AERONAUTICS

TWENTIETH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1934

INCLUDING TECHNICAL REPORTS
Nos. 475 to 507

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LETTER OF SUBMITTAL

To the Congress of the United States:

Pursuant to the act of March 3, 1915, which established the National Advisory Committee for Aeronautics, I submit herewith the annual report of that Committee for the fiscal year ended June 30, 1934.

Franklin D. Roosevelt.

The White House,
January 8, 1935.

LETTER OF TRANSMITTAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., December 15, 1934.

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 transmit herewith the Twentieth Annual Report of the National Advisory Committee for Aeronautics for the fiscal year ended June 30, 1934.

Attention is invited to the opening statements in the report in which the Committee reviews the factors underlying the technical progress in airplane design and efficiency, and summarizes the present outstanding problems.

In the conclusion of its report the Committee expresses its pride in the part which the liberal support of the Congress for the past two decades has enabled it to take in the field of scientific research on the fundamental problems of flight. Through this Committee the research needs of aviation in the War, Navy, and Commerce Departments have been coordinated and fundamental research has been conducted without duplication of effort. The new full-speed wind tunnel now under construction will enlarge the Committee's capacity to provide new knowledge of the natural laws governing air flow over airplane surfaces at speeds up to 500 miles per hour.

As organized scientific research is a fundamental factor underlying improved performance, efficiency, and safety of aircraft, the Committee believes that continued liberal support of its work offers the best assurance of continued rapid development of American aircraft, and also the best assurance of ultimately enabling commercial aviation to exist in this country on a self-sustaining basis.

Respectfully submitted.

JOSEPH S. AMES, *Chairman.*

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

TECHNICAL REPORTS

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. 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
MATERIALS FOR AIRCRAFT
PROBLEMS OF AIR NAVIGATION
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

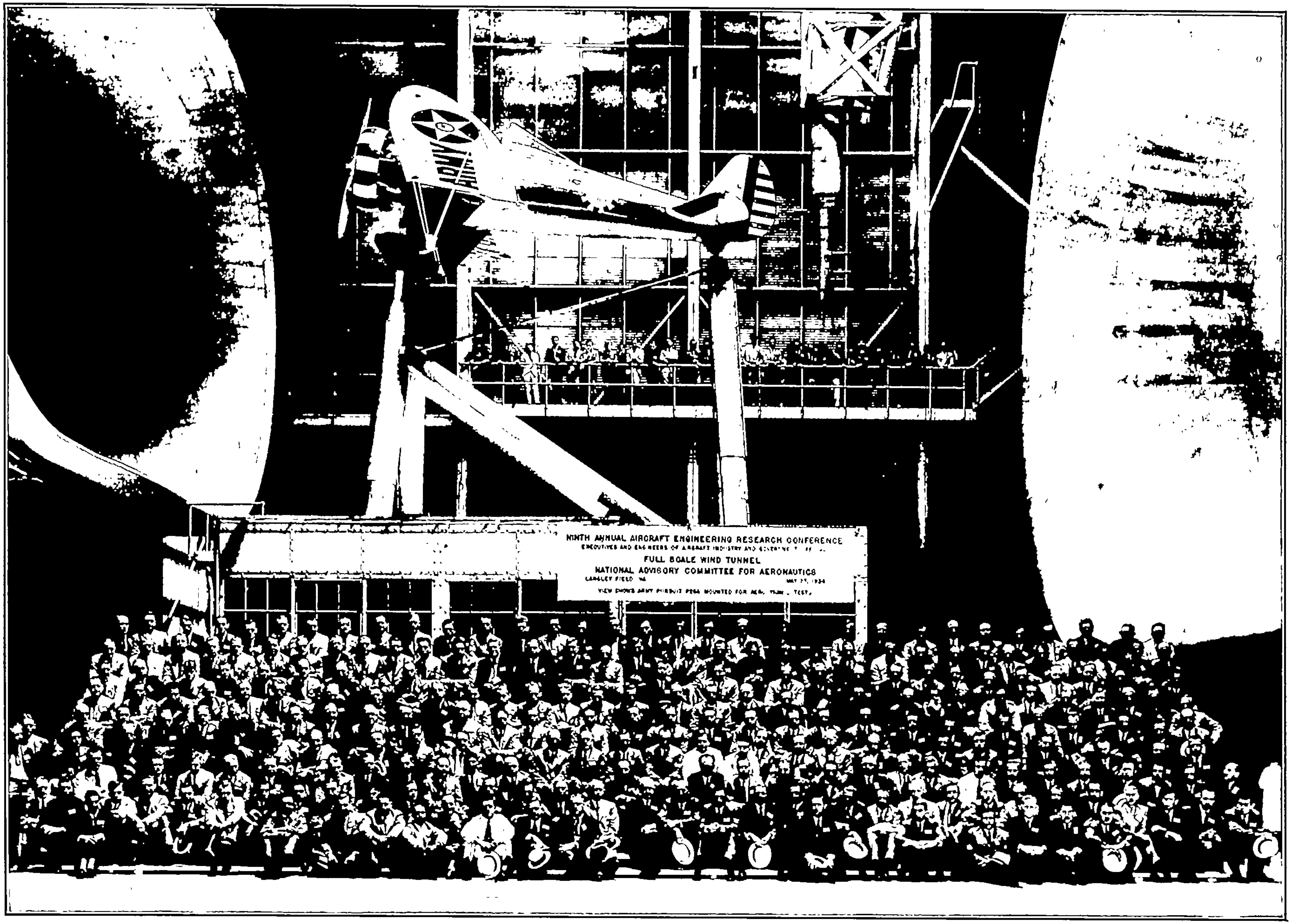
WASHINGTON, D. C.

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

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

MEETING, OCTOBER 18, 1934.

Left to right: J. F. Victory, Secretary; Dr. C. G. Abbot, Hon. H. F. Guggenheim, W. R. Gregg, Dr. L. J. Briggs, Dr. Joseph S. Ames, Chairman; Dr. G. W. Lewis, Director of Aeronautical Research; Comdr. R. D. Weyerbacher, Lieut. Col. H. C. Pratt, Rear Admiral E. J. King, Maj. Gen. B. D. Foulois, Dr. Orville Wright, Hon. W. P. MacCracken. (Four members absent: Dr. D. W. Taylor, Vice Chairman; Hon. E. P. Warner, Col. C. A. Lindbergh, E. L. Vidal.)



NINTH ANNUAL AIRCRAFT ENGINEERING RESEARCH CONFERENCE
FULL SCALE WIND TUNNEL
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TWENTIETH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 13, 1934.*

To the Congress of the United States:

In accordance with the act of Congress approved March 3, 1915, which established the National Advisory Committee for Aeronautics, the Committee submits herewith its twentieth annual report for the fiscal year 1934.

Twenty years ago the Congress of the United States laid the legislative foundation for American progress in the new science of aeronautics when it established the National Advisory Committee for Aeronautics as an independent scientific agency of the Government. The past year was one of the most notable in the remarkable record of progress in American aviation during the past two decades.

Factors underlying technical progress.—The outstanding improvement in airplanes has been in the multiengine type for both military and commercial purposes. The radial air-cooled engine, a distinctly American development, is now a reliable and efficient type of aircraft engine. With improved N. A. C. A. cowling, involving the use of cooling baffles, the power output of the engine has been greatly increased without increase either in drag or in specific fuel consumption. The improved cooling of the engine cylinders and the use of fuels having a higher octane number have permitted the use of higher compression ratios. This, combined with increased engine revolutions per minute, has made possible greater horsepower output without increase in size or weight of the engine.

Maximum propulsive efficiency in multiengine airplanes has been achieved by the proper use of the principle known as the "N. A. C. A. engine location and cowling." Up-to-date multiengine airplane designs generally now follow this principle. Its value is recognized not only in the United States but is attested by the number of foreign designs in which it is being embodied, and also by the number of American commercial-type multiengine airplanes being purchased in this country for use on foreign airways.

The increased efficiency and economy of operation of airplanes made possible by proper location and cowling of engines in the leading edge of the wing are so important that this principle will no doubt be applied by the American aircraft industry in new designs of airplanes for the private owner. The resulting greater safety in private flying would materially broaden the opportunities in this undeveloped field.

High-lift devices.—Another major contribution of new knowledge by this Committee during the past year resulted from researches on high-lift devices. The increased speed of modern aircraft, resulting from increased propulsive and aerodynamic efficiency, has been attended by undesirable and, in some cases, dangerous increase in landing speed. This Committee is conducting researches on a large number of high-lift devices which will permit lower landing speed, and some of these principles are now finding application in new designs. In the opinion of this Committee it is desirable that modern high-speed airplanes should use some form of high-lift device in order to land at lower speeds while retaining adequate lateral control. In the study of this problem this Committee has been fortunate in having available not only the results of tests in ordinary wind tunnels but also results obtained on full-scale airplanes and wings tested in the full-scale wind tunnel. These, coupled with accurate flight-test data, have proved valuable to American airplane designers.

Trend of development.—As aerodynamic efficiency increases with the size of airplanes, the trend of development probably will be toward larger aircraft of greater range and weight-carrying capacity. Larger aircraft can be made adaptable to simplified internal bracing and structural refinements, so that cost of construction need not increase proportionately with size.

For certain types of large airplanes, engines of larger horsepower are desirable, and a number of promising developments are now under way in this country. The National Advisory Committee for Aeronautics has conducted fundamental research on the fuel-injection principle necessary for the development of high-speed aircraft engines of this type. The results justify the early development of a compression-ignition type of aircraft engine, using Diesel-type fuel, and also the development of an engine using spark ignition and hydrogenated gasoline.

The direct-injection-type engine operating at a high compression ratio, together with the N. A. C. A. principle of large valve overlap, offers the prospect of further improving the power output.

With the development of large airplanes and large liquid-cooled engines, there will come a need to house the engines entirely inside the wings. This consideration will call for different types—different shapes—of engines. In the meantime, the horsepower and efficiency of the air-cooled engine are being materially increased. Recent developments indicate the present practicability of air-cooled engines of 1,000 or 1,200 horsepower.

The trend toward larger engines will probably stimulate the development of superchargers and research on the propeller problem.

Refinements in design, reduction in drag, and increased engine power will make possible greater speed. The 500-mile-per-hour wind tunnel to be added to the research equipment at the laboratories of the National Advisory Committee for Aeronautics at Langley Field, Va., should provide important new knowledge on problems of flutter, vibration, and the forces acting on aircraft structures, and thus make possible the use of the highest attainable speeds with relative safety.

Researches on the control of the flow of the boundary layer of air over the airplane wings indicate the development of suction slots in the wings. In general, the trend is toward higher speed in flight with the use of high-lift devices combined with satisfactory lateral control to secure acceptably low landing speeds.

Lighter-than-air craft.—An inquiry was propounded by the Federal Aviation Commission, to which this Committee replied, as follows:

Inquiry: "What special action should be taken to promote the development of intercontinental services by airplane or airship, or both, and their coordination with merchant marine policy?"

Reply: "In order to develop further the possibilities of lighter-than-air craft, it is believed advisable for the Federal Government to provide funds for the construction of two experimental rigid airships for intercontinental service. It is believed advisable also for the Government to encourage the private development and operation of large seaplanes for transoceanic and intercontinental air transportation.

"This Committee believes that it would be more economical to provide fast intercontinental transportation by the use of airships and large seaplanes than to engage in the competition which is now taking place among the nations of Europe in the building of high-speed superships for their merchant marine."

Committee's research facilities.—This Committee, in the discharge of its responsibilities under the law, has anticipated the research needs of aviation, and with the farsighted support of the Congress has developed at Langley Field, Va., a well-equipped aeronautical research laboratory, known as the "Langley Memorial Aeronautical Laboratory", comprising 12 structures and a research staff of 250 employees. There, under ideal conditions, are combined facilities for laboratory investigations and for researches on airplanes in flight. The equipment and methods used are largely unique and make possible the obtaining of information not obtainable in any other country. The present equipment includes such special items as the variable-density wind tunnel, refrigerated wind tunnel, vertical wind tunnel, the propeller research tunnel, the full-scale wind tunnel, and the seaplane tank. Significant additions have recently been made to the laboratory equipment. With allotments of funds from the Public Works Administration there have been constructed an engine research laboratory, a free-spinning wind tunnel, and a 24-inch high-velocity jet-type wind tunnel. The latter will be used primarily to study air flow over propeller tips at speeds approaching the velocity of sound in air, with a view to improving the aerodynamic characteristics of propeller tips. The free-spinning wind tunnel is of a type recently constructed in Great Britain, and has been built for the study of the spinning characteristics of airplane models spinning freely in an ascending air stream. The tunnel is 15 feet in diameter at the test section, and will be a valuable instrument for the study of the effect of variations in the dimensional properties and mass distribution of the airplane upon its spinning characteristics. The full-speed tunnel, previously referred to, is under construction.

The Committee's laboratories, although located on an Army field, are not under the control of the Army, but come under the direct control of this Committee. This is as it should be, for the status of this Committee as an independent Government establishment has given it the freedom of action that has largely made possible its success. There is not only complete harmony and actual cooperation between the military authorities and this Committee but the War Department has consistently opposed suggestions to place the Committee's work under its jurisdiction. Secretary of War Dern, in a letter to President Roosevelt in April 1933, said in part: "To place the Committee under any one executive department would impair its efficiency, lessen its usefulness, reduce existing cooperation between the governmental agencies concerned in its work, and definitely retard the progress of aeronautics."

Functions of the Committee.—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."

The National Advisory Committee for Aeronautics does not have under the law such broad advisory functions as its name may seem to imply. It was organized as a scientific research agency, and finds its prescribed field of activity extremely important—in fact, the most fundamental activity of the Government in the development of American aviation—and therefore worthy of undivided attention.

Comprehensive research programs. — Comprehensive programs of fundamental research in aeronautics are formulated largely by technical subcommittees on which all governmental agencies concerned are represented. In addition, there are other 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 engineering necessary to apply research results in the development of improved aircraft to meet varying needs. In the Army Air Corps this is done by the Matériel Division at Wright Field; in the Navy it is done at the Naval Aircraft Factory and at the Washington Navy Yard; and for civil and commercial aviation it is done by the manufacturers. 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 coördinated 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.

Private flying.—In the opinion of the National Advisory Committee for Aeronautics, the problem of promoting private flying on a large scale calls for a combination of improved economics and greater safety. The solution of the problem lies in reducing the cost of construction, maintenance, and operation of small aircraft, and at the same time increasing their efficiency and safety. Here again the problems involved are fundamental. No nation has as yet found a solution to them, despite many efforts. This Committee, in the preparation and execution of its program of fundamental research, has included an intensive study of the problems affecting the development of a satisfactory light aircraft for private use. The major problem has been one of devising means for obtaining satisfactory control at low or stalling speeds, combined with the problem of obtaining a satisfactory low landing speed. The results of this Committee's efforts have been applied in several promising types now being developed.

This Committee believes that the development of private flying will in time offer a new and enlarged outlet for the energies of the American people; and that the most reasonable expectation of developing a large aviation industry in the United States lies in the volume production at low cost, of safe and efficient airplanes for the private user. Although such a type of airplane will probably have no direct application to military employment other than for a possible use for messenger service, the enlarged industry, including pilots and personnel, that will be available as a result of the successful development of such a type will be an asset to the national defense.

There is close cooperation between the Bureau of Air Commerce and this Committee in making use of the latest scientific information in the preparation of maximum attainable performance requirements of small aircraft suitable for the use of Department of Commerce inspectors and incidentally suitable for private use. In this way the adaptation of new knowledge to this type of civil aircraft is made by the industry, which must eventually supply the demand of the private flyer.

Summary.—Significant and encouraging progress has been made, particularly in the last few years, in improving the economics of air transportation. Before commercial aviation can be fully self-sustaining, there must be further and material improvement in the performance and efficiency of aircraft, as well as improved methods of construction, affecting cost and facilities for maintenance. New knowledge must be obtained and applied that will enable commercial aircraft not only to fly faster with safety but also to land safely in smaller areas; to land at lower speed; and to have greater control at low speeds incident to taking off and landing. These are fundamental problems, the solution of which depends in a large measure upon the continuous prosecution of organized scientific research. Speed, still the most important factor in the development of military aircraft, is of major importance, consistent with requisite factors of safety and efficiency, in the development of commercial air transports.

The predominant characteristic of an aircraft for the private owner must be safety. The periods in the operation of an airplane in which improved safety is most desired are in the maneuvers of taking off and of landing. Extensive investigations have been made on aircraft with fixed wings, as exemplified by the modern airplane, and also on aircraft with rotating lifting surfaces, as exemplified by the autogiro, the gyroplane, and the cyclogiro.

Each improvement in the performance and efficiency of aircraft not only increases the relative importance of aviation as an agency of transportation but also increases its relative importance in the national defense. The United States cannot afford to fall behind other nations in the development of aviation. Leadership has been attained as a result of sound governmental policy of providing liberal support of scientific research in the interests both of national defense and of progress in the development of commercial aviation.

The Committee is of the opinion that an essential factor in a national aviation policy is the provision for the continuous prosecution of a well-organized program of fundamental research in aeronautics. The Committee believes this offers the best prospect for America to lead in the development and use of aviation, both military and commercial, and incidentally offers also the best prospect for ultimate success in placing commercial aviation upon a sound economic basis.

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 under the executive committee four main technical committees—the committees on aerodynamics, power plants for aircraft, materials for aircrafts, and problems of air navigation—and under these committees eight subcommittees. These technical committees prepare and recommend to the executive 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. 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 materials for aircraft is conducted by the Bureau of Standards. The experimental investigations in aerodynamics, aircraft power plants, aircraft materials, and air-navigation problems 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 four committees.

REPORT OF COMMITTEE ON AERODYNAMICS

SUBCOMMITTEE ON AIRSHIPS

In order that the committee on aerodynamics may be kept in close touch with the latest developments in the field of airship design and construction and that research on lighter-than-air craft may be fostered and encouraged, a subcommittee on airships has been established under the committee on aerodynamics.

The subcommittee formulates and recommends programs of airship investigations for conduct at the Langley Memorial Aeronautical Laboratory, and maintains close contact with the work in progress. The airship projects on the Committee's program at the present time include the study in the propeller-research tunnel of boundary-layer control for airships, the investigation in the full-scale wind tunnel of the forces on a large airship model at large angles of pitch and of yaw, and the effect of bow elevators on the resistance and controllability in pitch of an airship model. In addition, the Committee is cooperating with the Bureau of Aeronautics of the Navy by making available instruments and personnel for an experimental investigation of the pressure distribution on the hull and fins of the United States airship *Los Angeles* while riding to a mooring mast at Lakehurst.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

Landing Speed and Speed Range.—A year ago the speeds and wing loadings of military and commercial airplanes had increased markedly and designers were beginning to turn to high-lift devices, particularly flaps, to reduce the landing speed and to allow a steeper approach glide. The Committee had at that time investigated a number of high-lift devices for their general aerodynamic characteristics. During the past year nearly all high-performance airplane designs have included some form of flap and the Committee has directed its efforts toward investigating the most promising of the flaps in greater detail. The tests included such factors as the air load on the flaps, the control force required to operate them, the effect of the flaps on downwash at the tail, and their effect on the take-off characteristics of an airplane.

Flap modifications.—The work on split flaps in the 7- by 10-foot tunnel has been continued to include tapered wings with both straight and tapered flaps covering various portions of the wing span. The tests show that with full-span split flaps the lift and drag characteristics of the tapered wing at angles of attack up to the stall are similar to those of a rectangular wing with flaps of comparable size, but that the stall of the tapered wing with full-span flaps occurs at progressively lower angles of attack as the flap deflection is increased. For partial-span tapered split flaps on a tapered wing, it was found that the maximum lift and the drag at maximum lift are greater when the partial-span flap is located in the center of the wing than when it is located at the tip portion, the maximum lift varying with flap location in about the same manner as for a straight wing but the drag variation being the opposite. A report on this work is in preparation.

An investigation has been carried out in the full-scale tunnel with split trailing-edge flaps on a Fairchild-22 airplane. Flaps with chords 10, 20, and 30 percent of the wing chord were installed on the wing of the airplane with the hinge axis of each flap located at the 68, 80, and 88 percent points of the wing chord. The aerodynamic characteristics of the entire airplane were determined by force tests and the loads on the flaps were measured by means of a system of pressure-distribution orifices. In addition, the angle and velocity of flow back of the wing and in the neighborhood of the tail were surveyed to determine the effect of the flap upon the downwash from the wing. A report is being prepared covering the results of the complete investigation.

