TWENTY-SECOND ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1936

INCLUDING TECHNICAL REPORTS
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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 Twenty-second Annual Report of the Committee, covering the fiscal year ended June 30, 1936.

FRANKLIN D. ROOSEVELT.

THE WHITE HOUSE,
January 11, 1937.

LETTER OF SUBMITTAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., December 10, 1936.

MR. PRESIDENT:

In compliance with the provisions of the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 153), I have the honor to submit herewith the Twenty-second Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1936.

During the past year there was continued improvement in the safety, efficiency, range, speed, comfort, and capacity of American aircraft. This gratifying progress in technical development was based largely upon the results of organized fundamental scientific research.

With the support of the President and of the Congress the research laboratories of this Committee at Langley Field, Va., have kept pace with the growing research needs of aviation, and they are as yet unsurpassed by the aeronautical research facilities of any other single nation. Increased recognition abroad of the value and of the vital necessity of aeronautical research has led to recent tremendous expansion in research programs and to multiplication of research facilities by other progressive nations. Thus has the foundation been laid for a serious challenge to America's present leadership in the technical development of aircraft.

This committee, alert to its responsibilities, has prepared plans for continued gradual expansion and improvement of its research facilities. In view of the increasing significance attaching to aircraft development in all parts of the world for both military and commercial purposes, this committee urges the wisdom and ultimate economy of its policy as the best insurance against falling behind in the development of an instrumentality so vital to national defense and so effective in the promotion of commerce and in the advancement of civilization.

Respectfully submitted.

J. S. AMES, *Chairman.*

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

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, NAVY BUILDING, WASHINGTON, D. C.

LABORATORIES, LANGLEY FIELD, VA.

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 50, Sec. 151). 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 STRUCTURES AND MATERIALS
AIRCRAFT ACCIDENTS
INVENTIONS AND DESIGNS

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.

Unified conduct, 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.

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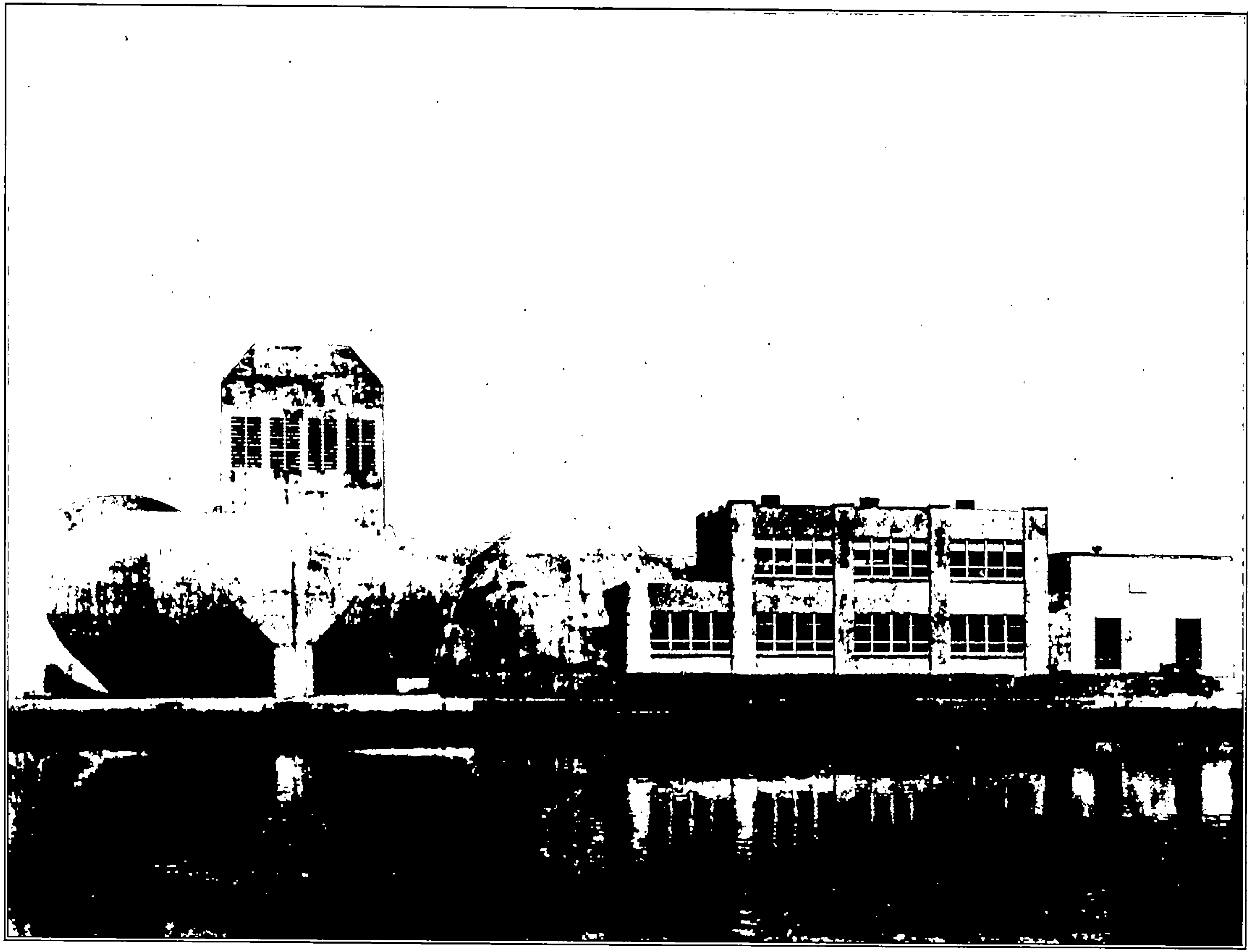

N. A. C. A. 8-FOOT HIGH-SPEED WIND TUNNEL, LANGLEY FIELD, VA.

TWENTY-SECOND ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 12, 1936.*

To the Congress of the United States:

In accordance with the act of Congress approved March 3, 1915 (U. S. C., title 50, section 151), which established the National Advisory Committee for Aeronautics, this Committee submits herewith its twenty-second annual report, covering the fiscal year 1936.

Present status of research.—Improvement in aircraft performance, characteristic of the past few years, was continued in 1936. Important factors underlying the recent remarkable development of American aircraft have now been largely incorporated in the airplane designs of foreign nations. In the major European countries there has been intense effort in the development of improved aircraft and great expansion in aircraft programs and in production facilities. But what most directly interests this Committee is the increased appreciation abroad of the basic importance of scientific research in aeronautics. During the past two years there has been abundant evidence of the greatly increased appreciation by foreign powers of the essential role that research plays in the development of aviation. Intensive activity in the major European countries in building larger air fleets has been accompanied generally by extensive programs providing for research and development. This emphasizes the fact that when large sums of money are to be expended upon procurement of aircraft it is wise to predicate such expenditure upon adequate research and experimental development as being the only means of assuring the best possible return on the investment.

Increased responsibilities of this committee.—One result of the growing appreciation by European nations of the significance of the airplane in commerce and in modern warfare has been to increase the responsibilities of the National Advisory Committee for Aeronautics. It is one of the duties of this Committee to anticipate, and, with the support of the President and of the Congress, to provide for, the research needs of aviation, civil and military. The fundamental problems arising out of the rapid development of military, naval, and commercial airplanes have broadened in scope and variety and have become more and more urgent. The War, Navy, and Commerce Departments are each requesting priority in the conduct of special investigations to meet their immediate requirements. In the rapidly advancing science of aeronautics the means and methods of conducting scientific research are changing and improving quite as rapidly as airplane design and performance change and improve. To meet adequately the increased requirements of the departments concerned, an enlarged research staff, modernization by this Committee of its research equipment, and provision of new research equipment are required.

Development of research facilities.—The Committee years ago recognized the importance and the value of conducting wind-tunnel investigations under approximately flight conditions; that is, at high values of Reynolds Number. In 1921 the Committee constructed the first variable-density wind tunnel. This was later duplicated abroad. In 1926 the Committee constructed what was then the largest wind tunnel in the world, having a throat diameter of 20 feet. With this wind tunnel it was possible for the first time to investigate full-scale propellers, engine nacelles, landing gears, and other parts of an airplane, but not a whole airplane. Wind tunnels of this size, improved in design and operating at higher wind velocities, have since been constructed in several countries. To study small full-size airplanes under flight conditions, the Committee constructed in 1930 the full-scale wind tunnel. This has since been duplicated abroad. The trend in the design and construction of wind tunnels abroad has followed in general the developments of large wind tunnels in this country.

In order to begin the study of air flow at very high speeds approximating the velocity of sound in air, the Committee constructed an 11-inch high-velocity jet-type wind tunnel and later a 24-inch tunnel of the same type.

During the past year this Committee placed in operation at Langley Field its new 500-mile-per-hour wind tunnel, which has a throat 8 feet in diameter. This new type of wind tunnel has more than met its designed performance. Early experience with its operation indicates that it will be a valuable addition to the Committee's research facilities and, by the use of larger models than can be used in the 24-inch tunnel, will make available to American airplane designers more accurate information and data regarding the natural laws governing air flow and the flight of aircraft at high speed than thus far are available to designers in any other nation.

Additions and improvements.—The large seaplane is becoming an important factor in the development of transoceanic air transportation and of long-range naval aircraft. To meet the problems presented by this development, this Committee secured during the past year a supplemental appropriation to lengthen by approximately 900 feet the present seaplane towing basin, known as the "N. A. C. A. Tank." This extension, on which work has been started, will make the tank 2,900 feet long and will make it possible to study the hydrodynamic characteristics of seaplane floats and flying-boat hulls at water speeds up to at least 80 miles per hour.

The increasing size and speed of aircraft have made necessary the development of a new type of wind tunnel. During the past year a supplemental appropriation was granted by the Congress for the construction of a large pressure-type wind tunnel in which relatively large models can, by increasing the pressure in the tunnel to three or more atmospheres and thus increasing the Reynolds Number, be tested under conditions that will give results more nearly corresponding to the actual performance of large airplanes flying at high speed than it is possible to obtain in any wind tunnel in the United States at this time. Since starting work on this wind tunnel, the Committee has learned that a wind tunnel of similar type has recently been completed abroad.

To maintain leadership in the development and use of aircraft, it is essential that research laboratories in the United States have the latest and most efficient equipment for the study of problems arising as a result of the higher speeds and increased size of aircraft. Advantage was taken of advances that have been made in wind-tunnel technique, and during the past year the propeller-research tunnel and the 7- by 10-foot wind tunnel were modernized and brought to a more satisfactory and efficient operating condition.

At the present time the laboratories of this Committee comprise the following units: The 8-foot 500-mile-per-hour wind tunnel; the full-scale wind tunnel; the propeller-research tunnel; the variable-density wind tunnel; a 7- by 10-foot wind tunnel; a refrigerated wind tunnel; a vertical wind tunnel; a free-spinning wind tunnel; two high-velocity jet-type wind tunnels of 11- and 24-inch throat diameters, respectively; the N. A. C. A. Tank (now being lengthened); an engine research laboratory; a flight research laboratory; and an instrument laboratory. In addition there is under construction at the present time the new pressure-type wind tunnel previously referred to. The Committee's laboratories are known as the Langley Memorial Aeronautical Laboratory and are located at Langley Field, Virginia, on land set aside by the War Department for the use of this organization. At the present time the laboratory staff comprises 370 employees.

Duplication avoided.—The Committee's laboratories as a whole are, we believe, as yet unexcelled by those of any other single nation. In this connection, it is worthy of note that during the preceding twelve months twenty-five delegations from twelve foreign nations have visited the laboratories of this Committee at Langley Field, Virginia. The Committee's laboratories, although located on an Army field, are under the direct control of this Committee. This Committee has been greatly assisted in its activities by the cordial and effective cooperation of the War, Navy, and Commerce Departments, and it has in turn endeavored in every way to meet their research requirements. In doing so, this Committee has coordinated the research needs of aviation, civil and military, and has effectively avoided duplication of effort in this field. The success of this Committee as a coordinating agency and as an agency to conduct in one central aeronautical laboratory the fundamental scientific research necessary to meet the needs of both military and civil aviation, has been made possible largely by the status of this Committee as an independent Government establishment, and also by the fact that all governmental agencies concerned with the development of aeronautics are represented on this Committee and on its subcommittees.

This Committee has also kept in close touch with the research needs of aviation as suggested by the aircraft industry. This Committee believes that the independent scientific direction of aeronautical research, together with the invaluable cooperation of the War, Navy, and Commerce Departments and of the aircraft industry, has promoted economy and efficiency and has been a vital factor in the successful development of American aircraft.

Functions of the Committee.—Any national aviation policy would be incomplete that did not provide adequately for the comprehensive planning and execution of long-range programs of fundamental scientific research. The law provides that this Committee shall "supervise and direct the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions." This Committee is also authorized by law to "direct and conduct research and experiment in aeronautics."

Thus the primary function of the National Advisory Committee for Aeronautics is to conduct scientific research. It does not have under the law broad advisory functions which its name may seem to imply. In 1926 a subordinate function was added by law giving to this Committee the duty of advising and reporting upon the technical merits of aeronautical inventions and designs submitted to any branch of the Government for Government use. This Committee regards its primary function as the most fundamental activity of the Government in connection with the development of American aeronautics and as worthy of its sole and undivided attention. It does not seek any enlargement or change in its functions.

The formulation of research programs.—The technical subcommittees formulate comprehensive programs of fundamental research. All governmental agencies concerned are represented on these subcommittees, and in addition there are in some cases members selected from the industry and from educational institutions. The Army and Navy air organizations depend upon this Committee for the scientific study and investigation of fundamental problems connected with the design of improved military and naval aircraft. The Bureau of Air Commerce and the manufacturers of both military and civil aircraft also rely upon this Committee for fundamental data. This Committee institutes investigations and researches on the request of these governmental agencies, on the suggestion of the aircraft industry, and on its own initiative. Researches are usually so broadened in scope as to make the results applicable alike to military and to civil aircraft.

Supplementing this policy, and of equal importance, is the experimental engineering necessary to apply research results in the development of improved aircraft to meet varying needs. This experimental engineering is conducted for the Army Air Corps by the Matériel Division at Wright Field, Dayton, Ohio. For the Navy it is conducted by the Bureau of Aeronautics and the Naval Aircraft Factory. For civil and commercial aeronautics it is conducted by the manufacturers, acting in some cases in cooperation with the Bureau of Air Commerce and with educational institutions. The facilities of the National Bureau of Standards are also used by the War, Navy, and Commerce Departments, and by this Committee, for the conduct of certain investigations for which that Bureau is particularly well equipped, principally in the fields of physics and of metallurgy. Such research activities are coordinated through the standing technical committees of the National Advisory Committee for Aeronautics. Thus one central governmental research organization, with the active cooperation of the War, Navy, and Commerce Departments, of the aircraft industry, and of educational institutions, supplies the research needs of aviation without overlapping or duplication of effort.

Summary.—The continued improvement in the safety, efficiency, range, speed, comfort, and capacity of American aircraft is especially gratifying to this Committee. The results, we believe, justify the long-continued and sound policy of coordination of effort and systematic prosecution of fundamental scientific research.

In the United States the airplane is an important factor in the development of our national defense and, with the extension of the air lines of Pan American Airways, will become a factor of tremendous importance in the development of commercial relations with South America and with the Far East. At the present time plans are nearing completion for the inauguration at an early date of regular air transportation across the North Atlantic.

We believe that fundamental scientific research in aeronautics is the foundation upon which the future of American aircraft development must be built. The maintenance of American leadership becomes more difficult in the face of tremendous expansion of research facilities in foreign nations. We recommend continued support by the Congress of a policy of gradual expansion of our research staff and equipment to meet the changing and increasing needs of American aviation development and also to insure that America shall not fall behind in an undertaking so vital to its national defense and at the same time so invaluable in promoting through commerce the progress of civilization.

PART I

REPORTS OF TECHNICAL COMMITTEES

In order to carry out effectively its principal function of the supervision, conduct, and coordination of the scientific study of the problems of aeronautics, the National Advisory Committee for Aeronautics has established a group of technical committees and subcommittees. These technical committees prepare and recommend to the main Committee programs of research to be conducted in their respective fields, and as a result of the nature of their organization, which includes representation of the various agencies concerned with aeronautics, they act as coordinating agencies, providing effectively for the interchange of information and ideas and the prevention of duplication.

In addition to its standing committees and subcommittees, it is the policy of the National Advisory Committee for Aeronautics to establish from time to time special technical subcommittees for the study of particular problems as they arise.

The Committee has three principal technical committees—the Committees on Aerodynamics, Power Plants for Aircraft, and Aircraft Structures and Materials—and under these committees eight standing and two special subcommittees. The membership of these committees and subcommittees is listed in part II.

The Committees on Aerodynamics and Power Plants for Aircraft have direct control of the aerodynamic and aircraft-engine research, respectively, conducted at the Committee's laboratory at Langley Field, and of special investigations conducted at the National Bureau of Standards. The greater part of the research under the supervision of the Committee on Aircraft Structures and Materials is conducted by the National Bureau of Standards. The experimental investigations in aerodynamics, aircraft power plants, and aircraft structures and materials undertaken by the Bureau of Aeronautics of the Navy, the Army Air Corps, the National Bureau of Standards, and other Government agencies are reported to these three committees.

REPORT OF COMMITTEE ON AERODYNAMICS

During the past year, two special subcommittees have been organized under the Committee on Aerodynamics. The first of these, the Special Subcommittee on Aerodynamic Problems of Transport Construction and Operation, was established in March for the purpose of determining the research problems of particular interest and importance to air-transport operators which should be investigated by the Committee. In conjunction with the establishment of this subcommittee, a special conference of airplane pilots representing the air-transport operators and Government agencies concerned was held for the discussion of the handling characteristics and piloting technique of large transport airplanes. The activities of this special subcommittee and the work of the pilots' conference are described in part II of this report under the heading "Cooperation with the Aircraft Industry."

In April 1936, a Special Subcommittee on Vibration and Flutter was organized. This subcommittee was established at the suggestion of the Army Air Corps in view of the vital interest in and importance of the general problem of vibration, both to the military services and to commercial aeronautics. The work of this subcommittee is described at the close of the report of the Committee on Aerodynamics.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

LANDING SPEED AND SPEED RANGE

Wing flaps are now used on nearly all high-performance airplanes and the Committee has continued its wind-tunnel and flight investigations of the promising forms. Some work has also been done on a new design of leading-edge slot.

Flaps.—The investigation of the external-airfoil flap, which consists of an airfoil pivoted at the rear of the main wing, has been extended in the 7- by 10-foot wind tunnel to include an N. A. C. A. 23012 flap having a chord 30 percent of that of the main airfoil, which was also of N. A. C. A. 23012 section. With this size of flap there is an increase of maximum lift coefficient over that obtained with the size 20 percent of the chord previously investigated (Technical Report No. 573) and similar low values of profile drag throughout the entire lift range. This investigation, moreover, has served to indicate a general method of combining airfoils of the well-known N. A. C. A. 230 series in external-airfoil flap arrangements, a method which not only will provide excellent speed-range characteristics but which should be definitely superior to devices now commonly used in such items of performance as take-off, range, endurance, and ceiling.

At the request of the Navy Department, external-airfoil flaps have also been investigated on a Fairchild 22 airplane, both in the full-scale tunnel and in flight. The flap covered practically the entire span of the wing and the right and left halves were differentially deflected for lateral control. The flap was of Clark Y section and had a chord length equal to 20 percent of the chord of the main wing, which was of N. A. C. A. 23015 section. The investigation in the full-scale wind tunnel included tests in which the slot between the flap and the wing was covered, and the results showed that the slot effect appreciably increased the slope of the lift curve, the maximum lift coefficient, and the maximum value of lift-drag ratio. The maximum lift coefficient was found to be 1.51 with the flap set for minimum drag in cruising and 2.12 with the flap deflected downward 30°. The flight tests showed that the use of external-airfoil flaps reduced the low speed from 47 to 41 miles per hour and also reduced the take-off and landing distances. The position of the flap was found to be not critical as it is for split flaps, the reduction in take-off distance being about constant for the last third of the flap travel.

At the request of the Navy Department, tests were also made in the full-scale wind tunnel and in flight on a Fairchild 22 airplane equipped with a Cunningham-Hall wing. An internal air passage through the wing was provided by deflecting vanes in the under surface of the wing near the leading edge. Split trailing-edge flaps of Cunningham-Hall design were located on the under surface of the wing. In the deflected position a gap existed between the flap and the under surface of the wing. With the trailing-edge flap closed, opening the front vane to allow a passage of air through the wing increased the maximum lift coefficient obtained from 1.27 to 1.55. The trailing-edge flap increased the value further to 2.04. With the flap open, no increase in the maximum lift coefficient was obtained by opening the forward vane.

In the installation of the Cunningham-Hall wing tested on the Fairchild 22 airplane, the flap was intended to be automatic in operation by means of the action of a spring system sufficiently powerful to deflect fully the flap against the aerodynamic forces at low speeds. In the flight tests it was found that the automatic operation of the flap was unsatisfactory, however, because of internal friction in the mechanism. The internal air passage was found to have a negligible effect on the flight performance or on the flying qualities of the airplane. The flap was found to be effective in reducing the landing speed and the take-off distance.

A rather complete investigation has been made of ordinary trailing-edge flaps to provide extensive correlated data on their characteristics. Three airfoil sections, the Clark Y, the N. A. C. A. 23012, and the N. A. C. A. 23021, were tested in the 7- by 10-foot wind tunnel with ordinary flaps of three widths on the Clark Y airfoil and a flap of one width on each of the others. For purposes of comparison, one simple split flap was also investigated on the N. A. C. A. 23012 and on the 23021 airfoil. The aerodynamic characteristics of the airfoils with all the different flaps were measured and, in addition, hinge moments were obtained for the ordinary flaps on the Clark Y airfoil.

The results of the investigation are reported in Technical Report No. 554. It was found that the optimum width of ordinary flap for maximum lift attainable was the same as that of the split flap, 20 percent of the airfoil chord. The split flap produced somewhat greater increase in maximum lift coefficient on the airfoils tested than did the ordinary flap of the same width, but the lift-drag ratio at maximum lift was practically the same for the two types of flaps. Any gap between the airfoil and the leading edge of ordinary flaps had a very detrimental effect on the value of maximum lift coefficient attainable. On the basis principally of factors affecting airplane performance, the relative order of merit of the airfoils tested with either ordinary or split flaps is the N. A. C. A. 23012, the Clark Y, and the N. A. C. A. 23021. The hinge-moment coefficients of the ordinary flaps were practically the same as those of full-span split flaps of corresponding widths.

The report referred to last year on the effect of sudden operation of a flap on the motion of an airplane has been published as Technical Note No. 548. The results of the investigation of the Fowler flap reported previously have been published as Technical Note No. 578. The technical note presenting data on the Zap flap is now in preparation.

