NATIONAL ACADEMY OF SCIENCES

# WILLIAM FREDERICK DURAND

*1859—1958*

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*A Biographical Memoir by*

FREDERICK EMMONS TERMAN

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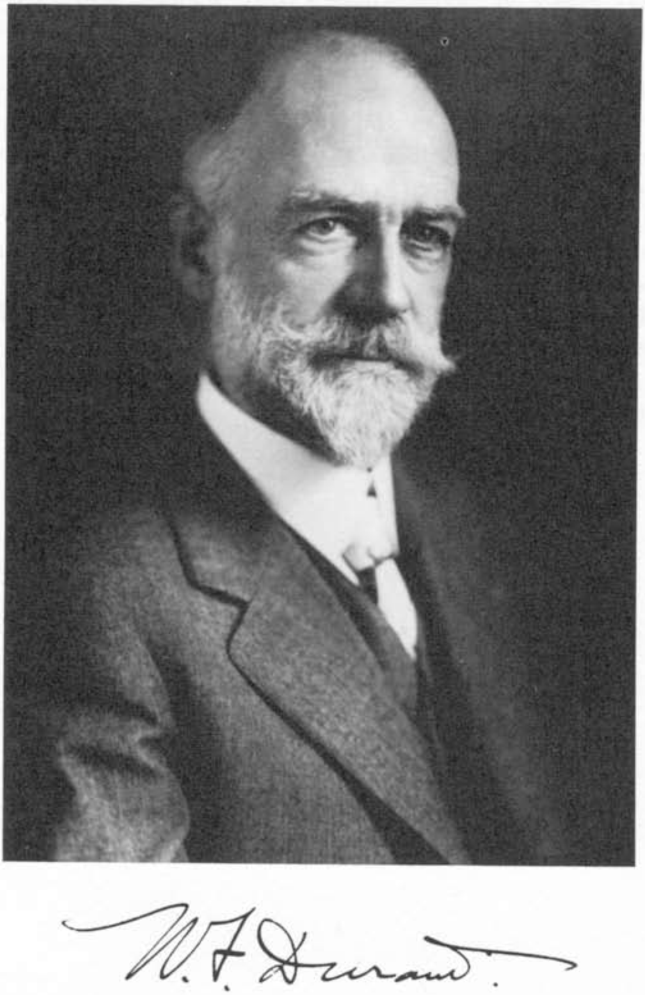
W. F. Durand.

# WILLIAM FREDERICK DURAND

*March 5, 1859–August 9, 1958*

BY FREDERICK EMMONS TERMAN

WILLIAM FREDERICK DURAND began his professional career in 1880, when upon graduation from the U.S. Naval Academy he was assigned to the U.S.S. *Tennessee* to look after its steam engine and associated boiler. This was the largest vessel in the U.S. Navy and was the flagship of the North Atlantic fleet. It had a wooden hull and was full-rigged with mast, sails, and spars; the steam engine was for use when the wind was not favorable. Durand's last important assignment was assumed in 1941 at age eighty-two, when Vannevar Bush, Chairman of the National Advisory Committee on Aeronautics, appointed Durand chairman of a committee that was assigned the responsibility of getting a jet engine for aircraft propulsion designed and manufactured in the United States. Durand carried this responsibility, as well as concurrently serving as Chairman of the Engineering Division of the National Research Council, until mid-1945, a few months beyond his eighty-sixth birthday.

Durand came from early New England stock and was of mixed English and French-Huguenot blood. He was born March 5, 1859, at a village now known as Beacon Falls, Connecticut, and grew up on a farm near Derby, Connecticut, which is approximately eight miles west of New Haven. His boyhood environment was that typical of New England farm and country town life in the period immediately after the Civil War.

In school Durand showed unusual aptitude and interest for mathematics. He also had a special fondness for working with tools in the way of devising implements and apparatus—usually related to some phase of farm work. As an example, he spent much time and effort on the design and construction of a horse-drawn hay rig with operating features that he regarded as superior to the rig then being used on the family farm.

On the basis of these qualities, his older brother urged him to compete for entrance to the U.S. Naval Academy because of its engineering course. The permit necessary to attend the entrance examination was obtained through a congressman friend. To further his chances for selection to Annapolis, he dropped attendance at the high school for the spring of 1876 and spent the time in the tool room of a factory in a nearby village, riding to work daily on horseback. Here he gained familiarity with machine tools, a factor in the examination at Annapolis. Also that summer he supplemented his rather skimpy high school education by an intensive coaching review of the subjects covered by the Annapolis examination offered at the Maryland Agricultural College (now the University of Maryland). In the entrance examination Durand ranked tenth among the eighty applicants. He entered the Naval Academy in the fall of 1876.