In order to reduce the landing speed of an experimental Vought fighter biplane a split trailing-edge flap was installed on the lower wing between the ailerons, and the airplane was tested in the full-scale tunnel at the request of the Bureau of Aeronautics of the Navy. The results show that the flap increased the maximum lift coefficient from 1.32 to 1.49, which should account for a reduction of 4.1 miles per hour in the landing speed.

At the request of the Army Air Corps a flap installation was made on a P-26A pursuit-type airplane, and tests were made in the full-scale tunnel to determine the effect upon the landing speed. Three sets of flaps were installed, each of which had a chord 20 percent of the wing chord. One set extended from the wing root to the inboard edge of the ailerons; the second set was approximately 3 feet longer and would require shorter ailerons. Each of these sets was tested in combination with the third, a curved flap under the fuselage. With the short-span flap the landing speed indicated by the wind-tunnel tests was reduced 6.2 miles per hour and with the longer flaps the reduction was 8.4 miles per hour. The addition of the curved flap under the fuselage did not give a material reduction in speed, but did cause a violent buffeting of the tail.

One disadvantage that has been apparent in the operation of split flaps as used to date is the time and effort required to operate them. In this connection an investigation is being made of possible means for balancing them aerodynamically to make their operation easier. Several arrangements have been tested in the 7- by 10-foot wind tunnel, and the results of the wind-tunnel tests, as well as those of preliminary flight tests on one of the more promising forms, have been given in a confidential memorandum report circulated to the Government air services and to airplane manufacturers. The reduction in hinge moments permitted the flap to be operated easily and quickly by means of a simple hand lever. The installation thus made possible an immediate adjustment of the gliding-angle range; whereas, many flap installations require considerable time for operation and thereby limit the ability of the pilot to control the path of the airplane as it descends for a landing. From the tests on the effects of quick operation of the flap, it was concluded that deflecting the flap quickly from its closed position has no dangerous results if the tail is designed to take care of the new conditions of longitudinal balance, and that with the exercise of reasonable judgment by the pilot, it seems unlikely that quick and easy operation of the flap can be regarded as anything but an unqualified advantage over the type of operation that requires considerable time and effort. At present the investigation is being continued with further tests in which actual measurements of the motion of the airplane following quick operation of the flap are being made.

The Wragg-type flap, which consists of an auxiliary airfoil pivoted at the rear of the main wing, has also been the subject of some investigation. Tests have been made in the 7- by 10-foot tunnel to find the optimum position of a flap having a symmetrical airfoil section and a chord 15 percent of the wing chord. The results of these tests, which showed that a maximum lift coefficient about the same as that for plain split flaps of the same size was obtained, are given in a confidential memorandum report, and certain of the results, including differential operation of the flaps as ailerons, are given in Technical Report No. 510. Tests are now under way with a Wragg flap consisting of a cambered airfoil having a chord 20 percent of the main wing chord.

The investigation of the Fowler flap has been continued during the past year principally to obtain information regarding the variation of maximum lift with flap size, but in addition to find the effect of flaps on take-off characteristics, downwash angle at the tail, and the air loads on the flaps. It was found that the maximum lift coefficient increased as the flap chord was increased up to 40 percent of the wing chord. The lift per unit of total area (wing plus flap), however, had no appreciable increase for flaps larger than 30 percent. Thus, for flaps larger than 30 percent, no further saving in the weight of wing surface giving a certain maximum lift may be expected.

Tailless airplanes.—Tests have been completed in the 7- by 10-foot tunnel and reported in Technical Note No. 477 on a tailless airplane arrangement having a wing with taper and sweepback and with a fixed auxiliary airfoil along the leading edge. The auxiliary airfoil substantially increased the maximum lift coefficient at which balance could be obtained, but it also increased the minimum drag coefficient and gave no improvement in speed range.

A model of a tailless airplane designed by Mr. Waldo Waterman was investigated in the 7- by 10-foot tunnel for its aerodynamic balance and static-stability characteristics at the request of the Bureau of Air Commerce of the Department of Commerce.

Wings of low aspect ratio.—A general program of tests to be made with airfoils of very low aspect ratio has been prepared. This program was planned to reveal the optimum combination of airfoil profile, aspect ratio, plan form, and curve of mean camber line for high values of maximum lift coefficient. Three airfoils have been tested in the 7- by 10-foot tunnel as part of the general program. Each of these airfoils was circular in plan form and had a Clark Y profile at each section except very close to the tips. They differed only in the amount of dihedral, which in each case varied smoothly from the center to the tips. The model having the greatest up curve of the tips was found to have the highest lift coefficient, 1.90.

Two airfoils of low aspect ratio having slots near the trailing edge were also tested. The slots gave very minor increases in the maximum lift coefficient in each case.

Boundary-layer control.—Experiments made a few years ago both by the Committee and by others indicated that the breakaway of the flow from the upper surface of wings could be prevented up to very high angles of attack by the use of air blown out or drawn in through slots of suitable size and location, with consequent large increases in the maximum lift coefficients. The early experiments were made with very small models and the arrangements were such that the important question of the energy required to produce the results could not be determined. The few full-scale experiments were not carried far enough to warrant any conclusions except that the method showed promise.

A year ago the study of this problem had been taken up again in a manner to eliminate the possible large scale effect of small model tests and to provide adequate means of determining the energy required. A large model wing had been constructed with a blower system built inside the wing and tests started in the 20-foot wind tunnel. The wing was made very thick to exaggerate the boundary-layer separation and incidentally to provide room for the blower and its driving motor. The tests have since been completed and the results demonstrated that suction was more efficient than pressure, and that for the thick wing one large slot properly located was better than a number of narrow slots. It was calculated that a lift coefficient of 3.0 could be maintained on a 95-horsepower 2-place airplane such as the Fairchild–22, with only 2 horsepower supplied to the blower. This value included losses in the blower fan and in the ducts, which were not especially designed as such but consisted of the entire interior of the wing with its numerous ribs and its spars; the losses could be considerably reduced by careful design.

These promising results were considered worthy of amplification, and experiments are now in progress with a wing of normal thickness with the blower mounted in a fuselage below. The experiments are not completed to the point where predictions can be made, but it is expected that they will be finished and reported upon in the near future.

Controllability.—The lateral control program of the Committee has been continued along two lines: First, the search for a device that gives entirely satisfactory lateral control throughout the entire speed range including angles of attack above the stall; and second, the investigation of devices suitable for use on wings having high-lift flaps along their entire spans. The ground work of this investigation consists of a series of comparable tests in the 7- by 10-foot tunnel on models having various types of lateral control devices, and a series of 13 reports has been prepared on these tests to date. The most promising of the devices are also being tested in flight. Technical Report No. 494 has been prepared on the first part of the flight work, including tests of conventional ailerons with various movements, tests of different types of spoilers, and tests of certain combinations of spoilers and ailerons.

Spoilers.—Tests have been made in the 7- by 10-foot tunnel with a simple retractable spoiler located in various positions along the wing chord to determine the effect of spoiler location on the rolling and yawing moments (Technical Note No. 499). The results show that there is a very definite advantage at angles of attack near the stall in locating the spoiler well forward on the wing. As stated in last year's report, in flight tests with the spoilers located well forward on the wing a time lag was found in the response of the airplane to a movement of the control stick. In order to investigate a possible means of eliminating this lag or reducing it to a negligible quantity, a large wing was constructed and mounted in the 7- by 10-foot wind tunnel in such a manner that the wing could move when the controls were deflected and the time of response be measured. It was found that as the spoiler was moved toward the trailing edge the lag was reduced and a negligible value, less than 0.1 second, was obtained when the spoiler was located at 80 percent of the chord from the leading edge. Other means of eliminating the lag were also investigated, and it was found that a satisfactory response to control movement could be obtained with the spoiler located at any point along the chord of the wing if a suitable slot permanently open were located directly in the rear of the spoiler. Force tests are now being made in the 7- by 10-foot tunnel with a standard-size model comparable with those used for the rest of the program to determine the effectiveness of spoiler-slot combinations in producing rolling and yawing moments.

External ailerons.—The thirteenth report in the series on lateral control tests under way in the 7- by 10-foot tunnel (Technical Report No. 510) covers external ailerons, or separate narrow airfoils mounted near the main wing and deflected for lateral control. The external ailerons were tested in many positions all around the profile of the main wing. The results of the wind-tunnel tests showed that no location was entirely satisfactory with respect to both performance and control. The best locations lay in a region between the leading edge and 30 percent of the chord back from the leading edge and from 3 to 9 percent of the chord above the upper surface. Choice of a particular location depends on a compromise between good performance, obtainable near the leading edge, and good control, obtainable near the rear of the favorable region. If it is desired to use the ailerons as flaps in addition to their function as lateral control devices, the best position lies slightly behind and below the trailing edge of the main wing. Flight tests made with the external ailerons in one of the positions over the forward part of the wing showed serious practical difficulties due to heavy hinge moments and irregular control-force variation.

Lateral controls for use with full-span flaps.—If split flaps are used along the entire span of a wing, the portion of the wing just above the split flap may be deflected upward on the right- and left-hand sides separately for lateral control. Tests were made with two sizes of control flaps of this nature, termed "upper-surface ailerons", on rectangular Clark Y wing models equipped with full-span split flaps (Technical Report No. 499). With flaps neutral and deflected various amounts up to maximum lift the upper-surface ailerons with up-only movement gave reasonably satisfactory rolling moments at angles of attack below the stall. The control forces, however, were much greater than those of ordinary ailerons of similar size having conventional movement. When tested in flight (report in preparation) the control was also found to be reasonably satisfactory below the stall, but the effort required to move the controls was found to be much too great. An investigation was then made in the 7- by 10-foot wind tunnel to find possible methods for balancing upper-surface ailerons by means of the proper shape and hinge location. The hinge moments were reduced to apparently satisfactory values but the control moments were weak for one condition of flight, that at low speed with the flaps retracted. A report is in preparation on this work.

Two satisfactory methods of obtaining lateral control with full-span flaps have been thoroughly tested, both in the wind tunnel and in flight. One of these is an arrangement in which a split flap retracts into the lower surface of the wing ahead of the narrow-chord ailerons of conventional form; the other arrangement has retractable ailerons or curved plates that retract into the upper surface of the after portion of the wing. This arrangement is such that no appreciable aerodynamic moment is transmitted to the control column, the resultant aerodynamic force passing approximately through the hinge axis. The effectiveness of each of these devices was found to be equal to or greater than that of the standard ailerons on the airplane with which the tests were made, the F–22, and in both cases the control force required was substantially less than for the original ailerons. The absence of aerodynamic hinge moment for the retractable ailerons was regarded as a minor objection, whereas their adaptability for use with various types of full-span flaps is an advantage. Both of the devices have been described in confidential memorandum reports, and, together with other devices suitable for use with full-span flaps, will be included in a regular technical report now in preparation.

Hinged-tip ailerons.—At the request of the Army Air Corps a form of hinged wing-tip aileron (hinge axis parallel to wing chord) was tested in the 7- by 10-foot wind tunnel. It was found that the ailerons gave large rolling moments near the stall, but as the angle of attack was reduced the rolling moments passed through zero and became negative.

Aerodynamic balancing of control surfaces.—A report is in preparation on a wind-tunnel investigation of tabs, or small hinged flaps on control surfaces. Tabs have been found to be practicable for trimming airplanes in the desired flight conditions and also for balancing the hinge moments and reducing the force required to operate the controls. The tests show the tabs to be very effective for balancing the hinge moments when the control surfaces are given small deflections, but they do not give satisfactory results for high deflections of the control surfaces.

Magnitude of control force available.—In connection with the measurement of the hinge moments and the forces required to operate various control devices, it has often been desired to know the amount of force that a pilot could be expected to apply. During the past year an arrangement simulating a pilot's cockpit with controls has been constructed, and measurements have been made of the forces that could be comfortably exerted on the control column and rudder pedals with the airplane in various attitudes and the controls in various positions, as well as of the maximum forces that could be applied. A report on this subject is in preparation at the present time.

Stability.—The longitudinal dynamic stability of several airplanes is being measured in flight for the purpose of verifying methods of calculating stability and also for the purpose of determining the degree of longitudinal stability desired for satisfactory flight characteristics.

An extensive study of longitudinal stability has provided material for a report now nearly completed dealing with longitudinal stability in power-off flight. This report presents as its principal portion a series of working charts from which dynamic stability in power-off flight can be readily estimated for any airplane. The results obtained by the use of the charts have been found to check within reasonable limits the results from all the above-mentioned flight tests that have been completed to date. Some work has been done on the study of the effect of power on the longitudinal stability but much remains to be accomplished in this portion of the field.

Material is being prepared for a report resulting from a study of lateral stability, which will consider in detail the effects of the more important of the airplane's characteristics. The spiral stability of several airplanes is also being investigated in flight for correlation with the analytical studies. In addition, the observed effect of varying the dihedral of a high-wing monoplane in steps from 0° to 9° has been determined in flight for the purpose of finding the influence of dihedral on the flight characteristics and stability, with particular reference to the relation between the effectiveness of the ailerons and rudder as regards lateral and directional stability and control (Technical Report No. 494).

Tests have also been made in the 7- by 10-foot wind tunnel of wings having both rounded tips and square tips and having various degrees of dihedral angle covering different portions of the span. It was found that the change in rolling moment due to yaw with dihedral was practically the same for a wing with rounded tips as for one with square tips. At angles of attack above the stall the greatest rolling moment due to yaw was obtained with wings in which the dihedral angle was confined to the outer 25 percent of the semispan.

Landing.—A paper on the results of tests to determine the effect of gusty air conditions on glide landings has been published (Technical Report No. 489). In this investigation air conditions close to the ground were measured as well as the motion of an airplane in fixed-elevator landing glides in gusty air.

At the request of the Department of Commerce an investigation was made of the landing characteristics of an autogiro (Technical Note No. 508). An interesting feature of this investigation is that an analysis of the data indicates surprisingly high force coefficients developed by the rotor in the execution of abruptly flared landings at very low speeds.

Take-Off.—The tendency in the new high-speed airplanes toward the use of higher wing and power loadings, resulting in greater distance required to take off, lends importance to means of improving airplane performance in this particular phase of flight. The increasing use of high-lift devices to permit shorter landings is desirable if, with little or no alteration, they can be made to improve the take-off characteristics. An analytical study has been made to determine the possible advantages inherent in high-lift devices, particularly flaps of various types, for shortening the take-off distance, the distance being considered as including a climb to a 50-foot altitude. The large number of variables involved makes the effect of such devices largely an individual problem for each design. It appears in general, however, that, despite some uncertainty in respect to some of the factors involved, airplanes with controllable propellers, high wing loading, and low power loading may be benefited to a considerable extent by the use of flaps during take-off. There is a marked dependence on the wing and power loading as well as on the type of flap used. The best results are generally obtained with partly deflected flaps, a fully deflected flap being in some cases a hindrance rather than a help.

A review of the available information concerned with the take-off of airplanes, including the results of both experimental investigations and mathematical analyses, indicates that there exists considerable uncertainty regarding some of the important factors of which a reasonably accurate knowledge is required to enable satisfactory quantitative prediction of the take-off distance. These factors are primarily ground friction, ground effect, the period of transition between the ground run and the beginning of steady climb, and propulsive characteristics for the take-off range. Research programs designed to furnish information on the first three of these factors have been prepared and work has been started on the determination of the friction between the airplane wheels and the ground. In this investigation a carriage that can be equipped with airplane wheels and tires of different sizes and types and subjected to various loads is towed at different speeds over several kinds of surfaces and the pull exerted in towing is measured by a suitable device.

At the request of the Bureau of Air Commerce, take-off performance tests of a small experimental airplane have been made as a part of a more general investigation of its flight chracteristics. The results have been analyzed particularly to throw light on the nature of the transition between the ground run and the beginning of steady climb.

As was mentioned last year, the propeller data in Technical Report No. 350 have been recomputed, a coefficient more suitable for determining low-speed propeller characteristics, as are required in take-off calculations, being used. The revised charts have been published in Technical Report No. 481.

Spinning.—The Committee's work on the subject of spinning has been continued both in flight and with the spinning balance in the 5-foot vertical tunnel. In addition a free-spinning tunnel of the type recently constructed in Great Britain has been built for studying the spinning of the dynamical scale models of airplanes when supported only by the air. This tunnel is 15 feet in diameter at the test section, having been designed to accommodate models of the same size as those regularly tested in the restrained-force tests on the spinning balance in the 5-foot vertical tunnel. It is expected that this tunnel will provide information for coordination of the results of spinning-balance tests and free-flight spins, and that in itself it will be a valuable instrument for the study of the effect of variations in the dimensional properties of the airplane upon its spinning characteristics.

At the request of the Bureau of Aeronautics of the Navy, spinning tests were made with a fighter-type airplane having unsatisfactory recovery characteristics. Various tail-surface arrangements were tested both in flight and on the spinning balance in the 5-foot vertical tunnel, and reports are in preparation for both sets of tests. The flight tests showed that as the fin area was increased for the several fins used the ease and uniformity of recovery were progressively improved. The best recoveries were obtained with the horizontal surface in high positions. These results demonstrated very definitely in flight the value of placing the horizontal surfaces in a high position and established this design feature as the most effective for correcting bad spinning tendencies. Since the spinning-balance measurements have shown that raising the horizontal surfaces increases the damping yawing moments, the results of these tests constitute a good confirmation of the conclusion previously reached from theory that damping yawing moments would be very effective in controlling bad spins.

Inasmuch as, in general, the main factor that must be overcome by the damping yawing moments is the yawing moment contributed by the wing arrangement, which always aids the spin, it was considered desirable to obtain fundamental information on the magnitude of the yawing moment produced by the wings alone. For this purpose tests are being made on the spinning balance of the 5-foot vertical tunnel on a monoplane wing and on a biplane arrangement with various gaps and staggers, in which all six components of air 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. A report is being prepared on the monoplane portion of the investigation, the biplane tests still being under way.

The yawing moments produced by the various parts of an airplane, including the wings, are also being measured on a Fleet training biplane for a range of spins having angles of attack from 40° to 65°. As the method of determining wing yawing moments in flight involves the measurement of aerodynamic yawing moment produced by the lateral pressure on the fuselage, fin, and rudder, some interesting results have been obtained regarding the relative importance of various parts of the airplane for producing yawing moments. In the case of the Fleet, the nose of the fuselage produces a small damping yawing moment, the tail of the fuselage produces the major portion of the damping yawing moment, and the fin and rudder combination produces moments either with or against spinning, depending upon the rudder setting. In the case of one other airplane on which pressure distribution was measured during spins, the nose produced the major portion of the damping yawing moment.

The results of the pressure-distribution measurements show one reason why large damping yawing moments are produced by raising the horizontal surfaces to a high position. The lateral force on the portion of the fuselage under the horizontal surfaces was found to be greater per unit area than on any other portion of the vertical surface of the airplane. This result is evidently an interference effect between the horizontal surface and the vertical surface in the vicinity of the tail. Thus raising the horizontal surfaces not only diminishes the area affected by the well-known unfavorable interference above the horizontal surfaces, but it increases the area on which the favorable interference disclosed by these tests is effective.

Tests have been made (Technical Note. No. 493) on the spinning balance in the 5-foot vertical tunnel to determine the effectiveness of floating wing-tip ailerons as an airplane control in the spin. The model, which was a tapered wing, was tested with and without the ailerons in 12 spinning attitudes chosen to cover the probable spinning range. The addition of the floating wing-tip ailerons to the model gave very large values of the rolling and yawing moment coefficients, both moments being in a sense to oppose the spin.

An investigation has also been made on the spinning balance to determine the change in aerodynamic forces and moments produced by split flaps in a steady spin. From the results it was concluded that split flaps will not prevent an airplane from attaining a balance of forces and moments in a spin, but in fact might be likely to cause a more dangerous spin.

It has long been realized that the factors affecting quickness of recovery might not be the same as those having a large effect on the steady spin; thus the alterations to a particular airplane that would change its spin from the so-called " flat " or uncontrolled spin to a steeper spin in which the controls retained their effectiveness might not include improvement in all the factors affecting recovery. A method has therefore been sought to measure the forces, moments, and motion during recovery or, in fact, in any type of asymmetric motion. Experiments for the development of the necessary apparatus have progressed to the point that the Committee is now in a position to construct service models of instruments that will make a complete measurement of forces, moments, and motion, including angle of attack and sideslip of each point on the airplane during the entire recovery.

In order to make more simple and efficient the complex work of mounting the instruments in airplanes upon which spinning tests are made, a set of especially designed instruments has been constructed with modifications that facilitate mounting and give sensitivities best suited to this type of work. It is expected that this set of instruments will greatly facilitate the accumulation of flight data on the steady spin and, together with the new instruments for measuring asymmetric motion, will increase the scope of possible flight testing so that, in conjunction with facilities now available for wind-tunnel work, the problems of spinning may soon be reduced to an exactly predictable basis.

