THIRTY-SECOND ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1946

INCLUDING TECHNICAL REPORTS
Nos. 834 to 862

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1949

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. - - - - - - - Price $3.50 (Buckram)

TECHNICAL REPORTS

Letter of Transmittal

To the Congress of the United States:

In compliance with the provisions of the Act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Thirty-second Annual Report of the Committee covering the fiscal year 1946, and containing a review of the unreported war years.

HARRY S. TRUMAN.

THE WHITE HOUSE,
FEBRUARY 24, 1947.

Letter of Submittal

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., January 10, 1947.

DEAR MR. PRESIDENT: In compliance with the provisions of the Act of Congress approved March 3, 1915 (U. S. C. title 49 sec. 243), I have the honor to submit herewith the Thirty-second Annual Report of the National Advisory Committee for Aeronautics, covering the fiscal year 1946.

The circumstances of war prevented detailed reports of the NACA's activities during the war years. It is the aim of this report to present a concise picture of significant activities since 1940. The financial report relating to 1946 is included in this document. Financial reports and summaries relating to the years intervening between the Twenty-eighth Annual Report published in 1942 and the present will follow.

The close of the war marked the end of one whole phase of development of the airplane as conceived by the Wright brothers. The airplane in its present form is no longer a sound basis for future planning for the national defense. The power available in jet propulsion systems brings flight through and above the speed of sound within reach. Yet, the attainment of practical flight at such speeds requires the application of new knowledge which must be obtained by diligent research with new tools and new methods. As with the Wright brothers at the first flight, we stand at a new frontier where research to establish the scientific principles and laws governing high-speed flight will determine our future in the air.

Respectfully submitted.

JEROME C. HUNSAKER,
Chairman.

THE PRESIDENT,
The White House, Washington, D. C.

National Advisory Committee for Aeronautics

Headquarters, 1500 New Hampshire Avenue NW, Washington 25, D. C.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, title 49, sec. 241). Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

TECHNICAL COMMITTEES

AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
AIRCRAFT CONSTRUCTION
OPERATING PROBLEMS
MATERIALS RESEARCH COORDINATION
SELF-PROPELLED GUIDED MISSILES
SURPLUS AIRCRAFT RESEARCH
INDUSTRY CONSULTING COMMITTEE

Coordination of Research Needs of Military and Civil Aviation

Preparation of Research Programs

Allocation of Problems

Prevention of Duplication

Consideration of Inventions

LANGLEY MEMORIAL AERONAUTICAL LABORATORY, Langley Field, Va.

AMES AERONAUTICAL LABORATORY, Moffett Field, Calif.

AIRCRAFT ENGINE RESEARCH LABORATORY, Cleveland Airport, Cleveland, Ohio

Conduct, under unified control, for all agencies, of scientific research on the fundamental problems of flight

OFFICE OF AERONAUTICAL INTELLIGENCE, Washington, D. C.

Collection, classification, compilation, and dissemination of scientific and technical information on aeronautics

CONTENTS

842951—50——2

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS: Meeting, Washington, D. C., October 24, 1946. Left to right: Dr. E. U. Condon, Director, National Bureau of Standards; Dr. Alexander Wetmore, Secretary, Smithsonian Institution; Maj. Gen. E. M. Powers, Ass't Chief of Air Staff–4, Army Air Forces; Gen. Carl Spaatz, Commanding General, Army Air Forces; Dr. Vannevar Bush, Chairman, Joint Research and Development Board; Dr. Orville Wright; A. E. Raymond, Vice President, Engineering, Douglas Aircraft Co.; R. M. Hazen, Chief Engineer, Allison Division, General Motors Corp.; Dr. J. C. Hunsaker, Chairman, NACA; Dr. G. W. Lewis, Director of Aeronautical Research, NACA; J. W. Crowley, Ass't Director of Aeronautical Research, NACA; J. F. Victory, Executive Secretary, NACA; W. A. M. Burden, Assistant Secretary of Commerce; Rear Admiral L. B. Richardson, Ass't Chief, Bureau of Aeronautics, Navy Department; Dr. T. P. Wright, Civil Aeronautics Administrator, Vice Chairman, NACA; William Littlewood, Vice President, Engineering, American Airlines; Dr. F. W. Reichelderfer, Chief, U. S. Weather Bureau. (Vice Admiral Radford, Deputy Chief, Naval Operations, Air, U. S. Navy, not present.)

THIRTY-SECOND ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Washington, D. C., November 21, 1946.

To the Congress of the United States:

IN accordance with the act of Congress approved March 3, 1915 (U. S. C. title 49, sec. 241), which established the National Advisory Committee for Aeronautics, the Committee submits herewith its Thirty-second annual report for the fiscal year 1946. Because the Committee's reports were suspended during the war years, the present report comprises a summary of important activities since the last published report, for 1942. It will be followed by brief reports for the intervening years.

The National Advisory Committee for Aeronautics is the Government agency charged with responsibility for scientific aeronautical research. It was established by the Congress in 1915 to "supervise and direct the scientific study of the problems of flight with a view to their practical solution," and was authorized to "direct and conduct research and experiment in aeronautics" in such laboratory or laboratories in whole or in part as may be placed under its direction.

To discharge its responsibilities, the NACA must endeavor to forecast the trend of aeronautical development, civil and military; to anticipate the research problems that will arise; to design and provide the special research facilities as needed to solve the problems; to coordinate the fundamental research programs of the Government; to conduct fundamental scientific investigations in its own laboratories, and to encourage and support research in scientific and educational institutions. The results of the Committee's research, in the form of consultations and reports, are made available to the military services and other governmental establishments, to industry, to air transport operators, to scientific and educational institutions and libraries, and to others concerned.

To assist in the discharge of these duties and in the determination of present and future research needs of aeronautics, civil and military, the Committee has established standing technical subcommittees on aerodynamics, power plants for aircraft, aircraft operating problems, and aircraft construction. The subcommittees are composed of specially qualified representatives of the governmental agencies concerned and of experts from private life. The members of the subcommittees, like the members of the main Committee, serve as such without compensation.

The subcommittees prepare and recommend research programs. Most of the problems recommended for investigation are assigned to the Committee's laboratories. Some problems are assigned to the National Bureau of Standards and to the Forest Products Laboratory when it is to the advantage of the Government to do so in order effectively to utilize existing governmental facilities. Problems are also assigned, by research contracts, to scientific and educational institutions. This policy, the Committee believes, makes effective use of non-governmental research facilities, stimulates and coordinates aeronautical research, and also has the advantage of training research personnel.

The Committee also has established an industry consulting committee to guide its fundamental research toward objectives of optimum value in meeting the needs of industry for fundamental information necessary in the design of aircraft of higher performance.

The state of basic aeronautical knowledge must be kept well in advance of application in order that the needs of the Nation may be served.

The results of the research efforts of the Committee have a broad influence on the national security and national economy. The fundamental aeronautical data thus provided are basically important to the forward planning of the development programs of the military services and the aircraft manufacturing and operating industries. This basic information insures not only the procurement of efficient air weapons for national defense, but also safer, faster, and more economical aircraft for the rapidly expanding air transport services, and safer, more efficient, and more useful airplanes for the rapidly expanding private flying activities in the United States.

During the war, the NACA devoted virtually its whole effort to making this country's aeronautical weapons more effective than the enemy's. This amounted to sacrifice of the future to the present.

In the recent war, the chief offensive weapon was the airplane. America's early strategy dictated its perfection rather than long-range research on new weapons. Therefore the Committee concentrated on improving the performance and military effectiveness of the airplane to a degree of development beyond the best the enemy had to offer. The climax came in the first complete defeat of an enemy without setting foot on its home soil. Now the reserve of knowledge available when we entered the war, and without which victory would have been greatly delayed, has been exhausted.

This forces us to face the urgent necessity for renewed emphasis on fundamental research. Without certain essential design data the development of very high-speed aircraft and guided missiles cannot proceed on a sound basis, nor can tactical or even strategic plans for air warfare be developed with any assurance of practicability.

The importance of applied science to the war effort was not fully realized until late in the war, and there was not an adequate appreciation of the important role of young men in any rapidly advancing technology. Two conflicting principles governed the action of Selective Service. One, that every citizen should sacrifice equally in the common cause, and the other that every citizen should be used where his talents could best contribute. Since these principles were not effectively differentiated, service was not truly selective. As a result, young scientists, engineers, and technicians were drafted from research laboratories and industry, and an unnecessary handicap imposed on the task of keeping the instruments of war in the hands of our fighting men superior to those of the enemy. America also sacrificed its future to its immediate needs by halting the processes of advanced education, thus creating a lack of scientific manpower from which it cannot recover for years.

The close of the war marked the end of one whole phase of development of the airplane as conceived by the Wright brothers. The airplane in its present form is no longer a sound basis for future planning for the national defense. The power available in jet-propulsion systems brings flight through and above the speed of sound within reach. We now see no definite limit to the power that may become available for aircraft propulsion. Nor do we see a definite limit to the speed that may be attainable.

It is the immediate objective of the NACA to solve, as quickly as facilities and personnel permit, the most pressing problems attendant on high-speed flight, and to provide for the future development of knowledge in this seemingly endless new field of research. In general, the NACA must continue to direct its research to the needs of military, commercial, and private aviation, to increase the performance, economy, and safety of aircraft.

In long range planning for the country's aeronautical future, there is greater need than ever before for Nation-wide teamwork, because of the great cost and manpower requirements of modern aeronautical research and development facilities. Important installations and their uses must not be unnecessarily duplicated. Only on the foundation of aeronautical science can the potentialities of national defense, of air transportation, of commerce, and of communication with other peoples be realized.

Part I
SUMMARY OF TECHNICAL ACTIVITIES

OWING to the large amount of research since 1940 to be covered by this report, and to the numerous changes of committees organized to handle this research, the technical activities of the NACA during the war years are here presented according to the major subject to which they belong. These are chiefly four: aerodynamics, propulsion systems, construction and materials, and operating problems. A more recent development is the category of self-propelled guided missiles.

AERODYNAMICS

Much of the work in aerodynamics during the war period was conducted of necessity at the specific request of the Army and Navy, and basic research, which is normally the principle field of endeavor, played a secondary role. From a review of the results obtained, however, it was found that the work accomplished can be readily classified under two main headings, namely, "Basic Aerodynamic Research," and "Wartime Applied Research."

During the past 6 years, the exigencies of military necessity in many instances have tended to convert pure research in basic aerodynamics to the more immediately required corrective research for the air arms of the military services. This situation, however, has not been an outright hindrance to basic research; additional impetus to research thinking has often resulted from development of practical applications. Such urgency has also required the utmost in ingenuity for devising quickly the best possible means for obtaining and analyzing aerodynamic research data, whether it be theoretical or experimental, basic or corrective, in order to insure early and proper application.

BASIC AERODYNAMIC RESEARCH

IMPROVEMENT OF TEST METHODS AND DEVELOPMENT OF NEW EQUIPMENT

Wartime necessity speeded the development of the low-turbulence, pressurized type of wind tunnel which was required for duplicating more quickly and accurately in model tests the conditions to be encountered in flight by actual aircraft. The first tunnel of this type was constructed at the Langley Memorial Aeronautical Laboratory in 1940. This year, a larger low-turbulence pressure wind tunnel, with a 12-foot diameter test section, was placed in operation at the Ames laboratory. It will permit testing of many models substantially at full scale. A unique feature of the design is that by partially evacuating the tunnel, it is also possible to test the same models at speeds very close to the speed of sound.

While wind tunnel techniques have been advanced considerably to permit tests at nearly the speed of sound, the tremendous difficulties involved in wind tunnel testing at a Mach number of 1.0 have proved to be an impetus in the development of new research techniques at and above the speed of sound. The use of rocket-powered missiles and freely falling bodies as test vehicles, with the development of radar tracking and photo-theodolite tracking techniques, has been successfully established. This item alone has proved the usefulness and importance of a whole new field of areodynamic research techniques destined to be considered on an equal footing with the theoretical approach, wind tunnel research, and standard flight research and, in fact, to have unique capabilities in the transonic range.

Another technique developed at the Langley laboratory involves the mounting of small models in the region of high-speed flow over the wing of a high-speed airplane and thus providing valuable data at all speeds up to, through, and somewhat above the speed of sound. This research technique is referred to as the "NACA wing-flow method."

The use of freon gas as a test medium to allow the same test equipment to cover independently the ranges of Reynolds number (effective scale of model) and Mach number (effective speed of model) has been developed. The most extensive use of freon has been in the Langley supersonic sphere, where model airfoils are whirled at subsonic, transonic, and supersonic speeds, and in the Langley free-flight gallery, where models are propelled from a compressed-gas catapult at various velocities into a long tank of air, freon, or air-freon mixture.

Steady improvements in techniques of supersonic wind tunnel research have also been made. At the present time, three supersonic wind tunnels are in operation at the Ames Aeronautical Laboratory, two at the Aircraft Engine Research Laboratory, and one at the Langley Memorial Aeronautical Laboratory. With the development of flexible nozzles, it is possible to obtain an over-all Mach number range of 1.2 to 3.4 with these tunnels. A distinctive feature of one of the Ames Aeronautical Laboratory's 1- by 3-foot supersonic tunnels is that the effects of scale can be investigated by changing the total pressure in the tunnel.

Increased operating speeds and altitudes of military airplanes have resulted in increased power requirements. This in turn has led to a demand for immediate basic research on compressor blading and other aerodynamic elements of jet-propulsion engines. The time urgency of this work resulted in the development of the "airfoil-cascade" technique, which allows rapid, inexpensive, and accurate duplication in fixed equipment of the conditions encountered by the rapidly moving blades of actual turbines and compressors.

It is apparent from the foregoing that substantial progress was made during the war by the NACA in developing new research techniques. It should be noted, however, that one of the primary factors affecting the success of all the new techniques developed has been the concurrent, successful, and rapid development of the research instrumentation required to obtain accurately and rapidly the quantitative data provided by these new research methods.

AIRFOILS

Prior to the war, results of NACA airfoil research were used by practically every nation in the world. This in itself was a testimonial to the value of the systematic investigations undertaken. With the advent of the NACA low-drag airfoil, however, even further improvements in speed and range of aircraft have now been realized. The development of the NACA low-drag series of airfoils began in 1938 and represented a new approach to the problem of airfoil design. The NACA low-drag airfoils were designed to have extensive laminar flow, and were the result of research undertaken in new wind tunnels designed to have turbulence levels approaching that of free air.

The very earliest results with this new airfoil and new research equipment showed that extremely low drag coefficients, about half the values of those previously observed for airfoils of comparable thickness, could be obtained. It should not be overlooked, however, that many problems in connection with the design of these airfoil sections had to be solved after the first tests. Extensive systematic investigations have been carried out both at Langley and Ames to determine the complete characteristics of low-drag airfoil sections over a wide range of Reynolds numbers and Mach numbers. Extensive studies of the effects of practical manufacturing irregularities on drag were also carried out and qualitative criteria for aerodynamic smoothness were determined. Practical application of the new airfoil sections was thus assured.

Extensive investigations have also been made of the effects of compressibility on airfoil section characteristics. Theoretical studies have shown that, for three-dimensional wings, deterioration of the aerodynamic characteristics at high Mach numbers can be postponed by using either low-aspect-ratio plan forms or large angles of sweepback or sweepforward. These predictions have been further verified in wind-tunnel tests. The characteristics of these wings have also been obtained at low speeds and at the high angles of attack corresponding to low-speed flight or landing.

PROPELLERS

Theoretical propeller work during the war period was devoted primarily to the development of improved methods of application of the existing theory and relating these applications to design procedures in the form of selection and design charts. This work, which covers the complete speed range, eliminated a major portion of the tedious calculations formerly required, and was developed to cover the prediction of propeller characteristics, including all of the important variables in propeller design.

During this same period the application of Goldstein's factors was extended to dual-rotation propellers having a large number of blades.

An increase in critical speeds of airfoil sections has been obtained for use in propeller design through research in the Langley 24-inch high-speed tunnel. These sections have been designated as NACA 16-series airfoils, and this development has permitted the use of airfoils in propeller design which delay the onset of compressibility effects to an important extent. At the same time this family of airfoil sections was so developed that selection of optimum airfoil sections for any range of lift coefficient could be more easily made through use of design camber variation. These airfoil sections have been found to have very low drag and, when used in a propeller, produce high efficiency.

Low-speed tests conducted in the Langley Propeller Research Tunnel extended the existing knowledge of the effects of blade width, number of blades, propeller pitch distribution, and propeller slipstream characteristics for single- and dual-rotation propellers.

An extensive amount of work was also accomplished in the propeller research tunnel on a number of typical propeller-body configurations. It was shown that the interference effects of tractor propellers operating in front of various types of NACA cowlings have an important effect on propeller performance. It was also shown that for efficient operation, propeller design should include consideration of the field of flow around such bodies. In addition, it was established that pusher propellers operating in the wakes of bluff bodies and deflected wing flaps suffer serious losses in performance. Modifications which eliminate a major portion of these losses have been evolved.

The increase in speed of aircraft, accelerated by the war, made it clear that extensive work on high-speed propellers was urgently required. A program was formulated therefore to provide information to permit the design of efficient high-speed propellers having high power-absorbing characteristics. The results of the tests in the Langley 8-foot high-speed tunnel of propellers embodying the NACA 16-series airfoils and utilizing thin airfoil sections along the entire blade to the spinner surface, and also designed to have optimum pitch distribution and loading for high speeds, yielded efficiency of from 90 to 95 percent through a speed range up to approximately 500 miles per hour. These efficiencies were about 7 percent greater at low speeds and about 22 percent greater at 500 miles per hour than could be obtained with propellers widely in use at the time of the investigation. These propellers were free from adverse compressibility effects at speeds approximately 100 miles per hour in excess of speeds attained with conventional propellers then currently used.

Investigations in flight and in the Langley 8-foot high-speed wind tunnel showed that at high speeds, losses in propeller efficiency of from 7 to 13 percent were attributable to the round shanks, and that propellers having good airfoil shank sections, with thickness ratios of from 18 to 20 percent, eliminated these losses. A program was also initiated in the 16-foot high-speed wind tunnel to make use of sweep-back in propellers to retard the adverse effects of compressibility at the blade tips. The preliminary results indicated that some delay in the onset of the adverse effects of compressibility could be obtained through the use of swept-back propeller blades, and studies are underway to incorporate the sweep principle throughout the blades to permit further gains in efficiency at high speeds.

SUPERSONIC RESEARCH

Theoretical analyses made at Langley have been fruitful in the development of improved wing plan forms for supersonic aircraft. Preliminary tests of a series of triangular wings in the Langley 9-inch supersonic tunnel verified this theoretical analysis.

In this country the drag-relieving properties of wing sweepback were discovered analytically at Langley in early 1945. Soon thereafter the results of independent German work became known. The theoretical benefits of sweepback were immediately confirmed through an experimental investigation using the unique techniques of free-falling bodies and the NACA wing-flow method. These methods permitted the experimental determination of the characteristics of swept wings continuously through the speed of sound and beyond into the supersonic range, thus yielding experimental data not available from any other source. Experimental results obtained indicate that by use of triangular or swept plan forms, the high pressure drag, which is an unavoidable characteristic of straight wings at supersonic speeds, can be virtually eliminated.

The sweepback theory has been extended by development of methods for computing the drag of arbitrary swept wings at high lift; the variation of drag with aspect ratio and sweep predicted by analysis using this theory is substantiated by the experimental data. The Rankine-Hugoniot shock equations have been used to calculate the lift, drag, and pitching moment of a large number of supersonic airfoil sections for Mach numbers up to 8.0.

An experimental investigation bearing on the drag of supersonic wings and bodies has also been conducted to establish skin friction coefficients at supersonic speeds. Predictions based on the von Karman-Prandtl theory relating the friction coefficients and the Reynolds number were in agreement with the test results.

Theoretical studies of bodies suitable for supersonic aircraft have resulted in the development of methods for calculating the lift, drag, and moment characteristics of slender bodies of revolution, including cases of air inlet openings at the nose. Data obtained in the Langley 9-inch supersonic tunnel verified the calculated characteristics. Additional experimental results have also been obtained from freely-falling-body tests and rocket-propelled test bodies. Preliminary tests have also been made establishing the characteristics of wing-body combinations. A model of a possible configuration for a supersonic airplane was also investigated in the Langley 9-inch supersonic tunnel; the results indicated that reasonable maneuverability and stability can be obtained in supersonic flight. Analyses based on the test data now available indicate that man-carrying supersonic flight in the Mach number range up to about 1.5 is possible with propulsion units of the gas-turbine and ramjet types at their present stage of development.

Original data from systematic investigations of supersonic body shapes in Germany and Italy, at Mach numbers ranging from 1.3 to 3.2, became available to the NACA in 1944 and have been analyzed and published. The results showed decreasing drag with increasing fineness ratio of the nose.

Investigations have been conducted at the Ames laboratory to evaluate the interaction of wings and bodies through a range of Reynolds numbers at supersonic speed. A supersonic investigation has also been undertaken at the Ames laboratory on bodies of revolution, the results of which show that viscosity effects are large and dependent to a considerable degree on the body shapes.

A preliminary investigation at Langley of the design of supersonic inlet diffuser systems, with particular reference to circular open-nosed types, has indicated efficiency values comparable to good low-speed diffusers.

Another type of inlet diffuser system employing an annular sharp-edged inlet with a pointed conical central body, gave an efficiency of over 90 percent at a Mach number of 1.85.

Conventional axial-flow compressors are limited to a tip Mach number of about 0.8 as a result of the occurrence of shock losses at higher speeds. An investigation was made at Langley of a new type of compressor specifically designed for supersonic flow, and high efficiencies were obtained.

An experimental investigation of the interaction of shock and boundary layer has been made at the Langley laboratory using supersonic nozzles. It was discovered that the pressure changes on the downstream side of a normal shock are transmitted upstream through the subsonic part of the wall boundary layer. The effect of the high-pressure region behind the shock was to cause a thickening of the boundary layer for some distance ahead of the shock, producing an effective contraction of the channel area, which in turn reduced the Mach number and intensity of the shock; the results are low shock losses and high boundary-layer energy losses.

VIBRATION AND FLUTTER

Flutter and vibration of aircraft continue to be important fields for investigation. Systematic studies, both of a theoretical and experimental nature, have been made during the war years. Theoretical studies based on retarded potential theory have been made at Langley on the air forces on oscillating airfoils moving at high forward speeds. This work includes both the supersonic and subsonic speed ranges, but not the near-sonic values. Applications of the results have been made to wing flutter in various degrees of freedom and to aileron reversal and wing divergence. Vibration modes and wing flutter have been studied theoretically, as has the effect of additional degrees of freedom.

A special wind tunnel for flutter research in which the density of the test medium can be varied in a ratio of 30 to 1 is now in operation at the Langley laboratory. The medium is air or Freon gas, and high subsonic stream Mach numbers may be obtained.

The flutter phenomenon in the transonic speed range is of especial importance since, in this range, the aerodynamic forces radically change in character. The transonic range is being investigated for wings both swept and unswept, by telemetered information obtained from freely-falling body tests and also by means of rocket-propelled bodies.

During flight tests of a jet fighter airplane, severe aileron flutter developed during a high-speed dive, resulting in damage to the aileron. This phenomenon of compressibility flutter, also called "aileron buzz," is identified as a 1-degree-of-freedom type of flutter; it has occurred on several other aircraft at transonic speeds. An investigation conducted in the Ames 16-foot high-speed tunnel indicated that this type of transonic flutter is caused by a coupling of the aileron motion and the shock wave motion on the wing. Further research is being conducted to investigate the nature of the phenomena in order to gain a better understanding of the problems of flutter in the transonic region.

The Langley vacuum sphere has been employed for propeller vibration and propeller studies. The work on propeller flutter as a function of disc loading has led to the development of a theory for predicting the stall flutter speed. Other tests in the Langley 16-foot tunnel have been the basis for a study of the vibration of dual-rotation propellers and of pusher propellers mounted behind wings.

Tail buffeting studies were made in the Langley 8-foot tunnel at high speeds; in the case of one important military airplane, severe buffeting was considerably reduced by relocation of the tail surface. In the case of another military airplane where buffeting occurred in high-speed flight, the problem was investigated in the Ames 16-foot high-speed wind tunnel with greater economy, safety, and convenience than could be realized by other test methods. As a result of the investigation, the buffeting was eliminated, and a diving tendency which the airplane had previously possessed was corrected.

INTERNAL AERODYNAMICS

The rapid increases in the power of aircraft engines, the advent of turbine and reaction engines, and the major increase in performance demanded of military and transport aircraft during the war years have greatly intensified the aerodynamic problems associated with the internal flow systems of aircraft. As major increases in engine power were accompanied in many cases by actual reductions in frontal area, the attainment of adequate heat dissipation and the provision of efficient ducting to handle the greatly augmented internal flow in the limited space available became increasingly difficult. The continued advances in operating altitude further complicated ducting problems because of the increase in internal flow quantities brought about by the corresponding decrease in air density. In addition, emphasis on the attainment of higher and higher speeds necessitated intensified study of means for minimizing the external and internal drag losses of internal flow systems.

Early in 1941, a special group was established at the Langley laboratory for the correlation and dissemination of information on the aerodynamics of power plant installations. This group worked directly with representatives of the various manufacturers in the design of new power plant installations to insure the incorporation of the latest research developments in the design of new airplanes. The special problems involved in the design of wing inlets were studied in a number of investigations at both the Langley and Ames laboratories. The general principles were established through which such inlets can be designed for high-pressure recovery without penalizing the maximum lift, the drag, and the critical speed of the basic wing. Work on the well-known NACA cowling for radial engines was extended during the war years by the development of a comprehensive series of high-critical-speed nose inlets. Systematic investigations of air inlets located in the nose of fuselages or nacelles have established the general principles of design for such inlets. Design charts have been prepared that permit the selection of these inlets to have high pressure recovery and high critical speed for the required inlet flow velocity.

An investigation of jet-nacelle installations on swept and unswept high-speed wings was conducted in the Ames 16-foot high-speed wind tunnel, and indicated that centrally-located nacelles caused less drag and smaller effects on the span-load distribution than do underslung nacelles. A number of investigations were conducted at the Langley laboratory in an attempt to increase the aerodynamic efficiency of air scoops through the removal of the boundary layer ahead of the scoop inlet. Boundary layer removal slots and scoops were developed and applied to a number of installations.

A project of timely importance was the elimination of a severe rumble which developed in the radiator duct of one of the high-performance fighters used during the war. Modifications to the inlet scoop and the diffuser by tests of the full-scale airplane mounted in the Ames 16-foot wind tunnel successfully eliminated the rumble and saved time in starting production on the airplane during a critical stage of the war.

One of the most promising inlet types for supplying air to jet engines located in the fuselage of a high-speed aircraft is an entrance which is located rather far aft of the nose of the fuselage and submerged below the basic fuselage contour. An investigation of submerged air inlets at the Ames laboratory has shown that excellent internal-flow characteristics may be obtained through careful design. From a systematic study of this type of entrance it was found that by diverging the walls of the ramp as the submerged entrance was approached, appreciable increases in pressure recovery could be obtained. This was found to be due to the fact that the divergence of these walls caused much of the boundary layer which is found next to the fuselage surface to flow around the duct instead of down the ramp. The entries developed were also found to possess excellent critical speed characteristics.

Specific investigations of air exits during the war demonstrated the necessity for adherence to the previously established design principles. An adequate theory was recently developed at Langley to cover the special case of the ejector-type exit which was introduced during the war years.

Since aircraft space limitations invariably require a duct system far from ideal, extensive studies, both from the general and specific viewpoints, have been undertaken to reduce or eliminate the losses in the power-plant duct system. Analytical and experimental studies have also been made to determine the effect of compressibility and heat absorption on duct performance.

The development of blade section shapes for axial-flow fans, compressors, and turbines has been impeded because of the difficulty in examining the airflow over the blades of rotating machines. Isolated airfoil data cannot be used because of the large interference effects present with the close blade spacing commonly used in compressors and turbines. Stationary cascades of airfoils have therefore been utilized at Langley to obtain detailed information on the flow and pressure distribution over compressor blades.

Compressor blade sections derived from the NACA 65-series airfoil have been tested in cascade at low air speed, and the results consolidated in design charts, from which the optimum section camber and the optimum angle of attack may be obtained from any desired turning of the air and operating stagger solidity. Low-speed tests in a rotating blower have verified the predicted turning angle and optimum operating condition. The experimental cascade development of compressor blade sections has recently been extended to high speeds (relative Mach number=0.83). It was found that there is little change in the turning angle for a given blade setting, and that the angle for optimum operation was the same as for low speeds in the Mach number range below shock stall.

Similar cascade data have been obtained for application to the design of entrance vanes for axial flow compressors or turbines. A new theoretical procedure for calculating the incompressible potential flow about arbitrary cascades of airfoils has recently been devised. The primary virtue of the new method is the relative ease and rapidity with which cascade blade pressure distributions can be completed.

CONTROL AND STABILITY AT TRANSONIC AND SUPERSONIC SPEEDS

Control and stability problems in the transonic and supersonic speed ranges have been attacked by various means during the interval since the start of the war. The most urgent problems of fighter behavior at high speeds were attacked initially in high subsonic wind tunnels and by flight tests of the particular airplane concerned. In the later war years, new methods, unique in the world, were used at Langley for studying basic stability and control problems at speeds through the speed of sound for application to guided missiles and to inhabited aircraft as well. These new methods, the NACA wing-flow method and the use of rocket-propelled models, have been described in a previous section under "Improvement of Test Methods and Development of New Equipment."