The years at the Naval Academy were a turning point in Durand's life. His school days in New England had provided little in the way of competition, and he had developed no special ambition, love of study, or definite purpose. Life at the Naval Academy, with its keenly competitive features, and with its appeal to the ambitions and visions of young adults, awakened him. Although the lessons were long and the examinations searching, he responded to the challenge. Seventy-three years later he wrote, "I give emphatic praise to the course of instruction and to the thorough training at Annapolis. Whatever I may have been able to accomplish in later years, I credit unreservedly to this institution and to the training received there." Scholastically, his class rank was four, three, two, and one in his successive years, with an overall rank for the four years of number two. In his last year he was also given the highest cadet rank for which he was eligible—the so-called three-stripe rank, which was based upon the general record, including not only class scholastic standing, but also aptitude for the service. This placed him in command of the four classes of engineering students at all general functions, such as dress parades, and also of his own class at all formalities. Thus did the farm boy from rural New England discover that he could achieve leadership in a broader world.

Upon graduation from the Naval Academy in 1880, Durand was assigned to the U.S.S. *Tennessee*, as previously indicated. The next three years were spent on cruises up and down the Atlantic Coast and among the West Indies. In June of 1883 he was detached from the *Tennessee* and ordered to duty in the design room of the Bureau of Steam Engineering of the Navy Department, in Washington, D.C. Here he worked on the design of the engines for the cruiser *Chicago*, one of the first four ships of the new steel navy that Congress had authorized a few years before.

During the three-year cruise on the *Tennessee*, Durand had begun to question whether a career in the Navy was best suited to his tastes and capacities. He also desired to be in a position to marry and to enjoy family life. A few years earlier a bill had been passed by Congress providing for the detail of officers in the Engineering Corps of the Navy to scientific and technical institutions of learning for the purpose of giving instruction in steam engineering and iron shipbuilding. Teaching had always appealed to Durand. He recognized that such an assignment would provide an opportunity to try out academic work in a provisional way without a final commitment. Accordingly, learning that Lafayette College at Easton, Pennsylvania, had applied for such a detail, Durand took the necessary steps and in due time was ordered there on temporary detached duty, where he spent two pleasant years. In the fall, on October 23, 1883, he married Charlotte Kneen, five months his junior and a classmate from Derby High School. On June 14, 1885, a son, William Leavenworth, was born, their only child.

After leaving Lafayette, Durand spent the next eighteen months on engineering assignments connected with the construction and testing of the new steel ships being built for the Navy. His most notable experience in this connection was as a member of the crew of the U.S.S. *Dolphin*, a so-called dispatch boat, when this vessel demonstrated its structural soundness by deliberately steaming full speed into the teeth of a storm off Cape Hatteras and coming through this ordeal unscathed. This ship had become the center of a political controversy, having been contracted for and designed under a Republican administration, but offered for acceptance to a succeeding Democratic administration that questioned its seaworthiness.

During this period, Durand continued to think about his future and looked with increasing favor upon a career in the academic world. He sought and obtained an assignment by the Navy to Worcester Polytechnic Institute in March 1887, with the thought that this could be a stepping-stone to something more permanent. The following summer he was offered a position at Michigan State College (now Michigan State University) to organize and direct a new Department of Mechanical Engineering. This he accepted and concurrently resigned from the Navy as of September 1, 1887. The following year Lafayette awarded him the Ph.D. degree as a result of studies that he had initiated during his tour of duty at that institution and had completed in absentia in 1887–1888.

Durand undertook the organization and development of the Michigan State Mechanical Engineering Department with great enthusiasm and within a few years had laid a good foundation for the future. However, fate had other plans in mind for him.

In the late spring of 1891 he was offered a professorship in Mechanical Engineering at Purdue University. Feeling this position would be a step upward in his academic career, he accepted, only to discover later in the summer that an opening existed at Cornell University as head of a new postgraduate program in Naval Architecture and Marine Engineering in Cornell's Sibley College. Naturally this opening was attractive to him, so he contacted Dr. R. H. Thurston, Director of Sibley College. After due consideration, Thurston informed Durand that they would like to have him as head of this new program if he could honorably clear himself of all obligation to Purdue. This he accomplished through finding a suitable substitute for his position.

At Cornell Durand had an opportunity for the first time to engage systematically in research and other creative work. He took full advantage of this situation, as is evidenced by the prodigious stream of publications that came from his pen during his thirteen years at Cornell.

Durand's most important work during this period was his study of the screw propeller. From his early days on the cruise of the *Tennessee,* Durand had been interested in the screw propeller and its theory of operation. It appeared to him that through tests on models it would be possible to relate the physical proportions and operating conditions of the propeller to its performance. Cornell had a Hydraulic Laboratory with a concrete-lined canal that was suitable for such an investigation if it could be equipped for carrying out the necessary experimental observations. The apparatus needed included: (1) a car with wheels running on rails laid on either side of the canal and fitted for carrying the model propeller and the necessary electrical equipment for its operation at any speed along the canal, at any desired number of revolutions per minute of the model, together with the measuring equipment for determining the thrust and input power to the propeller, as well as revolutions per minute; and (2) electrical equipment for propelling the car at any desired speed along the track with electrical contacts and registering equipment for determining such speed. Since Cornell had no funds for the necessary equipment, Durand applied to the Carnegie Institution of Washington for financial help and was awarded the necessary grant.