Maxwell slot.—Another investigation dealing with the improvement in speed range, carried out in the 7- by 10-foot wind tunnel at the request of the Bureau of Aeronautics, Navy Department, was concerned with the Maxwell leading-edge slot. This slot differs essentially from the Handley Page slot in that the moving parts operate solely by rotation. The Maxwell slot also provides a means for producing an unbroken leading-edge contour when it is in the closed condition. The test results, which are to be published in the form of a technical note, indicate that the aerodynamic characteristics of the Maxwell-type slot are substantially the same as those of the Handley Page type.

CONTROLLABILITY

In last year's report it was stated that in order to compute from the results of wind-tunnel tests the actual response to lateral-control devices in flight, it was found necessary to make a rather complete mathematical analysis. This analysis included the secondary factors, such as the yawing moments given by the controls, their effect on the damping in roll, all the other lateral-stability derivatives of the airplane, and the moments of inertia of the airplane. The use of this method has been continued throughout the past year and some of the results have been published in Technical Report No. 570. The study of conditions above the stall indicated that satisfactory control could not be expected without some provision to maintain the damping in rolling and that a dangerous type of instability would arise if the damping was insufficient. From the information gained by the use of this method a critical analysis and comparison are being made of various lateral-control devices that have been tested in the 7- by 10-foot wind tunnel during the past several years.

The provision of an adequate degree of control with the expenditure of small operating effort is being given primary consideration in these comparisons. A matter of some interest in this connection is the possibility of reducing the operating force of aileron devices by means of an ordinary differential linkage. This method of balancing has shown so much promise that a separate study has been made of it. As a result of this study, charts that enable the designer to select an appropriate linkage arrangement for a given control device have been prepared for publication.

In the calculations of the actions of airplanes following control deflections or other disturbances, the operational calculus has proved a valuable device. Such calculations have been applied in a study of two-control operation of an airplane. Here the effects of a variety of possible procedures of control have been investigated and it is felt that the outcome of this study has shed some light on more general questions relating to lateral controllability and stability. An account of the simpler applications of the operational method has been prepared and published as Technical Report No. 560. A description of some more extensive applications is being incorporated in a report on two-control operation.

Slot-lip ailerons.—The investigation of slot-lip ailerons mentioned in last year's report has been continued both in the wind tunnels and in flight. Tests in flight and in the full-scale wind tunnel were made with the ailerons fitted to a Fairchild 22 airplane. The ailerons were tested at two chordwise positions on the wing, one with the hinge axis at 20 percent of the chord behind the leading edge and the other with the hinge axis at 45 percent. The wing was fitted with a split flap. The results from the full-scale wind tunnel showed that the forward aileron slot increased the minimum drag coefficient of the airplane by 7 percent and that the rear one increased it by 4 percent. These drag increases are considered excessive for modern high-performance airplanes.

In the flight tests the ailerons in the forward position were found to be fairly effective in rolling the airplane for most flight conditions, but at moderately high speeds with the flap deflected the rolling action became very weak. It was apparent that unless otherwise limited, the maximum speed with flaps deflected would be limited by the value at which there was a total loss in lateral control. The control forces with the slot-lip ailerons were considerably greater than is desirable for an airplane of the size of the Fairchild 22. In the rear position, the ailerons were appreciably less effective than in the front position, but the effectiveness was maintained throughout the speed range. The control force was less than for the forward position. In both positions there was an apparent lag in the action of the ailerons. Instrument records showed that this was not exactly a lag between the operation of the aileron and the start of the response, but sluggishness in the attainment of maximum rolling velocity, or a low average acceleration in rolling.

The behavior of the slot-lip ailerons on this airplane did not seem to be in accord with the observed satisfactory behavior of the slot-lip ailerons on the W–1A airplane, as mentioned last year. To aid in the explanation of the apparent discrepancy between the results obtained with the two different installations of slot-lip ailerons, measurements of the rolling velocities were obtained with the W–1A airplane for comparison with similar measurements obtained with the Fairchild 22 airplane. These measurements showed that the W–1A ailerons were as effective as the ailerons in the forward location in the Fairchild 22 airplane and that they gave the same type of variation with speed as those located in the rearward position on the Fairchild 22 airplane. The results of measurements thus tend to verify the difference in observed behavior of the two airplanes but do not explain why this difference should exist. The slot-lip ailerons on the W–1A airplane were located at the point of 30 percent of the chord of the wing and were used in conjunction with a special type of slotted balanced flap instead of a split flap as installed on the Fairchild 22.

In this general connection a detailed analysis of flight records of the motion of the airplane following a movement of the control has been made and the relative sluggishness of ordinary and of slot-lip ailerons has been determined. A report is being prepared which will include results from both wind-tunnel and flight tests of slot-lip ailerons.

The investigation of the special form of slot-lip aileron, consisting of a plain aileron forming the trailing edge of an airfoil equipped with an external-airfoil flap, has been continued in the 7- by 10-foot tunnel, and a report on this work is being prepared. This type of aileron, which provides a means of lateral control in combination with a full-span flap without adding appreciably to the drag of the wing, appears to offer unusual control possibilities in connection with flight at high lift coefficients. The results of the investigation of slot-lip ailerons in connection with wings equipped with external-airfoil flaps of various sizes are now being prepared for publication.

External-airfoil flaps deflected as ailerons.—As noted previously in the discussion in connection with high-lift devices, the external-airfoil flap on the Fairchild 22 airplane was used for lateral control as well as for high lift. The flap was divided at the center and the two parts were deflected relative to each other for lateral control. Because a differential linkage could not be used on account of overbalance difficulties in the flap-down position, an equal up-and-down deflection of 10° was used. This arrangement gave satisfactory response except for the large adverse yawing moments produced, and for the fact that the control forces were greater than are considered desirable. Recent analyses indicate, however, that by proper design both of these disadvantages can be substantially reduced.

Ailerons on tapered wings.—At the request of the Army Air Corps, an investigation of lateral control is being made both in the full-scale wind tunnel and in flight on a full-scale tapered wing fitted to a Fairchild 22 airplane for direct comparison with a straight wing having ailerons of the same size. These tests are now in progress.

In view of the present widespread use of partial-span split flaps on tapered wings, it was considered desirable to provide information on aileron design for this general arrangement. Tests of two wings having medium and high taper ratios have recently been completed in the 7- by 10-foot tunnel, and the results are being prepared for publication. The data include the aerodynamic information necessary for aileron design, together with aerodynamic characteristics of the wings themselves. The report should provide a more clear-cut basis than has heretofore been available to designers for optimum proportioning of ailerons and split flaps on wings of various taper ratios.

Floating tip ailerons.—The above-mentioned tapered wing on the Fairchild 22 airplane is fitted with removable tips that can be replaced by floating tip ailerons. The flight tests will include a comparison of the floating tip ailerons with the conventional ailerons on the same wing.

Failure of one engine on a two-engine airplane.—Two problems of special importance arise in connection with the failure of one engine on an airplane having two wing engines: (1) A sudden yawing moment due to the failure of thrust on one side which usually cannot be overpowered by the rudder at low flight speeds; and (2) a large increase in drag and resulting loss of performance due to the yawed condition of the airplane and the deflected controls when flying on one engine.

These problems are of considerable importance to commercial operation and the Committee was asked to study the possibilities of improvement of the control and of reduction of drag. A large model of a low-wing airplane equipped with operating propellers was fitted with several new designs of tail surfaces and tested in the 20-foot tunnel. The model was tested with both single and double rudders, the latter inclined varying amounts in order to provide correcting yawing moments automatically. The nacelles were also inclined laterally to direct the slipstream on the vertical tail surfaces at an angle. Neither of these schemes provided more than about one-fourth the yawing moment needed to balance the thrust of the operating motor. One fact determined was that the tail surfaces of the low-wing monoplane were not completely in the slipstream on account of the fact that the downwash carried the slipstream down with it. The results of the yawing-moment tests, together with the results showing the loss of performance due to the increased drag in flight on one of two engines, are to be published in the near future.

Flying qualities of large airplanes.—An investigation has been initiated during the current year of the general stability, controllability, and maneuverability of large airplanes. This work has consisted of a review of the problem for the purpose of determining how much is known regarding the flying qualities of large airplanes in quantitative values, and also what the procedure should be in the investigation, on a quantitative basis, of the flying qualities of large airplanes. It is desired that all characteristics that influence the flying qualities of the airplane be actually measured and quantitative values obtained so as to remove guesswork concerning points of deficiency. This preliminary study has resulted in the preparation of a flight program of investigation in which all the quantities believed to be of importance will be measured. The procedure laid down is now being tried in flight on a five-place high-wing monoplane.

Magnitude of control forces available.—The paper mentioned in last year's report on the results of an investigation of the forces that a pilot is able to exert on the control column and rudder pedals of an airplane has been published as Technical Note No. 550. In accordance with a request of the Bureau of Air Commerce, the investigation has been extended to include measurements of the force that the pilot can exert on the wheel-type elevator and aileron control. The effect of wheel diameter and position and the difference between forces that can be applied with various hand grips have been investigated.

During the current year, considerable data pertaining to the control forces actually exerted by a pilot in flight have been obtained. In conjunction with investigations of lateral-control devices, the forces required to operate the ailerons have been recorded primarily for the purpose of determining the magnitude of the forces the pilots consider to be desirable and those that they consider to be excessive. For the Fairchild 22 airplane, with which most of the measurements were made, it appears that the stick forces required to operate the ailerons should be below, and possibly well below, about 8 pounds in order to be considered desirable. A lateral force of 15 pounds is considered to be excessive.

Measurements were also made of the control forces and movements on two naval airplanes in flight, primarily for the purpose of determining the requirements of an automatic pilot. On one of these airplanes, additional measurements were made in order to explain undesirable characteristics of the elevator control. Modifications of the airplane were recommended on the basis of these tests.

STABILITY

A review of all available previous and contemporary work on stability is now being undertaken. It is expected that a systematic correlation and analysis of available aerodynamic data will make possible the development of satisfactory semi-empirical formulas for the estimation of certain of the aerodynamic factors which govern stability characteristics.

A study is being made of the practicability of certain new types of apparatus that have been proposed for use in the determination of the stability characteristics of models. It is hoped that in the near future it will be possible to make systematic studies of the effects of changes in dimensional characteristics upon both the aerodynamic factors governing the free motion and the resulting free motion itself.

Lateral stability.—A report on lateral stability in power-off flight is being prepared for publication. This report will parallel Technical Report No. 521, which dealt with longitudinal stability. It will include a discussion of the problem and of the individual factors involved. A number of charts will be presented from which the lateral stability of a new design can be quickly and easily estimated.

Tests have been made in the 7- by 10-foot tunnel to determine the effect of dihedral angle and the effect of wing-tip shape on some of the aerodynamic characteristics affecting lateral stability, e. g., the rolling and yawing moments and the cross-wind force due to yaw and the damping in roll. The results of these tests are presented in Technical Report No. 548. It was found that the effect of dihedral angle could be predicted quite accurately but that the total "dihedral effect" depends upon the particular shape of the wing in plan and elevation. The addition of a deflected flap to a wing changes the effective dihedral. Experience has shown that high-wing monoplanes have more effective dihedral than low-wing monoplanes, which indicates that wing-fuselage interference probably has an important influence on the effective dihedral. It is planned to obtain quantitative data on the dihedral effect with various wing and fuselage combinations.

Longitudinal stability.—The results of the investigation to determine the relation between the longitudinal stability and the flying qualities of several airplanes, as mentioned in the last annual report, have been prepared for publication.

Tail surfaces for airplanes equipped with wing flaps.—An analysis is being made of the horizontal tail surfaces required for airplanes equipped with wing flaps. This analysis, although not complete, indicates the need of larger tail surfaces to compensate for the larger couple about the aerodynamic center of the wing which is experienced with flaps. Consideration must be given to the setting of the tail surfaces to make certain that they do not stall when the airplane is flying at low angles of attack with the flap deflected. With wing flaps, such factors as the retardation of the flow by the wings and turbulence in the wake of the wings assume even more importance than they do with plain wings.

TAKE-OFF

The results of calculations of the effect of various flaps on take-off mentioned last year have been published as Technical Note No. 568. One interesting point brought out by those calculations was that, for an aspect ratio of 5 assumed for the wings, there appeared to be a fairly definite theoretical upper limit to the maximum lift coefficient that would result in reduction in take-off distance, even for an ideal high-lift device in which the only increase in drag with increased lift was the increase of induced drag. Subsequent calculations have been made to determine what this limiting maximum lift coefficient is as a function of aspect ratio. These latter calculations indicate that 3.5 is about the maximum lift coefficient desirable with a wing loading of 30 pounds per square foot and an aspect ratio of 12. With lower wing loadings and aspect ratios or with high-drag wings the desirable maximum lift coefficient is lower.

In calculations of the take-off distance of airplanes, three distinct phases of motion are ordinarily assumed: a horizontal ground run, a transition period of curvilinear flight, and a steady climb. A preliminary study of the take-off problem indicated that existing information regarding the rolling friction of airplane wheels was inadequate. The investigation of rolling friction of airplane wheels mentioned last year was therefore undertaken. The results of this investigation are nearly ready for publication. As regards the second phase, or transition period, it was found that simplifying assumptions of unknown validity were required before the calculations could be made, and that an experimental study to determine the validity of these assumptions was advisable. Such a study is now being made. In this investigation the motion of an airplane during the transition period is being measured in flight and carefully studied.

As a result of experience obtained in making comparative take-off tests with various airplanes with high-lift wings on one type of airplane, as well as with different wing and power loadings, it has been found to be very difficult to obtain consistent data in consecutive runs. As a result of improvement in the apparatus used in measuring the take-off distance inconsistencies were traced in a large measure to air-speed variations. It was found that small differences between the speed at which the airplane in consecutive runs arrived at the point of take-off or a given altitude of, say, 50 feet, accounted for large discrepancies in the horizontal distance required for the ground run or the total run. It is very difficult for the pilot to reproduce speeds exactly enough for comparative performances without correction for these speed differences. This is particularly true with regard to an airplane having a rapid acceleration and a high initial rate of climb.

LANDING

Landing of airplanes equipped with wing flaps.—The technique of landing airplanes equipped with wing flaps has been discussed in Technical Note No. 553. Wing flaps cause the airplane to assume a steep nose-down attitude during the gliding approach to a landing. This fact must be accepted as inherent with conventional flapped airplanes. The use of power to hold the nose up during a glide may result in difficulty in placing the airplane in a three-point attitude for contact with the ground. Because of the steeper gliding angle and the more rapid deceleration resulting from the high drag of the airplane with wing flaps, it is essential that the airplane approach for the landing with a greater margin of speed above the stall than is normally the case with plain wings and that the elevator-control movements for leveling off prior to contact be made more abruptly.

Stable three-wheel landing gear.—The type of landing gear in which a swiveling wheel is located at the nose of the airplane and the fixed wheels are located slightly to the rear of the center of gravity has been utilized successfully by several designers of small light airplanes. The improvement in stability of the machine on the ground obtained with this type of landing gear, as well as certain other improvements in ground-handling characteristics, has given rise to considerable interest in this type. The Committee has given consideration to the problems attendant on the use of such a landing-gear arrangement on a large airplane. It appears that instability of the castering wheel or wheel shimmy is likely to be a serious problem. Wheel shimmy is frequently encountered in tail wheels of conventional landing gears but would be even more objectionable if experienced with the large swiveling wheel that would be required at the forward end of the machine.

In order to determine what factors influence wheel shimmy, and to develop means for avoiding it by suitable design, an analytical and experimental study of the stability of castering wheels is being made. The experimental work is being carried out with small models of landing gears and landing-gear wheels fitted with pneumatic tires.

SPINNING

The 15-foot free-spinning wind tunnel has been in regular operation, most of the time being devoted to investigation of the spinning characteristics of scale models of service airplanes. During the past year the spinning characteristics of eight such models have been investigated and reported upon. A total of 17 models have been tested in the tunnel to date. Of these, eight have had definitely satisfactory spinning characteristics; i. e., it has been impossible to obtain unsatisfactory spins without major changes in design. The others have each shown unsatisfactory behavior with certain loadings or certain methods of handling the controls.

Tests are being made with a model of a low-wing monoplane for the purpose of making a direct quantitative comparison with the behavior of the airplane. Similar comparisons for two biplanes have been reported in Technical Report No. 557. The spinning characteristics of the biplane models were in reasonably good agreement with those of the respective airplanes. It is felt, however, that a comparison is desirable for a monoplane before conclusions are drawn as to the reliability of the model results as an indication of full-scale behavior.

It has been found desirable to include a determination of the effect of aileron setting when spinning tests of models were made. In certain cases the spinning characteristics have been found to vary widely with change in aileron setting. No general rule as to the aileron effect has become apparent. In certain cases setting the ailerons against the spin has improved recovery, in other cases such a setting has retarded recovery, and in still other cases it has had no appreciable effect.

A series of tests has been made with one model to determine the effects of certain systematic changes in tail arrangement. The results have been published in

Technical Note No. 570. They show that the spinning characteristics of the particular model are critically dependent upon the tail arrangement and confirm previous conclusions as to the desirability of keeping the vertical tail surfaces unshielded. This conclusion was supported by the results of tests of several models with small amounts of additional fin area placed in various locations around the periphery of the vertical surfaces and the after portion of the fuselage. Vertical fin area added underneath the fuselage has always resulted in improvement of the spinning characteristics. The improvement has been most marked when the added area was under the horizontal surfaces.

The spinning balance in the five-foot vertical wind tunnel has been altered to provide more accurate results and a direct-indicating force-measuring system has been installed. All six components of the aerodynamic forces and moments may now be measured simultaneously and the testing time has been materially reduced.

The experimental work in an extensive investigation on the spinning balance with a model of the Fleet biplane has been completed and a report is being prepared. The purpose of this investigation was to obtain a complete comparison of results from the spinning balance, free-spinning wind tunnel, and flight on the spinning characteristics of this airplane. A preliminary analysis shows that the differences in the moments between spinning-balance and flight results correspond to those found for two other biplane models reported in Technical Note No. 517. Predictions for a condition of equilibrium in a spin on the basis of spinning-balance data as compared with results from the free-spinning wind tunnel indicate that the aerodynamic pitching and rolling moments are of the same order of magnitude. Aerodynamic yawing moments deduced from the results from the free-spinning tunnel are between those obtained with the spinning balance and those obtained in flight.

The investigation with the spinning balance in the five-foot vertical wind tunnnel on the spinning characteristics of wings to obtain fundamental information on the magnitudes of the aerodynamic forces and moments produced by the wings alone has been continued. In these investigations the six components of the aerodynamic forces and moments are measured for the entire ranges of angle of attack, rate of rotation, and angle of sideslip likely to be encountered in spins. The results of an investigation on a wing of rectangular plan form were reported in Technical Report No. 519. The tests have been completed on a Clark Y monoplane wing with elliptical tips. An investigation with a Clark Y monoplane wing having a taper of 5:2 and elliptical tips is planned to complete a series on the effects of plan form with the Clark Y airfoil section.

The report on the forces and moments acting on various parts of the full-scale Fleet biplane in spins has been published as Technical Report No. 559.

Technical Note No. 575 has been prepared describing the procedure for calculating the moments of inertia of an airplane from design data pertaining to weight, position, dimensions, and component parts of the airplane. The paper was intended to be of assistance to designers required to submit models for spin tests.

In response to requests, the spinning experiences and studies of the Committee's test pilots have been summarized in a paper dealing with the piloting technique for recovery from spins, which has been published as Technical Note No. 555.

DRAG AND INTERFERENCE

In view of the demand for greater refinement in the design of airplanes of today, many practices that were regarded as entirely satisfactory a few years ago must be carefully scrutinized for possibilities of improvement. A question arises, for example, as to what shape of fuselage will give the least drag or whether the shape may be improved from the standpoint of cargo space without increasing the drag. An investigation of fuselage drag has been started in the variable-density wind tunnel with six streamline bodies of revolution with a systematic variation of shape and a fineness ratio of 5. The tests were made over a range of effective Reynolds Number from about 4,000,000 to 66,000,000. The streamline bodies of revolution are to be followed by bodies of more practical shape, and protuberances such as windshields and other necessary departures from ideal forms are to be added later. The results of the preliminary tests are being prepared for publication as a technical note.

Supplementing an investigation made last year of the air drag of seaplane hulls, a series of wing-tip floats has been investigated in the 20-foot wind tunnel. This series of floats had previously been investigated in the N. A. C. A. tank. The results are being prepared for publication in connection with the results from the tests in the tank.

Wing-fuselage interference.—The investigation of aerodynamic interference between the wing and the fuselage has been continued during the past year in the variable-density wind tunnel. The results for some 28 additional wing-fuselage combinations that were indicated by the program outlined in the basic report (Technical Report No. 540) are included in Technical Report No. 575. The investigation described in this paper practically concludes the study of combinations with a fuselage of rectangular section and includes further information on the study of combinations of a round fuselage and a tapered wing.

An interesting conclusion of this phase of the study of wing-fuselage interference was the unexpectedly high speed-range index shown by the combination of the rectangular fuselage and the rectangular N. A. C. A. 4412 airfoil in a connected high-wing position. The study of the effect of fuselage cross-sectional shape was extended to cover tests of combinations with a fuselage of elliptical section and with a fuselage of modified triangular section. This phase of the investigation is almost completed and the results will appear as a technical note. Concurrently, further tests were made of combinations having split flaps, various wings, and various wing-root junctures. The most interesting development resulting from this part of the investigation is a type of wing-root juncture for certain low-drag combinations having efficient airfoils of moderate thickness and camber. This juncture eliminates the early flow breakdown at the wing roots and the loss in maximum lift that is usually associated with such low-drag combinations, even when the usual fillets are employed.

Wing - nacelle - propeller interference.—In connection with an investigation of wing-nacelle-propeller interference conducted in the 20-foot wind tunnel during the past two or three years, the question arose as to whether the span of the wing (15 feet) was sufficient to give the full effect of the wing-nacelle interference. To answer this question an investigation was made in the full-scale wind tunnel in which the same nacelle was tested on a wing of 30-foot span and the span later reduced to 25, 20, and 15 feet. Force and pressure-distribution measurements were made and the results showed that the influence of the propeller and nacelle extended laterally about five nacelle diameters or two propeller diameters from the thrust axis. The results thus established the validity of the method used in the 20-foot wind tunnel for a large number of wing-nacelle arrangements. The results of this investigation are published in Technical Report No. 569.

COWLING

As stated in previous reports, a systematic study of engine cowling has been under way in three main divisions: (1) the determination of the cooling requirements of an air-cooled engine; (2) the determination of the best cowling arrangement to obtain the necessary cooling with minimum drag; and (3) the verification of the results of divisions (1) and (2) by tests on complete full-size engines. Tests made on an actual engine were completed last year. The results did not completely verify those of divisions (1) and (2), and it was necessary to make an extensive series of supplementary tests in which the various elements of the cowling were separated and elaborate apparatus installed to enable the numerous factors to be separated and their influence on the problem to be quantitatively determined. This research is more completely covered in the report of the Committee on Power Plants for Aircraft.