At high subsonic speeds, conventional fighter aircraft experience uncontrollable diving tendencies and in some instances, aileron controls either overbalance with attendant wing failures or vibrate in a manner similar to wing-aileron flutter. The phenomenon responsible for this behavior has been studied in wind tunnels, in full-scale flight, and by the NACA wing-flow method. At speeds of approximately 80 percent of the speed of sound, thick wings suffer a marked loss in lifting capacity. This loss of lift, with the corresponding loss of downwash at the tail, results in tremendous increases in the control force required for dive recovery. Wind tunnel and flight tests, the latter performed by the Army Air Forces, showed that positive dive recovery could be provided by relatively small flaps located inboard on the wing, close to the leading edge. Later work has shown that the diving tendency can be relieved and even reversed by the use of a reflexed trailing edge of the wing itself.

Stability and control data from wind tunnel tests and from piloted flight tests are not avaliable at speeds greater than 0.97 of the speed of sound. By means of NACA wing-flow studies and tests using rocket-propelled aircraft models, the nature of the problem has been observed and means established for correcting some of the difficulties in connection with flight through the transonic range to speeds greater than the speed of sound. Wing-flow tests show that conventional flap-type controls lose their effectiveness in the speed range immediately surrounding the sonic speed. Free-flight tests of rocket-propelled aircraft models indicate a complete loss of control in passing from a Mach number of 0.93 to higher speeds. It also appears that the effects of wing camber are lost as the speed of sound is approached, and undesirable longitudinal trim change results.

Wing-flow tests have shown that the use of sweepback maintains control effectiveness in the speed range through the speed of sound, and rocket-powered models with swept-back wings have been flown under automatic control to the speed of sound. It has been found that in the speed region where conventional flaps lose their effectiveness, the controls become overbalanced. At higher speeds, the controls again become stable, but very heavy stick forces are indicated. NACA wing-flow measurements have indicated that for these conditions, sweep-back has the effect of delaying or minimizing these changes. Transonic control surface flutter, when observed by tests on rocket-propelled test models, appears to be delayed by use of sweepback but not necessarily prevented. Apart from the use of sweepback, tail surfaces of the all-movable type are indicated as a definite possibility for transonic and supersonic control. Aerodynamic data show that all-movable surfaces will provide control through the complete speed range; the problems in their use appear to be largely in structural design and in the required control-booster systems.

HYDRODYNAMICS

Basic hydrodynamic research has been focused sharply on applications to seaplane design and operation. The over-all accomplishment in this field in the last 6 years has been the broadening of scope of the research to include hydrodynamic stability and general seaworthiness as well as the primary subject of hydrodynamic forces. The timing of this change was such that the results obtained could be applied directly to the solution of urgent problems during World War II.

Systematic researches in the Langley tanks on the principal design parameters of seaplane hulls were highlighted by the establishment of fundamental relationships between the loadings and proportions in terms of the chief operational qualities of most concern. The results led directly for the first time to means of isolating the fundamental parameter of length-beam ratio, which previously had been obscured by simultaneous variations in hull size.

Other factors explored by the investigation of related families of hull models included the effects of dead-rise, step depth and plan form, afterbody angle and length, chine flare and chine rounding, step fairings, planing flaps, and propeller location. The important relationship between afterbody ventilation and hydrodynamic stability was discovered and extensively investigated.

The results of the fundamental researches named were applied to the accelerated development in the tanks of such famous wartime seaplanes as the Catalina, Coronado, Mariner, and Mars.

In the case of a 400,000-pound cargo flying boat, laid down for the movement of the heaviest military equipment over vast distances, the builders worked closely with the tank staff in the preliminary design with the result that no large changes in the hull were required at any stage in the development to obtain superior hydrodynamic and aerodynamic qualities.

In addition to the urgent military developments, a novel hull form was originated which was shown to have the lowest water resistance yet obtained in a tank. This form, termed the planing-tail hull, has also met all stability and aerodynamic drag standards.

The literature on the hydrodynamic characteristics of the planing surface, which is the fundamental lifting element for the surface of the water, was enlarged by the evaluation of the stability derivatives associated with seaplane "porpoising," and by the systematic investigation in the tanks of the stability of simple surfaces, singly and in tandem. This research led to methods of satisfactorily predicting the lower trim limit of stability of a seaplane hull, and to a means of isolating the effects of various hydrodynamic or aerodynamic derivatives on the stability limits.

The available knowledge on the hydrodynamic characteristics of submerged hydrofoils was enhanced by experimental investigations of practical combinations at water speeds up to 60 miles per hour. It was possible in the closely controlled tests in the tank to measure the effects on the hydrodynamic lift and drag of dihedral, partial submersion, tip shape, leading-edge shape, biplane interference, and strut interference. A special low camber section was developed which delayed the onset of cavitation to higher speeds in a manner analogous to delay of the critical compressibility speed for airfoils.

WARTIME APPLIED AERODYNAMIC RESEARCH

AIRCRAFT PERFORMANCE

During the war years of 1940 to 1945, considerable effort was expended by the NACA in studies of means of reducing the drag of aircraft and otherwise improving their performance. The Langley full-scale wind tunnel and the Ames 40- by 80-foot wind tunnel are well adapted to such investigations. Full-scale wind-tunnel investigations involved the drag evaluation and cleanup of 28 military airplanes.

Investigations of a similar character were carried out in flight with several airplanes, generally as a supplement to the investigations conducted in the wind tunnels. In many cases, it was possible to apply remedial modifications, although in most cases the optimum configuration could not be realized by practical modification of the airplane during the tests. Such investigations, however, assisted in improving aerodynamic design generally in industry to the extent that little reduction in drag can be realized with regard to the basic airplane of today.

Fundamental information gathered in various facilities at Langley and Ames was also especially valuable in indicating effective solutions of the problems of the detailed design of such elements as cowlings, cooling installations for both liquid and air-cooled engines, scoops for carburetor intakes, and intercooler and oil cooler scoops and ducts. It was shown that the detailed design of the airplane determined its aerodynamic cleanness to a far greater extent than the original selection of a basic combination of fuselage, wing, tail unit, cockpit enclosure, power plant and accessories. The repetition of inefficient design features on many of the airplanes investigated prompted the publication first in 1940 and again in 1945 of summary reports which analyzed the available results and presented them as a guide to designers. Unnecessary drag was found to result from projection of various items outside the basic contour, from roughness of surfaces, from unintentional leakage of air through the airplane structure, and from the use of large quantities of excess air for various cooling functions.

It was also pointed out that as airplane speeds increased gradually from about 300 miles per hour at the beginning of the war to about 500 miles per hour at the close of the war, the importance of good detail design and of maintaining adequately smooth surfaces over all the airplane increased accordingly. Investigations designed to reduce the drag of component parts of the aircraft have also been conducted. Application has been made of the principles of laminar airflow to attain low-drag wing-nacelle combinations suitable for high-speed bombers and transports.

An important aid in the performance of high-speed tactical airplanes is turning performance. A method was developed which enables the design engineer to calculate the turning performance of an airplane accurately. At high speeds and high altitudes, turning performance is greatly affected by changes in the maximum lift coefficient attributable to changes in Mach and Reynolds numbers. Consequently, an investigation has been made of the effect of Mach and Reynolds numbers on the maximum lift coefficients of a number of airplanes. Studies have also been made of the basic elements of aircraft with a view to the avoidance of adverse effects of compressibility.

STABILITY AND CONTROL

The need for quantitative design criteria for describing those qualities of an airplane that made for satisfactory controllability, stability, and handling characteristics had been realized for some years before the war. The NACA, therefore, undertook a program of research to increase the fundamental information on this subject, and to establish quantitative requirements for satisfactory flying qualities. The program required the construction of special research equipment and instrumentation, and the development of new techniques.

With the aid of this special instrumentation, measurements of the flying qualities of approximately sixty airplanes have been conducted by the NACA since 1939. The airplanes tested include representative bomber, transport, fighter, and commercial types, and range in size from light airplanes to the largest bombers. From the fund of information accumulated in these investigations, it has been possible to prepare a set of requirements for satisfactory flying qualities in terms of quantities that may be measured in flight or predicted from wind-tunnel tests and theoretical analyses. When an airplane meets the requirements which have been established by the NACA, it is fairly certain that it will be safe to fly and its handling characteristics will be desirable from the pilot's standpoint. The NACA requirements for satisfactory handling qualities were adopted by the Army and Navy during the war and used as a basis for specification and selection of satisfactory combat aircraft.

During the war, defects in stability and control characteristics of military airplanes were evaluated quantitatively by flight tests. The accumulated information on stability and control indicated the cures for these difficulties. This information is now available to increase the safety of personal airplanes, and to provide for more efficient operation of transport aircraft.

Since the publication of the original requirements for satisfactory flying qualities, additional research has been conducted on certain problems, such as control characteristics in rapid maneuvers. Theoretical work has also contributed to the understanding of these problems. The problems associated with instrument flying and blind landings of transport aircraft are of primary importance at present. The information now available on handling qualities allows a logical approach to the solution of these problems.

An extensive program was undertaken to study the stability and control of a large number of aircraft at high subsonic speeds to determine the effect of compressibility. As a result of these investigations, some of which were conducted in flight and others undertaken in the various wind tunnels of the Committee, not only were the faulty characteristics of the specific airplanes corrected, but information of a general nature applicable to new and future aircraft designs were obtained. In this category is a study of the problem of longitudinal stability and control at high speeds, which led to the development of the dive-recovery flap and the more recent stabilizer flap, which permits the pilot to effect a recovery from a high-speed dive.

An analysis of flight test results on numerous airplanes indicated that the rate of change of elevator deflection with airplane angle of attack bears a very close relation to the pilot's opinion of the longitudinal stability characteristics of an airplane. A desirable form of this parameter has been determined and a method derived for proportioning the horizintal tail. A method has also been developed for predicting from basic airplane characteristics the elevator deflection required to maintain the optimum landing attitude. Wind tunnel results on vertical tail surfaces have been used to develop a method of proportioning the vertical tail in order to meet specified criterions of directional stability and control.

Theoretical analyses have been made of the relation of the elevator and rudder hinge moment parameters to airplane stability with controls free and to transient elevator control forces in rapid maneuvers. A more accurate method based on lifting surface theory has been developed for predicting the control forces obtained in given flight conditions from a knowledge of the geometric shape of the control surfaces. Methods have been developed for reducing these control forces to desirable values by use of suitable types of areodynamic balance.

Analyses have been made of the application of servomechanisms to reduce the control forces. One mechanism of this type, the spring tab, has been shown by analyses made at the NACA to be particularly desirable for application to large airplanes. A method for predicting stick forces for elevators with spring tabs has been developed.

An analysis has been made of the effects of distortion of the control surfaces resulting from air loads. This analysis indicates means of avoiding undesirable effects of this distortion on the control forces.

Work on flap-type lateral-control devices has been extended to cover the selection of the optimum aileron plan form from considerations of maneuverability and control forces. Also, a method has been derived for determining the aileron size and deflections required to meet a given standard of performance for a wing of any known rigidity. The speed at which aileron control is lost because of wing twist, known as aileron reversal speed, also can be predicted with reasonable accuracy. Investigations have been made of a large number of lateral-control arrangements for use with full-span or nearly full-span flaps. One such arrangement has been successfully applied to a production military airplane.

The war years have seen a substantial improvement in the understanding of the effects of various basic stability factors on the flying characteristics of airplanes. Much of the experimental work to achieve this end was performed in the Langley free-flight tunnel, where the effects on the flying qualities of free-flying models may be observed as the basic stability factors are varied independently. An investigation of the effects of the center of gravity location and damping in pitch showed that the longitudinal flying characteristics of an airplane are virtually independent of the damping in pitch, and are almost entirely a function of the center of gravity location which determines the static longitudinal stability. Tailless airplanes thus appear to be as satisfactory for consideration of longitudinal stability as airplanes with horizontal tails.

Investigations were made to determine the effect of wing loading, mass distribution, lift coefficient, dihedral effect, directional stability, lateral area, and damping in yaw on the lateral flying characteristics. The results of these investigations showed that if the effective dihedral and the directional stability were properly proportioned, the lateral flying characteristics would be good, regardless of reasonable variations in the values of the other factors.

In addition to the factors previously mentioned, it is necessary that an airplane have good stalling characteristics. The loss of lateral stability and the attendant wing dropping tendency are perhaps the most serious features caused by wing tip and asymmetric stalling, and can generally be avoided by proper design. A method has been developed for using actual two-dimensional airfoil data to predict the maximum lift and stalling characteristics of plain wings. Of the variables considered, taper ratio has probably the greatest effect on the spanwise location and progression of the wing stall.

As a result of a large number of flight and wind tunnel tests made during the past several years, an analysis is continuing of the effect of fuselage or nacelles and propeller slipstreams on the stalling of wings. An extensive program on the stability and control characteristics of highly-swept wings of interest in connection with high-speed aircraft design has also been conducted. The effect of the angle of sweep on the efficiency of flaps and ailerons has also been investigated.

AUTOMATIC STABILITY AND CONTROL

Automatic stabilization systems had been applied to man-carrying aircraft prior to World War II, and the advanced development of such systems posed no great problems at that time. The use of the automatic equipment was optional and the human pilot could readily correct errors. Consequently, such a system was readily developed by trial and error methods.

The introduction of the guided missile as a military weapon during the war years altered the entire picture. A missile without adequate stabilization was merely an expensive projectile; with satisfactory stabilization, however, it was a weapon with limitless potentialities. Extensive research into automatic stabilization and control problems was required to exploit missile potentialities. Accordingly, the NACA attacked the problem along theoretical lines and the classic stability theory was expanded to include mathematically the action of the stabilization apparatus. The expanded theory was immediately applied to specific military projects with highly satisfactory results.

Experimental work on autopilot systems during the early war years took the form of wind tunnel investigations. In more recent years, full-scale flight research tests of automatic stabilization systems have been conducted. This work has now resulted in significant improvement in the design and action of automatic pilots at high velocity, and has resulted in the development of an automatic pilot capable of roll stabilizing up to sonic speeds.

AIRCRAFT LOADS

Accelerated production and increased performance of new military designs early in the war brought many serious structural problems. These problems were mostly associated with the unknown nature and magnitude of the loads impressed upon the structure under new conditions of operation caused by changed military tactics, by increased flight speeds, and by increases in airplane size. Numerous failures of several new models occurred as these airplanes were placed in operation. It became urgently necessary, therefore, to discover the causes of the failures and to correct the designs before production had become too far advanced. These failures, together with the continued development of new military designs during the war, pointed to the need for increased effort on fundamental loads research and for procurement of specific loads data during development tests of the new designs in wind tunnels. Research on structural loads therefore fell into three principal categories during the war—determination of the causes of structural failures of airplanes that went into service early in the war, fundamental research on all phases of structural loads, and procurement of loads data applicable to the design of airplanes still under development.

Early production models of an important long-range, high-speed fighter aircraft experienced frequent tail failures. These failures posed one of the war's first and most urgent loads problems. Maneuvering loads, load distribution, buffeting loads, compressibility effects, and flutter were all extensively investigated either by analytical procedures or by wind tunnel and flight tests.

As a result of these studies, the rudder was redesigned with metal covering to eliminate fabric bulging and a high-frequency vibration of the trailing edge. New design loads were also established for both the horizontal and vertical tail surfaces and the tail and fuselage structures were correspondingly reinforced.

Tail and wing failures occurred in experimental versions of a Navy dive bomber during test dives at high speeds. The aerodynamic derivatives for the calculation of dynamic tail loads in dive pullouts were established by wind-tunnel tests. Load studies to verify the calculated maneuvering tail loads and measurements of wing stresses and pressure distribution to determine the effects of compressibility were made in flight. An analysis of the combined effects of wing skin wrinkling and of compressibility on the breakdown of air flow over the wing indicated the cause of the tail buffeting. As a result, subsequent failures were eliminated by reinforcing the horizontal tail to provide an adequate margin of strength for maneuvering and buffeting loads. By adding local reinforcements and by using heavy gauge skin in the wing structure, wrinkling of the wing skin was prevented.

A Navy torpedo bomber which experienced wing failures during training and combat flights was also extensively investigated in flight and high-speed wind-tunnel studies. The failures were found to be due to a combination of circumstances, including occasional torsional weakness of a wing resulting from variations in construction, large aileron deflections at high speeds resulting from flexibility of the control system, and operating speeds in excess of that for which the airplane was designed. In some cases, failures were not catastrophic and were confined to such items as cockpit canopies and gun-turret domes. Through flight tests, complete pressure distribution investigations were made on cockpit canopies and gun-turret domes, and the results were utilized as a guide for the design of such items.

Tail failures on an important four-engine, long-range bomber led to an extensive investigation of the pressures and stresses occurring on the aircraft both in flight and in landing. In this particular investigation, the primary cause of the failure was found to be a large amplitude bending vibration of the tail in resonance with the fore and aft vibrations of the landing gear induced by the frictional drag impulse in landing.

The several tail failures specifically investigated by the NACA, together with a number of tail failures on other military airplanes, indicated that one of the gravest and most urgent aeronautical research problems was to establish methods for the accurate prediction of tail loads in maneuvering flight. In addition to being one of the most urgent problems, it was also one of the most difficult because aircraft tail loads are the result of a complex combination of many aerodynamic, kinematic, and vibration phenomena, some of which in themselves, such as compressibility, still require extensive studies. Numerous aspects of tail loads were nevertheless investigated at both the Committee's Langley and Ames laboratories in an effort to approximate a fundamental solution to the problem. After extensive studies, it was established that a basic change in flow phenomena had taken place which had led to the structural failures. This basic change was shown to be a breakdown of air flow over wings as a result of compressibility phenomena. Although the operating conditions of speed, load factor, and altitude were each not extreme, they combined in such a manner that with the high wing loadings of military airplanes, the wings were operating at considerably increased values of unit load or pressure as compared with the values for prewar designs. Flight investigations were undertaken at Langley covering a wide range of Mach numbers and lift coefficients to establish the relations between minimum pressure coefficients and the break-down of the air flow. With these results, and in conjunction with the use of available theoretical treatments of compressible flow, semi-empirical relationships between pressure coefficient, lift coefficient, and Mach number defining the break-down of the air flow were established. From such relationships, diagrams could be drawn defining the operating conditions of altitude, speed, wing loading, and load factor at which flow break-down, changes in airplane pitching moment, and buffeting would occur. Such diagrams, showing the "stalling" and "buffeting boundaries," were correlated with experiences in many tail failures and served to define further the important items of the tail load problem.

Studies were also directed toward the development of convenient methods for solving the equations of maneuvering flight for arbitrary controlling motions; toward the examination of the adequacy of wind tunnel and estimated values of stability derivatives and other aerodynamic parameters; and toward the establishing of limited and actual control motions. As a result, means for estimating tail loads resulting from manipulation of the control surfaces have been established. Important tail loads were found to result further from maneuvers, such as rolls, in which the movement of the tail control is not a primary variable.

Abnormal wing load distributions following breakdown of the air flow at the buffeting boundary was studied as the cause of the failures of the wings of several military aircraft. As a result a method was developed for obtaining approximate span load distributions at supercritical speeds through the application of wing section characteristics for high Mach numbers.

Other work on aerodynamic loads included the development of a theoretical method for deriving span load distributions over swept wings, and the use of wind tunnel and flight results, together with a theoretical analysis to establish a generalized method for the estimation up to the critical Mach number of the pressures on the canopies, gun turrets and blisters on military aircraft.

Inertia loads developed in various parts of the aircraft structure during landing impact became of increasing importance as the result of the increasing size of bombardment airplanes and because of the practice of carrying concentrated weights at extreme positions, such as wing tips.

In an earlier portion of this report, mention was made of the tests on a large four-engine bomber to determine the cause of tail failures which were later established as resulting from resonance between the landing gear and the horizontal tail. The data obtained during these tests were analyzed in generalized terms in order that the most comprehensive picture of the range of variations of the numerous parameters affecting the landing impact could be obtained. In this same connection, considerable research has been undertaken in the Langley impact basin on the load distribution on seaplane hulls resulting from hydrodynamic impact in landing. This work is discussed further in later sections.

Although research on atmospheric turbulence and gust loads was curtailed during the war because of the urgency of other loads investigations, considerable work was nevertheless accomplished. Part of this work is reported in the section on operating problems. Information was obtained on the gust structure, gust intensity, airplane behavior, and associated meteorological conditions from which it has been established that gust loads of high magnitude were equally probable at all altitudes within thunderstorms up to the maximum test altitude of 34,000 feet.

Through the use of the Langley gust tunnel, a number of investigations were made of the reactions of airplanes to gusts having known characteristics. Statistical data on gust loads during transport operations were collected through the use of the NACA V–G recorder and this information, together with previously collected data, were subjected to a number of analyses; the problem of overloaded airplanes was investigated; data on the frequency of the occurrence of gusts of various intensities were analyzed and reported.

Some research was conducted to devise means for the circumvention of turbulence either by avoidance or by alleviation. During this investigation a gust-alleviating flap device was tested in the Langley gust tunnel.

In addition to investigations undertaken to determine the causes of structural failures and to researches of a fundamental nature, considerable effort was applied to measurements of structural loads for specific designs. Many wind-tunnel tests conducted primarily for the development of prototype airplanes or major components thereof yielded extensive air loads information. In addition, flight measurements of loads distribution and analytical investigations of loads on the tail, bomb-bay doors, and structures for housing radar and other operational equipment on military airplanes were undertaken. While most wind-tunnel investigations conducted during the war on models of complete airplane configurations were directed at the determination of aerodynamic parameters affecting performance and stability and control, considerable information regarding the air loads distribution was also obtained. In this connection, large amounts of data were amassed on the total loads and load distribution on various wing, flap, and control surface arrangements. Pressure distribution measurements on wing inlets, cowlings, and scoops to investigate their aerodynamic and cooling efficiencies likewise yielded information as to the structural loads which these parts would be required to withstand.

HELICOPTERS

The war years have seen the development of the helicopter from a purely experimental aircraft to a machine having performance and handling characteristics which make it valuable for specialized military and commercial purposes. While considerable effort was spent in evaluating and improving existing designs for the armed forces, the Committee also was able to aid in the fundamental development of the helicopter by experimentally and analytically investigating the problems which vitally affected the craft in its early stages of development, and to lay a foundation for future helicopter research.

One of the most significant contributions made by the NACA to the science of rotary-wing aircraft is a refined yet easily applied general rotor theory. The method of analysis developed in this connection was used in preparing a much needed series of design charts summarizing the effect of changes in the major variables on the characteristics of a helicopter design. Flight and wind tunnel experimentation, as well as analytical studies, disclosed the nature of some modifications of rotor blade size and configuration, driving gear ratio, and engine supercharging, which made possible substantial increases in the general performance of machines of the type investigated.

Studies were also made of the effect of blade twist, plan form, rotor tip solidity, and type of airfoil section, by analyses which indicated the manner in which additional gains in efficiency could be affected by proper design. The full-scale experimental data obtained also were used in checking and extending existing rotor theory. In view of the specialized flow conditions encountered in the rotor, a series of airfoil sections designed particularly for use on helicopters was developed.

Considerable attention was also devoted to the vibration problems which are peculiar to the helicopter. One of the most dangerous of these problems which was investigated and solved was the phenomenon known as "ground resonance," which, prior to NACA studies, was responsible for the destruction of several rotary-wing aircraft. The problem of rotor blade flutter has also been investigated and a theory established in this connection.

SPINNING

Approximately 120 different military designs have been investigated in the Langley spin tunnel since 1940. In numerous instances, the spin tunnel results have influenced the final design of military airplanes. Based on the results which have been obtained during the spin tunnel tests, it has been possible to establish tail design requirements which indicate the minimum requirements for satisfactory recovery from a spin. The influence of the mass distribution of an airplane upon the effect of rudder, elevator, ailerons, and slots in spin and recovery has also been investigated.

A criterion has been established which combines values of design parameters with the airplane mass distribution and relative density. The minimum size of spin recovery parachutes required for emergency recovery from the spin has been determined from models. Control forces acting in the spin have been investigated on numerous models; also the effect of tail position on rudder hinge moments required for spin recovery. Information on angular velocities encountered during spins has also been determined. Spin tests have been extended to determine the best method of pilot escape from an uncontrollable spinning airplane. Inverted-spin characteristics have been summarized on the basis of existing information.

SEAPLANE DESIGN

In the design of seaplanes, the research objective has been to establish the fundamental parameters associated with various hydrodynamic qualities with a view toward establishing design criteria for the components of the airplane which can be varied to achieve the desired over-all performance. This objective has been reached in several important respects with the result that, as in the case of flying and handling qualities in the air, the research staff, design engineers, and pilots were able to proceed along parallel lines to obtain significant improvements in water-based aircraft.

The established dependence of take-off stability on the trim has provided a useful criterion for all the components affecting the longitudinal moments; that is, the moments must be balanced to obtain stable trims throughout the take-off speed range. When this balance has been obtained, the travel of the center of gravity for take-off is limited in the same way as for aerodynamic stability and control.

The tank research has shown that the most powerful hull parameter influencing the location of the hydrodynamic stable range is the fore and aft location of the step. Designers for sometime have therefore been able to locate the step with respect to the wing by this means, and costly mistakes in design have been avoided by determining the step location for stable take-offs on the basis of tests of models having all the moment-producing components properly simulated.

Tank research has established the dependence of landing stability on the afterbody ventilation, particularly that afforded by the depth and shape of the step, and the form of the afterbody adjacent to it. The application of this relation has proved to be useful in hull design and has resulted in marked improvement in the stability of the newer flying boats. In one wartime case the application of ventilation ducts based on the research findings made the use of approximately 300 four-engine flying boats practicable in the transportation of vital military personnel and supplies, even for night landings where the craft must descend on a steady glide path until the water is contacted.

With the military overloading of several naval flying boats, the resulting heavy spray seriously limited the seaworthiness and increased maintenance time. Methods were developed in the tanks for spray control which assisted in keeping the spray out of the propellers and off the aerodynamic surfaces. For one flying boat originally designed for 46,000 pounds gross weight, spray strips were developed in the tank which enabled take-offs at an overload of 76,000 pounds to be made without spray damage.

In a broader sense, research on spray has indicated the most favorable shape for spray-control devices, and an efficient form of "butterknife" chine suitable for retraction has been evolved. It has also been shown that the general seaworthiness is largely a function of the relationship of the loads and proportions decided upon in the preliminary design stage, thus affording useful criteria for the beam loading and length of forebody in the newer designs.

Emergency open-sea operations in the war demonstrated the importance of rough-water seaworthiness for naval aircraft. Methods have been developed for simulating the most severe maneuvers with models in the tank and criteria have been set up as a basis for design improvements for seaplanes designed to "go with the fleet." One important research finding has been that a very long afterbody greatly reduces the normal accelerations and "ballooning" during landings in waves.

Prior to the war, adequate information on seaplane landing loads was non-existent. Impact basin equipment had been constructed at Langley so that accurate data could be obtained under controlled conditions. Steps had been taken toward the improvement of existing theories. During the war, the impact basin was placed in operation, and much progress was made in experimental and theoretical research on seaplane landing loads. Several fundamental relationships were firmly established. The impact basin was also used in specific tests to obtain design data for naval seaplanes.

PROPULSION RESEARCH

PROPULSION SYSTEMS

Intensive research activity in the past few years has resulted in the more rapid advancement of propulsion systems than at any previous period in aeronautical history. A transition from researches for peak development of the reciprocating engine to fundamental researches on new high speed propulsion methods has been in progress. The period has been marked by the development of reciprocating engines of high power and efficiency and by the birth and development of gas turbines, ramjets, and rocket engines. Many of these achievements can be directly traced to the expansion of research effort in this country in the field of propulsion.

At the beginning of fiscal year 1940, research on aircraft propulsion systems was conducted for the Committee by the Power Plants Division at the Langley laboratory, at the National Bureau of Standards, and by various educational institutions on contract. In August 1939 the Special Survey Committee on Aeronautical Facilities recommended that the Committee construct a new engine research laboratory at the earliest possible date. A special committee on Engine Research Facilities submitted plans for a new aircraft propulsion laboratory. The new laboratory was approved by the Committee and the President and was authorized by Congress on June 26, 1940. Work on construction of the Aircraft Engine Research Laboratory at Cleveland, Ohio, was started immediately. The first research project at the new laboratory was initiated on May 8, 1942.

From 1940 through 1942 the research personnel and equipment of the Power Plants Division at Langley Field were increased to a maximum commensurate with the facilities available. The Power Plants Division, prior to 1940, was primarily concerned with fundamental problems of increasing the power, the efficiency, and reducing the fuel consumption of reciprocating aircraft engines. At the outbreak of the war, the engine research of the Power Plants Division was shifted to specific problems of increasing the power, the efficiency, and the reliability of military aircraft engines in the development and production stage. These aircraft power plants were all reciprocating engines.