Altogether some forty-nine models, each one foot in diameter, were tested for varying form and proportion, area, and pitch ratio. With the results of such model tests and by the use of laws of comparison in stepping from model to full scale, it was then a simple matter to determine the characteristics of a full-scale propeller to meet any proposed conditions of operation. The result was to make it possible to design and calculate the performance of a marine screw propeller on a systematic basis. Some years later Durand applied this same approach to pioneering studies of the airplane propeller, as will be subsequently recounted.

Durand's work at Cornell was not, however, limited exclusively to work on the screw propeller, as evidenced by the titles of various papers that he wrote during this period. Two additional contributions are worthy of particular attention. The first of these was the introduction around 1892 or 1893 of logarithmic cross-section paper. Durand was apparently the first ever to have had the idea of ruling cross-section paper with intervals corresponding to the logarithms of the numbers set down on the axis. As late as 1936 the general catalog of Keuffel and Esser Co. listed logarithmic paper under the title, "Durand's Logarithmic Paper."

Another important contribution during the Cornell period was the invention of a planimeter for averaging the ordinates of a diagram plotted in radial (polar) coordinates. As clock recording instruments were becoming common in power plants and elsewhere, Durand obtained a patent on the device and for years received royalties from a manufacturer of scientific instruments licensed under this patent.

The pleasant rhythm of the Cornell years was suddenly upset by the unexpected death of Thurston from a heart attack in October 1903. Durand, who had been made Secretary of Sibley College by Thurston some years before, was appointed Acting Director for the remainder of the year while a search was launched for a successor to Thurston. After the appointment in the spring of Professor A. W. Smith of Stanford University as the new Director of Sibley College, Durand decided to apply for a year of sabbatical leave during which plans could be made for the future.

However, late in the spring of 1904, fate again intervened in Durand's life, when President David Starr Jordan of Stanford persuaded him to fill the vacancy created at Stanford by the departure of A. W. Smith. Durand served as professor and head of Mechanical Engineering at Stanford until his retirement in 1924, and as Professor Emeritus until his death on August 9, 1958.

During his first year at Stanford, Durand was also in charge of the Electrical Engineering Department, along with an assignment from Dr. Jordan to find a head for that department. To this end he consulted extensively with his close friend Harris J. Ryan of Cornell, who had already achieved distinction for studies of corona generated by high-voltage electrical power lines. During the course of these consultations, he discovered that Ryan might himself be interested in this opening. The result was that Ryan came to Stanford in 1905 as head of the Department of Electrical Engineering, a position that he filled with great distinction, as indicated by his election to the National Academy of Sciences in 1920.

At Stanford the Durands quickly adjusted to their new circumstances. In 1905 they built a home on a hill that overlooked the university buildings and that also provided a breathtaking view of San Francisco Bay and the northern end of the Santa Clara Valley. They were delighted when the Ryans built a home on an adjacent lot in 1906.

The San Francisco earthquake of April 18, 1906, caused major damage to Stanford's buildings. During the following two years, Durand gave much of his spare time to service on a three-man faculty Board of Engineering responsible for making the temporary repairs required to enable the University to reopen in the fall, and for planning the permanent restoration of the damaged structures.

In planning for the Panama Pacific International Exposition, held in San Francisco in 1915, the major engineering societies of the United States decided to hold a worldwide Engineering Congress. Durand was appointed chairman of the local Committee of Management and spent much of his time for several years getting together an adequate staff, making plans for the Congress, and inviting delegates from the leading nations to write papers to be read before it. Finally came the Congress itself, with a great opening session, an address by General Goethals, who had accepted the post of Honorary President, receptions, banquets, technical sessions, etc. Thereafter came the work of gathering together all the papers read before the Congress and the related discussions, and preparing this material for publication. This latter phase was interrupted by World War I, and was not finally completed until around 1920.

With his fluid mechanics background, it was natural for Durand to become interested in the water and power problems of the western United States. He retained this interest until the end of his life. For some thirty years he served as a consultant to the Bureau of Power and Light of the City of Los Angeles in the construction and design of its water and electrical supply systems. For the City of San Francisco there was a period of three or four years' service in connection with the design and construction of the Hetch Hetchy Dam and the associated water supply and hydroelectric power installations. He also helped the Metropolitan Water District of California in the design and construction of pumping equipment for the Colorado River canal to bring river water to Los Angeles and other cities. As a by-product of these assignments, he did significant research on hydraulic machinery, the hydraulics of pipelines, and the theory of the surge chamber.