VIBRATION

The Committee has during the past year obtained numerous flight records of vibration in various airplanes. Such records are at the present time primarily useful in establishing a certain amount of practical information in regard to the magnitude and distribution of the vibrations to be normally expected. However, little has so far been achieved in regard to the explanation and classification of the vibrations. A systematic study of the engine proper as a source of vibration is planned as the next step in the program.

PROPELLER DESIGN

As mentioned last year, a program of propeller investigation has been prepared at the request of the Bureau of Aeronautics. The preliminary program has been reviewed by the Army Air Corps and by several propeller manufacturers and, as a result of many valuable suggestions, the final program will include tests of 2-, 3-, and 4-blade propellers of six different airfoil sections. The plan form of the propellers follows standard present-day practice and the airfoil sections include the familiar Clark Y and R. A. F. sections and four other sections which tests in the 12-inch high-speed tunnel and theoretical analysis indicate may show improved performance. The effect of various body shapes and pitch distributions will be determined. Apparatus is now being assembled and the tests are scheduled to be started soon.

The possibilities of propeller improvement and the indication of the direction that design changes should take have been studied by a comprehensive analysis of propeller application. The principal results have been given in a report, including several charts that enable the airplane designer to make a rapid yet fairly accurate estimate of the propeller requirements and performance of a design.

Complete tests were made of six full-scale propellers in conjunction with the investigation of propeller-cowling-nacelle combinations. These tests covered the complete range of flight conditions including ground, take-off, climbing, and normal high-speed flight. The range of the advance-diameter ratio has been extended far beyond that of earlier full-scale experiments, pitch settings up to 45° at 75 percent radius being included, which are equivalent to ari speeds of more than 300 miles per hour for propellers of normal size and diameter. The propollers were all tested in conjunction with a standard nacelle unit equipped with six different N. A. C. A. cowlings.

The results showed that the conventional propeller reached its peak efficiency in the range between 200 to 350 miles per hour and at a pitch setting of approximately 35°. The inadequacy of the unconditional use of the propulsive efficiency as a figure of merit is shown. This efficiency was found consistently to exceed 100 percent on a certain cowling owing to the fact that that cowling has a very much decreased drag in the presence of the slipstream. The adoption of a standard nacelle unit that is free from this peculiarity is recommended as a basis for the comparative testing of propellers.

A report (Technical Note No. 557) has also been prepared describing the relation of the propeller to the take-off problem. It is shown that the static thrust is of practically no importance in reducing the take-off run. It is rather the thrust at the latter part of the run that is important. The superiority of the propeller of R. A. F. section over that of Clark Y section is again shown. Although this fact was brought out some years ago, the Clark Y propeller is still in quite general use.

PROPELLER NOISE

Further experimental work on the sound output from propellers was carried out at the request of the Air Corps upon certain special propellers. The rate of increase of radiated sound with rotational speed was determined for various frequency bands, and the distribution in space of the sound about the propellers was investigated.

A careful measurement of the sound output from two selected propellers is under way for the purpose of obtaining material for theoretical studies.

Attempts are under way to find a physical theory suitable for practical use that will account for the complex phenomena of the rotation noise to a first approximation. Such a theory, if available, would permit the prediction of the rotation noise in any specified direction and, since these components are the ones that usually determine the loudness, the effect on the ear at any distance along that direction could be estimated.

The paper dealing with the vortex noise from rotating cylindrical rods published as Technical Note No. 519 has been reprinted in the Journal of the Acoustical Society of America for January 1936. A paper on the dual nature of modulation has been published in the Philosophical Magazine for May 1936.

THEORETICAL AERODYNAMICS

Biplane interference.—Further work is planned in which the general biplane theory recently developed is to be employed in a more specific and detailed study of the interaction of two bodies in a uniform air stream.

Compressible flow.—The calculation of the compressible flow about symmetrical Joukowsky profiles is being carried out for the purpose of obtaining information as to the effect of compressibility on the lift and moment characteristics of airfoils of varying thickness and angle of attack. The ratio of the stream velocity to the velocity of sound in the stream, at which compressible potential flow ceases to exist, may also be calculated. This point of breakdown of potential flow is important because of the immediate appearance of shock waves and a subsequent sudden rise in the resistance of the airfoil.

Flow about bodies of revolution.—The investigation of rectilinear flow about bodies of revolution, the results of which were published in N. A. C. A. Report No. 516, has been extended to the case of an arbitrary body of revolution in steady motion in a circular path. The results are included in Technical Note No. 554. Applications of the results contained in these two papers are being made to the model of the airship *Akron*.

Nonuniform motion.—As an outgrowth of the flutter theory developed last year, further studies were made on the nonuniform motion of an airplane wing. In particular, the thrust or drag force experienced by a flapping and oscillating wing in a uniform air stream has been analyzed and formulas have been developed giving expressions for these forces in the case of three degrees of freedom, namely: vertical flapping, torsional oscillations about a fixed axis parallel to the span, and angular oscillations of the aileron about a hinge. It is shown that pure flapping always results in a propulsion (profile resistance being neglected) of which the theoretical efficiency is between 50 and 100 percent, depending on a single parameter $k=pb/v$, which is a simple combination of the oscillation frequency p, the velocity v, and the chord length $2b$. Pure torsional oscillations about an axis parallel to the span may result in either a thrust or a drag force, depending on k. This work which has bearing on the "Katzmayr" effect is also intimately related to certain problems which nature presents in bird and insect flight as well as in fish locomotion. The results are being published as Technical Report No. 567.

AIRFOILS

Systematic research directed toward higher flight speeds or more economical operation at a given speed is, of course, one of the Committee's most important activities. For several years the major research in the variable-density wind tunnel has been directed toward the reduction of wing drag or, more precisely, toward supplying the designing engineer with the aerodynamic data that will enable him to design the most efficient possible wing for a given application.

The first investigations were concerned with the shape of the wing section. Data were obtained for a large number of related airfoil-section shapes under the standard test conditions in the variable-density wind tunnel. Although a few years ago these data were regarded as directly applicable to flight problems, as airplane design becomes more refined it is realized that they are not, in fact, directly applicable, owing partly to the fact that the tests were made at only one value of the Reynolds Number and partly to the fact that the characteristics derived were not the true section characteristics but were for complete airfoils, including tip effects. Nevertheless, the investigation resulted in the development of the now well-known N. A. C. A. airfoil section shapes, some of which have unusually desirable characteristics.

Applications of these airfoil data to wing design have emphasized the need for reliable airfoil section data for application to flight and for reliable methods of applying the section data to wing design. Such needs have been particularly emphasized by applications of the new efficient wing sections (such as those of the N. A. C. A. 230 series) to the wings that have been employed on many of the new airplanes that have been investigated in the Committee's large wind tunnels during the past year. The investigation of methods of obtaining reliable section data for this purpose and of applying them into flight at various values of the Reynolds Number has constituted a most important part of the airfoil research during the year.

A representative group of systematically related airfoils has now been investigated in the variable-density wind tunnel over a range of values of the Reynolds Number extending well into the flight range. The analysis of the results of the tests provides the information necessary for the application of the extensive airfoil data previously obtained from the variable-density wind tunnel. The result is that, for the first time, the designer will have reliable airfoil section data for direct application to the design of efficient wings.

This advance consists of three stages. The first stage, which is still in progress, is the correction of the test results for the turbulence present in the wind tunnel to the practically zero turbulence of flight conditions. Comparisons between results from the variable-density wind tunnel, full-scale wind tunnel, and flight permit the derivation of suitable corrections. Some comparisons of measurements on airfoils and spheres are presented in Technical Reports Nos. 530 and 558.

The second stage consists of the derivation, from the measurements on the models of rectangular plan form, of the true aerodynamic characteristics of the airfoil section itself. The problem is complicated by tip effects, by the variation of the lift along the span of the airfoil, and by certain shortcomings of the wing theory. A reasonably satisfactory empirical solution has, however, been reached so that airfoil section data are now derived from the test results.

The third and final stage consists of the determination of general scale-effect corrections; by the application of these corrections, the standard test data for one value of the Reynolds Number can be applied to flight at widely different values of the Reynolds Number. Satisfactory methods of correction were obtained as the result of the scale-effect tests of the related airfoils previously mentioned. The methods also supply a more satisfactory means than heretofore available of extrapolating the results to very large Reynolds Numbers above the range attainable in any existing wind tunnel. Thus reasonably satisfactory airfoil data are made available for the design of the new large and fast airplanes and flying boats. All this recent work on airfoil-section data for design is included in a report now being prepared for publication.

In addition to this more general work on airfoils, the tests of new airfoil sections have been continued to cover possible improvements of the N. A. C. A. 23012 section. These tests supply data for various related sections which, for some applications, will prove superior to that section.

Reference was made last year to an investigation of airfoil pressure distribution in the variable-density wind tunnel. It was pointed out that the differences between potential flow and measured pressures about the airfoil section were attributable to the neglect of the viscous boundary layer in the potential-flow theory. This investigation has been continued to study the variation of these differences with Reynolds Number and a report presenting the results is in preparation. It is shown that the scale effect on the aerodynamic characteristics can be traced to changes in the pressure distribution and that these changes are the result of changes in the character of the viscous boundary layer.

Aerodynamic effects at high speeds.—The more fundamental investigation of the compressibility burble, part of which was described in the last annual report, has been continued during the year to include the study of the flow conditions leading to the establishment of the compressibility burble (Technical Note No. 543). This work was conducted in the 24-inch high-speed wind tunnel and consisted chiefly of pressure-distribution measurements for the N. A. C. A. 4412 airfoil section. The experimental work has now been completed and these data are being analyzed. Measurements have also been made of the pressure loss in the compression shock that is associated with the compressibility burble. The measurements were made with a bank of total-head tubes placed 0.5 inch aft of the trailing edge of the model. These tests have also been completed and the data are being analyzed for inclusion in a report on the general investigation of the phenomenon.

An investigation of the drag of certain fundamental shapes, including circular and elliptical cylinders and square and triangular prisms, through a large range of air speeds and Reynolds Numbers in the 11-inch high-speed wind tunnel, is nearing completion.

Tapered wings.—An investigation of methods for the application of the new section data to the calculation of the characteristics of tapered wings has been made and the results published as Technical Report No. 572. The characteristics of a number of tapered wings included in this report were found to agree well with calculated values. A number of other tapered wings have been tested and a comparison is being made of the calculated with the section characteristics as experimentally determined. The comparison includes the slope of the lift curve as well as the pitching moment, maximum lift, and drag coefficients.

The determination of the spanwise position at which stalling begins and of the value of the maximum lift coefficient has been made possible by the use of scale-effect data on airfoil sections. These calculations and data have been used to investigate the effect of taper ratio. Three wings of widely varying taper ratio were compared on an equal aerodynamic basis; that is, equal minimum drag, induced drag, and minimum speed. The comparison showed that the highly tapered wing had no advantage of structural weight but had the disadvantage of stalling at the tips. Methods of controlling the character of the stall to avoid objectionable tip stalling have also been investigated. The best results appear to be obtained by combining a moderate taper ratio with a little (about 2°) washout of incidence toward the tips and changing the section near the tips to one having a higher maximum lift coefficient.

Boundary-layer control.—The earlier work on boundary-layer control mentioned last year, which consisted mainly of tests in the 20-foot wind tunnel of several wings with a slot along the upper surface for boundary-layer control by suction, has been extended during the year to include study of the slot width and suction distribution along the span of a tapered wing. The course of the main investigation has, however, been somewhat changed. It is now planned to confine further testing to more fundamental investigations of control methods. In the meantime, possible applications of boundary-layer control to airplanes will be analyzed and the characteristics of the uncontrolled boundary layer will be more thoroughly investigated.

The fundamental investigations of boundary-layer behavior have been started in the variable-density, the 24-inch high-speed, and the smoke tunnels and will later be extended to other tunnels and to flight. Although most of this work has not progressed far enough to give results, one publication (Technical Note No. 544) dealing with the laminar boundary layer and its separation has been completed.

THE 8-FOOT HIGH-SPEED WIND TUNNEL

The 8-foot high-speed wind tunnel, sometimes referred to as the "full speed" wind tunnel, was placed in operation during the past year. A thorough investigation of the characteristics of the tunnel has been started and preliminary results indicate that the designed maximum speed of 500 miles per hour will be exceeded. The minimum speed of the tunnel is approximately 85 miles per hour, thus making it possible for the results to overlap in air speed and Reynolds Number the results from other wind tunnels. The air speed is continuously controllable between the minimum and maximum values. The air stream is steady and uniform, both in velocity and direction of flow.

Before completion of all the equipment in the tunnel a request of one of the military services was met by testing certain full-size airplane components at speeds greater than those obtainable heretofore in any tunnel over 2 feet in diameter. Future tests will include measurements of lift, drag, and pitching moment on large-scale wings at air speeds equaling and exceeding the present-day diving speeds, which produce serious compressibility effects.

WIND-TUNNEL CORRECTIONS

A theoretical study was made of the interference of the boundaries of a wind tunnel on the downwash behind an airfoil, and correction factors were determined for wind-tunnel test sections of several different shapes. The results are presented in Technical Report No. 547 in a practical form for application to wind-tunnel results.

In order to obtain a comparison between flow conditions in flight and in wind tunnels to supplement that afforded by previous sphere tests in flight and in the various wind tunnels of the Committee (Technical Report No. 558) an investigation is being made to determine the scale effect on the maximum lift of an airfoil. Tests of a wing mounted on a Fairchild 22 airplane are being made in flight. Tests of this wing in the full-scale wind tunnel have been completed. An appreciable variation of the Reynolds Number in flight is obtained, chiefly by varying the wing loading, but some additional variation is obtained by varying the flight altitude and utilizing the effect of seasonal temperature changes.

It is known from experience that the climbing performance of an airplane may be considerably affected by variations in wind velocity with altitude. If the climbing airplane encounters a head wind of increasing velocity but maintains a constant air speed, the continuous deceleration of the airplane increases the rate of climb over that which would normally be obtained. The reverse effect is experienced if the wind velocity decreases with altitude. Inasmuch as it appears that such effects can be experienced not only at very low altitudes but also at high altitudes, it is planned to make a systematic investigation to determine how serious the effect is likely to be and how error in the estimation of climbing performance can best be avoided.

In the past, considerable difficulty has been encountered when attempts have been made to predict climbing performance from tests made with power on in the full-scale wind tunnel. In order to determine the source of the discrepancies and how such discrepancies may be eliminated, a comprehensive investigation has been started in which flight tests will be made with an airplane that will later be tested in the full-scale wind tunnel. Velocities at various points along the span of the airplane and also at various fore-and-aft locations are to be measured for correlation with similar measurements in the wind tunnel. In the flight tests it is planned to deduce climbing performance from data obtained in tests in which the airplane will tow parachutes of various sizes to absorb the excess horsepower while in level flight, rather than to rely on actual measurements of rate of climb. The force required to tow the parachutes will be measured by means of suitable apparatus mounted in the airplane.

ICE PREVENTION

The Committee has investigated the effectiveness of the use of chemical solutions to prevent the formation of ice on airplanes. A study of various solutions showed that a 7:1 mixture of alcohol and glycerin was the most effective ice inhibitor. The remaining study was concerned with methods of proper distribution of the liquid to the exposed airplane surfaces.

The distribution to wings, struts, and similar surfaces is accomplished by means of a porous leather covering. The liquid is fed through tubes to the inner surface and the leather absorbs and distributes it evenly over the leading edge. The amount of liquid required varies with the type of ice formation encountered. On a modern transport airplane, approximately 1 gallon per hour would be sufficient to prevent accumulations in wet clouds at low temperature, which constitute about 95 percent of the icing conditions. The more severe condition in an ice-storm region may require as much as 5 gallons per hour. Aside from the liquid, the additional gross weight of the system is less than 0.5 pound per foot of span, or about 50 pounds for a transport.

ROTATING-WING AIRCRAFT

The detailed development and steady progress of rotating-wing aircraft during the past year are attested by the construction of several new models of autogiros far superior to any previous ones. The steadily widening field of application of this type of aircraft more than justifies the vigorous prosecution of research directed toward increase in efficiency and the elimination of secondary difficulties arising in a design.

A report has been published (Technical Report No. 552) containing the results of wind-tunnel tests on a family of models of autogiro rotors of 10-foot diameter in the 20-foot wind tunnel. The investigation of systematic variations of blade airfoil section and blade plan form established the fact that the use of an airfoil 12 percent thick results in a higher lift-drag ratio than is obtained when an airfoil 18 percent thick is employed; and it was found that the reduction of blade chord near the rotor hub resulted in a reduction of rotor lift-drag ratio. The evaluation of the data obtained indicated the desirability of extending the tests to include other airfoil sections and established the necessity of making a study of blade twist in order to separate a composite influence on the test results into its constituent parts. The design of models to be used in this extension of the test program is well advanced.

During the past year two direct-control autogiros were purchased by the Army Air Corps for service test and experiment. The Committee conducted investigations in flight for the Air Corps of the control forces and general performance characteristics of these machines.

An experimental study of autogiro "jump take-off" on a rotor model of 10-foot diameter was recently completed. The maneuver involves the utilization of stored excess kinetic energy in the rotor blades for a take-off in which the flight path is initially vertical. The tests included a study of the three basic variables: blade pitch angle, initial rotor speed, and rotor disk loading. The experimental work was supplemented by an analysis of the problem through which it was found that the simple case of a jump take-off without forward speed could be accurately predicted from a solution of the differential equation of motion. The approximations required for the solution were justified by a comparison of analytical and experimental results. The results are to be published in a technical note.

Considerable study has been directed during the past year toward the extension of and improvement in the aerodynamic analysis of the autogiro rotor. One phase of this, which has been completed, is the analysis of the rotor-blade oscillation in the plane of the rotor disk. Study of this phenomenon disclosed that the flapping motion of the blade caused an oscillation in the plane of the rotor disk which was independent of the components of the air forces in the rotor disk and was the dominating factor determining the motion being studied. It was found that a satisfactory first approximation could be made if the air forces were neglected altogether. Experimental data were found to agree satisfactorily with predicted values. The results of this work also will be published as a technical note.

Additional analytical work on the autogiro rotor completed and awaiting preparation in report form includes: a study of the rotor-torque equation, including correction factors graphically derived; a study of the effect of periodic blade twist on the rotor thrust and blade motion; a study of the instantaneous forces on a rotor blade, and their effect on rotor vibrations and rotor pitching and rolling moments; and a study of certain factors affecting the profile drag of an autogiro rotor.

AIRSHIPS

At the request of the Bureau of Aeronautics of the Navy, a series of investigations was made in the 20-foot wind tunnel on a 1/40-scale model of the airships ZRS-4 and ZRS-5 with the object of determining: (1) the effect of the aspect ratio of the fins on the aerodynamic forces and load distribution over them; (2) the effect of fins of various aspect ratios on the pressure distribution on the hull near the tail surfaces; (3) the effect on the pressure distribution on the fin of slots between the fin and the hull; and (4) the pressure distribution on the fin when the airship was in various angles of yaw and pitch as high as approximately 24°. A supplementary investigation on the same model has been made for the purpose of determining the effect of bow elevators on the resistance and controllability in pitch of an airship. Reports on these projects are in preparation.

Theoretical studies have indicated that considerable decrease in the drag of an airship should result by proper control of the boundary layer. An investigation to be conducted in the 20-foot tunnel on the application of boundary-layer control to airships has been initiated. The models and apparatus required are now being constructed.

FIELD-OF-VIEW MEASUREMENTS

The measurement of field of view from pilots' cockpits has been continued throughout the year. To date, charts of the field of view from 54 different military and commercial airplanes have been made.

MISCELLANEOUS TESTS OF MODELS OF COMPLETE AIRPLANES

The rapidly increasing size of modern military airplanes, as well as the general use of metal construction, makes alterations extremely difficult and emphasizes the importance of tests of complete models during the design stage. It is impossible at the present time to predict with certainty how the performance and handling characteristics of a new design may be affected by flow conditions arising from interference of the parts or by the presence of the slipstream. It is important that such tests be made at as high a Reynolds Number as possible, and the Committee has received a number of requests during the past year from the Army and Navy for tests of large models in the 20-foot and the full-scale wind tunnels. Work of this nature interferes in a measure with systematic programs of research but, on the other hand, it has often been possible to take advantage of the presence of such models in the wind tunnels to make alterations and additional tests that fit in with established programs.

The Committee has also received a number of requests from manufacturers for tests of large models to be conducted at the expense of the manufacturers. If these tests are of such a nature that they cannot be conducted in existing commercial laboratories, it is the general policy of the Committee to make them. In these cases also it has often been possible to obtain data confirming results obtained in connection with established programs, and such projects have served the additional purpose of keeping the Committee in close touch with the current problems of designers. Several large commercial airplanes and seaplanes have been tested during the year in the larger wind tunnels, and there are indications that the Committee will be requested to do more work of this nature in the future.

NATIONAL BUREAU OF STANDARDS

WIND-TUNNEL INVESTIGATIONS

The aerodynamic activities of the National Bureau of Standards have been conducted in cooperation with the National Advisory Committee for Aeronautics.

Boundary layer near a plate.—A report has been completed on the air flow in the boundary layer near a plate. The paper reviews the published data of Burgers and van der Hegge Zijnen at Delft and of Hansen and Elias at Aachen, and presents the results of additional measurements carried out at the National Bureau of Standards on the distribution of speed and of the intensity of turbulence near a plate in the laminar, transition, and eddying regions. The report will be published as Technical Report No. 562.

Wind-tunnel turbulence.—Investigations of the nature of turbulence and its effects have been extended to cover the scale of the turbulence, or "average eddy size," as well as the intensity of the turbulence, which has hitherto been designated percentage turbulence. Work in this field was given additional impetus from the different response of the drag of a sphere to turbulence of given intensity produced by screens of different mesh sizes, which indicated that the aerodynamic effect of turbulence is dependent on its scale as well as on its intensity.

The scale of the turbulence was measured for screens varying in mesh from ¼ to 5 inches by the method outlined in the last annual report, in which two hot wires are utilized. With one wire fixed and the other movable, the correlation between the velocity fluctuations at the two wires was determined as a function of the cross-stream separation of the two wires. The correlation coefficient was found to vary approximately exponentially with separation, and the scale of the turbulence was defined as the area under the curve of correlation coefficient versus separation. The scale defined in this manner was approximately equal to the diameter of the wires of which the screen was made for points near the screen, but increased linearly with distance downstream to several times the initial scale.

The intensity of the turbulence produced by these screens was measured at several distances downstream to study the decay of the turbulence. These measurements, together with the measurements of scale, gave new information on the mechanism of decay. G. I. Taylor's theoretical formula was found to be correct when allowance is made for the variation of the scale with distance from the screen.

The aerodynamic effect of the turbulence was studied by the use of the "pressure sphere" described in Technical Report No. 558. The critical Reynolds Number was found to depend on the product of the intensity of the turbulence by the fifth root of the ratio of the diameter of the sphere to the scale of the turbulence, in conformity with Taylor's theory.

