NATIONAL ACADEMY OF SCIENCES

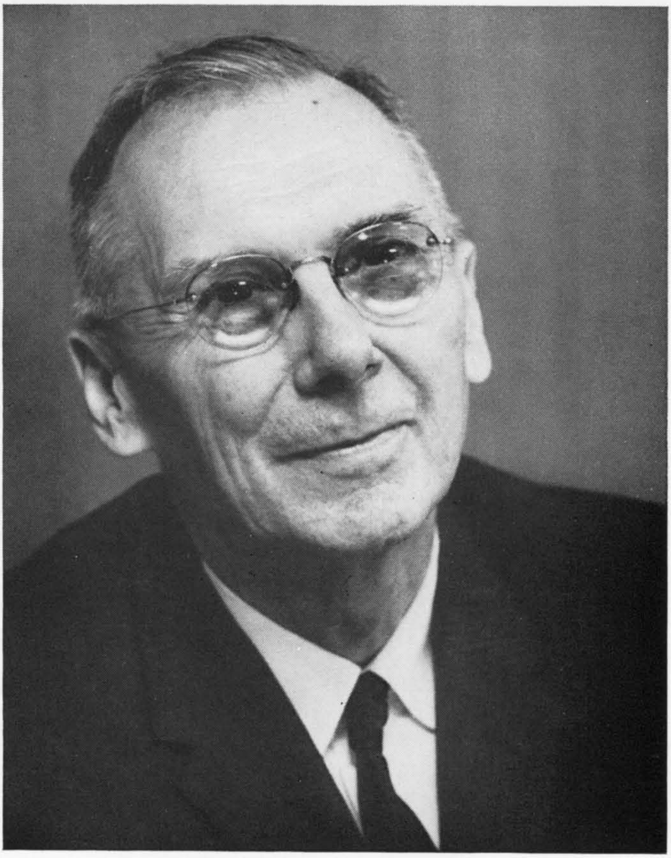
HUGH LATIMER DRYDEN

1898—1965

A Biographical Memoir by

JEROME C. HUNSAKER AND ROBERT C. SEAMANS, JR.

Biographical Memoir



Hugh L Dryden

HUGH LATIMER DRYDEN

July 2, 1898–December 2, 1965

BY JEROME C. HUNSAKER

AND

ROBERT C. SEAMANS, JR.

HUGH LATIMER DRYDEN was born in Pocomoke City, Maryland, July 2, 1898. His father taught school and later kept a general store. This business failed in the panic of 1907 and the family moved to Baltimore, where the father became a streetcar conductor, following this occupation for the rest of his life. Young Hugh attended public schools and a high school, called Baltimore City College, graduating in 1913 just short of age fifteen.

Entering The Johns Hopkins University with advanced standing, he completed a regular B.A. curriculum in three years, receiving his degree with honors in 1916 and his M.A. in 1918.

It is of interest to observe that Dryden did not come from a scholarly family. But he was endowed with the highest order of intelligence, brought this gift to the realms of physics, engineering, and government service, and developed a vigorous philosophy supported by strong Christian principles.

He married Mary Libbie Travers on January 29, 1920, and their three children were highly educated. The son, Dr. Hugh, Jr., an organic chemist, graduated from Hopkins and M.I.T. The elder daughter, Mrs. Mary Ruth Van Tuyl, graduated from Goucher College and is married to a mathematician at the Naval Ordnance Laboratory. Daughter Nancy Travers graduated from American University and teaches school in Montgomery County, Maryland. There are five grandchildren.

PERIOD OF ACTIVE RESEARCH

In June 1918 Dryden joined the staff of the National Bureau of Standards as an inspector of munitions gauges, intending to return to graduate school on a fellowship in the fall. However, because of World War I and with the encouragement of Dr. Joseph S. Ames, head of the Johns Hopkins Physics Department and Chairman of the National Advisory Committee for Aeronautics, his plans were changed. He obtained a transfer into the Bureau's newly-formed wind tunnel section. After Dr. Ames arranged to give courses to a number of Hopkins graduate students at the Bureau, Dryden was able to complete his thesis work on experiments carried on after hours in the wind tunnel. He was granted the Ph.D. in physics in 1919, when he was just under twenty-one, the youngest student ever to obtain a Ph.D. at Johns Hopkins. Dryden's thesis, entitled "Air Forces on Circular Cylinders," addressed itself to the fundamental problem of scale effects on the flow over circular cylinders normal to the wind. Its value lies in an early demonstration of the fact that Reynolds' Number based simply on a characteristic dimension of the body is not always the sole criterion for aerodynamic flow similarity. His results stimulated some of the more sophisticated inquiries into the same subject in the decade which followed.