In spite of these new activities, Durand never lost his interest in the problems of the screw propeller. With the development of the airplane, he began to give attention to the airplane propeller, and in the 1914 volume of the *Journal of the Franklin Institute* he has a twenty-seven-page paper, "The Screw Propeller; with Special Reference to Airplane Propulsion." In that same year he attended a conference in Washington, D.C., called by Charles D. Walcott, Secretary of the Smithsonian Institution, the purpose of which was to consider ways and means for awakening and stimulating interest in aeronautical science, with particular reference to activity on the part of the government. This conference developed a background that led to a bill enacted by Congress the following year providing for the organization of the National Advisory Committee on Aeronautics (NACA, now NASA), which was "to supervise and direct scientific study of the problems of flight with a view to their practical solution." President Wilson appointed Durand as one of the five civilian members of this Committee, which held its first meeting in the spring of 1915.

At this first meeting Durand set forth the need for experimental studies of the air propeller analogous to those of ship propellers he had carried on at Cornell. This proposal met with favor by the Committee, and led later to a contract with Stanford University for carrying out such an investigation under NACA sponsorship. This contract called for an expenditure of $4000 for the initial year, including the cost of building and instrumenting the wind tunnel that would be used in carrying out the tests. Even allowing for the change in purchasing power that has occured since 1916, this is indeed a modest sum for the first definitive investigation on a basic topic, especially when compared with present-day grants.

This was the beginning of a long series of researches on air propellers performed at Stanford with the help of Professor E. P. Lesley, which extended over the following dozen or so years.* Over one hundred model propellers were tested in a wind tunnel under widely varying conditions of operation, and principles of design were established. The resulting reports were the authoritative sources for design data for many years. This investigation included the first experimental study made in the United States of the variable-pitch propeller, which in time came into almost universal use in all propeller-driven airplanes. It also included a thorough comparison of the measured data with theoretically computed characteristics for eight of the model propellers, as well as a comparison of model results with full-scale flight-test data, which were obtained under Lesley's direction at the Langley Laboratory of NACA. The latter comparison, which necessarily involved the testing of the propeller in combination with a fuselage, gave rise to the important concept of *propulsive efficiency* for such combinations. This became a standard analytical tool in the design of propeller-driven aircraft.

At the second meeting of NACA, held in the fall of 1916, Durand was chosen chairman. Upon the entry of the United States into World War I in the spring of 1917, Durand took a leave of absence from Stanford and moved to Washington, D.C.

*It is significant that these studies of propellers were conducted with little or no involvement of graduate students. Neither were they used as a vehicle to recruit and develop young faculty members of outstanding promise. In spite of his diverse accomplishments and leadership qualities of high order, Durand was not notable as an organizer of academic programs or as a developer of faculty talent.

He was soon in the midst of feverish activity preparing for U.S. participation in the war. Under the general supervision of NACA, the Liberty airplane engine was designed and built by the American automotive industry; a cross-license agreement was negotiated whereby all important aircraft patents were pooled for common use during the period of the war; ground training schools for aviators were established at a number of universities; etc. In the autumn of 1917 Durand played an important personal role in initiating the development of the first successful airplane supercharger for increasing the performance of airplane engines at high altitudes. He was also a primary force in the establishment of the NACA Laboratory at Langley Field.

During this period Durand took his first flight in an airplane, a ride in an Italian triplane from Langley Field to Washington, D.C., some 120 miles.

In the spring of 1917 Durand was elected to membership in the National Academy of Sciences. With the onset of war, the Academy had come to the conclusion that it could more adequately meet its obligations as advisor to the government in scientific and technical matters by opening its membership to the engineering profession and, accordingly, in 1917 elected three engineers to membership. This nucleus of engineers was initially attached to the section of Physics, but later, with enlarged numbers, provided the basis of a section of Engineering. Durand soon became involved with the Engineering Division of the National Research Council (NRC), an operating arm of the National Academy of Sciences, and was made vice chairman of the Engineering Division, in charge of its Washington activities. The offices of NRC and NACA were in the same building, so his working day was spent shuttling between floors.

Among its other activities, NRC organized "a Research Information Service," which was to have liaison offices in London and Paris that would maintain continuous and close contact with developments in the application of science to warfare. Durand was offered and accepted the post at Paris. He picked Karl Compton, later President of MIT, as his chief assistant and left for France in January 1918 on a convoy bound for England. In England he looked up Admiral Sims, who was in charge of the U.S. Naval forces in Europe. Sims and Durand had been classmates at the Naval Academy and afterwards shipmates on the three-year cruise on the U.S.S. *Tennessee,* so they knew each other well. Sims arranged for Durand to be housed in the Paris headquarters of the Navy, and he saw to it that appropriate contacts were established with the U.S. Embassy and the French Army and Navy.

While in Paris, a young naval aviator, Harry F. Guggenheim, became closely associated with Durand. Some eight years later Harry Guggenheim became president of the Daniel Guggenheim Fund for the Promotion of Aeronautics, which played a critically important role in the development of the science of aeronautics and civil aviation in this country. Durand served as a Trustee of this Foundation for a number of years.

