AERONAUTICS

EIGHTEENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1932

INCLUDING TECHNICAL REPORTS
NOS. 401 TO 440

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1933

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - Price $2.50 (Buckram)

LETTER OF SUBMITTAL

To the Congress of the United States:

In compliance with the act of March 3, 1915, which established the National Advisory Committee for Aeronautics, I submit herewith the eighteenth annual report of the committee for the fiscal year ended June 30, 1932.

It is noted that the committee reports material and gratifying improvements in aircraft performance and reliability, and that the steady advances in technical development have increased the relative importance of aviation as an arm of national defense and as an agency of transportation.

In the new phase of the industrial age upon which the country is entering, substantial achievements will rest largely on the stimulation given to scientific research. The remarkable progress of aeronautics since the war is a demonstration of the value and necessity of research.

The National Advisory Committee for Aeronautics is the governmental agency for coordinating and conducting fundamental research in aeronautics. I concur in the committee's opinion that America should keep at least abreast of other nations in the development of aviation and believe that the best way to assure this is to provide for the continuous prosecution of organized scientific research.

HERBERT HOOVER.

THE WHITE HOUSE,
December 8, 1932.

LETTER OF TRANSMITTAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., November 25, 1932.

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 Eighteenth Annual Report of the National Advisory Committee for Aeronautics for the fiscal year ended June 30, 1932.

Technical progress as a result of scientific research in the field of aeronautical development during the past year has been most gratifying. Scientific data resulting from well-planned and coordinated research have found application in the improvement of both military and commercial types of aircraft.

The committee, in coordinating its research programs, has covered the problems in the whole field of aircraft research, both military and commercial, and has placed special emphasis on the major problems of increased safety, reliability, and efficiency of aircraft. The placing in operation of the new full-scale wind tunnel and the new N. A. C. A. tank has made it possible to undertake problems which will have a very important bearing on future aeronautical development. The use of these new pieces of equipment in conjunction with the other excellent facilities of the committee's laboratories makes it possible for the committee to carry out research programs which cover the needs of both military and commercial aviation and assure continued progress.

Attention is invited to Part IV of the report, presenting a summary of technical developments in aeronautics accomplished under the committee's direction during the past year.

Respectfully submitted.

JOSEPH S. AMES, *Chairman.*

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

CONTENTS

TECHNICAL REPORTS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

3841 NAVY BUILDING, WASHINGTON, D. C.

JOSEPH S. AMES, Ph. D., *Chairman*,
President, Johns Hopkins University, Baltimore, Md.
DAVID W. TAYLOR, D. Eng., *Vice Chairman*,
Washington, D. C.
CHARLES G. ABBOT, Sc. D.,
Secretary, Smithsonian Institution, Washington, D. C.
ARTHUR B. COOK, Captain, United States Navy,
Assistant Chief, Bureau of Aeronautics, Navy Department, Washington, D. C.
WILLIAM F. DURAND, Ph. D.,
Professor Emeritus of Mechanical Engineering, Stanford University, California.
BENJAMIN D. FOULOIS, Major General, United States Army,
Chief of Air Corps, War Department, Washington, D. C.
HARRY F. GUGGENHEIM, M. A.,
The American Ambassador, Habana, Cuba.
CHARLES A. LINDBERGH, LL. D.
New York City.
WILLIAM P. MACCRACKEN, Jr., Ph. B.,
Washington, D. C.
CHARLES F. MARVIN, Sc. D.,
Chief, United States Weather Bureau, Washington, D. C.
WILLIAM A. MOFFETT, Rear Admiral, United States Navy,
Chief, Bureau of Aeronautics, Navy Department, Washington, D. C.
HENRY C. PRATT, Brigadier General, United States Army,
Chief, Matériel Division, Air Corps, Wright Field, Dayton, Ohio.
EDWARD P. WARNER, M. S.,
Editor, AVIATION, New York City.
ORVILLE WRIGHT, Sc. D.,
Dayton, Ohio.
——— ———,
Bureau of Standards, Washington, D. C.

GEORGE W. LEWIS, *Director of Aeronautical Research*
JOHN F. VICTORY, *Secretary*
HENRY J. E. REID, *Engineer-in-Charge, Langley Memorial Aeronautical Laboratory, Langley Field, Va.*
JOHN J. IDE, *Technical Assistant in Europe, Paris, France*

THE EXECUTIVE COMMITTEE

JOSEPH S. AMES, *Chairman*
DAVID W. TAYLOR, *Vice Chairman*

CHARLES G. ABBOT.
ARTHUR B. COOK.
BENJAMIN D. FOULOIS.
CHARLES A. LINDBERGH.
WILLIAM P. MACCRACKEN.
CHARLES F. MARVIN.
WILLIAM A. MOFFETT.
HENRY C. PRATT.
EDWARD P. WARNER.
ORVILLE WRIGHT.

JOHN F. VICTORY, *Secretary*

EIGHTEENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 10, 1932.*

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 eighteenth annual report for the fiscal year 1932.

Gratifying progress.—The committee is pleased to report that gratifying improvement has been continued during the past year in the performance and reliability of airplanes. This is equally true for military and commercial types. This has been due to organized scientific research conducted by the committee and to the practical application of the results by the Army, the Navy, and the aircraft industry.