In 1920 Dryden was placed in charge of the wind tunnels. Here his research on the problems of wind tunnel turbulence and boundary-layer flow brought him international recognition. Dryden and his colleagues were first interested in accurately measuring turbulence in wind tunnels and in understanding its effects on force measurements. It became apparent to them early that the hot-wire anemometer provided a means of direct measurement of turbulence. The instrument in its original form could not, however, follow rapid fluctuations. Dryden and his colleagues devised an electrical network which restored the loss in amplitude and compensated for the lag. Extensive tests were made of the intensity and scale of turbulence produced by the wire screens at various distances from the working station. Having means for varying the intensity and scale of the turbulence and for measuring these quantities with a compensated hot-wire anemometer, Dryden built wind tunnels of very low turbulence and measured on models the effect of turbulence on aerodynamic forces. The experimental work showed the effect of turbulence on the transition from laminar to turbulent flow in the boundary layer near a solid surface. In NACA Technical Report 342 by Dryden and Kuethe, a curve was presented by which measurements of the air resistance of spheres could be interpreted to give the turbulence quantitatively. It was shown that discrepancies which had previously been observed in tests on standard airship models were mainly due to differences in the turbulence of the tunnel in which the tests were made. The theoretical equations of laminar flow within a boundary layer had been previously announced by Prandtl in 1907. Dryden and his collaborators were able experimentally to verify Prandtl's theories. They emphasized the practical importance of maintaining a laminar boundary layer over as much of the surface of the aircraft as possible in order to reduce drag.

Dryden summarized at various times the work of the Bureau of Standards group on turbulence and boundary layer, as in his Wright Brothers Lecture of 1939, entitled "Turbulence and the Boundary Layer." His most recent summaries of this subject were in his paper presented at the National Congress of Applied Mechanics in June 1958, entitled "Some Aspects of Boundary-

Layer Flow in Subsonic and Supersonic Air Streams," and another paper published in the *Journal of Applied Mathematics and Physics* (Vol. IXb, 1958), in honor of the sixtieth birthday of Jacob Ackeret, entitled "Combined Effects of Turbulence and Roughness on Transition."*

In collaboration with Dr. Lyman J. Briggs, Dryden made some of the earliest experimental measurements of the aerodynamic characteristics of airfoils at high speeds. The early motivation for this work had its origin in the effects of the high propeller tip velocities which were being encountered with high-powered engines. Dryden and Briggs carried out these investigations at a large compressor plant at the Edgewood Arsenal. Through this work, they furnished the propeller designer with airfoil data at high speeds and developed early insight into the effects of compressibility on lift coefficient and pressure distribution. They were among the first to observe experimentally the so-called "transonic drag rise." This early work was supported and published by NACA. NACA Technical Reports 207 (1924), 255 (1926), 319 (1929), and 365 (1930) by Briggs and Dryden summarize these experiments. Interest generated by this work led to the construction of many high-speed wind tunnels and was of pioneering significance when jet and rocket propulsion made supersonic and hypersonic flight feasible.

Although Dryden's career at the Bureau of Standards is characterized largely by his research on turbulence and boundary-layer flow, his inquiring mind led him to grapple with other engineering problems with many different collaborators. His investigations of wind pressures on chimneys, mill buildings, and skyscrapers laid the basis for rational design of structures subjected to wind loads. Dryden's principal collaborator in this field was G. C. Hill. Examples of their work are contained in Bureau of Standards Research Paper 545 entitled "Wind Pres-

* A listing of Dryden's papers may be found in "Publications of Hugh L. Dryden," NASA Historical Note (March 1966).

sure on a Model of the Empire State Building" (1933) and Bureau of Standards Research Paper 221 entitled "Wind Pressure on Circular Cylinders and Chimneys" (1930).