A report of this work is in process of publication.

Corrections to hot-wire measurements of intensity of turbulence.—The studies of correlation between velocity fluctuations at different points showed that the wires used for turbulence measurements are often sufficiently long to introduce errors, because the fluctuations are not completely correlated over the length of the wire. The corrections for this effect to be applied to measurements of intensity and scale of turbulence by the hot-wire method have been computed.

Boundary layer near an elliptic cylinder.—The measurements in the boundary layer near an elliptic cylinder described in Technical Report No. 527 are being extended to higher speeds at which the layer becomes eddying before separation occurs.

The pressure distribution around the central section of the cylinder has been determined with the major axis parallel to the wind. The line of separation has been accurately located by means of a thin layer of kerosene and lampblack spread over the surface. Minute surface irregularities such as small particles of dirt were found to effect the position of the line of separation. The same technique was used to study the disturbance produced by the prongs supporting the exploring wire in the boundary layer and the disturbance produced by the wire itself. These disturbances could not be entirely eliminated but were made quite small by the use of prongs and wire of small diameter.

Boundary-layer investigation by diffusion of heat.—The method of thermal diffusion described in Technical Report No. 524 is being applied to the study of a turbulent boundary layer. The boundary layer will be formed near a flat plate 10 feet wide and 24 feet long now being installed in the 10-foot wind tunnel. The traversing equipment has been constructed.

AERONAUTIC INSTRUMENT INVESTIGATIONS

The work on aeronautic instruments has been conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department.

Reports on aircraft instruments.—A report on the characteristics of aircraft compasses was published during the past year as Technical Report No. 551.

The development work on carbon-monoxide indicators for aircraft, which has been in progress for several years, is described in Technical Note No. 573.

The reports on electrical instruments in aircraft and on pressure drop in tubing used to connect aircraft instruments to vacuum pumps and pitot-static tubes are nearly completed.

Data are being collected for a report on the effect of vibration on service aircraft instruments.

Tests and test methods.—Work was completed during the year on an apparatus for testing aerographs. The apparatus consists essentially of a pressure-humidity chamber and a temperature chamber. The instruments under test are installed in the pressure-humidity chamber which in turn is placed within the temperature chamber, the temperature and pressure of the instruments being thus independently controlled. The relative humidity within the pressure-humidity chamber is controlled by means of a chemical drier and a device by means of which air bubbled through a water column is admitted to the chamber. A suction applied to the pressure-humidity chamber causes either dry or moist air to enter as desired.

Methods and equipment were devised for use in testing the suction-regulating valves used on aircraft to control the suction supplied to gyroscopic instruments.

New instruments.—Instruments designed and constructed for the Bureau of Aeronautics, Navy Department, include: A fuel-gas-volume indicator for the K airship; two improved models of a maximum-indicating accelerometer; and an improved design of a combination oxygen breathing mask and radio microphone.

SUBCOMMITTEE ON AIRSHIPS

The Subcommittee on Airships formulates and recommends programs of airship investigations for conduct at the Langley Memorial Aeronautical Laboratory, and maintains close contact with the work in progress.

During the past year an investigation has been completed in the full-scale wind tunnel on a large airship model at various heights above the ground board and at various angles of yaw with reference to the wind, in order to obtain information on the forces acting on an airship during ground handling. The results of this study have been published in Technical Report No. 566. In conjunction with this study, tests were also made in the full-scale wind tunnel of the pressure distribution on a 1/40-scale model of the Lakehurst airship shed.

A study of the theory of potential flow as extended to the curvilinear motion of bodies of revolution has been conducted and the results, which are applicable to airships in flight, are presented in Technical Note No. 554.

During the past year a report outlining the procedure for the determination of the speed and climbing performance of airships has been published as Technical Note No. 564. This report represents the results of the experience of the Committee's laboratory over a period of several years in conducting investigations on full-scale airships in flight for the Army and Navy.

The Committee has recently completed a study of the effect of aspect ratio on the presure distribution on airship fins, undertaken at the request of the Bureau of Aeronautics of the Navy for the information of the special airship subcommittee appointed by the Science Advisory Board.

The Committee's research program at the present time includes an investigation of boundary-layer control as applied to airship forms. This investigation is to be carried on in the 20-foot wind tunnel.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

During the past year the Subcommittee on Meteorological Problems has given consideration to a number of problems relating to atmospheric conditions which are of particular importance in connection with aircraft design and operation.

Gust conditions in relation to airplane acceleration.—The attention of the subcommittee was invited, as a result of discussion by the Special Subcommittee on Aerodynamic Problems of Transport Construction and Operation, to the desirability of obtaining all possible information on the structural effects of atmospheric disturbances. It was recognized that this problem was important from the viewpoint both of the correlation of structural effects with meteorological phenomena and of the determination of the most severe conditions for which design requirements must be formulated.

Arrangements are therefore being made for the installation of a number of special instruments to obtain records of accelerations, altitude, and air speed, to be installed on airplanes used in meteorological observations at Weather Bureau stations throughout the country.

The study of the effect of gust structure on airplane loads conducted at the Langley Memorial Aeronautical Laboratory has been extended to include measurements of the speed and accelerations on a Taylor Cub airplane and an Aeronca airplane in rough air. Data are being accumulated and analyzed for the purpose of establishing an effective gust gradient. The program as planned includes the obtaining of such records on towed gliders.

The accumulation and analysis of records of accelerations on transport airplanes in regular operation is being continued. A report presenting in a general way the information obtained in this study is now in preparation.

A program of triweekly flights to altitudes of about 19,000 feet is under way for the determination of a relation between effective gust velocities as measured by airplane accelerations and the degree of stability in the atmosphere at altitudes.

Investigation of wind gustiness.—The study of wind gustiness conducted for the past several years by the Daniel Guggenheim Airship Institute at Akron, Ohio, in cooperation with the Weather Bureau and the Bureau of Aeronautics of the Navy has been continued. This investigation includes two phases: first, a study of atmospheric turbulence under ordinary conditions; and second, a study of the fluctuations of wind velocity and direction during the passage of cold fronts. Records are being obtained from instruments installed in the radio tower at Akron and by means of balloons and theodolites. It is planned to extend the investigation by the addition of movable towers with instruments installed to obtain records at various positions.

Ice formation.—In accordance with recommendation of the Subcommittee on Meteorological Problems, the collection and analysis of data regarding the atmospheric conditions under which ice formation occurs on airplanes are being continued by the Weather Bureau. The problem of ice formation has been indicated by the transport operators as one of the most important in air-transport operation at the present time.

SUBCOMMITTEE ON SEAPLANES

The Subcommittee on Seaplanes was organized in 1935 to guide and direct the research on seaplanes and the work in the N. A. C. A. tank. With the continual improvement in the performance of seaplanes and the rapidly increasing demand for large, long-range flying boats, the work of the tank has become of greater and greater importance. The equipment at Langley Field permits the testing of larger models at higher speeds than can be done in other ship or seaplane tanks; hence there are many requests for quantitative information from agencies concerned with the problem of high speeds on the water. This year, as before, new fundamental data from a number of tests of large models have been made available to seaplane designers while tests of a specific nature have been conducted for the military services and for private concerns.

THE N. A. C. A. TANK

Plant and equipment.—After five years of continuous operation, the tank was emptied, cleaned, and thoroughly inspected. Despite the extremely severe conditions of salt water and moist air to which they are subjected, the concrete and structure were found to be in excellent condition. During the past year, the rails and steelwork were cleaned and painted. Truck-type guide wheels were substituted for the original single guide wheels of the towing carriage to reduce the magnitude of lateral movements and, as a safety measure, the original pneumatic tires on the main wheels were replaced with new ones.

Historical series.—It is of great assistance to the designers of present-day seaplanes and to the Committee's staff in planning future research to know accurately the characteristics of hull forms that have been used and have proved successful in the past. As a part of a program to obtain such information, a 1/7-size model of the hull of the famous NC flying boat was tested over a wide range of operating conditions. This model was approximately twice the size of those originally tested in the experimental model basin of the Washington Navy Yard in 1917, when the form of the hull was developed. Its performance in the N. A. C. A. tank was found to compare favorably with that of many hulls of more modern design. The data obtained are published in Technical Note No. 566.

Effect of variations in dimensions and form of hull on take-off.—In spite of the increased facility in taking off the water given by more powerful engines and controllable propellers, the resistance to motion offered by the water remains a most important limitation of the performance of large seaplanes. The reduction of this resistance is, therefore, one of the primary objectives of the work at the tank and the development of forms having low water resistance has been continued. The N. A. C. A. pointed-step hull has shown definite promise in this direction but a valid criticism of the earlier forms was that the small angle of dead rise might result in heavy impact loads on the bottom in alighting on the water. Tank tests of a family of these hulls having three different angles of dead rise are described in Technical Note No. 551. It is shown that, while the high-speed resistance is somewhat greater for higher angles of dead rise than for low angles, the low-speed operation and spray characteristics are not impaired, and that, in spite of the increase in resistance at high speeds, the apparent advantages of the pointed-step form over conventional hulls are retained.

The single-float system for small seaplanes has certain aerodynamic and structural advantages. It is used extensively by the United States Navy but very little by private and commercial operators. Last year, 2/7-size models of two typical Navy floats were tested in the tank to obtain information to be used in attempts to design an improved form of float for this type of service. The results of these tests are published in Technical Note No. 563 and afford designers an opportunity to consider the single-float arrangement from the standpoint of water performance. A comparison of the test data of the conventional floats with those of a generally similar float having a pointed step is included in this note.

The form of the planing bottom of a hull forward of the step has in general a marked effect on water resistance. A previous investigation having established the superiority of a planing bottom longitudinally straight over the pronounced convex or "rocker" type, tests were made of a model of a flying-boat hull having a slightly concave bottom forward of the step. The results of these tests, reported in Technical Note No. 545, indicate that there is no great advantage in the concave type of planing bottom as tested, although the high-speed resistance was slightly less than that of the straight bottom.

Design data for hulls for small flying boats and amphibians.—The problems encountered in the design of hulls for small flying boats or amphibians are in some ways more difficult than those encountered in large craft. The combination of adequate strength, light weight, and good water performance with small size does not permit the elaborate structure that may be used where dimensions are not restricted. Under these conditions simplicity of form with good water performance becomes of the greatest importance. Technical Report No. 543 furnishes hydrodynamic data for five forms designed to be suitable for hulls of small flying boats and amphibians. The types used are simple in form and were tested in the tank for all values of speed, load, and trim which it was believed would apply. The data obtained are intended to aid the designer in selecting the most suitable size and type of hull as well as in verifying take-off performance in the early stages of a proposed design. Included in the series is a novel form of forebody the bottom surface of which can be expanded into a flat surface and hence can be fabricated without shaping the plating or planking near the bow. The tank tests indicated that this simplified form compared favorably with the conventionally shaped bottom, at least for the smooth-water conditions simulated in the tank.

Work for private concerns.—From time to time the tank has interrupted its regular work to perform tests for the manufacturers when such tests could not be satisfactorily done elsewhere.

SPECIAL SUBCOMMITTEE ON VIBRATION AND FLUTTER

The Special Subcommittee on Vibration and Flutter has held two meetings since its organization. At these meetings the special problems relating to the general subject which are being investigated by the Army Air Corps, the Bureau of Aeronautics of the Navy, the National Bureau of Standards, and the National Advisory Committee for Aeronautics were briefly outlined and the general program of future work was discussed.

At the second meeting, representatives of propeller manufacturers were present and described the progress made by their organizations in connection with the problem of propeller vibration and its relation to vibration in other parts of aircraft and to flutter.

One of the most important investigations in connection with this general problem is the study of engine vibration and the design of engine mounts, which has been carried on by the Matériel Division of the Army Air Corps. A special vibration-isolating mount for radial engines has been developed which effected considerable improvement in one of the airplanes in which it was installed. The Matériel Division is also investigating the vibration characteristics of engines, propellers, and various wings.

Under the sponsorship of the Bureau of Aeronautics of the Navy an investigation has been conducted at the Massachusetts Institute of Technology which resulted in the development of a vibration meter of the electrical pick-up type for measurement of the vibratory translational and rotational motion of airplane engines and structures in flight or on the ground.

The National Bureau of Standards has been engaged in a theoretical study of the effect of centrifugal force on the stress distribution and vibration frequency of propeller blades. Further study is being made of the theory and the literature on harmonic vibrations and on the vibration of mounting stands.

The National Advisory Committee at its laboratory at Langley Field has studied the effect of centrifugal force on propeller vibrations and the torsional vibration of engines. A comprehensive program is being initiated for the investigation of the vibration characteristics of airplane engines, particularly the periodic mass and gas forces and moments.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

ENGINE POWER

The designs of new aircraft are based upon aircraft engines developing twice the maximum power of the present engines. This large increase in engine power will be obtained by operating at higher engine speeds, by increasing the weight of the charge pumped into the cylinder, by using fuels having higher antiknock ratings, and by improving the cooling of air-cooled engines. The investigations undertaken by the Committee indicate several promising methods by which this increased engine power may be efficiently obtained.

Increased engine speeds.—The power output of an engine is directly proportional to the rotative speed. The maximum rotative speed is limited, however, by the piston speed and by the loading of the engine bearings. In order to investigate the problems connected with higher rotative speeds a single-cylinder test engine is being designed to operate at a maximum speed of 4,000 r. p. m. The standard speed of the Committee's present laboratory test engines has been increased from 1,500 to 2,500 r. p. m. to simulate more closely the speed of multicylinder engines.

Improved fuels.—The maximum power that can be obtained from a given fuel is limited by its detonation characteristics. New processes of manufacture have made commercially available fuels having antidetonating characteristics superior to those of iso-octane. The use of these fuels results in a large increase in engine power because the aircraft engines can be operated at higher compression ratios and at increased manifold pressures. During the past year the necessary test equipment has been assembled for the determination of the maximum engine power available when fuels having a range of octane numbers from 87 to 100 are used. The engine tests will cover a range of inlet manifold pressures, air temperatures, and compression ratios. The fuels tested will be the same as those used by the Aviation Detonation Subcommittee of the Society of Automotive Engineers. Preliminary tests have been made of several types of detonation indicators for the purpose of obtaining a reliable indication of incipient detonation.

Detonation research.—Detonation in present aircraft engines is eliminated by the use of premium fuels. The development of aircraft engines capable of delivering high power outputs with cheaper fuels would result in an appreciable reduction in the operating cost of aircraft. A study of the detonation process occurring in internal-combustion engines is being made to obtain new knowledge concerning the phenomenon of detonation.

The N. A. C. A. combustion apparatus has been set up with a cylinder head having a pent-roof combustion chamber so that it can be operated as a spark-ignition engine. A rectangular glass window approximately 5 by 7 inches in size gives an unobstructed view of one-half the combustion chamber. The single fuel charge is injected through a fuel valve located in the cylinder head. The injection of the fuel, the occurrence of the spark, and the subsequent combustion are photographically recorded.

Three methods of photography are used. Motion pictures are taken of the fuel injection and the flame propagation across the combustion chamber by means of a high-speed camera taking 2,500 frames per second. With the windows masked by a metal plate, schlieren photographs of the flame propagation are taken through a ⅛-inch slot. These data show phenomena that are not visible in the flame photographs because the temperature front is recorded instead of the flame. Schlieren photographs are also taken of the combustion visible through the unmasked window. In this case the light source consists of 10 electric sparks discharging at the rate of 2,000 per second. The variables investigated have been air-fuel ratio, engine speed, spark-plug arrangements, and fuels having a range of octane numbers from 65 to 100. Interesting records of the flame have been obtained with the charge fired by two diametrically opposite spark plugs, which indicate that the combustion front is from ½ to 2 inches in depth. In all cases the flame occurring with detonation is decidedly more actinic than the flame preceding detonation.

Valve overlap.—At the request of the Bureau of Aeronautics, Navy Department, an investigation has been started to determine the increase in performance that may be obtained with a radial air-cooled engine equipped with a fuel-injection system and operating with a large valve overlap. The valve timing that will give maximum power will be determined from tests on a single-cylinder engine. The tests on a single-cylinder engine have been started with inlet and exhaust cams giving an overlap of 130 crank degrees.

Air intercoolers.—The inlet-air or the fuel-air mixture heated by the supercharger must be cooled before delivery to the engine cylinders to prevent the loss of engine power at high altitudes. Work has been continued on the study of air coolers for supercharged engines. Heat-transfer tests have been made on several samples of intercooler cores, and a few drag measurements have been made of an aluminum cooler, external fins being used to dissipate heat to the cooling air.

The 2-stroke-cycle engine.—The use of fuels having high antiknock ratings has permitted large increases to be made in the power output of aircraft engines. The favorable characteristics of the fuel should facilitate the obtaining of increased power and improved fuel economy for the spark-ignition 2-stroke-cycle engine operating with gasoline injection. A single-cylinder engine has been constructed and tests started to determine the performance characteristics of this type of engine for a range of speeds, scavenging pressures, injection methods, and inlet and exhaust timings.

FUEL CONSUMPTION

The demand for transport and military aircraft having a long range has intensified research on possible methods of reducing fuel consumption. At present, the use of automatic mixture controls has given an appreciable reduction in fuel consumption. A reduction in fuel consumption of air-cooled engines has been obtained by the use of improved designs of cylinder finning. The design of aircraft engines to operate with fuels of high octane number should result in further reduction in fuel consumption because of the higher permissible compression ratios.

Fuel distribution.—The use of a fuel-injection system instead of a carburetor on aircraft engines has been found to result in reliable engine operation at all attitudes of the airplane, in increased engine power, and in more uniform distribution of fuel between individual cylinders. The distribution of the fuel within the cylinder is being studied by means of a spark-ignition fuel-injection engine fitted with a glass cylinder. The injection of the fuel and the movement of the air in the cylinder are being photographically recorded.

The distribution of fuel to the various cylinders of a multicylinder engine has been determined for a 500-horsepower radial air-cooled engine operated in the 20-foot wind tunnel. The method used was to collect and chemically analyze the exhaust gases from each cylinder for several conditions of engine speed, power output, and specific fuel consumption. The results showed that the variation in the quality of the mixture among individual cylinders was 4 percent and was independent of fuel consumption, air-fuel ratio, and engine power. It was found that the temperature of the spark-plug boss was not a good indicator of fuel distribution. The results of this investigation will be published as a technical note.

Mixture control.—For long-range aircraft it is necessary that the pilot maintain, especially under cruising conditions, an air-fuel mixture as lean as is compatible with safety. The use of the constant-speed propeller has made the usual "leaning-out" method obsolete. The normal mixture controls are being replaced by mechanisms that automatically maintain an economical mixture ratio at all altitudes. An investigation has been made to determine the operating characteristics of a commercial mixture indicator. The operation of this indicator is based on the change in thermal conductivity of the exhaust gases from the engine with change in air-fuel ratio. On the basis of a chemical analysis of the exhaust gases, the instrument gives accurate readings for a range of air-fuel ratios from 8 to 15. The instrument will not indicate satisfactorily, however, air-fuel ratios greater than 16.

Fuel injection.—An investigation has been started to determine the comparative performance obtained with an air-cooled cylinder of late design when operated with a carburetor, with fuel injection into the manifold, and with fuel injection into the cylinder. In this comparison of the three methods of carburetion fuel consumption, power, and cylinder temperature are the important factors to be considered. Preliminary tests have shown that good performance can be obtained with any one of these methods; slightly greater power, however, is obtained by injecting into the cylinder and better fuel economy is obtained with the carburetor. The two injection-valve locations used in the cylinder head may not have given the maximum performance obtainable with injection into the cylinder. Locating the injection valve so as to take advantage of the air flow set up in the cylinder by the passage of the inlet air through the valve is expected to give an improvement in fuel consumption.

Long-range airplane.—A study is being made by the Committee of the factors affecting the design of long-range airplanes. One of the important phases of this study is to determine the fuel-consumption characteristics of the engine at various values of the engine speed and torque. The determination of these characteristics is being made on a single-cylinder air-cooled test engine having a compression ratio of 5.6. The results indicate that the improvement in the minimum specific fuel consumption becomes less as the engine torque is increased until, with a boost pressure of 5 pounds per square inch, no further improvement is secured. In addition, it has been found that the engine speed has no great effect on the minimum brake fuel consumption.

Exhaust-gas analysis.—Knowledge of the combustibles present in the exhaust gas of an internal-combustion engine makes possible the evaluation of the energy lost due to incomplete combustion. Analyses of exhaust gases by the use of several approved combustion methods have been found to give different results. A synthetic gas mixture of predetermined composition was prepared and analyzed by (1) slow combustion with air, (2) slow combustion with oxygen, (3) fractional combustion in a copper-oxide tube followed by slow combustion, and (4) fractional combustion in a copper oxide-cerium oxide tube followed by slow combustion. The fractional-combustion method depends on the oxidation of certain combustibles in the exhaust while others are unaffected. The tests indicated that the analysis by means of slow combustion with air gave the most reliable results.

COWLING AND COOLING

Cowling-propeller-nacelle investigation.—A comprehensive investigation has been carried on with full-scale models in the N. A. C. A. 20-foot wind tunnel, the general purpose of which is to supply information in regard to the physical functioning of the composite propeller-cowling-nacelle unit under all operating conditions of take-off, taxying, and normal flight. The tests included numerous combinations of more than a dozen nose cowlings, about a dozen skirts, six propellers, two sizes of nacelles, various types of spinners, and other devices.

The optimum shape of a low-drag cowling has been determined. The shape of the leading edge and the contours of the exit passage are the causes of large losses when improperly designed. The importance of providing means for regulating the quantity of cooling air so as to keep it to a minimum to prevent excessive losses at high speeds was demonstrated. An N. A. C. A. cowling shows a remarkably high efficiency when considered as a pump for the cooling air. The superiority of a baffled over an unbaffled engine has been verified and it has furthermore been shown that tightly fitting baffles are superior to the deflector type.

The problem of cooling a radial air-cooled engine on the ground has been studied in detail. The influence of various forms of skirts, flaps, propellers, spinners, and special blowers has been investigated. Among the more interesting results are the demonstration of the comparative inefficiency of the adjustable skirt flaps, the detrimental effect of small-diameter front openings of the cowling, and the very beneficial effect of a carefully designed airfoil section near the hub of the propeller. A small axial fan of simple construction was found to give efficient cooling on the ground.

The cooling of a complete full-scale engine was studied in detail. A constant amount of heat was supplied to the cylinder by the use of an electrical heater. This arrangement gave the cooling directly by measurement of the outside temperatures. It was found that the baffled part of the cylinder was cooled directly by velocity flow and consequently the cooling was a direct function of the velocity or of the pressure drop across the baffles. The cooling of the front of the cylinder was of a different nature, as it was good in spite of the fact that there was no measureable velocity flow. This phenomenon was studied by the use of smoke flow and hot-wire anemometers, and it was found that a large-scale turbulence in front of the cowling materially aided the cooling. Spinners were found to affect this cooling materially.

