, that in this country, at

least, received its principal impulse, not from a realization of the great engineering advantages attending it, but from the pressure of a world shortage of the limited supplies of that class of timber most suitable for light structural purposes.

North is quite likely referring to the situation that occurred during the latter part of the war, when a shortage of aircraft quality timber seriously threatened to disrupt British aircraft production. Brought on by Britain's need to rely on imported supplies of aircraft timber, one would expect to find a strong interest on the part of British engineers in promoting metal construction. Surprisingly, such a movement failed to materialize during the period of aeronautical stagnation, which beset Britain in the immediate postwar years. For some unexplained reason, British engineers ignored the progress in metal construction being made by their counterparts on the continent and in the United States, and adopted a strangely conservative and unprogressive approach. In 1924, as England moved to revitalize procurement of military aircraft, the Air Ministry conservatively ruled that all vital parts of future service aircraft were to be made of metal. Disappointingly short of a positive decision, which might have promoted development of all-metal aircraft designed to take advantage of the superior weight/strength properties of metals, the ruling did little more than foster continuation of fabric-covered biplanes with high alloy steel frames (Gibbs-Smith, 1970:182).

While progress toward efficient use of metals stagnated in England, German engineers continued to force the issue. Junkers had retained his belief in the advantages of all-metal construction, but had abandoned the "supporting cover" concept in favor of wing and fuselage skins of corrugated duralumin. To avoid introducing an unacceptable amount of drag, Junkers oriented the corrugations parallel to the wind direction, which greatly increased chordwise bending rigidity but reduced the amount of load that could be carried by the skins in the spanwise direction.

Other German designers soon followed Junker's lead. The most notable was probably Adolf Rohrbach, who introduced an efficient form of stressed-skin construction on production aircraft. Rohrbach had worked with Claudius Dornier on flying-boat design during the war and, in 1919, started building smooth-skin duralumin wing surfaces. The basis for Rohrbach's wing design was a central box-section girder of thick duralumin sheet stiffened by fore and aft bulkheads (Miller and Sawers, 1970:56), which allowed the wing skins to carry a substantial part of the primary load. Regarding failure to correspond with the onset of buckling, the wing and spars were designed to remain unbuckled under the anticipated loads. This practice certainly reflected contemporary thinking, for little was known about the behavior of thin sheet structure in the early twenties.

In 1925, Herbert Wagner made the important discovery that a structure of mutually perpendicular members covered with a thin skin did not fail if the skin buckled (Hoff, 1967:28). Wagner, who made the discovery while working for Rohrbach, had become dissatisfied with a fuselage structure Rohrbach had designed and felt the spacing of the frames that supported the skin should be changed to permit the skin to carry the greatest possible stress. Theoretical considerations prompted him to conclude that maximum stress occurred at an angle with the frame axes and would cause the skin to buckle into diagonal folds without failing. When laboratory tests confirmed the superior load carrying capabilities of panels designed according to Wagner's method, Rohrbach decided to use the method in his subsequent fuselage designs.

Wagner patented his discovery, but it remained largely unknown until he left Rohrbach and published his views on structural design in 1929. At first, structural authorities in both Great Britain and the United States were skeptical of Wagner's tension field theory, but it was finally accepted in the early 1930's and used in the design of many metal aircraft.

In the United States, engineers with the NACA closely monitored European progress in metal aircraft construction but refrained from structural activities that could alienate industry and jeopardize their advisory position. A small group were engaged in limited in-house studies of a predominantly theoretical or analytical nature (Gray, 1948:180). Since the NACA had no facilities for testing structural components, the activities of the group were supplemented with experimental investigations conducted at the National Bureau of Standards in Washington, D.C. An attitude of complete cooperation among the NACA, the Bureau of Standards, and the military had existed since the NACA was first founded in 1915. It was in this cooperative spirit that Louis Schuman and Goldie Back (Schuman and Back, 1930:519) of the Bureau of Standards undertook a series of tests to determine the strength of rectangular plates under edge compression for the Bureau of Aeronautics of the Navy Department. Shuman and Back reported on the unexpected behavior of the plates which, unlike columns, continued to take load beyond the critical value needed to cause buckling. Their report was published by the NACA in 1930 and widely disseminated (Hoff, 1967:29).

The following year, Ernest E. Sechler, a graduate student at California Institute of Technology, discussed Shuman and Back's research at a seminar attended by Theodore von Kármán, director of the Guggenheim Aeronautical Laboratory at Cal Tech (Hoff, 1967:28). Although von Kármán's major interest was aerodynamics, he was a superb analyst and had published several papers on solid mechanics while at the University of Aachen. Sechler's talk struck a responsive chord as von Kármán noted a striking similarity with a well-known concept he had analyzed in 1924 and published under the title "Die mittragenda Breite" (effective width) (von Kármán, 1924:114). Shortly following Sechler's talk, von Kármán produced an approximate expression for determining the ultimate load-carrying capacity of simply supported, edge loaded plates. Although the expression cannot be justified with rigorous theory, it was a key element in establishing that thin-sheet structure could safely carry load even after buckling. Accepting von Kármán's convenient formula on the basis of its agreement with experimental evidence, American industry greatly improved its ability to design efficient lightweight structures. Their success with stressed-skin semi-monocoque construction proved to be an important factor in the development of commercial aircraft, through which America gained a position of world leadership in air transportation in the mid-thirties.

Civil aviation in continental Europe, while adventurous in expansion of its route structure, continued to use the tri-motor monoplanes produced by Fokker and Junkers, rather than press for development of updated equipment. England was similarly complacent with regard to aeronautical progress. Adopting an overly conservative design posture, F. Handley Page retained the biplane tradition by producing the H.P. 42 and 45 in 1931. In the following year, Armstrong Whitworth produced the *Atalanta,* a 4-engine high-wing monoplane designed specifically to meet the needs of Imperial Airways African and Far Eastern routes (Gibbs-Smith, 1970:197). As the work horses of European air transportation, these aircraft types certainly must be considered operational successes, but they contributed little to the technical development of aeronautics.

Commercial aircraft under development in America during this period, differed substantially from their European counterparts. Combining the most advanced aerodynamic, propulsive, and structural technology available, American vehicles were twin-engined, low-wing monoplanes with flush riveted aluminum construction and supercharged air-cooled radial engines. Equipped with retractable landing gear, flaps and comparatively sophisticated flight instruments, they opened the way for all-weather operations and completely revolutionized the approach to civil air transportation (Gibbs-Smith, 1970:200).

Boeing's 247, which first flew in February 1933, was instrumental in setting the design standards used to mark the modern airliner of the thirties. A derivative of the earlier single-engine Monomail, by way of the B-9 bomber, the 247 was closely followed by the DC-1, a one-of-a-kind aircraft which first flew in July 1933. Recognizing an opportunity to capture a share of the world market, Douglas measured the DC-1's promise and immediately placed in production a stretch version, known as the DC-2, which spawned the well-known DC-3 of 1935. A landmark aircraft with an enviable service record, the DC-3 is recognized by authorities as the most famous and successful airliner in history (Gibbs-Smith, 1970: 201).

European industry, shocked from complacency by the comparative sophistication of American aircraft, began to develop similar vehicles in a determined effort to remain competitive. Using structural information gleaned from American practice, British and German designers proved equal to the task. A British derivative of the 247, the Bristol 142, first flew in 1935, the same year in which Germany's versions appeared in the form of the Junkers Ju 86 and the Heinkel He 111. Retired without much commercial success by the overwhelming competition of the DC-3, these aircraft later emerged as highly respected military vehicles. Heinkel's He 111, which saw no commercial service, was soon modified into a bomber, while the 142 became the prototype for the Bristol Blenheim. The Ju 86 survived to serve both commercial and military functions (Gibbs-Smith, 1970:201).

Political events following Adolf Hitler's appointment as Chancellor of Germany on 30 January 1933 completely changed the nature of Europe's aeronautical interests. Temporarily abandoning further development of commercial aircraft, European industry entered into an intense design program to produce an inventory of vehicles intended solely for warfare. The prototypes of a stable of aircraft, which would later earn recognition as some of the World's finest military aircraft, first flew in 1935 and 1936. Among the fighters were the British Hawker Hurricane (1935) and Supermarine Spitfire (1936) and the German Messerschmitt Me 109 (1936). A number of bomber prototypes including the British aircraft officially designated the Blenheim, Wellington, Whitley, and Hampden and the German ones known as the He 111 and Ju 86, also appeared in 1936 (Gibbs-Smith, 1970:203).

Like their American counterparts, many of these aircraft had aluminum stressed-skin shell structures made from intricate assemblies of skin, ribs, spars, and stringers, further complicated by the practical necessities for cut-outs and access holes. Such structures, of course, are not amenable to precise solution since the usual methods of stress analysis are based on certain mathematical idealizations, which are not directly applicable to practical situations. Although proper interpretation of results obtained from idealized analyses can provide guidance in resolving important practical problems, structural engineers were often unable to calculate structural behavior to the required levels of accuracy. In recognition of this fact, engineers would design and build major structural components, such as a wing or fuselage, with guidance from the best calculations they could perform. The component was then tested and, if necessary, redesigned in accordance with test results. Satisfactory structures were developed by repeating this design/testing sequence, but it was a costly and time consuming operation (Gray, 1948:179–204).

In 1936, Paul Kuhn, an engineer with the NACA at Langley Field, became interested in the way in which deformation affected the distribution of stresses in a stringer-stiffened box beam. Kuhn noted that the stresses in the skin were highest at the spars and became progressively less with each intermediate stringer. Thus, the first intermediate stringer next to a spar was more highly stressed than the second intermediate stringer and so on to the center stringer, which carried the smallest stress. Interpreting this behavior to be attributable to the shear deformation of the skin, Kuhn developed the so-called "shear lag theory." (Gray, 1948:185).

Between 1936 and 1943, Kuhn refined his shear lag theory, publishing his results in a total of seven technical papers and showing its applicability to structural elements around cut-outs and access holes. During this time, American engineers specializing in aircraft structures were finding that the accuracy of the new approach saved them the time and expense of repetitive testing. Shear lag theory was a great improvement over previous methods of analysis (Gray, 1948:185).

When expansion of the NACA was authorized in 1939, funds became available to begin construction of a structures research laboratory, which was completed and occupied in October 1940 (Gray, 1948:193). Following in the NACA traditions that had made the agency so effective in aerodynamics, the laboratory and its staff concentrated on the issues fundamental to sound structural practice. Analytical results, backed up with experimental evidence, were summarized in the form of convenient graphs and presented in carefully edited NACA Technical Notes. The information presented in these TNs was exceptionally reliable and was accepted without question by structural specialists throughout the industry.

With few exceptions, aircraft throughout World War II were fabricated from select aluminum alloys, but the postwar emphasis on supersonic flight forced engineers to assess the potential of materials previously considered undesirable for flight application. Modern metallurgy, which had been in an embryonic stage at the turn of the 20th century, had developed into a scientific discipline. New alloys were constantly being added to the inventory of available materials. Many of these materials, notably magnesium, K-monel, Inconel X and Titanium, exhibited properties that were considered superior to those of aluminum for sustaining high temperatures during flight. Each was flight-qualified and performed satisfactorily. More recently, a class of materials known as filament-reinforced composites have attracted interest as candidates for use in design of secondary structure. These materials are in the early stages of flight qualification proceedings with some already in use on high performance military vehicles. More extensive application of composite materials in aircraft structures is anticipated.

With the advent of electronic computers in the post-World War II era, engineers joined in the general movement to extend consideration to realistic structural arrangements not amenable to solution by conventional means. Originating in the mid-fifties as a process of structural analysis, the finite-element method has since been recognized as a versatile tool for treating a variety of complex engineering situations. In essence, the finite element method permits a realistic structure with infinite degrees of freedom to be approximated by an assemblage of subregions (or elements) each with a specified but finite number of unknowns. Each element interconnects with others in a way familiar to engineers. The simplicity with which the method can be used to model complex realistic structures has undoubtedly contributed to its wide acceptance (Zienkiewcz, 1971: vii). This method is now in general use throughout the industry.

Biographic Sketches

Lawrence Hargrave

1850–1915

Development of the box kite as a precursor of early biplanes

Lawrence Hargrave was born in Greenwich, England, but emigrated to Australia at the age of sixteen. After serving an apprenticeship with an engineering firm he explored for several years in New Guinea. In 1877 he was appointed an assistant at Sydney Observatory, a position he held until 1885 when he resigned to pursue his interest in aeronautics.

Working on his own, with a limited income, Hargrave originated the box-kite design, which was remarkably stable with great lifting power. While visiting England with his family in 1899, he delivered a paper on his kites to the Aeronautical Society in London and presented some of them to the Society for testing. Although Hargrave's box-kite designs attracted considerable interest and were published in the leading aeronautical journals, they were not acted upon for some time.

Hargrave was greatly handicapped by his remote location, but he corresponded with many of the leading aeronautical enthusiasts in Europe and with Octave Chanute in America. He was certainly one of the great aviation pioneers of history.

References: Charles H. Gibbs-Smith, *Aviation,* Her Majesty's Stationery Office, London, 1970; Raymond J. Johnson editor, *Above and Beyond,* New Horizons Publishers Inc., 1968.

Robert Esnault-Pelterie

1881–1957

Engineering advances which greatly influenced the course of aircraft development

Robert Esnault-Pelterie is remembered principally for his achievements in aviation, although he was one of the earliest pioneers of flight to recognize astronautics as a natural extension of aeronautics. The son of a textile manufacturer, he was born in Paris. He earned his degree in science at the Sorbonne in 1902 and immediately entered the budding field of aviation.

Known to many as "REP," he was responsible for many innovations which became standard components on aircraft. He was among the first to advocate metal aircraft, designed an early predecessor to the twin bank radial engine, and proposed a theory for metallic propellers. Perhaps best known for introducing the aileron, REP was constantly concerned with pilot safety and held patents for devices such as safety belts, speed indicators, dual controls for pilot instruction, and static testing of airframes.

An early advocate of astronautics, REP presented a report concerned with interplanetary travel to the Société Française de Physique in 1912. A reputable work, the report published by the *Journal de Physique* was edited ruthlessly, drastically distorting the original manuscript. He experimented with rocket fuels and reaction motors, but could not convince funding authorities of the value of his work. Much of his work anticipated the future of space exploration, yet REP retired to Switzerland unknown and misunderstood.

References: Charles H. Gibbs-Smith, *Aviation,* Her Majesty's Stationery Office, London, 1970; Raymond J. Johnson, editor; *Above and Beyond,* New Horizons Publishing, Inc., 1968; Robert Esnault-Pelterie, manuscript in Biographical Files, National Air and Space Museum, Smithsonian Institution, Washington, D.C.

Glenn Hammond Curtiss

1878–1930

Achievement in design and construction of aircraft and outstanding contributions resulting in the flying boat

Glenn Hammond Curtiss did more to popularize aviation and establish it as an industry than any other contemporary American. Born in Hammondsport, New York, Curtiss' life was little influenced by his parents, for his father died in 1880 and his mother remarried and left Curtiss' upbringing to his grandmother. Although his education was minimal, he excelled in mathematics.

A cycling enthusiast and competitor, he held several menial jobs before opening a business for the manufacture and repair of bicycles. Adapting a gasoline engine to a bicycle, he earned a national reputation as a motorcyclist before becoming interested in aeronautics. Curtiss became convinced of the future of aviation while delivering an engine to Alexander Graham Bell. Along with Bell, he was a founding member of the Aerial Experiment Association. Curtiss built his first aircraft, the *June Bug* in 1908 and won the Scientific American Trophy with it. In January 1911, Curtiss introduced the first practical seaplane in history. He subsequently fitted wheels to it, creating the first amphibian, and went on to become the world's leading pioneer and promoter of seaplanes.

With the outbreak of World War I, Curtiss accepted an order from England to produce "Curtiss Jennies." He moved his company to Buffalo, but kept open his plant in Hammondsport for experimentation. Following the war, Curtiss turned to non-aviation pursuits, but continued to serve on the board of Curtiss Aeroplane and Motor Company as an advisor on aircraft designs. He died in Buffalo from complications resulting from an appendectomy.

REFERENCES: Beckwith Havens, "A Synopsis of the Life of Glenn H. Curtis," in Raymond J. Johnson, editor, *Above and Beyond,* New Horizons Publishers Inc., 1968; Charles H. Gibbs-Smith, *Aviation,* Her Majesty's Stationery Office, London, 1970.

Louis Breguet

1880–1955

Creative engineering in design of the oleo strut and early application of metals in aircraft construction

An aeronautical pioneer whose name is synonymous with the development of French aviation, Louis Breguet maintained a family tradition of excellence in engineering. Born in Paris, Breguet graduated from the École Supérieure d'Électricité de Paris as an electrical engineer. Upon graduation, he entered the family business, which specialized in construction of electric motors and steam turbines. The exploits of the Wright brothers, however, soon attracted his attention. Turning to aeronautics, he designed an electrically actuated aerodynamic balance in 1906.

Experiencing limited success with a helicopter he designed and built in 1907, Breguet turned to conventional aircraft. By 1909 he designed and built his first airplane, an awkward tractor biplane. Although his 1909 aircraft was not too influential, Breguet continued and, in 1910, introduced a far superior vehicle, which established the tractor biplane as a rival to pusher aircraft. In 1911 he founded his company, the Société Anonyme des Ateliers d'Aviation Louis Breguet. Military contracts during World War I assured the success of his company, and many of the vehicles he produced proved to be highly effective throughout the war. In 1919, Breguet founded an air transportation company, the Compagnie des Messageries Aerienne, that later developed into the Air France Aviation Company.

Breguet remained one of the leading aircraft manufacturers in France until World War II and prepared numerous technical papers and reports. In addition to his other aeronautical activities, Breguet is credited with development of the oleo strut and the celebrated range equation that bears his name.

REFERENCES: Obituary, *The New York Times,* 5 May 1955; *Enciclopedia de Aviacion y Astronautica,* Edicions Garriga, volume 2, 1972; Tre Trycare, *The Lore of Flight,* Cagner and Co., 1970; Raymond J. Johnson, editor, *Above and Beyond,* New Horizons Publishers Inc., 1968.

Louis Bechereau

1880–1970

Introduction of monocoque construction in aircraft design

Louis Bechereau introduced the first practical streamlined fuselage to use a load-carrying skin when he designed the Deperdussin racer in 1912. The fuselage structure, designated "monocoque" (single shell) had no internal stiffening, a characteristic which, though short-lived, represents a major step toward general acceptance of "semi-monocoque" construction.