Dryden guided a three-year program to pave the way for introducing modern materials and construction methods in low-cost housing. This little-known chapter in his career resulted in Bureau of Standards Building Materials and Structures Report BMS 1 entitled "Research on Building Materials and Structures for Use in Low-Cost Housing" (1938).

Dryden's studies of turbulence led him naturally to an interest in mechanical vibrations. His collaborator here was L. B. Tuckerman. They published Bureau of Standards Research Paper 556 in 1933 entitled "A Method of Exciting Resonant Vibrations in Mechanical Systems" (also with H. B. Brooks) and Bureau of Standards Research Paper 678 in 1934 entitled "A Propeller-Vibration Indicator." The motivation for this work was undoubtedly the strong concern during the early 1930s for the structural integrity of propeller blades under increasing speeds and disc loadings.

A summary of Dryden's scientific and engineering research would be incomplete without mention of his interest in the measurement of the acceleration of gravity. This work took place during 1942 and 1943 and resulted in Bureau of Standards Research Paper 1502 entitled "A Reexamination of the Potsdam Absolute Determination of Gravity" (1942) and "Absolute Gravity Determinations" (published in *Transactions of the American Geophysical Union*, Vol. 24, 1943). This investigation, done in collaboration with E. A. Eckhardt, W. D. Lambert, and A. H. Miller, undertook to study the various determinations of the absolute value of gravity and to recommend a "best value." The results indicated that only three determinations had been made with sufficient attention to the elimination of systematic error to merit consideration.

Dryden was responsible for extensive studies of the aerodynamics of aircraft bombs and for the development of a practical method of designing the tail fins to ensure aerodynamic stability. With E. J. Lorin, a form of bomb geometry was standardized that remained in use for many years. His less-known contributions ranged over aircraft noise, ventilating fans, aerodynamic design of aircraft control surfaces, automobile streamlining, and aerodynamic cooling. He authored, for example, the division on "Aerodynamics of Cooling" in the well-known volumes on *Aerodynamic Theory,* Vol. VI, Division T (Springer, Berlin, Germany, 1936).

As time passed, Dryden's management responsibilities at the Bureau of Standards grew and he found less time for his own research. In 1934 he became Chief of the Mechanics and Sound Division. With the establishment of the National Defense Research Committee and later the Office of Scientific Research and Development in the early 1940s, Dryden became chief of a section developing a guided glide bomb. This section, located at the Bureau of Standards, was later expanded into the Navy Bureau of Ordnance Experimental Unit, with a staff of civilians from the Bureau of Standards and the Massachusetts Institute of Technology as well as officers and men of the U.S. Navy. The radar homing missile, BAT, which saw service in World War II in the Pacific, was designed by this team. The BAT missile destroyed many tons of Japanese shipping during the last year of the war. Fleet Air Wing One, under Rear Admiral John D. Price, used the BAT effectively against both ships and land targets. This was Dryden's first taste of the management of large projects, with which he would have so much to do later.

Dryden's wartime service was once described in his own words: "I headed an unusual group at the Bureau of Ordnance Experimental Unit which developed the radar homing missile, BAT. I also served as Deputy Director of the Army Air Force's Scientific Advisory Group headed by von Kármán. The group was appointed by General H. H. Arnold and many of us were in Europe on V-E day in uniform with simulated rank to study the use of science by the various European countries." *Towards New Horizons,* the series of reports by the von Kármán group, proved invaluable in future years.

Dryden advanced steadily in the Bureau's organization, becoming Assistant Director in January of 1946 and Associate Director a few months later. Dryden and the late Dr. Lyman J. Briggs, Director of the Bureau, formed a friendship which lasted throughout their lives. There was an almost filial relationship between these two eminent scientists that will always be a treasured memory of their surviving families. When Dr. Briggs died, Dryden, a licensed local preacher of the Methodist Church, conducted his funeral services—a last tribute to his old friend.