The investigation of the cooling characteristics of a cowled Pratt & Whitney Wasp H engine installed in a nacelle and mounted in the 20-foot wind tunnel has been completed. Equally good cooling, for a particular pressure drop, resulted from each of the cowlings tested. Cooling of the front of the cylinder depended very little on pressure drop for those tests in which the pressure drop was varied by changing the skirt exit; the cooling of the front was accomplished by means of large-scale turbulence of the air. A controllable propeller used in the tests had no beneficial effect on cooling, and an adjustable propeller only improved the cooling slightly.

A new type of N. A. C. A. cowling has been developed as a result of the complete investigation of the

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propeller-cowling-nacelle unit. This cowling is characterized by the feature that the exit opening discharging the cooling air is not, as usual, located behind the engine but at the nose of the cowling. This type of cowling is inherently capable of producing two to three times the pressure head obtainable with the normal type of cowling because the exit opening can be located in a field of considerable negative pressure. This arrangement makes possible more cooling at lower air speed or, if needed, more cooling at any speed. In general, the efficiency is found to be high, owing to the fact that higher velocities may be used in the exit opening. Flight tests made on a temporary installation have shown promising results.

The 2-row radial engine.—The results of an investigation conducted at the request of the Bureau of Aeronautics, Navy Department, on a 2-row radial engine installed in a service airplane and mounted in the full-scale wind tunnel have been given in Technical Report No. 550.

Fin dimensions.—The determination of the surface heat-transfer coefficients of closely spaced steel fins has been continued. Finned cylinders have been investigated having a range of fin width from 0.37 to 1.22 inches and of fin spacing from 0.022 to 0.131 inch. These cylinders were tested with and without baffles in a wind tunnel and with blower cooling, the cylinders being completely enclosed in a jacket. The results of an investigation in which the optimum fin spacing was determined for each of these three methods of cooling for cylinders having fins of 1.22-inch width are being prepared for publication. The results of an investigation made to determine the effect of fin width on the optimum fin spacing for each method of cooling are now being prepared for publication.

The effect of the conductivity of the metal of the fins on the heat transfer has been checked with aluminum, steel, and copper fins. The purpose of this investigation was to verify experimentally the use of the factor of thermal conductivity in the theoretical equation for the heat transfer from finned cylinders.

Flight tests have shown that for the same pressure drop across the cylinder fins the cooling in flight is considerably better than that obtained in laboratory tests with single-cylinder engines. This difference in cooling is attributed to the turbulent flow of air over the front of the cylinders that occurs in flight with the N. A. C. A. cowling. An investigation is being conducted to determine the effect of air turbulence on the cooling of finned cylinders.

Baffle study.—A study has been made to determine the effect of cylinder diameter, fin spacing, fin width, and baffle design on the energy loss of the air passing by the cylinder. The results show the relative cooling and the distribution of the energy loss for each baffle arrangement.

Blower power required.—For long-range airplanes, the air-cooled engines could be located within the wing and cooled by a blower. The results of the tests on two cylinders having widely differing fin pitches, enclosed in jackets and cooled with a blower, have been published in Technical Note No. 572. The minimum power required for satisfactory cooling with an over-all blower efficiency of 100 percent varied from 2 to 6 percent of the engine power, depending on the operating conditions. The shape of the jacket had a large effect on the cylinder temperatures. The drop in total head across the cylinder varied approximately as the square of the weight of the cooling air. The temperature difference between the cylinder and the cooling air varied as the 0.51–0.56 power of the indicated horsepower.

An investigation has been made to determine the effect of changes in fin width and fin spacing on the pressure drop and power required to force air around finned cylinders at air speeds from 15 to 230 miles per hour. The effect of changes in the shape of the entrance and exit of the jacket on the pressure drop and power required to force the air around the finned cylinders has been investigated. The results of this investigation are being prepared for publication.

Cooling-air temperature.—For safe operation the temperatures of air-cooled cylinders must not exceed certain limiting values. Since air-cooled engines are required to operate over a wide range of conditions, it is important that the effect of the operating conditions on cylinder temperatures be known. In the acceptance testing of airplane engines the problem often arises of predicting engine temperatures for summer operation from tests made in the winter or of predicting altitude temperatures from tests at sea level.

An investigation has been made at the request of the Bureau of Aeronautics, Navy Department, to determine the effect of cooling-air temperature on cylinder temperature for the six cylinders representing service-type engines. For the range of conditions studied it was found that a single correction factor could be used for all cylinders for the variation in cylinder-head temperature with cooling-air temperature. Similar correction factors were also obtained for the cylinder barrel and flange. A report covering this investigation is being prepared.

A theoretical study has been made of the heat-transfer process in an air-cooled engine to provide a better insight into the relation between the various engine and cooling conditions. Equations have been derived for the relationship between cylinder temperatures and the important engine and cooling variables. The several empirical constants in the equations may readily be obtained from engine tests. An investigation has been made on a single-cylinder engine with two different designs of air-cooled cylinders to check the theoretical development and to provide values for the constants in the equations applicable to the respective cylinders for the particular conditions of the tests. The results of this investigation are being prepared for publication.

An investigation has been made to determine the effect of engine power, mass flow of the cooling air, and atmospheric temperature on the cylinder temperature of a Pratt & Whitney 1535 supercharged engine under actual flight conditions. A Grumman Scout (XSF–2) airplane was used in these tests. The results indicated that the difference in temperature between the cylinder wall and the cooling air varied as the 0.38 power of the brake horsepower for a constant mass flow of cooling air, cooling-air temperature, and engine speed. The difference in temperature was also found to vary inversely as the 0.39 power of the mass flow for points on the cylinder head, and the 0.35 power for points on the barrel, provided the engine power, engine speed, and cooling-air temperature were kept constant. A report of the results of this study has been prepared for publication.

Cooling at altitude.—An analysis has been made for the Bureau of Aeronautics, Navy Department, of the comparative cooling at altitude and at sea level of supercharged air-cooled engines in a high-speed transport and a pursuit airplane. The estimated cooling was based on data obtained from wind-tunnel tests of a multicylinder engine mounted in a nacelle and from single-cylinder engine tests.

Flame temperature.—A new technique for measuring combustion engine temperatures by the sodium line reversal method has been developed. The preliminary results obtained by this method are presented in Technical Note No. 559. Further measurements with a new cylinder head in which the temperature distribution will be studied are in progress.

COMPRESSION-IGNITION ENGINES

The rapid development of the compression-ignition, or Diesel type, engine for use in all forms of automotive equipment has not been followed in this country by the development of a successful Diesel aircraft engine. The low fuel consumption and reduction in fire hazard obtained by the use of the compression-ignition engine should be of particular interest to operators of long-range transport aircraft. The research work of the Committee on the compression-ignition engine has been continued with the object of obtaining fundamental knowledge concerning the fuel-injection and combustion process and of increasing the specific power output. A form of integral combustion chamber in which high-velocity air flow is utilized for distributing and mixing the fuel and the combustion air is being investigated. The specific power output obtained with a single-cylinder liquid-cooled engine using this combustion chamber compares favorably with the maximum obtained from present supercharged spark-ignition aircraft engines.

Combustion research.—An investigation of the combustion characteristics of fuel sprays suitable for use in compression-ignition engines has been completed and the data are presented in Technical Report No. 545.

A constant-volume bomb has been used to investigate the effect of air temperature and density on the auto-ignition and subsequent combustion of Diesel fuel. The bomb is mounted in an electric furnace and can be heated to a maximum temperature of 1,100° F.; the density of the air in the bomb can be adjusted to any desired value. The minimum ignition lag obtained with this apparatus, the fuel being injected as in the compression-ignition engine, is 0.001 second. The amounts of ignition lag and combustion time obtained with the bomb are comparable with those obtained in the compression-ignition engine. An investigation is being conducted with the bomb to determine the effect of injection-nozzle design, air temperature, and pressure on the combustion.

The results of the investigation made of the combustion in a spherical bomb with a fuel-injection system at relatively low air temperatures have been published in Technical Report No. 544.

A research has been completed to determine the effect of increasing the degree of atomization of the fuel injected into a prechamber compression-ignition engine with forced air flow. The degree of atomization of the fuel was varied by increasing the fuel-injection pressure from 4,000 to 9,000 pounds per square inch. The results showed that the ignition lag decreased 35 percent and the brake mean effective pressure increased 19 percent with increase in the fuel-injection pressure. The results of an investigation covering the effects of several designs of fuel-valve nozzles on the fuel spray and flame formation in a high-speed compression-ignition engine have been published in Technical Report No. 561.

The effect on ignition lag and engine performance of heating the fuel oil before injection to a maximum temperature of 750° F. has been determined with a compression-ignition engine having a prechamber. The research is described in Technical Note No. 565.

Fuel-injection pumps.—Improved distribution of fuel within combustion chambers of certain forms for compression-ignition engines may be obtained by the use of more than one fuel-injection valve. An investigation has been completed on the rates of discharge from a single-cylinder fuel-injection pump connected to two injection valves. The variables investigated were pump speed, injection-tube length, injection valve-opening pressure, and discharge-orifice diameter. The results showed that by the proper choice of injection valve-opening pressures and discharge-orifice diameters of the two injection valves, time rates of discharge can be obtained that cannot be obtained with a single injection valve. The use of unequal tube lengths connecting the two injection valves to the fuel pump resulted in erratic operation when the speed of the pump was varied. When the two injection tubes were of the same length, this erratic operation with change in pump speed did not occur.

A research has been started to determine the rates of discharge from a fuel-injection system in which the injection pump is connected directly to the fuel-injection valve. Preliminary tests indicate that with this system the rates of discharge are more nearly a function of pump speed than is the case with a long injection tube. The tests are being conducted for a range of pump speeds, injection valve-opening pressures, discharge-orifice diameters, and throttle settings.

A comparison of the distribution of fuel with several types of fuel sprays has been published in Technical Report No. 565.

Prechamber-type of combustion chamber.—This investigation has been completed and a report is being prepared summarizing the research work on the prechamber type of combustion chamber.

Integral type of combustion chamber.—Technical Report No. 568 has been prepared summarizing the work completed on the performance of an integral combustion chamber with no air flow, and concluding this investigation.

The investigation of engine performance has been continued on a single-cylinder engine having a displacer piston and a combustion chamber of vertical disk form. Results have been published in Technical Note No. 569 of the engine performance obtained at 2,000 r. p. m. for boost pressures up to 10 pounds per square inch. For these conditions brake mean effective pressures of over 200 pounds per square inch have been obtained with a specific fuel consumption of 0.46 pound per brake horsepower-hour. An investigation has been started at 2,500 r. p. m. on a single-cylinder engine having a 5-inch bore and a 7-inch stroke to determine the characteristics and performance possibilities of the displacer-piston combustion chamber at the higher engine speed.

Engine friction.—An investigation of the friction characteristics peculiar to compression-ignition engines has been completed and the results presented in Technical Note No. 577. The investigation included the determination of the effect of combustion-chamber shape, air-flow quantities, and compression ratio on the friction of single-cylinder compression-ignition engines.

Altitude performance.—Information is lacking concerning the performance of compression-ignition engines at altitude conditions. Equipment has been assembled and an investigation started to determine the performance of a single-cylinder liquid-cooled compression-ignition engine in operation under conditions of inlet pressure and temperature and exhaust pressure equivalent to altitudes from sea level to a maximum of 30,000 feet.

Single-cylinder and multicylinder engines.—The problems of adopting the displacer-piston form of combustion chamber to a radial air-cooled engine and the requirements for adequate cooling have been given careful consideration. A preliminary design of air-cooled cylinder suitable for installation on a conventional radial engine has been completed. The necessary equipment is being assembled for an investigation of this design. In addition to giving information on power, economy, and cooling requirements, the results will permit direct comparisons to be drawn between the mechanical friction of spark-ignition and of compression-ignition radial air-cooled engines.

The 2-stroke-cycle engine.—Investigation of the 2-stroke-cycle compression-ignition engine has been continued with a determination of the optimum entry angle for the scavenging and combustion air with the inlet and exhaust systems arranged to eliminate ramming. An improvement of 15 percent in maximum performance was obtained by directing the air into the cylinder at a horizontal angle of 60° to the radial; all vertical entry angles with a flat-top piston adversely affected the engine performance. The single-cylinder engine developed 0.65 brake horsepower per cubic inch of displacement when operated at 1,800 r. p. m. with a scavenging air pressure of 8 pounds per square inch. The data indicate that a further improvement in performance may be expected by the use of higher scavenging pressures and engine speeds. A report presenting the results of this work is being prepared.

INSTRUMENTS

Fuel flowmeter.—The electrical type of indicating fuel flowmeter has been further developed to extend its range when either a potentiometer or a millivoltmeter is used for indication. The range of fuel flow that has been covered with a potentiometer is from 30 to 1,500 pounds per hour. The instrument is now being tested in flight.

High-speed camera.—The researches on combustion in a spark-ignition engine have indicated the need of taking high-speed motion pictures at rates greater than that of 2,500 frames per second now available with the present high-speed motion-picture camera. A new camera is being designed, to consist of a single rotating drum upon which will be mounted the photographic film and a system of prisms. The prisms are so arranged that the image focused on the film moves at the same linear speed as the film. The camera is being designed to take motion pictures of the combustion at rates up to 40,000 frames per second.

NATIONAL BUREAU OF STANDARDS

Phenomena of combustion.—The effects of the inert gases argon and helium upon flame speed and expansion ratio in mixtures of carbon monoxide, oxygen, and water vapor, measured by the bubble method, are described in Technical Report No. 553. The results of further studies of flame movement and pressure development in an engine cylinder are presented in Technical Report No. 556. A brief mimeographed note entitled "Practical Aims of Combustion Research" has been prepared for distribution to visitors and to others interested.

The construction of a spherical bomb of constant volume, equipped with (a) means for photographing the spread of flame from a central point of ignition, and (b) six indicators of the balanced-diaphragm type arranged to record the points at which predetermined pressures are reached, has been undertaken. Short cylinders of Pyrex glass, with ends ground parallel and with inside and outside surfaces given an optical polish, have been prepared to serve (singly) as windows through which the flame may be photographed.

The development of pressure indicators having sufficient accuracy has necessitated a special investigation of the characteristics of such instruments. These studies show that local regions of extremely high pressure may exist in passageways and crevices on the explosion side of the diaphragm. It is therefore desirable that the diaphragm be exposed directly to the explosive mixture. Studies of the effects of diaphragm diameter and thickness show that, for the present purpose, the inertia of the diaphragm is an important factor, particularly if measurements are to be made during the early stages of the explosion. An adequate compromise between sensitivity and inertia has been found experimentally, and the pressure indicators have been designed accordingly.

In the evolution of an accurate time-pressure record at least two other factors must be considered, namely (a) the time lag involved in the transfer of pressure from the flame front to the diaphragm, which is thought to be the time required for sound to travel from one to the other, and (b) the time between ignition and the attainment by the flame of its maximum, and temporarily constant, spatial speed. In the case of an explosive mixture for which flame speed and expansion ratio are already known, the observed and calculated time-pressure records are in good accord when the above corrections are determined and applied. Mathematical analyses of spherical burning at constant pressure (bubble) and at constant volume (bomb) have yielded fairly simple working equations whereby the desired characteristics may be derived from the observed quantities.

Ignition investigations.—The work on ignition problems for the Bureau of Aeronautics, Navy Department, has included laboratory tests of magnetcs, ignition cable, spark plugs, and spark-plug elbows. In addition to the routine testing of magnetos, attention has been given to the improvement of test methods and a study was undertaken to ascertain the influence of various factors on the electrical characteristics of magnetos. The development of ignition cable capable of withstanding higher temperatures has been encouraged and experiments are in progress with a view to the possible replacement of rubber insulation. The mathematical analysis of heat flow in mica spark plugs has been extended and the accompanying calculations made. The theoretical results are being correlated with test results on spark plugs designed according to the theoretical principles. Routine temperature surveys have been made on about 20 airplanes and various cases of overheating have been found and corrected. Repeat tests on the same airplane at different ground temperatures have tended to show that the correction factors in current use are too small. Special temperature measurements have been made in connection with flight tests of spark plugs and spark-plug elbows.

Endurance tests of engines.—At the request of the Bureau of Air Commerce, a 25-hour torque-stand endurance test of an inverted 4-cylinder in-line air-cooled aircraft engine, in which battery ignition was used in place of the magnetos, was undertaken and successfully completed. The same engine had been run previously for about 25 hours during the cooling investigation and was subjected later to about 100 hours of additional running during a propeller test. A final report has been prepared covering the performance of the ignition system, and other parts, for the entire 150 hours.

A popular vee-type automobile engine, subjected to dynamometer test at full throttle and rated speed for the information of the Bureau of Air Commerce, suffered a crankshaft failure after running about 100 hours. A second test was terminated in a few hours by a connecting-rod bearing failure. Tests of a new engine, embodying the 1936 changes, developed two piston failures in the course of about 85 hours' running.

A well-known two-cylinder motorcycle engine is being given a 300-hour torque-stand endurance test to determine for the Bureau of Air Commerce the suitability of its parts for use in small and inexpensive aircraft engines. The propeller in this installation is driven by vee belts. Two 50-hour runs have been satisfactorily completed, about 15 horsepower per cylinder being developed at 3,000 r. p. m. The engine valves have given some trouble because of distortion of the cylinders by the cylinder-head studs. During the remainder of the test the engine is to be run at 4,000 r. p. m.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

High octane number fuels.—The Subcommittee on Aircraft Fuels and Lubricants has prepared a program of tests of a single-cylinder engine to be conducted at the Langley Memorial Aeronautical Laboratory to determine the maximum performance that can be obtained with fuels having octane numbers from 87 to 100 without lead and for higher octane ratings with lead. The fuel to be used in these tests has been prepared for the Aviation Gasoline Detonation Subcommittee of the Society of Automotive Engineers. The maximum engine performance obtainable with a fuel having a specified octane number will be determined by two methods; first, by increasing the compression ratio and, second, by maintaining a constant compression ratio and increasing the boost pressure. The factor limiting each test will be the start of detonation. For check purposes, limited tests will be made by the laboratory on air-cooled single-cylinder engines and by the Matériel Division of the Air Corps on a liquid-cooled single-cylinder engine.

Detection and evaluation of knock.—A report on methods of measuring the intensity of knock in high-output aircraft engines was prepared at the request of the Bureau of Aeronautics of the Navy Department, and has been made available both to the Subcommittee on Aircraft Fuels and Lubricants and to the C. F. R. Aviation Gasoline Detonation Subcommittee. A satisfactory laboratory model of the photoelastic pressure gage has been completed and tested. This indicator will record directly either the pressure or the rates of pressure rise accompanying detonation. A portable instrument combining the pressure indicator and a thermal plug has been designed and is under construction.

Rating fuels in full-scale aircraft engines.—The results of the comparative tests of aviation fuels in representative aircraft engines, made by the National Bureau of Standards in cooperation with three engine companies, have been published. The final report includes a C. F. R. recommended procedure for rating fuels in full-scale aircraft engines and outlines the program of future work of the C. F. R. Aviation Gasoline Detonation Subcommittee with aviation fuels of high octane number. Arrangements have been made to set aside 70,000 gallons of technical iso-octane and 10,000 gallons of a straight-run gasoline of about 20 octane number for general use as reference fuels in full-scale engine tests of high octane fuels. The work of the C. F. R. subcommittee is being coordinated with the program of the Subcommittee on Aircraft Fuels and Lubricants so as to avoid possible duplication. The Army Air Corps, the Bureau of Aeronautics of the Navy, the National Bureau of Standards, and leading engine manufacturers are represented on both subcommittees.

Stability of aviation oil.—The investigation of the stability of aircraft engine lubricating oil, undertaken with the cooperation of the Bureau of Aeronautics of the Navy, was continued throughout the fiscal year. Engine tests with 22 representative aviation oils were completed after operation for approximately 30 hours each in a Pratt and Whitney Hornet engine at about 75 percent rated power. In cooperation with the Navy Department a large number of samples have been removed from engines in service and have been analyzed to provide a basis for further correlation with laboratory stability tests and a basis for recommendations regarding extension of the period between oil changes in service. A large volume of laboratory data was obtained on the 22 oils under various conditions of oxidation at various temperatures and a satisfactory correlation was found by the use of one set of laboratory test conditions and the results of the tests on the Hornet engine. Apparatus has been constructed for testing oil stability by an improved and somewhat simpler method which involves heating the oil in a cylinder under conditions analogous to those encountered in aircraft engines.

Oil acidity and bearing corrosion.—An investigation has been initiated for the Bureau of Aeronautics of the Navy involving a study of the effect of increase in oil acidity during service on the corrosion of master rod bearings. Apparatus for this purpose has been designed and the construction of a large part of it has been completed.

Wear and oiliness characteristics of aviation-engine lubricating oils.—An extensive investigation has been started with the cooperation of the Bureau of Aeronautics on the oiliness characteristics of lubricating oils and on the differences in cylinder-wall and piston-ring wear caused by different oils. Emphasis is being placed on the development of compounded oils which will have superior lubricating qualities and which will tend to reduce wear in high-output engines. Apparatus for this investigation has been designed and is practically completed. In conjunction with this investigation, data on oil stability and corrosion are being obtained on those compounded oils which show merit from the standpoint of wear reduction.

Aviation-engine wear.—In cooperation with the Subcommittee on Aircraft Fuels and Lubricants and a number of representative petroleum organizations, an investigation has been started on the relative wear with various oils in actual aircraft engines. In these tests it is planned to rely on accuracy of measurements rather than on long-time operation in order to obtain the desired information, and the engine will be largely rebuilt for each test, new pistons, cylinders, and rings being used each time. Considerable progress has been made in assembling the necessary equipment, both for measuring the various engine parts and for absorbing the power. A special sound absorber has been designed and constructed in order to minimize engine noise and preliminary tests have indicated a fairly high degree of effectiveness.

REPORT OF COMMITTEE ON AIRCRAFT STRUCTURES AND MATERIALS

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

Weathering of light-alloy structural sheet material.—The series of tests on aluminum-alloy sheet material which have been in progress at Washington, D. C.; Hampton Roads, Va.; and Coco Solo, C. Z., will be completed early in 1937 after four years' continuous exposure of the specimens to the weather. Although the initial test program was arranged to cover five years, it is felt that they will have essentially fulfilled the purpose in the somewhat shorter time. The results definitely establish the markedly superior properties, with respect to corrosion resistance, of the aluminum alloys containing magnesium as the alloying constituent over similar alloys containing copper as an esesntial alloying constituent. The tests have also given valuable information with respect to the coating processes which are dependable for use on aluminum-alloy structures which must withstand severe atmospheric conditions. The Alclad materials have proved very resistant under all conditions imposed upon them. These various classes of alloys can be depended upon to give eminent satisfaction over a stipulated minimum five-year service life of an aircraft.