During 1943 the program of research on the reciprocating engine for military use was greatly expanded as the research facilities at Cleveland were completed. The program on fuels and combustion studies started at Langley Field was continued at Cleveland on a more extensive scale. The need for fuel research was particularly acute because of the tremendous increase in the quantities of fuel required by the military forces. Investigations were started on lubricants and on the fundamentals of lubrication. As rapidly as the engine research building facilities became available in 1943 and early 1944, research projects concerned with complete engines, components of the engine, and auxiliaries were started. By 1944 investigations were being carried out on all the major components and auxiliaries of reciprocating aircraft engines for military use. In addition, investigations were under way on over-all engine performance, materials, and stresses and vibration in the laboratory and in flight.

In 1943, interest in the gas-turbine jet-propulsion engine for military use resulted in the building of two test cells for ground level investigations. Experiments were conducted in these facilities on the first type of gas turbine engine built in this country. When the altitude wind tunnel was completed early in 1944, the first investigation was a study of the altitude performance of the gas-turbine engine installation in a pursuit airplane. The design of this tunnel was such that gas turbine engines could be investigated over a wide range of altitude conditions. The shift in emphasis from research on reciprocating engines to gas-turbine engines was made in accordance with the research requirements of the development program for jet-propelled military aircraft. The jet-propelled airplane, however, did not reach service use by this country until the end of the war.

THERMODYNAMIC RESEARCH

Thermodynamic Properties of Gases

The design of efficient aircraft engines that involve the use of a gas turbine as the principal source of power or as an auxiliary, and the analysis of the performance of such engines and their components depend on a knowledge of the thermodynamic properties of the working fluids. Accordingly, tables and charts have been prepared for calculations of the thermodynamic quantities associated with the steady-state flow processes of gas-turbine engines and composite engines. The prepared charts permit, within the temperature limits used, the convenient and accurate calculation of the ideal and actual change of condition of the working fluid and the mass flow per unit area for each phase of the working process of a gas-turbine engine and for the auxiliary turbines and compressors of a composite engine.

Cycle Analyses

Analytical investigations of the turbojet and turbine-propeller engine cycles have been conducted to provide information to determine the most effective lines of research to be followed for improvement of these engines.

Turbojet engine. An analysis of the turbojet cycle was made and charts were developed that permit the rapid and accurate evaluation of the performance of the system for any given set of operating conditions and system parameters. The charts take into account turbine, compressor, and combustion efficiencies; discharge nozzle coefficient; losses in pressure in the inlet duct and combustion chamber; ambient atmospheric conditions; flight velocity; compressor pressure ratio; and combustion-chamber outlet temperature. It was shown that maximum thrust per unit mass rate of air flow occurs at a lower compressor pressure ratio than that of minimum specific fuel consumption; the thrust per unit mass rate of air flow increases as the combustion-chamber discharge temperature increases. For minimum specific fuel consumption, however, an optimum combustion-chamber discharge temperature exists, which in some cases may be less than the limiting temperature imposed by the strength-temperature characteristics of present materials.

Turbine-propeller engine. The analysis of the turbine-propeller system is an extension of the analysis of the turbojet and parallels it very closely, the design curves being very similar to those obtained for the turbojet. In this system the turbine power is in excess of the compressor power and, for any given pressure ratio, there exists an optimum division of available power between the turbine and the jet. An expression derived for the jet velocity gives this optimum power division.

A simplified analysis has also been made of the effects of intercooling, reheat, regeneration, and combinations of these factors on the performance of the turbine propeller engines. Results show that intercooling gives a moderate increase in power with little effect on specific fuel consumption, reheat causes an appreciable gain in power with a corresponding rise in specific fuel consumption, and with regeneration only little power is lost whereas large gains in efficiency are possible. Of the combination cycles, the addition of reheat and regeneration to the basic turbine-propeller system appeared the most promising because appreciable gains in both power and efficiency are obtainable.

Waste Energy Recovery, Reciprocating Engines

Exhaust jet stacks. A simple method of recovering some of the energy in the engine exhaust is to fit the engine with individual exhaust stacks directed to the rear to utilize for jet propulsion the kinetic energy of the exhaust gas produced in the exhaust ports by the residual high pressure in the engine cylinders at the time of exhaust valve opening.

An investigation was made on a single-cylinder engine to determine the optimum nozzle size for various engine operating conditions with short straight stacks and with stacks of representative shapes and lengths. It was found that data leading to a specification of the optimum exhaust nozzle area could be correlated for each stack shape.

Flight tests were made on a pursuit airplane with a radial engine fitted with jet stacks. The jet stack installation increased the flight speed 18 miles per hour (from 314 to 332 m. p. h.) at 20,000 feet as compared with the collector installation. Additional investigations were made on other engines and airplanes. The use of jet stacks, which was pioneered by the NACA, has found widespread acceptance in British and American aircraft.

Composite engine. One of the most efficient methods of recovering exhaust energy is by means of the exhaust-gas turbine (for example, by a turbo-supercharger). Additional gains in power and economy can be had by passing all the engine exhaust gas through the turbine and using any excess turbine power, over that required for supercharging, for propulsion of the aircraft. The optimum division of power between the engine and turbine is a function of the sensitivity of engine power to changes in exhaust pressure, operating altitude, power level, component efficiencies, and other variables.

Investigations on several single and multicylinder engines were made to determine the effect of exhaust pressure and other engine variables on the engine component performance. The single-cylinder engine included liquid and air cooled, two- and four-stroke cycle, spark- and compression ignition engines. The multicylinder engines included an 18-cylinder air cooled engine and a 12-cylinder liquid-cooled engine. Tests were also made with a 12-cylinder liquid-cooled and a 9-cylinder air-cooled engine each equipped with a blowdown turbine, which utilizes the kinetic energy of the engine exhaust gases in the individual cylinder exhaust stacks.

From the results of these investigations and from supercharger and steady-flow turbine characteristics, the performance of various composite engine systems was computed.

The results of the analyses of composite engines show that substantial reduction in specific fuel consumption is attained for the various types of composite engine investigated regardless of the nature of the basic engine. The best specific fuel consumptions were attained at about 30,000 feet by the use of both a steady-flow turbine and a blowdown turbine. Consideration of the weight of the engine as well as the weight of fuel shows that, for short flights at low altitudes, the engine with jet stacks is superior; at altitudes in excess of about 10,000 feet the engine with both geared blowdown turbine and geared steady-flow turbine is superior to all other types of combinations of piston engines with jet stacks or auxiliary turbines.

Heat Transfer

Intercoolers. A theoretical study was made of the cross-flow tubular type of intercooler as based on current heat transfer and pressure loss information concerning the flow of air through and across tubes. The results are presented in the form of working charts from which intercooler designs can be quickly made. The heat transfer and pressure loss basis for the analysis is supported by data obtained from a laboratory intercooler test unit. The principal conclusion indicated by the study is that, in order to achieve minimum intercooler size, the heat transferring surface elements should be closely spaced. In addition, it is indicated that an infinite number of intercoolers differing in size and shape can be designed to meet any specified set of operating conditions. Mathematical analyses of both the cross-flow tubular and plate intercoolers were accordingly made, and the results were presented to give the variation of the intercooler volume, surface, frontal area, and linear dimensions with variation in core dimensions for constant intercooler operating conditions.

A method was evolved for plotting intercooler performance data to permit convenient application of the data in the design or selection of intercoolers for a specific application. An analysis was made of the intercooler power losses in flight to determine the intercooler cooling air conditions that give minimum total power loss for any given intercooler cooling effectiveness.

Exhaust gas heat exchanger. The Committee has pioneered the use of thermal anti-icing methods wherein the large quantities of heat contained in the engine exhaust gas are transferred to air circulated through the wing and control surfaces. The exhaust gas heat exchanger is a critical component of such systems. Investigations have been conducted to provide the fundamental information required for the development of improved units. From analysis of heat transfer data, a unit was designed and constructed, and its performance was investigated in the laboratory under simulated conditions. The results indicated that the heat exchanger was an efficient and reliable unit, and that existing heat transfer data were suitable for designing such heat exchangers.

FUELS AND COMBUSTION RESEARCH

Reciprocating Engines

Effect of chemical structure of fuels on knock-limited power. The tendency of a fuel to knock places a limit on the power that can be obtained from a given fuel in a given engine. In connection with the effort of the military services to increase the power output of aircraft engines, a systematic study was made of the effect of chemical structure of fuels on their knock tendency in order to discover fuels of superior performance characteristics. A series of 102 hydrocarbons has been prepared and evaluated in small scale single-cylinder test engines and in a full-scale single-cylinder test engine. A series of paraffinic hydrocarbons, prepared at the National Bureau of Standards, and 30 compounds purchased from commercial sources were also examined as blending agents. A number of the materials investigated showed substantial improvements in permissible power over aviation gasoline of 100/130 performance number.

Fuel-blending relation. In order to avoid the need for engine tests of every possible combination of high performance blending agents, the Committee has conducted extensive studies of the relations between blend composition and knock-limited performance. As a result of these studies, equations were derived that showed the approximate knock-limited performance to be expected when various fuel components were blended.

Special fuel additive. During a critical period of the war it was imperative that aviation gasoline supplies be extended by any available means. It was suggested that the addition of a commercially available additive (xylidines) to certain gasoline stocks would produce a satisfactory fuel for use in aircraft engines.

In preliminary studies it was found that the addition of xylidines to current fuels raised the knock-limited performance to such an extent that 15 percent of lower-grade fuels could be blended into the additive fuel without exceeding the knock limit. Following these preliminary studies more extensive tests were made in various types of engine cylinders then being used in military aircraft.

Special blending agent. A comprehensive program to evaluate triptane (2,2,3-trimethylbutane) and certain other high antiknock components for use in aviation gasoline was undertaken. The program consisted of extensive studies in small-scale engines, in full-scale single-cylinder engines, and finally in a multicylinder engine mounted on a torque stand and in a similar multicylinder engine in flight. The results indicated that triptane could best be utilized in engines specifically designed to operate on high-performance fuels but that definite gains could be realized by its use as a component of fuel blends for current aviation engines.

Pre-ignition. A study was conducted on the influence of fuels on pre-ignition in small-scale single-cylinder engines. In these particular studies it was found that increases in compression ratio, spark advance, coolant temperature, or inlet-air temperature decreased the pre-ignition-limited performance.

Fuel-vapor loss. Laboratory investigations indicated that the fuel vapor loss from an aircraft fuel tank amounted to about 15 percent of the original fuel load during a climb to an altitude of 40,000 feet with an initial fuel temperature of 110° F. Flight investigations were conducted to check the simulated altitude laboratory results. The fuel vapor loss is affected by type of fuel, fuel temperature, altitude of climb, flight time, and fuel system. Preventive and recovery methods were studied in simulated flights.

Jet Propulsion Engines

The research program based on the combustion problems of jet propulsion engines has two broad over-all objectives: (1) to obtain generalized results and conclusions about combustion applicable to design, performance, and related practical problems currently encountered in jet propulsion engines, and (2) to obtain information leading to the eventual understanding of the physico-chemical processes in combustion. These two objectives are not mutually exclusive, and an investigation aimed at one generally contributes something to the other.

Effect of combustor operating conditions on combustion efficiency. An investigation in the altitude wind tunnel on a turbojet engine revealed that for each rotative speed of a turbojet engine an altitude existed above which the engine would not operate; that is, the engine had an altitude operation limit. An investigation was then made of the combustor alone in the combustion laboratory, where engine combustor conditions could be simulated, and it was found that the altitude operational limit of the engine could be explained in terms of the effect of the combustor inlet conditions on combustion efficiency. It was found that independently increasing the air velocity or decreasing the air temperature or pressure at the combustor inlet decreased the combustion efficiency. Under some adverse inlet conditions a peak combustor temperature rise was obtained that was considerably less than the theoretical temperature rise available and further increase in combustor temperature rise could not be achieved regardless of increase in fuel flow. The altitude operational limit of the engine coincided with the conditions in the combustor tests where the peak combustor temperature rise was less than that required for engine operation. The trends of combustion efficiency with combustor inlet temperature, pressure, velocity, and fuel-air ratio determined in these tests were verified in investigations of additional combustors of both the annular and individual tubular types.

Effect of combustor-air distribution on combustor efficiency. At the request of the Bureau of Aeronautics of the Navy Department the Committee investigated the effect of distribution of air flow in the combustor on combustion efficiency in order to increase the operational altitude of two turbojet engines. Changes in combustor design were investigated that provided a larger and more sheltered zone for the primary air. As a result of these design changes, the operational ceiling of the two turbojet engines investigated was more than doubled.

Ramjet combustion. With ramjet combustion chambers, investigations were made to determine the criteria of good flame holders. The influence on combustion of such geometric variables as amount of area restriction, size of individual shielded zones, distance of lateral flame travel between adjacent shielded zones, and presence of pilot flames is being studied. The effect of different types of fuel injection is also being studied; an intermediate degree of fuel atomization and dispersion with fuel-rich zones coinciding with the shielded zones behind the flame holders was found to be the better arrangement in many cases.

High energy fuels for turbojet engines. In addition to synthesis of compounds for studies in reciprocating engines, pure compounds of the types desired in turbojet engines are being prepared for investigation in a turbojet combustion chamber. Special emphasis is being placed on fuels of high energy content per unit volume.

Effects of fuel characteristics on performance of turbojet combustors. Different hydrocarbon types showed no appreciable differences in performance except in the case of aromatic hydrocarbons, which gave combustion efficiencies about 20 percent lower, under some conditions, than other types. Some of the differences between the performance of different fuels were decreased by better atomization of the low-volatility fuels. Other fuel studies showed that the rate of carbon deposition in turbojet combustors increased with increasing aromatic content and with decreasing volatility.

COMPRESSOR AND TURBINE RESEARCH

Centrifugal Compressors

Investigations were conducted on various impellers to determine the merits and the effect of changing each of several design variables. As part of a program to determine design criteria for impellers, a series of constant angular-acceleration inducers were investigated both as separate components and in combination with an impeller. The application of the inducer type developed in this program to a commercial centrifugal impeller resulted in a gain of eight points in compressor performance.

Combining the results of inducer research and of the preliminary impeller research, an investigation was started to determine the most effective blade and passage shapes for impellers. Six impellers having a wide range of blade loading conditions have been investigated; efficiencies of 85 percent, pressure ratios above 5, flow capacities double those of conventional impellers, and equivalent tip speeds of 2,000 feet per second have been reached.

Research on centrifugal-compressor types designed on the basis of flow theory (including a two-dimensional radial-inlet impeller and an axial-discharge impeller especially adaptable to gas-turbine power plants) was undertaken to develop a sound mathematical basis of impeller design. Initial investigations on the radial-inlet impeller have indicated the sources of losses and have established a method of analyzing the flow in impeller channels.

Methods of performance testing were investigated to establish a means of accurately rating compressors and to determine performance of existing service types and available experimental types of supercharger impellers. Tentative standards for testing and rating centrifugal compressors were prepared.

Matching. A convenient method developed for presenting the performance of a compressor system in relation to that of a power section consists in plotting on the same graph the performance of the compressor system and the power section in terms of variables common to both. Intersection of the performance curves determines the points of operation for the complete unit.

Application of this method of analysis to supercharged engines has shown that pressure losses through the compressor system, especially through the inlet elbows, considerably reduce over-all output of the power plant. The fundamentals of flow through elbows were investigated and an elbow was designed in which the total pressure losses through the elbow were 10 percent of the velocity pressure at the compressor inlet. An improvement in the velocity distribution at the compressor inlet was simultaneously obtained.

Surging. Analytical and experimental investigations were made of surging, a phenomenon that establishes the minimum flow at which a compressor can operate. The results show that surging is possible only when the pressure ratio of the compressor decreases with a decrease in volume flow. The maximum rate of change of pressure ratio with volume flow that can be tolerated without surging is dependent on the magnitude of the individual capacities and resistances of the entire compressor system. The results of these researches indicated several methods of extending the surge-free operation of a compressor. Experiments with one of these methods demonstrated that not only could the surge-free range of a centrifugal compressor be extended but that hitherto unattainable regions of high pressure ratio and efficiency could be realized.

Superchargers. Preliminary studies of a liquid-cooled type of aircraft engine having two stages of supercharging indicated that the supercharging and induction systems of the engine were critical. The individual performance characteristics of the superchargers were obtained for both sea level and simulated altitude conditions and the information thus obtained was used to determine the optimum supercharger operating conditions in the engine.

Axial Flow Compressors

Blade design and single-stage theory. The investigation of the individual stages of a multistage axial-flow compressor resolves itself naturally into two parts; study of the performance of the blade elements, and consideration of the effect of different velocity distributions along the radius. Factors affecting the blade-element performance are camber, solidity, and blade profile. Theoretical and experimental investigations have resulted in useful correlations between these two parts. Detailed theoretical studies made of the effect of the distribution of velocity in the radial direction have been used as a basis for the design of a number of single-stage research compressors.

Multistage compressors. The eight-stage axial-flow compressor designed and constructed in 1938 by the Committee on the basis of high-speed airfoil theory has been the subject of extensive investigations. An investigation of the performance of this compressor demonstrated that a maximum over-all adiabatic efficiency of 0.87 and a maximum pressure ratio of 5.4 were attainable. The effect of Reynolds number was investigated and it was found that when the simulated altitude at the compressor inlet increased from 27,000 to 50,000 feet, the efficiency decreased 4 points. The useful operating range of the compressor was extended as a result of an investigation on the use of adjustable stator-blade angles. Theoretical research on multistage axial-flow compressor design has led to criteria for estimating the effects of basic design variables on the performance of the compressor.

Compressor and turbine matching. An investigation was made to determine the interaction of compressors and turbines as components of a jet engine. The engine used for this investigation consisted of the NACA eight-stage axial-flow compressor and a specially designed turbine. The data from this investigation were studied to develop a theory for determining the performance of a jet engine from a knowledge of the performance of its components and for estimating how each of these components affects the performance of the other. The results of this work indicate that, in general, investigations of complete jet engines without knowledge of the performance of the components cannot be expected to indicate how well the components match, because only a small range of the possible field of operation of the turbine component is covered. The application of the developed method of analysis does permit, however, the evaluation of the effect of modifications of jet engine components on over-all performance without actually retesting the engine.

Tentative standard procedures for rating and testing. The NACA Subcommittee on Compressors, realizing the importance of standard procedures for rating and testing multistage axial-flow compressors, appointed a special panel to establish such procedures. Experimental techniques and calculation procedures were established that would give the highest accuracy and reproducibility of results.

Single stage-compressors. In order to improve the performance of axial-flow compressors, it is necessary that the effect of a large number of variables be determined. These variables include velocity diagram, blade section, blade camber, solidity, aspect ratio, tip clearance, blade-root radius, and blade finish. Because of the desirability of investigating these fundamental effects on simple compressors, where all the variables can be easily controlled, three 14-inch-diameter, single stage, variable-component compressors were designed; these three compressors simulated the intermediate, inlet, and outlet stages respectively, of a multistage compressor. The first two of these compressors are in operation under investigation.

Specific compressors. In cooperation with the military services, the research facilities of the Cleveland laboratory have been utilized to determine the performance of four axial-flow compressors designed for specific jet propulsion engines. Over-all and individual compressor stage performance data were obtained over the entire compressor speed ranges for both sea level and simulated altitude inlet conditions. In one instance, the interstage survey data were used as the basis for blading modifications that changed the air handling capacity of the compressor to the value for which the jet engine was designed, and increased the efficiency by approximately three points, with a corresponding increase in pressure ratio. The finding of each of these investigations were supplied to the military services and manufacturers as a guide in the design of future compressors.

Turbines

Design and performance. In order to design turbines with optimum efficiency, gas flow and power capacity, it is necessary to evaluate the effect of the internal gas-flow phenomena on turbine performance and to evolve a method of shaping the internal turbine members to obtain the optimum flow characteristics. The order of magnitude of the gains to be expected from this study is being evaluated. For this purpose a number of turbine blade-shape parameters have been varied in several sets of blades and a study is being made of the effect of such variations on single-stage turbines using these blades. A theoretical method has been developed that permits the determination of a blade-section shape under the simplifying assumption of two-dimensional flow of a perfect, incompressible fluid. Generalization to the case of the compressible perfect fluid with two-dimensional flow is now being studied. The effect of viscosity on the flow pattern has been experimentally investigated in a stationary set of turbine nozzles and some basic flow phenomena have been determined, which should prove helpful in the analytical treatment of this effect.

The program of turbine-blade investigations that accompanies the program of turbine blade design has two main purposes: (1) to provide experimental data to expand the theoretical studies, and (2) to indicate the changes in turbine performance that cannot at present be predicted by theoretical methods.

A Reynolds number correlation was obtained by studying the performance of a single-stage turbine over a wide range of intake pressures and intake temperatures. This investigation indicated that, if the intake temperature is altered, no change in turbine performance results as long as the ratio of inlet pressures to the 1.1 power of the inlet temperature is unchanged.

The turbine component from a representative jet-propulsion engine was selected for a basic investigation designed to establish a sound method of predicting gas-turbine performance at design operating conditions by means of performance data obtained at greately reduced pressures and temperatures and to examine, in detail, the flow through the various components of the turbine. Investigations have also been made on the air-cooled, mixed-flow turbine to determine the performance of this type of turbine at elevated temperatures.

A two-stage turbine was constructed for the ultimate purpose of studying the combined characteristics of a compressor and a turbine as components of a turbojet engine. An investigation of the turbine alone showed that the turbine had a maximum efficiency of 0.875, which indicated that the stream-filament theory used in designing the blades can produce turbine blades having reasonably high efficiencies.

Cooling. In order to determine the potentialities of various methods of turbine disk and blade cooling, analytical investigations were first undertaken. Four methods of cooling were considered; cooling by conduction to the rim of the turbine disk, admitting cool air through part of the nozzles, passing cool air through hollow blades, and circulating cooling liquids through internal blade passages.

Preliminary experiments to determine basic information on the heat transfer properties of hot gases were started. Methods of measuring blade temperatures on rotating turbine disks were devised.

LUBRICATION, FRICTION, AND WEAR

Research on lubrication, friction, and wear supplied fundamental and applied information for aircraft power plants that served as a primary factor in the continual increase in power output of all types of engines during the war period.

Surface Phenomena in Sliding Friction

A fundamental study of surfaces showed changes in geometric accommodation and physico-chemical changes during run-in of sliders. Surface failure of many new engine parts operating under conditions of sliding friction such as bearings, reduction gearing, and cylinder assemblies necessitated much work on run-in of surfaces. This study involved physico-chemical studies of surfaces after varied degrees of experimental operation that corresponded to extreme conditions. It was concluded that surface treatment prior to operation, which would condition the surface sufficiently to eliminate much of the prolonged run-in period considered necessary in service, could be accomplished.

Theoretical analyses of metallic thin-film lubrication showed that benefits could be expected from this application and experimental research verified the analyses. The experimental work was confined to studies of films of low shear strength on hard base material; under these conditions the coefficient of sliding friction is directly proportional to the shear strength of the film material. Metallic films of silver, lead, and tin as well as a graphite-base coating were used on experimental sliding surfaces operated under conditions of boundary lubrication and were found to provide effective supplementary means of reducing sliding friction and wear. Further work on metallic compounds, such as oxides and sulphides, without lubrication, showed these compounds to have a very marked effect on sliding friction.

Piston Rings and Cylinder Barrels

A fundamental investigation was made of materials for use as sliding surfaces in component parts of piston-ring and cylinder-barrel assemblies. The results of this investigation were applied in the selection of porous chrome plate as a salvage material for sliding surfaces in cylinder barrels. Porous chrome-plated cylinder barrels were found to have very good wear characteristics and high load capacity. Other cylinder-barrel material studied included alloyed steels, which were hardened by induction heating and nitriding. Piston-ring materials included cast irons of high tensile strength, chrome-plated cast iron, chrome steel, and nitrided steel. The results indicated that load capacity limitations of cast-iron rings could be increased by chrome plating and that for this application dense chrome plate could be as effective as porous chrome plate. Various methods of finishing slider surfaces for piston rings and cylinder barrels were studied and it was found that for plane surfaces, coaxial lapping with loose abrasive compounds accomplished very desirable geometric accommodation of the surfaces and otherwise improved performance.

Piston Lubrication and Oil Control

The problem of piston lubrication including oil control and ring sticking were investigated analytically and experimentally. Visual studies of cylinder lubrication with a glass-cylinder apparatus showed that, in accordance with hydrodynamic theory, the piston was inclined to favor the formation of a fluid film during the greater portion of the engine cycle and that the piston moved laterally under the influence of side thrust. The effect of the rings on lubrication and the action of the rings were observed; it was determined that the oil film on a loaded ring face was 0.0001 inch or less.

Journal Bearings

Dimensional analysis and the principle of similitude were applied to the computation of crankpin and main bearing loads for in-line and radial reciprocating engines. Charts were constructed to provide engine designers with an easily used tool to determine maximum and average bearing loads.

An analysis of the operating characteristics of a full-floating bearing and its experimental verification using visual study techniques has been made. This bearing can be operated over a wide range of speeds for a given shaft speed and results in low operating temperatures at high rotating speeds. This low operating temperature would be obtained at the expense of load capacity if clearances remain the same as for a plain journal bearing; clearance may, however, be adjusted to improve this condition.

MATERIALS, STRESS, AND VIBRATION RESEARCH

High-temperature Alloys

The fundamental theory of physics of solids has been extended to the study of failures of alloys at elevated temperatures under conditions of constant stress. Rate-process theory and dislocation theory have been employed to derive equations for rate of creep and for time to rupture under constant stress that are in good agreement with experimental data. The theory suggests the use of metals of high modulus of rigidity and states that a hyperbolic-sine relation exists between applied stress and both creep rate and stress-rupture time. Application has been made to several gas-turbine materials, which are now described in terms of four parameters. The methods have been shown to be applicable to gas-turbine alloys, pure metals, magnesium alloys, and aluminum alloys.

The crystal structures of a number of forged and cast high temperature alloys have been determined using X-ray diffraction methods. The usual structure at room temperature is face-centered cubic with lattice parameters ranging from 3.55 to 3.60 Angstrom units. An investigation of the structure of the microconstituents of such materials is being conducted and has resulted to date in detection and positive identification of the materials columbium carbide and chromium carbide ($Cr_{23}C_6$).

A program has been started on the evaluation of materials for gas turbine use at the request of the Army Air Forces and Bureau of Aeronautics of the Navy Department. Both experimental and commercially available types of alloys are being investigated under full-scale service conditions to determine the mechanisms of failure, the influence of non-critical alloying elements on performance, and the relative performance of these materials. Failures of a number of turbine buckets, combustion chamber liners, and other components have been examined. The lack of uniformity in temperature distribution in the engine indicates the need for a great amount of data for significant evaluation.

Ceramic Materials

A number of commercially available and experimental ceramic materials have been investigated to determine their suitability for use in gas turbines and rockets. The relative resistance to thermal shock, tensile properties at elevated temperatures, and general refractory behavior have been studied. Two turbines, each having blades composed of sillimanite have been constructed and some of the operating problems pertaining to the use of such ceramic materials have been investigated. Ceramic coated turbine buckets have also been considered. A number of ceramic combustion chamber liners were investigated and found to be unsatisfactory for use in turbines because of low thermal shock resistance.

A number of ceramic rocket nozzles were investigated and found to be unsuitable for use because of poor resistance to mechanical shock.

Stress and Vibration

Strain gages have been used to study static and dynamic stresses in reciprocating engine parts. Results included discovery of vibratory stresses in connecting rods and crankshafts not predicted by theory; permissibility of removing material in valve interiors for cooling without increasing stresses, and departure from theory of stresses in pistons, piston pins, and bearings.

Study of components of jet-propulsion engines led to a numerical method of calculating elastic and plastic stresses in rotating disks with temperature gradients. Such calculations were used to demonstrate the necessity of determining the variation with temperature of the elastic modulus, coefficient of thermal expansion, and tensile properties of turbine-disk materials. They also indicated that improper cooling was detrimental to turbine-disk life. Rim cracking in the turbine disk of a turbojet engine was found to be caused by residual tensile stresses that could be reduced by rim slotting and shrink fitting. High-temperature strain gages were used to measure turbine-blade stresses under operating conditions.

Vibration in the blades of the axial-flow compressor of a turbojet engine was found to be caused by all orders up to the tenth, although not predicted by analysis.

RESEARCH ON RECIPROCATING ENGINES

A wartime research of paramount interest was the investigation of methods of increasing the power of existing reciprocating aircraft engines. Intensive research was conducted on the factors limiting engine power with the object of discovering methods of circumventing these limitations.

Engine Cooling

Correlation of operating temperatures. The theoretical method previously derived for correlating external temperatures and engine operating variables has been applied to a number of liquid-cooled and air-cooled multicylinder engines operating on the test stand, in the altitude wind tunnel, and in flight. Additional terms have been incorporated in the original correlation equation to account for variables in flight at high altitude. These investigations indicate that the important variables for air-cooled engines from cooling considerations are cooling-air temperature, cooling-air mass flow, charge-air temperature, charge-air mass flow, fuel-air ratio, spark timing, and exhaust back pressure. The effects of internal coolants and cowling design have also been investigated and correlated.

Adaptation of the correlating equation to liquid-cooled cylinders was achieved by substituting the coefficient of heat transfer through a liquid film for the coefficient through air. The coefficient of heat transfer through the liquid film was expressed in terms of coolant temperature, coolant mass flow, and the properties of the coolant.