Drag and Interference.—The possibility of improving airplane speed, efficiency, and economy through further aerodynamic refinement still exists in spite of the marked improvements that have recently been made. The over-all improvement is accomplished by improving component parts such as the wing, fuselage, landing gear, tail surfaces, struts, and windshield, or by changing the arrangement of these parts in such a manner as to minimize adverse interference and to utilize any possible favorable interference between them. Among the investigations being conducted with the object of improving component parts may be mentioned the investigations of airfoils and airfoil sections, the investigation of cowlings, and measurements of the drag of landing gears and of flying-boat hulls. Of the investigations seeking better arrangements of parts, the wing-fuselage and wing-nacelle interference investigations may be regarded as typical.

The results of investigations of the drag of streamline wires and of a cabin windshield mentioned in last year's report have since been published (Technical Notes Nos. 480 and 481). Tests were made in the full-scale tunnel to determine the drag of standard landing lamps located respectively in the leading edge and at 5 and 10 percent of the chord on the lower surface of the wing. The results show that the best location is in the leading edge of the wing. A report has been published as Technical Note No. 497.

Effects of surface roughness.—Last year's report gave the results of measurements made in the variable-density wind tunnel to determine the importance of a perfectly smooth surface for an airfoil. During the past year the matter has been further investigated on a full-size fabric-covered airplane wing on an F–22 airplane in the full-scale tunnel. The wing, which initially had a normal commercial finish, was later given successively 12 coats of clear lacquer and 3 coats of wax, and polished. The polishing of the wing surface reduced the minimum drag coefficient of the entire airplane by 0.001, which if applied to a given airplane with a top speed of 200 miles per hour would increase the speed by 2.9 miles per hour, or if the speed were held at 200 miles per hour would effect a reduction of 4 percent in the power required. The results have been published in Technical Note No. 495.

Seaplane floats.—A study of the literature has revealed that very little data are available on the drag in air of seaplane floats and hulls and, for modern design shapes, such data are practically nonexistent. A number of large models that had been under investigation at the N. A. C. A. tank were accordingly tested in the 20-foot propeller-research wind tunnel to determine their air drag. A number of the models originally consisted only of the hull bottoms and, to simulate the whole body used in practice, the upper portions had to be built up. Some modifications of the shape were made progressively during the tests. The data are being prepared for a report that will be useful in design studies.

Landing gears.—The results of the investigation of the drag of airplane landing gears completed last year have been issued as Technical Report No. 485. Despite the wide selection of wheels, strut arrangements, and fairings tested in the original program, a large number of requests for further information were received from manufacturers and from the military services. A supplementary program was therefore carried out. This program was in two parts, the first covering retractable and partly retracted gears for use on low-wing transport airplanes, the results of which have been given in a technical report now being printed, and the second, a further study of landing gears for smaller airplanes. The results of the entire program are now being prepared for publication.

The tests have shown that the drag of partly retracted landing gears can be reduced to low values by suitable fairing, and that the streamline wheel which gave indifferent results in the original tests can be used to advantage if the interference is reduced by proper arrangement of struts and fairings. It may also be said that a fixed landing gear will have a low drag if properly arranged, the principal requirement being that the interference between parts be kept low, this interference constituting a large part of the total drag. Several landing gears of practicable form meeting these requirements were developed in the course of the tests.

Cowling.—As stated in last year's report, a systematic investigation of engine cowling and cooling is proceeding in three main parts: (1) Determining the cooling requirements of an air-cooled engine; (2) finding the best cowling arrangement to obtain the necessary cooling with minimum drag; and (3) verifying the results of parts (1) and (2) by cowling tests on the complete full-size engines. Part (1) of the cowling investigation is under the direction of the engine research division, and the results to date will be found in the report of the committee on power plants for aircraft. Part (2) has been practically completed with the study of a large number of models in the 7- by 10-foot tunnel. Comparisons of the results of parts (1) and (2) will soon be possible, and the necessary preparations for part (3) will then be made. In addition to the foregoing systematic program, a number of service airplanes have been tested during the year and their performance and engine-cooling characteristics have been determined both in flight and in the full-scale tunnel.

Interference.—The various component parts of an airplane often exert a mutual effect so that when combined their aerodynamic characteristics are different from those predicted from their known individual characteristics. Thus the drag of a wing and fuselage in combination is sometimes much greater than the sum of the wing and fuselage drags; on the other hand it is sometimes less. This variation of the actual drag of a combination from predicted drag based on the drag of the individual parts is referred to as the "interference drag", and may be either positive or negative.

During the past few years the importance of interference has been more highly appreciated as its effects have been brought into prominence by the progressive refinement of the component parts of the airplane. A systematic investigation of this subject has been in progress for several years, and in addition to the systematic program certain practical questions have been investigated from time to time on request of the military services. The basic investigation of interference has been carried out largely in the variable-density wind tunnel, and has included a study of the effects of small disturbing bodies at various positions on the surfaces of airfoils and streamline bodies. These results have all been previously reported. The investigation has been continued during the past year to include the interference effects resulting from various wing cut-outs such as are employed to increase the field of view. The results have been published in Technical Report No. 480.

Wing-fuselage interference.—Results of tests in the variable-density tunnel of a large number of combinations of wings and fuselages are now being analyzed and assembled for a report. The combinations tested, totaling over 200 different arrangements, represent the first phase of the wing-fuselage interference investigation. Various fuselage forms were combined with various wing forms in different geometrical relations. The wing variations included a rectangular N. A. C. A. 0012 airfoil, a tapered N. A. C. A. 0009–0018 airfoil, a rectangular N. A. C. A. 4412 airfoil, and an N. A. C. A. 0012 airfoil having a cut-out center section. The variation in fuselage form included a streamline body of revolution and a related body having rectangular cross sections; each fuselage shape was further altered by the addition of an air-cooled engine model at the nose, with and without cowling. These variations, together with the variations of the relative positions of the wing and fuselage and of the type of attachment and form of juncture fillet, made up the 200 above-mentioned combinations.

The data resulting from this investigation are of necessity very voluminous, and considerable time will be required to make an adequate summary of the results. A comparison of the various combinations as regards general aerodynamic efficiency indicates, however, that some of the parasol arrangements would be among the best were it not for the drag of the wing-supporting members. After the effects of the necessarily exposed interconnecting struts have been considered, the best locations for the wing seem to be between the mid-wing and the high-wing positions, although the usual high-wing position may be made nearly as efficient by the use of suitable fillets. Forward positions of the wing with respect to the fuselage appear to be favorable. Low-wing positions are unfavorable but, by adequately filleting the wing-fuselage juncture, the aerodynamic efficiency of the low-wing combinations may be made to approach that of the better high-wing combinations.

Wing-fuselage-propeller interference.—The investigation of wing-fuselage interference on the Army observation YO–31A airplane mentioned in last year's report has been continued in the full-scale tunnel, this investigation having been frequently interrupted by more urgent tests made at the request of the Army or Navy. Tests have been completed with the wing in two different parasol positions. Aerodynamic forces on the complete airplane and the pressure distribution over the wing have been measured for each wing position both with power off and with power on. The latter measurements show the effects of the slipstream on the characteristics of the wing. In addition to the above-mentioned measurements, surveys of the angle and velocity of flow at the tail have been made for each wing position. The investigation includes, in addition to the parasol positions of the wing, others ranging from the high-wing to the low-wing position. A report will be prepared covering the gull wing and three parasol positions.

Wing-nacelle-propeller interference.—The extensive program of research on the mutual effects of wing nacelle, and propeller, which has been in progress more than three years, has been continued, with the completion of reports on some of the phases of the problem studied last year. Technical Report No. 505 gives the results obtained with a number of nacelle arrangements with tandem propellers. Of several engine-cowling combinations, best results were obtained with an N. A. C. A. hood over the front cylinders and a ring over the rear cylinders, and the best position was found to be with the thrust axis close below the wing and with the nacelle faired into the wing, or with the thrust line about half a propeller diameter below the lower surface of the wing, both positions being inferior, however, to the best single-engine arrangements previously tested. Technical Report No. 506 contains the results of tests of biplane wings with cowled nacelle and tractor propeller. The best results were obtained with the propeller 50 percent of the chord ahead of the upper wing and the same position relative to the lower wing was found to give nearly as high efficiency. There is fair agreement between the results with biplane combinations and with similar monoplane combinations.

Technical Report No. 507 gives the results for pusher propellers with numerous nacelle locations and types. The most favorable location is with the thrust line about 60 percent of the wing chord below the center line of the wing and with the propeller between 10 and 30 percent of the chord length behind the trailing edge. The pusher nacelle tested was found in its most favorable position to be approximately as good as a tractor nacelle with a similar ring type of cowling in the most favorable tractor location, but inferior to the best tractor position with N. A. C. A. cowling.

Preparation is now being made to extend the program and to use a large airplane model on which the nacelles may be moved to various locations with respect to the central fuselage in order to determine the interference effects existing between the nacelle and fuselage. Further study of cowlings for nacelles with pusher propellers is contemplated to determine whether the present high drag of these arrangements cannot be reduced. A study of the mutual interference of wings with nacelles for in-line air-cooled engines is also to be made.

It does not appear that the present best tractor arrangement with completely cowled radial engine ahead of the leading edge of the wing will be much improved, although a slight advantage appears to be possible by placing the engine entirely within the wing and driving a pusher propeller through an extension shaft. Tests have shown that this propeller arrangement would have a high propulsive efficiency; the housing of the engine within the wing would obviously reduce the drag, but the practicability of the arrangement hinges on obtaining satisfactory cooling, which requires careful consideration.

It is gratifying to note the high performance now being realized in transport airplanes as a result of adopting the nacelle locations and cowlings recommended by the Committee. The location of a cowled radial engine near the front of the wing with a pusher propeller driven by an extension shaft at the rear, recommended in last year's report as a result of the various combinations tested, has been adopted during the year by one manufacturer with apparent success.

Specific requests are frequently made by the military services or by the Department of Commerce for information concerning practical problems requiring immediate solution on existing types. Such problems are usually solved by data obtained on the actual airplane in the full-scale tunnel. Tests on a Navy low-wing fighter airplane having a single radial engine with N. A. C. A. cowling showed that the interference between cowling and wing greatly increased the drag. When the skirt of the engine cowling was carried back over the leading edge of the wing to approximately the maximum thickness the maximum lift was increased 6.5 percent, and the minimum drag was decreased 5.5 percent. Such results may thus indicate the desired trend of the more systematic basic investigations.

Airfoils.—The Committee's investigations dealing with airfoils are conveniently subdivided according to whether they deal primarily with complete airfoils or with airfoil sections. The investigations of complete airfoils have dealt with tapered airfoils and with full-size wings. Airfoil investigations are also concerned with scale effect; that is, the variation of the aerodynamic characteristics with the Reynolds Number, and with compressibility effect; that is, the variation of the characteristics with air speed at very high speeds.

Complete airfoils.—For the purpose of verifying methods used in computing the characteristics of tapered and twisted wings a series of tapered airfoils, including airfoils with sweepback and twist, is now being tested in the variable-density tunnel. A number of rectangular airfoils with standard rounded tips are also being tested at the request of the Army Air Corps to furnish data for inclusion in the Army's handbook of instructions to airplane designers.

At the request of the Bureau of Aeronautics, Navy Department, four different wings were tested on the

F–22 airplane in the full-scale tunnel to determine the full-scale aerodynamic characteristics of the wings. The sections included were the N. A. C. A. 2212, the N. A. C. A. $2R_112$, the CYH, and the Boeing 112. The results indicated that for this application there was little to choose between the four wings except in the character of the break in the lift curve.

Airfoil sections.—The investigation of shape of airfoil section in the variable-density tunnel mentioned in last year's report has been continued. The original investigation of a large family of related airfoils indicated that the effects of the camber of the airfoil section in relation to the maximum lift are more pronounced when the maximum camber of the mean line occurs either forward or aft of an intermediate position. The after positions, however, are of lesser interest, owing to adverse pitching moments, and the forward positions could not be satisfactorily investigated with the mean lines included in the original family. Two new series of airfoil mean lines were therefore developed. Five mean lines of each series constituted a family of curves having maximum camber positions varying from 5 to 25 percent of the chord behind the leading edge. Instead of investigating each camber-line shape through a range of cambers, the camber for each was adjusted so that the minimum profile-drag coefficient would occur at a lift coefficient suitable for the high-speed or cruising condition of flight. As with the large family of airfoils, each of the ten airfoils was developed by combining the usual family thickness distribution of 12 percent chord maximum thickness with one of the mean lines.

The airfoils of the series designated by A appear to be the more promising, and an airfoil designated N. A. C. A. 23012 having the 15-percent chord camber position is one of the best. The characteristics show a reasonably high maximum lift, a small pitching moment, and only a slight increase in drag over that of the corresponding symmetrical airfoil, the N. A. C. A. 0012. The N. A. C. A. 23012 airfoil is a decided improvement over the N. A. C. A. 2212, the most closely related family airfoil.

Scale effect.—The subject of scale effect is concerned with the variation of aerodynamic characteristics with the dynamic scale as represented by the value of the Reynolds Number. Until recently scale effect was considered of importance mainly in connection with the interpretation of model tests in small-scale wind tunnels. It is now appreciated that marked variations of the aerodynamic characteristics of wings may occur within the full-scale range, which, together with the increased breadth of the full-scale range resulting from the greater size and speed of modern airplanes, has led to new interest in the subject of scale effect.

The Committee's investigations have dealt first with the scale effects for airfoil sections. Technical Report No. 502 presents the results of tests in the full-scale tunnel of four similar Clark Y airfoils having dimensions of 2 by 12 feet, 4 by 24 feet, 6 by 36 feet, and 8 by 48 feet. These results are known to be reasonably free from turbulence effects so that the variations of the coefficients within the full-scale range indicate definitely the existence of marked scale effects.

In order to provide further data concerning the nature of the scale effect for various types of airfoil sections, certain of the related family airfoils previously investigated for only one value of the Reynolds Number have more recently been investigated over a very wide (80-fold) scale range in the variable-density tunnel. The analysis of the results has not progressed far enough to permit final conclusions to be drawn. The indications from comparative tests in the variable-density tunnel, full-scale tunnel, and flight are that the most important effect of turbulence present in the variable-density tunnel is to make the results applicable to flight at a higher Reynolds Number. For example, results obtained in the tunnel at a Reynolds Number of 3,000,000 should be applied to flight problems as if they had been obtained at a Reynolds Number of approximately 7,400,000, which may be designated the "effective" Reynolds Number of the test. The tests that have been completed cover a sufficient range of Reynolds Numbers and a sufficient range of airfoil-section shapes that the results will provide designers with a reasonable basis for predicting airfoil characteristics for any desired Reynolds Number.

The subject of scale effect is also being investigated by fundamental studies of the nature of the air flow about airfoil sections. Air flows about airfoil sections have been observed and photographed in slow motion in the N. A. C. A. smoke tunnel, and by the Schlieren or Stria method in the high-speed tunnel. It is hoped that these observations can be correlated with pressure-distribution tests and with theoretical calculations. For this purpose the pressure distribution around the surface of the N. A. C. A. 4412 airfoil section has been very carefully measured over a wide range of values of the Reynolds Number in the variable-density tunnel, and a study of the results is being made.

Compressibility effect.—The study of the effects of compressibility was originally begun to throw light on the large efficiency loss exhibited by propellers having blades corresponding to airfoil sections and operating at speeds approaching the velocity of sound. The Committee's experiments have been conducted chiefly with airfoils rather than propellers because the use of the simpler body eliminates from the results the effects of certain other variables. While the investigation has been in progress, the speeds of airplanes have increased to a point where the lifting surfaces may experience compressibility phenomena, lending added interest to the results of this investigation. The airfoil tests so far made include the determination of the characteristics of 6 commonly used propeller sections and of 16 related airfoils chosen to bring out the effects of certain form variables, particularly at high speeds. These tests were conducted in the 11-inch high-speed wind tunnel over a speed range extending from 35 percent of the velocity of sound to speeds slightly greater than those at which a flow break-down or compressibility burble occurs (in some cases as high as 90 percent of the velocity of sound). A report (Technical Report No. 492) has been prepared presenting the results of the tests of the 16 related airfoils.

The nature of the flow at the compressibility burble is now being studied experimentally by means of the Schlieren method of flow observation. Preliminary experiments have already been made, and the flow associated with the compressibility burble has been observed and photographed. Apparatus is being developed for further study of the compressibility phenomena.

The investigation of the drag of fundamental shapes—circular, elliptical, and prismatic cylinders—mentioned in the last annual report has been continued.

Theory of pressure distribution.—Application of the theory of pressure distribution originally developed in Technical Report No. 411 has been continued. At the request of the Bureau of Aeronautics of the Navy, the pressure distribution has been determined for more than 30 typical wing sections, to be used as the basis for a rational design of wing structures.

A new method of obtaining the potential flow about elongated bodies of revolution has been devised. It is based on solutions of Laplace's equation, $\Delta^2\varphi=0$ expressed in elliptic coordinates. The velocity potentials for both axial and transverse flows about an arbitrary body of revolution are developed and from them the corresponding sink-source and doublet distribution are readily derived. An application to the system of bodies whose meridian curves are Joukowski profiles has been made. The results of this work may be used to obtain the pressure distribution and the transverse force coefficients. A paper is in preparation.

A rigorous theory has been developed which treats the general problem of potential flow about arbitrary biplane wing profiles. In addition to each profile shape of the biplane arrangement being arbitrary, the gap-chord ratio, chord-chord ratio, stagger, and decalage can be specified arbitrarily. The work is a natural generalization of the general monoplane wing-section theory already developed. The velocity and pressure at any point of the surface of either profile are determined in potential flow. The single slotted wing and the auxiliary airfoil wing are, of course, special cases of the general theory. A paper is in preparation.

Measurement of Air Speed.—For the purpose of determining for the Bureau of Aeronautics, Navy Department, the best location for a fixed-type service pitot-static head on a monoplane from the considerations of accuracy and freedom from accident in handling, surveys were made in the full-scale tunnel of the air flow about the wing of a monoplane at several angles of attack throughout the speed range. It was found that the best location on the airplane tested was a point about the center of the semispan 5 percent of the chord ahead and 27 percent of the chord above the trailing edge of the wing. Surveys around the tip indicated that a head mounted directly at the tip would give satisfactory readings at high and cruising speeds but at higher angles of attack might be in error as much as 8 percent.

An investigation of pitot tubes, designed to develop a standard N. A. C. A. pitot tube and to extend the pitot-tube calibration to high speeds, has been started. Pressure-distribution measurements along the barrel of a Prandtl-type pitot tube are now being made in the 11-inch high-speed tunnel for a speed range extending from 100 miles per hour to the speed at which a compressibility burble occurs (approximately 650 miles per hour).

Anemometer Research.—The Committee, at the request of and in cooperation with the United States Weather Bureau, has conducted an exhaustive investigation on the Robinson-type cup anemometer. This instrument is extensively used by the Weather Bureau, and it was the purpose of this study to provide information for the design of cup wheels of the greatest efficiency and the most desirable characteristics. The results are being prepared for publication and will cover the following specific investigations: (1) a study of the forces on individual cups through a wide range of Reynolds Number; (2) static torque measurements; (3) dynamic torque tests of the same cup wheels with the same arm lengths as used in the static torque measurements; (4) calibration tests of the same cup wheels on a regular service spindle as used by the Weather Bureau; (5) torque measurements on a single cup through a complete revolution under operating conditions, i. e., mounted in a cup wheel in such a manner that the torque produced by the individual cup could be measured, and a comparison of the plotted results thus obtained with results calculated from static torque measurements on individual cups; and (6) drag tests on complete cup wheels.

Wind-Tunnel Turbulence.—The effect of the turbulence of the air stream in a wind tunnel has been a subject of increasing interest the last few years, particularly in connection with its effect on the maximum lift of airfoils, and a decision was made some months ago to investigate the turbulence in all of the Committee's wind tunnels for comparison with the turbulence of free air. Measurements of the drag of spheres of several sizes had been made in a number of the Committee's wind tunnels as a means of determining the critical Reynolds Number when the suggestion was received from Dr. H. L. Dryden that the work might be expedited, particularly in the larger tunnels and in free air, by determining the pressure difference between the front and the back of the sphere as an indication of the flow characteristics instead of measuring the drag. Tests in some of the tunnels having turbulence values between 2.4 percent and 0.025 percent, according to the scale proposed in N. A. C. A. Technical Report No. 342, indicated that the measured "pressure coefficient" could be directly correlated with the drag coefficient, thus permitting the determination of the critical Reynolds Number.