PERIOD OF RESEARCH DIRECTION

In September 1947 Dryden transferred from the National Bureau of Standards to become Director of Research of the National Advisory Committee for Aeronautics (NACA). In 1949 he became Director of NACA, its senior full-time officer. He directed from Washington the activities of the Langley, Lewis, and Ames laboratories and the flight research stations at Edwards Air Force Base, California, and Wallops Island, Virginia. The magnitude of this responsibility grew to embrace, during the last year of NACA's existence, 8,000 employees and an annual budget of about $100 million. Under his leadership, NACA produced a vast body of new knowledge which made possible routine supersonic flight and laid much of the technological groundwork for space flight that was to come. We discern here, perhaps as much as in any other place, the impact of Dryden's leadership. The development of high-speed wind tunnels, flight testing, and a companion competence for theoretical research within NACA contributed substantially to the leadership of the United States in supersonic flight.

In 1954 Dryden became the Chairman of the Air Force–

Navy–NACA Research Airplane Committee formed to guide the development of an airplane to explore the problems of flight at the highest speeds and altitudes then feasible. The series of experimental aircraft, beginning with the X-1, X-2, X-3, D-558, and culminating with the X-15, are well known. Some of these aircraft were developed and tested prior to 1954; however, the hypersonic research airplane, the X-15, drawing on the previous flight experience, was from its conception the concern of this Committee. Before he died, Dryden saw the X-15 reach a maximum speed in excess of 4,000 miles per hour and an altitude of nearly seventy miles. It had been Dryden who carried the X-15 program through the political labyrinth of Washington where funds for basic research and development were not plentiful. Much of this technology of manned flight came to bear in Project Mercury.

It was during this period that Dryden pressed for a solution to the critical reentry heating problem. This solution, based on knowledge accumulated in research, made it possible for the United States to proceed with assurance in the development of its ICBM program and manned satellites.

As we study Dryden's publications, we find a transition from descriptions of his own research to broader discussions of research policies. His Wilbur Wright Memorial Lecture, for example, in April 1949, read in London and entitled "The Aeronautical Research Scene—Goals, Methods, and Accomplishments," sketched his own interpretation of aeronautical research directions and results. Here he made perhaps one of his most important observations. In his own words: "It [research] should not in its entirety be limited to exploratory research or to coordinated theoretical and experimental work on experimental situations where complete understanding of basic phenomena is the principal goal. The needs of designers for systematic surveys of various areas and for research in support of development must be recognized and promoted by frequent and close contact between designers and research workers. The selection of some common advanced technical development as the goal of both groups has proved to be an excellent means of promoting cooperation and of channeling research into directions permitting early application, without sacrificing the values inherent in the personal enthusiasm, initiative, and freedom of the research worker." This concept has lived and grown, and represents a fundamental policy of management in the conduct today of the programs and projects of NASA.

The days of closeness to the details of research were passing. Dryden would occasionally write invited summary papers in his own field of current importance. In 1956, for example, in collaboration with Duberg, he presented a paper at the Fifth General Assembly of AGARD in Ottawa, entitled "Aeroelastic Effects of Aerodynamic Heating." In the paper he pointed out by examples the degradations which could be expected in the aeroelastic properties of lifting surfaces at high speeds.

He sustained a continuous interest in applied mechanics. He served as president of the International Union of Theoretical and Applied Mechanics and as a member of the International Committee for the International Congress of Applied Mechanics. He took an active role in the organization of the Sixth International Congress for Applied Mechanics in Paris in 1946 and again at the Seventh International Congress in Istanbul in 1952. Together with von Kármán, he was an editor of *Applied Mechanics Reviews*. Contributions by Dryden may be found in the Proceedings of the 3rd, 4th, and 5th International Congresses of Applied Mechanics. He contributed to *Advances in Applied Mechanics*, Vol. I, 1948, with authorship of the section entitled "Recent Advances in the Mechanics of Boundary Layer Flow."

PERIOD OF PUBLIC POLICY

The final period in Dryden's life commenced dramatically in October 1957 with the launching of Sputnik I. The Executive

Branch and the Congress prepared immediately to establish a civilian agency to conduct explorations of space for peaceful purposes. With Dryden's help at critical moments, NACA was selected as the central building block of the new agency and he participated in the drafting of the legislation and its defense before the Congress. On August 8, 1958, President Eisenhower appointed Dryden as Deputy Administrator of the new agency, a position he held under three Presidents until his death.