A 1903 graduate from École d'Arts et Métiers d'Angers, France, Bechereau co-founded the Société de Construction d'Appareils Aériens with Clément Ader's nephew. In 1909, he received a visit from Armand Deperdussin which resulted in Bechereau's joining the Société pour les Appareils Deperdussin (SPAD) at Bethany, near Rheims. While with this company, Bechereau designed a series of racing aircraft, which stand among the most significant prewar types. When Louis Blériot acquired the company in 1913 and changed its name to Société Anonyme pour L'Aviation et ses Derives, Bechereau stayed with the firm.

During World War I, Bechereau designed the famous SPAD fighters used by the Allies. Shortly after the war, Bechereau left SPAD to found, with Marc Birkigt and Adolphe Bernard, the Société des Aériens Bernard, but he shortly moved on to the Salmonson Motor Company. He later founded the Kellner-Bechereau Company, which engaged in design and construction of racing aircraft. Bechereau's last racing aircraft was the ill-fated Kellner-Bechereau racer.

REFERENCES: T. G. Foxworth, *The Speed Seekers,* Doubleday and Company, 1977; *Enciclopedia De Aviacion y Astronautica,* Edicions Garriga, volume 2, 1972.

Sir Geoffrey de Havilland

1882–1965

Creative design of military and commercial aircraft and development of the first long-range jet transport

Geoffrey de Havilland's working career in aeronautics extended over half a century and brought him recognition as one of the world's greatest contributors to aviation. Knighted in 1944, de Havilland was the son of a parson whose family came from Guernsey, England. He was educated at St. Edwards, Oxford, and Crystal Palace School of Engineering before launching his career as a designer with London's motor industry. It was in 1908, when de Havilland was twenty-six and newly married, that he left the motor industry intent on building an airplane to fly.

With monetary support from his grandfather he built his first aircraft, a biplane powered by a 45-horsepower engine of his own design. Undaunted after the aircraft crashed on its first flight, de Havilland redesigned it around the same engine and taught himself to fly with the new machine. By the end of 1910, de Havilland had joined the Army balloon factory at Farnborough as a designer and pilot. Here he developed his own aircraft, renamed it the Farman Experimental No. 1, and later the F.E.2. While at Farnborough, he was also responsible for the Blériot Experimental No. 1, the BS-1, and the B.E. No. 2.

In 1914, de Havilland joined the Aircraft Manufacturing Co., Ltd., at Hendon as a chief designer and pilot. His first design with the company was the D.H. 1, a two-seat biplane fighter that started a long series of aircraft with the D.H. designation. Throughout the war with Germany, de Havilland was responsible for designing a number of military aircraft, and his designs dominated the total allied air strength.

Founding the de Havilland Aircraft Company, Ltd. at Stag Lane Aerodome, Edgeware, England, in 1920, de Havilland pioneered development of air transportation. He also entered the field of general aviation with the *Moth* series, which made possible a great interest in private flying. With the Second World War, de Havilland again returned to the design of military aircraft with the *Mosquito,* an outstanding high-speed general-purpose aircraft, and also entered the jet-engine and jet-fighter field. De Havilland's interest in jet aircraft continued after the war with introduction of the world's first jet airliner, the D. H. 106, *Comet.*

Geoffrey de Havilland lost two of his three sons in test flying, the youngest, John, in a *Mosquito* collision in 1943, and the oldest, Geoffrey, in high-speed flight research while a test pilot with his father's company.

REFERENCES: *The Guggenheim Medalists,* The Guggenheim Medal Board of Award, 1964; Charles H. Gibbs-Smith, *Aviation,* Her Majesty's Stationery Office, London, 1970; Raymond J. Johnson, editor, *Above and Beyond,* New Horizons Publishers, Inc., 1968.

Sir Charles Richard Fairey

1887–1956

Creative engineering in the early use of flaps and distinguished leadership in pioneering advances in variable pitch propellers and stressed skin structures

Perhaps best known for his accomplishments as founder and executive chairman of the Fairey Aviation Co., Ltd., Fairey was a capable and talented designer. The only son of a large Victorian family, Charles Richard Fairey was born at Hendon, England. He attended public school but when the death of his father, a city merchant in comfortable circumstances, left the family virtually penniless, Fairey went to work with the Jandus Electric Company. He covered his own expenses while attending night school at Finsburg

Technical College where he qualified as an electrical engineer.

Fairey's interest in aeronautics dates to 1910 when he won an airplane model competition with a monoplane model of his own design. The model inadvertently infringed on an earlier patent by John W. Dunne and the infringement led to a meeting with Dunne. In 1911, Fairey took a position with Dunne as manager of the Blair Atholl Syndicate, where he had the good fortune of working with leading aeronautical authorities. In 1913, Fairey joined the Short brothers as chief engineer. When war broke out, he registered The Fairey Aviation Company, as required by British law, in 1915. His first contract to build a dozen Short seaplanes was followed with an order to build 100 Sopwith 1½ Strutters. In June 1916, Fairey produced and patented the variable camber wing, which was the first use ever made of a trailing edge flap to increase lift. The first airplane to be designed and built by the company was a twin-engined fighter, the F2. This aircraft was the first of an unbroken chain of Fairey aircraft, which included such significant vehicles as The Fairey *Hamble Baby,* the *Fox I* day bomber of 1926 and the Fairey *Delta 2,* which set a world's speed record in 1956.

Awarded many honors in his career, Fairey was the director-general of the British Air Commission in Washington. He was knighted in 1942 for his work in this capacity.

REFERENCES: Anonymous, "Sir Richard Fairey," *Flight*, 5 October 1956; J. Laurence Pritchard, "Sir Richard Fairey—An Appreciation," *Journal of the Royal Aeronautical Society,* December 1956; Raymond J. Johnson, editor, *Above and Beyond,* New Horizons Publishers, Inc., 1968.

Anthony Fokker

1890–1939

Innovative engineering in aircraft design and significant contributions to passenger air transportation

Inventive, wealthy, and endowed with an able business sense, Anthony Fokker became a world-renowned aircraft designer and manufacturer. The son of a wealthy Dutch coffee planter, Fokker was born at Kedivi, Java, but returned with his family to Haarlem, Holland. A poor student in all subjects except physics, he convinced his father to send him to an aviation school at Salbach, Germany.

Fokker designed and built his first airplane in 1910, before teaching himself to fly. Within two years he had set himself up as a designer and manufacturer of military aircraft. In search of customers, Fokker offered his services to several countries, but only the German War Ministry was judicious enough to offer him a contract, which he readily accepted. Moving to Johanesthal Flying Field, near Berlin, he established his first aircraft factory. Within a few months he built a second factory at Schwerin, Mecklenburg.

With the outbreak of war, Fokker's fame as an aircraft designer and manufacturer soared. In 1915, Fokker's company was commissioned to produce the synchronized machine gun and later, the cantilever wing, which was used successfully on the D-VII, an aircraft that has been called the best German fighter of the war. With the cessation of hostilities, Fokker managed to get his equipment out of Germany and established the "Nederlandsche Vliegtwigenfabriek" (Dutch Aircraft Works) at Amsterdam, which soon became one of the leading producers of aircraft in Europe. Although Fokker continued to design and manufacture military aircraft, he also reacted to the growing needs of several newly founded airlines. In 1922, Fokker came to America and founded the Atlantic Aircraft Company. He later became president of the Fokker Aircraft Company of America, which subsequently changed its name to General Aircraft Company of America and then to General Aviation Corporation. He later left the Corporation and concentrated on selling American-built aircraft built by Douglas and Lockheed to European nations.

Fokker's activities in promoting commercial passenger travel have earned him a prominent place in aviation history. His trimotor aircraft was the foundation on which Royal Dutch Airlines was built.

References: A. R. Weyl, *Fokker, the Creative Years*, Putnam and Company Ltd., 1964; Raymond J. Johnson, editor, *Above and Beyond*, New Horizons Publishers, Inc., 1968; Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970.

Reinhold Platz

1886–1966

Innovative design leading to significant improvement in air frame structures and fabrication practice

An instinctive designer without formal training in design methodology, Reinhold Platz acquired an extraordinary sense of practical stress analysis by careful observation and experience. Platz was born at Cottbus, in the province of Brandenburg, near Berlin, and apprenticed as a gas welder. In 1905, when the Fouche acetylene-oxygen process of fusion welding was introduced in Germany, he learned the technique and experimented with its application.

Platz joined Fokker's company at Schwerin in 1912 as a welder. He later became the designer of the historic Fokker fighters of World War I and of the famous Fokker transports. When German Army authorities found fault with the performance and structural reliability of Fokker's airplanes, Platz was given the opportunity to try his hand at design of a new aircraft. Within weeks he designed a revolutionary biplane with cantilever wings, which became known as the V type, a designation reflecting the fact that no external bracing with struts and cables was employed. The cantilever wings were integral structures consisting of wooden box spars and wooden ribs covered entirely with plywood. The design features of Platz's wing were new to the Fokker firm, but soon became a hallmark of the company.

Although Fokker is recognized as an individual who withheld needed design information from his employees, it appears that he and Platz mutually inspired each other. It was Platz, however, who, tireless in pursuit of simplicity, evolved the structural concepts and fabrication techniques that resulted in superior aircraft. The Platz-designed D-VII has been called the finest aircraft of the First World War.

References: A. R. Weyl, *Fokker, the Creative Years*, Putnam and Company, Ltd., 1965; Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970.

Hugo Junkers

1859–1935

Pioneering work in aircraft structures and all-metal construction

Hugo Junker's concepts of the internally braced cantilever wing, which carries through or under the fuselage structure, and use of all-metal construction are embodied in virtually all modern aircraft. He was born, the son of a mill-owner, at Rheydt, Germany, and educated at the technical institutes of Berlin, Karlsruhe, and Aachen. Long before entering the aircraft industry, Junkers had earned an international reputation for his theories on internal combustion engines. In 1890, he established a company to make experimental gas engines, and later founded the Junker's Flugzeugwerk.

Junker's first aircraft patents were granted in 1910 for a tailless flying wing. In 1915, Junkers built the J-1, an all-metal aircraft made with corrugated sheet steel. The material of construction was changed to aluminum in 1916. The Junkers' aircraft factory was closed by the Treaty of Versailles in 1919, but opened again a year later. Entering the field of commercial aviation, Junkers' air service operated from 1921 until taken over by Lufthansa in 1925. A subsidiary factory was opened in Moscow in 1920 and another in Sweden. By 1930 Junkers' aircraft were used by many of the world's airlines.

Junkers retired from active management of his company in 1932 to devote himself to scientific interests. Among Junkers' accomplishments is the Junkers' "Jumo" diesel engine, which was one of the first diesels used successfully for aircraft.

Junkers died at Gauting, not far from Munich, on his birthday (3 February), at the age of 76.

REFERENCES: Anonymous, "Hugo Junkers," *Flight*, 7 February 1935; Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, 1970; Raymond J. Johnson, editor, *Above and Beyond*, New Horizons Publishers, Inc., 1968.

Adolf Rohrbach

1889–1939

Significant advances in aircraft structures including introduction of the stressed-skin concept

Adolf Rohrbach revolutionized the practice of aircraft structural design with his concept for stressed-skin construction in which the metal skin of an aircraft carries a significant part of the load. Born in Gotha, Germany, Rohrbach attended the Classical Schools at Gotha and Coburg before studying shipbuilding and receiving his engineering diploma from the Technische Hochschule Darmstadt. He then joined the firm of Blohm and Voss, but his interest changed from ships to aircraft. Shortly before the war he went to work for the Zeppelin-Werke, Berlin-Staaken, as an airplane designer. He remained with the Company from 1914 to 1921, during which time he produced the all-metal Staaken transport planes. In 1920, however, the Interallied Aeronautical Commission ordered that the planes be destroyed, with the result that the Staaken plants were closed. Earning his degree as a Doctor of Engineering from the Technische Hochschule Berlin-Charlottenburg in 1921, Rohrbach founded the Rohrbach Metal Airplane Company. To circumvent the terms of the Treaty of Versailles, Rohrbach established his plant in Copenhagen, Denmark, and specialized in the construction of metal flying boats.

Realizing that the Junkers corrugated metal surfaces produced high drag and could not bear a significant amount of load, Rohrbach, in 1919, started building smooth-skinned metal aircraft with metal box-like construction in the wings. This practice was the beginning of modern stressed-skin construction, in which the primary loads are carried by the wing surfaces. Although stressed-skin construction appeared revolutionary at the time, it became a widely accepted practice and influenced the entire course of aircraft structural design.

With the removal of the Versaille ban in 1927, Rohrbach abandoned the manufacture of military aircraft and concentrated on the Rohrbach-Romar transport planes for the Lufthansa. Rohrbach's lecture in the United States in 1926 helped materially to inspire the revolutionary American transport aircraft of the 1930's. In December 1929, Rohrbach established the Metal Flying Boat Corporation in Delaware, Maryland, but the United States government was unwilling to place orders with his firm, and early in 1931 he returned to Germany. He died of a heart attack at the age of 51.

REFERENCES: Obituary, *New York Times*, 10 July 1939; Anonymous, "Death of a German Pioneer Designer," *Flight*, 13 July 1939; Charles H. Gibbs-Smith, *Aviation*, Her Majesty's Stationery Office, London, 1970.

Claudius Dornier

1884–1969

Pioneering achievements in metal aircraft construction and large flying boats

Acknowledged as one of the world's leading pioneers in the manufacture of metal aircraft, Claudius Dornier spent his early career as an engineer involved with construction of metal bridges. Born in Kempton, Germany, Dornier graduated from the Munich Institute of Technology. He was first introduced to the field of aviation when, in 1910, he joined the Graf Zeppelin Company as a structural engineer. As a member of the experimental department his work on the static and dynamic behavior of dirigibles led to an appointment as technical advisor to von Zeppelin. With the outbreak of World War I, von Zeppelin helped him establish the Zeppelin-Werke Lindau GmbH, to construct large flying boats made of light guage metal.

In 1922 he founded Dornier Metalbauten GmbH, the original nucleus of what was to become the Dornier industrial complex. Continuing construction of flying boats at the Marina de Pisa in Italy, he produced the first Dornier Wal in November of 1922. Dornier flying boats of this type were considered the best and safest of their time, a reputation that earned him international recognition. Establishing a factory at Altenshein, Switzerland, in 1926, he began work on the Do-X, an aircraft which was the culmination of his ideas regarding flying boats for international traffic. The Do-X received world acclaim when in 1931, the giant 12-motor airplane flew from Germany to New York carrying 169 passengers.

In a 1932 reorganization, Dornier took full control of his company, changed its name to Dornier Werke GmbH and relocated in Friedrichshafen. He then turned to military aircraft, designing and building an advanced fighter plane in the same year. Two distinctive thin-fuselage, twin-engine bombers, the Do-17 and Do-25, were developed shortly afterward. Dornier's aircraft accounted for much of Germany's Luftwaffe's bomber-reconnaissance fleet during World War II. With the Allied victory, Dornier lost his business and went into brief retirement. He emerged from retirement to work on Swiss VTOL aircraft and worked on STOL aircraft for the Spanish army. He later resumed construction of aircraft in Germany and recreated the Dornier Werke GmbH, but left direction of the company to his children.

Typical elements of Dornier's marine aircraft were his stabilizing floats and tandem motor arrangements. He died in Zug, Switzerland, on 5 December 1969.

REFERENCES: Raymond J. Johnson, editor, *Above and Beyond*, New Horizons Publishers Inc., 1968; *Enciclopedia De Aviacion y Astronautia*, Edicion Garriga. volume 3, 1972.

Nikolai Polikarpov

1892–1944

Notable achievement in development of the first modern monoplane fighter aircraft

Nikolai Polikarpov was born in the township of Georgievsk in the province of Orlovsky, Russia. As the son of a minister he attended the theological seminary in Orlov from 1907 to 1911 and continued his education at the Polytechnic Institute in St. Petersburg. In 1913 he enrolled in the aeronautics course offered in the Department of Naval Architecture. Upon graduation in 1916 he joined the Aeronautics Department of the Russky Baltisky Vagon Zavod (Russo Baltic Wagon Factory), where he helped put the Sikorsky S–16 into production and worked on Sikorsky's Ilya Murometz.

Sent to the Duks factory in Moscow in 1918, after the revolution in Russia, he was assigned the task of organizing for production foreign-designed aircraft, including the French Spad VII. Polikarpov subsequently assumed direction of the company that came to be known as the State Aeronautics Factory No. 1. Named director of the design bureau of land aircraft in 1925, Polikarpov initiated work that led to production of some of the first Soviet designed aircraft. Polikarpov's successful designs of the mid-1920's led to his selection with Dimitri Grigorovich to design a new fighter aircraft in 1927. When, in 1929, their progress failed to satisfy the authorities, the two designers and their staff were placed in detention in a hanger of Factory No. 39 with orders to produce the fighter prototype. Design and production of two prototypes, designated the VTII, was completed in just over eight months.

Regaining political respectability in 1933, Polikarpov began design of two fighters, which proved to be highly successful. His TsKB-12 represented a major advance in Russian fighter aircraft. A low-wing monoplane with fully retractable landing gear, it was the first fighter aircraft to incorporate features that would later become standard characteristics of modern fighters. Designated the I-16, it entered service in 1934 and earned the distinction of a superior vehicle during the Spanish Civil War.

Polikarpov was signally honored by the Russian government for his contributions to Soviet flight technology.

REFERENCES: *Enciclopedia De Aviacion y Astronautia*, Edicion Garriga, volume 6, 1972; Nowarra and Duval, *Russian Civil and Military Aircraft*, Fountain Press, Ltd., 1971.

Alfred Verville

1890–1970

Pioneering contributions to aircraft design

Much honored as an "elder statesman" of American aeronautics, Alfred Verville rose to a position of international leadership in aircraft design. A native of Atlantic, Michigan, Verville attended Adams Township High School and, from 1907 to 1910, took a correspondence course in electrical lighting and railways operation. Becoming interested in aviation in 1914, Verville went to the Curtiss Aeroplane Company in Hammondsport, New York, to learn to fly. His unique perception of the mechanical and aerodynamic features of flight was quickly recognized. Accepting a position as engineer and design-draftsman with Curtiss, Verville took an active part in developing the transatlantic flying boat *America* and the Curtiss *Jenny* of World War I fame.

In 1922, Verville toured Europe with General Billy Mitchell, then assistant chief of the U.S. Army Air Service to study the development of European aviation. Returning to the United States, Mitchell requested Verville to design an aircraft devoid of external wire bracing. Verville's aircraft, a monoplane with thick low wings and then-revolutionary retractable landing gear, was an outstanding success. Later described by a panel of aviation leaders as one of the world's 12 most significant aircraft, the U.S. Army Verville-Sperry airplane won the Pulitzer Speed Trophy in 1923. It provided direction for subsequent development of military fighter aircraft.