Measurements have since been carried out in most of the Committee's wind tunnels and in flight, the sphere in the latter tests being suspended below an autogiro. The results of this investigation are still in process of analysis, and although it is too soon to draw final conclusions, it seems safe to say that the turbulence of the full-scale tunnel is so close to that of free air that the difference may be regarded as having a negligible effect; that the turbulence in the propeller-research tunnel is almost as low; and that the turbulence in the other tunnels is greater in the following order: 24-inch high-speed tunnel, model full-scale tunnel, 7- by 10-foot atmospheric wind tunnel, and variable-density tunnel. It is planned as an additional step to determine the critical Reynolds Number for a sphere mounted ahead of the towing carriage in the N. A. C. A. tank where the movement of the air is so slight that its effect can be disregarded.

Wind-Tunnel Boundary Interference.—As a result of very intensive work on boundary interference on airplane wings in different types of wind tunnels this problem may for all practical purposes be considered solved. This work has been carried on also in several foreign countries, particularly in England and Japan. Original contributions by the Committee to this work consist in the determination of the correction factor for open rectangular wind tunnel both for infinitely small and for finite wing spans. The first case was presented in Technical Report No. 410 and the case of finite span in Technical Report No. 461.

Theoretical results being available through recent investigations for all types of wind tunnels, an experimental investigation for the purpose of verifying the theoretical formulas was announced in last year's annual report. The results of this comprehensive investigation have been published in Technical Report No. 478. The majority of the tests were conducted in the full-scale wind tunnel, which afforded the rare opportunity of a direct comparison with flight results. The experimental boundary correction factor was found to agree with theoretical values within the limits of experimental error. The accuracy and sufficiency of the theoretical analysis in its present form has therefore been established.

Propeller Design.—The problems of propeller design have been the subject of study by the Committee for a number of years. Although no full-scale test data have recently been obtained, analysis of older data, some of which have not been published, has been continued. The particular problem at present under investigation is the determination of airfoil characteristics of operating propeller blade sections. Study of data obtained some years ago showed that the body behind the propeller introduced effects that could not be evaluated with the data at hand. The logical method of attack seemed to be additional experiments in which the effect of the body should be reduced to a minimum. A large number of measurements have accordingly been made on models in which the propeller is separated from the body by a long shaft. The laborious computations necessary are now nearing completion and the possibility of presenting airfoil characteristics which may be used in propeller analysis, accurately taking account of body effects, appears less remote than formerly.

The above-mentioned model tests also included experiments with the propeller pitch set at high angles within the range now being used on modern transport airplanes, but not so high as will be required in designs now contemplated. The results indicate that the maximum propulsive efficiency is reached at a pitch of about 30° at 0.75 R and that there is a slow falling off at higher pitches. This effect might be considered as a fortunate limitation of the pitch required, but analysis shows that the well-known tip-speed losses enter the problem and the best over-all result for high speed tests will be obtained with high pitches and geared engines. This fact is, of course, unfavorable to the take-off performance even when controllable propellers are used.

Rotating-Wing Aircraft.—Considerable effort has been devoted during the past year to a continuance of the theoretical and experimental work on rotating wings, for the principal reason that they are believed to constitute one of the best existing solutions to the problem of safe, stable, and controllable low-speed flight.

The original strip theory of the autogiro was refined and expanded to determine the influence of twisted blades. The altered theory was then used to predict the characteristics of the rotor of the Committee's autogiro and the results compared with data obtained from flight tests (Technical Report No. 475). Reasonable agreement was obtained up to a tip-speed ratio of 0.4, but appreciable discrepancies were found at higher values; also, no comparison of drag could be made, since it was impossible to determine the rotor drag in flight. The altered strip analysis and comparison of theory with experiment are contained in Technical Report No. 487.

In order to obtain data that would be of assistance in formulating methods of predicting the drag of an autogiro rotor, the rotor was tested alone in the full-scale wind tunnel. Lift, drag, angle of attack, and aerodynamic moments were measured at three rotor pitch settings and several rotor speeds, and surveys of the air flow immediately above the rotor were made at two different tip-speed ratios. The information obtained is being prepared for publication as a technical report, and is at the same time being utilized to add further refinements to the strip analysis. It is of interest that the results show the drag of the exposed fittings on the rotor to be about 5 percent of the total rotor drag.

A systematic investigation of the influence of the fundamental parameters of the autogiro rotor has been started in the propeller-research tunnel with tests on a series of model rotors of 10-foot diameter differing only in airfoil section and plan form. Measurements of air forces and moments and the rotor-blade motion are being made at several pitch angles over the entire angle-of-attack range of each rotor. The work is at present only partly completed, but it has been established that the airfoil section of the blade has a critical influence on the maximum pitch setting at which autorotation is obtained. It is expected that the results of these tests will be applicable to the gyroplane as well as the autogiro.

Flight tests on the autogiro disclosed that at high air speeds the rotor speed decreased dangerously and limited the safe high speed of the machine. A study of the load distribution between rotor and fixed wing indicated that this phenomenon might be caused by a transfer of load from rotor to wing at high speeds. Flight tests were consequently made with the fixed wing set successively to lower incidences, and measurements of the rotor speed and wing pressure distribution were made. The results confirmed the original hypothesis and showed that by a suitable choice of wing incidence the rotor speed could be made to increase at high speed instead of decrease. The results of these tests are being prepared for publication.

An analysis has been made of the gyroplane type of rotating-wing system and published as Technical Note No. 492, and in order to obtain experimental information concerning the aerodynamic characteristics of this type a 10-foot model gyroplane rotor with mechanical feathering was constructed and tested in the propeller-research tunnel. Force and moment measurements were taken from 0° to 90° angle of attack at seven pitch angles. This information is now being prepared for publication.

A model cyclogiro rotor, 8 feet in diameter and 8 feet in span, was built and tested in the propeller-research tunnel. Power input, lift, and drag were measured over the entire operating range of the rotor from conditions approximating hovering flight to those simulating high speed. The power required by the rotor was, in general, found to be disappointingly large, being about twice the predicted value for the blades after the tare power for the shaft and supports had been deducted. The results were such that it is now thought that the cyclogiro has very limited possibilities. The information obtained in the wind tunnel is being prepared for publication.

Field of View.—The investigation of the field of view from pilots' cockpits and cabins that was mentioned in last year's report has been continued throughout the year. A report is in preparation describing the method and apparatus employed and the type of chart developed and its uses, and giving representative charts for several airplanes. To date the field of view for 41 airplanes of many different types has been charted. At the same time, where possible, the reactions of different pilots in regard to the relative importance of view in various directions under different conditions of flight in these airplanes has been noted to aid in evaluating properly the various portions of the charts for the purpose of deriving figures of merit, or criterions. In order to assist further in formulating the criterions, a questionnaire asking for opinions as to the most important factors concerned with desirable field of view has been circulated to a large group of pilots. Blank field-of-view charts similar to those employed by the Committee in the investigation have been submitted to obtain their ideas concerning this method of measurement.

Airships.—The work during the past year has consisted chiefly in cooperation with the Army in tests of the TC–13 airship. Accelerations in the control car during heavy take-offs and measurements of the rudder-cable tension have been made. Data previously obtained in the full-scale pressure distribution tests on the U. S. airship *Akron* are being analyzed and assembled for the preparation of a report.

Miscellaneous Airplane Tests.—The general flying characteristics, and, to some extent, the performance of two small experimental airplanes of unusual design were investigated at the request of the Bureau of Air Commerce, Department of Commerce. Both of these airplanes were of interest to the Department of Commerce in connection with the development of a safe, cheap, light airplane. One of them was unusual in that the wing was nearly semicircular in shape and tailless in that the rudder and elevator were attached directly to the wing. Outstanding features of the other, which was a pusher-type high-wing monoplane, were a leading-edge auxiliary airfoil and a three-wheel landing gear with the two main wheels abaft the center of gravity and the third wheel, which was controllable and swiveling, located in the nose of the fuselage. Largely as a result of this landing-gear arrangement, the airplane was capable of being landed safely over an unusually large range of speeds and, in addition, was stable and very maneuverable on the ground. Tests were made of the latter airplane in the full-scale tunnel previous to the flight tests, to determine its aerodynamic characteristics and in general its suitability for flight.

At the request of the Bureau of Aeronautics, Navy Department, tests have been made in the full-scale tunnel of two service airplanes, an observation and a fighter type, to determine their performance characteristics. The tests have been completed but the results have not yet been evaluated.

Structural Loading.—With a few exceptions, particularly with regard to the effect of flaps, investigations of structural loads during the past year have been continuations of researches previously in progress.

Load factors.—Research on applied load factors has been almost entirely limited to an extension of the statistical data being collected on this subject. The information obtained to date on airplanes subjected to various maneuvers under service conditions has been found to verify the conclusions drawn from previous special tests made by the Committee. It is believed that from the information now in hand, load-factor specifications can be made to conform quite closely with the flight conditions to be expected in service operations.

The gust-load data now being obtained on transport airplanes are of particular interest because of the introduction of faster machines on the air lines. Cruising speeds at which measurements have been taken have increased from about 110 miles per hour to about 150 miles per hour, and the maximum measured accelerations have also increased, apparently at a greater rate than the speed. Whether this phenomenon indicates that the gust acceleration increases in greater proportion than the speed for similar gusts or that, because of the greater scope of the data, more severe gusts have recently been encountered, can only be surmised. In any case, maximum " effective " gust velocities, based on the sharp-edged gust assumption, have increased from about 27 feet per second at a cruising speed of 110 miles per hour to about 34 feet per second at a crusing speed of 150 miles per hour.

The maximum diving speed, or terminal velocity, has been the subject of analytical study during the past year with a view to establishing reasonable design values. Loads on engine mounts in maneuvers have also been studied to provide material for new design values, consideration being given to the unequal distribution of inertia forces in accelerated flight.

Load distribution.—Measurements of the pressure distribution on the wings of a Navy bomber and an Army observation biplane in flight have provided data from which the effect of the interference of the fuselage on the distribution of load between the upper and lower wings of conventional biplane arrangements has been evaluated. The data also indicate the effect of pitching velocity on the biplane lift distribution in normal and inverted maneuvers and have supplied further information on the effects of fuselage interference and structural distortion on the distribution of load along the span and chord.

The increasing use of flaps on modern airplanes has necessitated, for proper structural design, more specific knowledge of the loads experienced on flaps and the effects of flaps on the loads and the load distribution on the airplane structure, and several studies for this purpose have been conducted during the past year. In the 7- by 10-foot atmospheric wind tunnel tests have been completed (Technical Note No. 498) of the air loads on a wing equipped with simple split trailing-edge flaps. Flaps with chords of 25 and 15 percent of the wing chord were used on a Clark Y wing. The load on the flap, the division of the load between the flap and wing, and the hinge moment of the flap were measured. In connection with other research on Fowler type flaps in the 7- by 10-foot wind tunnel similar measurements were made of the loads resulting from the use of Fowler flaps with chords of 20 and 30 percent of the wing chord, a report on which is now in preparation. In the full-scale tunnel, tests have been made on a small high-wing monoplane to determine the loads on split trailing-edge flaps of various types. Flaps with chords equal to 10, 20, and 30 percent of the wing chord were used and were installed with the hinge axis at various percentages of the chord, thus covering the case of the Zap-type flap as well as the simple split flap. The loads were determined by measurement of the pressure distribution over the flap and a portion of the wing at the same time that force tests were made on the complete airplane. From the results, the load on the flap, its hinge moment, and the effect of the flap on the load on the wing are being determined. A report on this investigation is now in preparation.

On the basis of the information obtained in the flap tests mentioned above and of other information, charts have been devised from which design data on the lift, drag, pitching moment, hinge moment, and flap load can readily be determined for any airfoil with simple or split flap.

Tail loads.—Instruments and technique are in process of development for the statistical measurements of tail loads in rough air. Pressure-distribution measurements on the tail surfaces of an Army observation airplane in maneuvers have added to similar data previously obtained on different types.

Water pressures on seaplane hulls.—The Committee is now cooperating with the Bureau of Aeronautics, Navy Department, in the determination of the maximum water pressures experienced on flying boat and seaplane hulls, the Bureau having started a procedure requiring the measurement of the distribution of maximum water pressures as a part of the routine tests of new designs. To date the maximum pressures at a number of different stations on the bottom of a large 2-engine patrol flying boat have been measured. Pressures as great as 36 pounds per square inch were recorded on this machine close to the step. For the purpose of these tests the Committee has developed a maximum water-pressure recorder that utilizes a diaphragm actuating a stylus which scratches on a stationary smoked-glass target.

Methods for analysis of 2-spar wings.—A report is in process of publication outlining methods of analyzing 2-spar wings under large torque loads. Special efforts were made to reduce sufficiently the amount of computing required to obtain a method generally acceptable for routine design. Of immediate importance for designers in analyzing the rear spars of flapped wings is the necessity of more accurate methods of stress analysis than those commonly used heretofore. Perhaps not quite so apparent at the moment is the need for more accurate calculations of the wing stiffness, particularly in torsion. The rapidly increasing speeds of modern aircraft will, however, probably necessitate the setting up of definite stiffness requirements in addition to existing strength requirements in the not too distant future. These two distinct needs are filled by this report.

Theory of Airplane Flutter.—Flutter remains one of the least understood subjects of aerodynamics. Experimental work on the subject is still in a very preliminary stage, and with the exception of a few purely practical investigations no scientific work has been carried on in this country. Realizing the greater necessity of knowledge on flutter in relation to high-speed airplanes, the National Advisory Committee for Aeronautics has initiated a comprehensive program in flutter research.

The first step in this investigation consisted of a theoretical analysis of the general flutter problem. A report covering the general theory of aerodynamic instability and the mechanism of flutter has been completed (Technical Report No. 496). The aerodynamic forces on an oscillating airfoil or airfoil-aileron combination of three independent degrees of freedom have been determined, and the problem now resolves itself into the solution of certain definite integrals, which have been identified as Bessel functions of the first and second kind and of zero and first order. The theory, being based on potential flow and the Kutta condition, is fundamentally equivalent to the conventional wing section theory relating to the stationary case.

The air forces being determined, the mechanism of aerodynamic instability has been analyzed in detail. An exact solution, involving potential flow and the adoption of the Kutta condition, has been arrived at. The solution is simple in form and is expressed by means of an auxiliary parameter k. The flutter velocity, which represents the unknown quantity, may immediately be plotted as a function of frequency for any combination of the air-foil-aileron paramaters. The mathematical treatment also provides a convenient cyclic arrangement permitting a uniform treatment of all subcases of two degrees of freedom.

Supplementary experimental work on wing flutter has been carried on in one of the smaller wind tunnels, largely to verify the general shape of the flutter characteristics and the magnitude involved in the theoretically predicted results. This research has been limited to well-defined elementary cases, the wing employed being of a large aspect ratio and nondeformable, and allowing definite degrees of freedom by means of a supporting mechanism, with external springs maintaining the equilibrium position.

On the basis of existing experimental material, it is possible to state that the method of theoretical prediction of flutter velocities looks very promising. The agreement in several cases is almost perfect; not only are the flutter velocities found to correspond but the general dependency on the various rather numerous test parameters is substantially correct.

Research on Propeller Noise.—Analysis of the sound emitted from small propellers 18 inches in diameter shows the complex character of propeller noise. The sounds can be divided into two main groups. One group consists of a series of musical tones whose frequencies are all multiples of a fundamental tone. The frequency of this fundamental tone is equal to the number of blades times the revolutions per second. This group of tones is heard by the ear as the "roar." The second group of sounds consists of pressure disturbances created when vortices are released from the trailing edge of the blade. The frequencies of these sounds cover a very wide range and are unrelated to one another. The sounds are perceived by the ear as the "swish" or tearing sound. These two groups are not entirely independent of one another, and effects sometimes arise from the combination of the two which increase the loudness of the noise. The origin of the first group of sounds is not understood as yet and experiments are under way to give information on this subject. Attempts have been made to estimate the loudness level of various model propellers by the method of masking. The amplitude of a tuning fork when it is just masked by the propeller noise may be considered a measure of the propeller noise. Such measurements indicate that the sounds in group 1 have by far the greater effect upon the ear. Studies have been made of the apparent increase in loudness level due to the interrelations between the sounds of groups 1 and 2. Results show that the loudness level from a full-size propeller may rise by as much as 25 decibels, with no accompanying change in the physical intensity, as a result of this interrelation.

Full-scale propeller equipment for the study of sound has been completed and put in operation. A paper is being prepared for publication in which is described the sound-measuring equipment used in the Committee's sound laboratory for the study of propeller noise. Polar diagrams are given of the distribution of sound pressure about a 2-blade propeller absorbing 100 horsepower. The polar diagrams include not only the distribution of the total noise, but also the distribution of certain frequency ranges and, in addition, that of the first six harmonics individually. Estimates are given of the distribution of acoustical power among the various frequency ranges. An empirical formula is suggested for the prediction of propeller sound pressure at any point on an airplane in flight.

Vibration Research.—A report (Technical Report No. 491) has been prepared presenting results of experiments on the vibration-response characteristics of airplane structures on the ground and in flight. It also gives details regarding the construction and operation of vibration instruments developed by the Committee.

In the ground tests the vibration was obtained by applying sinusoidal forces and couples at various parts of the fuselage. The amplitudes of vibration were measured by means of a recently developed vibration-amplitude recorder. This instrument permits immediate reading of the magnitude of vibration of any particular point by simply touching the point in question by a small feeler unit, and thus makes possible the reading at a large number of points in a short time. The important modes of vibration were determined for two airplanes. It is hoped that a similar procedure may be found of value in connection with design problems.

In recognition of the need for more information in regard to the causes of propeller failures, a program on propeller-crankshaft vibration has been in progress for some time. The immediate object of this investigation is to test an engine-propeller unit by subjecting the system to high-frequency torsional vibration of the crankshaft. The source of vibration is a small air-driven rotor capable of any speed up to 20,000 revolutions per minute, and the piston system of the engine is replaced by a single equivalent weight at the crankpin. It is known that the main torsional response of the crankshaft may be at a frequency of more than 100 vibrations per second. The shafts will therefore be tested for frequencies up to 10,000 or 15,000 vibrations per minute. One of the purposes of this test is to determine whether the higher harmonics of the propeller may be excited from the engine torque vibration, and it is desired also to investigate the behavior of the main crankshaft propeller response, and to devise a practical method for testing propeller crankshafts for safety purposes. Very little is known at the present time in regard to the forces causing airplane propeller failures. There are always several explanations possible, or none at all. Practical experience is of little or no value, since in many cases the failure of the propeller causes the wrecking of the whole airplane, so that scientific examination is impossible. It is therefore desirable to develop a theory or some simple experimental method by which the dangerous response frequencies may be known in advance.

Seaplanes.—The quantity of work that can be done in a model basin is determined in part by the time required for the waves produced during one test run to become so small that they will not affect the performance of the model during the next test run. A new type of wave suppresser has been developed in the N. A. C. A. tank for the purpose of reducing the size of the waves with a maximum of rapidity. It consists of a series of narrow frames covered with fine-mesh screen and placed along the side of the tank with the screen horizontal and about 1 inch under water. A set of these wave suppressers about 24 feet long is now located every 50 feet on both sides of the tank. They have proved so effective that the limit on the number of runs that can be made in a day is now set by the speed with which the towing carriage can be returned to begin the succeeding run.

In most ship-model towing basins the models are made of wax, usually paraffin wax with some hardener such as beeswax or carnauba wax. The wax models are shaped with the aid of a machine that cuts guide lines in the block and the time and cost of making models are much less than for wooden models made with templates in the usual manner. The high temperatures prevailing at Langley Field during much of the year made it impracticable to use paraffin wax for models, and a search was therefore made for a suitable wax that would retain its form in hot weather. An experimental model has been made of a wax that melts at 270° Fahrenheit and that appears otherwise suitable. This model has been tested in the tank and by exposure to the heat of the sun in the shop and has retained its form about as well as a wooden model.

In order to take full advantage of the savings that may result, a model-cutting machine is being designed for use in making both wax and wooden models.

Effect of variation in dimensions and form of hull on take-off of flying boats.—Reduction in the water resistance of flying-boat hulls will always be a principal subject of investigation, for a reduction in water resistance at a given gross load means that the maximum gross load with which the machine can take off will be increased and the increase in gross load may be utilized by the operator as increased pay load, increased range, or otherwise, as he desires. For the purpose of finding the effect of systematic changes in the form and proportion of the hulls of flying boats on the water resistance and general performance, a series of models has been tested in the N. A. C. A. tank, the members of which have been derived from a parent form by a process of proportional extension and contraction in both longitudinal and transverse directions. A first result of these tests, as was mentioned last year, was the deriving of a form (Model 11–A) that was a considerable improvement over the parent form.