Project Mercury was conceived and organized with Dryden playing a major role. Later, Dryden participated in the important planning for the Gemini and Apollo projects. His hand was prominent in the studies and recommendations that led to the decision to mount a lunar exploration mission. His commitment to the Apollo mission was demonstrated in a notable letter dated June 22, 1961, to the late Senator Robert S. Kerr, then Chairman of the Senate Committee on Aeronautical and Space Sciences. Dryden said in part: "The setting of the difficult goal of landing a man on the Moon and return to Earth has the highly important role of accelerating the development of space science and technology, motivating the scientists and engineers who are engaged in this effort to move forward with urgency, and integrating their efforts in a way that cannot be accomplished by a disconnected series of research investigations in the several fields. It is important to realize, however, that the real values and purposes are not in the mere accomplishment of man setting foot on the moon, but rather in the great cooperative national effort in the development of science and technology which is stimulated by this goal. . . . The national enterprise involved in the goal of manned lunar landing and return within the decade is an activity with critical impact on the future of this nation as an industrial and military power, and as a leader of a free world." Had Senator Kerr heard the Wilbur Wright

Memorial Lecture of 1949, he would have perceived a remarkable thread of uniformity in Dryden's approach to widely separated problems, a thread which dominated his thinking and will most certainly dominate national planning in science and technology for years to come.

In the last month of his life Dryden delivered the Thurston Lecture before the American Society of Mechanical Engineers. He pointed out that men had been engineers for thousands of years before the basic concepts of science were known. Engineers now follow the scientists' step-by-step approach to develop the technology from which real benefits can arise. But Dryden had a keen sense of social responsibility in planning engineering programs. He made the difficult choice among the many possibilities available to change the state of the art. In his Thurston Lecture he explained that the space program was already having an impact on engineering because of new requirements in weight, size, performance, and reliability under extreme environmental conditions.

As Director of the National Advisory Committee for Aeronautics for ten years, Dryden had great success in leading scientific and engineering research into important technical applications. When NACA was abolished in 1958 and the National Aeronautics and Space Administration (NASA) was set up by the Congress in response to Sputnik, Dryden was proposed by senior NACA members to be the Administrator of the new agency. He was seriously considered by the White House. However, Dryden's professional integrity may have antagonized members of the House Select Space Committee when he objected to an untested crash program to put a man on top of a missile in a suborbital space flight for propaganda purposes. He said this would have no more value "than shooting a woman out of a cannon at a circus."

The first NASA Administrator, President T. Keith Glennan of Case Institute, insisted that Dryden be the Deputy Administrator and be overseer of all scientific and technical aspects of space research. In September 1958 Dryden was offered a distinguished professorship at M.I.T. In response he wrote: "When it became apparent that I would not be offered the position as head of NASA, I gave much thought to my future course of action. I decided that regardless of the action taken on appointments I would remain as long as I thought I could serve the national interest and ease the transition period for my associates of the last decade. Up to the present time I have been much encouraged by the attitude and actions of Dr. Glennan. He has successfully resisted great political pressure to make a certain appointment."

Dryden felt a special responsibility for the 8,000 civil service employees of NACA who were to be taken over by NASA. These people had been led, supported, chastised, or promoted and, in many instances, recruited by Dryden. Also Dryden carried over to NASA a most cordial and constructive relation with the military services, government regulating bodies, the universities, the air transport and manufacturing industries, and professional societies and research establishments. This was to prove invaluable to the U.S. space program.

Dryden's leadership capability itself was questioned in the report to President-Elect John F. Kennedy, January 12, 1961, by an *ad hoc* Advisory Committee on Space headed by Dr. Jerome Wiesner. This Committee found "a number of organizational and management deficiencies as well as problems of staffing and direction which should receive prompt attention. These include serious problems within NASA, within the military establishment, and at the executive and other policy-making levels of government." Specifically, the Wiesner Committee complained about the independent space programs of NASA and the military services with alleged overlap and duplication. The

Committee proposed central control in the Department of Defense of the Ballistic Missile Program, including "development of the missiles and associated control systems, base construction and missile procurement," and observed that "an adequate deterrent force is much more important for the nation's security than are most of the space objectives." It directly challenged the technical integrity of Project Mercury.