Verville designed and built a number of highly successful aircraft before joining the Bureau of Air Commerce (now the Federal Aviation Administration) in 1933. While with the Bureau he was, successively, aeronautical engineer, chief of the Manufacturing, Engineering and Inspection Service, and finally assistant chief of the Aeronautic Development Section. In 1945 he joined the Navy Department in Washington. From 1950 until he retired in 1961, Verville was technical advisor and consultant to the director of the Technical Data Division, U.S. Bureau of Aeronautics. He was also a consultant for Douglas and Curtiss-Wright aviation companies during his long professional career.

Reference: "Alfred Verville," manuscript in Biographical Files, National Air and Space Museum, Smithsonian Institution, Washington, D.C.

Fred E. Weick

1899–

Major achievement in lightplane design including the NACA cowl and steerable tricycle landing gear

A native of Chicago, Illinois, Fred E. Weick's efforts to improve lightplane safety have led to major design advances. Weick was educated at the Armour Institute of Technology and University of Illinois where he earned his Bachelor of Science degree in 1922. Upon graduation he began his professional career as a draftsman with the U.S. Air Mail Service. In 1923 he was superintendent of the Yackey Aircraft Company, but left to design propellers for the Bureau of Aeronautics. Joining the National Advisory Committee for Aeronautics as a research engineer in 1925, Weick became involved with a program to reduce the drag resulting from air-cooled engines. At the time, most American aircraft were equipped with air-cooled engines, and it was common practice to ignore the drag in order to assure adequate cooling. Placed in charge of the propeller research tunnel, Weick conducted an exhaustive series of tests which ultimately led to the NACA low drag cowl. Announced in a Technical Note in 1928, the cowl not only reduced drag, it promoted more efficient cooling.

Weick left NACA in 1929 to become chief engineer of Hamilton Aeronautical Manufacturing Company, but returned to NACA in 1930 as assistant chief of the Aerodynamics Division. In this capacity, he was the guiding force behind development of the W-1, a small airplane for private owners designed as a private venture. The W-1 was equipped with a tricycle undercarriage to make take-off and landing easier and prevent nose over. Other private plane manufacturers adopted the tricycle undercarriage in the mid-1930's and, after successful application on the DC-4E in 1938, all American airliners were designed with tricycle landing gear.

Weick again left NACA in 1936 to become chief engineer with the Engineering and Research Corporation and develop a commercial version of the W-1. Weick's most widely recognized achievement, the *Ercoupe* grew out of this association. The first production model of the *Ercoupe* was ready in 1940, but the war blocked further development. After the postwar lull caused the company serious financial problems, Weick was called to Texas A & M University to set up an aircraft research center. He concentrated his efforts on development of the revolutionary Ag-1 crash-proof agplane. This agricultural airplane and the Piper *Pawnee* that evolved from it set life-saving standards of lasting benefit to the entire agplane industry.

REFERENCES: Richard B. Weeghman, "Living Legends, Fred E. Weick," *Flying*, June 1976; R. Miller and D. Sawer, *The Technical Development of Modern Aviation*, Praeger Publishers, 1970.

Grover Loening

1888–1976

Creative engineering in design of the strut-braced monoplane and amphibious aircraft

A graduate of Columbia University, Grover Loening was awarded his Bachelor of Science degree in 1909 and in the following year received the Master of Arts degree in aeronautics, the first ever conferred in this country. In 1911 he graduated from the same institution with a degree in civil engineering. Born in Bremen, Germany, where his father was consul-general, Loening began his professional career as chief engineer of the Queen Aeroplane Company in 1911. He later was hired as Orville Wright's assistant and manager of the Wright brothers' Dayton, Ohio, factory. In 1914 Loening was appointed chief aeronautical engineer of the Aviation Section of the Army Signal Corps. A year later, he became vice-president of the Sturtevant Aeroplane Company and pioneered American use of steel frame aircraft. The next year he formed the Loening Aeronautical Engineering Corporation to work on two government contracts. The first was a Navy contract for a small plane to be launched from destroyers and the second, an Army contract for the M-8 Pursuit monoplane, which embodied use of rigid strut bracing that he patented.

Following World War I, Loening produced the *Flying Yacht*, a five-seat monoplane boat, which established world records. This project won Loening the coveted Collier Trophy in 1921. Within three years he introduced the *Loening Amphibian*, a daring metal design capable of taking off and landing on either land or water. The *Loening Amphibian* was adopted by both the U.S. Army and Navy.

Loening's pioneering activites in all facets of aeronautics won for him numerous awards and honors. He is a member of the Aviation Hall of Fame.

REFERENCES: *The Guggenheim Medalists*, The Guggenheim Medal Board of Award, 1964; *National Cyclopedia of Biography*, volume B, 1978; Raymond J. Johnson, editor, *Above and Beyond*, New Horizons Publishers, Inc., 1968.

Edwin A. Link

1904–

Invention and development of flight simulators

A creative inventor whose name is synonymous with flight simulators, Edwin Link was born in Huntington, Indiana, but subsequently located in Binghamton, New York. He was educated at Binghamton Central High School and the Belefonte Academy in Pennsylvania, before attending Lindsley Institute in West Virginia. Link learned to fly at the Binghamton airport and eventually qualified as a flight instructor.

Concerned about the high cost of flight training, Link built his first "pilot maker," a mechanical device with a stubby wooden fuselage mounted on a universal joint and actuated by organ bellows obtained from his father's factory. The bellows simulated pitch and roll as the trainee "flew" the trainer. It was soon being used in the flying school operated by Link and his brother, George, and substantially reduced the cost of flight training. It didn't sell immediately, however. Hard hit by the Depression, Link engaged in a variety of flying activities until, in 1934, the Army Air Corps placed a small order for his simulators. This order helped to start Link's flight simulator business.

Founding Link Aviation Devices, Inc., to manufacture and sell flight-training equipment, Link entered the field of flight simulation just two years before the United States entered World War II. With the outbreak of war, Link's company flourished with orders from both the Army and the Navy. His simulators were used to train more than half a million airmen.

In the postwar lull, Link expanded his operations, undertaking contracts for an aviation trainer, special radio aids, and flexible gunnery trainers. He also built the famous C-11, the first jet trainer, and later the B-47B, the world's first jet bomber simulator. Far removed from Link's earlier devices, these simulators were computer-driven replicas of the cockpits of the aircraft being simulated. Each was equipped with the latest simulated radio aids and navigation equipment. Duplicate cockpit instruments and facilities for introducing a number of hazardous emergency flight conditions and malfunctions were incorporated.

Link's simulators are also very much a part of the space age. His company was heavily involved in the development of Apollo mission simulators and lunar module mission trainers used by NASA during astronaut training.

In 1959 Link relinquished control of the organization to devote more attention to such other interests as deep sea submersibles.

REFERENCES: "Edwin Link," manuscript in Biographical Files, National Air and Space Museum, Smithsonian Institution, Washington, D.C.; John D. Barlage, "From Pilot Maker to Multimillionaire," *Naval Aviation News*, December 1968.

Elmer Ambrose Sperry, Sr.

1860–1930

Significant contributions to aircraft instrumentation

A prolific inventor and pioneer in the field of applied electricity, Elmer Ambrose Sperry, Sr., was granted over four hundred patents during his professional career. As an only child, Sperry was born to Stephen Decater Sperry and his wife Mary in Cortland, New York. Sperry was reared by his widowed aunt, Helen Sperry Willet, after his mother died during his birth. He attended classes at the State Normal School and proved a good student with an intense interest in electricity. While still attending Normal School, Sperry visited nearby Cornell University and enrolled as a special day student for the year 1879–1880. Adept with mechanical devices Sperry's inventive career began with contributions in the field of electrical machinery, specifically, dynamos and arc lamps. He eventually experimented with gyroscopic compasses and stabilizers for ships. In 1910, the Navy adopted his gyrocompass, a contract that guaranteed the economic stability of the Sperry Company.

In 1913 Sperry devised an award-winning aircraft gyro-stabilizer. Within four years he invented the Gyro Turn Indicator, which is considered by many to be the greatest flight safety instrument in aviation history. To this instrument was later added a ball in a curved tube, which acted as a bank indicator. The directional gyro and gyro horizon were added later to form an instrument cluster in use on every airplane flying today. James Doolittle first put this combination to test when he made history by making the first "blind" take-off, flight, and landing in an airplane.

Although the gyro-stabilizer did not find application directly to the airplane, it survives in modified form as the Sperry auto-pilot. It was the forerunner of all subsequent auto-pilots and has become standard equipment on all large aircraft, both civil and military.

A recipient of many honors and awards, Sperry was twice awarded the Collier Trophy, in 1914 for gyroscopic control and, in 1916, for his drift indicator. Under his able direction the Sperry Gyroscope Company blossomed into a research and development giant, the Sperry Rand Corporation.

REFERENCE: J. Hunsaker, *Biographical Memoir of Elmer Ambrose Sperry*, National Academy of Sciences, 1954.

James Doolittle

1896–

Professionalization of flight testing

Destined for a career marked by extraordinary versatility, James Doolittle was born in Alameda, California. Soon after his birth, his parents relocated in Alaska where he lived until he was eleven. He returned to California, completed his secondary education in Los Angeles, and entered the University of California. With America's entry into World War I, Doolittle interrupted his education after three years at the University and enlisted in the Signal Corps as an aviation candidate. He displayed such a talent for flying that he was assigned as a flight instructor after winning his wings at Rockwell Field, California. He continued his studies after the war and upon completion of the Aeronautical Engineering School at McCook Field, was awarded his Bachelor of Arts degree from the University of California in 1923. Doolittle entered the Massachusetts Institute of Technology the following year for special engineering courses and graduated in 1924 with a Master of Science. In 1925 he earned his Doctor of Science in aeronautical engineering from the same school.

During his assignment at MIT he also served on temporary duty at McCook Field. While there, he conducted flight tests on aircraft acceleration that resulted in rewriting the strength specifications for fighter aircraft. After flying demonstration tests in South America, Doolittle was sent to Mitchell Field in 1928 at the request of the Daniel Guggenheim Fund for the Promotion of Aeronautics to assist in fog flying experiments. As part of this assignment, Doolittle first demonstrated "blind" flying in an experimental plane equipped with an artificial horizon and directional gyroscope. He later pioneered in the development of 100 octane gasoline.

Recalled to active service in 1942, Doolittle organized and carried out a daring operation, which bombed the Japanese mainland from carrier-based B-25 bombers. Doolittle was later assigned to duty with the 8th Air Force in England and was named to command the 12th Air Force in Africa. In 1943 he became commanding general of the 15th Air Force and in 1944 commanding general of the 8th Air Force in the European Theater of Operations.

Retiring from active duty in 1946 with the rank of Lieutenant General, Doolittle returned to Shell Oil Company as vice-president. He has received many honors and awards for his aeronautical activities but is recognized here for his outstanding contributions to flight testing.

REFERENCES: *The Guggenheim Medalists*, The Guggenheim Medal Board of Award, 1964; W. B. Courtney, *Through Hell and High Brass*, Colliers, 1948; *News Release*, National Aeronautics Association, 18 May 1955.

Sir Sydney Camm

1893–1966

Creative design of fighter aircraft

Praised as "the man whose aircraft saved Great Britain," Sydney Camm was a recognized authority on fighter aircraft design. Born in Windsor, Camm became an aviation enthusiast while a schoolboy, forming, in 1912, the Windsor model airplane club. In 1914, he joined the Martinsyde Company as an apprentice and went through all the shops, acquiring a solid technical foundation. He eventually found his way into the drawing office where his talents attracted the attention of G. H. Handasyde, designer of Martinsyde aircraft. For two years these men worked together, until Camm joined the Hawker Aircraft firm as senior draftsman in 1923. Within two years, Camm became chief designer for Hawker.

During his career with Hawker, Camm designed a number of highly successful fighter aircraft including the *Cygnet*, the *Fury*, the *Hart*, and the *Osprey*. From these was developed the first of the great Camm monoplanes, the *Hurricane*, which accounted for more enemy aircraft during the Battle of Britain than all other British aircraft combined. Camm followed up with the *Typhoon*, the *Tempest*, and the *Fury*.

In the postwar years Camm mastered jet fighter design with the *Seahawk*, the P.1001 and the *Hunter*, before designing the world's first V/STOL fighter bomber, the P.1127. Designated the *Kestral*, it incorporated the revolutionary concept of an engine using rotating nozzles for thrust vectoring. This aircraft achieves at last the perfection of flight. It can hover, back up, land, and take off without need of a long runway and then fly supersonic.

Camm received many awards for his aeronautical accomplishments. He was knighted in 1953.

REFERENCES: Obituary, *Interavia*, 1966; R. H. Chaplin, "Sir Sidney Camm," *Journal of the Royal Aeronautical Society*, volume 70 (August 1966); *Current Biography Yearbook*, H. W. Wilson Company, 1942.

Sir Barnes Wallis

1887–

Creative achievements in developing the technology of geodetic construction and the variable geometry wing

Uniquely responsible for some of the most innovative design advancements in the history of British aeronautics, Barnes Wallis entered aviation by way of the rigid airship. Wallis was born at Ripley, Derbyshire, England, where his father had a medical practice. With the family left in poor financial circumstance when the father was crippled by poliomyelitis, Wallis was educated at Christ's Hospital where he excelled in mathematics and science, but failed to matriculate at the University of London. Deciding on a career in marine engineering, he apprenticed to the Thames Engineering Works, but transferred his indentures to Whites shipyard at Cowes where he became friends with H. B. Pratt. When Pratt was called to Vickers as chief draftsman-airships, Wallis joined him as chief assistant. In 1917, Wallis designed the R.80 praised by some as "the most beautiful airship ever built." By 1922, Wallis had gained the reputation as Britain's outstanding airship designer.

Returning to airship design after a stint teaching mathematics at Chillon College in Switzerland, Wallis designed the successful R.100. In this design, Wallis introduced radically new concepts, including geodetic principles. Wallis had already turned to aircraft design when the crash of the R.101 on 5 October 1930 destroyed for all time Britain's rigid airship program. Still at Vickers, he adapted geodetic construction to aircraft use and developed the *Wellesley* and *Wellington* bombers, both of which proved extremely durable under combat conditions.

Wallis finally gained recognition during World War II, not for design of aircraft, but for weapons systems in the form of special purpose bombs. With the cessation of hostilities, Wallis, now in the capacity of special director and head of a Research Department, turned to variable geometry design. By the summer of 1953 he had proven that use of a swing wing was practical and had demonstrated its performance.

Belatedly honored for his aeronautical achievements, Wallis was knighted in 1968.

REFERENCE: J. E. Morpurgo, *Barnes Wallis, A Biography*, St. Martins Press, 1972.

Edward Heinemann

1908–

Notable accomplishment in design of military and research aircraft

An accomplished designer with an enviable record of successful aircraft, Edward Heinemann earned his reputation without benefit of a formal education. Of German-Swiss extraction, Heinemann was born in Saginaw, Michigan, on 14 March 1908. When he was six the family moved to Los Angeles, where he was graduated from the Manual Arts High School. Attracted to aviation by the record setting flight of the Douglas World Cruisers in 1924, Heinemann joined the Douglas Company in 1926 as a draftsman. After several brief periods with different aircraft companies, he became a designer with Northrop Aircraft Co. in 1930. Six years later he returned to the Douglas Co. as chief engineer.

A Heinemann-designed dive bomber, the SBD *Dauntless* of World War II fame, proved highly effective against the Japanese naval forces. Although too late for World War II, his attack bomber, the AD *Skyraider* became the U.S. Navy's workhorse in Korea. More adaptations have been built from the *Skyraider*'s basic design than from any other aircraft.

Heinemann's design talents were not entirely devoted to design of military aircraft. When the United States entered into a flight research program to explore the problems of supersonic flight, Heinemann designed the D-558 *Skystreak* and the D-558-2 *Skyrocket*. The *Skyrocket* filled the need for a research vehicle to test the behavior of swept wing aircraft in transonic research. It later became the first aircraft to attain Mach 2. Heinemann returned to the design of high-performance military aircraft and produced a successful series of attack bombers and fighters for the Navy.

In 1958, Heinemann became vice president-military aircraft for Douglas. Two years later he joined Guidance Technology, Inc., as executive vice president. In 1962, he became vice president-special projects with General Dynamics Corp., the position from which he retired in 1973.

REFERENCES: F. S. Hunter, "Designer by Intuition," *American Aviation*, 1954; Nomination for Honorary Fellow, The Society of Experimental Test Pilots, R. E. Schleck, June 16, 1977; *News Release*, Douglas Aircraft Company, 21 January 1952.

Reimar Horten

1913–

Walter Horten

1915–

Notable achievements in the technology of flying wing vehicles

Reimar and Walter Horten were born in Bonn, Germany, where their father was professor of oriental sciences and cultures at the University of Bonn. Few details regarding their formal education are available. The two brothers began experiments with flying-wing gliders in 1931, after witnessing a flight of Alexander Lippisch's powered *Delta I* aircraft, while serving an aeronautical apprenticeship at Wasserkuppe. Their first project, a single seat glider, was known as the *Horten I*. It was built in their home at Venusbergweg, Bonn, and established a basic form of construction and aerodynamic form that continued throughout their succeeding designs. Most of the original ideas on tailless aircraft came from Reimar. Walter was more of the political type and had fairly good contacts in the RLM (German Air Ministry).

Both brothers entered the Luftwaffe in 1936, where they were encouraged to continue their design activities. By the time they left the Luftwaffe in 1938, they had completed preliminary work on several flying wing designs, including the *Horton III*, which enjoyed considerable success when flown in contests at Rhön. After a brief stint at the Technical University in Bonn, they returned to the Luftwaffe.

Traditionalists viewed the Horten's unconventional designs with suspicion. The brothers, however, completed design of a jet fighter, which they designated the *Ho IX*, and started construction of a prototype without authority of the RLM. When, in 1944, the RLM became aware of the Horten's unauthorized activity, Reichsmarschall Hermann Göring became intrigued with the *Ho IX* and gave the project his personal backing. After flight tests of a glider version of the *HO IX* proved highly favorable, further development was transferred to the Gothaev Waggonfabrik under the RLM designation *Go. 229*. With Allied occupation of the Friedrichsvoda plant, in 1945, development of the *Go. 229* was terminated.

After World War II, Reimar went to the Republic of Argentina where he worked as a designer in the DINFIA (National Directory of Aeronautical Construction and Investigation). He originally collaborated with Kurt Tank, but soon returned to his own flying wing designs.

Walter Horten returned to the New German Luftwaffe.

REFERENCES: William Green, *Warplanes of the Third Reich*, Doubleday and Co., 1970; Horten, manuscript in Aircraft File, National Air and Space Museum, Smithsonian Institution; *Enciclopedia De Aviacion y Astronautia*, Garrigas Edicion, volume 4, 1972.

