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FORTY YEARS OF AERONAUTICAL RESEARCH

BY

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Chairman, National Advisory Committee for Aeronautics
Regent, Smithsonian Institution

FROM THE SMITHSONIAN REPORT FOR 1955, PAGES 241–271
(WITH 10 PLATES)

(Publication 4237)

SMITHSONIAN INSTITUTION

WASHINGTON : 1956

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Before the Wrights' airplane flew, all the elements of the airplane were known: wings, rudders, engine, and propeller. The Wrights showed how to combine a man's senses and reflexes with the controls of a flying machine to make the machine both controllable about its attitude of equilibrium and steerable as desired. The secret of flight was manual control, in a three-dimensional fluid medium, in accordance with visual signals (the pilot's view of the ground and observation of his attitude relative to it—fixed axes of reference), and monitored by visual observation of the response to his control actions (feedback). The Wrights' airplane was, however, like the Wrights' bicycles, inherently unstable and was controllable only when it had sufficient forward speed. Controlled by the sight, brain, nerves, and muscles of man, the Wrights' unstable vehicle was the first practical flying machine in the history of the world!

The Wright airplane was quick to respond to control action because it had no righting tendency if disturbed. The pilot was expected to act at once to recover from any disturbance of equilibrium. There was no fixed tail to push it into a safe glide if the engine stopped.

The early pioneers of flight worked with gliders and with self-propelled models. They strove for inherent stability and conceived the ideal to be an inherently stable flying platform on which the pilot need do no more than steer. Pénaud's model gliders of the 1870's, with long tails, were stable; Lanchester developed prior to 1908 a theory of dynamical stability for his model "aerodromes"; Langley flew stable steam-powered models in 1896, and Bryan in 1903 published the dynamical equations of motion for a glider, and criteria for inherent stability. In all cases, stability was found to require a tail and slightly elevated wing tips.

As might be expected from complete and constant dependence on one man's sometimes defective judgments and reactions, the Wright air-

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plane could be tricky and even dangerous, especially in rough air. Furthermore, the gasoline engines of the day were notoriously unreliable. As a result of what later came to be known as the stall, Wright airplanes too often dived into the ground out of control. The press blamed it on an "air pocket" or "hole in the air."

European airplane builders were prompt to copy the Wrights' system of control but soon discovered the dangers of instability. They abandoned the Wrights' form of structure but retained their system of controls on airplanes shaped more like successful gliders.

The world was astonished in 1909 when Louis Bleriot flew across the English Channel in his little monoplane. It had a long tail, tractor propeller, and wheeled landing gear. It was, in fact, the prototype of the airplanes of the next 20 years.

After 1910, with the mounting tension of approaching war, aeronautical development in Britain, France, Germany, Austria, Russia, and Italy was intensively pushed. Scientists, engineers, and industrialists were encouraged by their governments to devote their skills and resources to the new art. European progress was rapid, and at times spectacular.

While development of the airplane in the United States was dependent largely upon the efforts of a host of amateur inventors, there was in Europe a quick recognition of the gains to be had from aeronautical laboratories staffed by competent engineers.

The French were among the first to utilize scientific techniques in aeronautics. The army's aeronautical laboratory at Chalais-Meudon and Gustav Eiffel's private wind tunnel clarified some of the principles of powered flight. As early as 1904 Riabouchinski had an aeronautical laboratory in Koutchino, Russia, and the same year Ludwig Prandtl began his classic aerodynamic research at Göttingen University, Germany. After 1908, German aeronautical work as rapidly expanded, first at Göttingen and later at the government establishment at Adlershof, near Berlin. Italy provided an aerodynamics laboratory for her Specialist Brigade of Engineers.

Great Britain was relatively late in undertaking a national program of aeronautical research. However, Great Britain could record a full century of experiment. In the first half of the nineteenth century, Sir George Cayley had made important contributions, and Stringfellow and Henson had succeeded, as early as 1848, in flying a steam-powered monoplane model a distance of 120 feet. In 1866 the Aeronautical Society of Great Britain was formed; it served to stimulate research and experiment by individuals, and to provide a forum for interchange of information. Wenham (the Society's first president) and Phillips were the first to devise and use wind tunnels.

After the public demonstration of practical human flight by Wilbur

Wright on his 1908 visit to France and Bleriot's 1909 cross-channel flight, the British Prime Minister was moved to appoint an Advisory Committee for Aeronautics with the great physicist Lord Rayleigh as chairman.

During this same period the United States made no special effort. The Army Signal Corps bought a few airplanes to train pilots and the Navy set up a flying school equipped with Glenn Curtiss seaplanes. When World War I erupted in 1914 it was reported that France had 1,400 airplanes, Germany 1,000, Russia 800, Great Britain 400, and the United States 23!

DRIVE FOR A NATIONAL LABORATORY

The backward position of the United States in the application of applied science to this new art was realized by a growing list of prominent Americans who believed the situation was not only a national disgrace, but a possible danger to our security. More Americans, including the leaders in Congress, were strong for neutrality, and felt that any special government concern with aeronautical development might imply belligerent intentions.

Capt. W. I. Chambers, USN, officer-in-charge of naval-aviation experiments, proposed in 1911 that a national aeronautical research laboratory be set up under the Smithsonian Institution. Along with objections by both the War and Navy Departments, the plan was referred to President Taft's Committee on Economy and Efficiency, from which it was never returned.

Two men who were more influential in the drive for a national aeronautical laboratory were Alexander Graham Bell and Charles Doolittle Walcott. The former, as a regent of the Smithsonian Institution, had been a supporter of Langley and had experimented with the lifting capabilities of kites. With Mrs. Bell he formed the Aerial Experiment Association in 1907 to support the airplane experiments of Glenn Curtiss, Lt. T. E. Selfridge, F. W. ("Casey") Baldwin, and J. A. D. McCurdy. Their efforts resulted in the development of the Curtiss biplanes and the use of ailerons to replace the Wrights' wing warping for lateral control.

Dr. Walcott was no aeronautical scientist; his field was geology. But Dr. Walcott, as successor to Professor Langley as Secretary of the Smithsonian, was determined that the Institution should resume its position as a leader of aeronautical science in America. How better than to have the new aeronautical laboratory attached to the Smithsonian!

The establishment of a national aeronautical laboratory was pressed by members of the National Academy of Sciences, notably by Bell and Walcott. The Academy had been created by Congress during the Civil War and had the duty of giving advice to the Government, when asked. The Academy, as a body, was not asked for advice on this matter, but its members appear to have been influential in persuading President Taft to appoint on December 19, 1912, a 19-man commission to consider such a national laboratory and its scope, organization, and cost, and to make a recommendation to the Congress.

The President's Commission was headed by Dr. R. S. Woodward of the National Academy of Sciences and the Carnegie Institution of Washington and included Dr. Walcott. The Army, Navy, Weather Bureau, and Bureau of Standards were represented, as well as interested civilians. The Commission recommended that the laboratory be established in Washington and administered by the regents of the Smithsonian Institution. President Maclaurin of the Massachusetts Institute of Technology objected to the location at Washington, which the majority report favored as "conveniently accessible to statesmen of the National Government who may wish to witness aeroplane demonstrations."

Unfortunately, the President had appointed the Commission without "the advice and consent of the Senate." Authorizing legislation failed to get unanimous consent and the Commission's report was buried in the archives.

Probably as a result of his service with the President's Commission, President Maclaurin in May 1913 persuaded the Corporation of M. I. T. to authorize a graduate course in aeronautical engineering and a wind tunnel for aerodynamic research in the Department of Naval Architecture. He requested the Secretary of the Navy to detail an officer of the Construction Corps to take charge. The writer was so detailed for 3 years.

At about the same time, the Smithsonian regents decided to reopen Langley's old laboratory, with Dr. Albert F. Zahm in charge. It was arranged by Walcott and Maclaurin to send Zahm and Hunsaker abroad, armed with personal introductions to scientific friends. Their objective was to visit the principal aeronautical research laboratories and, as far as possible, to learn how to operate the special facilities and equipment in use there with a view to duplicating them in this country.

Visits were made to the Royal Aircraft Factory, the National Physical Laboratory, and Cambridge University in England; to the St. Cyr, Chalais-Meudon, and Eiffel Laboratories in France; and to the Deutsche Versuchsanstalt für Luftfahrt and Göttingen University in Germany. In 1913, security restrictions did not apply to scientific and engineering work and the visitors were cordially received. In fact, the Massachusetts Institute of Technology later built its wind tunnel from drawings supplied by Sir Richard Glazebrook of the N. P. L. and had the N. P. L. aerodynamic balances duplicated by Sir Horace Darwin's Cambridge scientific instrument shops.

Dr. Zahm's report, published by the Smithsonian in 1914, made clear the width of the gap between European and American positions in aeronautical science. This report had an important influence on the decision of the Smithsonian regents in 1915 to memorialize the Congress once again on the subject of a national aeronautical laboratory.

Woodrow Wilson approved the Smithsonian plan of reopening Langley's laboratory with representatives of the War, Navy, Agriculture, and Commerce Departments serving on an Advisory Committee. However, the Comptroller ruled that, under an Act of 1909, such an Advisory Committee could not serve without the authority of the Congress.

On December 10, 1914, the Chancellor of the Smithsonian, Chief Justice White, appointed Dr. Alexander Graham Bell; Senator William J. Stone of Missouri; Representative Ernest W. Roberts of Massachusetts, and John B. Henderson, Jr., regents; and Dr. Walcott, Secretary, to consider once again "questions relative to the Langley Aerodynamical Laboratory." On February 1, 1915, a "memorial on the need for a National Advisory Committee for Aeronautics" was delivered to the Speaker of the House. Pertinent sentences from the memorial follow:

> This country led in the early development of heavier-than-air machines. Today it is far behind. . . . A National Advisory Committee for Aeronautics cannot fail to be of inestimable service in the development of the art of aviation in America. Such a committee, to be effective, should be permanent and attract to its membership the most highly trained men in the art of aviation. . . . Through the agency of subcommittees the main advisory committee could avail itself of the advice and suggestions of a large number of technical and practical men. . . . The aeronautical committee should advise in relation to the work of the Government in aeronautics and the coordination of the activities of governmental and private laboratories, in which questions concerned with the study of the problems of aeronautics can be experimentally investigated.