The Committee's concern for "the NASA preoccupation with the development of in-house research" and allegations that "space developments have all but halted any advance in the theory and technology of aerodynamic flight . . . and supersonic commercial aircraft" could be interpreted as pointing at Dryden's judgment. The Committee suggested that the Space Council might place the latter problem with another agency or make nongovernmental arrangements.

The Wiesner Committee recommended for NASA several "requirements that must be met." These were, in fact, outstanding features of Dryden's leadership. For example, "wide participation by scientists from universities and industrial laboratories. As the Home Secretary of the National Academy of Sciences, Dryden had close relations with the Academy's members and in particular with the Space Science Board that was established within the Academy to advise and assist NASA. "Exert the greatest wisdom and foresight in the selection of scientific missions and of the scientists assigned." This was one of Dryden's main concerns within the policy and budget limitations of the President and the Congress as the new NASA program gained direction and momentum.

The *ad hoc* Committee's report to President Kennedy, released to the press, did Dryden no harm. Probably it helped clear the air by requiring the new Administration to assess fully the space effort underway. When James E. Webb was asked by the White House to be the second NASA Administrator, he accepted upon the condition that Dryden remain as Deputy Administrator.

Dryden had a leading role in the sphere of international cooperation. In 1959 he was appointed to assist Ambassador Henry Cabot Lodge at the first meeting of the United Nations Committee on the Peaceful Uses of Outer Space. His activities were largely responsible for a proposal by NASA, in December of that year, for joint research with other nations to promote international space cooperation. In the years that followed, after an exchange of correspondence between Premier Khrushchev and President Kennedy, Dryden was appointed by President Kennedy as the nation's chief negotiator for peaceful space cooperation with the Soviet Union. He engaged in a continuing dialogue with Academician Anatole Blagonravov on the possibility of such cooperation; from these talks came agreements for limited, but nonetheless real, cooperation between the two countries, particularly in the fields of meteorology and communications. Dryden carefully insisted upon clear mutual exchange in these beginning steps.

Working toward international cooperation and peace fitted with Dryden's philosophy. A man of sincere religious faith, he was a licensed preacher for the Calvary Methodist Church in Washington during most of his adult life. He had found the bridge between science and religion.

In 1962 Dryden was named by the Methodist Union as the Methodist Layman of the Year. The Rev. T. R. Bowen of his church pronounced the citation containing these words:

"At the very top of his profession, yet humble, self-effacing, and accessible; engaged in events and activities of far-reaching importance and world significance . . . but all the while, devout Christian and dedicated churchman, as deeply sensitive to the fact of value as he is to the value of fact; as alert to the moral and spiritual perils and possibilities of applied intelligence as he is to the methods and data involved in his own specific discipline."

In an address at the Cosmos Club in 1954, Dryden said: "I am not one of those few who believe that we can abolish the use of force in the world. Policemen are still necessary and they must sometimes use force. As a nation we find it necessary to build great military power. I am confident that such strength is a greater contribution to the peace of the world at the present moment than military weakness." Dryden served a term as President of the Cosmos Club and was also a Life Trustee of the National Geographic Society.

Dryden was elected to the National Academy of Sciences in 1944. He served as the Chairman of its Section on Engineering from 1947 to 1950. In 1955 he was elected Home Secretary, a position he held until his death in 1965.

Dryden lived under a sentence of death after October 1961, when exploratory surgery disclosed a serious malignancy. Yet he continued on duty in spite of frequent hospital treatments. He conceded little to the illness that marked the last years of his life.

In a sermon he once said: "One major mark of rank in the organic world is the capacity to suffer. The aim of life, therefore, is not to abolish suffering, for that would abolish sensitivity, but to eliminate its cruel, barbarous, and useless forms. To willingly accept toil, trouble, and suffering, these are goals for scientists as well as for other men."

President Lyndon B. Johnson expressed the esteem of the nation when he said: "No soldier ever performed his duty with more bravery and no statesman ever charted new courses with more dedication than Hugh Dryden. Whenever the first American space man sets foot on the moon or finds a new trail to a new star, he will know that Hugh Dryden was one of those who gave him knowledge and illumination."