Ernest E. Sechler

1905–1979

Notable contributions in airframe structures technology

A distinguished educator and author of several books on airframe structural analysis, Ernest E. Sechler was born in Pueblo, Colorado, on 17 November 1905. He received his engineering education at the California Institute of Technology where he earned a Bachelor of Science degree in engineering, Master of Science degree in mechanical engineering, a Master of Science degree in aeronautics, and, in 1934, a doctorate in aeronautics. He remained with the Institute, attaining the rank of professor and later became executive officer (aeronautics), a position he filled until his retirement.

While a GALCIT graduate student, Sechler reviewed research on structural members fabricated from thin metal sheets. While many engineers predicted such structures would buckle under loading, John Northrop, Theodore von Kármán, and he demonstrated that multicellular construction did not fail when buckled and, indeed, retained almost their full prebuckled strength. This was verified beyond reasonable doubt on Northrop's *Alpha*.

Sechler remained active in structures research, producing numerous papers on shell structures. He served on the Sub-Committee on Structures of the National Advisory Committee for Aeronautics from 1949 until its reorganization as the National Aeronautics and Space Administration in 1958. Sechler was named chairman of NASA's Research Advisory Committee on Structural Design and later chaired NASA's Research Advisory Committee on Space Vehicle Structures.

A recognized authority on missile structures, Sechler was an Air Force consultant. He was also a consultant with several aircraft companies including Thomson Ramo Woolrich Systems, North American Aviation, and Lockheed Aircraft Company.

REFERENCES: *Who's Who in America*, Marquis Who's Who Inc., 1978; Official California Institute of Technology Biography; Hallion, R., *Legacy of Flight*, Washington University Press, 1977.

Robert J. Woods

1904–1956

Pioneering work on supersonic, variable geometry and hypersonic aircraft

Responsible for development of the world's first supersonic aircraft, the Bell X-1, Robert J. Woods was a brilliant designer with a flair for the unconventional. Born in Youngstown, Ohio, he attended the University of Michigan, where he earned both a BS in mechanical engineering and a BS in aeronautical engineering. Upon graduation in 1928, he joined the National Advisory Committee for Aeronautics at Langley Field where he shared the same desk with John Stack, with whom he became a life-long friend. Woods left NACA in 1929 to become assistant chief engineer with the Towle Aircraft Company. He subsequently worked briefly with the Detroit Aircraft Corporation and Lockheed Aircraft Corporation, before joining Consolidated Aircraft in Buffalo. When Lawrence Bell formed the Bell Aircraft Corporation, Woods joined him immediately. While with Bell, his engineering talent flourished and he became chief design engineer and director of the Corporation.

Together with Harlan Poyer, Woods developed the P-39 *Airacobra*, a single seat fighter with the engine mounted behind the pilot, driving a conventional propeller by means of an extension shaft. In 1937, Woods designed the FM-1 *Airacuda*, an unorthodox twin-engine fighter with pusher propellers, which did not enter active Air Corps service. Woods then designed a prototype experimental lightweight fighter, the XP-77 and, in 1943 began development of the XP-83 in an attempt to produce a successful long-range turbojet powered escort fighter.

In a conversation with Ezra Kotcher in 1944, Woods committed the Corporation to produce a research aircraft to investigate flight in the transonic region. When Bell decided to let the commitment stand, a team consisting of Robert Stanley, Benson Hamlin, Paul Emmons, Stanley Smith, and Roy Sandstrom was put to work. The resulting aircraft was the Bell X-1, the first aircraft to fly at supersonic speeds.

Woods continued to contribute to research aircraft with the X-5, the first aircraft to use the so-called swing wing. He also was active in promoting aircraft for hypersonic flight.

REFERENCE: R. Hallion, *Supersonic Flight*, McMillan Company, 1972.

Clarence L. ("Kelly") Johnson

1910–

Innovative application of technology to the development of advanced service aircraft

Named aviation's Man of the Year in 1956, "Kelly" Johnson showed indications of his budding aeronautical talents while still a high school student. A native of Ishpeming, Michigan, he attended the University of Michigan with the aid of academic scholarships. Earning his Bachelor of Science in engineering in 1932 and his Master of Science in engineering the following year, he had so distinguished himself as a student that he had become a consultant with the Studebaker Corporation before completing school.

Hired by Lockheed Aircraft Corporation as a draftsman and stress analyst and after assignments in flight test, aerodynamics, weights and wind tunnel tests, he became chief research engineer in 1938. Johnson had a leading role in the design of 40 of the world's finest aircraft—among them the F-80, America's first production jet, the high altitude U-2, the supersonic F-104 *Starfighter*, and the superb YF-12A and SR-71. Johnson's design achievements also include the *Hudson* bomber, *Constellation* and *Super Constellation* transports, the P-38, and the T-33 trainer.

In 1952 Johnson was named chief engineer at Lockheed's Burbank, California, plant, which later became the Lockheed-California Company. When the office of corporate vice-president, research and development, was established in 1956, he was chosen for the post. In 1958 he became vice-president of advanced development projects.

The holder of numerous design and structural patents, Johnson has received many awards for his unique contribution to aerospace developments.

REFERENCES: *Time*, 20 January 1975; Raymond J. Johnson, editor, *Above and Beyond*, New Horizons Publishers Inc., 1968; Clarence ("Kelly") Johnson, manuscript in Biographical Files, National Air and Space Museum, Smithsonian Institution, Washington, D.C.

James H. Kindelberger

1895–1962

Technical achievement in design and production of military and commercial air vehicles

Known to his friends as "Dutch," James Kindelberger was born in Wheeling, West Virginia. When his father died, Kindelberger left high school to support his family, but continued his studies at night. In 1913, he became a draftsman with the U.S. Army Corps of Engineers and, after three years, entered Carnegie Institute of Technology. He had only been with the University for a year when the United States entered World War I. Kindelberger left school and enlisted in the Army Signal Corps, where he qualified as a pilot and flight instructor.

After the war, Kindelberger returned to the aircraft industry as a designer and chief draftsman with the Glenn L. Martin Company in Cleveland. In 1925, he became chief engineer with the Douglas Aircraft Company in Santa Monica. While in this capacity, he engineered design of the DC-1, the DC-2 and the historic

DC-3, the last of which many authorities consider to be the most successful airliner in history.

In 1934, he became president and general manager of General Aviation Manufacturing Corporation, which later became North American Aviation and relocated in Los Angeles. Under his direction, the company played a major role in producing combat and training aircraft. These included the T-6 *Texan* trainer, the famous P-51 *Mustang*, and the B-25 *Billy Mitchell* bomber used on the historic Tokyo raid. By the time of Japan's surrender, North American had produced more aircraft than any other company in the world.

Although North American diversified its pursuit of high technology in the postwar era, Kindelberger kept the company active in aircraft production. Among others, the company produced the F-86 *Sabre* Jet and its successor, the F-100 *Super Sabre*, the A3J Navy attack bomber, and the X-15 research aircraft. His last contribution to aeronautics was the XB-70 *Valkyrie*.

Kindelberger became chief executive officer and chairman of the board of North American in 1948. He remained as chairman of the board until his death on 27 July 1962.

REFERENCES: *The Guggenheim Medalists*, The Guggenheim Board of Award, 1964; *Who's Who in Aviation, 1942–43*, Ziff-Davis Publishing Company, 1942.

Karel Jan Bossart

1904–1975

Significant contributions to missile and launch vehicle technology

As developer of the *Atlas* missile, Karel Jan Bossart produced the free world's first reliable intercontinental ballistic missile used to launch the Mercury series of manned space capsules without failure. Bossart was born in Antwerp, Belgium, on 9 February 1904. He was graduated from Brussels University in 1925 with a degree in mining engineering. In 1927 he earned a Master of Science degree in aeronautical engineering from the Massachusetts Institute of Technology.

Bossart worked with Sikorsky Aircraft, General Aviation Corp., and the E. G. Budd Company, before joining Convair in 1941 as chief of structures at the company's Vultee Field Division. When Convair was awarded an Air Force contract for study and development of a 5000-mile missile in 1946, Bossart was named project engineer. The following year the Air Force cancelled the contract because of budget difficulties, but Bossart convinced the company to continue development with its own funds. A new contract was awarded in 1951, and Bossart again headed the design team.

In 1953 Bossart was appointed assistant chief of Convair, San Diego, and two years later became chief engineer of the *Atlas* project. He was promoted to technical director of General Dynamics, Astronautics in 1957. He retained this position until his retirement.

Bossart was the recipient of several major awards for his work on *Atlas*.

REFERENCES: *Who's Who in World Aviation*, volume 2, American Aviation Publications Inc., 1958; General Dynamics/Astronautics Biography; Obituary, *The San Diego Union*, 5 August 1975.

Edward Polhamus

1921–

Development of the outboard-pivot which made variable-sweep wings practical

Edward Polhamus, assistant head of the 7 x 10 foot tunnel branch at Langley Research Center, was born in Washington, D.C. A graduate of Woodrow Wilson High School, he attended the University of Maryland from which he received his Bachelor of Science degree in mechanical engineering in 1944. Upon graduation he joined the research staff of Langley Research Center and was assigned to the Stability Research Division. Polhamus actively participated in research on aircraft stability and control, the aerodynamics of variable-sweep aircraft, and in the development of methods for prediction of aerodynamic characteristics. He is co-holder of a patent on the outboard-pivot variable-sweep wing and was instrumental in development of a double-pivot variable-sweep wing design.

From 1960 to 1962 Polhamus served as coordinator of Langley research in support of the TFX. He served as technical advisor to the Air Force on the TFX and coordinated Langley support of the F-111 program.

REFERENCE: Official NASA Biography.

William J. Alford, Jr.

1923–

Development of the outboard-pivot which made variable-sweep wings practical

Co-holder with Edward Polhamus of the patent entitled "Variable-Sweep-Wing Configuration," William Alford is currently manager, Energy Efficient Transport Office, Aircraft Energy Efficient Project at Langley Research Center, Hampton, Virginia. A native of Norfolk, Virginia, Alford graduated from Granby High School in 1942. From 1942 to 1954, he served with the U.S. Marine Corps Reserve, where he held the rank of Captain. During this time he was a dive bomber and fighter/bomber pilot.

Alford received his Bachelor of Science degree in aeronautical engineering from Virginia Polytechnic Institute and State University in 1949 and completed work for a masters degree with the same university in 1960. He began his career with the National Advisory Committee for Aeronautics in August 1949 as an aeronautical engineer and scientist. In 1965 he was named head, Stability and Control Section, Full-Scale Research Division. From 1970 to 1975 Alford was manager, Advanced Transport Technology Office, and from 1972 to 1975 he also served as assistant chief, Terminal Configured Vehicle Program Office. He was appointed head, Systems Analysis Branch, Aeronautical Systems Division, in 1975, and remained in that position until his present appointment.

The author or co-author of numerous publications, Alford has received a number of awards for his engineering achievements.

REFERENCE: William J. Alford Jr., Official NASA Biography.

Vertical Flight

In common with most engineering endeavors, growth in aeronautics was largely a matter of progressive refinement as engineers sought to improve specific aspects of performance. For conventional aircraft the main effort was directed toward increasing speed and altitude, while secondary efforts resulted in wing slats, flaps, and other high lift devices as designers tried to decrease landing speeds in the interests of safety. Concern with the hazards of landing stimulated interest in developing specialized aircraft that could take off and land vertically. Considered a shortcoming of conventional aircraft, the advantage of vertical flight was recognized by the distinguished inventor, Thomas Edison, who was moved to comment (in Taylor, 1968:2):

> The airplane won't amount to a damn until they get a machine that will act like a humming bird—go straight up, go forward, go backward, come straight down and alight like a humming bird. It isn't easy . . . somebody is going to do it. . . .

While Edison appears to have somewhat misjudged the future for conventional aircraft, his prophecy with regard to vertical flight was true. In time, the capacity to emulate the hummingbird was realized, but the price paid in terms of operating costs, payload and cruising speed has so far kept vertical-flight vehicles from serious consideration as commercial air transports or military fighters and bombers. Instead, machines of a type properly designated as helicopters have been developed into versatile utility aircraft. In this role they have proven capable of performing a variety of specialized civilian and military functions beyond the capability of other types of flight vehicles.

Autogiros

While vertical flight principles in the form of rotary wings can be traced to the time of Leonardo da Vinci, or even earlier to the ancient Chinese, this brief treatment is limited to the progress made since Juan de la Cierva first introduced the autogiro on 9 January 1923 (Gibbs-Smith, 1970:189). Cierva's early aeronautical activities had centered on design of conventional aircraft until he became convinced that the normal practice of landing was extremely hazardous. Landing, coupled with the frequency of engine failures, which was quite high in the early twenties, heightened his concern for aircraft safety. In Cierva's mind the way to improve flight safety was to make the generation of lift independent of aircraft speed (Johnson, 1974:380). With the state of flight technology in the twenties, the only way to accomplish this was to use a rotating wing. Starting with this premise, Cierva evolved the autogiro and demonstrated its potential with a fully controlled flight of 4 kilometers in 1923. Continuing with the concept, he introduced refinements and two years later demonstrated the full practicality of the system.

Although autogiros resemble helicopters in that both use rotary wings, they are otherwise entirely different vehicles. In an autogiro the rotor system is not power driven. Wing rotation is entirely due to aerodynamic forces. The rotor blades simply replace the wings of a conventional aircraft as a means for generating lift and do not contribute to the forward motion of the vehicle. Forward motion is achieved with a conventional engine/-propeller combination.

Since lift is not generated unless the rotor system is revolving, an autogiro cannot fly until the blades are moving with sufficient speed to generate the necessary amount of lift. In early autogiros it was necessary to taxi the aircraft until the rotor had attained the speed needed to sustain flight. In later systems the rotor was geared to the engine when preparing for takeoff but was disconnected prior to flight (Johnson, 1974:380).

Early autogiros were hybrids in that they used a conventional control system that depended on air pressure for effectiveness. While such controls were satisfactory for fixed wing configurations, they caused serious problems in autogiros attempting to land at speeds below 20 mph (32 kph). In this speed range, air pressure was insufficient to retain control effectiveness, and resulted in a number of ground looping accidents (Anderson, 1946:26). A different type of control specifically designed for rotary wing aircraft had to be developed to permit full control with no forward speed. Two distinctly different types of control were introduced. The first involved feathering the blades, while the second called for tilting the rotor head.

Sound in principle, but regarded as an oddity incapable of contributing to air transportation, interest in autogiros began to decline in the 1930's as attention shifted in favor of helicopters.

Helicopters

Although serious attempts to develop the helicopter as a vehicle type actually predate Cierva's autogiro concept by some fifteen years, they had been abandoned for want of an engine with enough power for vertical flight. Serious development of the helicopter as a practical vehicle was reinitiated in 1935 when French designers Louis Breguet and Rene Dorand developed and flew the *Gyroplane Laboratoire*, a single-engine helicopter with two coaxially mounted rotors and both collective and cyclic pitch controls (Munson, 1968:10). Vertical control was maintained with a collective pitch mechanism, which permitted the pitch angles of all main rotor blades to be altered by the same amount. Motion in the horizontal plane was controlled with the cyclic pitch mechanism, which continuously changed the pitch of each blade as it revolved. With this type of control, increasing the pitch of a given blade is countered by decreasing the pitch of the diametrically opposed blade. The net effect amounts to tilting the rotor assembly, which results in the horizontal force component used to control lateral motion.

Introduced within a year of the Breguet-Durand machine, the German designed Focke-Achgelis FW 61 challenged the French lead in helicopter design with a series of world height, speed, and distance records. Two years later, Igor Sikorsky, a Russian emigre famed for his multi-engined aircraft and "flying clippers," rekindled his previous enchantment with helicopters and persuaded the United Aircraft Corporation to develop a suitable machine. Sikorsky's illustrious career in aeronautics had started in 1909 when he designed a machine with two co-axial contra-rotating rotors. The machine, however, lacked an engine with the power required for vertical flight. When Sikorsky returned to helicopters in 1939, adequate power plants were readily available. After some two years of flight development, in which he experimented with various combinations of main and tail rotors, Sikorsky completed work on his VS-300. It emerged in 1941 as a practical vehicle that could carry a useful payload in addition to the pilot. Recognizing the significance of the VS-300, the Army Air Corps awarded Sikorsky a contract for an experimental machine, the XR-4. Leadership in helicopter development had passed to the United States (Hallion, 1977:209).

A series of Sikorsky machines including the R-4, R-5, and R-6 followed. Used mainly for utility and rescue missions during World War II, these vehicles served with distinction in every theater of operations (DeLear, 1961:4). By war's end, helicopters had established their future in civil and military aviation as a versatile utility aircraft.

In the years following the war, helicopters indeed came into their own, earning a reputation for accomplishing more humanitarian missions and practical functions than any other vehicle type. Applications made possible by a helicopter's ability to perform like a humming bird with a payload are legion, limited only by one's imagination and the commitment of development funds.

As with all aircraft, helicopters are a study in compromise. To achieve the flight characteristics that make them so versatile, they depend on rotary wing principles in a trade-off between versatility and speed. Since World War II, there has been a growing interest in developing vehicles that combine the speed of fixed-wing aircraft with the vertical-flight capabilities of helicopters. Known as VTOL (vertical take-off and landing) aircraft, these vehicles depend, in one form or another, on vectored thrust. Some, like the Bell X-22A of 1965, depend on ducted propellers mounted on rotatable engines, while others, like the Short SC-1 of 1960, use multiple turbojet engines oriented in the vertical and horizontal planes. The vertically oriented engines are used for take-off and landing and are shut down after power has been transferred to the horizontal engine for forward flight (Taylor, 1968:54).

While most VTOL aircraft are still categorized as experimental vehicles, the revolutionary Hawker Siddeley P.1127 *Kestral/Harrier* has recently become operational with the Royal Air Force and the United States Marine Corps. Work on the P.1127 began in 1958 to provide a test bed for evaluation of a vectored thrust engine developed by Bristol Siddeley. A subsequent contract, placed in 1961, provided nine prototype aircraft for joint testing by British, American, and German pilots. Upon completion of the tripartite test program, six of the *Kestrals* were shipped to the United States for further flight testing. After incorporating a number of modifications, the vehicle was redesignated the *Harrier* and made operational (Taylor, 1968:30). Despite the promise of imaginative visionaries, the future of vertical flight will rest on its ability to remain economically competitive.

Biographic Sketches

Juan de la Cierva y Codornice

1886–1936

Development of the autogiro

Juan de la Cierva y Codornice, son of Juan de la Cierva y Penafiel and Maria Codornice, was born at Murcia in Spain. Although his father was a prominent lawyer and statesman, Cierva aspired to be an aeronautical engineer. Since no technical school in Spain offered aeronautical engineering, Cierva attended the Special Technical College in Madrid, which provided the most complete training in mathematics and mechanics available in Spain. He graduated in 1919 as an Ingeriero de Caminos, Canales y Puertos (civil engineer).