The Navy heartily endorsed the idea in a letter dated February 12 and signed by Franklin D. Roosevelt as Acting Secretary.

ESTABLISHMENT OF NACA

The Joint Resolution establishing the Advisory Committee and authorizing the President to appoint its 12 members was given final form in February. The people of the United States were at the time generally anxious to avoid involvement in what was then called the War in Europe. President Wilson is said to have felt that the establishment of a new aeronautical enterprise might reflect on American neutrality. Such reasoning may explain why the Resolution was attached to the Naval Appropriation Bill; perhaps a more likely reason was that in the rush to clear the legislative "log jam" by March 4, the date for adjournment of the Congress, Representative Roberts, Smithsonian regent, had found it simpler to effect its adoption by introducing the measure, as a rider to the Naval Appropriation Bill, in the Committee on Naval Affairs, of which he was a member.

Following is the provision in the Naval Appropriations Act, approved March 3, 1915:

An Advisory Committee for Aeronautics is hereby established, and the President is authorized to appoint not to exceed twelve members, to consist of two members from the War Department, from the office in charge of military aeronautics; two members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, of the United States Weather Bureau, and of the United States Bureau of Standards; together with not more than five additional persons who shall be acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences: Provided, That the members of the Advisory Committee for Aeronautics, as such, shall serve without compensation: Provided further, That it shall be the duty of the Advisory Committee for Aeronautics to supervise and direct *the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems*[1] which should be experimentally attacked, *and to discuss their solution and their application to practical questions.* In the event of a laboratory or laboratories, either in whole or in part, being placed under the direction of the committee, the committee may direct and conduct research and experiment in aeronautics in such laboratory or laboratories: And provided further, That rules and regulations for the conduct of the work of the committee shall be formulated by the committee and approved by the President.

That the sum of $5,000 a year, or so much thereof as may be necessary, for five years is hereby appropriated, out of any money in the Treasury not otherwise appropriated, to be immediately available, for experimental work and investigations undertaken by the committee, clerical expenses and supplies, and necessary expenses of members of the committee in going to, returning from, and while attending meetings of the committee: Provided, That an annual report to the Congress shall be submitted through the President, including an itemized statement of expenditures.

This language establishing the NACA closely followed that used by the British Prime Minister when he announced the formation of a similar committee to the House of Commons on May 5, 1909, in the following words:

It is no part of the general duty of the Advisory Committee for Aeronautics either to construct or to invent. Its function is not to initiate but to consider what is initiated elsewhere, and is referred to it by the executive offices of the Navy and Army construction departments. The problems which are likely to arise in this way for solution are numerous, and it will be the work of the committee to advise on these problems and to seek their solution by the application of both theoretical and experimental methods of research.

The work desired thus falls into three sections: (1) *The scientific study of the problems of flight, with a view to their practical solution.* (2) Research and experiment into these subjects in a properly equipped laboratory with a

[1] Italics in this and the following quotation supplied by the author for emphasis.

trained staff. (3) The construction and use of dirigibles and aeroplanes, having regard mainly to their employment in war.

The Advisory Committee are to deal with the first section, and also *to determine the problems* which the experimental branch should attack, *and discuss their solutions and their application to practical questions.* The second section represents the work referred to the laboratory (the National Physical Laboratory), while the duties concerned with the third section remain with the Admiralty and the War Office.

On April 2, 1915, President Woodrow Wilson appointed to the new Committee: Prof. Joseph S. Ames, of the Physics Department of Johns Hopkins University; Capt. Mark L. Bristol, USN, Director of Naval Aeronautics, Navy Department; Prof. William F. Durand, of the Engineering Department of Leland Stanford University; Prof. John F. Hayford of the Engineering Department of Northwestern University; Dr. Charles F. Marvin, Chief of the U. S. Weather Bureau; Hon. Byron R. Newton, Assistant Secretary of the Treasury; Prof. Michael I. Pupin of the Physics Department of Columbia University; Lt. Col. Samuel Reber, USA, Officer-in-Charge, Aviation Section of the Signal Corps, War Department; Naval Constructor Holden C. Richardson, USN, Department of Construction and Repair, Washington Navy Yard; Brig. Gen. George P. Scriven, USA, Chief Signal Officer, War Department; Dr. Samuel W. Stratton, Director, National Bureau of Standards; and Dr. Charles D. Walcott, Secretary, Smithsonian Institution.

Of the initial 12 members, 6 were members of the National Academy of Sciences (within the period of their NACA membership). It is of interest to note that for 40 years all chairmen of the NACA except the first, General Scriven, have been members of the National Academy. In 1955, there are 5 Academy members out of 17 members of the NACA. This statistic is of significance in view of the increasing impact on aeronautics of advances in many fields of science: for example, physiology and psychology of pilots, chemistry of combustion, physics of metals, physics of the atmosphere, acoustics, communications, electronics. The Committee is strengthened by the special knowledge of its individual members.

By direction of the President, the Secretary of War called the first meeting. The date was April 23, 1915; the place, his office. Conforming with the designation in the call for the first meeting, the word "National" was prefixed to the title "Advisory Committee for Aeronautics." General Scriven was elected temporary chairman, and Naval Constructor Richardson temporary secretary. With formulation of rules and regulations, subsequently approved by the President, the temporary chairman and secretary were elected for one year.

Perhaps the most important regulation adopted was for an executive committee, composed of 7 of the 12 members of the Advisory

Committee. The full Committee was to meet only semiannually. The executive committee was set up to meet regularly throughout the year and was charged with the administration of the affairs of the Committee and "general supervision of all arrangements for research."

Dr. Walcott was the first chairman of the executive committee. The other members were Dr. Ames, Captain Bristol, Dr. Marvin, Dr. Pupin, Colonel Reber, and Dr. Stratton, with Naval Constructor Richardson, ex officio, as secretary. Improvised quarters in the Army's Aviation Section were used the first year.

In the beginning the executive committee was a working group; the NACA had no paid personnel. It was not until June 23 that the first employee was hired. He was John F. Victory; 41 years later he is continuing his faithful, effective service to the Committee. In 1917 he was named assistant secretary of the Committee; 10 years later he became secretary, and in 1945, executive secretary.

One of the first problems was to examine what aeronautical research was then in progress in the United States—both under Government auspices and by private organizations—and then to effect rational coordination to assure maximum value from the total effort. Congressman Roberts, reporting on the need for the NACA on February 19, 1915, had well stated the situation:

> Besides these governmental agencies [he named the Bureau of Standards, the Weather Bureau and the War and Navy Departments] for the development of aviation, individuals in civil life have devoted time and expense in the scientific study and practical development of aeronautics. At the present time all of these agencies, both governmental and private, work independently without any coordination of activities.

Ten years later Dr. Ames gave a prime reason for "the great success of the Committee, because the Committee is a success," the coordination, on a rational scale, of American aeronautical research. His comments were made before hearings of the President's Aircraft Board (often called the Morrow Board). He spoke as chairman of the executive committee, to which position he had been elected when Dr. Walcott became Committee chairman in 1919.

In part, Dr. Ames said:

> The organization has an Executive Committee which appoints a number of tchnical subcommittees whose function it is to coordinate the research work throughout the country . . . . The various problems which all the services of the Government and the people engaged in industry, so far as we know, have in mind are brought before these subcommittes. The importance of each problem is discussed, and a program is laid out . . . .
>
> Around our table meet . . . representatives from all the Government services involved . . . . We work for all the departments of the Government.
>
> Furthermore, there are discussions going on at our table between the Army and the Navy and all other people interested which otherwise would not take place. We are really a coordinating body and that function would be impossible

if our organization were to be transferred to any executive department as such, because if our Committee were to be a part of any department it would necessarily follow that the aeronautical needs of that department would be primarily served . . . .

We think, therefore, that in our independent existence we offer a wonderful opportunity for serving all the departments.

In 1915 one of the first projects undertaken by the executive committee was a survey of facilities available "for the carrying on of aeronautic investigations." It was determined that "a number of institutions have available mechanical laboratories and engineering courses capable of application to aeronautics, but only the Massachusetts Institute of Technology and the University of Michigan so far offer regular courses of instruction and experimentation." Note was made of the experiments with full-scale propellers mounted on a whirling table, being conducted at Worcester Polytechnic Institute.

"It appears that the interest of colleges is 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," the NACA commented in its first Annual Report. "Manufacturers are principally interested in the development of types which will meet Government requirements or popular demand, but which will not involve too radical or sudden changes from their assumed standard types."

The Committee recognized that "considerable work had already been accomplished with which the general public is not acquainted." The Annual Report said of this point: "This covers lines of development and investigation which if published would save money and effort on the part of individual investigators and inventors who are now duplicating investigations already made by others . . . . Some of this information is already embodied in reports which are only accessible to a few interested parties who know of its existence."

The Smithsonian Institution had published a bibliography of aeronautics, covering the period through the middle of 1909. Now the NACA undertook publication of later bibliographies compiled by Paul Brockett of the Smithsonian. The first such volume covered the period 1909–16; as soon as past years had been "caught up," the bibliography was published annually into the early thirties.

The Committee was fully aware that to fulfill its obligations would require not only a well-equipped, suitably staffed laboratory, but also a flight test center where engineers could determine "the forces acting on full-sized machines." It was felt, however, that "since the equipment of such a laboratory as could be laid down at this time might well prove unsuited to the needs of the early future, it is believed that such provision should be the result of gradual development."

In October 1916 the Committee recommended that the War Department (which alone had funds available) purchase land about 4 miles north of Hampton, Va., for use by the Army and Navy as an aircraft proving ground. Named Langley Field, this site became the home of NACA's first research center. The War Department used it for pilot training during World War I. Aircraft development work of both the Army and Navy was centered elsewhere.

Lacking its own facilities, the NACA took prompt steps to contract for research to be performed for it by others. The first annual report included seven reports, as follows:

No. 1. Report on behavior of aeroplanes in gusts, by the Massachusetts Institute of Technology.
 Part 1. Experimental analysis of inherent longitudinal stability for a typical biplane, by J. C. Hunsaker.
 Part 2. Theory of an aeroplane encountering gusts, by E. B. Wilson.