The introduction of an additional term in the correlation equation to represent the thermal resistance between the internal parts, such as the exhaust valve, and the exterior of the cylinder made possible correlation of the temperatures of critical internal parts with operating conditions. Study of these correlations showed that temperatures of the external parts of the cylinder were not reliable indicators of the temperatures of the critical internal parts.

Internal coolants. Military requirements made necessary large increases in the engine power output with little opportunity for major design changes. In many cases the power output required could not be obtained without special means for the prevention of fuel knock or overheating. The use of internal coolants appeared attractive and an extensive program was carried out to determine the amount of cooling possible by this means, the effects on the fuel-knock limitations, and the best methods of injection of the coolants. Investigations were carried out on full-scale and small-scale single-cylinder engines and on full-scale multicylinder engines.

Results of studies of special internal coolants conducted on small-scale engines showed that one such coolant allowed the specific power output of an engine to be increased to more than four times the value that could be obtained with aviation gasoline of 100/130 performance number.

The experimental investigations carried out on both the test stand and in flight indicated that the power of some cooling-limited and knock-limited engines could be increased by almost 60 percent. When the coolant was added far enough upstream to permit vaporization before entering the cylinder, the reduction in charge temperature caused a substantial increase in inducted air weight. This increase in air flow was reflected in a substantial power increase only when the spark was advanced sufficiently to offset the reduction in flame speed caused by the internal coolant.

The investigations revealed that water is more effective than fuel as an internal coolant when large increases in power are desired. Water was found to be somewhat less effective in cooling the exhaust valve seats and guides.

Cylinder coolants. The increase in power output of liquid-cooled engines during the war emphasized the necessity for improved cylinder cooling. Excessive thermal stresses and other operational difficulties were experienced as a result of high temperatures.

An investigation was undertaken to evaluate the heat transfer characteristics of different coolants. This investigation was conducted with an electrically heated tube, which simulated the heat fluxes and temperatures of liquid-cooled aircraft-engine cylinders. The data indicated that water or aqueous solutions of ethylene glycol were preferable to ethylene glycol, the coolant then in general use. When these data were subjected to checks in single-cylinder and multi-cylinder engines, the results showed that cylinder-head temperature reductions of as much as 100° F. were obtained by substituting water for ethylene glycol. This temperature reduction permitted an increase in the knock-limited power output of the engine of approximately 13 percent.

Piston cooling. The proper functioning of pistons and piston rings at high engine power is limited by the resulting high temperatures frequently associated with high power. Preliminary investigations of the cooling process were made with an electrically heated piston in a reciprocating cylinder. Effects of significant variables upon the heat transfer from the piston to the barrel were investigated. Measurements were made in both single-cylinder and multicylinder engines of the temperature distributions throughout the piston. The temperature distributions were used to compute the surface heat-transfer coefficients between the combustion gases and piston, the piston and cylinder, and the piston and crankcase atmosphere. The surface coefficients were used in computations by a network method of the effects of piston dimensions and under-crown cooling on the temperatures at the center of the crown and at the ring grooves. The analysis was shown to be in agreement with published data from many sources. The results indicated that in high-speed aircraft engines a large part of the piston cooling is through the crankcase atmosphere and that in such cases the piston dimensions should be governed by strength considerations.

Exhaust valve cooling. As engine power has been increased, overheating of exhaust valves has been encountered. The effect of overheating results in badly corroded and collapsed valve heads, poor seating due to distortion and corrosion, and preignition. In addition to these direct difficulties, hot exhaust valves result in lowered engine performance through a lowering of the knock limit and heating of the combustion air during the induction stroke.

An investigation of the heat-transfer characteristics of sodium-cooled valves has indicated that the most effective method of reducing the operating temperatures was to increase the area of the passage between the head and the stem and to increase the heat-transfer area between the stem and the guide. Further temperature reductions were obtained by increasing the heat-transfer area of the valve-guide bosses. In one case increasing the heat-transfer area of the stem made possible the elimination in laboratory tests of engine failures, which were at that time causing serious damage to combat airplanes. Increased external cooling without design modifications was in this case ineffective in reducing valve temperatures.

842951—50——8

Improvements in cylinder-cooling baffles. A study of methods of improving the cooling limitations of air-cooled cylinders has indicated that a direct means of cooling the overheated regions of the cylinders would permit raising the temperature of the adjacent over-cooled areas. A direct application of cooling air to the overheated regions at the rear of the cylinders by means of unrestricted, directed flow to these regions has resulted in reduction in the temperatures of the head and the exhaust-valve seat of approximately 50° F.

Investigation of tightly fitting baffles modified to maintain a constant free-flow area from the front to the rear of each interfin air passage showed that the weight of the cooling-air flow over the cylinder heads for a given pressure drop was increased approximately 35 percent and average head temperatures were reduced approximately 30° F.

Cylinder Charging

Aftercooling. An increase in the power of one of the combat, liquid-cooled aircraft engines was investigated by the use of an aftercooler that cooled the charge air before it entered the cylinders, thereby making a denser charge and permitting higher power before knock was encountered. Two such aftercoolers were made. The first was designed to require no significant engine or airplane modification for increasing sea level power. The use of this aftercooler resulted in increases in engine power of 35 percent. The second was designed to provide effective cooling with a very small pressure loss to prevent a reduction in the critical altitude of the supercharger system and involved complete manifold redesign. Negligible loss in manifold pressure resulted from installation of this aftercooler and preliminary data on engine power indicated a substantial gain in power.

Supercharger and induction system. A study was made of the supercharger and the induction system of a liquid-cooled engine to provide the highest possible manifold pressure to the cylinders. Analysis of data from an investigation of the basic engine showed that the following changes would be desirable if the maximum performance were to be approached: (1) Redesigning the auxiliary-stage supercharger inlet elbow and interstage duct to reduce the pressure loss and provide for better air flow; (2) changing the carburetor position from upstream of the auxiliary-stage supercharger to between the two superchargers to increase the manifold pressure and the air flow capacity; (3) increasing the degree of supercharging by increasing the auxiliary-stage supercharger gear ratio and making provision for increasing the crankshaft speed from 3,000 to 3,200 rpm. to increase the manifold pressure and air consumption without a detrimental effect on supercharger performance; and (4) reducing the charge-air temperature by installing an aftercooler and provisions for internal coolant injection to increase the knock limited power and air flow. As a result of these findings and in cooperation with the manufacturer the horsepower output of the engine was increased approximately 50 percent at 29,000 feet and 43 percent at 17,000 feet.

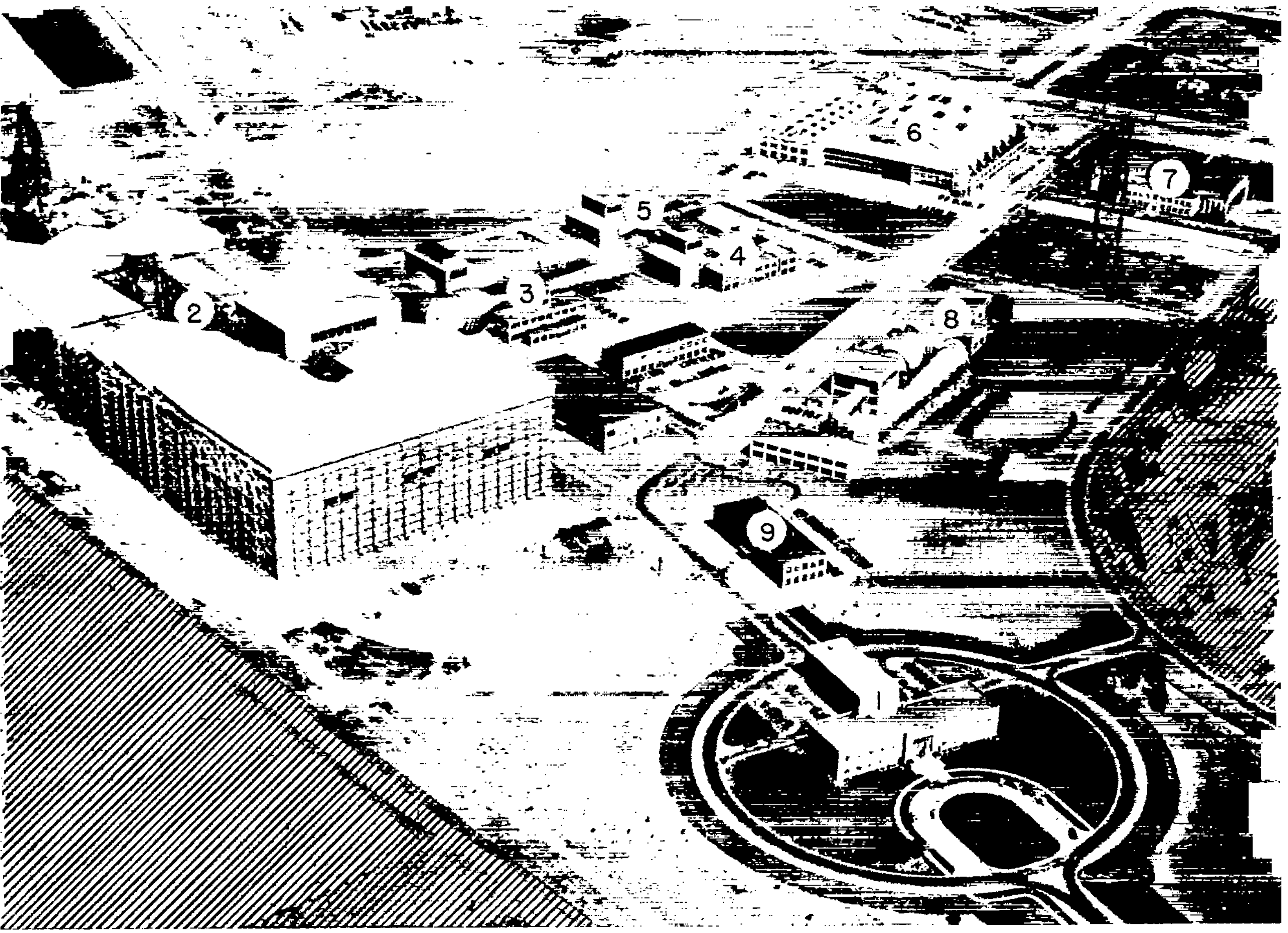
Valve design. An analysis of the intake and exhaust valves and the valve-seat inserts of a 12-cylinder liquid-cooled engine indicated that an improvement in flow coefficients was possible. Tests of modified valves and inserts showed an increase in flow coefficient of 8 and 12 percent for the intake and exhaust valve, respectively.

Boosting with oxygen and compounds of oxygen. An emergency means of increasing the engine power for short intervals of time at high altitudes is the introduction of additional oxygen either from high-pressure storage tanks or in some suitable chemical compound. The use of oxygen resulted in increases in engine power for a given manifold pressure. The addition of oxygen, however, led to high combustion temperatures with consequent overheating and a tendency toward preignition and knock. This tendency could be overcome by drastic increases in fuel-oxygen ratio. The response to this enrichment was limited and some means had to be used to increase the internal cooling. Results of investigations of various internal coolants indicated that large flow rates would be required to prevent knocking and overheating.

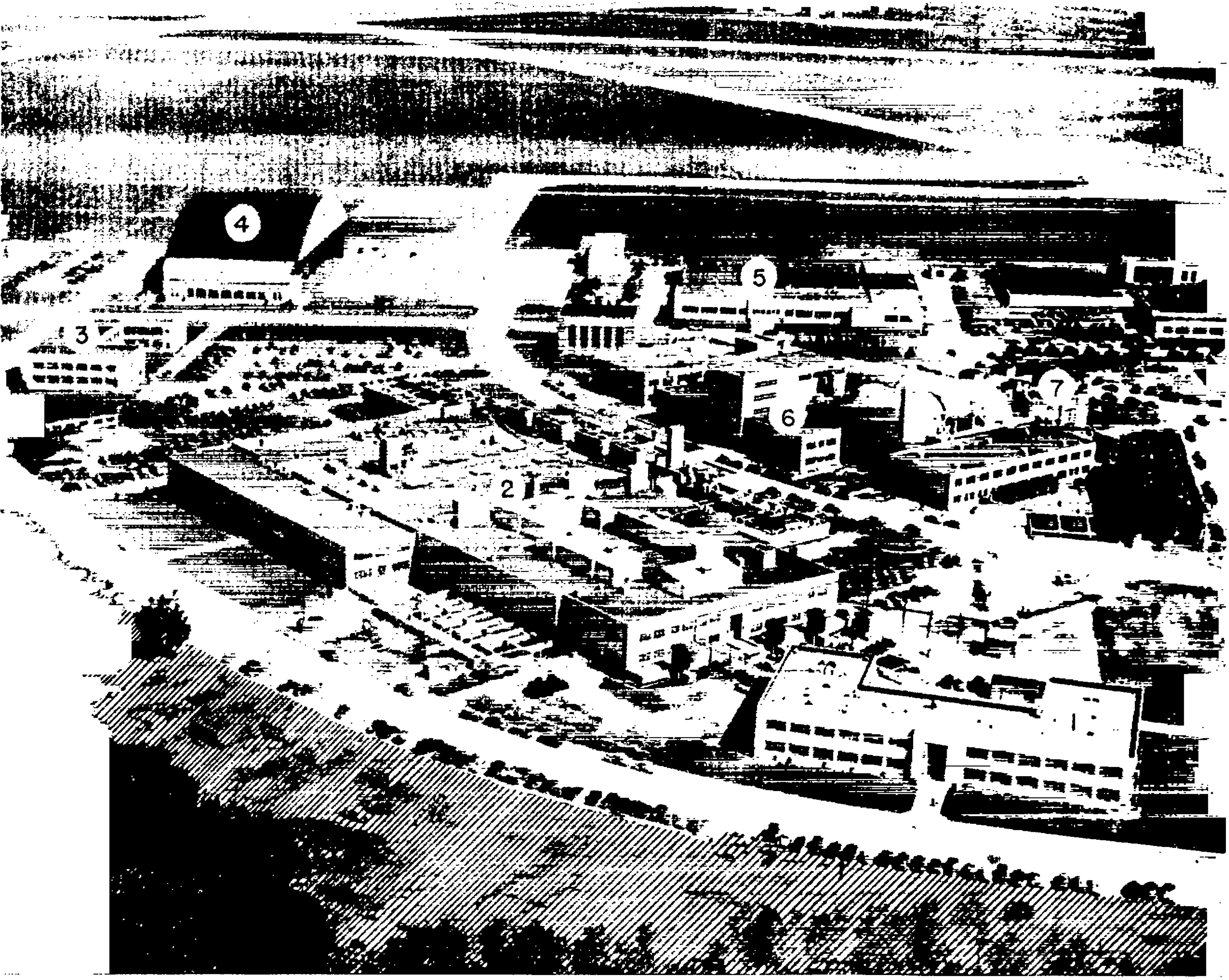
The use of nitrous oxide instead of oxygen was proposed because it has been found that nitrous oxide did not appreciably lower the knock limit and did not result in as high a degree of overheating as had been experienced with oxygen. An investigation conducted with nitrous oxide showed that, when knock was not a limitation, the overheating caused by the addition of nitrous oxide could be controlled to best advantage by the use of mixture enrichment. When knock is a limitation, the use of internal coolants is necessary.

Backfiring research. Explosions or "backfiring" in the intake manifolds of high-performance engines have been the source of a number of engine failures. An investigation was undertaken to determine the causes of backfiring and to find means of eliminating it. The first objective was to determine whether backfiring was caused by early burning (preignition) or to excessively slow burning.

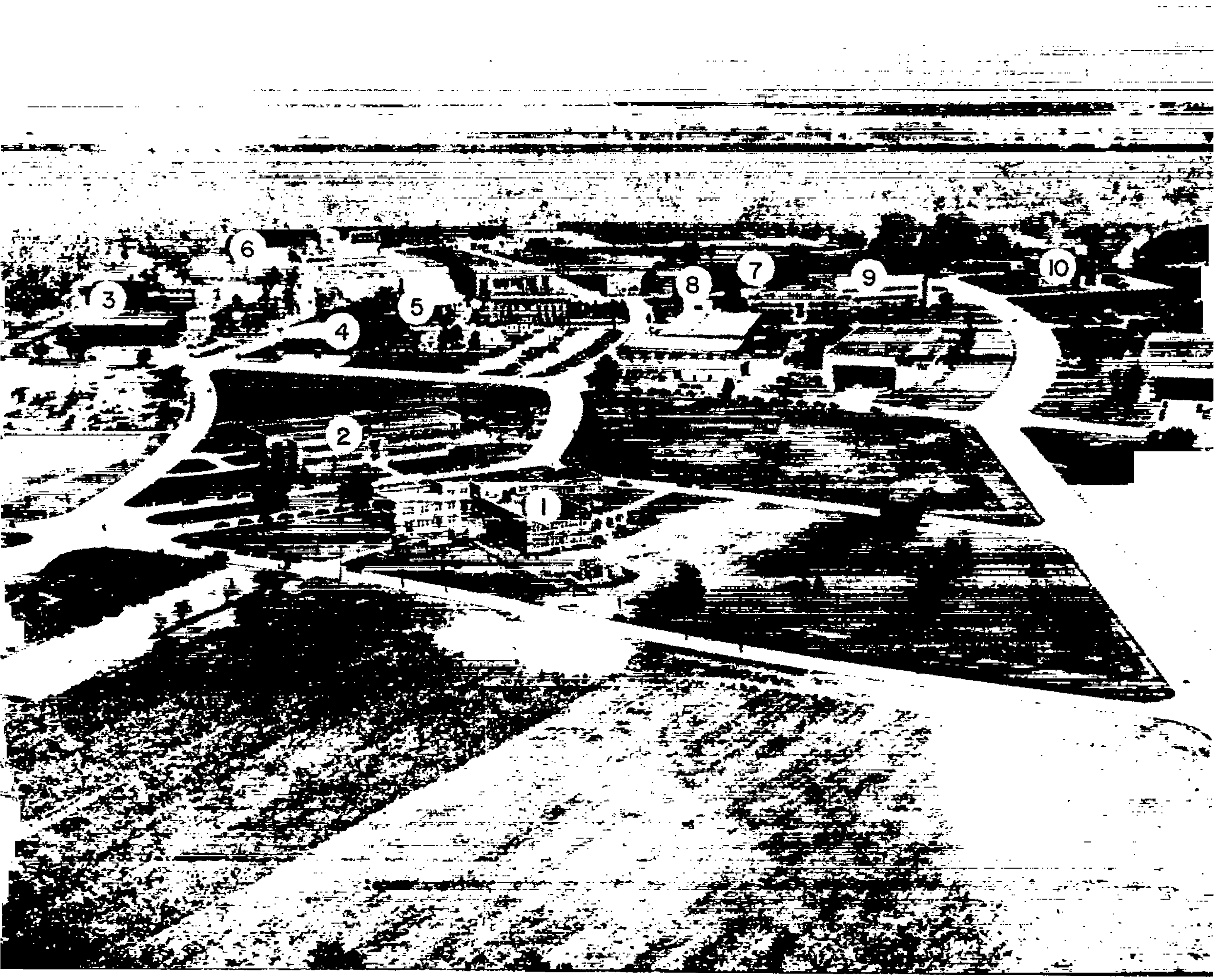
Data obtained from multicylinder and single-cylinder engines indicated that both pre-ignition and excessively slow burning could lead to backfiring. With preignition, the backfiring was most likely to occur with fuel-air ratios that produce maximum flame speed; in one particular engine, backfiring would occur when the ignition had advanced to approximately bottom center. With slow burning, the backfiring was most likely to occur at



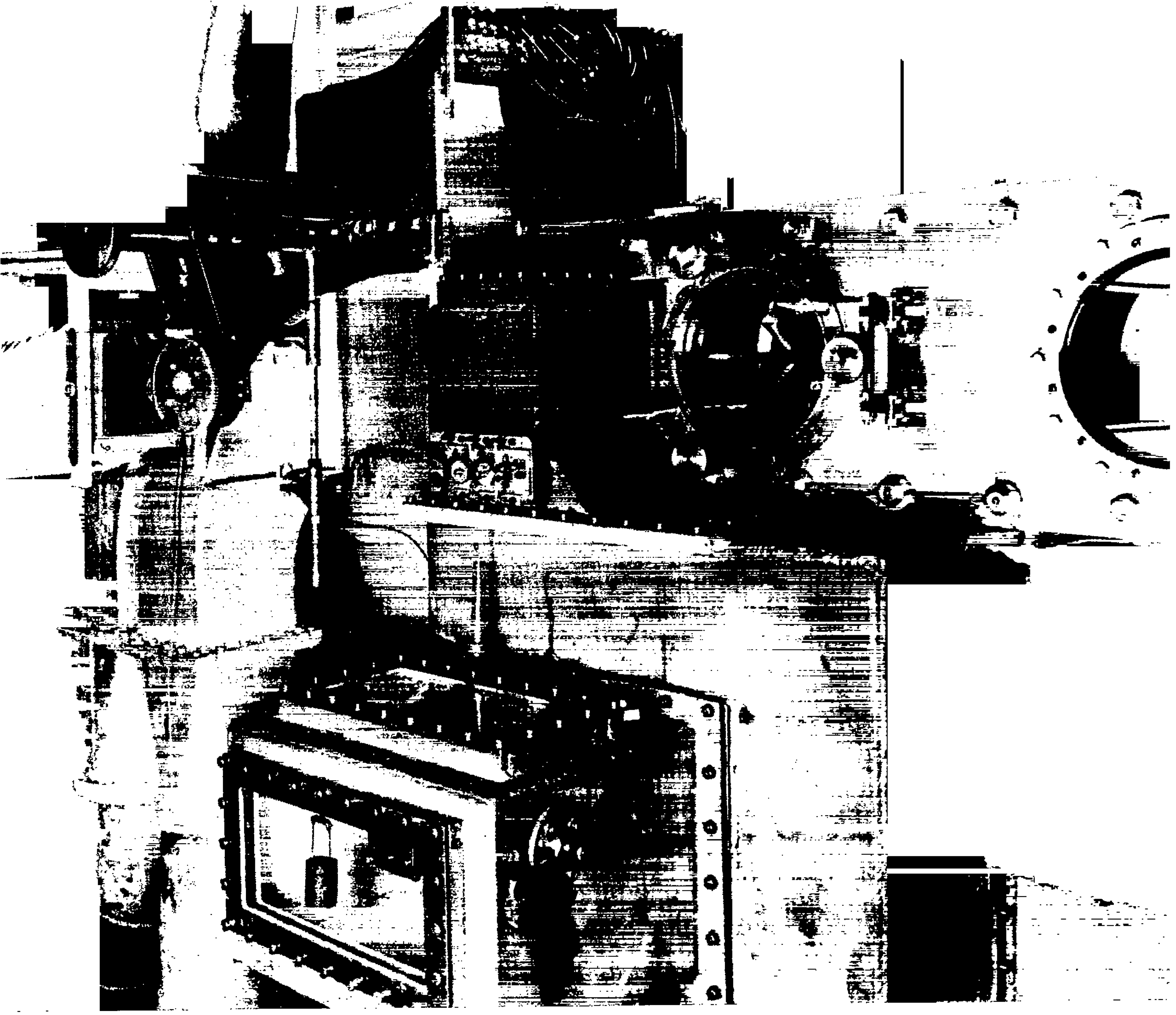
NACA Ames Aeronautical Laboratory facilities, Moffett Field, Calif.: (1) Administration Building, (2) 40- by 80-foot full-scale tunnel, (3) 16-foot high speed wind tunnel, (4) 7- by 10-foot tunnel No. 1, (5) 7- by 10-foot tunnel No. 2, (6) Flight Research Laboratory No. 2, (7) Flight Research Laboratory No. 1, (8) 12-foot low, turbulence pressure tunnel and supersonic wind tunnels, (9) Science Laboratory.



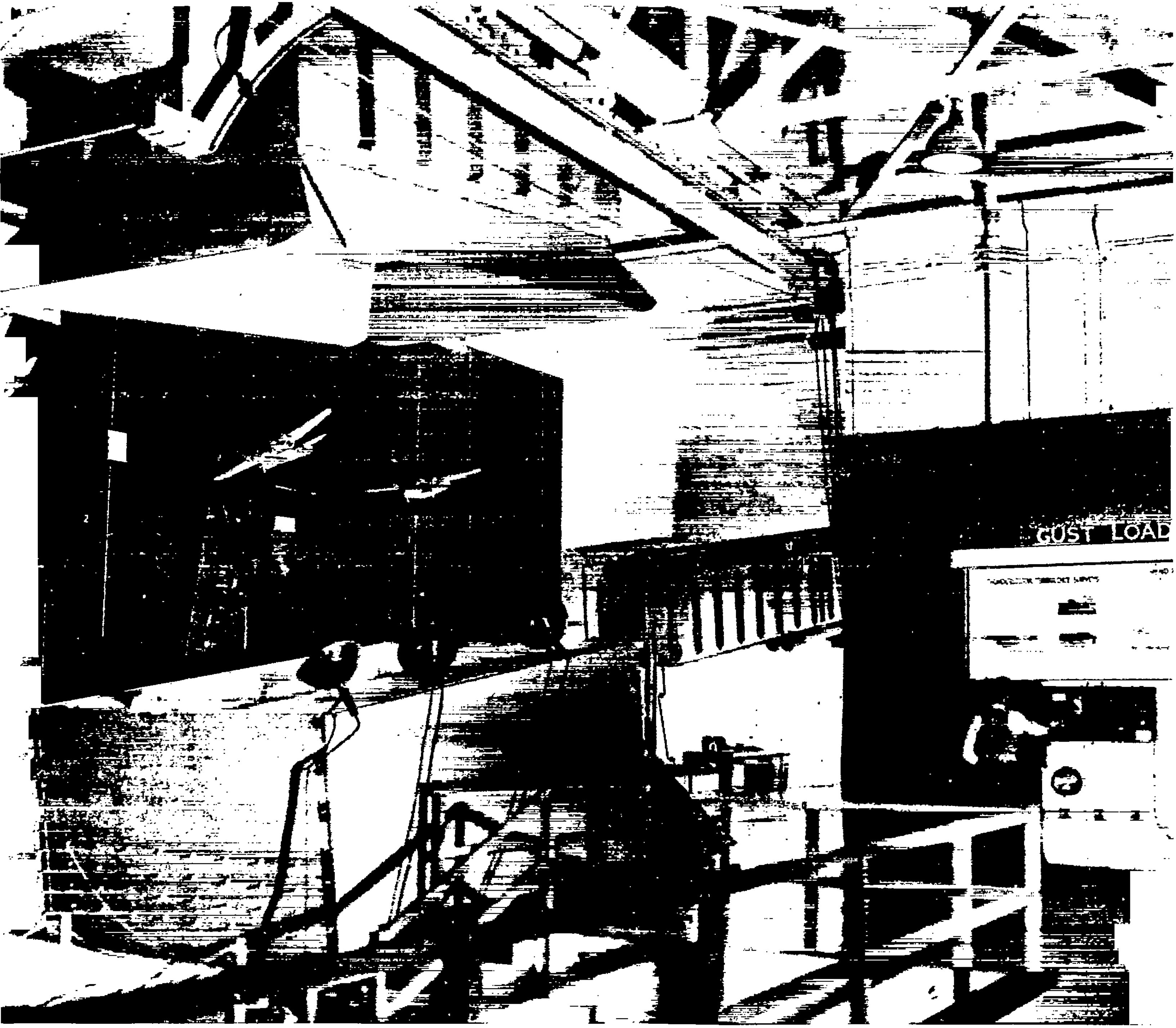
NACA Aircraft Engine Research Laboratory facilities, Cleveland, Ohio: (1) Fuels and Lubricants Laboratory, (2) Engine Research Laboratory, (3) Administration Building, (4) Flight Research Laboratory, (5) Instrument Research Laboratory, (6) Altitude Wind Tunnel, (7) Icing Research Tunnel.