Cierva's activities in aeronautics date to 1910, when he and some friends built two gliders, which proved only moderately successful. In the following year they built a powered aircraft, which flew surprisingly well. When the Spanish government sponsored a competition for military aircraft, Cierva, still an engineering student, decided to design and build a trimotor. The machine was completed and tested in May 1919, but was destroyed during tests due to pilot error. The aircraft had shown considerable promise, but Cierva was convinced that the normal practice of landing with conventional aircraft was extremely hazardous. He turned his attention to rotary wing aircraft and evolved the concept of the autogiro. In the succeeding years he developed his concept both theoretically and experimentally and achieved success in 1923 with a fully controlled flight of 4 kilometers. By 1925 he produced an autogiro that demonstrated fully the possibilities of the system.

Working energetically with manufacturing companies in England, the United States, France, and Germany to produce and promote the autogiro, Cierva was killed in the crash of an air transport at Croydon Airport, England, on 9 December 1936.

REFERENCES: *The Guggenheim Medalists*, The Guggenheim Medal Board of Award, 1964; Kenneth Munson, *Helicopters and Other Rotorcraft Since 1907*, The Macmillan Co. 1969.

Igor Sikorsky

1859–1935

Pioneering contributions in fixed-wing aircraft and successful development of the helicopter

Few men in aviation can match the span of personal participation and contribution that typify Igor Sikorsky's active professional life. Sikorsky was born in Kiev, Russia, the son of a physician and professor of psychology in the local university. His mother was also a physician but did not practice professionally. He entered the Naval Academy at St. Petersburg in 1903, but his interest in engineering caused him to leave the service three years later. After a brief period in which he studied engineering in Paris, Sikorsky returned to Kiev and entered the Kiev Polytechnic Institute. Dissatisfied with the practice of teaching engineering as an abstract science with little relation to practical problems, he left the following year.

Sikorsky began construction of his first helicopter in 1909, but abandoned it in favor of fixed-wing aircraft after the first two failed to fly. Sikorsky's S-1 biplane was tested in 1910, and when its engine proved inadequate he redesigned it with a more powerful engine to achieve limited success. A series of improved aircraft culminating in the S-6 followed in rapid succession. The S-6 series established Sikorsky as a potential supplier of military aircraft for the Russian army. His next aircraft, called *Le Grand* was the first four-engined airplane. It anticipated future multi-engine aircraft such as bombers and commercial transports. *Le Grand* was completed and successfully flown in 1913.

With the state of national unrest following the Russian Revolution and defeat of Germany, Sikorsky saw little future in European aviation and emigrated to the United States in 1919. Finding aviation in the United States to be in a state of stagnation, Sikorsky banded with a few associates and formed their own company, The Sikorsky Aero Engineering Corporation. By 1929, the company had become a division of United Aircraft Corporation, had relocated in Bridgeport, Connecticut, and was producing twin-engined amphibians in quantity. Sikorsky's *American Clipper* series pioneered Pan American World Airways mail and passenger service, and when they inaugurated transpacific and transatlantic service in 1937, Pan American used Sikorsky's four engined *Clipper III*.

Sikorsky returned to helicopters in the late 1930's, this time with great success. He produced his first successful helicopter in 1939 and two years later, in an improved version established an international endurance record. He retired as an engineering manager of his company in 1957 but remained active as a consultant until his death at Easton, Connecticut.

REFERENCES: *The Guggenheim Medalists*, The Guggenheim Medal Board of Award, 1964; Kenneth Munson, *Helicopters and Other Rotercraft Since 1907*, The Macmillan Co., 1969.

Heinrich Focke

1890–1979

Notable advances in helicopter design

With an interest in aeronautics that predates World War I, Heinrich Focke gained recognition as a leader in helicopter design in 1936. A native of Bremen, Germany, he was educated at the preparatory school and high school there before studying machine engineering at the Technische Hochschule Hannover. In 1908–1909 he experimented with gliding flight, first with models and then with a canard-type vehicle, which he called the *Ente*. He later built a small *Ente* airplane equipped with a 50 horsepower engine, which was flown by Georg Wulf, a noted test pilot. Focke entered the German infantry, but later transferred to a flight group. After crashing in 1917, he spent the remainder of the war as an engineer with the Airplane Ordnance Department in Berlin-Adlershof where he worked on aircraft skis and air brakes. Returning to the Technische Hochschule Hannover in 1920 he obtained his diploma in machine engineering. Employed as an engineer and department head at the Franke Works in Bremen, Focke cooperated with Wulf in design and testing of a new monoplane. In 1923, he founded the Focke-Wulf Flugzeugbau, which produced a long line of aircraft.

The Focke-Achgelis GmbH was an offshoot of the Focke-Wulf Flugzeugbau which was established after Focke had been dismissed from his company by the Nazis in 1933. His dismissal was meant as a political punishment to embarrass him. There followed in Germany a period of research and testing on rotary wing aircraft before the FwG1 prototype was introduced in 1936. The new helicopter broke all existing international helicopter records and made long distance flights. The vehicle's super controllability was convincingly demonstrated by the German aviatrix Hanna Reitsch, who flew the machine inside the Deutschlandhalle sports stadium in Berlin.

Focke's design was heralded as an extraordinary advancement in this type of aircraft. Continuing to develop helicopters, Focke designed an advanced vehicle as a feeder transport for Deutsche Lufthansa. By the time it was completed in 1939, however, it was adopted for a military role. Although most of these aircraft were destroyed by Allied air attacks, one surviving aircraft became the first helicopter to fly the English Channel in 1945.

REFERENCES: Kenneth Munson, *Helicopter and Other Rotorcraft Since 1907*, The Macmillan Co. 1968; Paul Lambermont and Anthony Pine, *Helicopters and Autogyros of the World*, A. S. Barnes and Co., 1959.

Anton Flettner

1885–1961

Notable contributions to helicopter technology

Anton Flettner's career in aeronautics dates to 1905 when, upon completion of his studies at the Real-Gymnasium in Hoechst am Main and the State Seminary, he was employed by the Zeppelin Company. He worked on the development of remote-control, which was used extensively on many aircraft.

Born at Eddersheim am Main, Germany, Flettner was president of the Flettner Ship Rudder Corporation at Rotterdam, Holland, and the Flettner Ship Rudder Corporation at Berlin from 1921 to 1926. In 1926, he founded the Anton Flettner Aircraft Corporation in Berlin; and in 1949 he expanded the company to include the American Flettner Corporation.

Developing an interest in rotary-wing aircraft, Flettner designed a torqueless drive helicopter, which was destroyed while undergoing tethered tests in 1933. In 1937, he designed the F1-265, a helicopter with intermeshing contra-rotating rotors. Tests of this vehicle proved highly successful and provided the experience required to design the F1-282, *Kolibri*, an advanced design incorporating the same intermeshing rotor principle. Although the F1-282 entered production during World War II, heavy air raids over Germany prevented completion of the entire order.

After the war, Flettner emigrated to the United States where he served as consultant to the Office of Naval Research before founding his American corporation.

REFERENCES: *Who's Who in World Aviation*, volume 2, American Aviation Publications Inc. 1958; Paul Lambermont and Anthony Pine, *Helicopters and Autogyros of the World*, A. S. Barnes and Company, 1959.

Alexander Klemin

1888–1950

Notable contributions to helicopter aerodynamics

A native of London, England, Alexander Klemin received his Bachelor of Science degree from London University in 1907. He came to the United States in 1914 and enrolled in Jerome Hunsaker's aeroengineering course at the Massachusetts Institute of Technology. Graduating with his Master of Science degree a year later, he stayed on at MIT. When Hunsaker left MIT in 1916 to head the Navy's Aircraft Division, Klemin succeeded him as director of MIT's Aeronautics Department. Klemin became a naturalized citizen in 1917. When the United States entered World War I, Klemin went to McCook Field, Ohio, where Colonel Virginius Clark, then the commanding officer, took Klemin on board as a sargeant and placed him in full charge of research. While at McCook, Klemin initiated the first scientific method for distributing sand bags during static test of aircraft. He also prepared manuals recommending flight test procedures.

After the Armistice, Klemin entered the aircraft industry before joining the faculty of New York University, where, in 1925, he was named Guggenheim Professor of Aeronautics. He had requested this position so that he might devote his time to research and teaching rather than administration. In 1937, he instituted the first course on the theory of rotary wings. Klemin's students went on to lead in helicopter technology and became chief engineers and research directors in important organizations throughout the country.

Long an expert on rotating wing aircraft and a stalwart advocate of their potential as general utility aircraft, Klemin initiated a series of courses in helicopter aerodynamics. He also conducted wind tunnel studies of helicopters, autogiros, and the revolutionary Henrick convertiplane. Klemin's paper "Principles of Rotary Aircraft" resulted in industry-wide approval of NYU's helicopter and autogiro research. This led to a specialized graduate-level series of courses in the aerodynamics and design of rotary-wing aircraft, the first offered anywhere in the world.

During his career, Klemin was consultant to the Bureau of Aeronautics, Department of Navy, the U.S. Air Mail Service, the Civil Aeronautics Administration, and numerous aircraft manufacturers. He also served with the National Advisory Committee for Aeronautics before his retirement in 1945.

REFERENCES: R. P. Hallion, *Legacy of Flight: The Guggenheim Contribution to American Aviation*, University of Washington Press, 1977.

Rocketry and Space Flight

The Formative Years

Technology in the early years of the 20th century was a long way from achieving a level of understanding and sophistication required of liquid-fueled rockets capable of flight beyond the sensible atmosphere of Earth. A limited amount of development had resulted in solid-fuel rockets for warfare, signalling, life-saving, and other purposes, but little serious consideration was given to the use of rockets for space flight until the prospect became the central preoccupation of Konstantin Tsiolkovskii.

Tsiolkovskii, a schoolteacher with a hearing affliction, never built a rocket; yet his grasp of the fundamental principles of rocketry and space flight was extraordinary. In 1883, he contributed a vital step in understanding the rocket's potential, when he proved it would work in the vacuum of space by the recoil effect of exhaust gases (Gatland, 1975:10). With remarkable vision and a superb appreciation of fundamentals, he proposed, in 1903, a rocket vehicle fueled by liquid hydrogen and liquid oxygen. In later years, he anticipated the technology of the future with conceptual illustrations of thrust control, gyroscopic stabilization, jet vanes, and the gimbaled nozzle for directional control. Tsiolkovskii's theoretical considerations detailed the advantages of staging and laid the foundations for escape from and re-entry into Earth's atmosphere (Gatland, 1975:11).

By 1914, Tsiolkovskii had progressed to the point of predicting pressurized cabins for human occupants and the use of space suits and airlocks for extra-vehicular activities. He wrote of the possibilities of space-assembled stations and the yet to be accomplished closed-cycle biological life-support systems (Gatland, 1975:11). While his prophecies occurred at a time when the state of technology was ill-suited and unprepared to transfer them to the realm of human accomplishment, many of them were later corroborated and extended by others. Given time to incubate and grow, technology finally acquired the expertise necessary to translate many of Tsiolkovskii's concepts into practice.

Although Tsiolkovskii indulged in theoretical speculations, it remained for Robert Hutchings Goddard to provide the world with its first demonstration of a liquid-fueled rocket. As a physics student at Worchester Polytechnic Institute, Goddard began to speculate on space exploration and travel. Later earning a Ph.D. at Clark University, his classic report, "A Method of Reaching Extreme Altitudes," was published in 1919 by the Smithsonian Institution. Turning from solid to liquid propellants in the 1920's, Goddard successfully fired the world's first liquid-fueled rocket at Auburn, Massachusetts, on 16 March 1926. With support from Clark University, the Smithsonian Institution, and the Guggenheim Foundation, Goddard continued his research with liquid-fueled rockets, gyroscopic controls, gimbal steering, and jetvane controls at a desert site near Roswell, New Mexico. In the 1930's, while at this site, Goddard developed large and successful rockets, which anticipated many of the features of future rocketry. Unfortunately, Goddard's pioneering demonstrations of rocket-engine capabilities failed to change the negative attitude toward rocket propulsion that prevailed in scientific circles (Malina, 1964:47).

While Goddard's work was certainly an important milestone on the road to space exploration, it has been said with some justification that were it not for formation in Germany of the Verein für Raumschiffart (VfR) in 1927, man would not have reached the moon in the decade of the sixties (Gatland, 1975:12). Originating as a small amateur rocket group motivated with the spirit of science and exploration, the VfR membership ultimately embraced a number of personalities whose accomplishments turned the vision of space exploration into reality. VfR membership included such giants as Hermann Oberth, Walter Hohmann, Guido von Pirquet, Klaus Riedel and Willy Ley before being joined by Wernher von Braun in 1930 (Gatland, 1975:12). Members of the VfR built a number of experimental liquid-fueled rockets, which were launched at their flying field at Tegal, a suburb of Berlin.

Germany in the early 1930's was experiencing a time of uncertainty brought on both by the wide-spread Depression and political events following Adolf Hitler's appointment as Chancellor on 30 January 1933. Membership of the VfR began to decline as bills went unpaid and resistance to rocket firings within city limits provoked police opposition. Finally crushed when the Gestapo intervened and confiscated all records and equipment, the society ceased to exist. By 1934, even their flying field had reverted to its former function as an army ammunition depot (Gatland, 1975:97).

Confronted with the painful alternatives of abandoning rocket research, with its potential for space exploration, and continuing its pursuit in support of military weapons, von Braun chose the latter as the only available means for salvaging the remnants of the VfR's lofty scientific objectives. He was soon relocated to the Kummersdorf proving grounds, where he conducted experimental research on rocket combustion for the army. Given a free hand to develop a progression of experimental rockets, von Braun experienced a series of disappointing failures. His failures, however, were tempered with enough partial successes to retain army interest. (Gatland, 1975:98).

By 1935, the quickening pace of Hitler's plans for aggression led to an enormous increase in funds earmarked for construction of improved research facilities. For rocket research, the immediate need was for a firing range from which to launch rockets over more respectable distances. Selecting a site near the village of Peenemünde, construction was started early that year. This experimental rocket establishment was completed in April 1937 and manned with a number of former VfR members who substantially increased von Braun's work force. Successful firings of the unguided A-5 were achieved by the summer of the following year and continued over the next two years as different types of control systems were tested (Gatland, 1975:99).

These experiments established the basis for design of a long range ballistic weapon of a size limited only by the practical requirement of transporting it through railway tunnels. As usual, increased size leads to more stringent design requirements, which, in this case, were increased size of thrust chamber and increased propellant volume. The latter problem meant changing from a pressure-fed propellant system to one dependent on an efficient pump. After investigating the various options available, a contract was placed for a turbo-pump capable of supplying the required quantities of alcohol and liquid oxygen. The new pump was ready for production by the summer of 1940, but the means for driving it was not available until the following year, when the first peroxide steam generator, using hydrogen peroxide and permanganate, was readied for installation (Gatland, 1975:100).

Dr. Walter Thiel was entrusted with engineering the needed thrust chamber improvements. Thiel, who was in charge of advanced rocket-engine design at Kümmersdorf, recognized the Achilles heel of performance to be the injectors used to spray the fuel and oxidant into the combustion chamber. Rather than attempting design of a single large injector, it was decided to design a system that coupled 18 smaller but well-proven injector units. Decidedly more complicated than a single injector, the coupled system proved to be highly efficient and was adapted for use in the operational rocket (Gatland, 1975:101).

Remaining, of course, were the critical problems of guidance and control. To meet the challange of this phase of weapons development, a flight mechanics computation office was established at Peenemünde under Dr. Hermann Steuding. Supported by a well-equipped laboratory under Dr. Ernst Steinhoff, analogue computors and electronic simulators were pressed into service to meet the demands of developing suitable guidance and control equipment (Gatland, 1975:101).

Designated the A-4, the prototype weapon was finally readied for flight test in the spring of 1942. After the first two vehicles failed because of a fuel supply malfunction and a structural deficiency, the third A-4, somewhat modified, turned in a flawless performance on 3 October 1942. Reaching an altitude of some 85.3 kilometers on a trajectory that carried the rocket for a distance of 190 kilometers, the A-4's performance greatly exceeded that of any previous rocket vehicle (Gatland, 1975:102).

Space flight was defined as any performance beyond an arbitrarily selected altitude of 80.5 kilometers. Based on that criterion, the A-4's flight of 3 October 1942 qualifies it as the first vehicle to penetrate the reaches of space. However, since such records are seldom of lasting significance, it seems more appropriate to simply state that the A-4's performance established, beyond question, the possibility of space exploration.

Unfortunately, Hitler did not see it that way. Pressed into operational service in retaliation for Germany's convincing defeat in the Battle of Britain, the A-4 was redesignated as the V-2 and, in December 1944, was employed to bomb indiscriminantly London and other allied cities. Branded as a weapon of destruction by Hitler's maniacal demands for revenge, the V-2, with all its potential as a prototype for opening the way to space exploration, became operational as a weapon of destruction. Its entrance in the war was, however, too late to decisively influence the war's outcome.

With the defeat of Germany, both Russia and America seized the opportunity to bolster their rocket engineering resources by acquiring seasoned German specialists. Many of the figures who were instrumental in developing the V-2 accepted America's offer to continue their work in the United States. Captured V-2's and rocket parts were immediately shipped to the United States for evaluation in a series of launchings that began at the White Sands Proving Ground in New Mexico on 16 April 1946 with von Braun as advisor (Gatland, 1975:111).

Intended principally to obtain an in-depth evaluation of the rocket's potential as a military weapon, the captured V-2's were fitted with experiment packages instrumented to explore the fringe of space. This opportunity to actively explore phenomena beyond the sensible atmosphere profoundly influenced scientific views, particularly with regard to the composition and environmental conditions of the upper atmosphere. The White Sands tests also gave military authorities cause to reappraise their posture for defense of the country against a rocket assault capable of causing immense destruction.

The rapid cooling of relations between the Soviet Union and the Allies, which occurred in the immediate postwar years, added to the sense of urgency surrounding military evaluation of the V-2's potential. Russia, while not obtaining the top German specialists, had indeed acquired a number of German rocket engineers and was testing long-range developments of the V-2 (Gatland, 1975:113).

Russian activities in practical rocketry were headed by Sergei Korolev, who had been involved with reaction propulsion since the early thirties. Directing his efforts toward development of long-range winged guided missiles and rockets, Korolev had introduced numerous advances that were widely used in Soviet rocketry. In 1947, Stalin's personal enthusiasm for military rockets resulted in Korolev's appointment as head of a design group responsible for development of Soviet long-range missiles. Although Russia's interest in rocket weaponry was known to embrace a variety of projects, the extent of their progress was not fully appreciated until 1957, when the *Pobeda* class ballistic missile was paraded through Moscow on mobile transporters hauled by tracked vehicles (Gatland, 1975:116).