No. 2. Investigation of pitot tubes, by the United States Bureau of Standards.
 Part 1. The pitot tube and other anemometers for aeroplanes, by W. H. Herschel.
 Part 2. The theory of the pitot and venturi tubes, by E. Buckingham.

No. 3. Report on investigations of aviation wires and cables, their fastenings and terminal connections, by John A. Roebling's Sons Co.

No. 4. Preliminary report on the problem of the atmosphere in relation to aeronautics, by Prof. Charles F. Marvin.

No. 5. Relative worth of improvements on fabrics, by the Goodyear Tire & Rubber Co.

No. 6. Investigations of balloon and aeroplane fabrics, by the United States Rubber Co.
 Part 1. Balloon and aeroplane fabrics, by Willis A. Gibbons and Omar H. Smith.
 Part 2. Skin friction of various surfaces in air, by Willis A. Gibbons.

No. 7. Thermodynamic efficiency of present types of internal-combustion engines for aircraft, by Columbia University.
 Part 1. Review of the development of engines suitable for aeronautic service, by Charles E. Lucke.
 Part 2. Aero engines analyzed with reference to elements of process or function, by Charles E. Lucke.

"What has already been accomplished by the Committee has shown that although its members have devoted as much personal attention as practicable to its operations, yet in order to do all that should be done technical assistance should be provided which can be continuously employed," the Committee said in its first Annual Report.

For the fiscal year 1917 the NACA asked for and received $85,000. Of the funds available, $68,957.35 (all that was not spent otherwise) went toward construction of the new laboratory at Langley Field. Its total cost was estimated at $80,000, a figure that later was revised upward.

The war was over before the "Committee's field station" at Langley Field could be said to be in useful operation. The Annual Report for 1919 noted that the Committee's first wind tunnel, with a 5-foot test section, was completed but inoperative for lack of power. The Army's power plant at Langley Field was incomplete, with construction stopped for lack of money.

With the Army planning to keep its experimental work in aeronautics at McCook Field, Dayton, and with the Navy's experimental aviation work centered at Norfolk, the NACA in 1919 felt it had good reasons for moving its field station activities to Bolling Field, just across the Anacostia River from the Capital. It asked Congress to authorize the move:

> The Committee believes it uneconomical and unsatisfactory to remain at Langley Field. The same work can be carried on more efficiently, more promptly, and more economically at Bolling Field, where the work can be closely watched by all members of the Committee, and where the members of the engineering staff in charge of work can have ready access to the Committee, to large libraries, and other sources of information, constant communication with the Bureau of Standards, a more satisfactory market for labor and supplies and adequate power supply, and relief from the perplexing question of securing quarters at Langley Field or in Hampton or other nearby towns.

Congressional approval for the move to Bolling Field did not come. In April 1920, the Committee, perhaps with a collective sigh, took action that accepted as permanent the Langley Field site for the "field station." It sought Presidential approval of the name, "Langley Memorial Aeronautical Laboratory." President Wilson concurred, and dedicatory exercises were conducted on June 11. Attendance included guests, it was later reported, "of whom a number had flown to the field."

This date, June 11, 1920, may be considered the real beginning of NACA's own program of aeronautical research, conducted by its own staff in its own facilites. The previous year a start had been made in obtaining full-scale performance data from flight tests, but now the availability of a wind tunnel made possible systematic investigations of critical aerodynamic problems, such as: (1) Comparison between the stability of airplanes as determined from full-flight test and as determined from calculations based on wind-tunnel measurements; (2) comparison between the performance of full-scale airplanes and the calculations based on wind-tunnel experiments, and (3) airfoils, including control surfaces, with special attention to thick sections, plus combinations and modification of such sections.

THE COMMITTEE'S ADVISORY FUNCTIONS

This has been essentially a chronological account, first, of events preceding establishment of the NACA, and then its early steps to undertake its responsibilities as the nation's aeronautical research establishment. At this point it is in order to glance briefly at some early activities of the Committee which were consonant with the "Advisory" in its name.

In 1916 the executive committee invited engine manufacturers to attend a meeting on June 18 in Dr. Walcott's office at the Smithsonian Institution to discuss the problem of obtaining more powerful and more reliable engines and to bring about a better understanding between builders and users. Representatives of the military services were in attendance, and although it is to be doubted that many problems were solved, unquestionable good was done by bringing them into sharp focus. Another benefit from the meeting was an arrangement whereby the Society of Automotive Engineers became active in providing assistance in the solution of aircraft powerplant problems.

Also in 1916 the Committee examined the problem of the carriage of mail by air. The Post Office Department had failed in efforts to establish a contract air-mail service in Alaska and from New Bedford to Nantucket Island. Air mail was then considered to be justified only over almost impossible terrain. "Conditions of both these routes were so severe as to deter responsible bidders from undertaking this service," the Committee decided. It felt, nonetheless, that because of the great progress made in aviation, the Post Office should set up one or more experimental routes, "with a view to determining the accuracy, frequency, and rapidity of transportation which may reasonably be expected under normal and favorable conditions, and therefrom to determine the desirability of extending this service wherever the conditions are such as to warrant its employment."

The above-stated opinion was transmitted to Congress in 1916 as a recommendation. In 1918, when $100,000 was appropriated for creation of an experimental air-mail service, the NACA invited the attention of the Secretary of War to the following facts: "Practically all aircraft manufacturing facilities in the United States were being utilized by the War and Navy Departments, and all capable aviators were in the military or naval air services . . . . [and] it was exceedingly desirable that Army aviators be regularly and systematically trained in long-distance flying . . . . [and that] it would appear to be to the advantage of the War Department and of the Government generally that military airplanes be used to render practical and effective service" in carrying mail between Washington, Philadelphia, and New York. In its 1918 Annual Report the NACA viewed with satisfaction the manner in which the experimental airmail service had been established along the lines recommended, and expressed the opinion it had already "been sufficiently well demonstrated since its inauguration to justify its extension generally."

In 1921, the Committee noted in a special report to the President that—

> There are several causes which are delaying the development of civil aviation, such as the lack of airways, landing fields, aerological service, and aircraft properly designed for commercial uses. The Air Mail Service stands out as a pioneer agency, overcoming these handicaps and blazing the way, so to speak, for the practical development of commercial aviation. As a permanent proposition, however, the Post Office Department, as its functions are now conceived, should no more operate directly a special air mail service than it should operate a special railroad mail service; but until such time as the necessary aids to commercial aviation have been established it will be next to impossible for any private corporation to operate under contract an air mail service in competition with the railroads.

In January 1917, the War and Navy Departments complained to the NACA about prohibitive prices for aircraft, said to be due to "the extra item of royalty added by each firm in anticipation of infringement suits by owners of alleged basic aeronautic patents who were then threatening all other airplane and seaplane manufacturers with such suits, and causing thereby a general demoralization of the entire industry."

The Committee held meetings with Government officials, owners of patents, and aircraft manufacturers. It then recommended organization of a Manufacturers Aircraft Association to effect the cross licensing of aeronautic patents and to make the use of all such patents available to any member firm at the relatively small cost of $200 per airplane. This happy solution was adopted, and resulted, in the Committee's opinion, in "the prevention of the virtual deadlock with danger of monopoly existing under the patent situation."

In many other ways the Committee gave advisory service on such varied matters as provision of insurance for aviators, naming of flying fields "in commemoration of individuals who had rendered conspicuous service," aerial mapping techniques, and selection of a site near Washington for a "landing field" to provide "accommodation of transient aviators."

A special subcommittee during World War I examined some 7,000 inventions and suggestions in the field of aeronautics. Of this work the NACA later said, "The great majority of the suggestions received are obviously of an impractical nature. Several, however, have seemed worthy of further consideration and have been referred to military or naval experts." In addition to this arduous task, the Committee served as arbitrator in the settlement of disputes involving technical questions between private parties and the military services.

Perhaps the most important of NACA's advisory services was the leadership which the Committee gave to the efforts for legislation necessary to the orderly development of civil aviation. With cessation of hostilities in 1918, the Committee promptly took up the basic question of what should be done about the civil use of aircraft. Although it would be nearly 8 years before the required Federal legislation was adopted (the Air Commerce Act of 1926), the recommendations made by the Committee in 1918 encompassed what was needed: "Federal legislation . . . . . governing the navigation of aircraft in the United States and including the licensing of pilots, inspection of machines, uses of landing fields, etc. . . . . . designed to . . . . . encourage the development of aviation . . . . ., and at the same time to guide the development . . . . . along such lines as will render immediate and effective military service to the Nation in time of war."

On April 1, 1921, President Harding directed the Committee to meet with representatives of interested Government departments to determine what could be done to achieve Federal regulation of air navigation without legislative action, and what new legislation was needed. April 9, the recommendations were formulated. The Committee was brief: "Federal regulation of air navigation cannot be accomplished under existing laws . . . . . . It is recommended that a Bureau of Aeronautics be established in the Department of Commerce."

There were other NACA proposals in 1921: That the Post Office be authorized to extend its air-mail routes across the continent, and that naval aviation activities be centered in a Bureau of Aeronautics within the Navy Department.

In its Annual Report for 1921, the NACA noted the principal reason for delay in passing the recommended legislation:

> The Committee is not unmindful of the legal sentiment that a constitutional amendment should first be adopted before such legislation is enacted, on the ground that effective regulation of air navigation as proposed would otherwise be unconstitutional as violating the rights of property and encroaching upon the rights of States. To postpone such legislation until a constitutional amendment can be proposed and ratified would have the effect of greatly retarding the development of commercial aviation, with no assurance that sufficient popular interest would ever be aroused to accomplish such an amendment. The Committee is of the opinion that the most effective course to be followed for the development of aviation would be first to enact the legislation deemed necessary for the Federal regulation of air navigation and the encouragement of the development of civil aviation, and let the question of the constitutionality of such legislation be tested in due course. In the meantime, there would be development in civil and commercial aviation, and if eventually the legislation which made possible such development should be definitely determined to be unconstitutional there would then, in all probability, be sufficient public interest in the subject and popular demand to adopt an amendment to the Constitution.