The Paris assignment turned out to be an interesting and pleasant episode in Durand's life. His effectiveness was facilitated by an excellent working knowledge of the French language gained while at the Naval Academy. This mastery had come about in an interesting way. The Academy curriculum included two years of French, but Durand found this subject uncongenial and give it little attention and effort, with the result that at the end of the first year his grade in French was barely above passing. Upon reflection this gave him a distinct feeling of shame. He thereupon gave himself the equivalent of a good scolding, and decided that since French was part of the curriculum, it was incumbent upon him to change his attitude toward the subject. Accordingly, before embarking on the summer cruise, he bought a French book and occupied his spare moments during the cruise reading this book with the aid of a dictionary, thereby acquiring a vocabulary. In this self-study he developed the technique of passing directly from the printed French word to its meaning without the intermediary of an English word. He thus acquired an appreciation of the quality and character of the French language. His grade in French showed a gratifying improvement in the next year. He also utilized every opportunity to practice conversational French. By these means his facility with both the spoken and printed language became so anchored in his memory that it remained with him throughout his life. Subsequently, Durand applied the same technique to Spanish during the one-year course required at the Academy. Having become interested in languages, Durand acquired a German grammar and dictionary while on the U.S.S. *Tennessee*, and, with the aid of a fellow officer of German extraction, taught himself to read and speak German with fair facility, without ever having a formal course in the subject. He then followed the same strategy with Italian. This learning of French, Spanish, German, and Italian illustrates how Durand, once having set a goal for himself, had the self-discipline to achieve his objective.

In the summer of 1918 the Royal Aeronautical Society of England invited Durand to deliver the Wilbur Wright Memorial Lecture, the first American to be so honored. This was the occasion for a memorable cross-channel trip from Paris to London. In the lecture he dealt with the problems of aircraft design, construction, and operation as factors in a war effort, carefully working out his ideas to avoid disclosing information of value to the enemy. It was attended by an appreciative audience of some 2,000. This occasion led to Durand's election as a Fellow in the Royal Aeronautical Society.

Shortly after the armistice Durand returned from Paris to Stanford. Here he resumed a normal program of university activities, including, in particular, active, direct participation in the airplane propeller studies that had continued at reduced pace during his absence. He also introduced a new course, "Theory of Flight," one of the first courses taught in the United States on this subject. He likewise resumed work in the field of hydraulics, with special attention to problems of hydraulic shock and surge chambers, as evidenced by several publications in the early 1920s, including the book *Hydraulics of Pipe Lines.*

In 1924 Durand reached Stanford's retiring age. This changed the character of his activities but not their tempo. In the fall of 1924 he was elected President of the American Society of Mechanical Engineers (ASME) and spent most of the year 1925 resident in New York City. During this year he traveled a great deal, carrying the Society's message to the local branches; his diary lists ninety addresses at fifty-seven different locations.

Toward the end of 1925 his work for the ASME was largely displaced by his appointment by President Coolidge as a member of a Board of Aeronautic Inquiry. This board was appointed as a response to the public uproar created by the episode in which General Billy Mitchell charged that the military services were neglecting and suppressing aviation in national defense. For these allegations, Mitchell was court-martialed. The Board of Aeronautic Inquiry was charged with studying the nation's situation in aeronautics and advising President Coolidge as to the best national policy to follow, with particular reference to national defense.

Working with Durand were financier Dwight Morrow, a U.S. judge, a senator, two congressmen, a retired general, a retired admiral, and an industrialist. When the Board organized, Morrow became chairman and Durand secretary. After extensive hearings and the assembly of a great mass of information, advice, and opinion, the Board undertook the task of analyzing, weighing, and judging the great variations in viewpoints that had been expressed. After many executive conferences, the task of drafting a report with a content acceptable to the full Board was done largely by Durand and Morrow. The final report, as submitted to President Coolidge and signed by all members of the Board, proposed a general plan of development for Army and Navy aircraft for the immediate future. It also recommended the creation of the offices of Assistant Secretary of War for Air and Assistant Secretary of Navy for Air in order that the War and Navy departments would each have an official whose whole time and effort could be directed to developing the role of the airplane in warfare. This recommendation was promptly implemented and provided the administrative basis for handling military aviation until after World War II, when the Department of Defense was established.

In early 1927 Secretary Work of the Interior Department set up a five-man Board of Advisors to make a study of the many problems associated with the development of the Colorado River. This subject was very much in the public eye at the time and, because of varying sectional and ideological interests, had become politically highly controversial. Besides Durand, the Board included a former Secretary of the Interior, the Governor of Wyoming, a former Governor of Nevada, and a U.S. Senator.

The Board consulted with many people, public and private, gathered together numerous collections of photographs, reviewed many documents covering earlier studies of the river, and traveled on and along the river by boat, automobile, and horseback from Lee's Ferry, in Arizona, to where the river disappeared in a reed morass just above its junction with the Gulf of California. Each member of the Board wrote individual reports. These reports were favorably received and facilitated the passage of legislation that led to the construction of a dam and the installation of associated hydroelectric power-generating equipment. Durand's report covered the engineering and economic problems involved and demonstrated the desirability and feasibility of the construction of what is now known as the Hoover Dam.