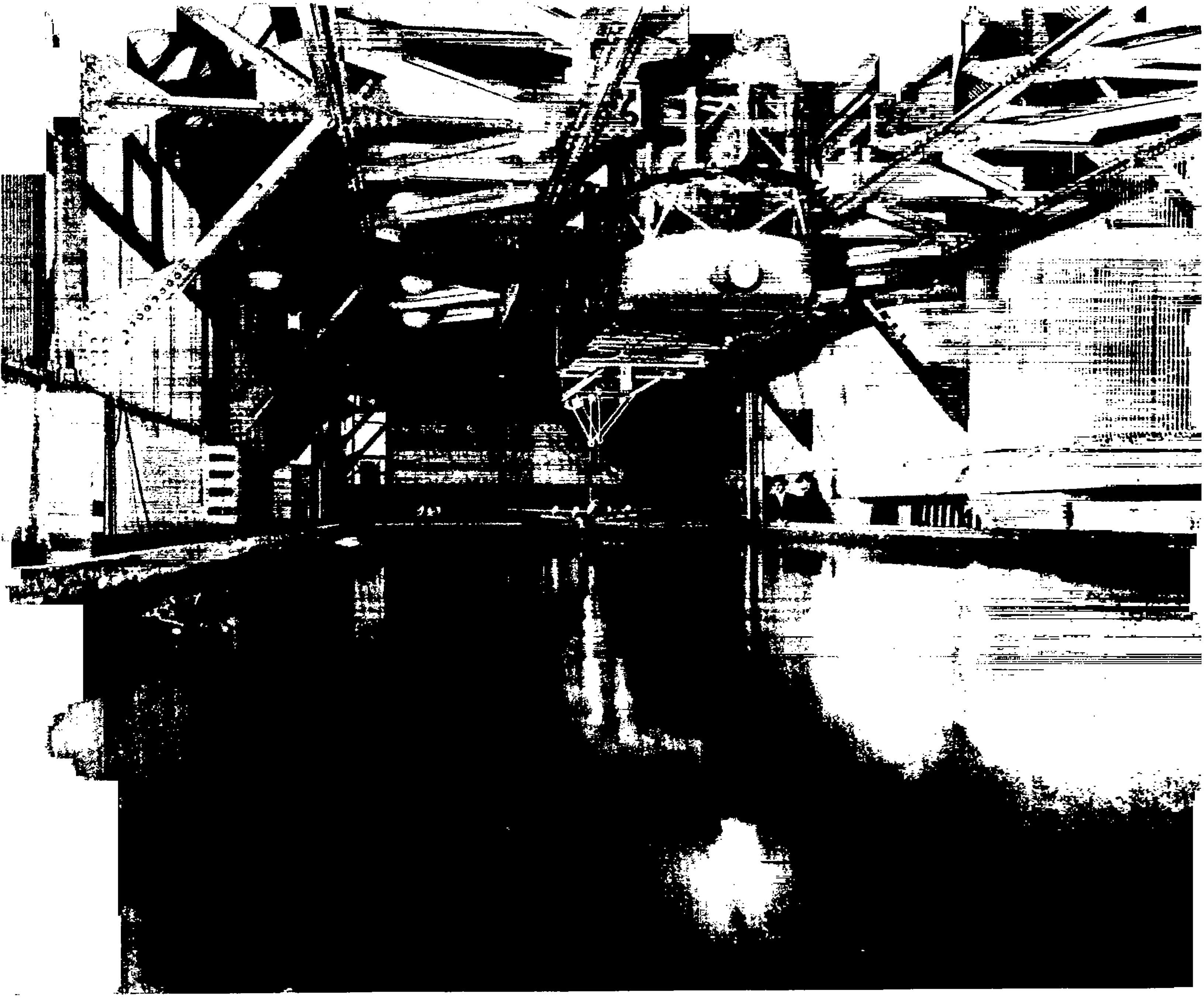
NACA Langley Memorial Aeronautical Laboratory, West Area facilities, Langley Field, Va.: (1) Instrument Research Laboratory, (2) Physical Research Laboratory, (3) 16-foot high speed tunnel, (4) Structures Research Laboratory, (5) Stability Tunnel, (6) 7- by 10-foot wind tunnels, (7) impact basin, (8) gust tunnel, (9) Aircraft Loads Calibration Laboratory, (10) Induction Aerodynamics Laboratory.



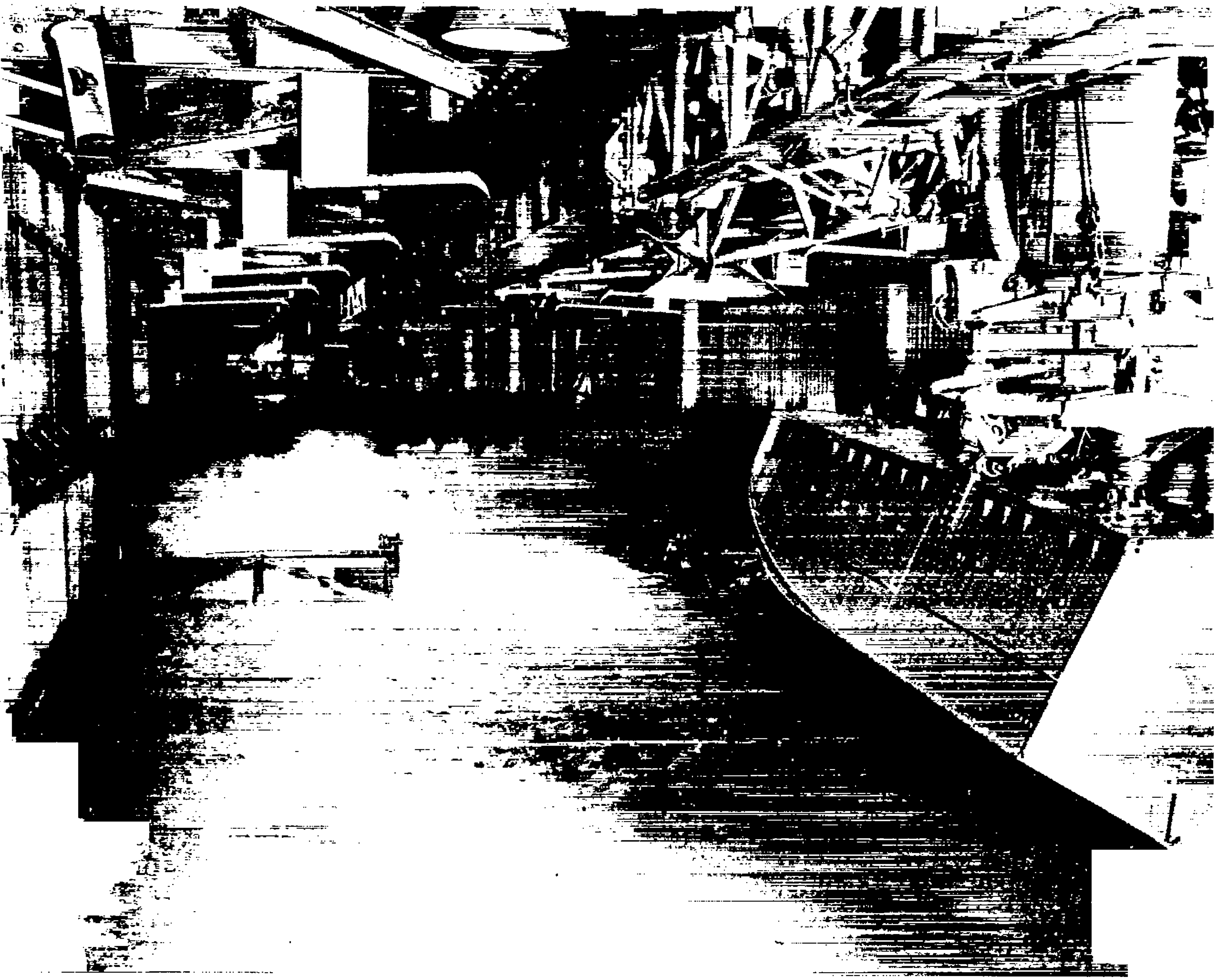
The 9-inch supersonic tunnel, built at the Langley Memorial Aeronautical Laboratory in 1942. This tunnel provides airspeeds up to Mach No. 2.5 and is used for general supersonic aerodynamics.



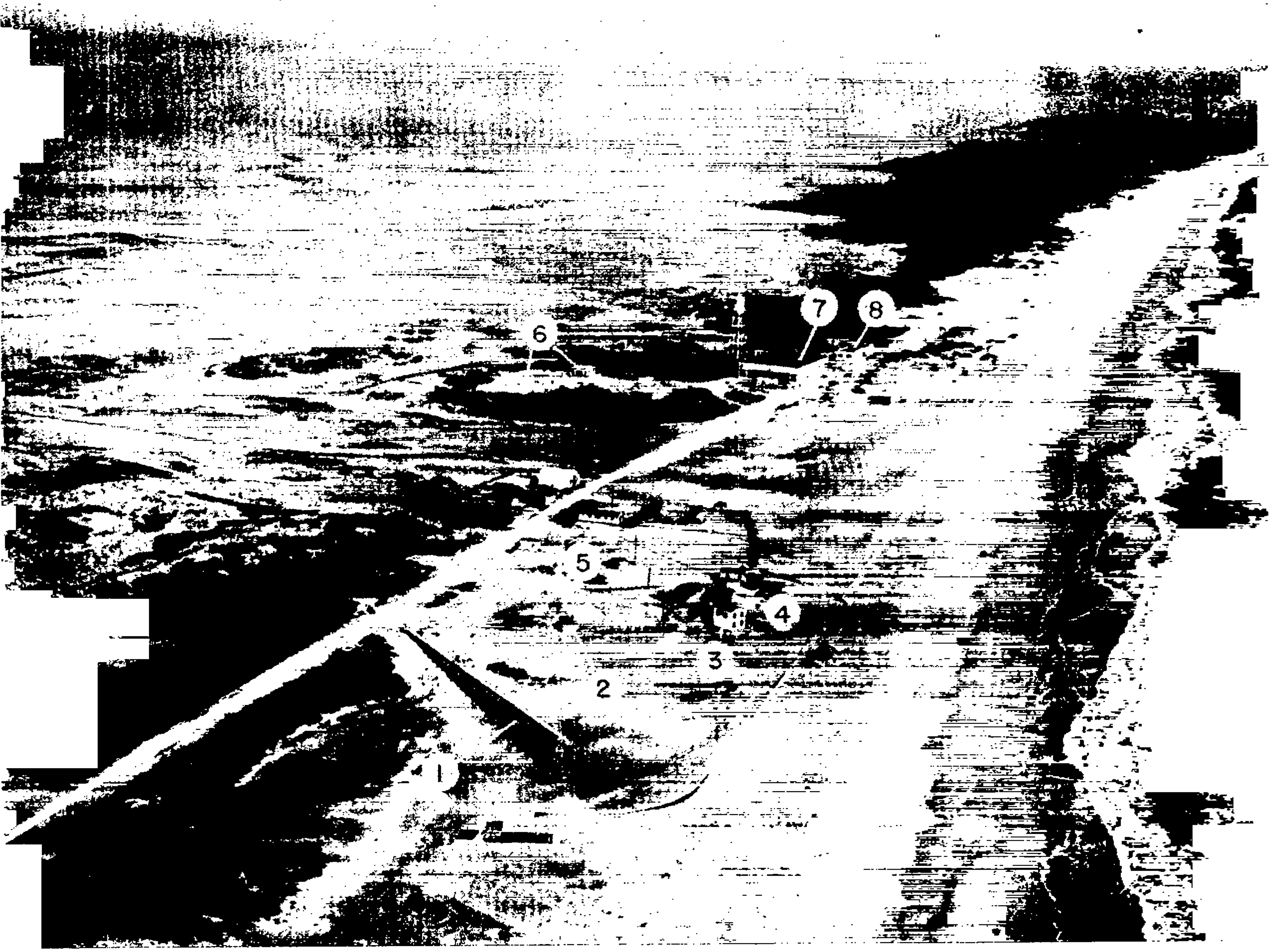
Airplane model photographed at three successive instants during its passage through an unsymmetrical gust in the Langley Gust Tunnel. This tunnel, completed in 1945, is the only facility of its kind for systematic gust load research. It has made possible accurate determination of gust loads, vital to sound design of aircraft.



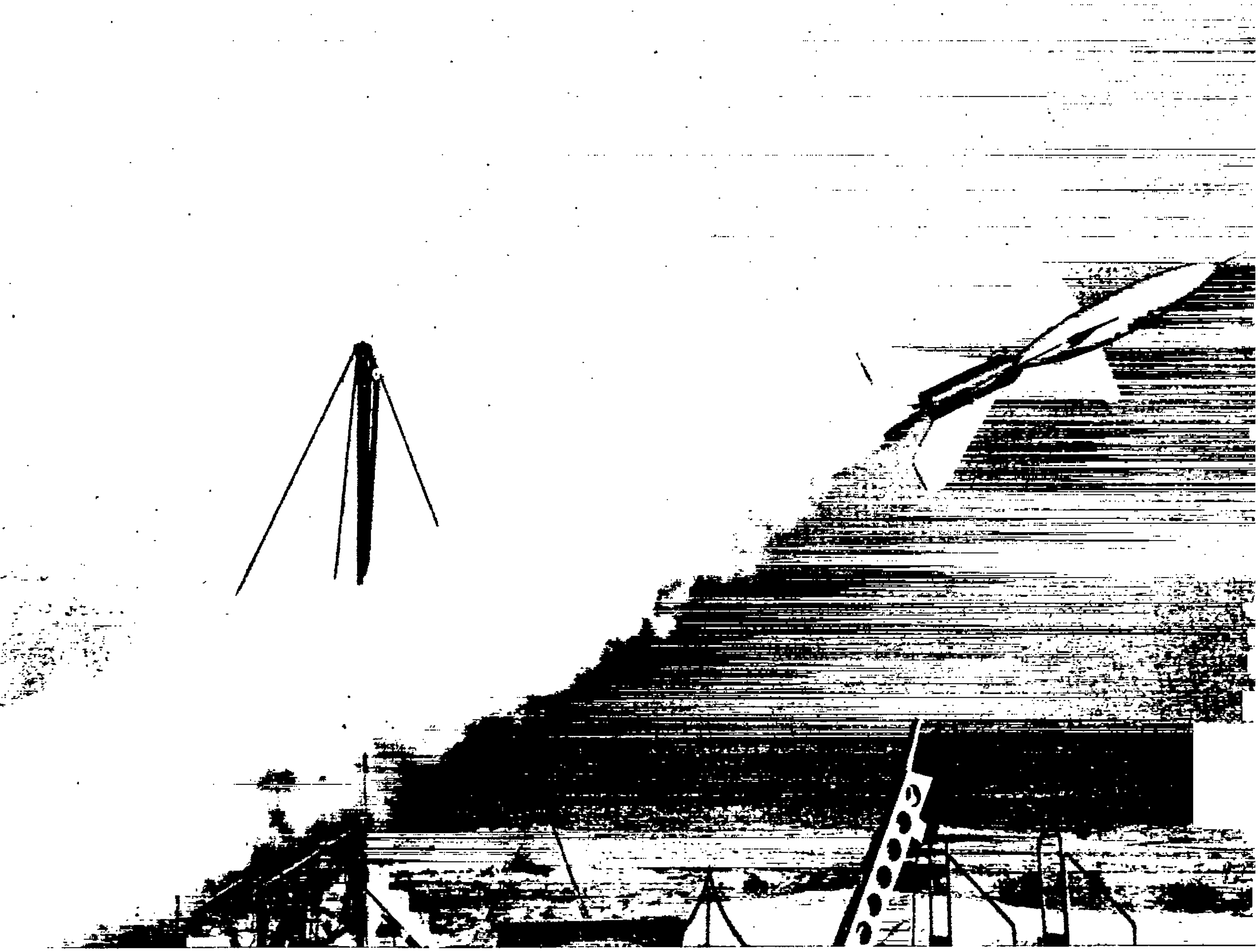
A second hydrodynamic towing tank, placed in operation at the Langley Laboratory in December 1942, provides towing speeds up to 60 miles per hour, and is used to study stability, control, and performance of flying boats, as well as ditching characteristics of landplanes.



The seaplane impact basin at the Langley Laboratory, first operated in November 1942, provides separate control of the variable factors in water landings. Picture shows wave breaking and model ready for catapulting.

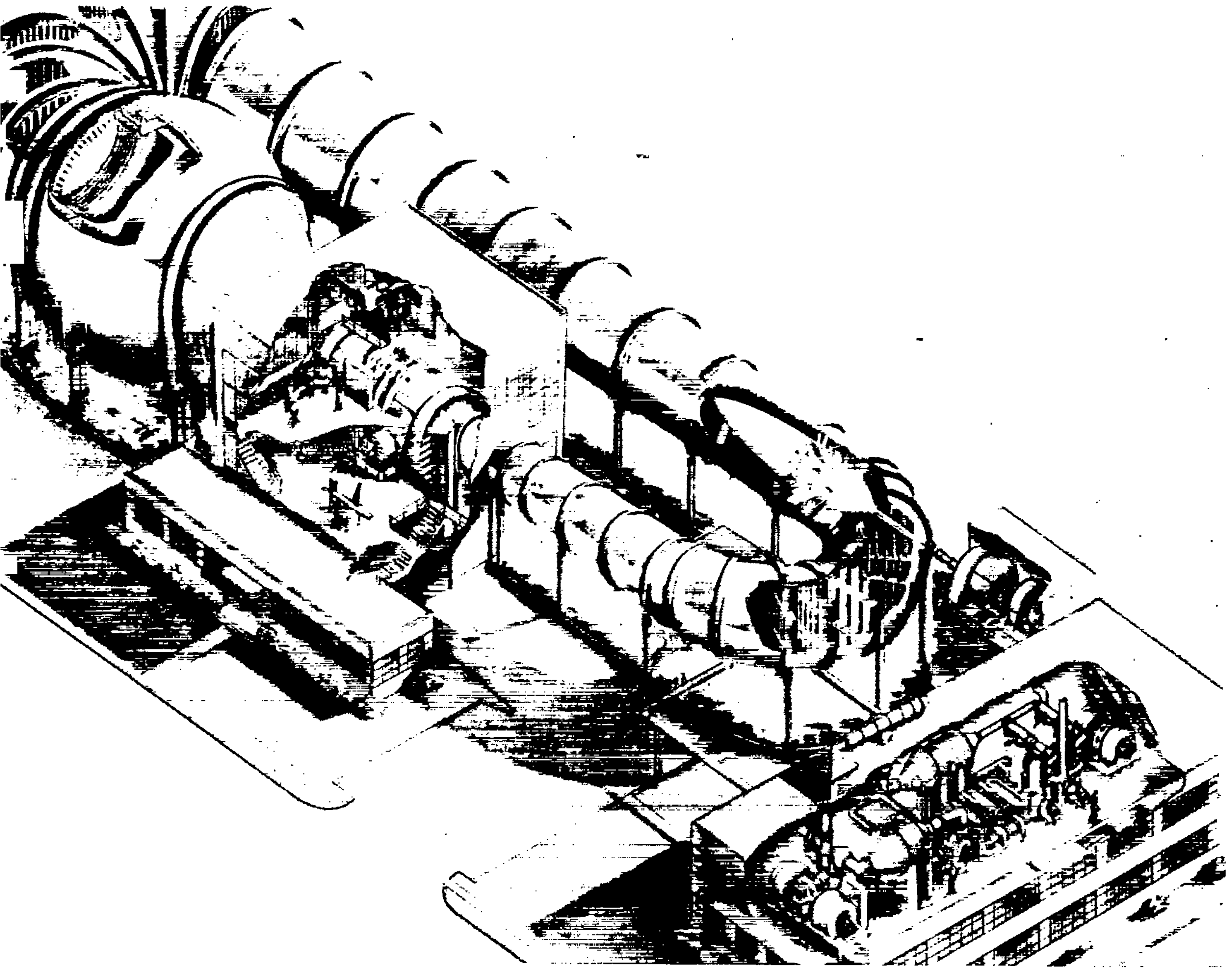


Pilotless Aircraft Research Station, a branch of the Langley Laboratory, contains the following facilities: (1) 400-foot launching ramp, (2) bombproof fire control station. (3) launching slab and shelter, (4) zero-length rail launcher, (5) final loading station, (6) preflight test slabs and control house, (7) final assembly shop and (8) office and radio building.

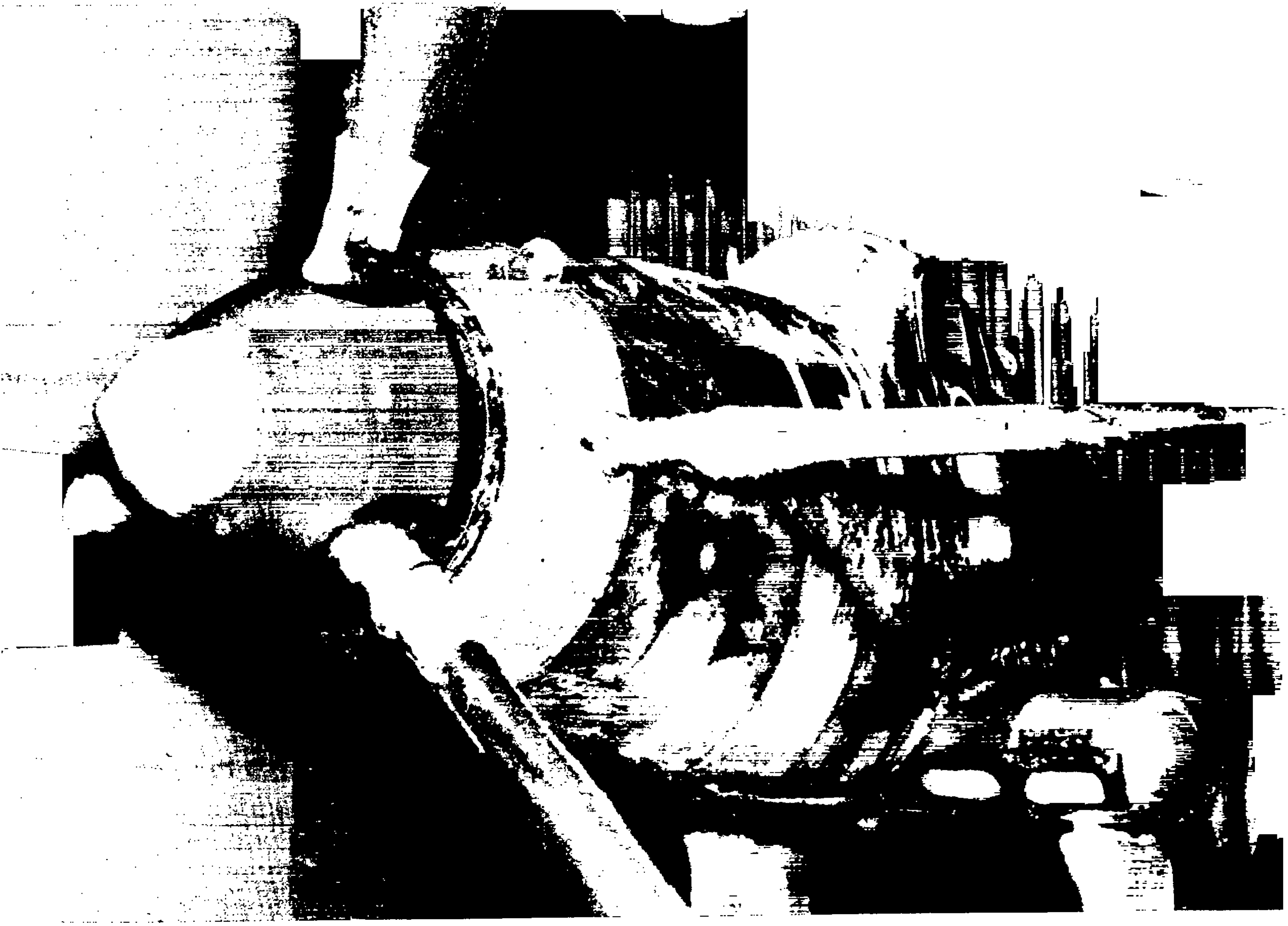


A guided research missile being launched at the Pilotless Aircraft Research Station. The use of missiles as vehicles for high speed flight research provides a new technique for obtaining fundamental high speed aerodynamic and propulsion data through the difficult transonic speed regime.

One of two 1- by 3-foot supersonic wind tunnels at the Ames Aeronautical Laboratory, first used in September 1945. They are variable density tunnels providing speeds up to Mach Nos. 2.4 and 3.4.



The 12-foot low turbulence pressure wind tunnel, completed at the Ames Aeronautical Laboratory in July 1946, provides low turbulence airflows at effective large scale by means of pressure. Speeds range up to 760 miles per hour.



A fighter airplane in the icing research tunnel showing ice formed during study of an operating propeller.

rich or at excessively lean mixtures. Several factors were found to contribute to slow burning; among these factors were poor fuel vaporization and the resulting poor mixture distribution, faulty ignition, water injection, and lack of turbulence. Among these factors, faulty ignition was found to be the most significant element contributing to backfiring. Induction-system design was found to have a marked effect on the backfiring phenomena.

GAS TURBINE ENGINES

Buckingham, in NACA Report No. 159 published in 1923, presented an analysis of the jet-propulsion system for use in propelling aircraft. His results indicated that for the flight speeds then in prospect the efficiency would be too low and the necessary equipment too heavy to make the system feasible.

In February 1939 the air-flow research staff at the Langley laboratory began a general study to investigate the possibilities of jet propulsion for aircraft. The purpose of the investigation was to reevaluate Buckingham's work, considering especially the application of jet-propulsion at speeds higher than he had considered practicable but which, at the later date, appeared attainable.

One problem that arose during this phase of the investigation was control of the combustion in the high-speed air stream in the burner. A series of combustion studies was undertaken with small-scale and full-scale apparatus to obtain combustion data for use in subsequent investigations.

The Special Committee on Jet Propulsion was established in March 1941 to guide jet-propulsion research. Under the guidance of this committee a full-scale test set-up was devised using the information obtained from the preliminary investigations and analyses, and a study was made of blower and duct characteristics as well as the action of burning. The experimental results indicated that combustion could be controlled and restricted to the desired space and that the mechanical structure was feasible for operating at the conditions required to give a reasonable efficiency at attainable flight speeds. The results were checked with theoretical calculations and were used as the basis for initial recommendations relative to jet-propulsion aircraft. Performance estimations were made for several possible airplanes with this type of power plant.

Research at the Cleveland laboratory has been devoted to investigation of the performance of typical turbojet engines. One of the principal problems was the investigation of methods of predicting performance at altitude from results of tests at ground level. Engine manufacturers lacked equipment for running tests at altitude. Flight tests could not be relied upon for providing the information because the detailed information desired required the use of extensive instrumentation not practicable for flight work and, in many cases, flight tests would have been very hazardous. The Cleveland altitude wind tunnel provided means of simulating air pressures and temperatures at altitude and made it possible to observe the effects of altitude on all component parts of the engine. Four turbojet engines had been investigated in the altitude wind tunnel. Two of the engines incorporated a double-entry centrifugal compressor and two incorporated multistage axial-flow compressors. The most significant finding of these researches was the existence of altitude limits above which combustion could not be maintained. With some designs blow-out was encountered at altitudes as low as 20,000 feet; with other designs the blow-out limit was at altitudes about 40,000 feet. The investigations proved that results of ground level tests could be used to predict the performance at altitudes below the blow-out limit. This prediction involves the use of special performance parameters derived by dimensional analysis.

The drag, or windmilling, characteristics of a "dead" turbojet engine were also investigated because the drag value must be known for the design of multiple-engine airplanes where it might be desirable or necessary to fly with one or more engines dead. The values of windmilling drag of 15 percent of the maximum net thrust at 500 miles per hour and 25 percent of the maximum net thrust at 650 miles per hour indicate that closing the inlet to the engine when the engine is inoperative in flight is desirable.

The acceleration characteristics of a turbojet engine were investigated because quick response to the throttle is essential during landing maneuvers. The engine was found to pick up speed and thrust at an undesirably low rate. If landing maneuvers were made at maximum engine speed and low thrust was obtained by means of a variable-area tail-pipe nozzle, maximum thrust could be regained almost instantly by changing the nozzle area.

Although the performance of the turbojet engine surpasses the performance of the reciprocating engine and propeller at high flight speeds, the thrust of the turbojet engine is low at the low speeds corresponding to take-off. Three methods were investigated for increasing take-off thrust: (1) Spraying coolants into the compressor inlet; (2) burning additional fuel in the tail pipe of the engine; and (3) bleeding air from the compressor discharge into an auxiliary combustion chamber from which products of combustion discharge through a nozzle.

The injection of water or other coolant into the inlet of the engine cools the air and results in higher compression pressures and increased air flow. The higher compression pressures and increased air flow, in turn, produce higher thrust and better thermal efficiency. When water was sprayed into the inlet of a turbojet engine having a centrifugal compressor, a maximum thrust increase of 35 percent was obtained. Mixtures of alcohol and water were also investigated.

The burning of additional fuel in the tail pipe of a turbojet engine increases the jet velocity in proportion to the square root of the increase in absolute temperature of the jet, and the take-off thrust increases in direct proportion to the jet velocity. Maximum jet temperatures from turbojets are limited to about 1700° F. because of temperature limitation set by turbine materials. The burning of fuel in the tail pipe avoids this limitation and the jet temperature can be raised to about 4,000° F. An experimental investigation of thrust augmentation by tail pipe burning was made in the jet propulsion static laboratory and a thrust augmentation of 40 percent was obtained by this means for the zero ram condition (take-off).

Because of the change in the discharge gas density when the tailpipe burner is operated it is necessary to provide an adjustable-area discharge nozzle for permitting change from the non-burning to the burning condition in flight. An adjustable-area nozzle was developed that showed no indication of overheating or failure during the tests. An experimental investigation of this type of nozzle indicated that it imposed no loss in thrust on the turbojet engine as compared with a conventional nozzle.

The limit imposed on jet temperatures by the turbine materials can also be obviated by bleeding air from the compressor discharge, burning it in an auxiliary combustion chamber, and discharging it as a jet that produces thrust. The deficiency of air entering the turbine can be replaced by injecting water into the combustion chamber; the volume of the generated steam replaces the air. Experiments with the turbojet engine showed that a 66 percent increase in thrust could be obtained with a total liquid consumption of 8.9 pounds per hour per pound of thrust.