Years of perseverance culminated, in April 1926, in a careful analysis by the Committee of fundamental differences of opinion respecting certain aspects of the basic legislation then before the Congress. The solutions then proposed by the NACA were accepted by the joint

Senate-House conferees, and the Air Commerce Act became law on May 20, 1926.

"This act provides the legislative cornerstone for the development of commercial aviation in America," the Committee said. It "gives an important measure of stability to commercial aviation as a business proposition and in its direct effects will go far toward encouraging the development of civil and commercial aviation."

AERONAUTICAL RESEARCH

The Air Commerce Act made the Secretary of Commerce responsible for the regulation of civil aviation, and for its encouragement. At the same time, this action freed the NACA from an "advisory" burden it had carried during its first 10 years. From now on, the Committee could concentrate upon its chief responsibility—the conduct of aeronautical research.

During the first 10 years of the Committee's existence, demands upon the time of NACA members were very heavy. From 1915 to 1919 the Committee had three chairmen: General Scriven, 1915; Dr. Durand, 1916–1918, and Dr. John R. Freeman, 1919. Dr. Freeman was sent on a mission to China and was succeeded as chairman in 1919 by Dr. Walcott, who had served as chairman of the executive committee since its formation in 1915.

Dr. Walcott was succeeded as chairman of the executive committee by Dr. Ames, who effectively supported Dr. Walcott until the latter's death in 1927. At that time Dr. Ames became chairman to serve until his retirement in 1939. The fact that he was located in Baltimore, where he headed the physics department of Johns Hopkins University until he became president of the University in 1929, proved no handicap. Dr. Ames was in Washington as often and as long as Committee business required.

With the development of laboratory facilities at Langley, the NACA began building a competent engineering staff. The Langley Laboratory attracted young men with good training, who could grow to do work of increasing importance. The independence of the NACA was one of the attractions, as was also the opportunity for the young engineer to sign the published report of his own research. So was the availability of superior research and test equipment.

In 1919 the Committee invited Dr. George W. Lewis, professor of mechanical engineering at Swarthmore College, to become its executive officer. In this capacity, he was called upon to guide the research programs and to plan and build the research tools needed. In 1924 Dr. Lewis' title was changed to one that more closely described his responsibilities, director of aeronautical research. From then until 1945, when his health failed under the tremendous burdens he insisted upon carrying during World War II, George Lewis gave devoted and effective leadership to the staff of the Committee.

While the Committee was acquiring the equipment at Langley necessary for the research programs envisioned, use was made of facilities available elsewhere for certain investigations. Before the end of World War I Dr. Durand was conducting most valuable research on air propellers at Leland Stanford University, and at M. I. T. the availability of a wind tunnel and staff made possible fundamental aerodynamic research on stability and control and on the characteristics of wing sections.

The National Bureau of Standards worked on aeronautical problems at the request of the NACA and with its financial support. The Bureau developed apparatus for the study of combustion problems under simulated conditions of high altitude and later equipped itself with wind tunnels for fundamental research on turbulence and boundary-layer problems.

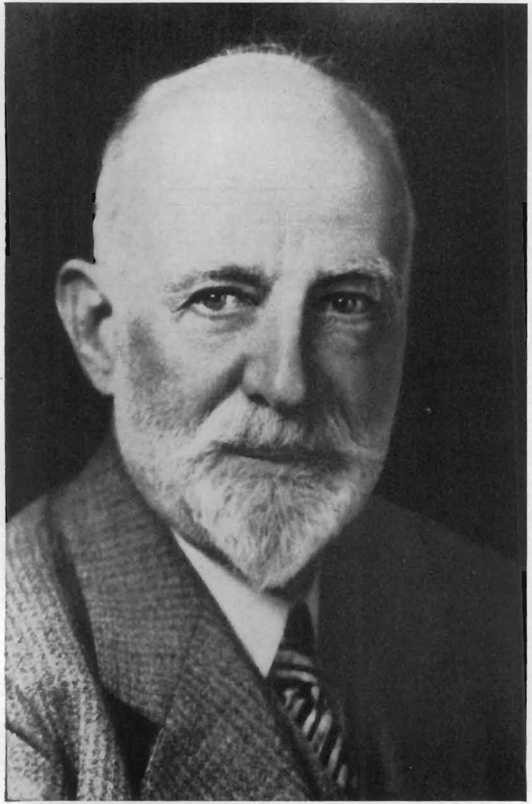
The aeronautical experimentation carried on at the Navy Yard in Washington and at McCook Field in Dayton was correlated with a comprehensive plan which the NACA formulated and which was kept up to date as military and industry needs changed. The pioneering work by Naval Constructor Richardson on seaplane hulls, and the later researches directed by Chief Constructor David W. Taylor, contributed significantly to the advancement of naval aviation. At McCook Field (later moved and enlarged to become Wright Field) the availability of a wind tunnel caused the NACA to detail one of its first technical employees, Dr. George de Bothezat (best known, perhaps, for his later work with helicopters) to Dayton to assist with aeronautical research there.

In 1920 the NACA's first wind tunnel was put to work. With relatively minor exceptions, this first major piece of equipment was patterned after one at the British National Physical Laboratory. The work that could be done with this tunnel was essentially no different from that which could be accomplished at the Navy Yard, McCook Field, M. I. T., or other locations where conventional wind tunnels were located.

In June 1921, the executive committee decided to build a new kind of wind tunnel. Utilizing compressed air, it would allow for "scale effects" in aerodynamic model experiments. This tunnel represented the first bold step by the NACA to provide its research personnel with the novel, often complicated, and usually expensive equipment necessary to press forward the frontiers of aeronautical science. It was designed by Dr. Max Munk, formerly of Göttingen.

The value of the new tunnel was explained in 1922 by Dr. Ames:

> When a new design of airplane . . . is made, it is customary to construct a model of it, one-twentieth the size or less, and to experiment upon this. The



1. Dr. William F. Durand, member National Advisory Committee for Aeronautics 1915–1933, 1941–1945; Chairman, 1916–1918.

2. Dr. Charles Doolittle Walcott, Secretary Smithsonian Institution 1907–1927; member National Advisory Committee for Aeronautics 1915–1927; Chairman, 1919–1927.

1. Dr. Joseph S. Ames, member National Advisory Committee for Aeronautics 1915–1939; Chairman, 1927–1939.

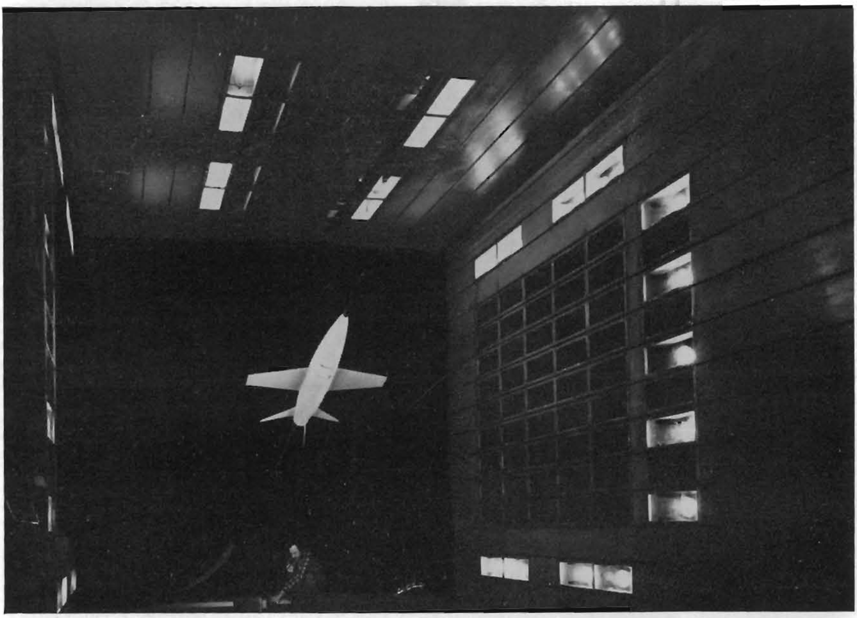
2. Dr. George W. Lewis, Director of Aeronautical Research, National Advisory Committee for Aeronautics, 1919–1947.

1. Application of NACA cowling on AT–5A Army pursuit training plane increased its speed from 118 to 137 mph. This was equivalent to providing 83 additional horsepower.

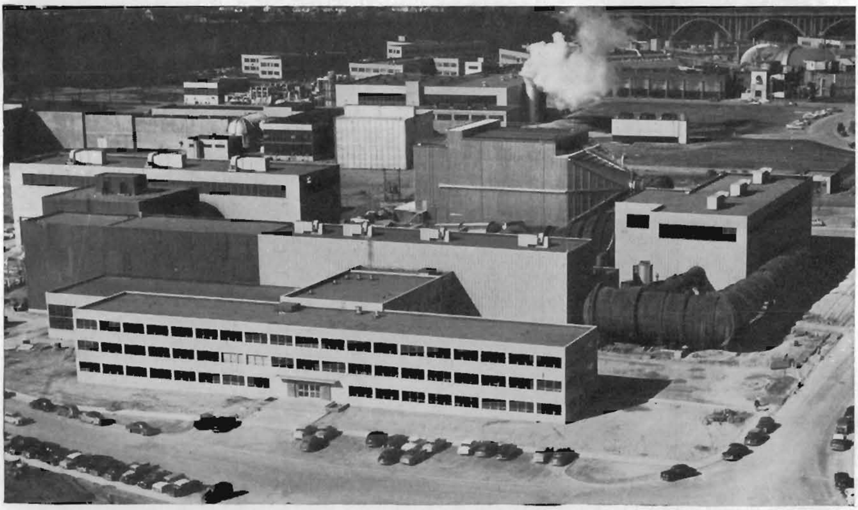
2. The NACA Langley Laboratory's low-drag wing was first used on the P–51 Mustang fighter, making it the fastest propeller-driven airplane of World War II.

1. An engineer in NACA's towing tank at Langley Aeronautical Laboratory prepares a dynamic model equipped with hydro-skis for a test run.