In the summarizing report, detailed information is given on the microstructural aspect of the corrosion of aluminum-alloy sheet and its relation to the lowering of the mechanical properties of the material. The correlation of the results of laboratory tests by the salt-spray method on a large number of specimens with the results obtained with similar materials exposed continuously serves as a basis for a practical evaluation of this method of testing, which is extensively used in specifications in the aircraft industry.

A program to supplement these tests has been authorized and tests have been planned to give information on specific items of general importance in aircraft construction, such as spot welding, riveting, faying or contact surfaces, as well as newly developed protective coatings.

Protective surface treatment of magnesium alloys.—An electrolytic method has been developed for the surface treatment of magnesium alloys which is analogous to the anodic process used for aluminum alloys. The process is being applied on a commercial scale at the Naval Aircraft Factory. This method for treating the surface of magnesium has proved superior in a number of ways to other processes for the same purpose, although it is not so simple in application as the corresponding anodic process for aluminum alloys, since the various types of magnesium alloys differ somewhat in their response to the treatment. Work is being continued for defining the proper conditions for each type of this class of alloy. The process has been described in a Research Paper of the National Bureau of Standards. Weather-exposure tests are in progress to supplement extensive laboratory tests by the salt-spray method to determine the relative merits of magnesium alloys treated by this and other methods, the treated specimens being coated with various kinds of priming and finishing coats recommended for magnesium.

Anodic oxidation for protective treatment of aluminum.—Work on this subject has been completed. The widely used chromic-acid method for this as initially described was essentially a batch process requiring an empirically determined voltage cycle. The work has demonstrated the feasibility of carrying out the process as a continuous one, and has, in addition, established the underlying principles for maintaining the bath in good working condition. The reasons for the deterioration of the bath with use have been set forth. The results are presented in a Research Paper of the National Bureau of Standards.

Elastic properties of high-strength aircraft metals.—In this investigation, which has recently been initiated, corrosion-resistant steel of the so-called 18–8 type is being used as the basis. This material already has been accepted for many important uses in aircraft. such as tie rods, cables, etc., and other important new uses are constantly being considered and tried. Austenitic steel of this kind owes its high strength to the cold working to which it is subjected in fabrication and definite information on the elastic properties and their limitations is very desirable, since, as is well known, the elastic properties of such a material are largely only nominal. None of the austenitic steels possess true elastic properties. In particular, information on the "over-load" characteristics of the material is desirable.

With the nominal elastic properties of the material as determined by the customary stress-strain measurements as a start, a study of the stress-permanent set relationship has been made, following which similar studies are being made of similar material which has undergone deformation prior to testing, such as might occur through accident in service. On the basis of the information secured by such studies it is expected that the maximum allowable stresses for materials of this kind which possess no true elastic properties can be fixed with more assurance than on a knowledge of only their nominal elastic properties or empirically determined yield strength.

Structural changes in aircraft metals occurring as a result of service stressing.—It is well established that marked structural changes which are conducive to short service life occur in certain soft alloys as a result of the stress conditions which occur in service. An investigation has been started to show whether or not highly stressed aircraft metals, particularly propeller materials, may be subject to similar detrimental structural changes. The work has been confined to the propeller aluminum alloy, 25S, with special emphasis on its behavior under fatigue stress.

X-ray study by reflection methods at an angle of grazing incidence of the same spot on the surface of a fatigue-test specimen as it is fatigue-stressed at successively higher maximum fibre stresses from 12,000 to 18,000 pounds per square inch has shown no significant changes in the reflection pattern.

A testing program on the aluminum-alloy propeller material is now under way to show to what extent, if any, fatigue-stressing may affect the other mechanical properties of the material. Special attention is being given to the possible effect of fatigue-stressing on the impact resistance of the material. Information on this point is urgently needed.

Certain microstructural features, "slip-plane precipitation" and "veining", observed in 25S which have aroused some suspicion as to origin and significance have been found in individual grains throughout most of the length of practically all the blades studied. These features are evidently not characteristic of areas of maximum service stresses. Their appearance is associated with heat-treatment procedure. Results have been obtained which indicate that this condition can be more readily revealed in material which has been fatigue-stressed than in the same material initially. However, the practical significance of this fact, if it has any, is not apparent as yet.

Results of a systematic study of the rate of "growth" of the heat-treated 25S alloy indicate that growth in the material continues long after the maximum hardness of the alloy has been attained, which fact may have some significance with respect to internal stresses in the finished material as it goes into service.

Aircraft metals at subzero temperatures.—A program of tests has been carried on during the year for obtaining information requested by the Bureau of Aeronautics on the common mechanical properties of aircraft structural metals at subnormal temperatures, approximately those which occur in service. These properties were determined at a series of temperatures ranging from room temperature to −78.5° C. (−109° F.). Information has been obtained on stainless steel, 18–8, and on the same material "stabilized" by means of titanium and by columbium; on representative aluminum alloys, cast and wrought; magnesium alloys, cast and wrought; chromium-nickel alloy, "inconel" (Cr 15 percent, Fe 6 percent, Ni 79 percent); chromium-nickel-molybdenum steel (C 0.47 percent, Cr 1.04 percent, Ni 1.80 percent, Mo .22 percent); high-chromium steel (C 0.11 percent, Cr 16.3 percent, Ni 1.72 percent).

Practically all of the materials have shown an increase in the yield strength and ultimate strength at the lowered temperature with no change in the modulus of elasticity and only slight or insignificant decrease in the ductility. A very reassuring result of the tests to date on many of the materials is the fact that the impact resistance of notched specimens determined at the low temperature, −78.5° C., is not materially different from the value obtained on the same material at room temperature. For a few of the materials, however, some decrease in this property was noted. A report summarizing the work is in preparation as a Research Paper of the National Bureau of Standards.

Propeller materials.—The steel used in welded hollow steel propellers is a chromium-vanadium steel (S. A. E. No. 6130) having an ultimate tensile strength in a heat-treated condition of 120,000 to 155,000 pounds per square inch. The endurance limit determined on specimens cut from blades was 60,000 to 72,000 pounds per square inch; on specimens cut from the blade so as to contain a portion of the welded seam, it may be considerably lower, possibly as much as 30,000 pounds per square inch.

Miscellaneous aircraft metals.—In cooperation with the Bureau of Aeronautics, study has been made of the localized corrosion of a pitting type on rods of cold-rolled 18–8 stainless steel after a few months' marine service. Occasional rod failures were found which were of the fatigue type and which had originated at a pit. Improper surface finish is believed to be an important factor in this unsatisfactory behavior of the material.

Experiments are under way to determine the optimum annealing treatment for relief of internal stress in cold-rolled stainless tie rods without entailing marked lowering of the strength and corrosion-resistance. Heating to 1000° F. may be necessary for this purpose.

At the request of the Bureau of Aeronautics, Navy Department, studies are being made of a number of selected steels in an attempt to obtain information on the significance of elongation and reduction of area values in tensile tests, apart from their use as indications of quality of the materials. Information is desired bearing on the significance of the fact that for some metals the values for elongation and reduction of area in a tensile test are required to be two or three times as great as in others. Ordinary tensile tests, tensile-impact, notched-bar impact, torsion-impact, and hardness tests, as well as studies of the microstructure, are being made on the steels in several conditions of heat treatment. Extensometer measurements are made of the elongations to the moment of fracture and reductions of area are measured simultaneously with the extensions.

SUBCOMMITTEE ON STRUCTURAL LOADS AND METHODS OF STRUCTURAL ANALYSIS

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

Applied Loads on Airplane Structures—Gust loads.—Statistical measurements of acceleration and air speed on transport airplanes in regular service have been continued on the land types and extended to include the large flying boats in the Pacific and Caribbean services. Records covering a total of over 16,000 airplane hours have been accumulated under a wide variety of conditions. With the exception of one case, in which a land transport flew through a line squall, the maximum gust velocities deduced from the records on the basis of the sharp-edge-gust assumption have not exceeded ±35 feet per second. In the exception noted the maximum gust velocities were +33 feet per second and −47 feet per second. In the case of the large flying boats, the maximum gust velocities have extended to the same limits, namely, ±35 feet per second, as those measured on the land transports, notwithstanding the much smaller total quantity of data on the flying boats.

Gust research.—Measurements of gust intensities and gradients have been made with light airplanes close to the ground under stable atmospheric conditions with large wind gradients. Analysis of a large number of gusts indicates that under these conditions the gust gradient decreases with increasing gust intensity so that the stronger gusts (30 feet per second) reach their maximum intensities in a horizontal distance of about 100 feet. This relation, however, cannot be considered well established without further verification by more extensive data.

A number of altitude surveys indicate that, aside from the gustiness associated with large wind gradients near the ground, strong gusts are usually found only within clouds of the cumulus type. An exception has been noted, however, at an altitude of 14,000 feet, in which case strong turbulence was found well under an alto-cumulus cloud layer associated with the overrunning of a polar air mass by the outer reaches of a distant tropical hurricane. The strong wind gradient that presumably existed at the turbulent level caused accelerations of the airplane that were nearly as great as those measured within cumulo-congestus clouds.

Acceleration Measurements on Racing Airplanes.—Acceleration measurements have been made on several racing airplanes in actual races to supplement data previously obtained. The results, which do not include accelerations higher than those previously reported, have been presented in Technical Note No. 556.

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Load Distribution.—A number of wind-tunnel experiments have been made to determine the pressure distribution on wings with flaps. Most of these tests have been made to establish the section characteristics, including the division of load between flap and wing, and the flap hinge moment. Flaps investigated in this section of the program include the split, plain (with and without tab), external-airfoil, and Fowler types. (See Technical Report No. 574).

Pressure-distribution measurements have also been made in the 7- by 10-foot wind tunnel and in the full-scale wind tunnel to determine the span-load distribution on wings with partial-span flaps (Technical Report No. 571). The results have been examined in the light of airfoil theory, and it has been found that the Lotz method of calculating the span-load distribution gives a sufficiently good approximation for structural purposes provided a sufficient number of harmonics are retained. A simple set of computing forms for determining the distribution by the Lotz method has been devised. These forms permit the use of a sufficient number of harmonics to obtain good precision, and at the same time keep the computations within reasonable limits.

NATIONAL BUREAU OF STANDARDS

Inelastic Behavior of Duralumin and Alloy Steels in Tension and Compression.—Tests by the pack method to study the behavior of thin sheet material in compression have been continued. The results suggest that the data from tensile tests on specimens cut transverse to the direction of rolling are more closely correlated with the compressive tests of specimens cut in the direction of rolling than the results from tensile specimens cut parallel to the direction of rolling.

Tubes Under Loads Other Than Torsion.—Some thirty odd 17ST tubes of varying length and of diameter-thickness ratios ranging from 15 to 70 have been tested for modulus of rupture under third point loading. The results are being analyzed, and the indications are that the test values of the modulus of rupture can be approximated within ±5 percent by the equations of surfaces in which the ratio of diameter to thickness and the ratio of slenderness are the independent variables.

The modulus of rupture of chromium-molybdenum steel tubing has been determined for tubing with diameter-thickness ratios varying from about 15 to 60 and with loads applied in such a way as not to deform the tubing locally. Tests have also been made in which the load is applied in such a way as to deform the tubing locally; but the scattering of results is too great to determine the effect on the modulus of rupture of this method of loading, without further tests.

It should be noted that the variation of modulus of rupture with length or ratio of slenderness is due solely to the method of applying the load. When the load is applied in such a way as not to deform the tube at the point of application of the load, the modulus of rupture is always found to be independent of the length of the tube. When, however, in the case of thin tubes, the load is applied as through a compression member, local deformation is produced by the load, which tends to dent the specimen, and failure occurs at lower values of the modulus of rupture for short specimens than for long. Thick tubes are little, if at all, affected. This effect of the method of applying the load has been studied and moduli of rupture have been determined under a conservative method of applying load, a method as severe as any likely to be met in practice. It has been found, of course, that the modulus of rupture increases with decreasing diameter-thickness ratio.

Work is in progress to correlate the results obtained from the tests for modulus of rupture and column strength of 17ST aluminum alloy tubing with the previous tests of this tubing under combined axial and transverse loads. In this connection it has been found that the so-called "add-area" method of designing is safe but probably uneconomical. It is hoped to improve the economy without endangering the safety.

Tubes with Torsional Loads.—The analysis of torsion tests of 61 chromium-molybdenum steel tubes and 102 tubes of 17ST had shown that the strength of the aluminum-alloy tubes could be expressed conveniently as a function of their wall thickness, outside diameter, length, and ultimate strength in tension. In the case of chromium-molybdenum steel tubes with their much more variable mechanical properties a knowledge of the yield point in tension is required in addition.

A report of this work has been prepared. It concludes with two design charts, one for chromium-molybdenum steel tubes and the other for 17ST tubes, from which the strength of such tubes within the range of sizes of those tested may be estimated with a minimum amount of labor.

Flat Plates Under Normal Pressure.—The tests so far made have given an answer to the problem of the amount of washboarding to be expected in a given plate, provided the plate is of the same material (17ST, 18–8) as those tested and provided it is supported in the same manner at the edges (clamped edges, supported edges) and falls into the range of sizes of those tested. To extend these results to cover other materials and other edge conditions requires either an extensive series of tests covering all the materials and all the edge conditions in question, or else the discovery of a satisfactory theoretical or semitheoretical relationship for these variables.

A comparison of the experimental results was made with the known theories for the deformation of rectangular plates of medium thickness in the hope of discovering such a theoretical or semitheoretical relationship. Unfortunately, the comparison did not lead to the desired results because of the incompleteness of the theory, on the one hand, and the difficulties of securing the theoretical edge conditions in actual plates on the other. It was finally decided to search for an explanation by making additional tests of circular plates with clamped edges and comparing the results of these tests with the relatively complete theory of circular plates of medium thickness proposed by Way in 1933.

A fixture for testing circular plates with clamped edges has been constructed for conducting these tests. A proof test of the fixture showed that it held the plate clamped firmly to a pressure of about 600 pounds per square inch. The center deflection and the permanent set at the center of these plates showed the same type of variation with pressure as that found for the rectangular plates. This supports the expectation that the results of the tests of circular plates may throw light on the behavior of rectangular plates.

Strength of Welded Joints in Tubular Members for Aircraft.—A detailed report of this investigation has been prepared and is now in process of publication.

This report supplements the work described in Technical Report No. 348, which had shown that the use of inserted gusset plates was the most satisfactory way of strengthening a joint. The additional tests of the present series show that joints of this type could be improved by cutting out the portion of the plate between the intersecting tubes.

T and lattice joints in thin-wall tubing 1.5 by 0.020 inch have somewhat lower strength than joints in tubing of greater wall thickness because of failure by local buckling. In welding the thin-wall tubing only the recently developed carburizing-flux process was found to produce joints free from cracks. The magnetic-powder inspection was used to detect cracks in the joints and flaws in the tubing.

Heat-treating the chromium molybdenum T, lattice, and butt joints materially increased the strength. Butt joints in chromium-molybdenum sheet and tubing made by low-carbon welds, chromium-molybdenum welds, and carburizing-flux welds had about the same strength in the "as welded" condition. When heat-treated the chromium-molybdenum and carburizing flux welds were the strongest.

A number of welded joints that had been tested in this investigation were sectioned at the welds and etched to compare the quality of the welds with that found in the sections of welded joints taken from two airplanes that had failed. The comparison showed a much more intimate bond and a more gradual transition in section for the welds made for this investigation than for those taken from the airplanes. This indicates that there is room for improvement in the welding technique used in assembling aircraft.

Strength of Riveted Joints in Aluminum Alloy.—The work done to date in connection with this project has been summarized in a report which has been mimeographed for distribution to Government agencies and manufacturers interested in the design of rivet connections.

The report contains a full account of the data obtained on the relation of head dimensions to driving stress, for various types of heads. The relation of shank upsetting to type of head used and to the ratio of rivet diameter to sheet thickness was also determined and the effects of this upsetting on the shearing strength of joints are discussed quantitatively. The tensile strength of joints for several types of driven rivet head was determined. Radial deformation of the sheet during driving of the rivets was investigated and found unsuitable as a criterion of excessive sheet buckling.

The report concludes with a tentative program for future work on this project. The exact nature of this program will be decided on the basis of the comments received relative to the report.

Investigation of Fatigue Resistance of Fabricated Structural Elements of Aircraft.—A machine for determining the endurance of wing beams under longitudinally reversed stress was constructed. The stress is provided by resonant motion of two weights relative to each other, one attached to each end of a section of the beam. The weights were chosen to resonate at a frequency of about 60 cycles per second; their motion is maintained by means of a push-pull or reciprocating motor. The weights required are so heavy (about 800 pounds) compared to the weight of the beam (25 pounds) that all sections of the beam are subjected to practically the same longitudinal force.

The test to destruction of one wing beam has been completed with the aid of this machine. In tests at constant over-all strain amplitude with zero mean stress, the nominal stress amplitude dropped continuously from 8,650 to 8,280 pounds per square inch during the test while the resonant frequency dropped steadily from 54.8 to 53.65 cycles per second. Failure occurred after 452,000 cycles. Cracks had formed at several points scattered over the length of the specimen, all but one being in the web. The crack distribution showed that substantially uniform load conditions had prevailed throughout the length of the specimen, and that cracks were generated more often at open holes than at rivets.

A comparison of the stress history of the beam with the diagrams of stress against cycles to failure of similar material indicated that failure should have occurred at the time it did if the stress concentration at the points of origin of the cracks was of the order of 3.

Beams and Stressed-Skin Research.—Compression tests have been completed on two sheet-stringer specimens submitted by the Bureau of Aeronautics of the Navy Department to obtain a comparison with the strain distribution and the ultimate strength of similar sheet-stringer specimens tested at the Navy Model Basin.

The strain distribution was obtained from readings of twelve pairs of Tuckerman optical strain gages attached to various portions of the sheet and the stringers. The shape of the buckles was recorded by plaster casts. The progression of failure was followed by a large number of pointers attached to each stringer to indicate the amount of buckling and of twisting.

An analysis of the measured strains for one of the specimens showed that the median fiber strain in the center between stringers became a tensile strain under high compressive loads. This agrees with the paradoxical result predicted by Timoshenko for the stress distribution in square plates after buckling. Timoshenko's theory has been extended to include rectangular plates in order to apply it to the present case.

The comparison of the observed stringer loads with those calculated from Timoshenko's theory, extended to rectangular plates, leads to a fair agreement up to loads within about 20 percent of the ultimate load. The theory also predicts the strain distribution accurately and may, therefore, be taken as a good first approximation in the design of sheet-stringer combinations of the type tested and under conditions approaching those of the test.

Propeller Vibration.—A theoretical analysis of the effect of centrifugal force on the stress distribution and frequency of propeller blades vibrating with the fundamental mode in bending and second harmonic mode in bending (with one node near the tip) has been completed. The analysis shows that the stress per unit tip deflection changes only 10 to 20 percent at speeds of rotation around 1,700 r. p. m. It seems, therefore, that the ordinary engineering procedure of taking the extreme fiber stress at any point in a vibrating blade as the sum of the centrifugal stress and the bending stress for no rotation is adequate. The effect of rotation on frequency can be predicted conveniently from Lord Rayleigh's energy method provided the deflection curve for no rotation is known. The values so obtained agree satisfactorily with the more exact theoretical values and also with the values observed by Theodorsen at Langley Field on a particular type of propeller.

The above analysis rests on the assumption that the propeller blade bends like a simple beam when it vibrates with one of its modes in bending. This assumption was checked for the extreme case of a solid steel propeller blade whose section was so curved in shape that its neutral axis lay outside the blade near the center. The ratio of measured strain amplitudes for pairs of points on opposite sides of this blade were found to be nearly equal to the ratio of extreme fiber distances as given by the simple-beam theory.

Airplane Vibrations.—In the investigation of a case of undesirable vibrations in an airplane, it was found that air impulses from a two-blade propeller with a frequency of about 3,200 per minute excited resonant vibrations in the wings with a frequency of about 1,600 cycles per minute and these in turn excited resonant vibrations in the tail assembly with a frequency of about 800 cycles per minute. The natural frequencies of the wing and tail differed enough from the ratio 2:1 to produce strong beats by the interchange of energy between wing and tail. It was concluded that the vibration was a case of double submultiple resonance.

No direct reference was found to this phenomenon in the engineering literature, but it seems probable that submultiple resonance has been the unrecognized cause of a number of baffling cases of undue vibration in engineering structures.

A review of the literature on submultiple resonance has disclosed several interesting characteristics distinguishing it from ordinary resonance. Submultiple resonance requires either a modulation of the exciting force by the excited motion, or a marked deviation from the proportionality between load and deflection assumed in ordinary vibration problems; the amplitude of the resonant motion is not proportional to that of the exciting force; a finite initial impulse is required to start the vibration. A mechanical model has been constructed which demonstrates the characteristics of this type of resonance.

SUBCOMMITTEE ON RESEARCH PROGRAM ON MONOCOQUE DESIGN

Research on stressed-skin or monocoque structures for aircraft is in reality research in elasticity, structures, and strength of materials. The results of the research conducted under the supervision of this subcommittee, therefore, have broad applications in other fields besides aeronautics. Conversely, the results of much of the research conducted on these subjects in fields other than aeronautics have aeronautical applications. The objective of each research undertaken by the Committee is to obtain results that can be used directly in analysis or design.

Elastic axis of shell wings.—A report on the elastic axis of shell wings has been prepared and published as Technical Note No. 562. In the report the definitions of flexural center, torsional center, elastic center, and elastic axis are discussed. The calculation of elastic centers is also dealt with in principle and a suggestion is made for the design of shear webs.

Strain measurements on box beams in bending.—Strain-gage measurements were made on a number of small-size rectangular box beams subjected to bending. The main conclusion is that there is an inevitable scattering of test results in such structures and that this scattering is sufficient to overshadow the effect of varying sheet thickness or bulkhead spacing within wide limits.

Although measurements were made chiefly on the tension side, some measurements were made on the compression side. One conclusion drawn from the latter tests is that the von Kármán formula for effective width gives very conservative values unless the yield point is approached.

Strength of stiffeners.—For several years a general study of the compressive strength of stiffeners used in stressed-skin structures has been in progress. This study is, in effect, a study of the strength of columns formed of thin metal. This year the study has resulted in the preparation of a report dealing with a theory for primary failure in straight centrally loaded columns, which is in the process of publication.

When a skin-stiffener combination fails by deflection normal to the skin, the accepted column curve for the material is applicable. When failure occurs by deflection of the outstanding portion of the stiffener in a direction parallel to the skin, however, there is a combined action of bending and twisting in the stiffener that requires for its solution a more general theory for primary failure in columns than has been available heretofore. "Primary failure", as here used, is any type of column failure in which the cross sections are displaced, rotated, or both displaced and rotated but not distorted. In keeping with this definition of primary failure, any failure in which the cross sections are distorted but not displaced or rotated is designated "local failure."