RESEARCH ON RAMJET ENGINES

Steady Flow Ramjet

A theoretical investigation of the performance of the ramjet engine was undertaken to determine the interrelation of the pertinent fundamental variables. On the basis of the theory, a series of performance parameters was chosen for presentation and correlation of the experimental data. The investigation of a 20-inch ramjet engine in the altitude wind tunnel confirmed the theoretical trends and provided experimental data for a ramjet engine at altitudes up to 47,000 feet and equivalent flight Mach numbers up to 1.84. By comparison of the experimental thrust coefficients of the ramjet engine with corresponding drag coefficients obtained in supersonic wind tunnels, the feasibility of the ramjet engine as a power plant for supersonic aircraft was established.

During the course of the research, a systematic study of the various engine components was undertaken. An extended investigation of flame holders produced several burners that would allow the ramjet to operate at altitude and at high Mach numbers.

Experiments were also conducted to determine the increase in the combustion efficiency that might be achieved by the use of preheated fuel. When the transition was made from unheated to preheated fuel, the long yellow flame of the exit jet shortened and became a pale blue. Simultaneously, the operation of the engine was less erratic and the combustion efficiency improved by about 10 percent. Concomitant increases were obtained in the temperature ratio across the unit, the over-all efficiency, and the net thrust.

Further research showed that there was sufficient heat rejected to the shell of the ramjet engine to preheat the fuel. An automatic system was devised to combine the operation of fuel preheating and shell cooling. On the 20-inch ramjet engine, the heat rejected to the shell amounted to about 0.2 percent of the total heat released by the combustion process per foot of combustion chamber and nozzle length.

Experiments undertaken to determine the feasibility of the two-dimensional ramjet indicated uniform, smooth combustion and quite satisfactory operation.

Intermittent Flow Ramjet

The pulse-jet engine in the form introduced by the Germans as the propulsive unit for the V–1 bomb is severely limited by its performance and operating life. An analysis of the ideal processes involved in the operating cycle of the pulse-jet engine was made, and the results showed that the German engine operates substantially below its theoretical performance. A study of the mechanism of combustion occurring within the pulse-jet engine was made on a model equipped with a glass window through which high speed photographic records of the flow and combustion processes were taken. Various methods of controlling the combustion process to obtain a working cycle more closely approaching the idealized cycle were investigated. The motion of the pressure waves within the combustion chamber, as photographed during operation, qualitatively agree with the recently advanced wave theory of the operation of the engine. Low-loss inlet-air valves and intermittent fuel injection into the combustion chamber were investigated.

Thrust stand investigations were conducted on a replica of the German pulse-jet engine with several valve modifications to determine sea level performance at simulated airspeeds of 0, 190, 280, and 340 miles per hour.

ROCKET ENGINE RESEARCH

The chief problems of the rocket power plant, as analyzed, were found to be: (1) To obtain high thrust for low weight flow and low volume flow of propellant in order to increase range and pay load; (2) to increase combustion chamber and nozzle life; and (3) to achieve ease and safety of operation and control. Virtually the entire effort in rocket research at the Cleveland laboratory was directed toward finding propellants capable of giving high specific impulse and devising ways in which to use the high energy reactions without burning the combustion chamber and nozzle.

The study of high performance propellants was initiated with a complete survey of those reactions capable of highest energy release. Because high energy release means high temperatures and therefore dissociation, subsequent computations of theoretical performance of propellant systems utilized thermal data and equilibrium constants. Graphical aids for these computations were devised. An investigation was then started to evaluate the performance of propellants and to find ways of approaching experimentally the optimum theoretical performance. Another investigation was a study of the ignition characteristics of propellants. A short ignition lag is desired because of the attendant hazard that occurs when unignited propellant accumulates in a motor and then ignites. Two lines of attack were followed in experiments directed at seeking ways and means of cooling the inner walls of the rocket chamber and nozzle.

ENGINE INSTALLATIONS

Reciprocating Engine Installations

An investigation was conducted in the altitude wind tunnel to evaluate the effect on engine cooling and nacelle drag of several modifications to the cowling of a four-engine heavy bomber. The substitution of a 43-inch-diameter cowl inlet for the original 38.5- by 35-inch oval inlet reduced the cooling drag by an amount equivalent to a saving of about 60 horsepower per engine at cruising power at an altitude of 15,000 feet and an indicated airspeed of 190 miles per hour. Modified cowl-exit flaps on a slightly enlarged cowl afterbody caused a further drag reduction equivalent to about 35 horsepower per engine under the same conditions. Engine cooling baffles modified to direct more air to the region of the rear-row cylinder exhaust ports were found to appreciably reduce the temperatures of the rear spark-plug gaskets, rear spark-plug bosses, and the exhaust valve seats of rear row cylinders.

A study was also made in the altitude wind tunnel of the installation in a torpedo bomber of a 28-cylinder air-cooled engine with a dual-rotation propeller. Low pressure recoveries at the face of the engine were found to be caused by propeller interference. At high angles of attack the air flow into the upper half of the cowling was further blocked by the long spinner.

A flight investigation was conducted to determine the cruising performance of a four-engine heavy bomber when equipped with engines modified by the incorporation of the NACA fuel-injection supercharger impeller and ducted head baffles. The use of the NACA injection impeller reduced the spread of fuel-air ratios among the cylinders to less than one-half its original value. The temperatures of the exhaust-valve seats were reduced approximately 50° F. by the ducted head baffles. Analysis of the flight data indicated that the cooling improvements allowed either an increase of more than 10,000 feet in operating altitude at a given airplane weight or a gross weight increase of from 10,000 pounds at sea level to 35,000 pounds at all operating altitudes above 10,000 feet.

Turbojet Engine Installations

A revised nacelle configuration for a two-engine turbojet-propelled fighter airplane was compared in the altitude wind tunnel with the original configuration. The revised boundary-layer removal duct was found to reduce the boundary layer in the plane of the nacelle inlets approximately 60 percent at the high speed of the airplane. Use of the revised nacelle inlet and boundary-layer removal duct increased the total pressure recovery at the compressor inlets approximately 16 percent over the pressure recovery with the original configuration. A revised cooling-air seal reduced the quantity of cooling air approximately 75 percent without causing excessive nacelle temperatures.

The power plant installation of a single-engine turbojet-propelled fighter airplane was investigated in the altitude wind tunnel. The losses in the induction system were evaluated over a wide range of altitudes and ram ratios, and data were obtained on the engine performance and operational characteristics.

Ejector Cooling

An investigation was conducted on a single-cylinder engine to provide criteria for designing an exhaust ejector cooling system. The effectiveness of exhaust ejector systems as a means of increasing the cooling air flow through air-cooled engines has been studied in flight on a twin-engine airplane. The investigation was conducted to permit a direct comparison between the engine cooling provided by the ejector installation and that provided by the conventional installation. It was found that at low speeds, where the cooling with the conventional installation was insufficient, large increases in cooling air flow were obtained by use of the ejectors. Slight increases in cooling-air flow were also obtained at high speeds.

High-Altitude Cooling

The increase in altitude of aircraft operation during the war introduced additional problems in the cooling of air-cooled engines. The problems are a result principally of the low density of the air at high altitude, which increases the cooling-air pressure drop required for cooling and at the same time decreases the available pressure drop.

In order to obtain information on the cooling characteristics of air-cooled engines at altitude conditions and, in particular, to check existing methods of extrapolating the data obtained from sea-level or low-altitude cooling tests to high-altitude conditions, a flight cooling investigation was conducted on an 18-cylinder, twin-row radial, air-cooled engine installed in a high-performance pursuit airplane. The investigation consisted of flights at variable engine and flight operating conditions at altitudes ranging from 5,000 to 35,000 feet. The cooling data obtained were correlated by the previously developed cooling-correlation method, modified to account for compressibility effects. The satisfactory correlation of the data obtained, irrespective of altitude, indicated that sea-level tests may be used to predict cooling at altitude when the test results are plotted in accordance with the correlation method.

A flight investigation of the cooling performance of a two-row radial aircraft engine in a twin-engine medium bomber revealed that the temperature-distribution patterns among the cylinders are determined chiefly by fuel-air ratio and cooling-air distribution. The cooling-air distribution was, however, appreciably affected by airplane flight conditions. Satisfactory correlation of the cooling variables was obtained at both low and medium altitudes. Analysis of the correlation equation indicated that cooling performance at medium altitudes (20,000 ft.) may be predicted with sufficient accuracy by use of the low-altitude correlation equations.

ENGINE AUXILIARIES AND CONTROLS

Reciprocating Engines

Fuel and air metering. Fuel and air metering were the first control functions to receive attention at the Cleveland laboratory. Research in fuel metering consisted of investigations of the mass air-flow metering-control system and the engine parameter-type metering-control system. Considerable improvement in fuel distribution was achieved by the use of the supercharger impeller to distribute the fuel and by means of an improved carburetor spray bar.

Ignition and ignition systems. Investigations of ignition and ignition systems included means of reducing lead fouling of spark plugs and the effect of variable ignition conditions on combustion in reciprocating engines. Several methods were found of alleviating lead fouling in reciprocating engines.

Gas Turbine Engines

Turbojet-engine controls. Control requirements of the basic turbojet engine with direct-coupled compressor and turbine and with fixed exhaust nozzle area were analyzed. This analysis resulted in the selection of parameters suitable for engine control during steady-state operation, acceleration, and deceleration, as dictated by engine requirements and limitations. Restricted control possibilities of the basic turbojet engine indicate that additional controllable variables, such as variable exhaust nozzle area and throttled inlet, may provide information to improve both engine control and performance.

Fuel systems. Methods of improving the fuel distribution to burners were investigated. New methods evolved indicate that variations in fuel distribution may be reduced to approximately 1.5 percent. New methods also indicate the feasibility of a low pressure fuel system with its attendant advantages.

AIRCRAFT CONSTRUCTION AND MATERIALS

THE Committee's program relating to aircraft construction and materials has centered around the work of the Structures Research Division at Langley Field and a considerable number of research contracts with educational and other non-profit organizations. In the past year and a half, however, materials programs initiated at the Cleveland laboratory have shown promise of being sufficiently fundamental to be applicable to airframe materials as well as power plant materials. Because Cleveland's work is directed toward power plant problems it is not included herein but is outlined under the section on Propulsion Systems.

For the sake of presenting the various parts of this program in an orderly fashion, it will be divided into three sections; one on aircraft structures, one on wood and plastics, and one on structural metals.

AIRCRAFT STRUCTURES

Although the stressed-skin type of airplane structure was used as early as the first world war and became the dominant type about 1930, research on this type of structure was carried on sporadically in all countries until about 1935. At that time several research men in the NACA started to work on structural problems and it was this group that formed the nucleus of the present staff of the Structures Research Division at Langley Field. In 1939, Congress appropriated funds for the construction of a structures laboratory building; in October 1940 the building was sufficiently completed for the staff to move in. The first major item of research equipment was put into operation in January 1942. The expansion of the structures research staff paralleled the expansion of the research facilities.

The fruits of structures research are not so obvious to the eye as those of some other types of research because they are not often in the form of radically new shapes or devices. The two main benefits for wartime purposes may be classified as:

(a) Increased performance of the airplane.

(b) Reduction of delays in production.

The increased performance arises from the saving in weight that is made possible by better structural design. This saving in structural weight can be translated into higher rate of climb, greater radius of action (by increasing the amount of fuel carried), more powerful armament, or better protection in the form of armor or bulletproof fuel tanks.

The second benefit is perhaps even less obvious. In peacetime it was universal practice to build one example of an airplane for static testing, and plans for production were not made in detail until the static test had proven the airplane satisfactory. This procedure was dictated by economics; the strength calculation was not sufficiently reliable, and an unstatisfactory strength test might entail a major redesign and thus annul all previous production planning. The large-scale production in wartime made production planning a major task requiring many months. In order to avoid delays it became the custom to start production planning in the early stages of design, and the static test was made on the first or second airplane off the production line. If this test showed structural weaknesses, the production line would have to be held up and retooled. Delays of this nature are reduced by structural research which provides data for more accurate initial design. The importance of delays in production in wartime is too well known to require comment.

Skin-stiffened Panels

The largest single item of research in the Structures Research Division during the war period was on the strength of skin-stiffened panels. Such panels are the most important element of the airplane structure, at least as far as total weight is concerned. In the past, designers have usually tested panels for each individual design. The scope of these individual tests, however, was insufficient to draw general conclusions. A broad program was therefore instituted to cover the entire design range. Theoretical work had been carried on for several years, but the theory alone was inadequate over a large and important portion of the range. Consequently, while the theoretical work was being expanded, a comprehensive test program was carried out. The results were disseminated to the industry as soon as they were obtained. The results of the entire program were combined into a set of design charts which practically eliminates any need for future individual testing. Even more important perhaps is the fact that a method of design has been developed, based on these charts, which makes it possible to find the best design for any specified condition, whereas in the past the designer had no method for finding out how close his design was to being the best possible one.

The panel program just described was carried out first for Z-section stiffeners, the most commonly used type. It was generally believed, however, that closed-section (hat section) stiffeners were more efficient structurally although they are not nearly so widely employed because of difficulties in construction and maintenance. In the design of very long-range bombers intended for the Pacific war (B-35 and B-36), structural efficiency was so important that it was decided to use hat-section stiffeners. At the request of the Army Air Forces, the Structures Laboratory therefore conducted tests on about 800 panels with hat stiffeners to cover the design range for the airplanes involved. The panels for the B-36 program—about 700—were constructed by the Consolidated Aircraft Co., designers of the airplane, and the test results were transmitted to the company in daily reports. A similar, although much smaller, program was carried out for the Northrop B-35, for which the panels were built by the Martin Aircraft Co. which was carrying out the production design of the airplane.

Flush Rivets

Some time before the war, early work on panels had brought up the question of riveting. The aerodynamics division of the NACA had just developed the now well-known laminar-flow airfoils, which promised large gains in speed. However, the advantages from these airfoils could not be realized unless the surfaces were perfectly smooth; conventional rivets robbed the airfoils of most, if not all, of their advantages. In order to solve the problem of smooth airfoil surfaces, a new technique for flush riveting was developed. The most important feature of the process was that the countersunk head was intentionally formed so as to leave some excess material above the surface; the excess was then removed with a specially developed hand milling tool. The final finishing operation, either polishing or painting, left the surface in a high degree of aerodynamic perfection.

Although this riveting technique was originally devised in order to insure aerodynamically smooth surfaces, it was found to give also an important structural advantage; it produced tighter rivets than any other technique. This is an important factor wherever rivets are subjected to vibration or repeated loading, because initial looseness will rapidly become worse under such conditions. This riveting technique, in a modified form, is now in use on several high speed aircraft. A considerable amount of work was also done to provide design data on more conventional rivets as well as on rivets for special work, such as blind rivets for repair work or for use in inaccessible places.

Effect of Structural Rigidity on Aerodynamic Smoothness

Aerodynamic smoothness of the wing surfaces required not only special riveting techniques, but improved construction techniques. The conventional thin skin buckled too easily under load, and the skin of the wing showed the ribs and other internal structure sticking out. This condition had to be remedied by modifying the conventional structure, and a number of tests were made on various proposed types of structure. Sample wing sections were subjected to load, and careful observations were made of their deformations. Some of the sample wings were first tested in the wind tunnel to measure their drag, then subjected to loads representing the highest loads expected in flight, and finally tested again in the wind tunnel to determine whether the permanent deformations left were serious enough to increase the drag. Part of this work was done at the request of the armed forces on specimens representing actual proposed airplane designs and built by the company in question. This investigation and that on skin-stiffened panels has shown that over a wide range of design conditions the maintenance of buckle-free surfaces on longitudinally stiffened compression panels does not conflict with the achievement of high structural efficiency and lowest possible weight.

New and Improved Theories for Stress Analysis

The theoretical demonstration that a newly designed structure has the required strength is furnished by the stress analysis. This analysis is intended to prove that the bending and twisting loads imposed on the airplane in flight or in landing do not cause, anywhere in the structure, stress large enough to cause failures. The accuracy of the proof depends, of course, on the accuracy of the theories used. Conventional theory of strength of structures is confined in general to simple structures such as plates, shafts, beams and trusses. Much more advanced theories are necessary to deal with the stresses in the complex reinforced shell structure of an airplane. Before the war, only a beginning had been made in the development of such theories, and much of what was available was too complicated for everyday use. During the war period, considerable progress was made in developing additional theories and in improving the accuracy and ease of application of the theories. One important example is the so-called shear-lag theory which deals with the bending stresses in a wing. The usefulness of this theory was well illustrated in the redesign of one of the leading fighter airplanes of the war. The static test made by the company showed that the conventional theory was in error by 15 percent, the shear-lag theory by 2 percent. A 15-percent error would call for a substantial change in design, upsetting the production schedule; a 2-percent error would cause little, if any trouble in adjusting the production methods. Other theories were developed for the torsion action of wings, which became a very important problem during the war because the flying and diving speeds of all airplanes were greatly increased over those of pre-war airplanes. Simple methods were developed for calculating the stresses around cut-outs such as bomb-doors, escape hatches, gas-tank installation doors, and wheel wells. Convenient design methods were found for diagonal tension girders; that is, girders with very thin webs which are typical of aircraft construction. In addition to the work on all these theories and formulas dealing with major structural items, there was, of course, a considerable amount of work dealing with items which are small individually but together are responsible for an important portion of the total design work on an airplane.

Evaluation of Structural Materials

Under the spur of the war, manufacturers accelerated their research work to produce stronger materials or to improve the strength of existing materials by new methods of heat-treating. If advantage was to be taken of these improvements, the designer had to be provided as quickly as possible with the necessary structural design data such as tensile strength, compressive strength, and column strength of these materials. The NACA developed techniques for quickly determining these properties, and considerable effort was devoted to evaluating the properties of new and improved materials by these methods. Closely related to this was the extensive and systematic work carried out on local buckling of stiffeners. Work on this subject had previously consumed a large portion of the working effort of manufacturers' research departments without giving commensurate benefits, because no single manufacturer could afford to cover the entire design range systematically.

Ditching

The largest amount of specific testing was carried out in connection with the ditching problem. Bombers returning from missions in Europe and later in the Pacific were often forced by combat damage to land on the ocean. When such a landing was successfully made, there was a very good chance of saving the crew. Unfortunately, the landing was often unsuccessful. The problem of how to increase the percentage of successful landings was so important that it was attacked simultaneouly by a number of organizations. Within the frame of a multisided NACA program, the Structures Division investigated the structural phase by subjecting several bomber fuselages (B–17, B–24, B–25) to loads simulating the water loads experienced in a ditching. These tests furnished one criterion for determining whether the great differences in the ditching characteristics of these airplanes were primarily caused by difference in structural strength or by difference in hydrodynamic and aerodynamic properties of the airplane.

WOOD AND PLASTICS

NACA wartime research in the field of wood and plastics has been concentrated chiefly upon materials of this type which appear to have promise in structural and semistructural applications. These materials include natural and compressed wood, plywood, laminated plastics, transparent plastics and adhesives.

Adhesion and Its Application to the Bonding of Structural Components

Adhesion is a basic and important problem in wood and plastics construction, since adhesives are used in the laminating and bonding of all these materials. In addition, adhesives are employed for bonding plastics and wood to metals and in bonding metals to metals. A considerable amount of NACA research has, therefore, been devoted to evaluation of the natural forces and concepts involved in adhesives. Research has shown that the use of adhesives in the fabrication of certain types of aircraft structures, such as sheet stringer panels, can result in a marked increased in the strength and at the same time a saving in production time and costs. Adhesives are, therefore, being employed for regular production use in the assembly of some types of aircraft components.

Research has also been carried out on the effects of acidity or alkalinity on the strength and durability of adhesive bonds and plywood. Investigations have been conducted on the effects of high and low temperatures on the bonding strengths of synthetic resins. These latter investigations are pertinent in view of the wide range of temperatures in which aircraft operate. Programs have also been conducted to determine the thermal expansion of the various types of wood and plastic materials in order that these materials could be more intelligently utilized in the design of structural parts.

The NACA has sponsored a basic study of the curing of resin glue bonds in laminated wood construction. This study has found application in the curing of adhesive bonds through the use of high-frequency electrical heating. This process is now employed in the gluing of laminated wood spars and in other wood structural members used in the construction of light airplanes.

Laminated Plastics

A series of investigations have been carried out to evaluate the strength characteristics of laminated plastics in which glass fabrics are employed as the reinforcing materials. The data thus obtained include static and impact strengths at normal, high and low temperatures, fatigue strengths and creep characteristics. The results of this research have shown those materials which are generally superior to the more common laminated plastics. An indication of the extent of wartime application of this type of laminated plastic is seen in the example of the North American B–25 medium bomber, in which about 800 pounds of these materials are employed.

Sandwich Materials

Sandwich materials, so-called because they consist of thin gage faces of a high strength material bonded by a resin adhesive to a much thicker low-density core material, are of considerable interest for use in aircraft structures because of their high strength-to-weight ratios. The development and application of sandwich materials has been impeded somewhat by the lack of a satisfactory low density core material. An investigation of this problem was undertaken and resulted in the development of a very promising paper-base honeycomb material. Current production applications wherein sandwich materials are used include radar housings and radar antenna housings in both Army and Navy installations.

Wood and Plastic Structural Properties

Some work has been directed toward the solution of problems surrounding the use of wood and wood products. Investigations have been performed on the compressive strength characteristics of stiffened plywood panels and this project resulted in the formation of a new concept for explaining the failure of these panels under compressive stress.

Investigations have been conducted on the factors affecting the strength properties of plastics when fabricated as finished molded parts, as compared to those strength properties of the same materials but fabricated in the form of standard test specimens.

Fairing Compounds

Airplane wings incorporating NACA low-drag airfoil sections must be carefully built to have smooth, faired surfaces which accurately follow the airfoil profile in order to realize the low-drag characteristics of these airfoils. Plastic materials are employed to fill in depressions in wing surfaces around rivets, gaps between the metal skin sheets, and small waves in the skin which occur in the course of manufacture. These plastic fairing compounds must be easy to apply, must not become brittle at low temperatures, must adhere to the metal wing surfaces, and must resist vibration. Research conducted on fairing compounds resulted in the development of new compositions which are superior to generally available commercial materials.

Windshield Installations

Aircraft windshields are designed to carry steady airloads and in addition they must absorb impacts of various magnitudes while in flight. Investigations have been conducted on plastic mountings for the installation of windshields in order to increase their flexibility and strength.

STRUCTURAL METALS

The majority of the work in the field of structural metals, as in the case of wood and plastics, has been carried out through the medium of research contracts with educational and other non-profit organizations.

Spot Welding

In the fall of 1940, the Army Air Forces, the Bureau of Aeronautics, and the NACA entered into a cooperative program of spot welding research. This program was under the surveillance of a special subcommittee which acted in an advisory capacity to this and other projects on welding research as applied to aircraft. The results of this investigation include reports on the spot welding of dissimilar aluminum alloys, spot welding of multiple thickness combinations of sheet alloys, the effects of cold working on spot welds in aluminum alloys, various heat treatments as applied to spot welds in the welding machine, and the effects of surface treatments on spot weld efficiency. This information was distributed to the aircraft industry at a time when it was vitally important because of the many problems that were encountered in the construction of military aircraft.

Effects of Corrosion

Another cooperative program sponsored by the Army Air Forces, the Bureau of Aeronautics and the NACA was that on the effects of salt water and atmospheric exposure on the corrosion rate of aircraft structural alloys. This program was quite extensive and even included the testing of some of the spot welded panels prepared under the spot welding program. Not only was the corrosion susceptibility of many alloys tested but protective coatings used on these alloys were also evaluated. This work proved particularly valuable in preparing specifications for the protection and care of aircraft used in the South Pacific and on aircraft carriers.

Improved Metals

Some development work was sponsored on aluminum and magnesium alloys for use at high temperatures and under specialized conditions. These alloys were of interest to the designers of both reciprocating engines and gas turbines.

In addition to the development of new alloys, it was found that there was need for considerable information on the properties of existing alloys. Therefore, a program of evaluation of these alloys was conducted.

Numerous other properties of structural metals were investigated. These properties included impact strength and sensitivity to stress concentrations. The effect of electro polishing was also investigated, as was the influence of the rate of deformation on the properties of these alloys. More recently, programs on the plastic flow and deformation of metals have been initiated in order to provide a more thorough understanding of the nature of fracture of metals under combined stresses.

OPERATING PROBLEMS

The chief problems of aircraft operations which have required research during the war years are icing, gust loads produced by atmospheric turbulence, and landing loads. The latter problem includes both normal ground landings and emergency water landings of landplanes, known popularly as "ditching." Lightning hazards to aircraft have also been the subject of study. However, metal aircraft are not seriously affected by lightning, and therefore the research in this field was devoted to a study of the effects of lightning on non-conducting composite structures and on wood aircraft brought into use during the war.

These branches of research are handled by the Committee on Operating Problems and its three subcommittees: the Subcommittee on De-Icing Problems, the Subcommittee on Meteorological Problems and the Subcommittee on Lightning Hazards to Aircraft. The Committee on Operating Problems was organized in 1942 and during the war its work was devoted largely to research on aircraft icing. However, numerous other problems were reviewed and many items of research were guided by this committee in all three NACA laboratories.

ICING RESEARCH

Icing is one of the most serious hazards to the safety of flight and thus is a major problem in the operation of both military and commercial airplanes. NACA research on aircraft icing has been expanded considerably during the past 6 years. Much of this research has been accomplished by the Ames Aeronautical Laboratory, which has attacked the problem chiefly through actual flight investigations in icing conditions. Early in 1944 a program of icing research was begun at the Committee's new Cleveland laboratory, which has in operation a 6- by 9-foot wind tunnel designed especially for icing research. A wide range of icing conditions can be produced and controlled in this tunnel at speeds up up to 400 m. p. h.

Thermal Ice Prevention

Early NACA icing research carried out during the 1930's indicated that the waste heat present in the exhaust gas of airplane engines could be employed advantageously to prevent ice formation on airplane surfaces. The NACA has concentrated its recent research in this field on development of such thermal systems of ice prevention. In order to obtain operational verification of the earlier investigations, the Ames Laboratory has designed and installed exhaust-heat thermal ice-prevention systems in several airplanes, including a Lockheed 12A, Consolidated Vultee B–24, Boeing B–17 and Curtiss-Wright C–46. Thorough tests of each of these airplanes have been carried out in natural icing conditions.

In the thermal ice-prevention system heated air is circulated through carefully shaped passages in the wings, tail surfaces, and windshields to protect these components of the airplane against icing. For this purpose the temperature of the air used as the heating medium is raised to about 300° F. by passing it through exhaust-gas-to-air heat exchangers located in the airplane engine nacelles. Ice forms most rapidly over the forward facing portions of airplane surfaces, and thus the thermal ice-prevention system is designed to concentrate most of the heat available within these sections of the wings and empennage. The windshields of the several research airplanes are of a special double-pane construction, with a gap between the inner and outer panes through which the heated air flows. This arrangement has the advantage of preventing frost from forming on the inner windshield surface as well as providing protection against icing.

In beginning its icing research program the Ames laboratory found that there were no heat exchangers available which were capable of extracting large amounts of heat from the engine exhaust of airplanes required for operation of thermal ice-prevention systems. An investigation to develop such heat exchangers was therefore undertaken, and in this research the cooperation of several heat exchanger manufacturers was secured. The laboratory was successful in this project in developing several types of heat exchangers now in general use which had capacities up to 300,000 B. t. u. per hour.

In summary it can be stated that the NACA exhaust heat thermal ice-prevention system has been found through the Committee's extensive research investigations to be a practical system and that it provides considerably more effective protection against icing than any previously employed means of aircraft ice prevention or removal. During the course of the flight research the several research airplanes were flown with complete safety through icing conditions that were sufficiently severe to warrant the grounding of all other aircraft in the area affected. As a result of this successful research, thermal ice-prevention equipment is being incorporated in most new transport airplanes to be operated by the airlines, and this equipment is also being installed in numerous types of military airplanes.

The Committee's laboratories are continuing their research on aircraft thermal ice prevention with a view toward determining as precisely as possible the relationships between the meteorological factors of the atmosphere that are conducive to icing and the heat-transfer characteristics of the thermal system. The most important meteorological factors of concern are the liquid water content and the size and distribution of water droplets. The research includes flight tests in which newly designed meteorological instruments are employed to take measurements in icing clouds. This research is expected to make possible a more complete and fundamental understanding of the thermal ice-prevention system.

Propeller Icing

Propeller icing is a serious problem because even light ice formations impair the efficiency of propellers, thus reducing the speed of airplanes. In addition icing creates dangerous propeller vibration. All three of the Committee's laboratories have been engaged in research on thermal means of propeller ice protection during the past few years, and the problem has been attacked both analytically and experimentally. Considerable service experience on electrical heating systems for propellers designed by the NACA staff has been obtained by the Ames Laboratory through the necessity of providing adequate propeller protection in icing research flights.

Electrical heating equipment for propeller ice protection consists essentially of rubber pads containing electrical resistance heating elements installed over the leading-edge regions of propeller blades. The electrical energy for the blade heating shoes is supplied either from the airplane's electrical system through slip rings on the propeller hub or by a specially designed propeller-hub generator. In the Cleveland laboratory icing research tunnel an investigation was carried out recently to study the effect of energizing such electrical heating systems cyclically, with the heated shoes on the propeller blades being energized "off" and "on" in a controlled sequence. The results showed that adequate ice-removing effectiveness can be achieved in this way with considerably less total electrical power expenditure than with the continuous type, and thus a reduction in weight of electrical generators was made possible.