2. This rocket-powered model, one of a series tested by the NACA to investigate the flutter characteristics of low aspect ratio wings, shoots skyward toward the Atlantic Ocean from its launching ramp at the NACA Pilotless Aircraft Research Station, Wallops Island, Va.



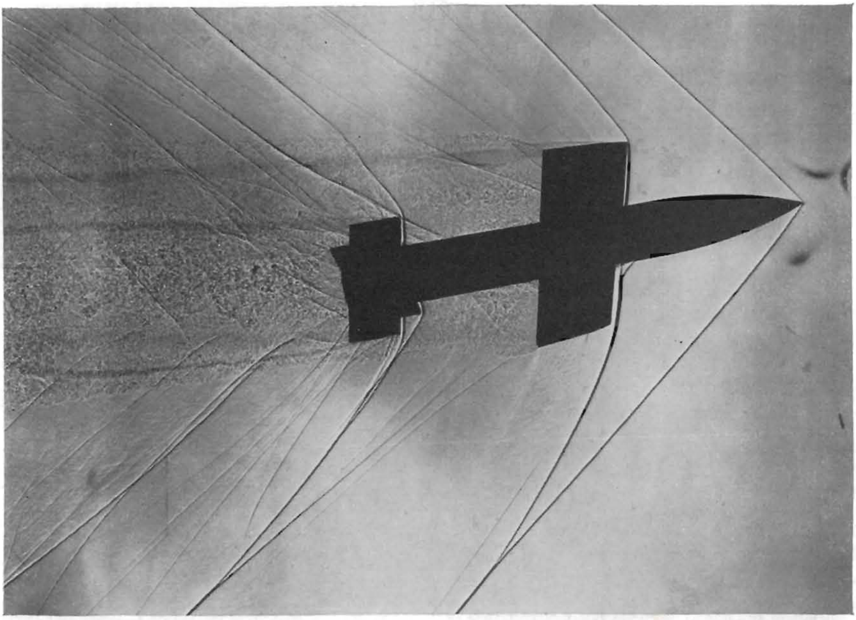
1. The 14-foot test section of the Ames Unitary Plan wind tunnel. It is capable of operating smoothly from subsonic speeds through the speed of sound to low supersonic values, a region where conventional wind tunnels are not usable, owing to choking. The perforated or slotted walls of the tunnel permit flow disturbances to pass through the open parts while retaining sufficient solid area to guide the air uniformly past the model. Two other test sections operate at speeds up to Mach No. 3.5.



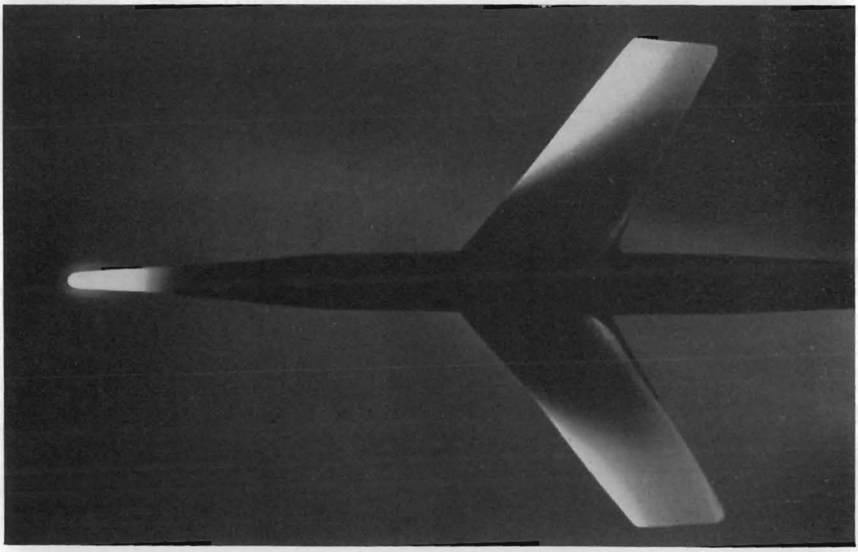
2. The NACA Lewis Laboratory's new 10-by-10-foot supersonic wind tunnel is used for research of aircraft power plants. This tunnel is designed for speeds of Mach Nos. 2 to 3.5.

1. Six dummies, seated in various positions and in several types of seats, rode a service-weary Lodestar transport plane through a severe crash, one of a series staged by a research group of the NACA Lewis Flight Propulsion Laboratory. Objective of the crash program is to gather data on passenger and pilot survival problems in aircraft accidents.

2. Damage was heavy but fire was prevented in this experimental crash because of a fire-inerting system devised by the NACA Lewis Flight Propulsion Laboratory. A series of crashes was staged with worn-out turbojet- and piston-powered aircraft to study problems of fire and human survival in crash accidents. The white cloud in the picture is jet fuel issuing from the ripped tank in the right wing.



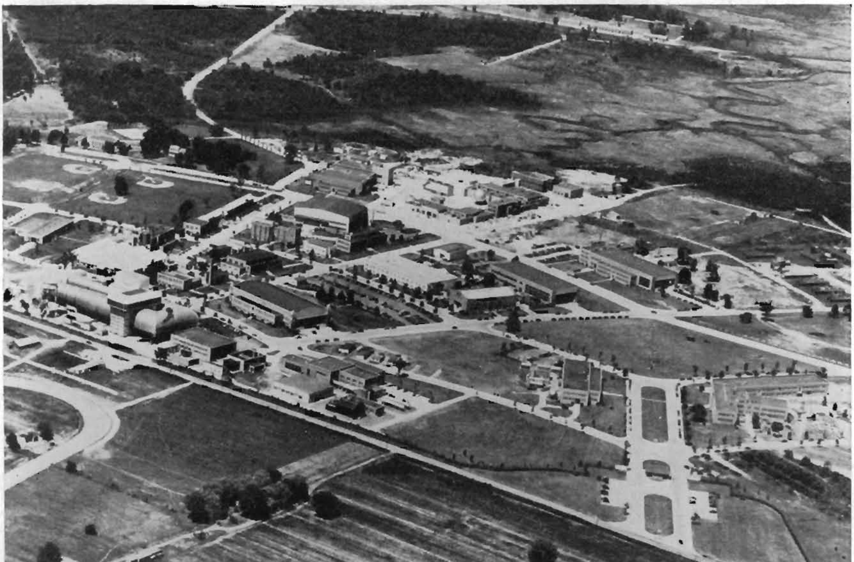
1. Caught in flight by shadowgraph technique, this free-flight research model shows the complicated pattern of shock waves and vortexes associated with high-speed flight. Vortexes are left in the wake of the model. The unsymmetrical shock-wave pattern shows that the model is turning. The model is 7 inches long and has just been fired from a 3-inch smooth-bore Naval gun into still air. Mach number at the instant of this photograph is 1.6.



2. Infrared photograph of a laboratory experiment simulating aerodynamic heating. At 2,000 miles per hour, sustained flight could produce temperatures up to 1,200° F. Much additional research is required to permit successful operation under such conditions.

Flying regularly at transonic and supersonic speeds, these research airplanes are exploring new fields for data needed to design the military and civil airplanes of the future. In center is the Douglas X–3; at lower left, the Bell X–1A flown late in 1953 at a record 1,650 mph. or 2.5 times the speed of sound. Continuing clockwise from the X–1A are the Douglas D–558–I "Skystreak"; Convair XF–92A; Bell X–5 with variable sweepback wings; Douglas D–558–II "Skyrocket," first piloted airplane to fly at twice the speed of sound; and the Northrop X–4. The National Advisory Committee for Aeronautics, the Air Force, the Navy, and the aircraft manufacturing industry are joined to design, build, and fly these and other advanced airplanes in a high-speed flight research program.

1. Grumman F11F–1. Use of the NACA-developed "area rule" concept for decreasing drag rise at transonic speeds gave this "Tiger" fighter plane supersonic performance. The "wasp-waisted" Navy carrier plane uses one-third less thrust than other airplanes of equivalent performance.



2. West Area, Langley Aeronautical Laboratory, Langley Field, Va.

1. Ames Aeronautical Laboratory, Moffett Field, Calif.

2. Lewis Flight Propulsion Laboratory, Cleveland, Ohio.

method now in universal use is to suspend the model from suitable balances in a stream of air . . . at a velocity of 60 mph . . . The balances register the forces and moments acting on the model. From the results of such measurements one decides whether the original design is good or not. But is one justified in making such a decision? Why should the same laws apply to a little model inside the wind tunnel, as it is called, and to the actual airplane flying freely through the air? Evidently there is ground for grave uncertainty. The Committee has perfected a method for obviating this. It has been known from aerodynamic theory for some time that the change in scale, from airplane to its model, could be compensated by compressing the air from ordinary pressure to 20 or 25 atmospheres; as the structure moving through the air is reduced in size from 50 feet to 2 feet, the molecules of the air are brought, by comparison, closer and closer together until their distance apart is one twenty-fifth of what it was originally. The effect of scale is thus fully compensated and experiments upon a model in this compressed air have a real meaning. The Committee has constructed a large steel tank, 34 feet long and 15 feet in diameter, inside which is placed a wind tunnel with its balances, etc., and in which the air may be kept in a state of high compression. The information to be obtained from the apparatus will be the most important ever given airplane designers.

Experience with simple airplane models without propellers in the variable-density tunnel encouraged the NACA, in June 1925, to construct a wind tunnel large enough to test full-scale airplane propellers under conditions of flight. This was a costly decision, but the cost was repaid manyfold by improved airplane performance.

The propeller research tunnel was put into operation in 1927. It had a circular test section 20 feet in diameter and was powered by two Diesel engines rated at 1,000 hp. each. Its air speed was 110 mph. and, at the time, it was the largest wind tunnel in the world. Almost from the beginning of its use, the PRT provided information leading to design changes which resulted in dramatic improvements in airplane performance.