Durand's report found particular favor with Dr. Mead, the Commissioner of Reclamation. He told Durand that if the dam and its associated installations were to be built, he planned to establish a Board of Consulting Engineers to advise the Bureau of Reclamation on the details of its design and construction. Accordingly, when construction of the Hoover Dam was assured, Durand was appointed a member of such a board, and at its first meeting became its secretary. It thus became his duty to record the discussions, findings, conclusions and recommendations, and to develop this material into suitable reports for the signature of the members. Durand's membership on this Board of Consulting Engineers continued until he became absorbed in World War II activities, and it led to his involvement with a number of other large dams, including the Grand Coulee, Shasta, and Friant, as well as numerous smaller ones in various parts of the West and Southwest.

Around 1926 Durand was asked by Mr. Daniel Guggenheim to become a member of the Board of Trustees of the Daniel Guggenheim Fund for the Promotion of Aeronautics. Early in its life this Board received a number of suggestions proposing some form of encyclopedic treatment of the entire field of aeronautics. Durand was asked by the Board to review the situation in this respect and to make recommendations as to a suitable Board policy. He concluded that airplane design and methods of construction were changing so rapidly that an encyclopedic treatment of these topics would be out of date before the work could be completed. On the other hand, he stated, there was beginning to appear a core of fundamental knowledge springing from the theory of fluid mechanics and the application of such theory to aeronautical problems that was sufficiently basic to be definitely secure from marked change with time. The resulting report was well received by the Board of Trustees, who decided that the fund would finance such an undertaking, provided Durand would serve as editor.

The resulting project occupied his time almost completely during the period 1929–1935. He decided that the work should be fully international, and, to achieve this, enlisted the help of

Theodore von Kármán. In a meeting at the University of Aachen, where von Kármán was then teaching, the two developed a complete plan for the work, together with a list of desirable contributors to be contacted and won over. As laid out, the project was divided into twenty divisions, of which Durand wrote three himself. The grant from the Guggenheim Fund provided only for the preparation of the various manuscripts. The work was expected to stand by itself as far as publication was concerned. However, as the first set of manuscripts became ready for the printer, the American firm that had originally agreed to undertake the publication work hesitated due to a feeling of uncertainty as to prospective sales. Accordingly, the agreement lapsed. At this critical juncture the publishing firm of Springer and Co. of Berlin, Germany, contacted Durand with an offer to assume all risks and to publish the complete work in English. In 1936 the last of the six volumes, totaling 2200 pages, was published.

The work was so well received that early in 1939 the publishers proposed the preparation of a supplementary volume to cover new developments. Again working with von Kármán, a plan was blocked out and potential authors contacted. However, the outbreak of World War II put an end to the project, although not before one manuscript had actually been received.

The great importance of the airplane in World War II resulted in a renewed demand for the volumes of the original edition. However, by this time the original edition was entirely sold out. To meet this situation, a limited private company was formed at the California Institute of Technology, which reproduced the entire work by the photo offset process.

The above paragraphs by no means catalog all of Durand's activities in the years between his retirement in 1924 and the onset of World War II. Thus in 1936 he served on a five-man committee to look into the question of tidal power at Passamaquoddy Bay, Eastport, Maine. The construction of dams and a tidal basin for the generation of hydroelectric power based on the abnormally high tide at this location had become a very live political issue, and President Roosevelt had asked Secretary of the Interior Ickes to appoint a special committee to look carefully into the matter. As in previous work of this type, the project involved on-site visits, the gathering and analysis of data, and consultation with many individuals. The resulting report was that the project was possible as an engineering undertaking, but was uneconomic as a source of power in comparison with other sources. The report furnished the means of quietly burying the proposal for the time being.

In the middle 1930s Durand was chosen as the President of the World Power Conference scheduled to be held in Washington, D.C., in September 1936, and this consumed much of his time in early 1936. Durand's welcoming address to the visiting delegates was first presented in English, and then repeated by him in French, German, and Spanish, the official languages of the conference. This multilingual performance was the occasion of much complimentary comment. Other speakers at the conference included President Roosevelt and Secretary of State Hull. The conference was well attended, with the result that no hotel had a dining room large enough to accommodate the entire group at the grand banquet. This problem was finally solved by using the large waiting room at the Union Railroad station as the banquet hall.

After the loss of the airships *Akron* and *Macon*, the Secretary of the Navy in 1935 appointed Durand as chairman of a Special Committee on Airships to study technical and policy questions relating to airships. Three comprehensive reports were made to the Secretary of the Navy over a period of three years.

In 1891, while a faculty member at Cornell, Durand had been elected to membership in the Society of Sigma Xi. That organization had been founded five years earlier at Cornell to provide a place in the domains of science and engineering comparable with that held by Phi Beta Kappa for the humanities. In 1936 and 1937 Durand served as national president for the Society. Since 1936 was the fiftieth anniversary year of Sigma Xi, it involved more than the usual activities.