Experimental studies have been conducted to evaluate the merits of circulating heated air through the blades of hollow-steel propellers as a means of icing protection. Results accomplished thus far indicate that a satisfactory air heating system can be attained if provisions are made in the blade design to concentrate the heated air near the leading-edge region of the blades. Other studies have shown that heated-air flow through hollow propeller blades, leaving the blade through outlets at the tips, has very little effect on propeller performance.

Windshield Icing

Recent research on windshield icing has been directed toward determining whether thermal methods of ice protection can be devised which are more advantageous than the double-pane type of heated windshield previously described, and also to determine windshield configurations which by their geometry require the least amount of heat for ice protection. The latter was proved to be an important and favorable factor, flight tests showing that the small water droplets present in clouds are deflected by the airstream around a windshield which presents no abrupt change to the fuselage nose shape.

In addition to its research on windshield ice protection the Ames laboratory has made some fundamental studies of the heating required to prevent fog from forming on windshields, including the thick bullet-resistant type as well as the thinner windshields of transport aircraft.

Induction System Icing

Ice formation in the induction system of aircraft engines is a serious and treacherous problem. Such icing occurs at temperatures considerably above freezing, in some cases up to 100° F. Thus induction system icing is a year-round problem, not necessarily associated with bad weather, clouds, or any particular geographical area. Investigations have been carried out at the Cleveland laboratory on the engine induction systems of several military aircraft.

One of the basic findings of the research was that serious icing in induction systems could be reduced considerably by preventing free water, such as rain, from entering the carburetor air-intake duct. This problem was, therefore, given further study with the result that a special carburetor air scoop capable of excluding all free moisture from the intake air was developed. The use of this water-separating air scoop, which is designed on the principle of inertia separation of the water droplets, does not cause any loss in pressure of the intake air.

A second important finding of the research was that icing caused by evaporation of the fuel, one of the principal causes of induction system icing, could be greatly reduced by the simple expedient of locating the fuel nozzle further downstream in the induction system. Spinner-type fuel injection nozzles were developed in the research which direct the fuel spray into the eye of the supercharger impeller. This method of fuel injection was found to be practically as effective a means of ice prevention as direct fuel injection into the individual engine cylinders and has the added advantage of simplicity.

The research has shown that preheated carburetor air removes ice from induction systems rapidly if the air temperature is sufficiently high (90° F. wet bulb temperature). In general, it can be stated that the research has made possible a more precise determination of the preheat requirements for induction systems. However, the use of alcohol injection proved to be disappointing and unreliable for removing ice.

Jet Engine Icing

Icing is expected to be a serious hazard in the operation of turbojet engines because ice formations may quickly stop these engines by choking over the air inlets and also may have a destructive effect on the compressor blades. The Cleveland laboratory is conducting an extensive investigation to provide means for protecting turbojet engines against icing, with research being carried out both in flight and in the icing research tunnel. The investigation includes studies to develop water-separating air inlets and also work on the application of exhaust heat to remove ice formations. Results of the research obtained thus far indicate that the centrifugal compressor-type turbojet engine will be affected detrimentally only by very serious icing, but that it is essential to prevent all possible ice from entering the air intakes of the axial-flow type of engine.

TURBULENCE AND GUST RESEARCH

Research on atmospheric turbulence and gust loads was curtailed during the war because of greater priority of other research on aircraft loads. However, the reduced program provided several important results. An investigation of turbulence within thunderstorms was completed in which airplanes surveys were made at altitudes up to 34,000 feet. A large amount of data was obtained on the structure and intensity of gusts, and on airplane behavior and associated meteorological conditions. It was established that gust loads of high magnitude were equally probable at all altitudes within thunderstorms up to the maximum test altitude of 34,000 feet, and correlation was established between airspeed fluctuations and accelerometer measurements as indices of turbulence. Good correlation was established between maximum gust intensities and quantities representing thermal energy potentially available for convection. The data were also analyzed statistically to determine the characteristics of repeated gusts. Methods have been derived for determining continuous gust structure from the flight measurements.

A model of a canard-type airplane was tested in the new Langley Gust Tunnel and it was found that the gust load increments were greater than the conventional case. Tests of models of two other unconventional types, one having a low-aspect-ratio wing, were also made in the gust tunnel to establish gust loads for use in design. An analysis of dynamic stress in single and repeated gusts were made for two large airplanes to provide information during the design stage of these airplanes, and gust tunnel tests were made with flexible models to estabish the validity of the calculations.

Statistical data on gust loads under transport operating conditions were collected and these data, together with previously collected data, were subjected to a number of analyses. Statistical methods for the proper analysis of V–G data were established and the effects of various operating parameters on the probable loads for operations of two commercial aircraft were determinded by these methods. The problem of overloaded airplanes was analysed to determine the increased probability of critical stress both in the static and fatigue cases. Data on the frequency of occurrence of various gust intensities were analyzed and reported to provide a basis for fatigue analysis and these results were in turn utilized in a general analysis of the importance of the fatigue problem.

Several projects were conducted for the purpose of devising means for the circumvention or alleviation of turbulence. A gust-alleviation flap device was tested in the gust tunnel with promising results. Several turbulence indicators and recorders for flight use were investigated and reported to the Army. Means to assist the forcaster in predicting turbulent intensity of thunderstorms were devised, and a cloud detector, based on the principle of infrared radiation, was developed.

The data obtained during the various turbulence investigations were made available and explained to other research agencies to permit them to accomplish studies of bombing and firing accuracy and to permit the design of stabilizing units for radar bomb sights.

CABIN HEATING, COOLING, AND VENTILATION

A study has been made at the Ames laboratory of the large amount of uncorrelated data available for the design of convective heating and ventilating systems for airplane cabins. The data have been analyzed and evaluated and a design report prepared. The amount of available design information was considered adequate with the exception of data relating to the rate of infiltration of ambient air into the cabin. A flight-test method for measuring this quantity has been devised and is based on the determination of the rate of dilution of an initially established carbon-dioxide concentration in the cabin.

Research has also been undertaken on the cooling of high-speed airplane cockpits. An analytical investigation has been made of the various factors, such as solar radiation and air friction, which contribute to the heating load for an airplane flying at high subsonic speeds, and flight tests to check the analysis have been undertaken. Consideration is also being given to the cockpit cooling problems associated with supersonic flight and an analysis has been made of various ram-air-operated air cycles for application to these high-speed aircraft.

DITCHING STUDIES

The thousands of over-water flights by landplanes under the combat conditions of World War II unavoidably resulted in many forced landings at sea. The ability of airplane crews to survive such ditchings depended largely on how well the airplanes withstood the impact of striking the water. At the NACA's Langley laboratory dynamic model tests were made to predict the ditching characteristics of service airplanes, to determine how the pilots could obtain the safest ditching performance, and to develop devices that would reduce the hazardous conditions found. Motion pictures of the tests were used to instruct airplane crews.

The ditching characteristics of 17 Army and Navy airplanes were determined from such tests made in towing tanks and on an outdoor catapult. These studies led to the development of the NACA "Hydroflap" as a ditching aid almost universally applicable to new designs, and capable of giving smooth ditching performance under a wide variety of landing conditions. Load design data for hydroflaps were obtained from tests made in the Langley impact basin.

Because failure of relatively weak bomb doors proved to be one of the major causes of disastrous ditchings, the strength of bomb doors and the use of special ribs was prescribed by the Army for the bomber airplanes most used in the war.

In cooperation with the Army, the Langley laboratory conducted the only two experimental full scale ditchings that were made during the war. These tests substantiated the value of model ditching investigations and emphasized the importance of personnel location in an airplane that previously had been extremely unsafe for ditching. Changes in the airplane that would permit the use of this ditching station were subsequently made.

INVESTIGATION OF CONDENSATION TRAILS

Condensation trails generated by high-flying airplanes proved a serious problem during the war in that they greatly simplified the task of locating the airplanes in flight, either from ground stations or from attacking enemy fighter airplanes. Early in the war research at the Langley laboratory on condensation trails established and explained the several types, provided methods for forecasting the zones and altitudes at which trails would occur and suggested means for avoiding the generation of trails. The results of these researches were available to the armed services during the greater part of the war.

GUIDED MISSILES

The NACA is responsible for the conduct of research in aerodynamics, controls, and propulsion and has cooperated with the Army, the Navy and the National Defense Research Committee in the development of guided missles.

Investigation of guided missile problems in the NACA laboratories started in June of 1941 at request of the Army Air Force. More than 18 specific guided missile projects have been undertaken by the NACA for the Army, Navy, and NDRC in the period from the summer of 1941 through the present. At first these projects involved only the conduct of wind tunnel tests on proposed configurations to insure satisfactory functioning of the control system. As the results from other fields of wartime research made the guided missile appear more promising, increased effort was placed by the NACA on problems of the stability and control of a missile guided by an automatic pilot.

As the emphasis changed from gravity powered missiles to self-propelled missiles, the problems of form and control became more critical. The higher speeds required to decrease vulnerability to antiaircraft fire necessitated aerodynamic refinement in the form of the missile. One of the first self-propelled missiles with an aerodynamically refined shape was the JB-3, or Tiamat. This form, proposed by a member of the NACA staff, was taken under development by the Army Air Forces and at the same time its configuration was used by the NACA for a study in free flight of some of the general problems involved in the control of guided missiles, such as the response of the missile to deflection of control surfaces, the size of control surface required, and the servo-mechanism and remote control device needed to operate such a missile along a desired path. As the flight speed increased the requirements for the precision of the guiding equipment became increasingly severe. In its free flight research, the NACA is conducting an extensive investigation of the aerodynamic characteristics of guided missiles.

The NACA Cleveland laboratory is conducting research on the ramjet power-plant which shows particular promise for use on an expendable high-speed missile.

Under this Committee's over-all supervision, research in the following fields having application to guided missiles is in hand:

Rocket fuels and combustion.

Turbojets, ramjets, and other forms of power plants having possible applications to guided missiles.

Aerodynamics of wings, bodies, and control surfaces at high speeds for all configurations of interest.

Radio control and the telemetering of research data by radio from the missiles to ground receiving stations.

The dynamics of controlled flight, which includes:

Stability of missiles in flight.

Requirements of servo-control mechanisms to operate controls.

WARTIME UNIVERSITY RESEARCH

To secure the benefits of additional outstanding scientists and research facilities for the Government, the NACA has supported a well-integrated and coordinated contract research program administered to supplement and contribute to the research carried out in the NACA laboratories or conducted by other government agencies. Technical reports resulting from the research were given the same distribution to the military services, their contractors, and other interested groups as those resulting from the laboratories' research. More than 40 educational institutions, as well as the National Bureau of Standards and the Forest Products Laboratory which are operated by the Government, participated in research in the fields of aerodynamics, aircraft propulsion, construction, and operating problems.

Administration of contract research is carried out effectively by close coordination with the technical subcommittees of the NACA. Research projects are approved for contract with the NACA only after they are studied carefully and recommended by the appropriate NACA technical subcommittee. The membership of these technical subcommittees is made up of experts from the NACA, CAA, AAF, Navy Bureau of Aeronautics, other Government organizations, and private industry who are acquauinted with the needs of the Nation as well as the available information and background relating to the research.

Wartime increases in aircraft operational speeds introduced the grave problem of compressibility. For low speeds of flight, air may be considered incompressible, but as speeds approach that of sound, serious aerodynamic design problems are introduced. The NACA has engaged some of the Nation's foremost mathematical physicists in the theoretical solution of high-speed flow problems. Substantial progress has been made in this, one of the most difficult of modern applied mathematics.

Since the power output and operating efficiency of jet engines increases with operating temperatures, much attention was given to the development of structural alloys capable of withstanding corrosive gases operating at temperatures up to 1,800° F. Much of the advance in the high-temperature alloy development has been due to research or evaluation carried on under the sponsorship of the NACA.

The mechanism of boundary layer flows has been the subject of research for many years by workers in the field of fluid mechanics. Great increases in aircraft performance could result if efficient means were developed by which boundary layer flows could be controlled. During the war theoretical and experimental boundary layer studies were carried out, notably at the National Bureau of Standards and the California Institute of Technology, and have contributed greatly to the knowledge of boundary-layer phenomena. Specially significant were theoretical studies of the boundary layer in compressible fluids and experimental investigations of turbulence, transition and flow stability by means of hot-wire anemometry.

As aircraft power plants increase in output the problem of dissipation of waste heat becomes increasingly important. Efficient design of heat exchangers for the utilization of waste heat for cabin heating or anti-icing or to reduce weight of oil coolers becomes necessary as airplane and power plant size is increased. Valuable contributions toward the increase of efficiency of heat exchangers have been made under the sponsorship of the NACA.

Problems of vibration and flutter of aircraft have been emphasized with increases in aircraft speed. Speed advances attained during the war have forced the problem to a prominent place in aircraft design. Theoretical research, carried on under the Committee's sponsorship utilizing mathematical methods of considerable complexity, have yielded results allowing for the determination of flutter characteristics of actual airfoil systems. Experimental research into the effects of forced and self-excited oscillations have yielded considerable information concerning the phenomenon of flutter.

Increases in airplane size have altered some aircraft structural design problems. Monocoque structures, where the sheet metal covering of the fuselage acts as a structural member, have increased in size to where general instability failures have become possible. Contract research carried on during the war has yielded more accurate method of stress analysis for the efficient design of large airplanes.

As in the early years of the Committee's existence before the opening of the research laboratories, when contracts were a major means by which aeronautical research was pursued, contributions in specific fields made by outstanding scientists in educational and research institutions during the war have indicated that contract research represents a valuable adjunct to the effort of the NACA in its laboratories.

OFFICE OF AERONAUTICAL INTELLIGENCE

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the Committee's activities. Its functions are the collection and classification of technical knowledge on the subject of aeronautics, including the results of research and experimental work conducted in all parts of the world, and dissemination to the military and naval air organizations, aircraft manufacturers, educational institutions, and others interested. It it the officially designated Government depository for scientific and technical reports and data on aeronautics.

Promptly upon receipt, all American and foreign reports are analyzed, classified, and brought to the special attention of the subcommittees having cognizance and to the attention of other interested parties through the medium of public and confidential bulletins. Foreign reports are translated and duplicated where practicable, and distributed to the best advantage.

To handle efficiently the work of procuring and exchanging reports in foreign countries, it is the Committee's policy to maintain a Technical Assistant in Europe. It is his duty to visit the governmental and private laboratories, centers of aeronautical information, and private individuals in European countries, and to endeavor to procure for America not only printed matter which would in the ordinary course of events become available in this country, but more especially advance information as to work in progress and technical data not prepared in printed form, which would otherwise not reach this country. John Jay Ide, of New York, served as the Committee's Technical Assistant in Europe from April 1921 until the office was closed for the duration of World War II. The Office of the Technical Assistant in Europe will be reopened as soon as it becomes expedient to do so.

Technical Publications.—The Committee's own technical publications are the official means of communicating to the proper responsible officials of the military services, the aircraft industry, and others concerned, the results of scientific investigations conducted in its own laboratories and other investigations conducted under research contracts in private scientific and educational institutions. During the war such publications constituted "classified" information, designated as "restricted," "confidential," or "secret" and their status was protected by the provisions of the Espionage Act. This resulted in a limitation in the distribution of such information during the war period. The volume of reports greatly increased during the war period due to expanding research activity and to the advancing requirements of the military services and the aircraft industry for technical data.

In order to get new knowledge into use with the least possible delay, the Committee followed a policy of releasing preliminary and advance data prior to the issuance of a final report. There has resulted a vast accumulation of valuable scientific data worthy of preservation in permanent form and immediately needed by units of industry, educational institutions, libraries, and individuals whose access to such information was restricted during the war period.

The results of scientific investigations conducted or sponsored by the NACA during the war period are being reissued in public form as "Wartime Reports." Those of more permanent value are being printed in final form as technical "Reports."

The Committee is continuing the publication of "technical memorandums" containing translations and reproductions of outstanding aeronautical articles originating in foreign countries. This series is available for general distribution.

AERONAUTICAL INVENTIONS

By Act of Congress approved July 2, 1926 (U. S. Code, title 10, sec. 310-r), an Aeronautical Patents and Design Board was established consisting of the Assistant Secretaries for Air of the Departments of War, Navy, and Commerce. In accordance with that Act as amended by the Act approved March 3, 1927, the National Advisory Committee for Aeronautics is charged with the function of analyzing and reporting upon the technical merits of aeronautical inventions and designs submitted to any agency of the Government. The Aeroautical Patents and Design Board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed $75,000."

In August 1940 the Secretary of Commerce created the National Inventors Council to serve as a central Government clearinghouse to which can be submitted inventions and suggestions that might prove valuable to the national defense. The Committee's Director of Aeronautical Research, Dr. George W. Lewis, serves as Chairman of the Council's Technical Committee on Aircraft and Aeronautics.

During the war years the NACA has continued to discharge its function of consideration of aeronautical inventions. A large number of aeronautical inventions were submitted directly to the NACA by individuals and concerns, and many were forwarded by other Government agencies, including the National Inventors Council of the Department of Commerce, for proper evaluation.

The activities of the Aeronautical Patents and Design Board have become dormant since the National Inventors Council has been established, and the NACA has recently recommended the repeal of that Section of the Act of Congress creating the Aeronautical Patents and Design Board.

Part II

EXTENSION OF FACILITIES

Construction Since 1940

AMES LABORATORY

The year 1940 saw the beginning of the Ames Aeronautical Laboratory at Moffet Field, Calif. The facilities of this laboratory were built to extend aeronautical research to higher speeds and larger scale, in a location less limited by space considerations and electric power supply than the more crowded area at Langley Field.

The first unit completed was the flight research laboratory, which went immediately to work on the problem of aircraft icing. In August of 1941, three new wind tunnels were put into operation. The first two were the 7- by 10-foot tunnels, extensively used for general aerodynamics and stability and control studies. They provide a much needed addition to the facilities at Langley Field for this type of work. The third tunnel was the 16-foot high-speed tunnel. This facility makes possible aerodynamic investigation at high speeds, up to 680 miles per hour, and at larger scale than was possible in any other tunnel, at those speeds.

In May of 1942 the science laboratory was completed. This building houses equipment for design and construction of the complex and precise instrumentation required in research.

The administration building, which houses the central management and research offices of the laboratory, was completed in November of 1943.

In 1944 two new wind tunnels came into operation. The 1- by 3½-foot high-speed tunnel, completed in January, provided an economical means for studying problems of high-speed airflows where size was not especially important. Many preliminary investigations are conducted in this tunnel before being extended to larger scale in the 16-foot high-speed tunnel. A full scale tunnel, 40 by 80 feet at the test section, was put in operation in June of 1944. The 40- by 80-foot wind tunnel is the largest in the world. During the war it provided the means for rapid correction of military designs already in or about to go into production. In basic research it allows investigations to be made at very large Reynolds numbers.

By December of 1945 the 8-by-8-inch supersonic tunnel was completed. This is the first of three supersonic facilities at this laboratory. The other two are 1-by-3-foot supersonic tunnels, completed in March and May of 1946. These facilities provide a range of speeds up to Mach number 3.4. In addition, the 1-by-3-foot tunnels are of variable density, providing a range of possible Reynolds numbers. They are the first of the larger supersonic facilities, much needed to provide information for ultra-high-speed aircraft.

In July of 1946, the 12-foot low-turbulence pressure tunnel was placed in operation. This tunnel represents the latest advance in wind-tunnel design, and was built to provide more accurately controlled, low turbulence airflows at speeds up to the speed of sound and also at effective large scale by means of pressurized air.

CLEVELAND LABORATORY

The NACA Aircraft Engine Research Laboratory at Cleveland, Ohio, authorized in November of 1940, has provided urgently needed facilities for studying the problems of aircraft propulsion systems. With the advent of new engine types these problems have multiplied and the research equipment has been correspondingly converted and enlarged.

The year 1942 brought completion of some of the initial construction at Cleveland. The flight research laboratory was placed in operation, extending the facilities for flight investigations at the Langley and Ames laboratories. Research on fuels and engine cooling have been among the principal studies. The first of two engine-propeller research buildings was completed in August. In November, the fuels and lubricants building was completed. The building is provided with equipment for the scientific study of fuel and lubricant characteristics and their improvement.

In March of 1943 the administration building was completed, providing the laboratory with its central offices, library, and auditorium. By August the engine research building was completed. This facility provides for investigation of complete engines and their components. Included are combustion research, compressor and turbine research, and friction and wear studies. The equipment involves engine test cells and extensive services for supplying refrigerated, compressed, and evacuted air in the large volumes demanded by jet-propulsion engines and compressors.

In 1944 most of the originally planned propulsion research facilities at Cleveland were completed. The altitude wind tunnel was placed in operation in January. This tunnel provides altitude pressures up to 50,000 feet and temperatures of 40° F. below zero, at speeds up to 500 miles per hour. It is the only facility where full-scale engines of all kinds may be investigated in operation under accurately controlled conditions of high altitude. The icing research tunnel was completed in March. It is cooled by a large capacity refrigeration plant that also serves the altitude tunnel. It provides the means for studying every type of aircraft icing, including engine and propeller icing during operation, under controlled conditions not possible in flight. In May, a second engine-propelled research facility was completed. A jet-propulsion static test laboratory was completed in August, providing much needed facilities for investigating the performance of complete jet engines. By November the compressor and turbine research facilities were completed. These are located in the engine research building, and constitute an important part of the equipment for study of major engine components.

In June of 1945 two supersonic wind tunnels were put into operation. These are the 18- by 18-inch tunnel and the 20-inch tunnel. They provide the laboratory with the means of studying the special problems of propulsion at supersonic speeds, including aircraft and engine shapes and ducts for air.

The high-pressure combustion laboratory was completed in October. This facility is devoted to the study of rocket fuels and their cumbustion for high-speed propulsion.

Close of the year 1946 has brought an addition to the jet-propulsion static-test laboratory, extending these facilities to accommodate a larger number of jet engines, which have almost entirely replaced the reciprocating engine in fundamental propulsion research.

LANGLEY LABORATORY

Facilities at the Langley Memorial Aeronautical Laboratory at Langley Field, Va., have been continually modernized, enlarged, and extended as the need has arisen. In June of 1941, a stability research wind tunnel and laboratory were placed in operation. This laboratory makes possible specialized study of stability problems under controlled conditions. In December, the electric power supply for the laboratory was augmented by installation of a 10,000-horsepower Diesel-electric generating plant, that was to permit the required operation of high-powered wind tunnels in the critical war period.

In January of 1942 the 16-foot high-speed tunnel was placed in operation. This tunnel is similar to the one constructed at Ames Laboratory but it is of slightly lower speed. It provides the means for high speed aerodynamic research at large scale. By July the 9-inch supersonic tunnel was completed, providing the laboratory with a facility for general supersonic aerodynamic research. A second hydrodynamic towing tank was completed in October, as well as the seaplane impact basin for studying water-landing loads. These facilities amplify the laboratory's equipment for hydrodynamic research, and have made possible more extensive work on land problems, many of which were of immediate specific importance during the war.

The next important additions come in 1945. The physical research laboratory was completed in April to provide for the study of fundamental and abstract problems in physics. A large number of these problems have to do with high-speed and supersonic flight. In August the gust tunnel was completed. This is a unique facility designed for research on aircraft loads produced by atmospheric turbulence, under accurately controlled conditions impossible to duplicate at will in flight. In September the flutter tunnel of the physical research division was completed. This is one of several specialized facilities, for investigation of the flutter and vibration phenomena that occur at high speeds. In November a new 7- by 10-foot high-speed tunnel was completed. This is similar to those constructed at Ames laboratory, except that it is equipped with variable test sections which provide speeds up to 700 miles per hour.

The end of 1946 has brought one more addition to the physical research division in the form of a helicopter test tower. Valuable work has been performed by this division on basic problems of the helicopter rotor. The tower is designed to permit research on rotors high enough from the ground to be substantially free of "ground effect." Another smaller addition has been a stratosphere chamber for instrument testing. Accurate instrumentation, calibrated for all conditions to be encountered, is a vital part of research equipment, and one that must keep abreast of the search for new knowledge.

Part III

COMMITTEE ORGANIZATION AND MEMBERSHIP

THE National Advisory Committee for Aeronautics was established by Act of Congress approved March 3, 1915, and the membership increased from 12 to 15 by act approved March 2, 1929 (U. S. C., title 49, sec. 241). Its members are appointed by the President and include two representatives each of the War and Navy Departments from the offices in charge of military and naval aeronautics, two representatives of the Civil Aeronautics Authority (Civil Aeronautics Act of 1938), one representative each of the Smithsonian Institution, the United States Weather Bureau, and the National Bureau of Standards, together with six additional persons who are "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." These latter six serve for terms of 5 years. The representatives of the Government organizations serve for indefinite periods. All members serve as such without compensation.

During the period since the publication of the Committee's last annual report, for the year 1942, the following changes have occurred in the membership of the main Committee:

Rear Adm. Sidney M. Kraus, U. S. N., was relieved on April 9, 1943, because of his transfer to duty away from Washington. Rear Adm. Edward M. Pace was appointed to succeed him.

Mr. William Littlewood, vice president (Engineering), of American Airlines, was appointed February 10, 1944, for a term expiring October 1, 1948, to succeed Dr. George J. Mead, who resigned because of ill health.

Vice Adm. John S. McCain, U. S. N., was relieved on August 17, 1944, because of his transfer to duty away from Washington, and Vice Adm. Aubrey W. Fitch, his successor as Deputy Chief of Naval Operations (Air), was appointed a member to succeed Admiral McCain.

On October 11, 1944, the President appointed Rear Adm. Lawrence B. Richardson, U. S. N., to succeed Rear Adm. Edward M. Pace, transferred to duty outside of Washington.

Dr. Alexander Wetmore, Secretary, Smithsonian Institution, was appointed a member on January 20, 1945, to succeed Dr. Charles G. Abbot, who had recently retired as secretary of that institution.

On June 11, 1945, the President appointed Brig. Gen. (now Major General) Edward M. Powers, U. S. A., Assistant Chief of Air Staff–4, to succeed Maj. Gen. Oliver P. Echols, relieved, on his transfer to duty away from Washington.

On his appointment as Deputy Chief of Naval Operations (Air), Vice Adm. Marc A. Mitscher, U. S. N., was appointed a member of the NACA July 24, 1945, to succeed Admiral Fitch, relieved.

Dr. William F. Durand, the last of the twelve original NACA members to serve on the Committee, resigned August 24, 1945, to retire to his home at Stanford University, Calif., after serving two terms of membership of 18 years and 3 years, respectively.

On September 20, 1945, Dr. Edward Warner, vice chairman of the Civil Aeronautics Board, resigned from the Committee to accept the presidency of the Interim Council of the Provisional International Civil Aviation Organization at Montreal.

Dr. Edward U. Condon, newly appointed Director of the National Bureau of Standards, was appointed to the Committee November 19, 1945, to succeed Dr. Lyman J. Briggs, retiring Director of the Bureau and NACA member for many years.

Vice Adm. Arthur W. Radford, U. S. N., was appointed a member of the Committee January 17, 1946, to succeed Rear Admiral Mitscher, transferred to other duty.

Under date of April 8, 1946, President Truman filled the vacancies caused by the resignation of Dr. Durand and Dr. Warner by appointing Dr. Theodore P. Wright, Administrator of Civil Aeronautics, who had previously been appointed a member from private life, as a member representing the Civil Aeronautics Administration succeeding Dr. Warner; appointing Arthur E. Raymond, vice president (Engineering), Douglas Aircraft Co., to succeed Dr. Wright for a term expiring December 1, 1946; and appointing Mr. Ronald M. Hazen, chief engineer, Allison division, General Motors Corporation, as member to succeed Dr. Durand for a term expiring December 1, 1949.

General Carl A. Spaatz, Commanding General of the Army Air Forces, was appointed a member of the Committee April 12, 1946, succeeding Gen. Henry H. Arnold, his predecessor as Commanding General.

In accordance with the regulations governing the organization of the committee as approved by the President, the chairman and vice chairman are elected annually, as are also the Chairman and Vice Chairman of the Executive Committee.

Since 1942, Dr. Jerome C. Hunsaker has been reelected annually as Chairman of the NACA and of the Executive Committee. As Vice Chairman of the NACA, Dr. Lyman J. Briggs served from his election in October 1942 to October 25, 1945, just prior to his retirement as a member, and on the latter date Dr. Theodore P. Wright was elected Vice Chairman.

Dr. Charles G. Abbot served as Vice Chairman of the executive committee until his retirement from the committee, January 20, 1945. At the following annual meeting, October 25, 1945, Dr. Francis W. Reichelderfer was elected Vice Chairman of the Executive Committee.

The main committee is supplemented by a system of technical committees and subcommittees to prepare and recommended to the main Committee the programs of research to be conducted in their respective special fields. In addition, these subcommittees assist in coordinating research programs, and act as mediums of interchange of ideas and information among all groups concerned with a particular field of research.

Due to the increase in complexity and specialization of aeronautical research, the number of technical committees has been increased to cover the needs of this broadening field. In addition it is necessary from time to time to set up a special committee to deal with some particular project. All these committees change according to the need for them.