Dryden was always in advance of his fellows. He avoided the usual handicap of the precocious youngster. Instead of showing up his colleagues by his own quick wits, he consistently helped them to find solutions to their own problems. At the Bureau of Standards in the 1920s he helped Dr. Briggs determine the aerodynamic effects of the high-tip speed of propellers for the more powerful engines being introduced. He helped his Hopkins professor, Dr. Joseph S. Ames, when the latter was Chairman of NACA, as he did all of Dr. Ames's successors.

During World War II, Dryden supported the work of Dr. Vannevar Bush's National Defense Research Committee, most notably on the development of a radar-homing missile. As Scientific Deputy, he also assisted General H. H. Arnold's Scientific Advisory Group led by Dr. Theodore von Kármán. Everyone who came in personal contact with Dryden came to know and to appreciate his wisdom and help.

After Dryden's transfer to NACA in 1947, he assumed leadership in the fundamental research effort in the field in which he had made basic contributions twenty-five years before. It is fair to state that Dryden's 1920 work on supersonic aerodynamics led consistently to operational supersonic airplanes, the famous rocket-propelled X-15, and successful manned space flight. On February 10, 1966, the President of the United States presented to Mrs. Dryden the National Medal of Science awarded posthumously to Dr. Dryden: "For contributions, as an engineer, administrator, and civil servant for one-half century, to aeronautics and astronautics which have immeasurably supported the Nation's preeminence in space."

Hugh L. Dryden's life was given to helping good men get good results.

HONORS AND DISTINCTIONS

PROFESSIONAL AFFILIATIONS

National Academy of Sciences, Member and Home Secretary
Académie des Sciences of the Institut de France, Corresponding Member and Foreign Associate Member
American Philosophical Society, Member
American Academy of Arts and Sciences, Fellow
Washington Academy of Sciences, Member
Philosophical Society of Washington, Member
American Institute of Aeronautics and Astronautics, Honorary Fellow, former President
Royal Aeronautical Society, Honorary Fellow
British Interplanetary Society, Honorary Fellow
Canadian Aeronautics and Space Institute, Honorary Fellow
American Physical Society, Fellow
American Society of Mechanical Engineers, Fellow
National Geographic Society, Life Trustee
National Academy of Engineering, Charter Member
National Committee for Geophysical Year, Member

HONORS AND AWARDS

Wright Brothers Lecture of the Institute of the Aeronautical Sciences (1938)
Sylvanus Albert Reed Award of the I.A.S. (1940)
U.S. Medal of Freedom (1946)
Presidential Certificate of Merit (1948)
Order of the British Empire (civil division) (1948)
37th Wilbur Wright Memorial Lecture of the Royal Aeronautical Society (1949)
Daniel Guggenheim Medal (1950)
Wright Brothers Memorial Trophy (1955)
Ludwig Prandtl Memorial Lecture of the Wissenschaftliche Gesellschaft für Luftfahrt (1958)
Career Service Award of the National Civil Service League (1958)
Baltimore City College Hall of Fame (1958)
President's Award for Distinguished Federal Civilian Service (1960)

Elliott Cresson Medal of the Franklin Institute (1961)
First von Kármán Lecture, American Rocket Society (1962)
Langley Medal of the Smithsonian Institution (1962)
John Fritz Medal (1962)
Rockefeller Public Service Award (1962)
Goddard Memorial Trophy (1964)
National Medal of Science (1965)

HONORARY DEGREES

Polytechnic Institute of Brooklyn (Sc.D., 1949)
New York University (D.Eng., 1950)
Rensselaer Polytechnic Institute (D.Eng., 1951)
University of Pennsylvania (Sc.D., 1951)
Western Maryland College (ScD., 1951)
Johns Hopkins University (LL.D., 1953)
University of Maryland (D.Eng., 1955)
Adelphi College (LL.D., 1959)
South Dakota School of Mines and Technology (D.Eng., 1961)
Case Institute of Technology (Sc.D., 1961)
American University (L.H.D., 1962)
Northwestern University (Sc.D., 1963)
Politecnico Milano (M.E., 1964)
Worcester Polytechnic Institute (Sc.D., 1964)
Swiss Federal Institute of Technology (Sc.D., 1964)
Princeton University (Sc.D., 1965)