For several years around 1937 Durand was occupied from time to time with the problem of how to care for the salmon that were prevented by the Grand Coulee Dam from reaching their normal spawning grounds on the Columbia River, above the dam. This problem was of sufficient importance that the Reclamation Bureau appointed a special three-man committee —Durand, an ichthyologist, and an economist—to investigate and report on the situation. After the usual site visits, assemblying of data, and conferences with various people, a report was written that made up a substantial little book. It recommended that the salmon collecting in shoals at the foot of Rock Island Dam (a low dam a few miles below Grand Coulee) be trapped in elevator cages and transported to fish culture stations on tributaries of the Columbia *below* Grand Coulee, where they would reach final maturity, and that the eggs then be removed from the females, fertilized, and hatched. The young fry were then to be fed and tended until large enough to be put back into the tributaries, from where they would go to the Columbia, and thence to the ocean, there to live until old enough to return to the upper reaches of the particular tributary in which they spent their youth, and so to repeat the cycle. This plan was adopted with apparently satisfactory results. Later, a study was made of the analogous problem associated with the Shasta Dam, on the Sacramento River.

Not all of Durand's extracurricular activities were associated with engineering and science. For some twenty years, beginning in the early 1920s, he was Vice Chairman of the Board of the Stanford Convalescent Home and Chairman of its Committee on Buildings and Grounds. This was a charitable organization that provided special care for children from underprivileged homes during the final stages of convalescence and was located on the grounds of the Leland Stanford family home at the edge of the Stanford campus.

In March 1941 Durand was called to Washington by Vannevar Bush, who was developing a national research program for defense under the auspices of the White House and who was also Chairman of NACA. Durand had been Chairman of NACA in 1917–1918, as previously noted, and had served as a member for eighteen years (1915–1933). His new assignment was to become a member of NACA again and to chair a new NACA committee charged with the study and development of jet propulsion for application to aircraft.* After considering the problem, this Special Committee on Jet Propulsion proposed that a turbojet approach be tried out in addition to the more conventional turbine-driven propeller. Rapid progress was made, with the result that the first test flight of a jet-propelled aircraft using a U.S.-built jet engine† took place in the latter part of 1942. A foundation was thus laid that enabled U.S.-made jet engines to assume a strong position in international aviation. With reference to these historic events of 1941 and 1942, Robert Schlaifer has written:

"It was apparently owing in large part to Durand, who was an especially energetic chairman, that jet propulsion was very seriously considered by the Committee. . . . Until this time almost no one in the U.S. had believed that jet propulsion was practical. Engineers generally had previously tended to think of the gas turbine purely as a substitute for the reciprocating engine driving a propeller."‡

*It was reported by the late Hugh Dryden that, when Bush requested President Roosevelt to make this appointment, the President suggested that a man of Durand's age should be allowed to enjoy his retirement and that a younger man be sought. Bush was persuasive, however, and got his way.

†This engine was a modified version of a British design.

‡See Robert Schlaifer and S. D. Heron, *Development of Aircraft Engines and Fuels* (Cambridge: Harvard Univ. Press, 1950), p. 460.

Durand was barely settled in Washington in 1941 when he was asked to take on the chairmanship of the Engineering Division of the National Research Council as an added duty. After studying the situation, he decided that he could handle the two jobs with the aid of a highly qualified executive secretary for the NRC activity. Once again, as in World War I, Durand found himself dividing his time between NACA and the Engineering Division of NRC. He had two offices and typically spent mornings at NACA and afternoons at NRC. The NRC duties involved the supervision of various committees, the drafting of reports, receiving callers, conferring with government officials and civilians, attending meetings, and so on.

One of the by-products of these World War II activities was service on a committee set up by the National Defense Research Committee (NDRC). This committee was charged with supervisory responsibility over research on the phenomena associated with the movement of a ship in a circular path, as when making a sharp turn, and over research on cavitation phenomena associated with the movement of bodies in water at high speeds. These activities led to his appointment as Chief of Section 12.1 of NDRC.

Durand also served as chairman of an NRC committee set up to advise as to the order of need under war conditions of six additional wind tunnels that had been proposed by certain airframe manufacturers. The resulting report served as a guide to the War Production Board in granting priorities for materials and equipment.

In the summer of 1945 when it was clear that the war was coming to an end, Durand resigned from all of his Washington activities and returned to Stanford. He was then more than eighty-six years old and had begun to realize that four years of war activity in Washington had taken something out of him physically. He accordingly decided that in the future he would avoid outside work of all description and settle down to a condition of full retirement. The next five years passed quietly but pleasantly, punctuated by special events such as receipt in 1946 from the hand of General Spaatz of the Presidential Medal for Merit for his services in World War II and of the first award of the Wright Memorial Trophy for notable work in aeronautical science.