There are now 8 technical committees and 23 subcommittees. Their titles and membership are as follows:

COMMITTEE ON AERODYNAMICS

Dr. Theodore P. Wright, Administrator of Civil Aeronautics, Chairman.
Dr. Hugh L. Dryden, National Bureau of Standards, Vice Chairman.
Maj. Gen. L. C. Craigie, Air Corps, Air Matériel Command.
Col. Paul H. Kemmer, Air Corps, Air Matériel Command.
Col. Paul H. Dahe, Air Corps, Air Matériel Command.
Capt. Walter S. Diehl, U. S. N., Bureau of Aeronautics.
Capt. Robert S. Hatcher, U. S. N., Bureau of Aeronautics.
Rear Adm. L. C. Stevens, U. S. N., Bureau of Aeronautics.
Mr. Harold D. Hoekstra, Civil Aeronautics Administration.
Mr. John F. Parsons, National Advisory Committee for Aeronautics.
Mr. Floyd L. Thompson, National Advisory Committee for Aeronautics.
Dr. G. W. Lewis (ex officio), National Advisory Committee for Aeronautics.
Mr. Abe Silverstein, National Advisory Committee for Aeronautics.
Mr. Paul S. Baker, United Aircraft Corp.
Mr. John G. Borger, Pan American Airways System.
Prof. John R. Markham, Massachusetts Institute of Technology.
Mr. L. E. Root, Douglas Aircraft Co.
Mr. George S. Schairer, Boeing Aircraft Co.
Dr. Theodore von Karman, California Institute of Technology.

Subcommittee on Seaplanes

Mr. Grover Loening, Chairman.
Mr. H. L. Anderson, Air Matériel Command.
Capt. H. C. Richardson, U. S. N., Naval Air Matériel Center.
Capt. Walter S. Diehl, U. S. N., Bureau of Aeronautics.
Capt. H. E. Saunders, U. S. N., David Taylor Model Basin.
Capt. C. H. Schildhauer, U. S. N. R., Navy Department.
Mr. Albert A. Vollmecke, Civil Aeronautics Administration.
Mr. John B. Parkinson, National Advisory Committee for Aeronautics.
Prof. K. S. M. Davidson, Stevens Institute of Technology.
Capt. H. E. Gray, Pan American Airways System.
Mr. B. V. Korvin-Kroukovsky, Edo Aircraft Corp.
Mr. J. D. Pierson, Glenn L. Martin Co.
Mr. E. G. Stout, Consolidated Vultee Aircraft Corp.

Subcommittee on Vibration and Flutter

Dr. E. J. Reid, National Advisory Committee for Aeronautics, Chairman.
Mr. Benjamin Smilg, Air Corps, Air Matériel Command.
Mr. L. S. Wasserman, Air Matériel Command.
Capt. Walter S. Diehl, U. S. N., Bureau of Aeronautics.
Mr. Bernard A. Wiener, Bureau of Aeronautics, Navy Department, Washington, D. C.
Mr. E. Forest Critchlow, Civil Aeronautics Administration.
Dr. Walter Ramberg, National Bureau of Standards.
Dr. Theodore Theodorsen, National Advisory Committee for Aeronautics.
Mr. Sam Loring.

Subcommittee on Propellers for Aircraft

Mr. Frank W. Caldwell, United Aircraft Corp., Chairman.
Dr. Roscoe H. Mills, Air Matériel Command.
Mr. Daniel A. Dickey, Air Matériel Command.
Lt. Comdr. David W. Watkins, Jr., Bureau of Aeronautics.
Mr. Gerald L. Desmond, Bureau of Aeronautics.
Mr. John C. Morse, Civil Aeronautics Administration.
Mr. E. C. Draley, National Advisory Committee for Aeronautics.
Prof. Shatswell Ober, Massachusetts Institute of Technology.
Mr. Werner J. Blanchard, General Motors Corp.
Mr. George W. Brady, Curtiss-Wright Corp.
Mr. Erle Martin, Hamilton Standard Propellers.
Mr. Fred E. Weick, Engineering & Research Corp.

Subcommittee on Helicopters

Mr. Grover Loening, Chairman.
Lt. Col. K. S. Wilson, Air Corps, Air Matériel Command.
Maj. W. E. Zins, Air Corps, Air Matériel Command.
Capt. Walter S. Diehl, U. S. N., Bureau of Aeronautics.
Commander J. C. Lawrence, U. S. C. G., Bureau of Aeronautics.
Commander James W. Klopp, U. S. N., Bureau of Aeronautics.
Mr. B. L. Springer, Civil Aeronautics Administration.

Mr. Frederick J. Bailey, National Advisory Committee for Aeronautics.
Dr. Theodore Theodorsen, National Advisory Committee for Aeronautics.
Mr. Donnell W. Dutton, Georgia School of Technology.
Mr. Michael Gluhareff, Sikorsky Aircraft.
Mr. F. N. Piasecki, Piasecki Helicopter Corp.
Mr. Richard H. Prewitt.
Mr. Arthur M. Young, Bell Aircraft Corp.
Mr. H. L. Hanson, Bureau of Aeronautics, Navy Department.

Subcommittee on High-Speed Aerodynamics

Dr. Hugh L. Dryden, National Bureau of Standards, Chairman.
Mr. R. G. Robinson, National Advisory Committee for Aeronautics, Vice Chairman.
Mr. John Stack, National Advisory Committee for Aeronautics.
Mr. H. Julian Allen, National Advisory Committee for Aeronautics.
Mr. Abe Silverstein, National Advisory Committee for Aeronautics.
Commander Cedric W. Stirling, U. S. N., Bureau of Aeronautics.
Mr. F. A. Louden, Bureau of Aeronautics.
Lt. David Shore, Air Matériel Command.
Prof. John von Neuman, The Institute for Advanced Study.
Prof. Howard W. Emmons, Harvard University.
Dr. Francis H. Clauser, John Hopkins University.
Mr. Vladimir Morkovin, Navy Department.
Mr. Paul C. Spiess, Civil Aeronautics Administration, Washington 25, D. C.

Subcommittee on Stability and Control

Mr. L. E. Root, Douglas Aircraft Co., Chairman.
Mr. Melvin Shorr, Air Matériel Command.
Mr. H. A. Soulé, National Advisory Committee for Aeronautics.
Mr. Paul C. Emmons, Bell Aircraft Corp.
Mr. Harry J. Goett, National Advisory Committee for Aeronautics.
Mr. Edward J. Horkey, North American Aviation.
Prof. Otto Koppen, Massachusetts Institute of Technology.
Prof. C. D. Perkins, Princeton University.
Mr. Joseph Matulaitis, Civil Aeronautics Administration.

Special Subcommittee on the Upper Atmosphere, Committee on Aerodynamics

Dr. Harry Wexler, U. S. Weather Bureau, Chairman.
Col. D. N. Yates, Army Air Forces Weather Service.
Col. Paul H. Dane, Air Corps, Air Matériel Command.
Capt. H. T. Orville, U. S. N., Navy Department.
Capt. Walter S. Diehl, U. S. N., Bureau of Aeronautics.
Commander Harvey Hall, U. S. N. R., Bureau of Aeronautics.
Dr. Fred L. Whipple, Harvard University.
Dr. C. N. Warfield, National Advisory Committee for Aeronautics.
Dr. E. H. Krause, Naval Research Laboratory.
Dr. W. G. Brombacher, National Bureau of Standards.
Dr. L. V. Berkner, Executive Secretary, Joint Research and Development Board, Washington 25, D. C.
Dr. B. Gutenberg, California Institute of Technology.

Subcommittee on Internal Aerodynamics

Membership not yet decided upon.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Mr. R. M. Hazen, General Motors Corp., Chairman.
Prof. E. S. Taylor, Massachusetts Institute of Technology, Vice Chairman.
Col. R. L. Wassell, Air Corps, Air Matériel Command.
Col. R. J. Minty, Air Corps, Air Matériel Command.
Capt. John L. Ewing, Jr., U. S. N., Bureau of Aeronautics.
Capt. A. L. Baird, U. S. N., Bureau of Aeronautics.
Mr. Stephen Rolle, Civil Aeronautics Administration.
Dr. G. W. Lewis (ex officio), National Advisory Committee for Aeronautics.
Mr. Carlton Kemper, National Advisory Committee for Aeronautics.
Mr. A. M. Rothrock, National Advisory Committee for Aeronautics.
Mr. A. G. Herreshoff, Chrysler Corp.
Mr. L. S. Hobbs, United Aircraft Corp.
Mr. William S. James, Ford Motor Co.
Mr. R. P. Kroon, Westinghouse Electric Corp.
Mr. William C. Lawrence, American Overseas Airlines.
Mr. D. F. Warner, General Electric Co.
Mr. Raymond W. Young, Wright Aeronautical Corp.
Mr. William Littlewood, American Airlines.

Subcommittee on Aircraft Fuels and Lubricants

Mr. W. H. Holaday, Socony-Vacuum Oil Co., Inc., Chairman.
Prof. Edwin R. Gilliland, Massachusetts Institute of Technology, Vice Chairman.
Commander S. M. Adams, U. S. N., Bureau of Aeronautics.
Mr. Kenneth S. Cullom, Civil Aeronautics Administration.
Mr. Donald B. Brooks, National Bureau of Standards.
Dr. L. D. Gibbons, National Advisory Committee for Aeronautics.
Dr. D. P. Barnard, Standard Oil Co. of Indiana.
Mr. T. A. Boyd, General Motors Corp.
Mr. S. D. Heron, Ethyl Corp.
Dr. J. Bennett Hill, Sun Oil Co.
Mr. C. R. Johnson, Shell Oil Co.
Mr. A. Nerad, General Electric Co.
Mr. Earle A. Ryder, Pratt & Whitney Aircraft.
Dr. W. J. Sweeney, Standard Oil Development Co.
Mr. E. C. Phillips, Air Technical Service Command.

Subcommittee on Lubrication, Friction, and Wear

Mr. Arthur F. Underwood, General Motors Corp., Chairman.
Mr. Edgar A. Wolfe, Air Matériel Command.
Commander J. C. Eckhardt, U. S. N., Bureau of Aeronautics.
Dr. William Zisman, Naval Research Laboratory.
Mr. John H. Collins, Jr., National Advisory Committee for Aeronautics.
Dr. Haakon Styri, SKF Industries, Inc.
Dr. O. Beeck, Shell Development Co.
Professor John T. Burwell, Massachusetts Institute of Technology.
Dr. Russell W. Dayton, Battelle Memorial Institute.
Mr. Hans Ernst, Cincinnati Milling & Grinding Machines.
Mr. Morris Muskat, Gulf Research & Development Co.

Subcommittee on Compressors

Dr. John H. Marchant, Brown University, Chairman.
Mr. Opie Chenoweth, Air Matériel Command.
Captain A. L. Baird, U. S. N., Bureau of Aeronautics.

Mr. Robert O. Bullock, National Advisory Committee for Aeronautics.
Mr. John Stack, National Advisory Committee for Aeronautics.
Mr. Walter Doll, Pratt & Whitney Aircraft.
Dr. William Bollay.
Mr. Rudolph Birmann, DeLaval Steam Turbine Co.
Prof. Howard W. Emmons, Harvard University.
Mr. R. S. Hall, General Electric Co.
Mr. A. H. Redding, Westinghouse Electric Corp.
Mr. John Talbert, Wright Aeronautical Corp.
Comdr. H. Sosnoski, U. S. N., Bureau of Aeronautics.

Subcommittee on Turbines

Mr. John G. Lee, United Aircraft Corp., Chairman.
Col. R. L. Wassell, Air Corps, Air Matériel Command.
Commander F. K. Slason, U. S. N., Bureau of Aeronautics.
Mr. John V. Becker, National Advisory Committee for Aeronautics.
Mr. Oscar W. Schey, National Advisory Committee for Aeronautics.
Mr. Alan Howard, General Electric Co.
Mr. E. V. Farrar, Wright Aeronautical Corp.
Mr. A. H. Redding, Westinghouse Electric Corp.
Dr. J. T. Rettaliata, Illinois Institute of Technology.
Mr. Ronald B. Smith, The Elliott Co.
Prof. C. Richard Soderberg, Massachusetts Institute of Technology.
Lt. Col. Paul F. Nay, Air Matériel Command.

Subcommittee on Propulsion Systems

Prof. Joseph H. Keenan, Massachusetts Institute of Technology, Chairman.
Mr. R. V. Kleinschmidt.
Mr. Benjamin Pinkel, National Advisory Committee for Aeronautics.
Dr. Kennedy F. Rubert, National Advisory Committee for Aeronautics.
Mr. Opie Chenoweth, Air Matériel Command.
Mr. K. A. Browne, Chesapeake & Ohio Railway Co.
Prof. Frank J. Malina, California Institute of Technology.
Mr. Perry W. Pratt, Pratt & Whitney Aircraft.

Subcommittee on Heat Exchangers

Prof. W. H. McAdams, Massachusetts Institute of Technology, Chairman.
First Lieut. Louis B. Peltier, Jr., Air Matériel Command.
Lt. Comdr. R. A. Gulick, U. S. N., Bureau of Aeronautics.
Mr. M. J. Brevoort, National Advisory Committee for Aeronautics.
Mr. Alun R. Jones, National Advisory Committee for Aeronautics.
Mr. Eugene J. Manganiello, National Advisory Committee for Aeronautics.
Dr. Allen P. Colburn, University of Delaware.
Mr. Don S. Hersey, Pratt & Whitney Aircraft.
Mr. W. M. S. Richards, Wright Aeronautical Corp.
Mr. L. P. Saunders, General Motors Corp.

Subcommittee on Combustion

Prof. Glenn C. Williams, Massachusetts Institute of Technology, Chairman.
Col. Ralph L. Wassell, Air Corps, Air Materiel Command.
Dr. Bernard Lewis, Bureau of Mines.
Lt. Comdr. C. C. Hoffman, U. S. N., Bureau of Aeronautics.
Dr. Ernest F. Fiock, National Bureau of Standards.
Mr. A. M. Rothrock, National Advisory Committee for Aeronautics.
Dr. W. T. Olson, National Advisory Committee for Aeronautics.
Mr. A. J. Nerad, General Electric Co.
Prof. Robert N. Pease, Princeton University.
Dr. William J. Sweeney, Standard Oil Development Co.
Dr. Steward Way, Westinghouse Electric Corp.

Subcommittee on Heat-Resisting Alloys

Mr. W. L. Badger, General Electric Co., Chairman.
Mr. J. B. Johnson, Air Matériel Command.
Lt. Comdr. C. C. Hoffman, U. S. N., Bureau of Aeronautics.
Mr. N. E. Promisel, Burau of Aeronautics.
Mr. John H. Collins, Jr., National Advisory Committee for Aeronautics.
Mr. C. T. Evans, Jr., Elliott Co.
Mr. Russell Franks, Electro Metallurgical Corp.
Dr. James W. Freeman, University of Michigan.
Dr. Marcus A. Grossmann, Carnegie-Illinois Steel Corp.
Mr. Norman L. Mochel, Westinghouse Electric Corp.
Dr. Gunther Mohling, Allegheny Ludlum Steel Corp.

Subcommittee on Induction-System De-Icing

Mr. Arthur A. Brown, Pratt & Whitney Aircraft, Chairman.
Lt. James E. DeRomer, A. D. Air Matériel Command.
Mr. Stephen Rolle, Civil Aeronautics Administration.
Mr. Willson H. Hunter, National Advisory Committee for Aeronautics.
Mr. M. G. Beard, American Airlines.
Mr. Robert E. Johnson, Wright Aeronautical Corp.
Mr. R. D. Kelley, United Air Lines Transport Corp.
Mr. Milton J. Kittler, Holley Carburetor Co.
Mr. William C. Lawrence, American Airlines.
Mr. Frank C. Mock, Bendix Aviation Corp.

COMMITTEE ON AIRCRAFT CONSTRUCTION

Mr. Arthur E. Raymond, Douglas Aircraft Co., Chairman.
Capt. Robert S. Hatcher, U. S. N., Bureau of Aeronautics, Vice Chairman.
Col. Paul H. Kemmer, Air Corps, Air Matériel Command.
Mr. J. B. Johnson, Air Matériel Command.
Commander C. W. Stirling, U. S. N., Bureau of Aeronautics.
Capt. James E. Sullivan, U. S. N. R., Bureau of Aeronautics.
Mr. Paul F. Voigt, Jr., Carnegie-Illinois Steel Co.
Mr. A. A. Vollmecke, Civil Aeronautics Administration.
Dr. Gordon M. Kline, National Bureau of Standards.
Dr. G. W. Lewis (ex officio), National Advisory Committee for Aeronautics.
Mr. D. O. Benson, Northwest Airlines.
Mr. S. K. Colby, Aluminum Co., of America.
Mr. R. L. Templin, Aluminum Co. of America.

Subcommittee on Aircraft Structural Design

Mr. R. L. Templin, Aluminum Co. of America, Chairman.
Lt. Col. E. H. Schwartz, Air Corps, Air Matériel Command.
Lt. Col. Benjamin Smilg, Air Corps, Air Matériel Command.
Commander Cedric W. Stirling, U. S. N., Bureau of Aeronautics.
Mr. Charles B. Lyman, Bureau of Aeronautics.
Mr. E. I. Ryder, Civil Aeronautics Administration.
Mr. George Snyder, Boeing Aircraft Co.

Dr. Walter Ramberg, National Bureau of Standards.
Dr. E. E. Lundquist, National Advisory Committee for Aeronautics.
Mr. Richard V. Rhode, National Advisory Committee for Aeronautics.
Mr. G. L. Bryan, The Glenn L. Martin Co.
Prof. E. W. Conlon, University of Michigan.
Prof. Joseph S. Newell, Massachusetts Institute of Technology.
Mr. R. L. Schleicher, North American Aviation.

Subcommittee on Aircraft Methods

Mr. Paul P. Voigt, Jr., Carnegie-Illinois Steel Corp., Chairman.
Mr. J. B. Johnson, Air Matériel Command.
Mr. N. E. Promisel, Bureau of Aeronautics.
Mr. William F. Roeser, National Bureau of Standards.
Mr. E. I. Ryder, Civil Aeronautics Administration.
Mr. John H. Collins, Jr., National Advisory Committee for Aeronautics.
Mr. E. H. Dix, Jr., American Magnesium Corp.
Dr. J. C. McDonald, The Dow Chemical Co.
Dr. Maxwell Gensamer, Pennsylvania State College.
Mr. R. B. Gray, Reynolds Metals Co.

Subcommittee on Wood and Plastics for Aircraft

Dr. Gordon M. Kline, National Bureau of Standards, Chairman.
Mr. Robert Temple, Bureau of Aeronautics.
Mr. James E. Dougherty, Civil Aeronautics Administration.
Mr. L. J. Markwardt, Forest Products Laboratory.
Mr. George H. Clark, Formica Insulation Co.
Dr. Harry C. Engel, The Glenn L. Martin Co.
Dr. Milton Harris, Milton Harris Associates.
Mr. Bernard Budiansky, National Advisory Committee for Aeronautics
Dr. Lorin B. Sebrell, Goodyear Tire & Rubber Co.
Mr. J. H. Tigelaar, Haskelite Manufacturing Co.
Mr. Robert T. Schwartz, Air Technical Service Command.

COMMITTEE ON OPERATING PROBLEMS

Mr. William Littlewood, American Airlines, Chairman.
Brigr. Gen. Haywood F. Hansell, Jr., Air Transport Command.
Col. J. M. Gillespie, Air Corps, Air Matériel Command.
Capt. Robert S. Hatcher, U. S. N., Bureau of Aeronautics.
Commander Homer F. Webster, U. S. N. R., Naval Air Transport Service.
Mr. Donald Stuart, Civil Aeronautics Administration.
Dr. Francis W. Reichelderfer, United States Weather Bureau.
Dr. G. W. Lewis (ex officio), National Advisory Committee for Aeronautics.
Capt. Harold E. Gray, Pan American World Airways.
Mr. Richard V. Rhode, National Advisory Committee for Aeronautics.
Mr. M. G. Beard, American Airlines.
Mr. K. R. Ferguson, Northwest Airlines.
Mr. H. H. Gallup, Transworld Airways.
Mr. Ben O. Howard, Douglas Aircraft Co.
Mr. Jerome Lederer, Aero Insurance Underwriters.
Mr. W. C. Mentzer, United Air Lines Transport Corp.
Mr. Charles F. Dycer, Civil Aeronautics Administration.

Subcommittee on Meteorological Problems

Dr. Francis W. Reichelderfer, United States Weather Bureau, Chairman.
Col. Marcellus Duffy, Air Corps, Headquarters Signal Corps, Ground Signal Agency.
Col. D. N. Yates, Air Corps, American Air Force Weather Service.
Dr. Ross Gunn, Naval Research Laboratory.
Capt. Howard T. Orville, U. S. N., Bureau of Aeronautics.
Mr. Delbert M. Little, United States Weather Bureau.
Mr. George M. French, Civil Aeronautics Board.
Mr. Eugene Sibley, Civil Aeronautics Administration.
Mr. Philip Donely, National Advisory Committee for Aeronautics.
Mr. C. E. Buell, American Airlines.
Mr. E. J. Minser, Transworld Airways.
Dr. Carl G. Rossby, University of Chicago.
Prof. E. J. Workman, University of New Mexico.

Subcommittee on De-Icing Problems

Mr. L. A. Rodert, Stewart-Warner Corp., Chairman.
Mr. Clare I. Valentine, Air Matériel Command.
Mr. H. C. Sontag, Bureau of Aeronautics.
Mr. Alan L. Morse, Civil Aeronautics Authority Experimental Station.
Mr. B. C. Haynes, United States Weather Bureau.
Mr. Duane M. Patterson, Army Air Forces, Air Matériel Command.
Mr. Alun R. Jones, National Advisory Committee for Aeronautics.
Mr. Willson H. Hunter, National Advisory Committee for Aeronautics.
Prof. H. G. Houghton, Massachusetts Institute of Technology.
Mr. R. L. McBrien, The Glenn L. Martin Co.
Mr. Howard Schmidt, Consolidated Vultee Aircraft Corp.

SPECIAL COMMITTEE ON MATERIALS RESEARCH COORDINATION

Mr. Russell G. Robinson, National Advisory Committee for Aeronautics, Chairman.
Mr. Bernard Rubinstein, Executive Secretary.
Mr. J. B. Johnson, Air Matériel Command.
Capt. James E. Sullivan, U. S. N. R., Bureau of Aeronautics.
Mr. Albert A. Vollmecke, Civil Aeronautics Administration.
Dr. Clyde Williams, Battelle Memorial Institute.
Lt. Comdr. George Vaux, U. S. N. R., Navy Department.
Mr. Albert Epstein, Republic Aviation Corp.
Mr. A. T. Gregory, Fairchild Engine & Airplane Corp.
Mr. Raymond P. Lansing, Bendix Aviation Corp.
Mr. F. R. Shanley, Lockheed Aircraft Corp.
Mr. Robert Q. Barr, National Advisory Committee for Aeronautics.

SPECIAL COMMITTEE ON SELF-PROPELLED GUIDED MISSILES

Dr. Hugh L. Dryden, National Bureau of Standards, Chairman.
Maj. Ezra Kotcher, Air Corps, Air Technical Service Command.
Brig. Gen. Alden R. Crawford, Air Corps.
Capt. Delmar S. Fahrney, U. S. N., Bureau of Aeronautics.
Capt. W. T. Rasieur, U. S. N., Navy Department.
Dr J. C. Hunsaker (ex officio), National Advisory Committee for Aeronautics.
Dr. G. W. Lewis (ex officio), National Advisory Committee for Aeronautics.
Mr. R. R. Gilruth, National Advisory Committee for Aeronautics.
Dr. J. C. Boyce.
Capt. Kenneth H. Noble, U. S. N., Navy Department, Bureau of Ordnance.
Col. J. G. Bain, War Department, Rocket Development Division.

Mr. Abe Silverstein, National Advisory Committee for Aeronautics.

SPECIAL COMMITTEE ON SURPLUS AIRCARFT RESEARCH

Dr. Theodore P. Wright, Administrator of Civil Aeronautics, Chairman.
Col. Paul H. Kemmer, AAF.
Col. George C. Price, AAF.
Capt. R. S. Hatcher, U. S. N., Bureau of Aeronautics.
Mr. R. B. Maloy, Civil Aeronautics Administration.
Mr. John W. Crowley, Jr., National Advisory Committee for Aeronautics.
Mr. A. W. Dallas, Air Transport Association of America.
Mr. William Littlewood, American Airlines, Inc.
Mr. I. O. Peterson, Aircraft Industries Association of America, Inc.
Mr. F. R. Shanley, Lockheed Aircraft Corporation.
Mr. Ralph Lockwood, War Assets Administration.

INDUSTRY CONSULTING COMMITTEE

Mr. J. H. Kindelberger, North American Aviation, Chairman.
Mr. H. M. Horner, United Aircraft Corp., Vice Chairman.
Mr. Lawrence D. Bell, Bell Aircraft Corp.
Mr. Jack Frye, Transworld Airways.
Mr. Robert E. Cross, Lockheed Aircraft Corp.
Mr. Fred E. Weick, Engineering & Research Corp.
Mr. C. Bedell Monro, Pennsylvania-Central Airlines.
Mr. William T. Piper, Piper Aircraft Corp.

Part IV
FINANCIAL REPORT

Appropriations for fiscal year 1946. The following funds were appropriated for the Committee for the fiscal year 1946 in the Independent Offices Appropriation Act, 1946, approved May 3, 1945:

Salaries and expenses	$25, 990, 393
Printing and binding	15, 000
Total appropriations	26, 014, 393

Subsequent actions of the Congress and the Bureau of the Budget reduced the availability of the appropriated funds by $3,000,000, as follows:

First Supplemental Surplus Appropriation Recision Act, 1946, approved February 18, 1946	$2, 000, 000
Placed in reserve by the Bureau of the Budget, May 22, 1946	1, 000, 000
Total recisions	3, 000, 000

Obligations incurred during the fiscal year 1946 are listed below. The figures shown are total obligations and include the costs of personal services, travel expenses, utility services, supplies, equipment, etc.

Activity and obligations—1946

Headquarters Office, Washington, D. C.	$435, 934
Langley Memorial Aeronautical Laboratory	9, 700, 904
Ames Aeronautical Laboratory	2, 918, 166
Aircraft Engine Research Laboratory	9, 473, 173
Research contracts—educational institutions	276, 204
Transfer to the National Bureau of Standards	127, 000
Printing and binding, all activities	14, 961
Total obligations	22, 946, 342
Recisions	3, 000, 000
Unobligated balance	68, 051
Total appropriations	26, 014, 393

No new appropriations were provided in fiscal year 1946 for the construction and equipment of laboratory facilities. However, the following amounts were obligated during 1946 from construction and equipment appropriations made available in prior fiscal years:

Langley Memorial Aeronautical Laboratory	$4, 155, 087
Ames Aeronautical Laboratory	4, 307, 368
Aircraft Engine Research Laboratory	5, 548, 036
Total	14, 010, 491

Appropriations for the fiscal year 1947. The following funds have been appropriated for the Committee for the fiscal year 1947 in the Independent Offices Appropriation Act, 1947, approved March 28, 1946:

Salaries and expenses	$26, 500, 000
Printing and binding	75, 000
Construction and equipment of laboratory facilities:	
Langley laboratory	2, 990, 000
Cleveland laboratory	108, 000
Total	29, 673, 000

Supplemental and deficiency estimates of appropriations for the fiscal year 1947 have also been submitted to the Bureau of the Budget in the following amounts:

Salaries and expenses	$2, 089, 000
Construction and equipment of laboratory facilities:	
Langley laboratory	5, 805, 990
Cleveland laboratory	1, 674, 200
Total	9, 569, 190

CONCLUSION

Aeronautical science stands on the threshold of a new era. New forms of propulsion, even excluding the possibilities of atomic energy, open up new speed concepts for both military and commercial aviation.

The recent war saw the full development of aerial warfare using conventional aircraft operating at subsonic speeds. The possibilities of supersonic military aircraft and of guided missiles indicate that present types of military aircraft are becoming obsolete. As we prepare to enter the new era, we see no definite limit to the power that may become available for aircraft propulsion, nor to the speed that may be attainable. These possibilities confront the NACA with whole new fields of scientific problems requiring the provision of new facilities for supersonic research. And, after fundamental research has disclosed the design data and new shapes for supersonic aircraft, there will be another entirely new field of research to provide stability and control at the low speeds necessary for take-off and landing.

In the meantime, the aircraft industry remains essential for future national security. It is national policy to sustain that industry with orders for the necessary production of service aircraft and for the design and development of new and improved types. This results in an increased burden on the staff and facilities of the NACA to provide as quickly as possible the fundamental data needed by the military services and the industry as a basis for new designs. Teamwork between the military services, industry, and the NACA was never more essential, nor more effective.

Laboratory facilities of the NACA are being expanded to provide some of the urgently needed research facilities. The basic research activities of the NACA are the foundation of progress in America in improving the performance, efficiency, and safety of both military and civil aircraft.

Respectfully submitted.

JEROME C. HUNSAKER, *Chairman.*
National Advisory Committee for Aeronautics.