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KEY TO ABBREVIATIONS

Aeron. Eng. Rev. = Aeronautical Engineering Review
AIBS Bull. = Bulletin of the American Institute of Biological Sciences
Appl. Mech. Rev. = Applied Mechanics Review
Bur. Stand. Res. Pap. = Bureau of Standards Research Papers; in 1934 changes to National Bureau of Standards Research Papers
Bur. Stand. Sci. Pap. = Bureau of Standards Scientific Papers; in 1934 changes to National Bureau of Standards Scientific Papers
J. Aeron. Sci. = Journal of the Aeronautical Sciences
J. Appl. Mech. = Journal of Applied Mechanics
J. Wash. Acad. Sci. = Journal of the Washington Academy of Sciences
Mech. Eng. = Mechanical Engineering
NACA Tech. Note = Technical Note of the National Advisory Committee for Aeronautics
NACA Tech. Rept. = Technical Report of the National Advisory Committee for Aeronautics
NASA EP = Educational Publications of the National Aeronautics and Space Administration
NASA SP = Special Publications of the National Aeronautics and Space Administration
NASA Tech. Memo. = Technical Memorandum of the National Aeronautics and Space Administration
Nat. Geog. Mag. = National Geographic Magazine
NUEA Spectator = Bulletin of the National University Extension Association
Pennsylvania State College Eng. Exp. Sta. Tech. Bull. = Pennsylvania State College Engineering Experimental Station Technical Bulletin
Phys. Today = Physics Today
Proc. Am. Phil. Soc. = Proceedings of the American Philosophical Society
Proc. Internat. Congr. Appl. Mech. = Proceedings of the ____ International Congress of Applied Mechanics
Proc. Nat. Acad. Sci. = Proceedings of the National Academy of Sciences
RTCA Paper = Radio Technical Commission for Aeronautics Paper
U.S. Dept. State Bull. = United States Department of State Bulletin
Z. Flugwiss. = Zeitschrift für Flugwissenschaften

1920

Air forces on circular cylinders, axes normal to the wind, with special reference to dynamic similarity (Ph.D. dissertation, Johns Hopkins University, 1919). Bur. Stand. Sci. Pap. 394.

1921

With W. F. Stutz and R. H. Heald. Some comparative tests of roof ventilators. Journal of the American Society of Heating and Ventilating Engineers, 27:93-100.

1924

With L. J. Briggs and G. F. Hull. Aerodynamic characteristics of airfoils at high speeds. NACA Tech. Rept. 207.

1926

With G. C. Hill. Wind pressures on structures. Bur. Stand. Sci. Pap. 523.

With R. H. Heald. Investigation of turbulence in wind tunnels by study of the flow about cylinders. NACA Tech. Rept. 231.

With L. J. Briggs. Pressure distribution over airfoils at high speeds. NACA Tech. Rept. 255.

With L. J. Briggs. Aerodynamics. International Critical Tables, 1:402-11.

1929

With L. J. Briggs. Aerodynamic characteristics of twenty-four airfoils at high speeds. NACA Tech. Rept. 319.

With A. M. Kuethe. The measurement of fluctuations of air speed by the hot wire anemometer. NACA Tech. Rept. 320.

1930

Sections on wind pressure and aeronautics. In: *Merriman's Civil Engineers Handbook,* 5th ed., pp. 289-302. New York, John Wiley & Sons, Inc.

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The pressure of the wind on large chimneys. Proc. Nat. Acad. Sci., 16:727-31.

With G. C. Hill. Wind pressure on circular cylinders and chimneys. Bur. Stand. Res. Pap. 221.

With L. J. Briggs. The effect of compressibility on the characteristics of airfoils. Proc. 3d Internat. Congr. Appl. Mech., 1:417-22.

With A. M. Kuethe. The effect of turbulence in wind tunnel measurements. NACA Tech. Rept. 342.

With L. J. Briggs. Aerodynamic characteristics of circular-arc airfoils at high speeds. NACA Tech. Rept. 365.

1931

With P. S. Ballif. Further measurements of propeller fan characteristics. Bur. Stand. Res. Pap. 283.

With G. C. Hill. Wind pressure on a model of a mill building. Bur. Stand. Res. Pap. 301.

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