During this period Mrs. Durand's health gradually failed, and she passed on in December 1950 at the age of ninety-one years. A few months later Durand closed his house at Stanford and established himself in an apartment hotel in Brooklyn, New York, a three-minute walk from the home of his son and not too far from his various grandchildren.

Here Durand spent the final seven years of a long and productive life. During this period he was frequently visited by friends, who found him very much alert mentally and also surprisingly active physically, considering his age. In these last years he would attend the parties associated with aeronautics seminars and conferences at nearby Polytechnic Institute of Brooklyn whenever the speaker was a well-known aerodynamicist. At these affairs he would speak fluently in French, when there were French guests. At one such party, held in Durand's ninety-sixth year, he confided to von Kármán that in the last year or two he had begun to notice that he was getting a little old!

Many honors came to Durand during his life. In addition to those that have already been mentioned in this narrative, items of special significance include: Gold Medal, American Society of Naval Engineers (1889); election to membership in the American Philosophical Society (1917); Daniel Guggenheim Medal (1935); John Fritz Medal (1935); Franklin Institute Medal (1938); J. J. Carty Medal of the National Academy of Sciences (1944); Medal of the American Society of Mechanical Engineers (1945); also, honorary degrees from the University of California (1923), University of Utah (1927), and Worcester Polytechnic Institute (1938).

The period of years during which Durand was highly productive was most unusual. Thus, if his life had ended upon retirement in 1924 at the age of sixty-five, he would have been considered as having had a distinguished career. On the other hand, if his life work had consisted only of those things that he carried out after sixty-five, he would have been equally, if not more, distinguished.

Durand had broad interests and an extraordinary ability to grasp and retain ideas dealing with a great diversity of subjects. To quote a statement of one of his close friends, Hugh Dryden, he was "the engineering statesman at work, with sound technical knowledge, creative and imaginative, tactful, intellectually honest, and trustworthy," with an unusual ability to find common ground in the midst of divergent viewpoints. He further had an exceptional gift for both verbal and written expression, such that in informal discussions words and ideas flowed with a polished eloquence that made complex situations clear and understandable even to nonspecialists. This lucidity also characterized his writing, with the result that in a committee he was commonly the man who was asked to draft the report.

These same qualities of scientific expertise, breadth, articulateness, intellectual integrity, and the ability to see all sides of a question, made Durand particularly effective in dealing with complex situations where political, economic, and social problems were intertwined with engineering. Examples include his influential role in such groups as the Morrow Board, the original Colorado River Board, and the Passamaquoddy Committee, where politically controversial questions of a socio–economic–engineering character were at issue.

Durand was not only respected but was also beloved by all who came in contact with him. In spite of his great achievements and many honors, Durand was a modest man, gentle, kind, generous, and without a trace of conceit or selfish ambition. While dignified and reserved to an extent that he had very few close intimates, he was fundamentally friendly and genuinely enjoyed interesting himself in the problems and activities of others. He had innumerable friends whose attachment to him was based upon mutual respect. Although at the time of his death on August 9, 1958, at the age of ninety-nine years and five months, Durand had outlived all of his contemporaries, he left behind a great number of devoted friends made up of former students and of men who had worked with him at one time or another. While these admirers were saddened by Durand's passing, their feelings were tempered by the fact that he led a life that was rich in significant contributions to mankind, made continuously over an unusual span of years.

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*KEY TO ABBREVIATIONS*

Am. Electr. = American Electrician
Am. Mach. = American Machinist
Am. Microsc. J. = American Microscopical Journal
Automot. Ind. = Automotive Industries
Cassier's Mag. = Cassier's Magazine
Electr. World = Electrical World
Eng. News = Engineering News
Eng. Rec. = Engineering Record
J. Am. Soc. Mech. Eng. = Journal of the American Society of Mechanical Engineers
J. Am. Soc. Nav. Eng. = Journal of the American Society of Naval Engineers
J. Electr. Power Gas = Journal of Electricity, Power, and Gas
J. Franklin Inst. = Journal of the Franklin Institute
Mar. Eng. = Marine Engineering
Mar. Rev. = Marine Review
Mech. Eng. = Mechanical Engineering
Pac. Mar. Rev. = Pacific Marine Review
Proc. Am. Assoc. Adv. Sci. = Proceedings of the American Association for the Advancement of Science
Proc. Electr. Soc. and Soc. Mech. Eng. Cornell Univ. = Proceedings of the Electrical Society and Society of Mechanical Engineers of Cornell University
Sci. Am. Suppl. = Scientific American Supplement
Sibley J. Eng. = Sibley Journal of Engineering
Trans. Am. Soc. Civ. Eng. = Transactions of the American Society of Civil Engineers
Trans. Am. Soc. Mech. Eng. = Transactions of the American Society of Mechanical Engineers
Trans. Soc. Nav. Archit. Mar. Eng. = Transactions of the Society of Naval Architects and Marine Engineers
Univ. Mich. Eng. Annu. = University of Michigan Engineer's Annual

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