The first and most spectacular of these productive researches brought about the development of what became known as the NACA cowling for air-cooled radial engines. In its 1928 report, the Committee said that "by the application of the results of this study to a Curtiss AT–5A Army pursuit training plane, the maximum speed was increased from 118 to 137 mph. This is equivalent to providing approximately 83 additional horsepower without additional weight or cost of engine, fuel consumption, or weight of structure. This single contribution will repay the cost of the Propeller Research Tunnel many times."

The Collier Trophy, awarded annually "for the greatest achievement in aviation in America, the value of which has been thoroughly demonstrated by actual use during the preceding year," went to the NACA for the development of this form of cowling. President Hoover made the presentation on January 3, 1930 (for the year 1928), and after the reading of the citation Dr. Ames responded that "a scientist receives his reward from his own work in believing that he has added to human knowledge; but he is always gratified when his work is recognized as good by those competent to judge."

A second important benefit accruing from work in the PRT was more positive information about the best location of engine nacelles. The engines of the Ford Tri-motor, and similar aircraft of the twenties, were hung below the wing. As a consequence of research reported confidentially in 1930, multiengine aircraft designed thereafter had their engines faired into the leading edge of the wing with an important gain in speed.

The systematic work accomplished in the PRT led to other practical design changes. For example, it was possible to obtain an accurate estimate of the drag caused by such apparently insignificant details as the location of a gasoline filler cap. Similarly, engineers studied the aerodynamic interference of wings and fuselage, and the use of fillets to reduce the interference was proposed. (In 1928 the NACA published its first Technical Note on this subject, by Melvin N. Gough.)

That the fixed landing gear represented a large amount of drag had long been appreciated, but it was not until the PRT became operative that the drag penalties of fixed landing gear could be determined precisely. The higher speeds made possible by use of the NACA cowling, the wing positioning of the engine nacelles, the filleting of wing–fuselage junctures, and other aerodynamic refinements now made attractive the investment of added cost and weight implicit in retractable landing gear.

In 1933, looking at the gains from the research at its Langley Laboratory, the Committee said: "No money estimate can be placed on the value of superior performance of aircraft in warfare . . . nor can a money estimate be placed on . . . improved safety. . . . The value in dollars and cents of improved efficiency in aircraft resulting from the Committee's work can, however, be fairly estimated. For example, the results of . . . researches completed by the Committee within the last few years, show that savings in money alone will be made possible in excess annually of the total appropriations for the Committee since its establishment in 1915."

The economic depression that began with the stock-market crash of 1929 was not an unmixed evil for the NACA. Although there were strong pressures to reduce operating expenditures, these were successfully resisted, in the main, by such impressive evidence of the money value of the Committee's work as that just cited. On the favorable side was the opportunity for the NACA to construct at depression costs new research equipment with funds already appropriated, and the availability of engineers, from whom many of its future leaders have developed.

The 30- by 60-foot, "full-scale" wind tunnel and the 2,000-foot towing tank (for study of hydrodynamic characteristics of water-based aircraft) were completed in 1931. The designer of the $900,000 "full-scale" wind tunnel (then the world's largest) was Smith J. DeFrance, who became director of the Committee's second research center, at Moffett Field, Calif., when it was established in 1941.

A somewhat later "depression baby" was the 500-mph. 8-foot wind tunnel. For some time after its completion in 1936, it was known, somewhat optimistically, as the "full-speed wind tunnel." Other novel research equipment constructed at Langley in these years included a free-spinning wind tunnel and a refrigerated wind tunnel (for study of icing problems).

In this depression period NACA engineers first disclosed the ability to use air more than once. Soon after the variable-density tunnel was rebuilt following a fire in 1927, it was suggested that some use should be made of the air released each time the tunnel was returned to atmospheric pressure. Why not discharge the pressurized air through an appropriate nozzle and thus obtain a really high-speed air stream? The result was a blow-down device, with a 12-inch test section in which aerodynamic phenomena could be studied at speeds almost that of sound (about 760 mph. at 60° F.).

Thus far, the discussion of research by the NACA has been largely concerned with aerodynamics where the greatest effort was made. Nevertheless there was fruitful work on powerplants, loads, and structures, which will be noted later. In retrospect, one marvels that so much could be accomplished. At the beginning of 1930, for example, the total employment at the Langley Laboratory was only 181.

By the mid-thirties, the work of the NACA had become internationally known and respected. Somewhat earlier the British journal Aircraft Engineering had commented about the Committee: "They were the first to establish, and indeed to visualize, a variable-density tunnel; they have led again with the construction of the 20-foot propeller research tunnel; and . . . [with] a 'full-scale' tunnel in which complete aeroplanes up to 35-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."

Somewhat wryly, A. J. Sutton Pippard of the University of London observed in 1935 "that many of our most capable design staffs prefer to base their technical work upon the results of the American NACA."

An important effort of the NACA was to make its research findings fully available for use. First, there were Reports, comprehensive presentations expected to have lasting value. Then there were Technical Notes, preliminary or narrower in scope. Technical Memorandums were reprints, or translations, from the aeronautical literature of other nations. Aircraft Circulars reported information about foreign aircraft and engines. In later years Research Memorandums were added; these were limited in distribution for reasons of military security or because they contained proprietary information.

Recognizing the importance of knowing what was available in the aeronautical literature of the world, Dr. Ames had been instrumental in the formation of an Office of Aeronautical Intelligence as an integral part of the Committee's program, and for years he served both as its director and as chairman of the NACA's subcommittee on publications and intelligence. Beginning soon after World War I and continuing (except for a break in World War II) until 1950, the Committee maintained a technical assistant in Europe. From 1921 the post was held by John Jay Ide, who faithfully and intelligently served the NACA both as European reporter and in a liaison capacity with foreign aeronautical research organizations. It was decided in 1950 to close the NACA's European office because the art and science of aeronautics had become too complex for reportage by a one-man bureau. International interchange of information is now handled by other means.

Beginning in 1926, the Committee sponsored an annual conference at the Langley Laboratory with representatives of the military services and the industry. In addition to the opportunity to see what the NACA was doing, guests had an occasion to criticize and to suggest new research on problems they felt were especially pressing. In the first years of the conference, "everyone" from the industry and the military services attended; even so, the guest list numbered little more than 200, and the journey to and from Langley, via Potomac River steamer, resulted in many unofficial but profitable sessions. After World War II, it became necessary to provide two types of meetings: (1) Technical conferences concerned with a specific subject, usually classified for security reasons, e. g., supersonic aerodynamics. (2) Inspections. Held annually, on a rotating basis at each laboratory, the NACA inspections seek to give the industry and military services a comprehensive view of technical progress. As many as 1,500 attend these meetings, which are not classified.

Also of importance from the standpoint of communication is a steady traffic of industry and military visitors to NACA research centers. Much is accomplished by discussion of matters of specific concern to those involved. No less important are the visits by NACA technical personnel to specific industry plants.

Beginning in the mid-thirties, the NACA reported annually to the Congress and to the President that certain European nations were making a determined effort to achieve technical and quantitative supremacy in aeronautics. Each year the Committee's comments on this subject were stronger. In 1937, for example, Dr. Ames reported: "The greatly increased interest of the major powers in fostering aeronautical research and their determined efforts to excel in this rapidly expanding engineering science constitute a scientific challenge to America's present leadership." He explained:

Up to 1932 the Committee had constructed at its laboratories at Langley Field . . . . special equipment such as the variable-density tunnel, the propeller-research tunnel, the full-scale tunnel, and . . . . . a seaplane towing basin. They were at the time of construction the only such pieces of equipment in the world. The possession of such equipment was one of the chief factors in enabling the United States to become the recognized leader in the technical development of aircraft. Since 1932 this research equipment has been reproduced by foreign countries and in some cases special research equipment . . . . . abroad . . . . . is superior to the equipment existing at Langley Field.

This condition has impressed the Committee with the advisability of providing additional facilities promptly as needed for the study of problems that are necessary to be solved, in order that American aircraft development, both military and commercial, will not fall behind.

EXPANSION OF FACILITIES

In 1938, the Committee reported that its laboratory employees at Langley Field were "working under high pressure." It warned that "the recent great expansion of research facilities by other nations will bring to an end the period of American leadership in the technical development of aircraft unless the United States also constructs additional research facilities." Dr. Ames, in October 1938, appointed a Special Committee on Future Research Facilities to make recommendations.

But even before the Special Committee met, the NACA was making a strong recommendation for special facilities for research on aircraft structures. "With the advance in size and speed of aircraft . . . . . the problems involved require the conduct of laboratory research on structures on an increasing scale," the Committee wrote Congress. "This is the greatest single need for additional research equipment and . . . . . in the interests of safety and of further progress in aeronautics, it should be provided at the earliest possible date."

On December 30, 1938, the Special Committee recommended immediate establishment of a second NACA research center, in California, to relieve what the late Maj. Gen. Oscar Westover (then Chief of the Army Air Corps and a member of the NACA) called "the congested bottleneck of Langley Field." Although the recommendations had been presented as emergency in character, it was not until midsummer—August 9, 1939—just before the start of World War II, that the second laboratory was authorized by Congress. Hardly a month later, September 14, ground was broken at Moffett Field, some 40 miles south of San Francisco, for what became the Ames Aeronautical Laboratory.

Earlier that year an expansion of Langley facilities was authorized by Congress. S. Paul Johnston (now managing head of the Institute of the Aeronautical Sciences) was named Coordinator of Research to assist Dr. Lewis. Further intensification of research effort obviously was needed in the face of war in Europe, and a second Special Committee, headed by Charles A. Lindbergh, was appointed. This group recommended, October 19, 1939, that a powerplant research center be established at once.

"There is a serious lack of engine research facilities in the United States," Lindbergh's committee stated. "The reason for foreign leadership in certain important types of military aircraft is due in part to the superiority of foreign liquid-cooled engines. At the present time, American facilities for research on aircraft powerplants are inadequate and cannot be compared with the facilities for research in other fields of aviation." It was June 26, 1940—after Belgium and Holland had been overrun—that Congressional authorization for the new flight-propulsion laboratory was forthcoming.