While the *Pobeda* missile was certainly cause for military concern, its capability was soon surpassed by Korolev's impressive giant, which was first launched in August 1957. A multistage rocket with an intercontinental range, it was reported by the Tass news agency to have reached an "unprecedented" altitude before impacting in the target area. On 4 October 1957 Russia shocked the world from complacency by placing *Sputnik I* in Earth orbit. Accomplished by simply adapting Korolev's intercontinental ballistic missile as a satellite launcher, the feat unmistakedly established Russia's lead in rocket development.

With completion of the V-2 evaluation program in 1952, America's fledgling space plans were rich with promise and exciting projects. The NACA, now long established as the world's leading source of authoritative information on flight technology, had reacted to the recognized need for research results pertinent to ballistic reentry. Materials research under the general direction of

Robert Gilruth confirmed the advantage of heat control by ablation, while H. Julian Allen formulated the basis of blunt body theory and Alfred Eggers worked on the mechanics of ballistic reentry (Anderson, 1976:11).

As part of America's participation in the International Geophysical Year (IGY) for 1957-58, plans were formulated to launch a small satellite into Earth orbit. Narrowing the competition to a choice between the National Academy of Sciences/Navy proposal (*Vanguard*) and the Army/Jet Propulsion Laboratory entry (*Explorer*), the green light was given to the Navy project in order to avoid any disruption that could delay the Army's ballistic missile program. Although the Navy's proposal was based on the premise of using a new booster derived from the *Viking* project, the *Vanguard* was being readied for its first test flights when *Sputnik I* shattered America's confidence in its command of technology (Anderson, 1976:12).

As if to add insult to injury, Russian space spectaculars in the months following *Sputnik* continued to electrify the world while the *Vanguard* test vehicle failed dismally. With America's technical honor at stake, the Army reacted swiftly, and on 31 January 1958 successfully launched an instrumented *Explorer* developed by the Army Ballistic Missile Agency and Jet Propulsion Laboratory. The experimental package aboard the satellite included radiation counters intended to probe the radiation environment of space. When the counters revealed an abnormally high amount of radiation at altitudes of around 966 kilometers, James Van Allen, who had designed the experiment, interpreted the results to imply the existence of a dense radiation belt surrounding Earth at that altitude (Anderson, 1976:14).

The Transition to Space

Recognizing the need for a national space program, Congress passed the National Aeronautics and Space Act (Public Law 85-568), which President Eisenhower signed into law on 29 July 1958. The act established a broad charter for civilian aeronautical and space research and specifically cited the NACA as its nucleus. On 1 October 1958, the NACA was formally abolished and the National Aeronautics and Space Administration was established. T. Keith Glennan was appointed administrator, and Hugh L. Dryden, deputy administrator (Anderson, 1976:17).

Within a week after NASA was formed, Glennan committed the agency to Project *Mercury* and set in motion an intense two-year period of organization and planning. In February 1960, Congress was presented with NASA's first ten-year plan. It outlined an ambitious program for manned and unmanned space exploration, continued aeronautical research, and launch vehicle development. Having earlier acquired the Jet Propulsion Laboratory and its contract staff from a reluctant Army, Glennan continued his efforts to acquire the Army Ballistic Missile Agency at Huntsville Alabama. On 15 March 1960, ABMA's Development Operations Division, headed by Werhner von Braun was transferred to NASA along with the *Saturn* launch vehicle project (Anderson, 1976:22).

With Project Mercury underway, other offices within the newly formed NASA structure continued their programs of unmanned space exploration. While launch vehicles remained somewhat unpredictable throughout much of 1959, the success ratio was greatly improved during 1960, resulting in successful launches of *Pioneer V*, intended for interplanetary exploration, *Tiros I*, a prototype weather satellite and *Echo I*, a passive communications satellite. Precursors of the sophisticated scientific and applications satellites and planetary probes of the sixties and seventies, these vehicles were instrumental in evolving the launch and trajectory insertion technology later used on more ambitious space exploration projects.

The situation surrounding the presidential elections of 1960 was not particularly reassuring for the infant space program. President-elect, John F. Kennedy had named Jerome Wiesner his science advisor with broad responsibility to chair a committee and apprise him of NASA's programs. The committee's report took issue with the Agency's performance and was openly doubtful for its future (Anderson, 1976:28). Then, as if by design, Russia successfully launched Cosmonaut Yuri Gagarin for a single orbit around Earth in *Vostok I* on 12 April 1961. Russia had gambled and the United States was unable to match their feat with Astronaut Alan Shepard's ballistic flight in a *Mercury* spacecraft in the succeeding month.

Gravely concerned, President Kennedy asked Vice President Lyndon Johnson to determine what could be done to gain the initiative and surpass the Soviet lead in space. James Webb, NASA's new administrator, proposed a bold plan escalating America's space commitment. The plan would focus America's space objective on manned lunar exploration. If Russia was to remain competitive, both nations would have to greatly extend their booster and spacecraft capabilities. President Kennedy endorsed the plan and, before a joint session of Congress on 25 May 1961, proposed a national goal to achieve the objective within the decade of the sixties. The President's proposal was quickly ratified by Congress.

As the agency responsible for meeting the awesome challenge of civilization's greatest technological endeavor, NASA approached the problem of manned lunar exploration on a war emergency basis. Earlier studies, conducted to measure the state of technology readiness, had revealed certain operational unknowns but had concluded that a lunar mission could be accomplished without major technological breakthroughs. Once detailed, the *Apollo* program and all intermediate steps required to fill voids in operational experience were systematically implemented. Since many of the operational problems would require performance beyond the capability of *Mercury* and would be grossly expensive to accomplish with *Apollo* hardware, the decision was made to develop an intermediate capsule.

Gemini began as a vehicle of expediency to "scale up" *Mercury* and provide an effective bridge to *Apollo*. The *Gemini* program soon developed budgetary problems, as engineers sought to extend its function to that of a full fledged test vehicle. To reduce costs, flight schedules were stretched out and many proposed refinements simply abandoned and dropped. By the end of 1964, the worst of *Gemini's* troubles had been resolved. On 19 January 1965 *Gemini* was determined safe for manned flight (i.e., "man-rated") when the reentry integrity of the heat shield and operational status of all equipment was confirmed. *Gemini* henceforth was used primarily to establish the techniques required of rendezvous, docking, and extravehicular activity (EVA). These activities provided vital experience for astronauts, launch crews, control room crews, and the tracking network. *Gemini* greatly advanced the technology of fuel cells, environmental control systems, space navigation, and a myriad of other technical advances that later proved of immeasurable value to the *Apollo* program (Anderson, 1976:55).

Throughout the *Gemini* operational period, *Apollo* was making steady progress toward its scheduled goal of becoming man-rated during 1967. Then, on 27 January 1967, the program suffered a tragic reversal that threatened to place the national goal beyond reach. A fire in Block I command module killed astronauts Virgil Grissom, Edward White, and Roger Chaffee as they moved through countdown toward a simulated launch. Shock and disbelief in the wake of the space program's first fatal accident eroded Congressional confidence in the spacecraft's ability to fulfill its mission. Months of inquiry and investigation followed as materials and design faults were isolated and corrected during redesign of an otherwise sound spacecraft. Although the fire delayed scheduling a manned flight in an *Apollo* for some eighteen months, the technical improvements introduced in the Block II spacecraft made it a superior and far safer vehicle (Anderson, 1976:57).

The first manned space flight in the improved command module was made on 11 October 1968 when *Apollo 7* was placed in Earth orbit for an eleven-day test. With only a year and a half remaining in the decade of lunar commitment, bold measures were taken to accelerate the flight test program and gain the advantage of experience at lunar distances. Three flawless flights and all systems were pronounced ready to attempt the ultimate mission of *Apollo* (Anderson, 1976:68).

On 16 July 1969, a *Saturn V* launched *Apollo 11* on its historic flight, carrying astronauts Neil Armstrong and Edwin Aldrin, Jr., to the lunar surface. The third astronaut, Michael Collins, piloted the command module in lunar orbit and performed the exacting tasks required of his solitary station. The crew and all systems performed superbly. Four days after lift-off a concise message from Tranquility Base announced to an anxious world the stirring news of the lunar module's landing. After checkout, a second message: Armstrong was on the moon. The first task: set up the television camera. Then, joined by Aldrin, the two methodically implanted the U.S. flag and deployed scientific experiments, which would be left behind. After collecting rock samples for later laboratory analyses, the two astronauts climbed back into the lunar module and prepared for their departure. The following day the ascent module left the moon's barren surface and returned to lunar orbit where it rendezvoused with the command module.

The tension of reentry followed; then splashdown in full view of the recovery carrier, *Hornet.* The bold national commitment to land men on the moon and return them to Earth in the decade of the sixties had been fulfilled. Later flights extended the area of lunar investigation to different sites and established space technology at an unprecedented level of sophistication.

While mankind's thirst to explore the reaches of space had been whetted by the successful lunar exploration program, the enormous expenditure required to continue the pace had become a matter of political concern. Drastic budget reductions imposed in the wake of the manned lunar program forced NASA to reduce or eliminate many of its planned programs in order to provide adequate funding to continue space exploration with fewer high-priority programs.

The next manned space flights were flown in support of the *Skylab* Program, which was originally intended to obtain answers to biological questions concerned with the future of manned spaceflight. Budget constraints limited the program to a single launch of an orbital workshop and three flights with astronauts. Determined to obtain as much information as possible from a restricted opportunity, NASA devised an ambitious experiment schedule. Experiments designed to use the *Apollo* telescope mount covered the range of solar physics, while other experiments concentrated on recording Earth resources observations and medical data from the three-man crew. Still other experiments explored the influence of weightlessness on industrial processes.

Skylab I, an impressive two-story unmanned orbital workshop was launched by a *Saturn V* on 14 May 1973. Crippled when inadequate pressure venting tore the meteoroid-heat shield away during early ascent, *Skylab's* future as a usable spacecraft was in serious jeopardy. When the meteoroid shield failed, one wing of solar cells was completely torn from the spacecraft. The other was fouled and prevented from deploying (NASA TM X-64813). If the immediate news was disquieting, the news from orbit was worse. Loss of the heat shield had left the workshop with no protection against the unfiltered energy from the sun. Internal temperatures soared! Soon beyond tolerable limits for habitation, the steadily climbing temperature approached levels that could destroy film and generate poisonous gas.

For ten frantic days ground support teams worked around the clock in a desperate scramble to devise appropriate fixes. Two major problems required immediate solution: devise a deployable shade to protect the workshop from direct sunlight and provide the astronauts with a versatile tool to release the fouled solar wing. Neither task would be routine in the weightless environment of space.

On 25 May 1973, *Skylab 2*, consisting of an *Apollo* command or service module, was orbited. The crew's mission was to assess the damage, try to repair the workshop and, if salvable, inhabit the workshop and complete as much of the original mission as possible. It was a tall order, but when a gas detector revealed no trace of poisonous gas, the crew entered and deployed a makeshift parasol. Once shaded, internal temperatures began to drop, but the testy problem of deploying the crippled solar wing remained.

A crucial test of man's ability to perform useful work in the environment of space occurred on 7 June, when astronauts Conrad and Kerwin left the workshop to attempt repair of the snarled solar wing. After a tense struggle they finally succeeded in cutting away the wreckage that prevented the wing from deploying. Once freed, the wing deployed slowly. Vitally needed electric power flowed into storage batteries. Raw courage, ingenuity, and the dedication of a ground-support team had pulled a chestnut from the fire. The workshop was operational.

In comparison, the remainder of the mission and the follow-on *Skylab 3* and *4* were anticlimactic. When completed, the *Skylab* missions had amassed such an abundance of astronomical and earth-resources data that years will be needed to analyze them. Biological data showed conclusively that, with exercise, no physiological barriers barred the way for space exploration. The exploratory experiments on industrial processing also resulted in promising evidence. In the weightlessness of space, single crystals obtained during solidification were of much better quality and some five times larger than those produced under the best laboratory conditions on Earth. Once precariously close to disaster, the *Skylab* program had been rescued and turned into a remarkably successful investment.

Beyond *Skylab* lies the vision of true transportation—*Space Shuttle.* The concept of *Shuttle* promises a whole new way of space exploration: a way that may some day soon open the reaches of space to active exploration by nonpilots; a way that could well be an effective bridge, for those bold enough to entertain the notion, to space colonization. How successful *Shuttle* may prove is a matter of conjecture, but who among us would have dreamed that flight technology would bring civilization from the sands of Kitty Hawk to the reaches of space in less than three-quarters of a century?

Biographic Sketches

Sir William Congreve

1772–1828

Revolutionary advances in rocket technology

A remarkably prolific inventor who may be said to have precipitated the rocket age, William Congreve was born in Marylebone, Middlesex, England, on 20 May 1772. Aware of earlier wartime uses of rockets in China and India, he was prompted to develop them by the Napoleonic threat of French invasion. With official permission granted by the Ordnance Board, Congreve began a program of intensive development. He revolutionized fabrication practice and mass-produced rockets in a variety of calibers and types. He also instituted required advances in propellant technology by using granulation machines for refining the mechanical mixture of black powder and pile-driver presses to charge rocket tubes with a uniform and dense propellant. These advances resulted in far higher impulses and uniform burns than had previously been possible.

Although initially developed as a military weapon, Congreve rockets found many humane uses. These included rescue rockets, rockets for effecting geodetic surveys, and signal rockets for distressed ships.

References: Frank H. Winter, "William Congreve: A Bi-Centennial Memorial" *Spaceflight*, volume 14, number 9 (September 1972).

Konstantin E. Tsiolkovskii

1857–1935

Scientific study of rocket dynamics and related problems of astronautics

A Russian pioneer in rocket and space science, Konstantin E. Tsiolkovskii was born in Ishevskoye, Ryazan Province, Russia. At the age of 10 he was handicapped by near deafness resulting from scarlet fever, an affliction that prevented him from continuing normal schooling. Self-taught, Tsiolkovskii soon developed an interest in mathematics and physics and avidly read all he could obtain on these subjects. At 16, his father sent him to Moscow, where he remained for three years attending lectures on chemistry, astronomy, mathematics, and mechanics with the aid of an ear trumpet.

In 1882 he moved to the village of Kaluga where he spent the remainder of his life teaching school and doing research in aeronautics and astronautics. In the course of his long life the prospect of space flight was to remain his central preoccupation and he contributed much to basic astronautics. Although his most valuable contributions were made in the theory of reactive propulsion, he also deduced the laws of motion of a rocket as a body of variable mass, determined rocket efficiency, and developed the fundamental principles of liquid propellant engines. Numerous technical ideas expressed by Tsiolkovskii have been incorporated in the design of modern rocket engines and space vehicles.

REFERENCES: H. E. Ross, "K. E. Tsiolkovsky—Selected Works," *Spaceflight*, volume 11, number 7, July 1969; *Encyclopaedia Britannica*, volume 22, William Benton Publisher, 1974; Kenneth Gatland, *Missiles and Rockets*, Macmillan, 1975; *The Soviet Encyclopedia of Space Flight*, MIR Publishers, Moscow, 1969.

Robert Hutchings Goddard

1882–1945

Pioneering research resulting in the foundations of modern developments in rocketry and space flight

Robert Hutchings Goddard was born in Worchester, Massachusetts. In 1883 his parents, Nahum and Fannie, moved to Boston where Nahum worked in a machine shop which he and another employee purchased. Due to poor health, Goddard's early schooling was largely the consequence of self-education. As a physics student at Worchester Polytechnic Institute, he began to speculate on space exploration and travel. He earned his doctorate at Clark University in 1911 and became a member of the Clark faculty. Goddard later attained the rank of full professor.

Goddard's classic report "A Method of Reaching Extreme Altitudes," was published in 1919 in the *Smithsonian Miscellaneous Collections*, which Institution also provided modest monetary support for his research. He turned from solid to liquid propellants in the 1920's and in 1926 successfully fired the world's first liquid propellant rocket at Auburn, Massachusetts. With support from Clark University and the Guggenheim Foundation, Goddard continued his research with liquid fuel rockets, gyroscopic controls, gimbal steering, and jet vane control at a desert site near Roswell, New Mexico. In the 1930's, while at this site, Goddard developed large and successful rockets, which anticipated many of the features of the German V-2 rockets of the future.

During World War II, Goddard was director of research for the Bureau of Aeronautics of the Navy Department. While serving in this capacity he developed rocket motors and jet-assisted take-off devices for aircraft at his laboratory in Annapolis, Maryland. He was engaged in this work at the time of his death on 10 August 1945. His patents were used by the German government in its V-2 rocket program and later by the U.S. in its space exploration efforts. In 1962 the National Aeronautics and Space Administration (NASA) dedicated the Goddard Space Administration Center at Greenbelt in commemoration of Goddard's extensive contributions to rocketry and space flight.

REFERENCES: *Congressional Recognition of Goddard Rocket and Space Museum*, National Air and Space Administration, 1970. *Encyclopaedia Britannica*, volume 10, William Benton Publisher, 1966; Esther G. Goddard and G. Edward Pendray, *The Papers of Robert Goddard*, 3 volumes, McGraw-Hill Book Company, 1970; Milton Lehman, *This High Man*, Farrar, Straus and Company, 1963.

Fridrikh Arturovich Tsander

1886–1933

Early contributions to rocket technology and space flight

Inspired by the earlier writing of Tsiolkovskii, Fridrikh Arturovich Tsander advanced theories on rocketry and interplanetary flight to the point of practical demonstration. Tsander was born in Riga, Russia, where his father, a medical doctor, was employed at the Zoological Museum. Tsander attended the Riga High School, graduating at the top of his class in 1905. While at high school, his astronomy teacher introduced him to an article on space research by Tsiolkovskii, which deeply impressed him. In 1907 he enrolled in the mechanical department of the Riga Polytechnic Institute, from which he earned an honors degree in engineering. After graduation Tsander earned a reputation as the first Russian engineer to devote himself to the practical solution of problems connected with interplanetary flight and rocket technology.

Throughout his life, Tsander worked intensively in the field of theoretical interplanetary flight. He also developed a new thermal cycle for rocket engines and proposed the use of metals as fuel for propulsion. Two of his articles, both entitled "Thermal Estimates of a Liquid Rocket Engine" contain estimates of the combustion chamber wall temperature and of the chamber's capacity required for full combustion of all fuel components.

In 1919, he started work at the aviation factory No. 4 "Motor." In order to unify his work on the development of a spaceship, Tsander joined the staff of Aviatrests Central Bureau of Construction as a senior engineer in 1926. He later (1930) worked at the Central Institute for Aircraft Motor Construction, where he experimented with the OR-1 jet engine fueled by gasoline and gaseous air. When, in the following year, a jet-engine section was established within the Central Council of Osoaviakhim, Tsander was appointed its director. With the formation of the Moscow Group for the Study of Jet Propulsion (GIRD) in 1932, Tsander devoted full attention to the development of the OR-2 rocket engine.