Analysis of the completed tests showed that the method of deriving the forms was not entirely suitable for use with models of flying-boat hulls. Such craft do not have a constant displacement, or weight on the water, as do surface craft. Instead it varies continuously with the speed and is radically affected by the form and dimensions of the bottom below the chines. Hence the effects of changes in any one dimension were obscured by the effects of other changes. This conclusion had been anticipated somewhat and the investigation was in effect conducted to find what could be done by the method used. Among other things, the results showed that increasing the dimensions of a hull for a given design load led to a decrease in resistance at hump speed and increases in the resistance at speeds near get-away. A further conclusion, immediately applied to designs for new models, as in Model 11–A, was that fore-and-aft curvature of the bottom of the forebody, as frequently found in earlier designs, led to increased water resistance, and that the keel line and bottom should be carried as far forward of the step in a straight line as other conditions of the design made feasible. This work is reported in Technical Note No. 491.

Model no. 22, the first with a pointed main step, had shown a gratifying reduction in water resistance over the more usual form, but when its performance was examined in the light of the results from the tests referred to above, it was concluded that increasing the length of the straight forebody would improve the performance. A new model (no. 22–A) incorporating this change was made, together with another (no. 35) having a still greater length-beam ratio, to represent a possible application of the type as a seaplane float. Both models showed consistently lower resistances for all conditions than conventional forms, especially at the hump speeds. When used in take-off computations for a typical design having a gross load of 15,000 pounds, two engines totaling 1,000 horsepower, and a wing area of 1,000 square feet, a reduction in take-off time and run of 4.5 seconds and 490 feet was obtained with model 22–A, and of 6.5 seconds and 550 feet with model 35. This work is reported in Technical Note No. 504.

Take-off tests of the Navy P3M–1 flying boat had shown that large quantities of spray were thrown while taking off and landing, and that the propellers suffered erosion from the spray that they encountered. A model of the hull and side floats of this craft was tested with and without several types of spray strips to see if the spray could be reduced. Some improvement was obtained by fitting the spray strips, but not enough to overcome the handicap produced by the engines being set too low. However, it was concluded that spray strips could be used quite effectively to reduce the spray thrown by a hull with floats set quite close to it. This work is reported in Technical Note No. 482.

A more extensive and more general series of tests to determine the effect of spray strips on the take-off performance of a flying boat was made with the model of the hull of the Navy PH–1 flying boat (model no. 1) and is described in Technical Report No. 503. Spray strips were fitted along the chine in four different widths and at three different angles at the step for each width. In the neighborhood of the hump speed the general effect of the spray strips was to reduce the resistance, the widest strip (3 percent of beam) giving the greatest reduction. The resistance at the higher speeds nearing get-away seemed to be practically unaffected by the spray strips. A notable effect was the reduction in the trimming movements in the region of the hump, which promised to make the aerodynamic controls effective at lower speeds. The reduction in spray thrown seemed to parallel the reduction in resistance, but a downward angle of 30° to 45° at the step seemed to give the best results.

The desirability of holding a seaplane during take-off to the best trim angles—those that give minimum resistance—has been generally recognized, but accurate quantitative data on the effect of deviations from that angle have been lacking, nor has it generally been possible to define the angle throughout the run from the tests usually made. The general method of testing models as used in the N. A. C. A. tank makes it possible to determine the best angle for water resistance throughout the entire run. From the data obtained in tests of models nos. 11–A, 16, and 22, a study was made of the effects of trim angle on the take-off performance of flying boats. The trim angle giving lowest water resistance was found to give lowest air resistance also, and hence lowest total resistance. Deviations from best angle of more than 1° in the region of low excess thrust (hump speed) and more than 2° to 3° during the remainder of the take-off run will produce increases in the time and distance required.

In the report on this work (Technical Note No. 486) a simple instrument is described which will indicate the trim, so that if the pilot of a seaplane desires, he may control the trim to those angles that have been found by tank tests of a model to give minimum resistance for each speed and thus may obtain the quickest take-off. Hydrovanes, fitted either below or at the sides of a hull of reduced dimensions, have been proposed by many as a substitute for a hull with the usual planing bottom and have been applied in practice on seaplane floats by Guidoni. The results of the applications have not convinced designers generally that the method has merit, but the idea remains attractive. In Technical Note No. 490 comparative tests are described of a model of the hull of the U. S. Navy PN–8 flying boat and of a model of a modification of this hull in which the "sponsons" providing the wide beam of the hull were removed and replaced by lifting vanes projecting from the chines. The modification was not successful, for the substitution of the vanes caused a large increase in resistance and in spray thrown.

Tank tests on models of the hulls of several well-known and typical flying boats have already been described in reports and others will be added as the data are made available to the Committee. Such tests are always of particular interest as they show the effects on take-off performance of the measures adopted by individual designers and thus permit useful comparisons to be made. By courtesy of the Sikorsky Aviation Corporation, the lines and other data necessary for a tank test of the hull of the Sikorsky S–40 (American Clipper class) flying boat were obtained. The results of these tests, together with a study of the take-off as computed from the tank tests, is being published in Technical Note No. 512.

The successful application of trailing-edge flaps to the wings of land types of airplanes brought the natural suggestion that fitting flaps on the wings of seaplanes should result in improved take-off performance. It was anticipated that the increase in the lift of the wing would reduce the weight on the water and thus reduce the water resistance and total resistance. A study of this possible use of trailing-edge flaps is reported in Technical Note No. 510. From the data obtained in a "general" tank test of a model hull, the effect on the water performance of a typical flying boat of fitting the flaps at three different settings was investigated in detail. The large increase in drag that accompanied the increase in lift resulting from the use of the flaps proved to be the disturbing element. Despite a reduction in water resistance the total resistance might easily increase until it exceeded the thrust. The principal conclusion is that the take-off performance of a flying boat in a condition in which it has a large excess of thrust over resistance will be improved by the use of flaps; but if heavily loaded, with little excess thrust, the improvement will not be obtained and take-off may be prevented.

Fundamental information regarding planing surfaces.—The bottoms of flying-boat hulls in the neighborhood of the step are usually made up of two surfaces that meet at a dihedral along the keel. These surfaces may be planes or may be curved transversely or fore and aft in different manners according to the ideas of the designer. In model tests the effects on the performance of the model of the form of bottom that has been selected is usually masked more or less by the effects of other elements of the form of the hull. For the purpose of obtaining information on the characteristics of the form of the bottom alone it is planned to test an extensive series of planing surfaces that will include, among others, surfaces with different angles of dihedral, different transverse curvature, and different longitudinal curvature. Technical Note No. 509 has been issued describing the tests of a part of the series of planing surfaces, consisting of flat Vees at 0°, 10°, 20°, and 30° angle of dead rise. The surfaces having transverse and longitudinal curvature have not yet been tested. The tests of the complete series will be described in a technical report.

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.

Apparatus for measuring turbulence.—A modification has been made of the sphere method of measuring turbulence in wind tunnels, which makes the method much simpler in application. The difference in pressure between a hole at the upstream stagnation point of a sphere and a hole in the downstream octant is measured. A tail spindle is used, no balance is required, and the installation in wind tunnels of any size is readily made. The critical Reynolds Number is defined as the Reynolds Number for which the ratio of the pressure difference for the sphere to the velocity pressure is 1.22, this value being selected in view of experiments by the staff of the Langley Memorial Aeronautical Laboratory which showed that this value of the pressure ratio gave about the same critical Reynolds Number as the force measurements on a sphere with a drag coefficient of 0.3.

The correlation of the pressure-sphere method with hot-wire measurements has been studied in the turbulence produced behind a series of wire screens. The pattern of the screens was found to persist to about 70 times the diameter of the wires of the screens, and oscillographic records of the speed fluctuations at a point showed no great difference in the frequency characteristics at distances of this magnitude or greater. The magnitude of the fluctuations for geometrically similar screens was approximately a function of the ratio of the distance from the screen to the diameter of the screen wire. Small systematic deviations for the several screens could be attributed to a small effect of Reynolds Number.

The critical Reynolds Number for a sphere was found to be a function of the ratio of sphere diameter to some measure of the screen size. There must therefore be some length characteristic of the turbulence which influences the flow around a sphere.

Separating laminar boundary layer.—A paper has been completed describing experimental determinations of the speed distribution in a separating laminar boundary layer formed in the two-dimensional flow around an elliptical cylinder. The experimental results were compared with Pohlhausen's approximate solution of the boundary-layer equations. It was found that the approximate solution was fairly good in the region where the pressure was decreasing downstream, but that the solution failed to predict the separation which actually occurred.

Aeronautic Instrument Investigations.—The work on aeronautic instruments was conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department, and included the investigations and the instrument development outlined below.

Lubricants for instrument mechanisms.—The investigation to determine the characteristics of animal and vegetable oils, including those with antioxidants, for use as lubricants for aircraft instruments has continued. Two tests are in progress the results of which it is hoped to correlate: (*a*) an accelerated oxidation test and (*b*) a life test. The apparatus for the life test consists of a bank of 50 watch balance wheels, 3 or 4 of which are lubricated with the same oil, and which are maintained in oscillation by an electrically operated mechanical device. The condition of the lubricant in each balance wheel is checked from time to time by measuring and comparing the time for the amplitude of the freely oscillating balance wheel to decrease from a given to final value. The friction of the balance wheel is assumed to be proportional to the reciprocal of this time. For the oils available the variation in friction with temperature of a balance wheel, the friction being measured in the same way as in the life test, has been determined in the temperature range from +50° to −50° C. Porpoise-jaw oil had a superior performance.

Reports on aircraft instruments.—A report on measurement of altitude in blind flying was prepared and published as Technical Note No. 503. Considerable progress has been made on a report on aircraft gyroscopic instruments.

Tests and test methods.—A determination of the performance characteristics of aircraft compasses in the temperature range from +50 to −50° C. is in progress.

A new and more accurate method of testing aircraft oxygen regulators than that given in Technical Report No. 130 has been developed. Flow is measured under equilibrium conditions of pressure and temperature by means of a suitable gas meter.

Methods of simply and conveniently testing the thermocouple-type aircraft thermometer have been developed both for laboratory and field use. The field tester enables a check to be made of the accuracy of the indicator and of the operating condition of the leads and thermocouples.

New instruments.—A number of new instruments were developed and constructed. These developments include the following:

An oil-quantity gage has been developed similar in principle to the pneumatic-type fuel-quantity gage commonly used on airplanes.

A vibrometer has been developed and constructed which indicates the double amplitude of vibration in the range from 0.001 to 0.030 inch in the frequency range of about 12 to 40 cycles per second. A well protected plunger follows the vibration against the action of a spring designed so as to give a natural frequency to the system well above 40 cycles per second. The means of indication is novel. The long pointer vibrates in synchronism with the plunger and is seen as two pointers at its extreme positions. The intersection of the pointers in these two positions is read on a suitably graduated dial.

Progress has continued in the development of the venturi fuel-flow meter described in the report for 1933. Difficulty in securing the performance expected upon the basis of theory has been traced to the suction-control diaphragm, the design of which is being modified.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

In connection with the programs of research conducted by the Committee, conferences are held from time to time with representatives of the governmental agencies and of the manufacturers interested, for the interchange of information and ideas and for the discussion of the future programs of investigation. Two special conferences of this nature were held during the past year at the Committee's headquarters in Washington for the consideration of problems of aircraft-engine research.

The first of these, a conference on fuel-injection research, was held on March 30, 1934, and was attended by representatives of the Matériel Division of the Army Air Corps, the Bureau of Aeronautics of the Navy, the Aeronautics Branch of the Department of Commerce, the Bureau of Standards, the National Advisory Committee, and the principal manufacturers interested in the development of fuel-injection engines for aircraft use or of equipment for such engines.

At the request of the Bureau of Aeronautics of the Navy, a special conference on the cowling and cooling of radial air-cooled engines was held on April 20, 1934. At this conference representatives of the military services, of manufacturers of radial air-cooled engines in use in military airplanes, and of this Committee were present.

In addition, two simultaneous conferences on the same two problems were held on May 23 at Langley Field as part of the Committee's Ninth Annual Aircraft Engineering Research Conference.

On all of these occasions the recent results of the Committee's researches were described, and suggestions for future investigations were presented. These suggestions were later given careful consideration by the committee on power plants for aircraft in the preparation of the power-plant research program of the Committee, and in a number of cases the program was modified to include the problems proposed.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

Compression-Ignition Engines.—The range of aircraft flight is dependent to a great extent upon the specific fuel consumption of the aircraft engine. For long-range multiengine bombers having radial air-cooled engines, the fuel load represents 30 to 40 percent of the useful load of the airplane. The compression-ignition engine operates with specific fuel consumption considerably less than that obtained with the conventional aircraft engine. At the present state of development, however, the power output per unit of weight and displacement is considerably less for the compression-ignition engine. The research of the Committee on compression-ignition aircraft engines has been directed toward improvement in the performance. The Committee is investigating the factors influencing the performance of high-speed compression-ignition engines operating on both the four-stroke cycle and the two-stroke cycle. The outstanding result obtained during the past year is the development of a particular design of combustion chamber for the four-stroke-cycle compression-ignition engine that increased the brake horsepower obtained, with no excess air, 18 percent and reduced the specific fuel consumption 15 percent.

Fuel-spray characteristics.—A comparison has been made of the characteristics of fuel sprays from the following types of injection nozzles: Plain round-hole orifice, slit orifice, multiple round-hole orifice, annular orifice, pintle-type nozzle, impinging-jet nozzle, centrifugal stem nozzle, and combination multiple round-hole and slit orifice. The fuel-spray characteristics were obtained by taking high-speed motion pictures of the development of the fuel sprays and by observing the impression made when the spray was injected into plasticine. By means of the two sets of data it was possible to determine just which part of the spray consisted of the core and which part of the envelope. The density of the air into which the fuel was injected was varied from 1 to 14 times the air density under atmospheric conditions. The results have been prepared for publication in the form of a technical report. A discussion is included on the suitability of each type of spray for different combustion requirements, both the compression-ignition and spark-ignition engines being considered.

A research has been started on the distribution of the fuel in the sprays from the nozzles discussed in the preceding paragraph. It is the purpose of the investigation to determine the air-fuel ratio in different parts of the fuel spray so that methods can be evolved for improving the distribution in compression-ignition engines.

Injection-system characteristics.—A research has been conducted on the effect of the dimensions of the injection pump plunger and of fuel viscosity on leakage past the lapped surfaces of an injection system. The results showed that the leakage between a lapped plunger and sleeve varies directly as the density of the liquid, the pressure producing the leakage, the diameter of the plunger, and as the cube of the mean difference between the diameter of the plunger and the diameter of the sleeve. The leakage varies inversely as the length of the lapped fit and the viscosity of the liquid. With a commercial injection system the leakage was found to be between 0.2 and 0.01 percent of the fuel injected provided that the plunger clearance was not greater than 0.0001 inch.

The effect of fuel viscosity on the injection characteristics of a cam-operated fuel pump and an automatic fuel-injection valve has been investigated. The liquids tested varied in viscosity from 0.0042 poise (gasoline) to 3.07 poise (S. A. E. 30 lubricating oil). The results show that if sufficient primary pressure is used to fully charge the injection pump, the effect of the fuel viscosity on the mass rates of discharge is negligible. The results of this investigation have been published as Technical Report No. 477.

An investigation has been completed on the distribution of fuel from the separate cylinders of a six-cylinder cam-operated fuel-injection pump. The results show that the injection pump can be adjusted so that the deviation in distribution for all conditions of load above half load and for all speeds that will be encountered in use will not exceed ±2 percent. At one-tenth load the deviation may reach ±15 percent. The rates of injection on successive cycles can be adjusted so as to show no appreciable variation. When a check valve is employed between the injection tube and the injection pump, however, intermittent injections may occur at very low speeds and light loads. The results of this investigation are being prepared for publication.

Combustion research.—The research on the effect of low air velocities on the distribution of fuel spray after injection cut-off has been completed and the results published as Technical Report No. 483. The data show that in fuel-injection engines that have no effective air movement and in which ignition takes place a considerable time after the end of injection, most of the fuel will tend to penetrate to the side of the chamber away from the injection nozzle and will thus concentrate in one side of the combustion chamber. Consequently, the final mixing of the fuel and air must be accomplished through the vaporization and diffusion of the fuel vapors, through the use of air flow, or both. After spray cut-off, air velocities of 15 or 20 feet per second are effective in aiding the distribution of the fuel. The best spray distribution is obtained by the use of some type of high-dispersion nozzle in conjunction with suitable air flow.

An investigation of the combustion characteristics of fuel sprays suitable for use in compression-ignition engines has been continued with the N. A. C. A. combustion apparatus. The apparatus has been altered so as to auto-ignite the injected fuel under the same operating conditions as experienced in a compression-ignition engine. Motion pictures are now taken of the fuel sprays within the engine at the rate of 2,000 frames per second by means of a commercial high-speed motion-picture camera. The results from an investigation made to determine the effect of engine-jacket temperature, injection advance angle, and engine speed on the combustion showed that the rate and the extent of the combustion depend on the conditions to which the fuel has been subjected during the ignition-lag period as well as the temperature and pressure of the cylinder gases at the time of ignition. The results also show that when the engine is knocking the flame may spread throughout the combustion chamber in less than 0.0005 second. When the combustion starts during the fuel injection the flame starts in one or more places around the cores of the fuel sprays. From these photographic data the conclusion is drawn that the ignition lag in a high-speed compression-ignition engine should be decreased to a value that prevents rough running or knocking of the engine. Any further decrease will not result in any advantages but will result in a decreased combustion efficiency. A 700-foot reel of 16 mm motion pictures showing the flame photographs and the indicator cards has been assembled. The material is being prepared for publication as a technical report.

A spherical constant-volume bomb has been constructed to be used with a fuel-injection system and spark ignition. This bomb will permit an investigation to be made of the separate effects of pressure and temperature on the course of the combustion as indicated by the time-pressure relationship determined with an optical indicator. The variables investigated have included air-fuel ratio, initial pressure and temperature of the air, and the time interval between fuel injection and ignition. The time interval has been varied from 0.004 second to several minutes, the latter representing the homogeneous reaction. The results obtained in the bomb were found to check those obtained with the N. A. C. A. spray-combustion apparatus. In addition, it was found that, whereas with the heterogeneous reactions the time of reaction varied inversely with the air density and the extent of the reaction directly with the air density, with the homogeneous reactions the time of reaction varied directly with the air density and the extent remained almost independent of air density. These results are being prepared for publication.

Technical Note No. 485 has been published describing several methods of measuring the ignition lag in compression-ignition engines.

Preliminary engine tests have indicated that a possible method of reducing the combustion knock of compression-ignition engines is to preheat the fuel oil prior to its injection into the engine cylinder. An injection system has been assembled which permitted the fuel to be heated to a maximum temperature of 750° F. before injection into the engine cylinder. The fuel was maintained in the injection system as a liquid by operating with an injection pressure of 9,000 pounds per square inch. An investigation of the engine performance obtained with this injection system on a compression-ignition engine having a prechamber form of combustion chamber has been completed. Operation with fuel at a temperature of 750° F. gave an appreciable reduction in the combustion knock, a reduction in ignition lag of 30 percent, and slight improvements in indicated power and thermal efficiency. These data are being prepared for publication as a technical report.

Hydrogen as an auxiliary fuel for compression-ignition engines.—The equilibrium of an airship may be maintained during flight by recovering water from the exhaust gases. The water recovered usually varies between 45 and 80 percent of the fuel consumed, depending upon the humidity of the air and the temperature of the exhaust gases leaving the condensers. An investigation of the use of hydrogen as an auxiliary fuel for compression-ignition engines shows that the recovered quantity of water can be materially increased when the hydrogen is burned with the inlet air. In the range of normal cruising operation water vapor is present in the exhaust, weighing approximately 1.5 times as much as the oil fuel consumed, and this ratio can be increased to about 2.5 with the smaller oil-fuel quantities and larger amounts of hydrogen. The results of this investigation are being prepared for publication.

Combustion-chamber investigation—Integral type with air flow.—An increase in the power output per unit of weight and displacement is dependent upon the improvement in the combustion efficiency of high-speed compression-ignition engines. The distribution of the fuel spray within the combustion chamber is an important factor affecting the combustion efficiency. In previous investigations with combustion-chamber forms having no effective air movement the mixing of the fuel and the air has been accomplished by injecting the fuel through properly proportioned and directed multiple orifices. During the past year means have been developed for obtaining better mixing of the fuel and air by creating a high-velocity air flow in the combustion chamber at the time of fuel injection. Engine tests have shown that this air flow is very effective in improving the performance over that obtained with the combustion chamber having no effective air flow. At 1,500 revolutions per minute the engine performance with no excess air has been improved from a brake mean effective pressure of 104 pounds per square inch and a specific fuel consumption of 0.54 pound per brake horsepower per hour to a brake mean effective pressure of 123 pounds per square inch and a corresponding specific fuel consumption of 0.46 pound per brake horsepower per hour.