A site was made available by the city of Cleveland adjacent to its municipal airport. Immediate steps were taken by Dr. Lewis to plan and construct a complex of laboratories equipped with facilities for the investigation of airplane engines, their parts and materials, fuels and lubricants, ignition and combustion, heat transfer and cooling, intake and exhaust aerodynamics, as well as for the fundamental physics, chemistry, and metallurgy of power generation. In addition, facilities were provided for flight testing in laboratory-instrumented airplanes—practical flying laboratories for propulsion research.

There is no doubt that this flight-propulsion center was a large step in advance of any comparable facility in the world. It has cost up to date about $110,000,000 and now employs about 2,800 people.

After the death of Dr. Lewis in 1948, the Committee decided on the name "Lewis Flight Propulsion Laboratory," as a memorial of that great engineer's crowning achievement.

Here it may be proper to explain why the research effort on powerplants and on structures had been so much less than that devoted to aerodynamics. In the first place, it must be remembered that between World Wars I and II, the United States was an intensely peace-minded nation. In addition, the thousands of miles of ocean to our east and west gave a feeling of safety from attack, a complacent sense of detachment. The Congress was unwilling to expend really large sums for national defense or on research to improve it.

Until the eve of Pearl Harbor, the annual expenditure by the United States to support aeronautical research was indeed modest. Even as late as the summer of 1939, the NACA's total complement was 523, including only 278 technical people.

The major effort by the NACA over the years had been deliberately concentrated on aerodynamic problems. Here, for a given expenditure, the possible gains to be achieved were very large, particularly in view of the relatively few engineers who could be assigned to the work.

Powerplant research and structural research are expensive, and require extensive facilities for full-scale investigations. Small models are of limited utility in powerplant research. Furthermore, powerplants and structures are the immediate concern of strong and highly competitive industrial firms. The Committee evidently felt that under its fiscal restrictions, it would do better to concentrate on basic aerodynamic problems and might, hopefully, leave research and development of powerplants and structures to the industry and the military services.

However, the Lindbergh committee in 1939 said that this past policy was wrong, and the NACA agreed. It appeared that leaving fundamental research to the industry meant, in effect, that such research would be indefinitely postponed.

A competitive engine firm must concentrate on what its customers want. The firm improves its engine with small changes based on experience. It seeks the minimum risk of interruption of production. The military services, its principal customers, conduct competitive trials based on standard performance specifications. After quantity orders are placed, no major changes are possible. The services, of course, welcome small changes based on experience, if the risk of trouble be slight. As a result, engine development tends to adhere to a definite pattern and progresses slowly.

An engine manufacturer must make a relatively heavy investment in plant and tooling for production of a particular engine. The manufacturer is naturally inclined to concentrate on improvements in this engine to prolong its commercial life. These improvements are essentially proprietary in character.

Similar remarks apply to the airplane industry. Every effort is made to improve a particular airplane to prolong its vogue in production. This development effort is restricted to conservative changes in a basic design acceptable to the customer.

In this country, the Navy standardized on air-cooled radial engines that met Navy requirements, while the Army insisted on 12-cylinder liquid-cooled engines to power the fighters in their program.

However, there were important fundamental applications of science to engine design that needed investigation in 1940.

From the beginning, one of the principal technical committees of the NACA was concerned with powerplants. During World War I, a few research projects in the powerplant field were carried on under its auspices, notably in the altitude facility at the Bureau of Standards, where engines could be operated under conditions simulating those experienced by high-flying aircraft. A program of systematic tests was conducted there for the NACA, including supercharging with a Roots-type blower.

At Langley the small but expert powerplant staff made some important contributions, in addition to their cooperation with the wind-tunnel people in developing the remarkable NACA cowling for air-cooled engines. One recalls improved finning for air-cooled engine cylinders, methods to decrease the octane requirements of high-compression engines, and work on such fundamental matters as the behavior of fuels—how they ignite, how they burn, and how this burning corrodes critical parts of the engine. A principal tool in the study of these latter questions was high-speed photography, and cameras capable of taking pictures at the rate of 400,000 per second were developed by the NACA.

In the field of jet propulsion the NACA exhibited an early awareness of its possible advent but did little about it. In 1923, in Report No. 159, "Jet Propulsion for Airplanes," Edgar Buckingham of the Bureau of Standards, reported that: "The relative fuel consumption and weight of machinery for the jet decrease as the flying speed increases; but at 250 mph. the jet would still take about four times as much fuel per thrust horsepower-hour as the air screw, and the power plant would be heavier and much more complicated. Propulsion by the reaction of a simple jet cannot compete, in any respect, with air screw propulsion at such flying speeds as are now in prospect." This conclusion was entirely rational on the basis of the technology at that time.

In the early thirties, the NACA was asked by a representative of the airframe industry to resurvey jet-propulsion prospects and, although airplane speeds by then had passed the 250-mph. mark which Buckingham considered a goal, the story was much the same. The inefficiency of the jet engine at the speeds contemplated ruled it out of consideration.

Near the end of the 1930's, some preliminary experimental work on jet propulsion was undertaken at the Langley Laboratory. These experiments indicated that jet engines would be so fuel-thirsty as to limit their useful application to very high-speed, very short-range aircraft. American thinking, perhaps because of geography, was focused on long-range performance where fuel economy was paramount. This idea served to discourage any real jet-development effort in the United States until intelligence of British and German experiments reached us.

In March 1941, Dr. Durand was recalled from retirement to head a special NACA Committee on Jet Propulsion. The fact that he was in his 82d year was only a matter of calendar counting. The vigor with which he and his committee launched a belated development effort would have done credit to a man less than half his age. Later in 1941, Gen. H. H. Arnold secured from the British one of the earliest of the Whittle jet engines to aid the development program initiated by Dr. Durand. In this program, the Durand committee was handicapped by the fact that the country had just been plunged into a war for which it was ill prepared and the principal airplane-engine firms were overloaded. The decision came "from the summit" that we would fight with the weapons in hand. First priority was given their production in immense quantity. Consequently, the Durand committee had to arrange with nonaeronautical firms to undertake the development of turbojet engines for possible later use to power fighter airplanes.

Over some 20 years, aerodynamic and powerplant improvement, much of it based on application of research results, permitted the top speed of military airplanes and the cruising speed of commercial airplanes to be doubled; the air loads imposed on the faster airplanes were severely increased, especially in rough air and when maneuvering.

The loads research group at the Langley Laboratory consisted of but 20 men in 1939, but their contribution was considerable, notably the V-G recorder (V for velocity, G for gravity) by R. V. Rhode and H. J. E. Reid. It was devised to measure continuously the loads experienced by an airplane flying in rough air. This was but one of many novel instruments which NACA engineers have devised for precise measurements in flight.

The research problem directly related to loads deals with structures to carry the loads. Here again the manpower available at Langley prior to World War II was small; as late as October 1940, only 10 men were working on airplane structures. Their work was concerned, principally, with fundamental knowledge about structures from which a trustworthy theory could be developed for design application. Delicate experiments and mathematical analyses dealing with the behavior of thin-walled cylinders, stiffened panels, and other structural units produced useful conclusions that were used on our World War II aircraft.

On October 7, 1939, Dr. Ames resigned from the Committee because of failing health. His responsibilities as chairman of the Committee were given to Dr. Vannevar Bush, who had been serving both as vice chairman and as chairman of the executive committee.

Note has been made already of the manner in which Dr. Ames had provided leadership of the highest quality to the Committee for nearly a quarter-century. The letter President Roosevelt wrote upon the occasion of his retirement contained this statement:

> Our Republic would not be worthy of the devoted service you have rendered for over 24 years without compensation if it could not on this occasion pause to pay tribute where it is so justly due . . . . That the people generally have not known of your brilliant and patriotic service is because it has been overshadowed by your passion for accomplishment without publicity. But the fact remains, and I am

happy to give you credit, that the remarkable progress for many years in the improvement of the performance, efficiency, and safety of American aircraft, both military and commercial, has been due largely to your own inspiring leadership in the development of new research facilities and in the orderly prosecution of comprehensive research programs.

The Committee's resolution, tendered to Dr. Ames in Baltimore by a special delegation, said:

When aeronautical science was struggling to discover its fundamentals, his was the vision that saw the need for novel research facilities and for organized and sustained prosecution of scientific laboratory research. His was the professional courage that led the Committee along scientific paths to important discoveries and contributions to progress that have placed the United States in the forefront of progressive nations in the development of aeronautics. His was the executive ability and far-sighted policy of public service that, without seeking credit for himself or for the Committee, developed a research organization that holds the confidence of the governmental and industrial agencies concerned, and commands the respect of the aeronautical world. Withal, Dr. Ames was an inspiring leader of men and a man beloved by all his colleagues because of his rare qualities.

In July 1941, the President appointed Dr. Bush director of the newly established Office of Scientific Research and Development, and he resigned as chairman of the NACA. The writer was elected chairman, an honor he has been privileged since to hold.

WORLD WAR II AND AFTER

The war years for the NACA were plagued by the necessity for rapid expansion of the civil-service staff from hardly 500 in 1939 to more than 6,800. Trained engineering personnel were unavailable. Consequently, it was mandatory that professionals be spread ever thinner, while loom fixers, toymakers, mechanics, blacksmiths, and women school teachers were recruited for jobs they could do or for which quick instruction could be given.

Especially in the matter of skilled management of research programs, the NACA might have been expected to be sorely weak. And yet, somehow, with each expansion of effort, new leaders were found from within the permanent NACA staff. No sooner did Henry J. E. Reid, director of the Langley Laboratory, see some of his best men on their way to build the new laboratory at Moffett Field—named in 1944 in honor of Dr. Ames—than the process of designating the leaders of the new engine laboratory—named in honor of Dr. Lewis in 1948—was begun. Smith J. DeFrance was named director of the Ames Aeronautical Laboratory, and later Edward R. Sharp became director of the Lewis Flight Propulsion Laboratory. Both of these men were senior members of the permanent staff at Langley.

NACA's war effort was of necessity devoted very largely to applied research, the business of finding "quick fixes" to make existing aircraft better performers, and production engines more powerful. Fortunately, a considerable backlog of design data was available for application to such subjects as low-drag wings, high-speed propellers, stability and control, and improved systems for cowling and cooling engines. Between December 1941 and December 1944, the Committee's research centers worked on 115 different airplane types. In July 1944, 78 different models were under simultaneous investigation.