Tsander was not destined to see his rockets in flight. His heavy schedule of activities and long hours led to serious signs of overwork. When finally persuaded to go to Kislovedsk for rest and treatment, he arrived suffering from typhoid fever. Tsander succumbed to the fever on 28 March 1933 at the age of 46.

REFERENCES: L. K. Korneev, *Problems of Flight by Jet Propulsion*, NASA TTF-147, National Aeronautics and Space Administration, 1964; *The Soviet Encyclopedia of Space Flight*, MIR Publishers, Moscow, 1969.

Hermann Oberth

1894–

Pioneering contributions in rocketry and space flight

Hermann Oberth, mathematician and physicist, envisioned manned space exploration in the early 1920's and pioneered in the development of liquid fueled rockets in the 1930's. A school teacher turned scientist, Oberth was born in Sibiu, on the northern slopes of the transylvanian Alps, at the time a part of the Austro-Hungarian Empire. When only two, his father, a medical doctor moved to Sighisoaro where Oberth attended elementary school. An avid reader, he developed a consuming interest in space flight from reading Jules Verne's *From the Earth to the Moon.* This diverted his interest from medicine, but, encouraged by his father, he entered the medical school at the University of Munich. Oberth was still a student when World War I began, but he was inducted into the army as an infantryman. Wounded, he was transferred to the 22 Field Ambulance Unit, a relatively inactive post, which allowed him sufficient time to think about space flight.

Oberth resumed his studies after the war in Germany at Göttingen, Heidelberg, and Klausenberg; but he dropped all pretense of a career in medicine and concentrated on mathematics, astronomy, and physics. He attempted to obtain a doctorate in physics with a dissertation on space travel, but the topic was considered too radical. By 1922 Oberth had formulated detailed theories regarding the firing of a space projectile and the means by which it would escape the earth's gravitational pull. After a period, during which he conducted his private research on rocketry, he conducted research on liquid fueled rockets at the Reich Institute of Chemistry and Technology.

In 1938 Oberth was summoned by the German government to take part in a rocket research program at the Vienna College of Engineering. From there he was sent to the University of Dresden to develop a fuel pump for large liquid fueled rockets. He became a German citizen in 1943 and was transferred to the Peenemünde Rocket Development Center. With the end of the Second World War, Oberth spent several years working as a rocket consultant in Switzerland and Italy before returning to teaching at Nüremberg. Invited to work on guided missiles at the U.S. Army's Redstone Arsenal, Huntsville, Alabama, in 1955, Oberth accepted the position of supervisory physicist until 1958. He then retired and returned to Germany.

In addition to his many technical contributions, Oberth did much to popularize the space movement through his writings and served as the technical advisor on Fritz Lang's *Die Frau im Monde*, the first movie about space travel.

REFERENCES: *Current Biography Yearbook*, The H.W. Wilson Company, 1957; Fred C. Durant III, "Rockets and Guided Missiles," *Encyclopaedia Britannica*, volume 19, William Benton Publisher, 1966; "Hermann Oberth," *Encyclopaedia Britannica*, volume 16, William Benton Publisher, 1966; Raymond J. Johnson, editor, *Above and Beyond*, New Horizons Publishers, Inc., 1968; Hermann Oberth, manuscript in Biographical Files, National Air and Space Museum, Smithsonian Institution, Washington, D. C.; Shirley Thomas, *Man of Space*, volume 8, Chilton Company, 1968.

Gaetano Arturo Crocco

1877–1968

Notable contributions in rocket technology

Gaetano Arturo Crocco's distinguished career in aeronautics and astronautics brought him recognition as Italy's leading space scientist. Born in Naples on 26 October 1877, he initially elected to pursue a military career. After completing his studies at the University of Palermo in 1897 he attended the School of Applied Artillery and Engineering at Turin, graduating in 1900 with the rank of lieutenant. He later specialized in electrotechnical engineering at the Montefiore Institute of Liege, Belgium.

Becoming interested in flight and its related technology, in 1902, he published a rigorous treatment of airship stability, which brought immediate international recognition. Crocco's early work in aeronautics was indicative of his versatility. In addition to design of semi-rigid and rigid airships, he conducted theoretical and experimental research on aerodynamics, flight mechanics, and airframe structures. He also founded and directed a Research Institute for Aeronautics, Italy.

Resigning from his military position in 1920, Crocco served as an advisor to an industrial concern on the possibilities for commercial aviation before becoming director of Italian industry at the Ministry of National Economy. He returned to aviation in 1926, when he was appointed to a chair at the School of Aeronautical Engineering. A year later he was named director of construction with the Air Ministry, and in 1932 became director of aeronautical research.

Crocco began working with solid and liquid propelled rockets as early as 1927, an interest carried on by his son, Luigi, an aerospace engineer. In his later years, Crocco's vision extended to space flight and interplanetary travel. An able administrator, he was responsible for founding several Italian and international societies dedicated to rocketry and astronautics.

REFERENCES: Luigi Crocco, "Gaetano Arturo Crocco," *Astonautica Acta*, volume 14, number 6 (October 1964); *Enciclopedia De Aviacion y Astronautica*, Edicion Garriga, volume 3, 1972.

Sergei Korolev

1906–1966

Pioneering design of first space vehicles and booster rockets

Responsible for many of the great achievements in Soviet space technology, Sergei Korolev was known in Russia as a brilliant scientist and administrator. The son of a school teacher, he was born in Zhitomir in the Ukraine. He completed his studies in an Odessa vocational school for construction workers in 1922 and enrolled in the Kiev Polytechnic Institute. In 1926 he transferred to the Moscow Technical School of Higher Learning and completed his studies in the Department of Aeronautical Engineering in 1929. Entering the aviation industry in 1927, he designed gliders and light aircraft before turning to rocket design and space exploration.

In 1931, Korolev met Fridrikh Tsander and collaborated with him to organize the Moscow Group for Study of Reactive Motion. In 1932, he was one of the organizers, and later, the head of the Group for Study of Reactive Motion (GIRD), which built and launched the first Soviet liquid-propellant rocket in August 1933. After founding the Rocket Research Institute, Korolev was appointed its deputy director for science. His scientific and technological ideas were widely used in Soviet rocketry. Korolev headed projects for the development of many ballistic and geophysical rockets, carrier rockets, and the *Vostok* and *Voskhod* series spaceships, the vehicles for the first manned space flight and the first walk in space. The space rocket systems developed under his guidance made possible the launchings of artificial satellites of the earth and the sun.

Korolev was highly respected and won the esteem of all who worked with him. In 1953 he was elected a corresponding member of the Academy of Sciences of the USSR and in 1958 an academician. His outstanding work was marked by high government awards. He died in January 1966 of a coronary arrest during surgery.

REFERENCES: N. D. Anoshenko, *History of Aviation and Cosmonautics* NASA TT F-11, 430, National Aeronautics and Space Administration, 1967; G. V. Petrovich, *The Soviet Encyclopedia of Space Flight*, MIR Publishers, Moscow, 1969.

Eugen Sänger

1905–1964

Achievements in rocket propulsion and the concept of the antipodal bomber which influenced design of postwar research aircraft

A brilliant and inspirational theoretical physicist who contributed extensively to the field of rockets and space vehicles, Eugen Sänger was considered one of Europe's foremost space scientists. Born in Pressnitz, Bohemia, which is now in Czechoslavakia, he received his early education in Hungary and Austria. He later studied at the Technische Hochschule at Graz and Vienna obtaining his doctorate in 1931; his dissertation concerned statics of multiple spar wings.

From 1929 to 1935, he published numerous papers on high-speed aerodynamics, rockets, and gas dynamics. In 1936, he became the first director of a German government rocket research establishment at Trauen. Sänger's important book *Racketenflugtechnik* was published in 1933. Sänger was one of the first to investigate the use of liquid hydrogen as a fuel and to try mixing metal powders with rocket fuels for increased effectiveness. Both ideas were extensively adopted.

With his wife, Dr. Irene Bredt, a mathematician and physicist, Sänger made a study for a global bomber, which was published by the German government under the title "Rocket Propulsion of Long Range Bombers." This work became one of the best known works in space literature after World War II. The concept, known as the antipodal bomber, was to have taken off from a supersonic carrier, climb vertically beyond the atmosphere, and then reenter and travel along a skip trajectory consisting of successive glides and climbs with diminishing airspeed. This concept later influenced design of postwar research aircraft in the United States.

After World War II, Sänger worked in France; then in 1954 he went to Stuttgart as head of the Institute of Jet Propulsion Physics. He later returned to lecturing at West Berlin's Technological University.

REFERENCES: Author unknown, Obituary, *New York Times*, 11 February 1965; Anonymous, "Dr. Eugen Sänger," *Journal of British Interplanetary Society*, volume 29 (June 1949).

Robert Rowe Gilruth

1913–

Achievements in the flying and handling qualities of aircraft, pilotless aircraft research, and direction of Project Mercury

Known as a driving force behind the U.S. manned space-flight program, Robert R. Gilruth had already earned international recognition for his research on the characteristics of aircraft in flight when emphasis shifted to space exploration. An aeronautical engineer with both bachelors and masters degrees from the University of Minnesota, Gilruth was born in Nashwauk, Minnesota. After graduation he began his career in flight research with the National Advisory Committee for Aeronautics at Langley Field in 1937. Assigned to the Flight Research Division he undertook investigations related to the flying and handling qualities of airplanes. The work culminated in a now-classic report, which provided the basis for establishing quantitative requirements for the flying and handling qualities of military and civil aircraft.

Early in 1945 he was selected to create and establish an organization and facility for conducting free-flight experiments with rocket-powered models at transonic and supersonic speeds. His leadership in this activity led to formation of the Pilotless Aircraft Research Division and the NACA Wallops Station launching site. Gilruth's activities gained international recognition for contributions to transonic and supersonic flight and resulted in test techniques that have since been adopted throughout the Western world.

In 1952 he was designated an assistant director of the Langley Laboratories responsible for research in pilotless aircraft, structures and dynamic loads. Assigned to direct the nation's initial manned space-flight programs in 1958, his contributions to the Mercury Project made him best qualified to head the Manned Spacecraft Center when that facility was established in 1961. Gilruth's leadership has been largely responsible for this country's rapid progress in manned space flight.

References: Official NASA Biography; "Man-In-Space Chief," *New York Times*, 9 July 1969; Maxine A. Faget, "Dr. Robert Rowe Gilruth Biography," in *The Eagle Has Returned, Proceedings of the Dedication Conference of the International Space Hall of Fame*, Ernst A. Steinhoff, editor, volume 43, American Astronautical Society, 1976.

Arthur Kantrowitz

1913–

Significant contributions to the development of shock tube technology and ballistic missile reentry

Known for his research in physical gas dynamics and particularly for his pioneering application of the shock tube to high temperature gas problems, Arthur Kantrowitz proved crucial to American progress in space flight. A member of a talented family of achievers, Kantrowitz was born in the Bronx, New York City. Although an average student throughout elementary and high school, he excelled in science and mathematics. In 1931, he enrolled at Columbia University as an engineering student, but soon changed his major to physics. Receiving his Bachelor of Science degree in 1934 and his Master of Arts degree in 1936, Kantrowitz joined the NACA research staff at Langley Laboratories in Hampton, Virginia. Here he worked with Eastman Jacobs and Robert T. Jones on aerodynamics problems until 1940 when he took a year's leave to complete courses for his doctorate. When the United States entered World War II, Kantrowitz interrupted his studies and returned to Langley where he contributed significantly to the development of the supersonic diffuser and compressor for jet engines.

Becoming interested in gas dynamics while at Langley he earned his doctorate from Columbia in 1947 with a dissertation on quantum effects in gas dynamics. Upon invitation from Professor William Sears, he accepted an associate professorship at Cornell University's School of Aeronautical Engineering prior to completing his doctorate. With a subsidy of research contracts from the Office of Naval Research he began to develop the knowledge of high temperature gases, which was later to prove so useful to reentry problems. Becoming aware of the reentry problem that Avco Corporation was having with the intercontinental ballistic missile, Kantrowitz was able to duplicate the conditions in his shock tube at Cornell. He reduced his teaching load and undertook to put his theory into practice.

In 1956, after Avco had established the Avco Everett Research Laboratory in which he could conduct his studies, Kantrowitz left Cornell to devote himself exclusively to his work. When Avco's Research and Development Division introduced Avcoite and it was successfully used on the RVX 1-5 nose cone, Kantrowitz's theoretical expectations were confirmed within engineering accuracy. Arthur Kantrowitz had received many awards for his lasting contributions to reentry technology.

REFERENCE: *Current Biography*, H. W. Wilson, Co., 1966.

Klaus Riedel

1907–1944

Significant contributions to rocketry and rocket engine technology

Credited with design and development of the first water-cooled liquid-fueled rocket, Klaus Riedel was born in Wilhelmshaven, Germany, on 2 August 1907. The son of Lieutenant Commander Alfred Riedel, he attended the Gymnasium at Wilhelmshaven, but transferred to the Askanische Gymnasium in Berlin during the war in order to become eligible for entry in the Real Gymnasium in Wilhelmshaven. Riedel's aspiration to become an engineer was seriously disrupted by the death of his mother in 1919 and of his father in 1921. Completing his secondary education in 1923, Riedel became a volunteer with the Kapler Werken in order to gain practical experience. Recognizing his determination to become an engineer, his uncle, Carl Riedel, encouraged him to apprentice with the firm of Loewe and Company. He entered into a formal apprenticeship agreement with the company in October 1923.

While working as an apprentice, Riedel attended night school and, upon completing his apprenticeship, in 1927, he attended a private school in Berlin. He then audited the course of study in mechanical engineering at the Technische Hochschule in Berlin. In 1929, he joined Herman Oberth's rocket development team as a rocket engineer and contributed to development of the first liquid oxygen-gasoline rocket engines in Germany.

In 1934, Riedel became an engineer with the firm of Siemans Apparate and Maschinen GmbH in order to get further involved in the expanding field of rocket technology. While with the company he developed the first water-cooled liquid fueled rocket. In 1937, Riedel became director for ground equipment at Peenemünde's Rocket Development Center. While returning home on the night of 4 August 1944, Riedel was killed in an automobile accident.

REFERENCE: Resumé of Klaus Riedel, manuscript in Biographical Files, National Air and Space Museum, Smithsonian Institution, Washington, D. C.

Wernher von Braun

1912–1977

Pioneering achievements in rocketry culminating in space, lunar, and interplanetary exploration

Wernher von Braun, a talented engineer and proponent of space exploration, contributed substantially to the program for manned exploration of the moon undertaken by the United States. He was one of three sons born to Baron Magnum von Braun, a cabinet member of the Weimar Republic, later minister of agriculture, and a banker. Wernher von Braun was born in Wirsitz, Germany on 23 March 1912. In 1925 he acquired a copy of *Die Rakete zu den Planetenräumen* (The Rocket into Interplanetary Space) by rocket pioneer Hermann Oberth, which proved little short of inspirational.

Enrolled in the Berlin Institute of Technology, where he assisted Oberth in liquid-fueled rocket motor tests, von Braun joined the German Society for Space Travel. Graduating from the Institute with the degree of Bachelor of Science in mechanical engineering in 1932, he entered Berlin University. With the aid of a research grant from the Army Ordnance Department, von Braun continued his rocket research at a small development station. In 1934 he received a doctorate in physics with a dissertation on rocket engines. Upon graduation he became technical director of the Rocket Development Center at Peenemünde. While at Peenemünde von Braun participated in development of the V-2 rocket and the supersonic aircraft missile *Wasserfall.* Under his leadership, the level of rocket and missile technology at Peenemünde was advanced beyond that of any other nation.

Surrendering to U. S. troops at the end of World War II, von Braun and the entire rocket development team were brought to the United States, where they continued their research activities with the U.S. Army Ordnance Corps at Fort Bliss, Texas. Named technical director of the U.S. Army ballistic weapon program at Huntsville, Alabama, in 1959, he actively engaged in development of the *Redstone, Jupiter-C, Juno,* and *Pershing* missiles.

In 1955, von Braun became a U.S. citizen. When the Soviet Union launched the *Sputnik* satellites in 1957, von Braun was given authority to mount a competitive effort. The first U.S. satellite, *Explorer I* was launched in 31 January 1958 by von Braun and his Army team. With formation of the National Aeronautics and Space Administration, von Braun was named director of the Marshall Space Flight Center in Huntsville. While in that capacity he led the development effort that produced the *Saturn I, IB* and *V* launch vehicles. The *Saturn V* vehicle was used to launch the successful flights to explore the lunar surface.

In July 1972, von Braun retired from NASA to become corporate vice-president for engineering and development with Fairchild Industries, Inc.

REFERENCES: Fred C. Durant III, "Missiles and Rockets," *Encyclopaedia Britannica,* volume 19, William Benton Publisher, 1966; Erik Bergaust, *Wernher von Braun,* National Space Institute, 1976.

Ernst Stuhlinger

1913–

Electrical propulsion systems for space vehicles

Born in Niederrimbach, Württemberg, Germany, Ernst Stuhlinger received his doctorate in physics at the University of Tübingen in 1936 with a dissertation on the ionization rate of cosmic rays. Upon graduation he joined the faculty of the Berlin Institute of Technology as an assistant professor in the Physics Department. Inducted into the German army in 1941 as a private in the infantry, he spent two years in the military before being ordered to Peenemünde as a member of the rocket development team headed by Wernher von Braun.

From the end of World War II until 1950, he worked with the von Braun team for the U.S. Army Ordnance Corps at Fort Bliss, Texas. When the team was transferred to Redstone Arsenal at Huntsville, Alabama, in 1950, Stuhlinger was assigned as director of the Research Projects Laboratory of the Army Ballistic Missile Agency. In 1960, the von Braun group transferred to NASA, with Stuhlinger remaining director of the Marshall Center Research Projects Laboratory (later the Space Sciences Laboratory), Huntsville, Alabama. He was named associate director for science in 1969.

Stuhlinger has come to be recognized as the nation's leading spokesman for electric rocket propulsion systems, as well as for his pioneering contributions in space vehicle design, satellites, and instrumentation.

He has received many honors and awards for his achievements in astronautics. He retired from Federal service in 1975 and is currently working at the Center for Energy and Environmental Studies, University of Alabama in Huntsville.

REFERENCES: Author unknown, Official NASA Biography; B. J. Casebolt, "A Physicist Retires, Work Doesn't End," *Huntsville Times,* 1 February 1976; Ernst Stuhlinger, manuscript in Biographical Files, National Air and Space Museum, Smithsonian Institution, Washington, D. C.