The overload capacity has been greatly increased by the ability of the combustion chamber to burn richer fuel-air mixtures more efficiently. A technical report giving the details of the combustion chamber and the engine performance is being prepared for publication.

Combustion-chamber investigation—Prechamber type with high-velocity air flow.—In the prechamber, or divided, combustion chamber air is forced at a high velocity through a restricting passage into the prechamber to cause mixing with the injected fuel spray. The ensuing combustion ejects a rich mixture into the cylinder air to complete combustion. The investigation of the characteristics and power-output possibilities of this type of combustion chamber for high-speed compression-ignition aircraft engines will shortly be completed.

By means of engine performance tests the optimum relations of the parts and conditions have been determined. The clearance distribution between cylinder and chamber was varied through a wide range. The air-flow velocity was varied by using a series of connecting-passage areas. Shapes and directions of the connecting passage and shape of the prechamber have been investigated. Various types and locations of fuel sprays have been used in conjunction with the combustion-chamber tests. As a result of these tests an optimum combustion-chamber fuel spray and fuel-spray location have been developed and the performance characteristics definitely determined. The engine performance has been greatly increased by the proper selection of the variables. To complete this entire investigation there remains only the determination of the proper shape for the cylinder clearance so that the air in this part of the combustion chamber may be utilized.

Two-stroke-cycle investigation.—The research on the two-stroke-cycle compression-ignition engine has been continued. Investigations have been conducted to determine the effect of exhaust-stack length and gas-flow area on the performance of the two-stroke-cycle compression-ignition engine. The power output of the engine at low scavenging pressures has been found to be very susceptible to the length of the exhaust stacks. The effect of altering the original cylinder head to give smaller or larger total exhaust gas-flow areas has been to reduce the engine performance, although the less restricted passages allowed an increase in the air consumed by the cylinder at all engine speeds. The effect of exhaust and inlet timing on the power performance will be determined with the cylinder head having the largest exhaust passages. The description of the two-stroke-cycle engine and results of the preliminary engine tests have been published as Technical Report No. 495.

Increase in Engine Power.—Increase in engine speed.—A single-cylinder test engine that will permit extending the range of engine speeds from 2,200 to

3,000 revolutions per minute has been constructed. The bronze bearings supporting the rotating balancing weights on the crankshaft have been replaced by kelmet bearings. The engine has been motored in at speeds up to 3,000 revolutions per minute and found to be particularly free from vibration. The engine will be used to extend the investigation on hydrogenated safety fuels to higher boost pressures and a range of compression ratios from 7.0 to 10.0.

Cowling and Cooling of Aircraft Engines.—Cooling properties of finned surfaces.—The power output of internal-combustion engines is limited by the quantity of waste heat that can be dissipated to the cooling medium. The problem of satisfactorily cooling present-day air-cooled engines has been intensified by the use of N. A. C. A. cowlings, controllable propellers, and high-altitude superchargers. A research to determine the effect of fin width, pitch, and thickness on the quantity of heat dissipated from a finned cylinder mounted in a wind tunnel has been completed and the results presented in Technical Report No. 488. The results are given in the form of surface heat-transfer coefficients. An equation has been developed for calculating the heat dissipated from the cylinders, the experimentally determined surface heat-transfer coefficients being used. The most important factors governing the quantity of heat dissipated from a finned cylinder to an air stream are the average air speed between adjacent fins, and the air speed. The surface heat transfer was found to vary with the 0.80 power of the air speed.

Baffles are used with cowled radial air-cooled engines to limit the quantity of air flowing through the cowling and to insure that the cooling air washes the engine cylinder. The design variables of the shell-type baffle, which is the type in general use, have been investigated with an electrically heated cylinder mounted in a wind tunnel. The results show that for maximum heat dissipation the external opening of the baffle should subtend an angle of 145°, the baffle should fit tightly against the cylinder fins, and the ratio of the exit area to the clear flow area between the fins should be 1.6. This investigation on baffles for air-cooled cylinders has been completed and the results will be published as a technical report.

In order to insure satisfactory engine cooling in full-throttle climb when controllable propellers are used, several aircraft-engine manufacturers are developing blowers for high-output radial air-cooled engines. The Committee has investigated the effect of fin dimensions on the cooling of finned cylinders when the cooling air is supplied by a blower. The results of this investigation showed that the fin pitch was the only dimension that affected the heat-transfer coefficient appreciably and that the power required for cooling varied directly with the fin width. Better cooling could be obtained with the cylinder completely enclosed and the cooling air furnished by a blower than could be obtained with the best baffled cylinder. The results of this investigation are being prepared for publication.

As a part of the research on the factors affecting the performance of N. A. C. A. cowlings being conducted by the Committee, an investigation has been made to determine the minimum quantity of air required for the satisfactory cooling of a completely enclosed air-cooled cylinder when operating at various engine speeds and manifold pressures. At the same time, measurements were made of the pressure drop across the cowling so that the power required for the cooling at each condition could be established. In general, the results of these tests showed that from 2 to 5 percent of the brake horsepower of the engine was required for satisfactory cooling, depending on the operating conditions, and that the pressure drop across the cylinder varied from 5 to 11 inches of water as the quantity of cooling air was increased from 0.9 to 1.3 pounds of air per second. A report of the results of this investigation is now being prepared for publication.

Two-row radial engine.—A report of the results of an investigation conducted at the request of the Bureau of Aeronautics, Navy Department, on a two-row radial engine installed in a service airplane and mounted in the full-scale tunnel has been prepared for publication. The investigation showed that an increase of 50 percent in the brake horsepower by either increasing the engine speed or the manifold pressures resulted in an increase in the temperature difference between the cylinders and the cooling air of approximately 13 to 20 percent. The use of 2- or 3-blade propellers had little effect on the cylinder temperatures at 120 miles per hour, although at 80 miles per hour there was an average reduction of 17° F. with the 3-blade propeller.

Instruments.—Hub dynamometer.—Flight tests have been continued on the hub dynamometer developed by the Committee for measuring the power developed by an aircraft engine in flight. By a careful selection of the steel forgings and by improving the degree of polish on the diaphragms, the life of the diaphragms has been appreciably increased. One set of these diaphragms has been used in flight tests for 19 hours.

Engine indicator.—An improvement has been made in the method of recording pressure-time cards with the modified Farnboro indicator. In the new method a thin white sheet is used for the record paper with a suitable carbonized paper interposed between it and the revolving drum. The high-tension spark deposits the record on the white sheet in the form of a black dot line. These records may be observed before removing them from the drum and can be readily and cheaply reproduced by blueprinting.

Air-speed measuring apparatus.—A method has been developed for measuring the air speed between the closely spaced fins of air-cooled cylinders. The apparatus consists of static and impact tubes of very small diameter connected to precision manometers. The apparatus will be used to determine the velocity distribution in flight over the cylinders of an air-cooled engine fitted with pressure baffles.

NATIONAL BUREAU OF STANDARDS

Phenomena of combustion.—The details of the soap-bubble or constant-pressure method of studying gaseous explosive reactions were investigated at length. Refinements in the apparatus and technique have resulted in a considerable increase in the accuracy of the results which can be obtained by this method. The explosive oxidation of carbon monoxide at constant water-vapor concentration has been investigated over a wide range of mixture ratios. A report on explosions of carbon monoxide and oxygen, which is being prepared for publication by the National Advisory Committee for Aeronautics, will include (*a*) experimental results showing the effect of water vapor on the spatial speed of flame in equivalent mixtures of carbon monoxide and oxygen, (*b*) a detailed description of the improved apparatus and technique for the bubble method, and (*c*) experimental results showing the effect of varying the ratio of carbon monoxide to oxygen upon the speed of flame in space and relative to the active gases, upon expansion ratio, and upon the temperature attained, at constant water-vapor concentration.

Combustion in the engine cylinder.—An investigation of the variations in the intensity and spectral distribution of the energy emitted by the flame during normal and knocking explosions is described in Technical Report No. 486. Since infrared radiation from the flame in an engine appears to be emitted almost exclusively by the final reaction products, water vapor and carbon dioxide, measurements of this kind provide a means of determining the effect of operating conditions upon the depth of the reaction zone behind the flame front or the duration of combustion in a given element of charge. The full significance of the experimental data is obscured at present by lack of fundamental information regarding the effects upon radiation of flame depth, density, temperature, and pressure—much of which could be secured by suitable observations of burner and engine flames, with hydrogen and carbon monoxide used as fuels separately and in known mixtures.

Amospheric temperature versus volumetric efficiency.—Measurements made on a single-cylinder engine with no valve overlap show the weight of air drawn in per cycle to vary inversely with the temperature of the entering air to a power between one-half and one-third when the engine is being motored. No consistent variations with air temperature were found in the pressures at (*a*) the point where the residual was trapped by the closing exhaust valve, or (*b*) the point where the fresh charge was trapped by the closing inlet valve. If pressures at these points are generally independent of atmospheric temperature, it follows that variations in volumetric efficiency with atmospheric temperature must be due solely to the influence of air temperature upon the amount of heating or cooling of the charge during the induction period, i. e., upon the degree of departure from adiabatic conditions.

Investigation of aviation spark plugs.—Possibly the most exacting conditions to be met by aviation spark plugs are presented by supercharged air-cooled engines in airplanes operating at sea from the deck of a carrier, since they must withstand both fouling and preignition. Early in the year an investigation of aviation spark plugs was undertaken under the joint sponsorship of the Society of Automotive Engineers and the Bureau of Aeronautics, Navy Department. Present methods of laboratory testing have been studied and it appears that the spark plugs which make the best showing in a liquid-cooled test engine are not necessarily the most satisfactory for use in air-cooled service engines. The need for supplementary tests and for test conditions of increased severity is recognized. Analysis of the thermal characteristics of aviation spark plugs has led already to the production of experimental plugs which show good resistance to fouling and preignition and have exceptionally low terminal temperatures. A study of the cause and the prevention of lead fouling is contemplated.

Ignition research.—The ignition laboratory has also continued to work on various problems submitted by the Bureau of Aeronautics, Navy Department.

Apparatus for testing aviation magnetos or observing their performance characteristics under a wide range of conditions as regards pressure, temperature, humidity, speed, and load has been developed and put into service. An essential part of the apparatus is a small, cylindrical altitude chamber, provided with steam and ammonia coils for temperature control, in which the magneto is mounted for test. The magneto is driven by a variable-speed motor located outside the chamber and the pressure within the chamber can be reduced to that corresponding to an altitude of 50,000 feet.

Ignition-system temperatures have been measured on the test stand and in flight on a variety of airplanes and it is found that cable temperatures as high as 170° C. may occur in the harness of a shielded ignition system near the spark plug. Efforts are being made to obtain ignition cable insulated with materials which will stand higher temperatures without deterioration, to encourage the development of spark plugs having lower terminal temperatures, and to retard heat flow from the shielded spark plug to the cable.

In order to obtain evidence of chemical changes occurring within the combustion chamber of an engine which may be related to the phenomena of preignition and detonation, photographic records of the progressive variations in engine-absorption spectra for a variety of liquid and gaseous fuels have been made by means of a low-dispersion spectrograph with a film drum driven at precisely one-half crankshaft speed. The principal absorption bands identified on the records obtained are those characteristic of formaldehyde and OH.

Detonation rating of aviation gasolines.—The cooperative aviation fuel program, which involves matching each of three reference fuels with three or four groups of test fuels in representative military and commercial aircraft engines, is about 50 percent completed. The National Bureau of Standards has completed 10 out of 11 comparisons, using a Wasp SD engine (compression ratio 6:1, blower ratio 10:1) made available for this purpose by the Bureau of Aeronautics. The following engines are being used in tests at the manufacturers' plants: Hornet SD (compression ratio 6.5:1, blower ratio 12:1), Lycoming R–680–2 (compression ratio 6.5:1), and Super-Conqueror SV–1570 (compression ratio 6.5:1, blower ratio 10:1). The outstanding indication thus far is the observation that blends containing benzol are rated distinctly lower in the full-scale aircraft engines than in the ASTM–CFR laboratory test, whereas such blends tend to be rated higher in automobile engines than in the laboratory test.

Ice formation in the induction systems of aircraft engines.—The results of the experimental study of ice formation as affected by fuel volatility indicate that the 50-percent ASTM evaporation temperature is the most suitable single index of the ice-forming tendency of a fuel, although this conclusion requires verification by data on additional gasolines. The theoretical formula, relating the volatility of a gasoline to the cooling which will result when it is supplied in any ratio by weight to air of known temperature, pressure, and humidity did not fit the facts observed. This failure to agree was found to be due to the fact that the aqueous vapor in the entering air, instead of condensing at the dew point, became momentarily supercooled and remained so long enough for the vaporization of the gasoline to proceed approximately to equilibrium at the minimum temperature reached. The supercooled vapor then condensed, thereby warming the mixture several centigrade degrees. When the formula was modified to include this process, its agreement with the facts was reasonably good. This formula leads to a theoretical index of ice-forming tendency, namely, the percentage evaporated in equilibrium air distillation at 0° C. from the (given) supplied air-fuel ratio. It also enables the computation of the humidity-temperature region of hazard for any given fuel and engine, and shows the greatest hazard to be operation at high humidities at air temperatures slightly above 0° C.

REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT

SUBCOMMITTEE ON METALS

Weathering of sheet aluminum alloys.—During the past year, a report on "The Weathering of Aluminum Alloy Sheet Materials Used in Aircraft" (Technical Report No. 490) was published. This report summarizes the results obtained in an extended series of exposure tests of alloys of the duralumin type which were available at the time this testing program was started 7 years ago. Changes in the tensile and other properties were determined periodically for materials exposed continuously to the weather at three widely separated locations typical of different climatic conditions, namely, Washington, D. C.; Hampton Roads, Va.; and Coco Solo, C. Z. The results are very reassuring as to the dependability of alloys of this general type for structural use for aircraft purposes as well as for clarifying the causes and remedy for deterioration by the development of intercrystalline brittleness which occasionally occurs.

The current series of outdoor exposure tests which were undertaken for the study of present-day materials developed since the inception of the first test program are beginning to give results upon which tentative conclusions can be based. After 18 months' continuous exposure to the weather aluminum alloys containing magnesium as the chief alloying constituent are still in excellent condition as compared with the companion materials containing copper as an important constituent. Baking aluminum alloys as is necessary in some coating processes is deleterious, as the corrosion-resistance is impaired. Of the processes used to produce a protective surface oxide film, the electrolytic or anodic process is far superior to the rapid "dip" process.

Weathering tests of magnesium alloys.—Exposure tests of 5 years' duration at Washington have been completed on a series of commercial magnesium alloys, and a report is being prepared. Further tests of the more recently developed alloys are under way at two locations, Washington and Coco Solo. A special study has been started of methods of surface treatment for the protection of magnesium alloys against atmospheric corrosion. The permanence in service of all of the light alloys, both aluminum base and magnesium base, is dependent in a large measure on the development of a resistant surface. The development of a highly resistant surface film analogous to that produced on aluminum by the electrolytic oxidation process would be a decided advance in the usefulness of magnesium for structural purposes.

Protection of duralumin, anodic oxidation.—This subject has continued to receive considerable study during the year. A new procedure for using chromic-acid solutions in the production of the surface oxide coating by electrolysis has been developed and perfected. Chemical analysis of electrolytic baths in various stages of their useful life and after being "spent" have been continued. A knowledge of the chromium, aluminum, and iron contents is usually sufficient for the successful operation of the process. A report on this study will soon be available.

Salt-spray test.—This test, in which the materials are exposed in an enclosed space to a "fog" or mist of a salt solution, is now widely used in the testing of light structural alloys, both bare and coated, such as are used in aircraft construction. Although testing engineers are agreed as to the shortcomings of this test, no other test as simple and as useful has yet been suggested. In order to obtain definite information on the causes of the lack of reproducibility in salt-spray testing, a series of tests on duplicate samples of duralumin has been carried out in cooperation with the Naval Aircraft Factory and with manufacturers. The lack of close control of temperature is evidently the most potent variable in causing nonreliable results. A temperature of 30° C. (86° F.) is a very suitable temperature for tests which must be maintained over long periods during which the normal outdoor temperature may vary widely, as from winter to summer.

Propeller materials.—Although no systematic research on structural materials of this kind has been made, numerous specimens have been examined as a result of failures which have occurred. Twelve such cases have been recently studied. Of the 9 aluminum alloy propellers, structural conditions arousing suspicions were found only in 2 which had been rejected by inspectors. In the 7 which failed in service, no evidence of faulty material was disclosed to which the fatigue failure could be attributed. Three welded hollow-steel propellers were examined; structural defects were located in two of them, the third being uncertain.

SUBCOMMITTEE ON AIRCRAFT STRUCTURES

At the suggestion of the Army Air Corps, presented to the National Advisory Committee for Aeronautics by the Bureau of Air Commerce of the Department of Commerce, the Committee held on September 21, 1934, a special conference on standard symbols for use in structural-design calculations in aeronautics, with a view to the establishment of a standard group of symbols for aircraft structural design to be used by all the Government agencies concerned. The conference was attended by representatives of the Matériel Division of the Army Air Corps, the Bureau of Aeronautics of the Navy, the Bureau of Air Commerce, the National Bureau of Standards, and the National Advisory Committee. A list of symbols was agreed upon, and is now being given further consideration by the organizations interested prior to formal recommendation for adoption as standard.

In connection with the investigation of engine and propeller vibration, which has been undertaken with a view to determining the causes of propeller failures, a conference on this problem was held by the Committee on October 1, 1934, and was attended by representatives of the Army and Navy air organizations, the National Bureau of Standards, and this Committee. At this conference the test methods followed by the Army Air Corps at Wright Field to indicate the vibration characteristics of a given aircraft engine, involving the use of the Prescott torsiograph, and the investigation being conducted jointly by the Bureau of Standards and the National Advisory Committee to determine the engine- and propeller-vibration characteristics of a Navy airplane and to develop a method of measuring vibration characteristics and determining their effect, were described. There was general discussion of the relation of resonant vibration to propeller failures, which is not well understood, and of the various methods of testing being followed to indicate dangerous or undesirable vibration characteristics. As a result of the conference, the information so far obtained was made available to all the interested organizations, and the various lines of further study of the problem were coordinated.

Inelastic behavior of duralumin and alloy steels in tension and compression.—The inelastic behavior of a number of steels and aluminum alloys has been studied. Set and the usual stress-strain data in tension have been obtained on a columbium-treated 18–8 steel. These results showed that the stresses corresponding to a given "measured set" were significantly greater than those corresponding to the departure in strain from a straight line passing through the origin and with a slope equivalent to the slope of the stress-strain curve at the origin.

The compressive stress-strain properties of thin sheet and thin-walled structures have been obtained using the "pack method", wherein a number of coupons are cut from the material and placed together like leaves in a book. Buckling of the outer leaves is prevented by a number of steel studs inserted between the specimen and an auxiliary frame. Data have been obtained from portions of wing beams fabricated from 17ST and 24ST aluminum alloys. These results have been found to be more useful in predicting the strength of some beams than those from tensile stress-strain data, as differences have been found between the yield strengths in tension and compression. For one particular specimen of 24ST material the longitudinal compressive yield point was found to be only 45,000 pounds per square inch, while the tensile yield point was 50,000 pounds per square inch. For some 17ST sheet (0.08 inch thick) a divergence of some 10 to 15 percent was found in the compressive yield strength with the direction of rolling, the yield strength in compression being higher at right angles to the direction of rolling than in the direction of rolling, while the reverse was true for the tensile specimens.

End fixation of struts.—The investigation has been continued with heat-treated chromium-molybdenum steel tubing, both round and streamline, and with streamline chromium-molybdenum steel, duralumin, and stainless steel tubing. Apparatus was designed for determining the least radius of gyration of the cross-sectional areas of the streamline tubing by applying known equal and opposite moments at the ends of the tubes and measuring the deflection in a definite gage length.

Difficulty was experienced in obtaining compressive yield points on some of the relatively thin tubing of high strength because of the occurrence of buckling before the stress reached the yield point. This trouble was largely overcome after considerable experimentation by filling the compressive specimens with Wood's metal except for clearance at the ends.