Wagner and Pretschner (see Technical Memorandum No. 784) present a theory for torsion-bending failure of open-section columns formed of thin metal when the cross sections rotate about an axis which is parallel to the column and passes through the center of twist for the section. When the column is attached to the skin of a stressed-skin structure, the stiffness of the skin in its own plane and the anchorage of the skin at the sides of the panel force the axis of rotation to lie in the plane of the skin. Consequently, for the solution of the skin-stiffener problem the Wagner-Pretschner theory was extended to include rotation of the cross sections about axes other than the one passing through the center of twist. The extended theory includes both Euler bending and the Wagner-Pretschner theory for twisting failure as special cases.

In the report mentioned above consideration is given only to primary failure and the application of the theory to a column of I section is given in detail. Its application to a number of other sections more commonly used as stiffeners in stressed-skin structures is now in progress. In addition to the study of primary failure, progress is also being made in the study of local failure in columns, but no reports have as yet been prepared.

Cross method of moment distribution.—A report on convergence of the Cross method of moment distribution is nearing completion. In this report it is shown how simple criterions can be derived by the methods of moment distribution to check the stability of compression members in rigid joint structures. These same criterions can also be used to determine the fixity coefficient for stiffeners in stressed-skin structures.

Compressive strength of corrugated sheet.—A report on the strength of corrugated sheet is being prepared in cooperation with Professor A. S. Niles of Stanford University.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

The problems under the cognizance of the Subcommittee on Miscellaneous Materials and Accessories during the past year, which are being investigated by the National Bureau of Standards, concern the development of a flexible substitute for glass and the development of substitutes for linen webbing and silk shroud lines for parachutes. Consideration has also been given to the possibilities of plastics as a material for aircraft structures.

Development of flexible substitute for glass.—Commercial and experimental transparent plastics which have been investigated to determine their suitability for aircraft windshields and windows include acetate, nitrate, ethylcellulose and cellulose-acetobutyrate materials, and the acrylate and vinyl resins. Tests were made to determine their resistance to water and organic solvents; their dimensional stability on aging; and the effect of outside exposure on light transmission, haze, and general appearance.

During the latter part of the year, however, the importance of the impact resistance of a windshield which would withstand collision with relatively large hailstones and wild birds became apparent. Attention was accordingly directed to this phase of the problem, and the possibility of using laminated glass and plastic, as well as plastic alone, was given consideration. Impact tests have been made both with the Charpy apparatus and by using falling weights. The results to date indicate that cellulose nitrate, cellulose acetate, ethylcellulose, and vinyl acetal materials are the strongest, while the polyvinyl-chloride, acetate, and acrylate resins are relatively weak.

Substitute for linen webbing.—At the suggestion of the military services, cotton manufacturers have been contacted to ascertain the possibility of making an all-cotton webbing to have the same properties as that now made from imported flax. The opinions are encouraging. It seems that certain mill experiments must be carried out to find out just how such a webbing should be made, but there is little doubt of the ability to do so. One mill has indicated its willingness to make the experiments provided that there is a sufficient potential market for the material. Data on this point are now being collected.

Substitute for silk shroud line.—The question of finding a domestic substitute for the imported silk now used in shroud lines has been under consideration. Inquiries have revealed that two manufacturers are willing to undertake the necessary experimental work. One plans to use Cordura rayon, the other American cotton. These experiments are now under way.

Development of plastic material for aircraft structures.—Consideration has been given to the compilation of information regarding the strength properties of plastics and reinforced plastics, with a view to their use as structural members. It is apparent that the collection of this information is in itself a large task, but it is necessary as a basis for planning any investigation of the subject. After a thorough review of the literature on the subject and contact with the manufacturers of plastics, a tabulation of the physical properties and weathering characteristics of laminated plastics will be made. Other points that will be determined are the uniformity of the material, the adhesion and corrosion between the plastic and the reinforcing metal, fabrication facilities, and relative cost as compared to other aircraft structural materials.

PART II

ORGANIZATION AND GENERAL ACTIVITIES

ORGANIZATION

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915 (U. S. Code, title 50, sec. 151). The Committee is composed of fifteen members appointed by the President and serving as such without compensation. The law provides that the members shall include two representatives each from the War and Navy Departments and one each from the Smithsonian Institution, the Weather Bureau, and the National Bureau of Standards, together with not more than eight additional persons "who shall be acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." One of these eight is a representative of the Bureau of Air Commerce of the Department of Commerce. Under the rules and regulations governing the work of the Committee as approved by the President the Chairman and Vice Chairman of the Committee are elected annually. At the meeting held on October 22, 1936, Dr. Joseph S. Ames was reelected Chairman for the ensuing year and Dr. David W. Taylor was reelected Vice Chairman.

During the past year there were three changes in the membership of the main Committee, as follows:

Major General Oscar Westover, Chief of the Air Corps, United States Army, who had succeeded Major General Benjamin D. Foulois, Air Corps, United States Army, in that post on the latter's retirement from active duty, was appointed by the President a member of the National Advisory Committee for Aeronautics on January 25, 1936, to succeed General Foulois on this Committee.

Rear Admiral Arthur B. Cook, United States Navy, who had succeeded Rear Admiral Ernest J. King, United States Navy, as Chief of the Bureau of Aeronautics, Navy Department, was appointed by the President a member of the National Advisory Committee for Aeronautics on June 16, 1936, to succeed Admiral King on this Committee.

Captain Sydney M. Kraus, United States Navy, who had succeeded Commander Ralph D. Weyerbacher, United States Navy, as head of the material branch of the Bureau of Aeronautics, Navy Department, was appointed by the President a member of the National Advisory Committee for Aeronautics on June 17, 1936, to succeed Commander Weyerbacher on this Committee.

The executive offices of the Committee, including its offices of aeronautical intelligence and aeronautical inventions, are located in the Navy Building, Washington, D. C., in close proximity to the air organizations of the Army and Navy.

The office of aeronautical intelligence was established in the early part of 1918 as an integral branch of the Committee's activities. Scientific and technical data on aeronautics secured from all parts of the world are classified, catalogued, and disseminated by this office.

To assist in the collection of current scientific and technical information and data, the Committee maintains a technical assistant in Europe with headquarters at the American Embassy in Paris.

CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, an Aeronautical Patents and Design Board was established consisting of Assistant Secretaries 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 passes upon the merits of aeronautical inventions and designs submitted to any aeronautical division of the Government, and submits reports thereon to the Aeronautical Patents and Design Board. That 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."

During the past year the inventions section received for consideration 2,049 new submissions. It conducted the necessary correspondence and granted interviews as requested by the inventors. Approximately twelve percent of the new submissions were received through the Aeronautical Patents and Design Board. In those cases reports on the merits of the submissions were made to that board, and in all other cases replies were submitted directly to the inventors.

ANALYSIS OF AIRCRAFT ACCIDENTS

During the past year the Committee on Aircraft Accidents has completed a revision of the report on the standard method for the analysis of aircraft accidents, and the revised report has been published as Technical Report No. 576, superseding the previous report, No. 357.

The Committee on Aircraft Accidents includes in its membership representatives of the air organizations of the War, Navy, and Commerce Departments, and the method of analysis and classification of aircraft accidents prepared by this Committee and revised from time to time has been followed for the past several years by these three departments in their study of accidents under their jurisdiction. The standard method includes provision for the classification of accidents according to their nature and according to their results, and a chart, together with explanatory definitions, for their analysis according to both immediate and underlying causes. The practical value of the method and the importance of the information which may be obtained by its use have been clearly demonstrated in its application in service in the three departments.

The revised report includes modifications in definitions and nomenclature introduced to answer questions of interpretation and provide against certain inadequacies of classification which had been encountered as a result of the recent rapid advances in aeronautics. These modifications, however, are in general conformity with the classifications previously established.

AERONAUTICAL RESEARCH IN EDUCATIONAL INSTITUTIONS

The recommendations of the Federal Aviation Commission on the subject of aeronautical research in educational institutions were put into effect by this Committee with the appropriation by Congress of $25,000 for this purpose carried in the Second Deficiency Act approved August 12, 1935. Contracts for special reports requiring original research in aeronautics have been made by this Committee with eight educational institutions at a total cost of $23,942.50.

COOPERATION WITH THE AIRCRAFT INDUSTRY

In formulating its program of research the Committee makes provision for the study of those problems that are of particular interest and importance to commercial aeronautics, both in design and operation. The problems of aircraft manufacturers and operators are frequently being presented to the Committee in correspondence and by personal contacts and informal conferences, and by these means the Committee is kept in continuous touch with the research needs of the aircraft industry. The Committee takes advantage of every opportunity which is afforded to obtain the comments and suggestions of the industry in connection with its research programs.

Every effort is made to place in the hands of the industry as promptly as possible the results of researches which are of particular value to commercial aeronautics. When in the course of an investigation it appears that the results so far obtained will be of special interest and importance to the industry prior to the preparation of a formal report for publication, the Committee issues the data in advance form to American manufacturers and to the Government services for their confidential information. Some of the important subjects on which information has been made available to American manufacturers in this form during the past year are the new N. A. C. A. nose-type cowling, the cooling of airplane engines on the ground, the relative efficiencies and design characteristics of various engine-propeller combinations, corrections for scale effect for the application of airfoil section data from the variable-density wind tunnel, airfoil-section characteristics in relation to air forces and their distribution on airplane wings, and the wing-fuselage interference of twenty-eight combinations as determined in the variable-density wind tunnel.

Conferences With Aircraft Operators.—As previously stated, a Special Subcommittee on Aerodynamic Problems of Transport Construction and Operation was organized during the past year under the Committee on Aerodynamics. This subcommittee was established on recommendation of the Aerodynamics Committee with a view to determining the problems of particular importance in connection with transport operation which should be investigated by the National Advisory Committee. In conjunction with the establishment of this subcommittee a special conference of airplane pilots was held to discuss the handling characteristics and piloting technique of large transport airplanes.

The membership of both the special subcommittee and the pilots' conference included representatives of the principal commercial aircraft operating agencies in this country, namely the Air Transport Association of America, American Airlines, Eastern Air Lines, Northwest Air Lines, Pan American Airways, Transcontinental and Western Air, and United Air Lines; and representatives of the Army Air Corps, the Bureau of Aeronautics of the Navy, the Bureau of Air Commerce, and the National Advisory Committee for Aeronautics. In addition, the special subcommittee included representation of the United States Weather Bureau, and the pilots' conference was attended by representatives of the two principal manufacturers of large commercial flying boats, as well as by well-known individual pilots. Honorable Edward P. Warner, a member of the National Advisory Committee for Aeronautics and Chairman of the Committee on Aerodynamics, served as chairman both of the special subcommittee and of the pilots' conference.

The Special Subcommittee on Aerodynamic Problems of Transport Construction and Operation met on March 17, 1936, at the Committee's headquarters in Washington. The following problems, many of which are not within the scope of the functions of the National Advisory Committee, were presented by the transport operators at this meeting as of particular interest and importance:

1. Ice formation including the aerodynamic effect on wings and control surfaces, the aerodynamic effect of de-icers, and the elimination of ice in carburetors.
2. Instrument landing—development and installation of equipment.
3. Problems of high altitude flying.
4. Snow static in connection with radio.
5. Improved cowling providing better engine cooling.
6. Means of avoiding collisions in the air over crowded airports.
7. Development of alternate current source of electrical energy for various uses.
8. Increased propeller efficiency and proper location of propellers.

Each of these problems was discussed and the present status of development outlined by the representatives of the various agencies engaged in such development. In connection with problems 5 and 8, the work conducted by the National Advisory Committee and the program planned for the future were described briefly.

The conference of airplane pilots was held on March 16, 1936. Among the problems discussed at this conference were the effect of flaps on airplane performance; the effect of rough air on transport operation; the desirability of the establishment of a criterion for the proper control and stability characteristics of airplanes; handling problems such as crosswind landings, ground-looping tendencies, and lateral control in taxying; the effect of ice formation, particularly on windshields; hull-bottom pressures on flying boats; and piloting technique in the landing of large flying boats in rough waves.

Annual Research Conference.—An important means of keeping the Committee in close contact with the needs of the aircraft industry is the annual aircraft engineering research conference held at the Committee's laboratories each May. This conference, which was initiated in 1926, has two principal purposes: first, to enable representatives of the industry to obtain first-hand information on the Committee's research facilities and the results obtained in its investigations; and second, to afford them an opportunity to present to the Committee their suggestions for investigations to be included in the Committee's research program.

Owing to the large number of those who desired to attend, the conference this year was for the first time held in two sections. Section A, which was held on May 20, 1936, included in general the representatives of aircraft manufacturers and operators and Government officials. Section B, held on May 22, included the personnel of governmental agencies using aircraft, representatives of engineering societies, and members of the faculties of professional schools, as well as representatives of manufacturers and operators who were unable to attend Section A.

In the absence of the Chairman of the conference, Dr. Joseph S. Ames, who was prevented by illness from attending, Honorable William P. MacCracken, a member of the National Advisory Committee and Chairman of its Committee on Power Plants for Aircraft, presided over Section A, and Dr. Lyman J. Briggs, also a member of the Advisory Committee and Chairman of the Committee on Aircraft Structures and Materials, presided over Section B. At Section A the Committee was represented by its officers, members of the main Committee, and members of the Committees on Aerodynamics and Power Plants for Aircraft. Section B was attended by the officers of the Committee and by members of the Committee on Aircraft Structures and Materials and of the Subcommittee on Structural Loads and Methods of Structural Analysis.

At the morning session of both sections, the principal investigations under way at the laboratory, both in aerodynamics and power plants, were explained by the engineers in charge of the work, and charts were exhibited showing some of the results obtained. The guests were then conducted on a tour of inspection of the laboratory, and the research equipment was shown in operation.

In the afternoon, seven simultaneous conferences were held for the discussion of seven different subjects, namely, flying and handling characteristics, aerodynamic efficiency and interference, aerodynamic consideration of cowling and cooling, power plant consideration of cowling and cooling, aircraft-engine research, seaplanes, and autogiros. At these conferences the results of the Committee's researches were presented in further detail, and suggestions were submitted by the representatives of the industry for problems to be added to the Committee's program. These suggestions were referred to the Committee on Aerodynamics and the Committee on Power Plants for Aircraft and were considered by them in their preparation of the Committee's research program.

SUBCOMMITTEES

The Advisory Committee has organized three main standing technical committees, with subcommittees, for the purpose of supervising its work in their respective fields. The three main technical Committees on Aerodynamics, Power Plants for Aircraft, and Aircraft Structures and Materials and their subcommittees supervise and direct the aeronautical research conducted by the Advisory Committee and coordinate the investigations conducted by other agencies.

During the past year the Subcommittee on Methods and Devices for Testing Aircraft Materials and Structures, which was a subcommittee of the Committee on Aircraft Structures and Materials, was discharged, as it was considered that the purpose for which the subcommittee had been organized had been served for all practical needs by special reports which had been prepared by the subcommittee for the Government agencies interested, and that any future work on the subject of methods and devices for the testing of aircraft materials and structures could be conducted under the direction of the Subcommittee on Structural Loads and Methods of Structural Analysis.

As previously stated, in accordance with the Committee's policy of establishing special subcommittees for the study of particular problems as they arise, two special technical subcommittees were organized during the past year under the Committee on Aerodynamics, namely, a Special Subcommittee on Aerodynamic Problems of Transport Construction and Operation, and a Special Subcommittee on Vibration and Flutter.

The work of the standing technical committees and subcommittees and of the Special Subcommittee on Vibration and Flutter have been described in part I. The activities of the Special Subcommittee on Aerodynamic Problems of Transport Construction and Operation have been outlined in part II under the heading "Cooperation with the Aircraft Industry."

The organization of the committees and of the standing and special subcommittees is as follows:

COMMITTEE ON AERODYNAMICS

Hon. Edward P. Warner, Chairman.
Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.
Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. L. J. Briggs, National Bureau of Standards.
Theophile dePort, Matériel Division, Army Air Corps, Wright Field.
Lt. Comdr. W. S. Diehl (C. C.), United States Navy.
Dr. H. L. Dryden, National Bureau of Standards.
Lt. Col. O. P. Echols, Air Corps, United States Army, Matériel Division, Wright Field.
Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.
Hon. Willis Ray Gregg, United States Weather Bureau.
Lawrence V. Kerber, Bureau of Air Commerce, Department of Commerce.
Lt. Comdr. R. D. MacCart (C. C.), United States Navy, Naval Aircraft Factory.
Commander A. C. Miles (C. C.), United States Navy.
Elton W. Miller, National Advisory Committee for Aeronautics.
Dr. David W. Taylor.
Dr. A. F. Zahm, Division of Aeronautics, Library of Congress.

SUBCOMMITTEE ON AIRSHIPS

Hon. Edward P. Warner, Chairman.
Starr Truscott, National Advisory Committee for Aeronautics, Vice Chairman.
Dr. Karl Arnstein, Goodyear-Zeppelin Corporation.
Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.
Commander Garland Fulton (C. C.), United States Navy.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Ralph H. Upson, Ann Arbor, Mich.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Hon. Willis Ray Gregg, United States Weather Bureau, Chairman.
Dr. W. J. Humphreys, United States Weather Bureau.
Dr. J. C. Hunsaker, Massachusetts Institute of Technology.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Delbert M. Little, United States Weather Bureau.
Dr. Charles F. Marvin.
Lt. Comdr. F. W. Reichelderfer, United States Navy, Naval Air Station, Lakehurst.
Dr. C. G. Rossby, Massachusetts Institute of Technology.
Capt. B. J. Sherry, United States Army, Signal Corps, War Department.
Eugene Sibley, Bureau of Air Commerce, Department of Commerce.

SUBCOMMITTEE ON SEAPLANES

Capt. H. C. Richardson (C. C.), United States Navy, Chairman.
Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.
Theophile dePort, Matériel Division, Army Air Corps, Wright Field.
Lt. Comdr. W. S. Diehl (C. C.), United States Navy.
Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.
J. T. Gray, Bureau of Air Commerce, Department of Commerce.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Lt. Comdr. A. O. Rule, United States Navy.
Starr Truscott, National Advisory Committee for Aeronautics.

SPECIAL SUBCOMMITTEE ON AERODYNAMIC PROBLEMS OF TRANSPORT CONSTRUCTION AND OPERATION

Hon. Edward P. Warner, Chairman.
E. T. Allen, New York City.
Paul Collins, Boston and Maine Airways.
D. B. Colyer, United Air Lines.
Smith J. DeFrance, National Advisory Committee for Aeronautics.
Lt. Col. O. P. Echols, Air Corps, United States Army, Matériel Division, Wright Field.
Col. E. S. Gorrell, Air Transport Association of America.
Croil Hunter, Northwest Airlines.
L. V. Kerber, Bureau of Air Commerce, Department of Commerce.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
D. M. Little, United States Weather Bureau.
William Littlewood, American Airlines.
Commander A. C. Miles (C. C.), United States Navy.
A. A. Priester, Pan American Airways.
Richard V. Rhode, National Advisory Committee for Aeronautics.
Paul Richter, Transcontinental and Western Air.
Capt. E. V. Rickenbacker, Eastern Air Lines.
Maj. R. W. Schroeder, Bureau of Air Commerce, Department of Commerce.
Wesley L. Smith, Cranford, New Jersey.
Fred E. Weick, National Advisory Committee for Aeronautics.

SPECIAL SUBCOMMITTEE ON VIBRATION AND FLUTTER

Henry J. E. Reid, National Advisory Committee for Aeronautics, Chairman.
Lt. Comdr. W. S. Diehl (C. C.), United States Navy.
C. H. Helms, National Advisory Committee for Aeronautics.
Capt. P. H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
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Dr. Walter Ramberg, National Bureau of Standards.
F. R. Shanley, Bureau of Air Commerce, Department of Commerce.
Capt. T. A. Sims, Jr., Air Corps, United States Army, Matériel Division, Wright Field.
Dr. Theodore Theodorsen, National Advisory Committee for Aeronautics.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Hon. William P. MacCracken, Jr., Chairman.
Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.
Dr. H. C. Dickinson, National Bureau of Standards.
John H. Geisse, Bureau of Air Commerce, Department of Commerce.
Carlton Kemper, National Advisory Committee for Aeronautics.
Lt. Comdr. T. C. Lonnquest, United States Navy.
Gaylord W. Newton, Bureau of Air Commerce, Department of Commerce.
Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.
Prof. C. Fayette Taylor, Massachusetts Institute of Technology.

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Dr. O. C. Bridgeman, National Bureau of Standards.
H. K. Cummings, National Bureau of Standards.
Lt. C. E. Ekstrom, United States Navy.
L. S. Hobbs, The Pratt & Whitney Aircraft Company.
Capt. F. D. Klein, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Lt. Comdr. T. C. Lonnquest, United States Navy.
Gaylord W. Newton, Bureau of Air Commerce, Department of Commerce.
Arthur Nutt, Wright Aeronautical Corporation.
Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.
Addison M. Rothrock, National Advisory Committee for Aeronautics.

COMMITTEE ON AIRCRAFT STRUCTURES AND MATERIALS

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Prof. H. L. Whittemore, National Bureau of Standards, Vice Chairman.
Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.
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Lt. C. F. Cotton (C. C.), United States Navy.
Warren E. Emley, National Bureau of Standards.
Commander Garland Fulton (C. C.), United States Navy.
Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.
J. T. Gray, Bureau of Air Commerce, Department of Commerce.
C. H. Helms, National Advisory Committee for Aeronautics.
Dr. Zay Jeffries, American Magnesium Corporation.
J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
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E. C. Smith, Republic Steel Corporation.
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SUBCOMMITTEE ON METALS USED IN AIRCRAFT

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Dr. Zay Jeffries, American Magnesium Corporation.
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Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
E. C. Smith, Republic Steel Corporation.
John Vitol, Bureau of Air Commerce, Department of Commerce.
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M. P. Crews, Bureau of Air Commerce, Department of Commerce.
Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.
Lt. Comdr. L. M. Grant (C. C.), United States Navy.
Maj. C. F. Greene, Air Corps, United States Army, Matériel Division, Wright Field.
Capt. P. H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

Lt. Comdr. R. D. MacCart (C. C.), United States Navy, Naval Aircraft Factory.

Prof. J. S. Newell, Massachusetts Institute of Technology.

Lt. Comdr. H. R. Oster (C. C.), United States Navy, Naval Aircraft Factory.

Henry J. E. Reid, National Advisory Committee for Aeronautics.

Richard V. Rhode, National Advisory Committee for Aeronautics.

Dr. L. B. Tuckerman, National Bureau of Standards.

SUBCOMMITTEE ON RESEARCH PROGRAM ON MONOCOQUE DESIGN

Dr. George W. Lewis, National Advisory Committee for Aeronautics, Chairman.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

Lt. Comdr. L. M. Grant (C. C.), United States Navy.

Maj. C. F. Greene, Air Corps, United States Army, Matériel Division, Wright Field.

Capt. P. H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.

Eugene E. Lundquist, National Advisory Committee for Aeronautics.