Charles Stark Draper

1901–

Development of inertial guidance systems and their application to commercial air transportation and space exploration

Born in Windsor, Missouri, Charles Stark Draper had originally intended to pursue a career in medicine. After graduating from Stanford University with a degree in psychology, he registered at Massachusetts Institute of Technology in electrochemistry and earned his Bachelor of Science degree in that field in 1926. Upon completion of his work at MIT, he accepted a commission with the Army Air Corps and took flight training at Brooks Field, Texas. He returned to MIT to pursue a Master of Science degree in 1928, where one year later he was appointed as research assistant. He was made a research associate in 1930 while teaching courses in aircraft instrumentation and working toward a doctorate in physics with a minor in mathematics. He was awarded his doctorate in 1938.

Draper had met Elmer Sperry, Sr., earlier and had worked with him to invent, build, and test unconventional flight instruments. In 1939 Sperry Gyroscope provided financial support for Draper's navigational work by sponsoring a project to make new gyroscopic turn indicators. Although successfully developed, there was no immediate need for the instruments until the onset of World War II, when Draper's rate of turn indicator became the basis for gyroscopic gunsights. Draper continued to develop gunsights and later missile fire-control systems for the military until 1957.

Concurrent with his fire control work, Draper continued to work on inertial guidance systems for air navigation. His efforts culminated with the demonstration of the first full inertial transcontinental flight from Massachusetts to California in 1953. As a consequence, military aircraft and submarines were using inertial equipment in the early 1960's, and commercial aircraft adopted them in the 1970's.

As head of the Instrumentation Laboratory at MIT, Draper committed the Laboratory to its most dramatic undertaking when he proposed to design an inertial navigation guidance and control system to be used aboard the *Apollo* spacecraft. The remarkable accuracy of Draper's guidance systems was demonstrated to a world-wide audience when splashdown of the *Apollo 11* was accomplished within visual contact of the aircraft carrier deployed to retrieve the crew.

More than an educator, scientist, and inventor, Draper's technical and administrative leadership have established him as preeminant in the field of inertial technology.

REFERENCES: Robert Duffy, "Dr. Charles Stark Draper Biography" in *The Eagle Has Returned, Proceedings of the Dedication Conference of the International Space Hall of Fame*, Ernst A. Steinhoff, editor, volume 43, American Astronautical Society, 1976; *American Men and Women of Science*, 12th edition, R. B. Bowker Co. 1972; *Who's Who in World Aviation and Astronautics*, volume 2, American Aviation Publications, 1958.

Frank Malina

1912–

Early work in the practical application of liquid and solid rocketry to sounding rockets, jet assisted take-off (JATO) and early ballistic missiles

A co-founder with Theodore von Kaŕmán of Aerojet General Corporation, Frank Malina was born in Brenham, Texas. Educated in mechanical engineering, he received his Bachelor of Science degree from the Agricultural and Mechanical College of Texas (now Texas A & M University). Upon graduation he received a scholarship to continue study at the California Institute of Technology and obtained his Master of Science in mechanical engineering in 1935, a Master of Science in aeronautical engineering in 1936 and, in 1940, his doctorate in aeronautical engineering.

While at Caltech, Malina had the opportunity of working with von Kármán and his senior staff at GALCIT (Guggenheim Aeronautical Laboratory, California Institute of Technology). At the time, the Laboratory was conducting studies on the problems of high-speed flight and the limitations of engine-propeller propulsion were beginning to be recognized. Malina proposed a program of research on rockets to von Kármán, who gave permission to pursue it at GALCIT without funding. This early rocket work attracted considerable interest, and in 1938 Consolidated Aircraft Company approached GALCIT for information on rocket-assisted take-off of large aircraft. In answering the inquiry, Malina concluded that the rocket was admirably suited for this purpose. It was not until 1943, however, that liquid propellant rocket engines built at Aerojet-General Corporation were tested in a Consolidated Aircraft Company flying boat.

In 1942 Malina and von Kármán founded Aerojet General Corporation, but Malina remained active with GALCIT, where he was instrumental in working on research with sounding rockets, particularly the *WAC Corporal.*

REFERENCES: Frank Malina, manuscript in Biographical Files, National Air and Space Museum, Smithsonian Institution, Washington, D. C.; *Who's Who in World Aviation and Astronautics*, volume 2, American Aviation Publications, 1958.

Edmund S. Buckley

1904–

Development of range instrumentation, tracking networks, and data acquisition systems vital to flight research and space exploration

Born in Fitchberg, Massachusetts, Edmund S. Buckley earned a Bachelor of Science degree in electrical engineering at Rensselaer Polytechnic Institute in 1927. Buckley joined the National Advisory Committee for Aeronautics at Langley Research Center in 1930. In 1943, he was named chief of the Instrument Research Division. While in this capacity, he was responsible for the development and construction of electrical, mechanical, optical, and electronic instruments in support of research in wind tunnels, specialized laboratories, and in-flight vehicles, including high-speed research aircraft and rockets. Buckley was largely responsible for development of the NASA Wallops Island rocket test area and for the flight and ground instrumentation used at the NASA Flight Research Center, California.

In 1959, he was named assistant director for Space Flight Operations of the National Air and Space Administration. Under his direction, the Project Mercury, and lunar and interplanetary networks were established and the scientific satellite network was updated and expanded. He also directed establishment of the *Gemini* network, the plans for the *Apollo* network and organization of a NASA world-wide cable and radio communication system.

Buckley was later appointed associate administrator of NASA's Office of Tracking and Data Acquisition, where he continued to oversee planning, development, and direction of the ground instrumentation system. Retiring from NASA in 1968, he continued to serve as special assistant to the administrator.

REFERENCES: *NASA News Release* Nos. 68-17 (26 January 1968), 59-107 (25 March 1959).

Arthur C. Clarke

1917–

Originator of the concept of the communications satellite

A truly prophetic figure with an intense interest in space and its exploration, Arthur C. Clarke is perhaps best known as the author of over 40 books and numerous articles on science fiction. Clarke was born on 16 December 1917, in the town of Minehead, in Somerset, England. Educated at Huish's Grammar School in Taunton, he entered the British civil service in 1936 as auditor in the H. M. Exchequer and Audit Department. With the onset of World War II, Clarke joined the Royal Air Force and became an instructor at the radar school. After working awhile on early-warning radar systems, he was assigned to work on installation of the first ground controlled approach landing system. It was during this period that he conceived his idea for a communications satellite. His paper, written in 1945, describes in detail the geostationary satellite system now used by all commercial communication satellites.

Early in 1946, Clarke managed to get a grant and entered King's College, London. He graduated two years later with a Bachelor of Science degree in pure and applied mathematics and physics with first class honors. Shortly after graduation he accepted a position as assistant editor of *Science Abstracts*, but within a year turned to full time writing. Since 1954, Clarke has been engaged in underwater exploration on the Great Barrier Reef of Australia and the coast of Ceylon.

Clarke became widely known to the general public when he and Stanley Kubrick wrote *2001: A Space Odyssey*. A frequent lecturer, Clarke has received many awards and honors for his writings and contributions to the field of aerospace communications.

REFERENCES: "Profiles," *New Yorker Magazine*, 9 August 1969; Biography of Arthur C. Clarke, manuscript in Biographical Files, National Air and Space Museum, Smithsonian Institution, Washington, D. C.; *Current Biography*, H. W. Wilson Co., 1966.

Hubertus Strughold

1898–

Significant contributions in space medicine

Internationally recognized as the father of space medicine, Hubertus Strughold has made significant contributions to such space travel problems as weightlessness, visual disturbances, and disruption of normal time cycles. The son of a local school principal, he was born in Westtünnen in the Province of Westphalia, Germany. After graduating from the Gymnasium in Hamm in 1918, he studied the natural sciences at the Universities of Göttingen and Munich and received his Doctor of Philosophy degree in physiology at the University of Münster in 1922. The following year he received his Doctor of Medicine degree from the University of Würzburg. After receiving his degree he remained at Würzburg as a research assistant.

Impressed with the transoceanic flight of Charles Lindbergh in 1927, Strughold recognized flight as an area in which physiological problems would be encountered. He immediately began assimilating all available literature on the subject of high altitude physiology and initiated research on sensor motoric tests in a low pressure chamber. In 1928 he came to the United States on a Rockefeller Foundation fellowship and studied the effects of oxygen deficiency upon the heart. Returning to Würzburg in the fall of 1929 he resumed his lectures in flight physiology. When the German Aeromedical Research Institute was established in Berlin in 1935, Strughold was appointed director and began an investigation into the effects of oxygen deficiency. With the Allied occupation of Germany in 1945, Strughold was taken prisoner but released to head an aeronautical project at the University of Heidelberg under American direction.

In 1947 Strughold emigrated to the United States to accept a position on the staff of the Air Force School of Aviation Medicine at Randolph Field, Texas. Using a variety of equipment, Strughold and others investigated the effects of high speed, oxygen deficiency, decompression, and ultraviolet rays on animals and men. Appointed chief scientist of the Aerospace Medical Division in 1962, he continued research on the visual problems of space flight and the effect of orbital flight on the day-night cycles of the human body. He has authored more than 170 professional papers on physiology, aviation, and space medicine and has written several books. Strughold has received numerous awards for pioneer research in space medicine.

REFERENCE: *Current Biography Yearbook*, The H. H. Wilson Company, 1966.

William Randolph Lovelace

1907–1965

Pioneering work in aerospace medicine and development of advanced high-altitude breathing devices

A brilliant surgeon and imaginative researcher, William Randolph Lovelace successfully combined his love for flying with his devotion to medicine. Born in Springfield, Missouri, he spent most of his youth in New Mexico, where his physician-uncle inspired him to pursue a career as a surgeon. Lovelace attended high school in Alburquerque, New Mexico, entered medical school at Washington University in St. Louis, and after graduation continued his studies at Harvard

University where he received his Doctor of Medicine in 1934. After serving his internship at Bellevue Hospital he entered the Mayo Foundation in Minnesota. In 1940 he was awarded his Master of Science in surgery from the University of Minnesota.

Lovelace had learned to fly as a medical student and with his keen interest in aviation he became chief of the Aero Medical Laboratory at Wright Field, Dayton, Ohio, in 1943. It was while in this capacity that he personally tested bail-out oxygen equipment while testing his theories for high altitude survival. He made a hazardous jump from an altitude of 40,500 feet (12,100 m) to perfect the parachute technique of delayed opening that helped hundreds of flyers thereafter. Lovelace was awarded the Collier Trophy in 1940 for his part in developing the first advanced high-altitude breathing device, the oxygen mask which became standard equipment for both military and commercial aviators.

In 1947 he helped found the Lovelace Foundation for Medical Education and Research at Albuquerque, which pioneered in aerospace medical studies. In addition to other vital activities, this foundation devised the first physical tests for prospective astronauts and developed computer techniques for medical diagnosis and research.

Lovelace died, with his wife and their pilot, in an aircraft accident near Aspen, Colorado. At the time of his death he held a reserve assignment with the Air Force at the rank of brigadier general. He was promoted to the rank of major general posthumously.

REFERENCES: Obituary, *Astronautica Acta*, volume 12, number 2 (1966); John F. Loosbrock, Obituary, *Air Force Magazine*, 20 December 1965; *NASA News* Release, number 63-274 (13 December 1963); *Who's Who in Space 1966–1967*, Space Publications Incorporated, 1965.

Literature Cited

Anderson, Frank W., Jr.
1976. *Orders of Magnitude.* 100 pages. Washington, D.C.: National Aeronautics and Space Administration.

Anderson, R. G.
1946. History of Rotary Wing in the United States. *The American Helicopter Quarterly*, 1(1):26–38.

Anonymous
1911. [On Aircraft Fatalities and Their Causes.] *The Aeronautical Journal*, July:125.

Armytage, W. H. G.
1961. *A Social History of Engineering.* 350 pages. New York: Pitman Corporation.

Atwater, Gordon I.
1974. Petroleum. *Encyclopaedia Britannica*, 14:164–189. Chicago: Willian Benton Publisher.

Bryan, G. H.
1911. *Stability in Aviation.* 192 pages. London: Macmillan and Co., Ltd.

Bryant, Lynwood.
1967. The Beginnings of the Internal Combustion Engine. *In* Melvin Kranzberg and Carrol W. Pursell, Jr., editors, *Technology and Western Civilization*, 1: 648–664. New York: Oxford University Press.

Crouch, Tom D.
1979. Engineers and the Airplane. *In* Richard P. Hallion, editor, *The Wright Brothers: Heirs of Prometheus*, pages 3–19. Washington, D. C.: Smithsonian Institution Press.

Delear, Frank J.
1961. *The Story of the Helicopter.* 35 pages. Connecticut: Sikorsky Aircraft, A Division of United Aircraft Corporation.

Durand, W. F.
1953. *Adventures: A Life Story.* 212 pages. New York: McGraw-Hill Book Company.

Ege, Lennart
1974. *Balloons and Airships.* 234 pages. New York: The Macmillan Company.

Gatland, Kenneth
1975. *Missiles and Rockets.* 256 pages. New York: The Macmillan Company.

Giacomelli, R., and E. Pistollesi
1963. Historical Sketch. *In* W. F. Durand, editor, *Aerodynamic Theory*, 1:305–394. New York: Dover.

Gibbs-Smith, Charles H.
1970. *Aviation.* 316 pages. London: Her Majesty's Stationery Office.

Gilmor, C. Stewart
1971. *Coulomb and the Evolution of Physics and Engineering in Eighteenth-Century France.* 328 pages. New Jersey: Princeton University Press.

Grahame-White, Claude, and Harry Harper
1911. *The Aeroplane Past, Present and Future.* London: T. Werner Laurie.

Gray, George W.
1948. *Frontiers of Flight.* 362 pages. New York: Alfred A. Knopf.

Hallion, Richard P.
1972. *Supersonic Flight.* 248 pages. New York: The MacMillan Company.
1977. *Legacy of Flight.* 292 pages. Seattle: University of Washington Press.
In Prep. To Study the Problems of Flight: The Creation of the National Advisory Committee for Aeronautics.

Hart, Clive
1972. *The Dream of Flight.* 193 pages. New York: Winchester Press.

Hoff, Nicolas J.
1967. Thin Shells in Aerospace Structures. *Aeronautics and Astronautics*, February:26–45.

Hunsaker, J. C.
1915. Experimental Analysis of Inherent Longitudinal Stability for a Typical Airplane. In *First Annual Report of the National Advisory Committee for Aeronautics*, pages 25–75. Washington, D. C.: National Advisory Committee for Aeronautics. [Also printed as *NACA Technical Memorandum*, 1.]

Johnson, S. Paul
1974. History of Aviation. *Encyclopaedia Britannica*, 2:380–406. Chicago: William Benton Publisher.

Jones, B. M.
1929. The Streamline Airplane. *The Journal of the Royal Aeronautical Society*, May:358–385.

Jones, R. T.
1977. Recollections from an Earlier Period in American Aeronautics. *Annual Review of Fluid Mechanics*, pages 1–11.

Judge, Arthur W.
1917. *The Design of Aeroplanes.* 242 pages. London: Sir Isaac Pitman and Sons, Ltd.

Junkers, Hugo
1923. Metal Aeroplane Construction. *Journal of the Royal Aeronautical Society*, 28:406–449.

Lanchester, F.
1907. *Aerodynamics.* 442 pages. London: A. Constable & Co., Ltd.
1908. *Aerodonetics.* 433 pages. London: A. Constable & Co., Ltd.

Malina, Frank S.
1964. Origins and First Decade of the Jet Propulsion Laboratory. *In* Eugene M. Emme, editor, *History of Rocket Technology*, pages 46–66. Detroit: Wayne State University.
1974. MSFC Skylab Orbital Workshop. *Marshall Space Flight Center, NASA Technical Memorandum*, X-64813, (1): 562 pages.

McFarland, Marvin W.
1953. *The Papers of Wilbur and Orville Wright.* Volumes 1 and 2, 1278 pages. New York: McGraw-Hill Book Co.

Miller, Ronald, and David Sawers
1970. *The Technical Development of Modern Aviation.* 351 pages. New York: Praeger Publishers.

Munson, Kenneth
1968. *Helicopters and Other Rotorcraft Since 1907.* 178 pages. New York: The Macmillan Company.

NACA (National Advisory Committee for Aeronautics)
1915. *First Annual Report of the National Advisory Committee for Aeronautics.* 303 pages. Washington, D. C.: National Advisory Committee for Aeronautics.

Nayler, J. L., and E. Ower
1965. *Aviation: Its Technical Development.* 290 pages. London: Vision Press, 1965.

North, John D.
1923. The Case for Metal Construction. *The Journal of the Royal Aeronautical Society*, 28 (January):3–25.

Rae, John B.
1967. The Invention of Invention. *In* Melvin Kranzberg and Carrol W. Pursell, Jr., editors, *Technology in Western Civilization*, 1:325–336. New York: Oxford University Press.

Schlaifer, Robert, and S. D. Heron
1950. *Development of Aircraft Engines and Fuels.* 753 pages. Boston: Harvard University Press.

Schuman, Louis, and Goldie Back
1930. Strength of Rectangular Flat Plates under Edge Compression. In *Sixteenth Annual Report of the National Advisory Committee for Aeronautics*, pages 515–538. Washington, D. C.: National Advisory Committee for Aeronautics.

Taylor, C. Fayette
1971. Aircraft Propulsion: A Review of the Evolution of Aircraft Piston Engines. *Smithsonian Annals of Flight*, 4:134 pages.

Taylor, John W. R.
1968. *Helicopters and VTOL Aircraft.* 93 pages. Garden City: Doubleday and Company.

Timoschenko, Stephen P.
1953. *History of Strength of Materials.* 452 pages. New York: McGraw-Hill Book Company.

von Kármán, Theodore
1924. Die Mittragenda Breite. *Beitrage zür technischen Mechanik*, pages 114–127.
1954. *Aerodynamics.* 203 pages. Ithaca: Cornell University Press.

Wagner, H.
1929. Structures of Thin Sheet Metal: Their Design and Construction. *National Advisory Committee for Aeronautics Technical Memorandum*, 490: 25 pages.

Warner, E. P.
1923. Factors of Safety. *National Advisory Committee for Aeronautics Technical Memorandum*, 242:1–6.

Weyl, A. R.
1965. *Fokker, the Creative Years.* 420 pages. London: Putnam and Company, Ltd.

Williamson, Harold F., and Arnold R. Daum
1959. *The American Petroleum Industry.* 864 pages. Evanston, Ill: Northwestern University Press.

Zienkiewicz, O. D.
1971. *The Finite Element Method in Engineering Science.* 521 pages. London: McGraw-Hill Book Company.

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Copy must be typewritten, double-spaced, on one side of standard white bond paper, with 1¼" margins, submitted as ribbon copy (not carbon or xerox), in loose sheets (not stapled or bound), and accompanied by original art. Minimum acceptable length is 30 pages.

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