The column tests of the heat-treated chromium-molybdenum steel specimens (tensile strength in the neighborhood of 175,000 pounds per square inch) indicate an extremely efficient material for columns, the P/A, L_o/r curve being representable by a seventh-degree parabola and the Euler curve.

There is no indication that the effect of the shape of the streamline cross section affects the column strength as determined from tests on round tubes. A report on this investigation has been prepared.

Form factors for tubing of duralumin and steel under combined column and beam loads.—The original report on this investigation has been examined and, as a result of this examination, further tests seemed desirable to determine the modulus of rupture in pure bending. Apparatus has been designed for making these tests.

Torsional strength of tubing.—Progress has been made in analyzing the results of torsion tests of 17ST duralumin tubes of various lengths and dimensions which are to be included in the report, together with the results of tests on chromium-molybdenum steel tubes.

Torsion and tension stress-strain curves have been computed for each specimen. These stress-strain curves did not show the same relationship as those obtained for chromium-molybdenum steel tubes. In the steel tubes the tension curves could be reduced approximately to the torsion curves by dividing stresses by $\sqrt{3}$ and multiplying strains by 1.5. A corresponding relationship has not yet been determined for the duralumin tubes, but it is already apparent that the ratio between tensile yield point and torsional yield point is closer to 2 than $\sqrt{3}$. The strengths of the 17ST tubes will therefore have to be described by an empirical formula of a different type from that already derived for the strength of the steel tubes. The data on 17ST tubes are being grouped from various points of view to lead to a formula of suitable type whose coefficients will then be determined by least squares.

The stress-strain curves in shear are in this work derived from the measured moment twist curves under the simplifying assumption that the stress distribution in the tubes is the same as that in a tube with infinitely thin walls. A study was made of error introduced by this assumption. It was found to be less than 1 percent for the thickest tube tested (ratio of wall thickness to diameter, 0.12).

Vibration tests of propellers.—Measurements of stress distribution have been made on an additional number of blades since those reported last year, some set to vibrate with their fundamental mode and others with the second harmonic mode with node near the tip. These measurements, together with some of the older measurements, have been included in a paper which it is expected will be published in the near future.

The paper also contains a résumé of the theoretical work on propeller vibrations. The theoretical stress distribution and frequencies have been calculated for the following ideal conditions of fixity: Blade fixed at center of hub, fundamental mode, and second harmonic mode; blade fixed at point 15 percent of plate length away from center of hub, fundamental mode, second harmonic mode; blade free at hub, fundamental mode. It was found that these extreme variations of fixity conditions—which must include in their range those possible in the case of an actual propeller—have considerable effect on the frequency, but much less on the stress distribution; a variation in natural frequency of the fundamental mode of about 26 percent was found to correspond to a variation in maximum stress of only about 8 percent.

It may be concluded from this that computation, while giving good approximations for the stresses, is not in general a reliable means for determining the natural frequency of a propeller blade and that it is safer to rely on direct measurements of resonant frequencies in sofar as they are obtainable.

A vibration indicator has been developed at the National Bureau of Standards, which was designed to detect torsional vibrations in the shaft of a rotating propeller before these vibrations have reached an amplitude that may lead to failure anywhere in the propeller-shaft system. The device was tested on propellers vibrating without rotation. A series of tests was then made with rotating propellers by mounting the indicator on the propeller hubs of some airplanes at Langley Field. The tests indicate that the vibration of propellers, at least outside the resonance ranges, depends very materially upon engine conditions, vibrations on one airplane being reduced approximately 5 to 1 by the regular 20-hour top overhaul of the engine. Stress measurements made with deForest gages at the same time showed stresses well below the endurance limit of the material. Characteristic differences of the vibrations were found between a fixed-pitch propeller and a variable-pitch propeller. In no case were vibrations found large enough to produce stresses beyond the endurance limit of the material.

The vibration indicator has been repaired several times and has once been thoroughly rebuilt, but it is still not rugged enough to function continuously over long periods of time. A new design is being worked out.

Airship girders and airship structural members—*MC-2*.—Tests have been made on specimens of Alclad sheet 0.009 inch thick cut from the hull of the metalclad airship *MC-2* after 5 years of service. The results of these tests indicate that the corrosion present has not appreciably lowered the strength of the material.

Metallographic examination showed that in general corrosive attack was relatively slight, being confined to small isolated areas and not penetrating the aluminum protective layer.

There exist, however, some larger isolated areas of localized corrosive attack on which the greater part of the protective aluminum coating has disappeared. In its present stage the attack on these limited areas is progressing in the direction of the complete disintegration of the aluminum coating. The attack has penetrated to the base metal in only a relatively few instances. It may be assumed, however, that, should a sufficiently large area of the aluminum coating be completely removed, the tendency will be for the attack to commence penetrating the sheet. The condition of this thin sheet after 5 years of exposure is further evidence of the great efficiency of aluminum coatings in protecting structural aluminum alloys.

U. S. airship *Los Angeles*.—Tensile tests have been made on lattice and channel specimens cut from girders of the U. S. airship *Los Angeles*. Whatever increase in corrosion or change may have taken place since the last sampling is not great enough to be shown by the tests. No sample of channel was as badly corroded as one sample taken in 1927 and no sample of lattice as badly corroded as the one sample taken in 1926. No sample had its tensile strength lowered sufficiently to weaken the girder from which it was taken, in its resistance to axial compression and the side loads it was designed to carry.

U. S. airship *Akron*.—Tensile tests have been made aircraft wire and specimens from portions of the aluminum alloy girders, and compression tests have been made on two fragments of aluminum alloy girders which were salvaged from wreckage of the U. S. airship *Akron*. The tensile tests on the aircraft wire show that the material met specification requirements for maximum load. No specimen cut from the aluminum alloy failed in tension at a stress of less than 63,000 pounds per square inch or an elongation over a 2-inch gage length of less than 7.0 percent.

U. S. airship *Macon*.—A résumé of the results of the compression tests on the *Macon* girders was prepared, the areas as determined by spline measurement being used for the computation of the stresses. The more accurate volumetric measurements have now been obtained and can be used for these computations. Structures of formed sheet metal such as these present a difficult problem in the accurate determination of cross-sectional areas. A study of these volumetric measurements indicates that the cross-sectional areas of these structures can be obtained by this method within 0.5 percent. Comparison of these results with preliminary values of chord-member area obtained from measurements on the girders indicates that the preliminary values of area are high by from 0.5 percent to 9 percent. A report describing the procedure used in determining the cross-sectional areas of these structures is being prepared.

Wire loops.—A number of wire loops and forked bulkhead wires salvaged from the U. S. airship *Akron* have been forwarded to the National Bureau of Standards. While these specimens had been immersed in sea water and consequently were quite badly rusted, there were no definite indications of cracks in the more highly deformed bent portions.

The studies of the stresses in bent wires have been continued. In this connection computations have been made of the residual compressive stresses found in some helices of aircraft wire, based on data obtained by sectioning methods, wherein successive segments of the wire or ground off the extrados of a helix and the change of curvature of the helix noted. While these data are incomplete, so that the results are only tentative, the average residual compressive stress in the first segment ground off (about 0.0066 inch thick) was certainly as high as 100,000 pounds per square inch and probably more nearly 140,000 pounds per square inch.

The computations were carried out on the basis of the Bach-Winkler theory for the bending of curved beams. The correctness of this theory was checked for the case of a curved beam of rectangular section by comparing the stresses computed from it with those computed from the exact theory. Agreement within 0.1 percent was obtained for beams of relative dimensions corresponding to those of the wire loops. The Bach-Winkler theory seems, therefore, an excellent approximation for the stress distribution in such wires.

Flat plates under normal pressure.—The dominant feature of all flat-plate tests carried out at the National Bureau of Standards has been a straight-line relationship between pressure and center deflection at high pressure. An explanation of this effect was sought. The existing literature on flat plates was reviewed carefully and finally it was decided to compare the observed deformation for long plates with that predicted by Boobnoff in his relatively rigorous analysis of the long plate of medium thickness. Charts have been prepared from Boobnoff's analysis to facilitate this comparison. It is hoped that with the extension of the comparison to all long plates tested, a clearer picture will be developed of the behavior of the actual plates due to the combination of bending stresses, median fiber tensile stresses, and shearing stresses at the edges.

Strength of welded joints in tubular members for aircraft.—All of the specimens of the second series of this investigation have been tested, and the data have been computed and are now being plotted in graphs for presentation in the report. About 750 specimens were tested, of which two-thirds were welds; the remainder were specimens of the base metal.

The investigation covers in particular the strength of joints heat-treated after welding. While it was found possible to develop strengths exceeding 200,000 pounds per square inch in heat-treated butt joints made in chromium-molybdenum plate with either chromium-molybdenum welding rod or the "carburizing flux" method, another type of joint, the "cross T" had a maximum strength after heat treatment of only 130,000 pounds per square inch. This joint was composed of two thin-walled tubes having the same axis and welded at right angles to a thick-walled tube. The lower strength probably was due to the sharp change in section.

Joints were also tested in which the tubular members were loaded under bending stresses at the weld. These joints showed a marked increase in strength when heat-treated, as did also the "lattice" joints.

Tests made on joints having thin-walled tubular members of chromium-molybdenum steel of 1.5-inch diameter by 0.020-inch wall showed that it is possible to make satisfactory welds in this material by the "carburizing flux" method. As was expected, T and "lattice" joints made in this thin-walled tubing had lower strengths than joints made in thicker tubing because of their greater susceptibility to local buckling and concentrated stresses.

TEMPORARY SUBCOMMITTEE ON RESEARCH PROGRAM ON MONOCOQUE DESIGN

Stressed-skin, or Monocoque, Structures.— It has been said by some aeronautical authorities that the coming of the high-speed, internally braced monoplane was delayed for a number of years by the lack of a proper type of construction. As the speed of airplanes increases both the strength and stiffness of the structure must be increased. In the modern high-speed airplanes the increased strength and stiffness required in the structure are obtained by the use of stressed-skin construction.

As in the past, the study of monocoque design has continued along fundamental lines so that the results will have lasting value. In thin-metal structures where the results of tests are often widely scattered it is essential to obtain a proper understanding of the phenomena involved in a given problem. Theory alone or tests alone are insufficient—the two must be carried along together.

Torsional stiffnesss of thin shells.—As part of an investigation of the stiffness of stressed-skin structures a report has been prepared presenting a method of estimating the torsional stiffness of thin duralumin shells subjected to large torques (Technical Note No. 500). The method is based on the assumption that the efficiency of the thin covering in resisting deformation decreases linearly with the average stress calculated by the Wagner beam theory. An application of the method to the available tests on box beams and stressed-skin wings shows good agreement with observed stiffnesses.

Strength of thin-walled cylinders.—A report on the strength of thin-walled cylinders in pure bending was published during the past year (Technical Note No. 479). During the coming year it is expected to complete additional reports on the strength of truncated cones and both elliptic and circular cylinders subjected to various bending conditions.

Study of stiffeners.—The study of the Ford test data on the strength of stiffeners mentioned in last year's report has been continued. In these data many types of failure are involved, some of which do not seem to have been treated in previous literature. For example, it seems that primary twisting failure is closely associated with bending failure of the Euler type. Consequently, for a complete understanding of twisting failure in struts with any nonsymmetrical cross section, combined bending and twisting failure should be studied. In stressed-skin structures, failure of open-section stiffeners often occurs by buckling in a plane parallel to the skin, and hence involves both bending and twisting.

Under local failure both critical buckling loads and ultimate loads are considered because in some cases the strength is dependent upon one and in some cases on the other. Since the columns tested by the Ford Company were formed from thin metal, the parts that fail locally may be classed as flat plates and circular arcs. For the flat plates the effect of lightening holes, longitudinal corrugations, and turned edges on outstanding flanges will be discussed in a report now in preparation.

Design of rings.—During the past 3 years several papers on the stress analysis of rings for monocoque fuselages have appeared in American aeronautical literature. In these papers consideration has been given to the special case of either a circular or an elliptic ring of constant cross section. As the greater number of monocoque fuselages actually constructed are probably not mathematically circular or elliptic in shape with rings of constant cross section, the equations derived for shear, axial load, and moment, are not generally applicable. At the suggestion of the Bureau of Aeronautics, Navy Department, a report has therefore been prepared, in which equations applicable to the general case are developed. The application of the general equations presented in the report to practical problems in the stress analysis of rings should make it possible to shorten, simplify, and systematize the calculations for all cases not covered in the previous literature.

SUBCOMMITTEE ON METHODS AND DEVICES FOR TESTING AIRCRAFT MATERIALS AND STRUCTURES

The subcommittee held one meeting during the past year, at which time the possible scope of the subcommittee's work was discussed. It was agreed that unless the work of the subcommittee was greatly restricted there was a wide field in which its activities might extend. It was decided, therefore, to consider only those problems that were especially peculiar to aircraft structures. In this respect the needs as expressed by the members of the subcommittee may be summarized as follows:

(1) An accurate strain gage that can be used to study the strain distribution in aircraft structures. The strain gage should be of the distant-reading type, although a local-recording gage would be satisfactory in some cases.

(2) A brief but clear report that will explain the significance of the properties of materials with particular regard to acceptance testing. At present many tests are required in the acceptance of material that are of doubtful value.

(3) Standardization of certain tests for the time being with methods and devices now available. The drop-testing of landing gears is an example of this need.

(4) A method for disseminating information on methods and devices for testing aircraft materials and structures.

Consideration of the above needs resulted in the following actions: That instrument makers be informed as regards (1); that a paper be prepared regarding (2); and that photographs and brief notes be prepared for circulation by the Committee in an effort to supply need (4). No action was taken regarding (3).

In line with (4) above, a report has been prepared in rough-draft form and circulated to members of the subcommittee. The purpose of this report is to make known the existence of strain gages now built by various manufacturers and to summarize in condensed form pertinent information regarding them.

REPORT OF COMMITTEE ON PROBLEMS OF AIR NAVIGATION

In response to the need for the coordination of scientific research being conducted by a number of different agencies, both within and without the Government, on the problems of air navigation, the National Advisory Committee for Aeronautics established a committee on problems of air navigation, with members representing the principal agencies concerned with the development of aids to air navigation.

In order to cover effectively the large and varied field of research and development on problems of air navigation, the following subcommittees have been organized under the committee on problems of air navigation: subcommittee on instruments and subcommittee on meteorological problems.

PART II

ORGANIZATION AND GENERAL ACTIVITIES

ORGANIZATION

The National Advisory Committee for Aeronautics is composed of 15 members appointed by the President and serving as such without compensation. The law provides that the members shall include 2 representatives each from the War and Navy Departments and 1 each from the Smithsonian Institution, the Weather Bureau, and the Bureau of Standards, together with not more than 8 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.

The first vacancy in the Committee's membership during the past year was caused by the relief on May 31, 1934, of Capt. Arthur B. Cook, United States Navy, on account of his transfer from duty as Assistant Chief of the Bureau of Aeronautics to service with the fleet. Under date of May 31, President Roosevelt appointed Commander Ralph D. Weyerbacher (C. C.), United States Navy, of the Bureau of Aeronautics, a member of the Committee to succeed Captain Cook.

The second vacancy during the year was occasioned by the resignation of Dr. Charles F. Marvin because of his retirement from active duty with the Weather Bureau, of which he had formerly been Chief, upon completion of 50 years of continuous service. Dr. Marvin was one of the original members of the Committee appointed by President Wilson in 1915, and during his membership had rendered faithful and efficient service on a number of subcommittees, of several of which he had been chairman, and had also served with great ability and distinction from time to time as Acting Chairman of the National Advisory Committee and of the executive committee. Dr. Marvin's resignation was transmitted to President Roosevelt on September 22, 1934, and under date of October 10 Mr. Willis Ray Gregg, who succeeded Dr. Marvin as Chief of the Weather Bureau, was appointed to succeed him as a member of the 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. It is the designated depository for scientific and technical data on aeronautics secured from all parts of the world. The material is classified, cataloged, and disseminated.

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

In accordance with act of Congress approved July 2, 1926, as amended by act approved March 3, 1927, the Committee passes upon the merits of aeronautical inventions and designs submitted to any branch of the Government and submits reports thereon to the Aeronautical Patents and Design Board, consisting of Assistant Secretaries of the Departments of War, Navy, and Commerce. 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."

The work of considering aeronautical inventions and designs submitted is under the supervision of the Committee on Aeronautical Inventions and Designs.

ANALYSIS OF AIRCRAFT ACCIDENTS

A standard method for the analysis of aircraft accidents proposed by the committee on aircraft accidents, approved by the executive committee, and published as Technical Report No. 357 has been followed for the past several years by the War, Navy, and Commerce Departments. During this period the practical value of the method has been definitely proved. However, questions of interpretation of some of the definitions have arisen and instances have occurred for which the specified classifications seemed inadequate.

The committee on aircraft accidents, which includes in its membership representatives of the air organizations of the War, Navy, and Commerce Departments, is therefore considering these problems with a view to the adoption of modifications in the analysis method to meet the difficulties, and a subcommittee has been appointed to study the problems in detail and submit recommendations.

The committee on aircraft accidents is also considering the desirability of the further study of the correlation between the physiological and psychological examination of pilots and aircraft accidents. This question is being referred to the medical representatives of the air organizations of the three departments, and their recommendations will be presented to the accidents committee.

COOPERATION WITH THE AIRCRAFT INDUSTRY

In the formulation of the Committee's program of research, provision is made for the inclusion of those problems that are of particular interest and importance to commercial aeronautics. The Committee keeps in continuous touch with the research needs of the aircraft industry, as the problems of the manufacturers are constantly being presented to the Committee in correspondence and through personal contacts and informal conferences, and advantage is taken of every opportunity to obtain the comments and suggestions of the industry in connection with the Committee's 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. During the past year information in this form has been made available to American maufacturers on the investigation of a number of lateral-control and high-lift devices; on the study of wing-nacelle-propeller interference with pusher propeller arrangements, with tandem propeller arrangements, and with a biplane cellule; and on the drag of nonretractable and partly retractable landing gears.

Annual research conference.—Another means of keeping the Committee in touch with the needs of the industry is the annual aircraft engineering research conference held at the Committee's laboratories each May. The purpose of this conference, which was first held in 1926, is 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 to afford them an opportunity to present to the Committee their suggestions for investigations to be included in the Committee's research program.

The Ninth Annual Aircraft Engineering Research Conference was held on May 23, 1934, at the Committee's laboratory at Langley Field, and was presided over by Dr. Joseph S. Ames, Chairman of the Committee. At this conference the Committee was represented by its officers, members of the main Committee, and members of the committees on aerodynamics and power plants for aircraft.

At the morning session 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 representatives of the industry were then conducted on a tour of inspection of the laboratory, and the research equipment was shown in operation.

In the afternoon five simultaneous conferences were held for the discussion of five different subjects, namely, flutter and vibration, high-lift devices and lateral control, compression-ignition engine combustion, seaplanes, and cowling and cooling of air-cooled engines. 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 executive committee has organized a number of standing committees, with subcommittees, for the purpose of supervising its work in their respective fields. The four technical committees on aerodynamics, power plants for aircraft, materials for aircraft, and problems of air navigation, and their subcommittees supervise and direct the aeronautical research conducted by the Advisory Committee and coordinate the investigations conducted by other agencies. Their work has been described in part I.

The organization of the committees and subcommittees under the executive committee is as follows:

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Dr. David W. Taylor, chairman.
Capt. Howard Z. Bogert, United States Army, Matériel Division, Air Corps, Wright Field.
Dr. L. J. Briggs, National Bureau of Standards.
Theophile dePort, Matériel Division, Army Air Corps, Wright Field.
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Dr. H. L. Dryden, National Bureau of Standards.
Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.
Willis Ray Gregg, Weather Bureau.

C. W. Howard, United States Army, Matériel Division, Corps, Wright Field.

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

Comdr. R. D. MacCart (C. C.), United States Navy.

Comdr. Donald Royce (C. C.), United States Navy.

Alfred V. Verville, Bureau of Air Commerce, Department of Commerce.

Hon. Edward P. Warner.

Dr. A. F. Zahm, Division of Aeronautics, Library of Congress.

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

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COMMITTEE ON POWER PLANTS FOR AIRCRAFT

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Dr. H. C. Dickinson, National Bureau of Standards.

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S. K. Colby, Aluminum Co. of America.

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Lt. N. A. Draim (C. C.), United States Navy.

Warren E. Emley, National Bureau of Standards.

Commander Garland Fulton (C. C.), United States Navy.

Dr. H. W. Gillett, Battelle Memorial Institute.

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).

H. S. Rawdon, National Bureau of Standards.

E. C. Smith, Republic Steel Corporation.

G. W. Trayer, Forest Products Laboratory.

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Dr. H. W. Gillett, Battelle Memorial Institute.