Perhaps the best comment on the value of NACA's World War II work is to quote from a statement by the late Frank Knox, made in 1943 when he was Secretary of the Navy:

> New ideas are weapons of immense significance. The United States Navy was the first to develop aircraft capable of vertical dive bombing; this was made possible by the prosecution of a program of scientific research by the NACA. The Navy's famous fighters—the Corsair, Wildcat, and Hellcat—are possible only because they were based on fundamentals developed by the NACA. All of them use NACA wing sections, NACA cooling methods, NACA high-lift devices. The great sea victories that have broken Japan's expanding grip in the Pacific would not have been possible without the contributions of the NACA.

The end of World War II marked the end of the development of the airplane as conceived by Wilbur and Orville Wright. The power available in the newly developed turbojet and rocket engines for the first time brought within man's reach flight through and beyond the speed of sound.

In the years following World War II there were changes, too, in the membership of the Committee. In 1948, the death of Orville Wright closed 28 years of his membership on the NACA. Though he was but one among many strong men who had given of time and talent to the work of the Committee, his passing sharpened the realization that in the working years of one man's life—between December 17, 1903, and January 30, 1948—the speed of the airplane had been increased from hardly 30 mph. to almost 1,000 mph.

In 1948 the membership of the Committee was increased to 17. This permitted the inclusion of a representative from the Department of Defense, presently the Assistant Secretary (Research and Development). Since the war the Committee has included one Presidentially appointed member from the airframe, the engine, and the air-transport industries, thus insuring awareness of the needs of those major segments of American airpower.

In 1948 Dr. Lewis died. In 1945, his health broken by the war effort, he had been forced to withdraw from active participation in the work of the Committee. For almost two years, John W. Crowley, Jr., served as acting director of aeronautical research. With the Committee since 1921, Crowley had been chief of research at Langley for a number of years. He provided vitally needed leadership during a critical period.

To succeed Dr. Lewis, the Committee in 1947 chose the Associate Director of the National Bureau of Standards, Dr. Hugh L. Dryden. He was no stranger to the NACA. Trained in physics and mathematics by Dr. Ames at Johns Hopkins University, he had gone to the Bureau of Standards in 1917, where he soon earned an international reputation by his aerodynamic researches in turbulence and boundary layer. His new task at the NACA was extremely difficult, yet it was vital to the Nation that a "new look" at the postwar situation be taken, and new objectives defined in terms of supersonic jet-propelled vehicles potentially available for the worldwide exercise of air power and, eventually, for civil air transportation.

At the end of World War II, the most urgently sought goal was attainment of practical flight at supersonic speed. It was realized that success in this effort required new knowledge which could be obtained only with new tools and new techniques. Even before the end of the war efforts were made to acquire needed data. Efforts to develop useful transonic aerodynamic theory had failed and it was necessary to resort to direct experimentation at velocities passing through the speed of sound. The fact that the principal tool of aerodynamic research, the wind tunnel, was subject to "choking" phenomena near the speed of sound forbade its use for the critical experimentation. Entirely new techniques had to be devised. The NACA's attack was broadened to include all approaches which offered promise.

The earliest attempt used especially instrumented aerodynamic bodies dropped from a high altitude, but it was not until late in 1943 that advances in radar and radiotelemetering equipment made it possible to obtain reliable data by this method. Even then, the velocity of a free-falling body seldom went much beyond a Mach number of 1 ($M=1$ equals the speed of sound).

Other attempts sought to use the acceleration of airflow above a curved surface. Small model wings were mounted near the leading edge of the wing of an airplane. In this way, lift, drag, and other aerodynamic characteristics of the model were measured. The method was employed also to study stability and trim of airplane shapes in the transonic speed range. The same principle of accelerating airflow was tried with small models positioned over a "hump" in the test section of a subsonic wind tunnel, but scale effects complicated the interpretation of test results for use in design.

Use of rocket-propelled models fired from the ground followed the first work with free-falling bodies by about a year. As instrumentation has been improved, this technique has become a valuable tool for transonic research. By the addition of powerful booster rockets, models of this kind are being used to study aerodynamic problems at speeds ranging up to a Mach number of 10 and higher. The fact that very high speeds are reached at low altitude, where the air is dense, makes the aerodynamic data readily usable for plane and missile design. In 1945, the NACA established a Pilotless Aircraft Research Station at Wallops Island off the Virginia coast, to carry on this work. It is attached to the Langley Laboratory.

In 1943, the idea was advanced of using specially designed piloted airplanes to explore the transonic speed range. Propelled by powerful rocket engines and provided with elaborate data-recording equipment, the research airplane could be safely flown at high altitudes where the density of the air, and hence the loads imposed on the structure, would be low.

The spectacular accomplishments of the research airplanes—the supersonic flight of the Bell X-1, October 14, 1947; the twice-the-speed-of-sound flight of the Douglas D-558-II, November 20, 1953, and the even faster flights of the Bell X-1-A which followed soon after—have sometimes obscured the fact that these airplanes were tools for research. These flights are historic; all agreed as to the rightness of the Collier Trophy award to three men for the year 1947: John Stack, Langley Laboratory, for conception of the research airplane program; Lawrence D. Bell, for design and construction of the X-1, and Capt. Charles E. Yeager, USAF, for making the first supersonic flight.

But even more valuable than the dispelling of the myth about the sound barrier was the accumulation of information about the transonic speed region. The shape and the performance of tactical military aircraft which have been designed since reflect the use of data obtained by the research airplane program centered at the NACA's High-Speed Flight Station at Edwards Air Force Base, Calif.

Despite the success of this flight program, there remained the need for a technique whereby transonic experimentation could be carried on under the closely controlled conditions possible only in the laboratory. Actually, the data coming from the research airplanes accented this need, because they pointed up the fundamental problems of fluid mechanics that would have to be studied in great detail for the design of useful supersonic aircraft.

By late 1950, following intensive theoretical work, there was put into operation at the Langley Laboratory a new type of wind tunnel. Incorporating a "slotted throat" at the test section, it was free from choking near the speed of sound and truly could be described as a transonic wind tunnel. Again, the Collier Trophy was awarded to John Stack and his Langley associates for the conception, design, and construction of his most useful research tool.

One must appreciate the very great difference between airplane design in the past and today. In the past, the difference between the best design and the second best, assuming the same power, might be at most only a few miles an hour. Now the difference may be measured in hundreds of miles an hour. The art is being extended so rapidly that no longer is there a comfortable time margin between the acquisition of research data and its application.

Hardly had the first of the NACA's transonic wind tunnels gone into full operation, in 1951, when Richard T. Whitcomb, a young engineer at the Langley Laboratory, began the experimental verification of what has since become known as the "area rule." In essence, Whitcomb worked out a rational way to balance the lengthwise distribution of volume of fuselage and wings to produce an airplane form with minimum drag at high speeds. Seemingly slight modifications to the shape of the airplane fuselage greatly improved performance.

As soon as the new design principle was verified in preliminary form, it was made available in confidence to the designers of military airplanes and the new information was promptly applied.

In one instance, the prototype of a new fighter aircraft was unable on test to attain supersonic speeds. With the deceptively subtle modifications dictated by the "area rule," the airplane enjoyed a performance gain in speed of as much as 25 percent.

At the velocities contemplated for our future missiles and airplanes, temperatures measured in thousands of degrees Fahrenheit will be encountered owing to aerodynamic heating—friction. The consequent structural problems are little short of fantastic and, with presently available materials of construction, the solution is not in sight. More research is needed.

The performance possible from the harnessing of nuclear energy for airplane propulsion would be nonstop flight over virtually unlimited range. Again, one is faced with problems of enormous complexity and difficulty, but national security requires that research and development be carried forward with imagination and vigor.

Millions of passengers are now carried by air. Air transportation also expedites the delivery of great volumes of mail and goods. Airliners regularly span oceans and continents, and smaller utility planes serve remote regions in the Arctic and tropical jungles. There is promise of helicopter service between nearby cities, with no need for large outlying airports.

The safety record of civil aeronautics is remarkably good, but it is never good enough. We still read, from time to time, of disasters from collision, fire, storm, human error, and, rarely, from structural or mechanical failure of the airplane itself. The human pilot is aided by wonderful instruments and by radio, radar, gyros, etc., but we still depend on his judgment and skill. He must be better protected against noise and fatigue—subjects for research.

Air transportation is fast and can be faster. But greater flight speed is illusory if it requires too long a climb to reach the high altitude necessary for economy. Furthermore, higher-speed airplanes tend to require longer runways and bigger airports. This could mean a new program of airport building at colossal expense, with the new airports even farther from the passengers' ultimate destination. Getting to and from the airport could consume more time than is saved by faster flight. Research continues on improving landing and takeoff characteristics of airliners.

It may be that airliners of the future will be designed to the limitations of the airports they are to serve, just as transatlantic steamers are designed to enter only a few major seaports, where the channel and piers have adequate depth of water.

Civil aeronautics can make its greatest contribution to trade and commerce under a favorable international climate of free interchange of people, goods, and ideas. Greater economy, efficiency, and safety are prerequisites for its full utilization. Research can show the way to advance toward these goals.

Through the years the NACA has been provided by Congress with the most modern research equipment at a total cost of approximately 300 million dollars, and the present operating staff numbers about 7,600 persons of whom over 2,000 have professional degrees. These resources, in the present hostile and threatening international climate, are directed for the most part toward research helpful to national security. Research to improve military aircraft is ultimately applied to civil aviation, when proved to be thoroughly practical by experience, but there are differences in emphasis, because safety, comfort, and economy are relatively more important in civil airplanes. The Committee has numerous investigations in progress which are directed toward the immediate problems of civil aviation, as for example the work on noise, icing, fire prevention, atmospheric turbulence, and reduction of landing speed.

A more favorable international climate would permit greater emphasis on civil aviation, but it is likely that for some time to come the national security will require a great effort to penetrate more rapidly into the vast region of the unexplored and unknown. The Committee feels its responsibility for guidance of the over-all research effort in aeronautics, and it is hoped that through its work aeronautics may make the maximum possible contribution to human welfare.

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