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Dr. L. B. Tuckerman, National Bureau of Standards.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

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John Easton, Bureau of Air Commerce, Department of Commerce.

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Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

J. E. Sullivan, Bureau of Aeronautics, Navy Department.

G. W. Trayer, Forest Service, Department of Agriculture.

P. H. Walker, National Bureau of Standards.

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Lieut. J. F. Greenslade, United States Navy.

Maj. E. V. Harbeck, Jr., Air Corps, United States Army.

J. W. Lankford, Bureau of Air Commerce, Department of Commerce.

Dr. George W. Lewis, National Advisory Committee for Aeronautics.

Lt. Comdr. A. O. Rule, United States Navy.

J. T. Shumate, Bureau of Air Commerce, Department of Commerce.

Maj. Lowell H. Smith, Air Corps, United States Army.

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Brig. Gen. A. W. Robins, Air Corps, United States Army, Matériel Division, Wright Field.

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COMMITTEE ON PUBLICATIONS AND INTELLIGENCE

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Miss M. M. Muller, Secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

Dr. Joseph S. Ames, Chairman.

Dr. David W. Taylor, Vice Chairman.

John F. Victory, Secretary.

TECHNICAL PUBLICATIONS OF THE COMMITTEE

The Committee has four series of publications, namely technical reports, technical notes, technical memorandums, and aircraft circulars.

The technical reports present the results of fundamental research in aeronautics. The technical notes are mimeographed and present the results of short research investigations and the results of studies of specific detail problems which form parts of long investigations. The technical memorandums are mimeographed and contain translations and reproductions of important foreign aeronautical articles. The aircraft circulars are mimeographed and contain descriptions of new types of foreign aircraft.

The Committee issued during the past year a bibliography of aeronautics for the year 1932. It had previously issued bibliographies for the years since 1909. All issues of the Bibliography of Aeronautics to date were prepared by Paul Brockett.

The following are lists of the publications issued:

LIST OF TECHNICAL REPORTS ISSUED DURING THE PAST YEAR

No.

542. Potential Flow About Arbitrary Biplane Wing Sections. By I. E. Garrick, N. A. C. A.
543. Tank Tests of N. A. C. A. Model 40 Series of Hulls for Small Flying Boats and Amphibians. By John B. Parkinson and John R. Dawson, N. A. C. A.
544. Combustion in a Bomb with a Fuel-Injection System. By Mildred Cohn and Robert C. Spencer, N. A. C. A.
545. Effects of Air-Fuel Ratio on Fuel Spray and Flame Formation in a Compression-Ignition Engine. By A. M. Rothrock and C. D. Waldron, N. A. C. A.
546. The Effect of Turbulence on the Drag of Flat Plates. By G. B. Schubauer and H. L. Dryden, National Bureau of Standards.
547. Wind-Tunnel Interference with Particular Reference to Off-Center Positions of the Wing and to the Downwash at the Tail. By Abe Silverstein and James A. White, N. A. C. A.
548. Effect of Tip Shape and Dihedral on Lateral-Stability Characteristics. By Joseph A. Shortal, N. A. C. A.
549. Wind-Tunnel Investigation of the Aerodynamic Balancing of Upper-Surface Ailerons and Split Flaps. By Carl J. Wenzinger, N. A. C. A.
550. Cooling Characteristics of a 2-Row Radial Engine. By Oscar W. Schey and Vern G. Rollin, N. A. C. A.

551. Aircraft Compass Characteristics. By John B. Peterson and Clyde W. Smith, Bureau of Aeronautics, Navy Department.
552. Wind-Tunnel Tests of 10-Foot-Diameter Autogiro Rotors. By John B. Wheatley and Carlton Bioletti, N. A. C. A.
553. Some Effects of Argon and Helium upon Explosions of Carbon Monoxide and Oxygen. By Ernest F. Fiock and Carl H. Roeder.
554. Wind-Tunnel Investigation of Ordinary and Split Flaps on Airfoils of Different Profile. By Carl J. Wenzinger, N. A. C. A.
555. Air Flow Around Finned Cylinders. By M. J. Brevoort and Vern G. Rollin, N. A. C. A.
556. Further Studies of Flame Movement and Pressure Development in an Engine Cylinder. By Charles F. Marvin, Jr., Armistead Wharton, and Carl H. Roeder, National Bureau of Standards.
557. Preliminary Tests in the N. A. C. A. Free-Spinning Wind Tunnel. By C. H. Zimmerman, N. A. C. A.
558. Turbulence Factors of N. A. C. A. Wind Tunnels as Determined by Sphere Tests. By Robert C. Platt, N. A. C. A.
559. The Forces and Moments Acting on Parts of the XN2Y–1 Airplane During Spins. By N. F. Scudder, N. A. C. A.
560. A Simplified Application of the Method of Operators to the Calculation of Disturbed Motions of an Airplane. By Robert T. Jones, N. A. C. A.
561. Effect of Nozzle Design on Fuel Spray and Flame Formation in a High-Speed Compression-Ignition Engine. By A. M. Rothrock and C. D. Waldron, N. A. C. A.
562. Air Flow in the Boundary Layer Near a Plate. By Hugh L. Dryden, National Bureau of Standards.
563. Calculated and Measured Pressure Distributions Over the Midspan Section of the N. A. C. A. 4412 Airfoil. By Robert M. Pinkerton, N. A. C. A.
564. Tests of a Wing-Nacelle-Propeller Combination at Several Pitch Settings up to 42°. By Ray Windler, N. A. C. A.
565. Measurements of Fuel Distribution within Sprays for Fuel-Injection Engines. By Dana W. Lee, N. A. C. A.
566. Ground-Handling Forces on a 1/40 Scale Model of the U. S. Airship "Akron." By Abe Silverstein and B. G. Gulick, N. A. C. A.
567. Propulsion of a Flapping and Oscillating Airfoil. By I. E. Garrick, N. A. C. A.
568. The Quiescent-Chamber Type Compression-Ignition Engine. By H. H. Foster, N. A. C. A.
569. Wing-Nacelle-Propeller Interference for Wings of Various Spans. Force and Pressure-Distribution Tests. By Russell G. Robinson and William H. Herrnstein, Jr., N. A. C. A.
570. The Effect of Lateral Controls in Producing Motion of an Airplane as Computed from Wind-Tunnel Data. By Fred E. Weick and Robert T. Jones, N. A. C. A.
571. Pressure Distribution Over a Rectangular Airfoil with a Partial-Span Split Flap. By Carl. J. Wenzinger and Thomas A. Harris, N. A. C. A.
572. Determination of the Characteristics of Tapered Wings. By Raymond F. Anderson, N. A. C. A.
573. Aerodynamic Characteristics of N. A. C. A. 23012 and 23021 Airfoils with 20-Percent-Chord External-Airfoil Flaps of N. A. C. A. 23012 Section. By Robert C. Platt and Ira H. Abbott, N. A. C. A.
574. Pressure Distribution Over an Airfoil Section with a Flap and Tab. By Carl J. Wenzinger, N. A. C. A.
575. Interference of Wing and Fuselage from Tests of 28 Combinations in the N. A. C. A. Variable–Density Tunnel. By Albert Sherman, N. A. C. A.
576. Aircraft Accidents. Method of Analysis. Prepared by Committee on Aircraft Acidents, N. A. C. A.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

No.

543. The Compressibility Burble. By John Stack, N. A. C. A.
544. An Application of the Von Kármán-Millikan Laminar Boundary-Layer Theory and Comparison with Experiment. By Albert E. von Doenhoff, N. A. C. A.
545. Tank Tests of a Model of a Flying-Boat Hull Having a Longitudinally Concave Planing Bottom. By J. B. Parkinson, N. A. C. A.
546. Comparative Tests of Pitot-Static Tubes. By Kenneth G. Merriam and Ellis R. Spaulding, Worcester Polytechnic Institute.
547. Development of the N. A. C. A. Slot-Lip Aileron. By Fred E. Weick and Joseph A. Shortal, N. A. C. A.
548. Flight Tests of a Balanced Split Flap with Particular Reference to Rapid Operation. By H. A. Soulé, N. A. C. A.
549. Drag of Prestone and Oil Radiators on the YO–31A Airplane. By S. J. DeFrance, N. A. C. A.
550. Limitations of the Pilot in Applying Forces to Airplane Controls. By M. N. Gough and A. P. Beard, N. A. C. A.
551. Tank Tests of Three Models of Flying-Boat Hulls of the Pointed-Step Type with Different Angles of Dead Rise—N. A. C. A. Model 35 Series. By John R. Dawson, N. A. C. A.
552. Wind-Tunnel Tests of Wing Flaps Suitable for Direct Control of Glide–Path Angle. By Fred E. Weick, N. A. C. A.
553. Notes on the Technique of Landing Airplanes Equipped with Wing Flaps. By Melvin N. Gough, N. A. C. A.
554. Circular Motion of Bodies of Revolution. By Carl Kaplan, N. A. C. A.
555. Piloting Technique for Recovery from Spins. By W. H. McAvoy, N. A. C. A.
556. Further Measurements of Normal Accelerations on Racing Airplanes. By N. F. Scudder and H. W. Kirschbaum, N. A. C. A.
557. Considerations of the Take-Off Problem. By Edwin P. Hartman, N. A. C. A.
558. The Performance of a DePalma Roots-Type Supercharger. By Oscar W. Schey and Herman H. Ellerbrock, Jr., N. A. C. A.
559. Combustion-Engine Temperatures by the Sodium Line-Reversal Method. By Maurice J. Brevoort, N. A. C. A.
560. A Comparison of Corrosion-Resistant Steel (18 Percent Chromium—8 Percent Nickel) and Aluminum Alloy (24ST). By J. E. Sullivan, Bureau of Aeronautics, Navy Department.
561. Full-Scale Wind-Tunnel Tests to Determine a Satisfactory Location for a Service Pitot-Static Tube on a Low-Wing Monoplane. By John F. Parsons, N. A. C. A.
562. Remarks on the Elastic Axis of Shell Wings. By Paul Kuhn, N. A. C. A.
563. Tank Tests of Models of Floats for Single-Float Seaplanes—First Series. By J. B. Parkinson, N. A. C. A.
564. Procedure for Determining Speed and Climbing Performance of Airships. By F. L. Thompson, N. A. C. A.

565. Influence of Fuel-Oil Temperature on the Combustion in a Prechamber Compression-Ignition Engine. By Harold C. Gerrish and Bruce E. Ayer, N. A. C. A.
566. Tank Tests of a Model of the NC Flying-Boat Hull—N. A. C. A. Model 44. By Joe W. Bell, N. A. C. A.
567. Tests of N. A. C. A. Airfoils in the Variable-Density Wind Tunnel. Series 230. By Eastman N. Jacobs and Robert M. Pinkerton, N. A. C. A.
568. Calculated Effect of Various Types of Flap on Take-Off Over Obstacles. By J. W. Wetmore, N. A. C. A.
569. Boosted Performance of a Compression-Ignition Engine with a Displacer Piston. By Charles S. Moore and Hampton H. Foster, N. A. C. A.
570. Effect of Changes in Tail Arrangement upon the Spinning of a Low-Wing Monoplane Model. By C. H. Zimmerman, N. A. C. A.
571. A Method of Estimating the Aerodynamic Effects of Ordinary and Split Flaps of Airfoils Similar to the Clark Y. By H. A. Pearson, N. A. C. A.
572. Performance of Air-Cooled Engine Cylinders Using Blower Cooling. By Oscar W. Schey and Herman H. Ellerbrock, Jr., N. A. C. A.
573. Carbon-Monoxide Indicators for Aircraft. By S. H. J. Womack and J. B. Peterson, National Bureau of Standards.
574. Tank Tests of Models of Flying-Boat Hulls Having Longitudinal Steps. By John M. Allison and Kenneth E. Ward, N. A. C. A.
575. Estimation of Moments of Inertia of Airplanes from Design Data. By H. W. Kirschbaum, N. A. C. A.
576. Tank Tests of a Model of the Hull of the Navy PB-1 Flying Boat—N. A. C. A. Model 52. By John M. Allison, N. A. C. A.
577. Friction of Compression-Ignition Engines. By Charles S. Moore and John H. Collins, Jr., N. A. C. A.
578. Full-Scale Wind-Tunnel and Flight Tests of a Fairchild 22 Airplane Equipped with a Fowler Flap. By C. H. Dearborn and H. A. Soulé, N. A. C. A.
579. Charts for Calculating the Performance of Airplanes Having Constant-Speed Propellers. By Roland J. White and Victor J. Martin, California Institute of Technology.
580. A General Tank Test of a Model of the Hull of the British Singapore IIC Flying Boat. By John R. Dawson and Starr Truscott, N. A. C. A.
581. A Study of Autogiro Rotor-Blade Oscillations in the Plane of the Rotor Disk. By John B. Wheatley, N. A. C. A.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

No.

777. Tests of Spheres with Reference to Reynolds Number, Turbulence, and Surface Roughness. By S. Hoerner. From Luftfahrtforschung, March 28, 1935.
778. Method for the Determination of the Spanwise Lift Distribution. By A. Lippisch. From Luftfahrtforschung, June 17, 1935.
779. Weldability of High-Tensile Steels from Experience in Airplane Construction, with Special Reference to Welding Crack Susceptibility. By J. Müller. From Luftfahrtforschung, October 1, 1934.
780. Glider Development in Germany. A Technical Survey of Progress in Design in Germany Since 1922. By B. S. Shenstone and S. Scott-Hall. From Aircraft Engineering, October 1935.
781. Reduction of Lift of a Wing Due to Its Drag. By J. Stüper. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, August 28, 1933.
782. Status of Wing Flutter. By H. G. Küssner. From Luftfahrtforschung, October 3, 1935.
783. Analysis of the Three Lowest Bending Frequencies of a Rotating Propeller. By F. Liebers. From Luftfahrtforschung, August 31, 1935.
784. Torsion and Buckling of Open Sections. By H. Wagner and W. Pretschner. From Luftfahrtforschung, December 5, 1934.
785. Methods and Formulas for Calculating the Strength of Plate and Shell Constructions as Used in Airplane Design. By O. S. Heck and H. Ebner. From Luftfahrtforschung, February 6, 1935.
786. The Formation of Ice on Airplanes. By H. Noth and W. Polte. From Luftwissen, vol. II, no. 11, 1935.
787. Investigations on the Amount of Downwash Behind Rectangular and Elliptical Wings. By H. Muttray. From Luftfahrtforschung, March 28, 1935.
788. The 5- by 7-Meter Wind Tunnel of the DVL. By M. Kramer. From Luftfahrtforschung, October 3, 1935.
789. Turbulent Jet Expansion. By E. Förthmann. From Ingenieur-Archiv, vol. V, no. 1, 1934.
790. Ignition and Flame Development in the Case of Diesel Fuel Injection. By Otto Holfelder. From supplement to Forschung auf dem Gebiete des Ingenieurwesens, September–October 1935.
791. Behavior of Turbulent Boundary Layers on Curved Convex Walls. By Hans Schmidbauer. (Thesis)
792. General Instability Criterion of Laminar Velocity Distributions. By W. Tollmien. From Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen (Mathematik), vol. I, no. 5, 1935.
793. Bending of Beams of Thin Sections. By Maximilian T. Huber. From Instytut Badań Technicznych Lotnictwa Sprawozdanie Kwartalne No. 3, Warsaw, 1930.
794. Chief Characteristics and Advantages of Tailless Airplanes. By A. Dufaure De Lajarte. From Association Technique Maritime et Aéronautique, June 1935.
795. Similitude in Hydrodynamic Tests Involving Planing. By M. F. Gruson. Paper presented on the occasion of the inauguration of the Institute of Mechanics of Fluids of the University of Lille, April 5–8, 1934.
796. Contribution to the Problem of Airfoils Spanning a Free Jet. By J. Stüper. From Luftfahrtforschung, December 25, 1935.
797. Ignition Process in Diesel Engines. By W. Wentzel. From Forschung auf dem Gebiete des Ingenieurwesens, May–June 1935.
798. Flow Phenomena on Plates and Airfoils of Short Span. By H. Winter. From Verein deutscher Ingenieure, Special Issue (Aviation), 1936.
799. The Transport of Vorticity through Fluids in Turbulent Motion. (In the light of the Prandtl and Taylor theories.) By C. Ferrari. From L'Aerotecnica, November–December 1935.
800. Charts for Checking the Stability of Compression Members in Trusses. By K. Borkmann. From Luftfahrtforschung, January 20, 1936.
801. Correction of Downwash in Wind Tunnels of Circular and Elliptic Sections. By Irmgard Lotz. From Luftfahrtforschung, December 25, 1935.
802. Automatic Stabilization. By Fr. Haus. From L'Aeronautique, October 1935; January and February 1936.
803. Details of the Construction and Production of Fuel Pumps and Fuel Nozzles for the Airplane Diesel Engine. By W. S. Lubenetsky. From Dieselestroyenie, No. 6, Moskva, 1935.

804. The Stress Criterion of a Tension Member with Graded Flexural Stiffness. (Contribution to the Problem of "Clamping Effect" Outside of the Elastic Range.) By Hans W. Kaul. From Luftfahrtforschung, June 20, 1936.

LIST OF AIRCRAFT CIRCULARS ISSUED DURING THE PAST YEAR

No.

200. The Short "Scion Senior" Commercial Airplane (British). A Four-Engine High-Wing Cantilever Monoplane. From Flight, October 31, 1935; and The Aeroplane, October 30, 1935.
201. The Avro "Anson" General-Purpose Airplane (British). A Two-Engine Low-Wing Cantilever Monoplane. From Flight, January 30, and The Aeroplane, January 29, 1936.
202. The Latécoere 521 "Lieutenant de Baisseau Paris" Commercial Flying Boat (French). A Two-Deck Six-Engine Semicantilever Sesquiplane. From L'Aéronautique, November 1935.
203. The Vickers-Supermarine "Scapa" (British). A Military Flying Boat. From Flight, April 26, 1934; Flight, February 27, 1936; and The Aeroplane, February 26, 1936.

FINANCIAL REPORT

The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1936, as contained in the Independent Offices Appropriation Act approved February 2, 1935, was $820,800. The Second Deficiency Act of 1935, approved August 12, 1935, provided an additional amount of $338,050 for the same purposes, making the total amount available for expenditure during the fiscal year 1936 $1,158,850. The amount expended and obligated was $1,157,746, itemized as follows:

Personal services	$775,114
Supplies and materials	63,364
Communication service	3,192
Travel expenses	16,085
Transportation of things	3,329
Furnishing of electricity	29,418
Repairs and alterations	18,746
Special investigations and reports	89,493
Equipment	159,005
Expended and obligated	1,157,746
Unobligated balance	1,104
Total, general appropriation	1,158,850

The appropriation for printing and binding for 1936 was $18,700, of which $18,663 was expended.

The amount of the regular appropriation for the fiscal year 1937, as provided in the Independent Offices Appropriation Act approved March 19, 1936, is $1,158,850. A supplemental appropriation of $1,367,000 was made available in the First Deficiency Appropriation Act, fiscal year 1936, approved June 22, 1936, for the same purposes specified in the Committee's regular appropriation act for 1936, to continue available until June 30, 1937. It provided not to exceed $1,100,000 for the construction and equipment of an additional wind tunnel, and not to exceed $267,000 for increasing the length of the present seaplane model testing tank and for additional equipment therefor. The total amount available for general expenses during the fiscal year 1937 therefore is $2,525,850. An additional amount of $18,700 was appropriated for printing and binding, fiscal year 1937.

The amount expended and obligated during the fiscal year 1936 for the completion of the 500-mile-per-hour wind tunnel at Langley Field was $8,741.20, under the total allotment of $478,300 made for this purpose by the Public Works Administration during the fiscal year 1934.

The sum of $5,945 was received by this Committee during the fiscal year 1936 as special deposits to cover the estimated cost of scientific services to be furnished private parties. The total cost of investigations completed for private parties during the fiscal year 1936, amounting to $2,795.80, was deposited in the Treasury of the United States to the credit of Miscellaneous Receipts.

Of the allotment of $3,000 for participation by this Committee in the California Pacific International Exposition which opened at San Diego, California, on May 27, 1935, there was on June 30, 1935, an unexpended balance of $2,045.74. The exposition closed in November 1935, and in March 1936 the unexpended balance of $610.13 was deposited in the Treasury. The amount of $1,410.13 was on April 4, 1936, allotted to this Committee for continued participation in the exposition, which reopened in February 1936. Of this allotment the amount of $545.79 was expended and obligated as at June 30, 1936, leaving a balance of $864.34.

An allotment of $15,500 was received by this Committee for participation in the Texas Centennial Exposition at Dallas, Texas, which opened June 6, 1936. Of this allotment the amount of $12,652.82 was expended and obligated as at June 30, 1936, leaving a balance of $2,847.18.

From allotments from the Department of Commerce to a working fund during the fiscal years 1934 and 1935 for work performed by this Committee in connection with the furtherance of the improvement of safety and efficiency in civil aviation, there was an unexpended balance of $403 as at June 30, 1935. An additional allotment of $8,000 was received in July 1935, making the total amount available for this purpose $8,403. Of this amount $6,314.16 was expended and obligated during the fiscal year 1936, leaving a balance of $2,088.84 as at June 30, 1936.

An allotment of $7,600 was received from the State Department for payments during the fiscal year 1936 to employees stationed abroad, on account of exchange losses due to appreciation of foreign currencies, and of this amount $5,409.79 was paid to employees of the

Committee stationed in the Paris Office during the fiscal year, leaving a balance of $2,190.21 to be turned back into the Treasury.

CONCLUDING STATEMENT

The continued progress in aviation is shrinking distances and bringing the nations of the world closer together. Air trade routes are being extended by progressive nations in order to develop their commercial and national influence. Scheduled air passenger transportation across the North Atlantic by airship and across the Pacific by seaplane was inaugurated in 1936. It is expected that regular seaplane service across the North Atlantic will soon be inaugurated.

Air travel in the United States is increasing. Comfortable sleeping berths are being provided for overnight transportation. Mail and express are being carried in greater quantities. The economic status of air transportation is improving to such an extent that cargo airplanes are being developed for freight only. The safety of the airplane and the safety precautions surrounding air travel are being steadily improved. Commercial aeronautics is more highly developed in the United States than in any other country.

Military aircraft developed in the United States are highly efficient and dependable. In the major European nations tremendous emphasis is being placed upon the military significance of aircraft. Their construction programs and factories are being enlarged and research laboratories and facilities multiplied.

The development of superior aircraft is dependent upon fundamental scientific research. The encouragement and freedom of those engaged in scientific research is essential to this development. The status of the National Advisory Committee for Aeronautics as an independent Government establishment gives it the necessary freedom of action, and its researches are largely responsible for the present superiority of American aircraft. The United States may justly take pride in the remarkable development of American aviation to date. But in order to insure that this country shall not fall behind, this Committee urges the wisdom and ultimate economy of increased appropriations for research personnel and for new research equipment.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS,
JOSEPH S. AMES, *Chairman.*