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.

Starr Truscott, National Advisory Committee for Aeronautics.

Prof. H. L. Whittemore, National Bureau of Standards.

SUBCOMMITTEE ON AIRCRAFT STRUCTURES

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C. P. Burgess, Bureau of Aeronautics, Navy Department.

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Charles Ward Hall, Hall-Aluminum Aircraft Corporation.

Lt. Lloyd Harrison (C. C.), United States Navy, Naval Aircraft Factory.

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

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TEMPORARY SUBCOMMITTEE ON RESEARCH PROGRAM ON MONOCOQUE DESIGN

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Capt. Howard Z. Bogert, United States Army, Matériel Division, Air Corps, Wright Field.

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Eugene Sibley, Bureau of Air Commerce, Department of Commerce.
Capt. Alfred H. Thiessen, United States Army, Signal Corps, War Department.

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Dr. George W. Lewis, National Advisory Committee for Aeronautics.
W. Fiske Marshall, Bureau of Air Commerce, Department of Commerce.
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Lt. Comdr. J. D. Price, United States Navy.
Capt. Max F. Schneider, United States Army, Air Corps, War Department.
Lt. H. B. Temple, United States Navy.

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COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

Dr. Joseph S. Ames, chairman.
Dr. David W. Taylor, vice chairman.
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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 of important foreign aeronautical articles. The aircraft circulars are mimeographed and contain descriptions of new types of foreign aircraft.

The following are lists of the publications issued:

LIST OF TECHNICAL REPORTS ISSUED DURING THE PAST YEAR

No.

475. Wing Pressure Distribution and Rotor-Blade Motion of an Autogiro as Determined in Flight. By John B. Wheatley, N. A. C. A.
476. Relation of Hydrogen and Methane to Carbon Monoxide in Exhaust Gases from Internal-Combustion Engines. By Harold C. Gerrish and Arthur M. Tessmann, N. A. C. A.
477. Effect of Viscosity on Fuel Leakage between Lapped Plungers and Sleeves and on the Discharge from a Pump-Injection System. By A. M. Rothrock and E. T. Marsh, N. A. C. A.
478. Experimental Verification of the Theory of Wind-Tunnel Boundary Interference. By Theodore Theodorsen and Abe Silverstein, N. A. C. A.
479. Stability of Thin-Walled Tubes under Torsion. By L. H. Donnell, California Institute of Technology.
480. The Aerodynamic Effects of Wing Cut-Outs. By Albert Sherman, N. A. C. A.
481. Working Charts for the Determination of Propeller Thrust at Various Air Speeds. By Edwin Hartman, N. A. C. A.
482. Wing-Fuselage Interference, Tail Buffeting, and Air Flow about the Tail of a Low-Wing Monoplane. By James A. White and Manley J. Hood, N. A. C. A.
483. Effect of Moderate Air Flow on the Distribution of Fuel Sprays after Injection Cut-Off. By A. M. Rothrock and R. C. Spencer, N. A. C. A.
484. A Flight Investigation of the Effect of Mass Distribution and Control Setting on the Spinning of the XN2Y-1 Airplane. By N. F. Scudder, N. A. C. A.
485. The Drag of Airplane Wheels, Wheel Fairings, and Landing Gears—I. By William H. Herrnstein, Jr., and David Biermann, N. A. C. A.
486. Infrared Radiation from Explosions in a Spark-Ignition Engine. By Charles F. Marvin, Jr., Frank R. Caldwell, and Sydney Steele, Bureau of Standards.
487. An Aerodynamic Analysis of the Autogiro Rotor with a Comparison between Calculated and Experimental Results. By John B. Wheatley, N. A. C. A.
488. Heat Transfer from Finned Metal Cylinders in an Air Stream. By Arnold E. Biermann and Benjamin Pinkel, N. A. C. A.
489. Air Conditions Close to the Ground and the Effect on Airplane Landings. By F. L. Thompson, W. C. Peck, and A. P. Beard, N. A. C. A.
490. The Weathering of Aluminum Alloy Sheet Materials Used in Aircraft. By Willard Mutchler, National Bureau of Standards.
491. Vibration Response of Airplane Structures. By T. Theodorsen and A. G. Gelalles, N. A. C. A.
492. Tests of 16 Related Airfoils at High Speeds. By John Stack and Albert E. von Doenhoff, N. A. C. A.
493. The Physical Effects of Detonation in a Closed Cylindrical Chamber. By C. S. Draper, Massachusetts Institute of Technology.
494. A Flight Investigation of the Lateral Control Characteristics of Short Wide Ailerons and Various Spoilers with Different Amounts of Wing Dihedral. By Fred E. Weick, Hartley A. Soulé, and Melvin N. Gough, N. A. C. A.
495. A Description and Test Results of a Spark-Ignition and a Compression-Ignition 2-Stroke-Cycle Engine. By J. A. Spanogle and E. G. Whitney, N. A. C. A.
496. General Theory of Aerodynamic Instability and the Mechanism of Flutter. By Theodore Theodorsen, N. A. C. A.

No.

497. Computation of the Two-Dimensional Flow in a Laminar Boundary Layer. By Hugh L. Dryden, National Bureau of Standards.
498. Improved Airplane Windshields to Provide Vision in Stormy Weather. By William C. Clay, N. A. C. A.
499. Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. XII—Upper-Surface Ailerons on Wings with Split Flaps. By Fred E. Weick and Carl J. Wenzinger, N. A. C. A.
500. The Influence of Tip Shape on the Wing Load Distribution as Determined by Flight Tests. By Richard V. Rhode, N. A. C. A.
501. Relative Loading on Biplane Wings of Unequal Chords. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.
502. Scale Effect on Clark Y Airfoil Characteristics from N. A. C. A. Full-Scale Wind-Tunnel Tests. By Abe Silverstein, N. A. C. A.
503. The Effect of Spray Strips on the Take-Off Performance of a Model of a Flying-Boat Hull. By Starr Truscott, N. A. C. A.
504. On the Theory of Laminar Boundary Layers Involving Separation. By Th. von Karman and C. B. Millikan, California Institute of Technology.
505. Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. IV—Thick Wing—Various Radial-Engine Cowlings—Tandem Propellers. By James G. McHugh, N. A. C. A.
506. Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. V—Clark Y Biplane Cellule—N. A. C. A. Cowled Nacelle—Tractor Propeller. By E. Floyd Valentine, N. A. C. A.
507. Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. VI—Wings and Nacelles with Pusher Propeller. By Donald H. Wood and Carlton Bioletti, N. A. C. A.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

No.

473. Tank Tests of Two Floats for High-Speed Seaplanes. By Joe W. Bell, N. A. C. A.
474. Effect of Stabilizer Location upon Pitching and Yawing Moments in Spins as Shown by Tests with the Spinning Balance. By M. J. Bamber and C. H. Zimmerman, N. A. C. A.
475. The Effect of Split Trailing-Edge Wing Flaps on the Aerodynamic Characteristics of a Parasol Monoplane. By Rudolf N. Wallace, N. A. C. A.
476. The Effect on Engine Performance of Change in Jacket-Water Outlet Temperature. By E. A. Garlock and Greer Ellis, National Bureau of Standards.
477. Aerodynamic Tests of a Low Aspect Ratio Tapered Wing with an Auxiliary Airfoil for Use on Tailless Airplanes. By Robert Sanders, N. A. C. A.
478. The Effect of Slots and Flaps on Lateral Control of a Low-Wing Monoplane as Determined in Flight. By Hartley A. Soulé and J. W. Wetmore, N. A. C. A.
479. Strength Tests of Thin-Walled Duralumin Cylinders in Pure Bending. By Eugene E. Lundquist, N. A. C. A.
480. The Drag of Streamline Wires. By Eastman N. Jacobs, N. A. C. A.
481. The Reduction in Drag of a Forward-Sloping Windshield. By Eastman N. Jacobs, N. A. C. A.
482. The Effect of Spray Strips on a Model of the P3M-1 Flying-Boat Hull. By John R. Dawson, N. A. C. A.

No.

483. Charts for Determining the Pitching Moment of Tapered Wings with Sweepback and Twist. By Raymond F. Anderson, N. A. C. A.
484. A Method of Calculating the Performance of Controllable Propellers with Sample Computations. By Edwin P. Hartman, N. A. C. A.
485. A Comparison of Several Methods of Measuring Ignition Lag in a Compression-Ignition Engine. By J. A. Spanogle, N. A. C. A.
486. The Effect of Trim Angle on the Take-off Performance of a Flying Boat. By James M. Shoemaker and John R. Dawson, N. A. C. A.
487. Tests of Three Tapered Airfoils Based on the N. A. C. A. 2200, the N. A. C. A.-M6, and the Clark Y Sections. By Raymond F. Anderson, N. A. C. A.
488. A Complete Tank Test of a Flying-Boat Hull with a Pointed Step—N. A. C. A. Model No. 22. By James M. Shoemaker, N. A. C. A.
489. Aerodynamic Characteristics of Anemometer Cups. By M. J. Brevoort and U. T. Joyner, N. A. C. A.
490. Tank Tests of Auxiliary Vanes as a Substitute for Planing Area. By John B. Parkinson, N. A. C. A.
491. Tank Tests of a Family of Flying-Boat Hulls. By James M. Shoemaker and John B. Parkinson, N. A. C. A.
492. The Aerodynamic Analysis of the Gyroplane Rotating-Wing System. By John B. Wheatley, N. A. C. A.
493. Aerodynamic Rolling and Yawing Moments Produced by Floating Wing-Tip Ailerons, as Measured by the Spinning Balance. By Millard J. Bamber, N. A. C. A.
494. Hazards to Aircraft Due to Electrical Phenomena. Report of Special Committee on Hazards to Aircraft Due to Electrical Phenomena.
495. Effect of the Surface Condition of a Wing on the Aerodynamic Characteristics of an Airplane. By S. J. DeFrance, N. A. C. A.
496. A Preliminary Motion-Picture Study of Combustion in a Compression-Ignition Engine. By E. C. Buckley and C. D. Waldron, N. A. C. A.
497. Full-Scale Drag Tests of Landing Lamps. By C. H. Dearborn, N. A. C. A.
498. Wind-Tunnel Measurements of Air Loads on Split Flaps. By Carl J. Wenzinger, N. A. C. A.
499. Effect of Retractable-Spoiler Location on Rolling- and Yawing-Moment Coefficients. By J. A. Shortal, N. A. C. A.
500. The Torsional Stiffness of Thin Duralumin Shells Subjected to Large Torques. By Paul Kuhn, N. A. C. A.
501. Landing-Shock Recorder. By M. J. Brevoort, N. A. C. A.
502. Aerodynamic Investigation of a Cup Anemometer. By John D. Hubbard and George P. Brescoll, N. A. C. A.
503. Measurement of Altitude in Blind Flying. By W. G. Brombacher, National Bureau of Standards.
504. Complete Tank Tests of Two Flying-Boat Hulls with Pointed Steps—N. A. C. A. Models 22–A and 35. By James M. Shoemaker and Joe W. Bell, N. A. C. A.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

No.

724. The 1933 Contest for the Deutsch de la Meurthe Trophy. Airplanes Participating in the Contest. By Pierre Léglise. Engines Used on the Airplanes. By L. Hirschauer. Lessons Learned from the Contest. By Raymond Saladin. From L'Aéronautique, July and August 1933; l'Aérophile, June 1933; and La Nature, August 1933.
725. Development of Air-Cooled Engines with Blower Cooling. By Kurt Löhner. From Automobiltechnische Zeitschrift, July 25, and August 10, 1933.
726. Attaining a Steady Air Stream in Wind Tunnels. By L. Prandtl. From Handbuch der Experimentalphysik, vol. IV, part II, 1932.
727. The Theory of the Strandgren Cyclogiro. By C. B. Strandgren. From l'Aérophile, July 1933.
728. Aerodynamic Forces and Moments of a Seaplane on the Water. By M. Kohler. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, August 28, 1933.
729. The Flight of an Autogiro at High Speed. By J. A. J. Bennett. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, September 14, 1933.
730. Practical Experiences with Lightning Discharges to Airplanes. By Heinrich Koppe. From Zeitschrift für Flugtechnik and Motorluftschiffahrt, November 4, 1933.
731. Trend of Airplane Flight Characteristics. By Joachim von Köppen. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, September 28, 1933.
732. Evaluation of Scavenging in Two-Stroke-Cycle Engines. By Herbert J. Venediger. From Automobiltechnische Zeitschrift, June 25, 1933.
733. Aerodynamic Principles of the Direct Lifting Propeller. By Martin Schrenk. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, August 14, August 28, and September 14, 1933.
734. The Small Wind Tunnel of the DVL. By Friedrich Seewald. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, October 28, 1933.
735. The High-Speed Tank of the Hamburg Shipbuilding Company. By G. Kempf and W. Sottorf. From Werft-Reederei-Hafen, June 1, 1931.
736. Effect of Fuselage and Engine Nacelles on Some Aerodynamic Properties of an Airplane Wing. By Joan Vladea. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, October 28, 1933.
737. Conversion of Energy in Cross-Sectional Divergences under Different Conditions of Inflow. By H. Peters. From Ingenieur-Archiv, March 1931.
738. Investigation of a Rateau Supercharger for a 700-Horsepower Airplane Engine. By Hermann Oestrich. From Automobiltechnische Zeitschrift, August 25, 1933.
739. Experiments with Planing Surfaces. By W. Sottorf. From Werft-Reederei-Hafen, October 1, 1932; February 15 and March 1, 1933.
740. The Development of Floats and Equipment for Research in Promoting It. By Wilhelm Pabst. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, December 14, 1932.
741. The Calculation of Lateral Stability with Free Controls. By Gotthold Mathias. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, April 14 and April 28, 1932.
742. Supplemental Data and Calculations of the Lateral Stability of Airplanes. By Gotthold Mathias. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, October 14 and October 28, 1933.
743. Fatigue Strength of Airplane and Engine Materials. By Kurt Matthaes. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, November 4 and November 28, 1933
744. Torsional Stresses in Box Beams with Cross Sections Partially Restrained against Warping. By Hans Ebner. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, December 14 and December 28, 1933.
745. High-Speed Aircraft. By M. Schrenk. From Zeitschrift des Vereines deutscher Ingenieure, January 13, 1934.

No.

746. The High-Speed Heinkel He 70 Mail Airplane. By Ernst Heinkel. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, December 28, 1933.
747. Analysis of Spinning in a Monoplane Wing by the Induction Method as Compared with the Strip Method. By L. Poggi. From L'Aerotecnica, October 1933.
748. Impact Buckling of Thin Bars in the Elastic Range Hinged at Both Ends. By Carel Koning and Josef Taub. From Luftfahrtforschung, July 6, 1933.
749. Impact Buckling of Thin Bars in the Elastic Range for Any End Condition. By Josef Taub. From Luftfahrtforschung, July 6, 1933.
750. Influence of Cut-Outs in Elevator on the Static Longitudinal Stability and on the Static Elevator Effect. By Curt Biechteler. From Luftfahrtforschung, May 15, 1934.
751. Investigation of Boundary Layers on an Airplane Wing in Free Flight. By J. Stüper. From Luftfahrtforschung, May 15, 1934.
752. Additional Test Data on Static Longitudinal Stability. By Walter Hübner. From Luftfahrtforschung, May 15, 1934.
753. Stipa Monoplane with Venturi Fuselage. By Luigi Stipa. From Rivista Aeronautica, July 1933.
754. Contribution to the Mutual Interference of Wing and Propeller. By C. Wieselsberger. From Abhandlungen aus dem Aerodynamischen Institut an der Technischen Hochschule Aachen, No. 13, 1933.

LIST OF AIRCRAFT CIRCULARS ISSUED DURING THE PAST YEAR

No.

184. The Comper "Mouse" Commercial Airplane (British). A Three-Seat Cabin Low-Wing Monoplane. From The Aeroplane, September 27, 1933, and Flight, September 28, 1933.
185. The Dewoitine D.332 Commercial Airplane (French). A Three-Engine All-Metal Low-Wing Monoplane. By Maurice Victor. From Les Ailes, September 7, 1933, and L'Aéronautique, October 1933.
186. The D.H.85 "Leopard Moth" Airplane (British). A Three-Seat Cabin High-Wing Monoplane. From The Aeroplane, November 1, 1933.
187. Fokker F.XX Commercial Airplane (Dutch). A High-Wing Cantilever Monoplane. From Fokker Bulletin Nos. 5–6, 1933.
188. The Avia 51 Commercial Airplane (Czechoslovakian). A Cantilever High-Wing Monoplane. From Flight, January 18, 1934.
189. D.H.86 "Express Air Liner" (British). A Four-Engine Biplane. From Flight, February 22, 1934.
190. The Short "Scylla" Commercial Airplane (British). An All-Metal Biplane. From Flight, April 5, 1934.
191. Avro 642 Commercial Airplane (British). A High-Wing Cantilever Monoplane. From Flight, April 5, 1934.
192. The Bernard 82 Military Airplane (French). A Long-Range Monoplane. From L'Aéronautique, March 1934.
193. The Avro "Commodore" Touring Airplane (British). A Cabin Biplane. From Flight, May 31, 1934.
194. The Comper "Streak" Single-Seat Airplane (British). A Low-Wing Cantilever Monoplane. From Flight, April 19, 1934.
195. The British Klemm "Eagle" Commercial Airplane. A Low-Wing Cantilever Monoplane. From The Aeroplane, July 25, 1934.
196. Avro C.30 Direct-Control Autogiro (British). By C. N. Colson. From Flight, August 2 and August 9, 1934.

FINANCIAL REPORT

The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1934, as carried in the Independent Offices Appropriation Act approved June 16, 1933, was $676,000, with provision for payment of compensation to employees upon a basis of 85 percent. The Independent Offices Appropriation Act approved March 28, 1934, provided for a restoration of 5 percent compensation deductions, effective February 1, 1934. The amount expended by this Committee for that purpose was $14,250, making the total amount available for expenditure during the fiscal year 1934, $690,250. The amount expended was $690,240, itemized as follows:

Personal services	$581,846
Supplies and materials	27,690
Communication service	2,221
Travel expenses	10,324
Transportation of things	1,375
Furnishing of electricity	24,139
Rent of office (Paris)	240
Repairs and alterations	7,134
Special investigations and reports	14,141
Equipment	21,130
Expenditures	690,240
Unobligated balance	10
Total, general appropriation	690,250

The appropriation for printing and binding for 1934 was $19,000, of which $18,692 was expended. A saving of $300 out of this appropriation was effected at the request of the Bureau of the Budget.

The sum of $1,145.94 was collected by this Committee during the fiscal year 1934, for scientific services furnished private parties, and this amount was deposited in the Treasury to the credit of Miscellaneous Receipts.

The appropriations for the current fiscal year 1935 are $707,792 for general expenses and $18,700 for printing and binding. The amount estimated as necessary to carry out the provisions of the Independent Offices Act for a further restoration of 5 percent compensation deductions, effective July 1, 1934, is $33,194, making the total amount available for general expenses for the fiscal year 1935, $740,986.

In the preceding annual report the Committee reported the receipt of allotments from the Public Works Administration of $200,000 for needed items of construction and repair at its laboratories at Langley Field, Va., and $47,944 to repair damages caused by the severe storm of August 23, 1933. Of the total allotments thus received of $247,944, the sum of $247,294.18 has been expended, leaving an unexpended balance of $649.82.

On July 17, 1934, the Public Works Administration allotted to this Committee $478,300 for the construction at Langley Field of a full-speed wind tunnel for the testing of models at speeds up to 500 miles per hour. Contracts have been let for work on this project and it is expected that it will be ready for use by the fall of 1935.

CONCLUSION

In closing this, its Twentieth Annual Report to the Congress, the Committee wishes to express its appreciation of the liberal support that has been uniformly accorded its work in the fields of pure and of applied research in aeronautics by the Congress of the United States. This Committee is proud of the part it has thus been enabled to play in helping to make possible the remarkable progress in American aviation. It is keenly aware of the research needs of aviation and of its responsibilities in this field. Additional new research equipment which will be in full operation during the coming year will enlarge this Committee's capacity to provide the War, Navy, and Commerce Departments, and the aircraft industry, with the new knowledge that is so necessary to continued progress in the development of aeronautics.

This Committee is convinced that its present status as an independent Government establishment has been largely responsible for its success; that its activities are a fundamental factor underlying improved performance, efficiency, and safety of American aircraft; that it is chiefly through continued support of organized scientific research that continued rapid progress can be achieved; and that, in the last analysis, its work offers the best assurance of keeping America in the forefront of progressive nations in the development of aviation, and of eventually placing commercial aviation in America upon a sound economic basis.

Respectfully submitted.

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