Importance of speed.—Speed is the most important single factor in increasing the relative value of aircraft for national defense and in extending their use for commercial purposes. During the past year the speed of military bombers was increased to a rate greater than that of pursuit-type airplanes of two years ago, and the normal cruising speed of large commercial air transports was increased 20–40 per cent. This notable advance was made possible primarily by improvements in aerodynamic efficiency resulting in large measure from researches conducted by the committee, including especially investigations of the cowling of engines and the determination of the best positions of engines with reference to the wings of multi-engine airplanes. An important factor in this advance was the development of more efficient and reliable engines sponsored by the Army and Navy. This advance in speed, coupled with the development of reliable schedules of passenger and express service at reasonable rates, is making air transportation more attractive to the public and enabling it to make progress toward a self-sustaining status. Notwithstanding the difficulties of the period, air passenger and express transportation have materially increased during the past year.

Facilities for fundamental research.—With the far-sighted support of the Congress the committee's laboratory, known as the Langley Memorial Aeronautical Laboratory and located at Langley Field, Va., has become unsurpassed in the development of original and ingenious equipment and methods for fundamental research. The development of this laboratory represents an accomplishment in which the Congress and the country can take pride, for the excellence of its product has gained for the United States an advantageous position among nations in the development of aeronautics.

Comprehensive researches serve all needs.—The facilities of the committee's laboratory are used largely for the conduct of researches requested by the Army and Navy air organizations, which depend upon the committee for the investigation and study of fundamental problems to enable them to improve the design of military and naval aircraft to meet their particular needs. The aircraft manufacturers and operators also rely upon the committee for fundamental data, and the committee frequently broadens its researches to obtain as much fundamental information as possible in order to meet the needs of commercial aviation. To determine these needs the committee holds at its laboratory an annual conference with representatives of the aircraft industry. As a result the research programs of the committee, formulated largely by the various technical subcommittees, are comprehensive in scope and embrace the problems deemed necessary for the further improvement of military, naval, commercial, and civil airplanes and also airships.

Coordination increases value of research.—The research needs of aviation are thus effectively determined in cooperation with the Army, the Navy, and the aircraft industry. This policy and practice of coördinated planning of fundamental research and its continuous and orderly prosecution under the single and direct control of the committee assure results of the greatest value to aeronautics, and at the same time prevent duplication and waste.

Special attention to safety.—The committee is devoting special attention to investigations of various possible means of obtaining greater control of an airplane at low speeds incident to taking off and landing, with a view to increasing safety and reliability, and in this connection is also investigating the possibilities of several autorotative-wing types of aircraft.

The committee's new full-scale wind tunnel and towing tank for seaplane models have been developed into indispensable items of research equipment, permitting full-scale research hitherto not possible.

Transoceanic air transport.—The development of air transport service to South America is considered a helpful factor in promoting foreign trade. Such service, involving long over-water flights, will require the development of more efficient large seaplanes. The new N. A. C. A. tank for the testing of models of seaplane floats and flying-boat hulls will provide much-needed information. For trans-Atlantic air transport service to Europe, greater cruising range and carrying capacity are required than can be efficiently provided in heavier-than-air craft at the present stage of aeronautical development. Rigid airships at this time offer a prospect for air passenger service to Europe. They are already being used by a European nation in providing regular air passenger service across the South Atlantic. The Congress has done much to establish a rigid-airship industry in this country by appropriations for the construction of the naval airships *Akron* and *Macon*. The Navy's experience with lighter-than-air craft has provided valuable information and data for commercial airship development and operation. The committee believes that the United States should continue to encourage the development and use of rigid airships as a means of ocean transportation.

Continue research to keep abreast.—Because of its increasing importance for both military and commercial purposes it is essential that America strive constantly to keep at least abreast of other nations in the rapidly developing science of aeronautics. With the present disturbed conditions in the world it is vitally necessary to continue aeronautical research, experimentation, and development for the national defense. To fall behind would not only endanger our security but would retard definitely the progress of civilization.

Factors in increased importance of aircraft.—Since the Great War gave to the world indications of the possibilities of aircraft, the material improvement from year to year in their performance and reliability has greatly increased their relative importance for national defense and also as an agency of transportation. The scientific researches conducted by the committee have been the chief factor contributing to the technical development of aircraft. Other important factors in the general development of aviation have been: (*a*) The engineering and experimentation activities of the Army and Navy in the development of efficient military aircraft and aircraft matériel; (*b*) the regulation and encouragement of civil and commercial aviation by the Aeronautics Branch of the Department of Commerce, including especially the establishment and maintenance of airways and aids to air navigation unsurpassed in any country; (*c*) the effective assistance of the Weather Bureau in the field of meteorology and special weather report service in aid of air navigation; and (*d*) the policy of the Congress in enabling the Post Office Department to supply air mail service to all parts of the country, and, through contracts for the carriage of air mail, to give that indispensable support that has made possible the development of air passenger transportation in the United States.

Effect of sound governmental policy.—The present advanced state of aeronautical development in America is largely the result of long-continued sound governmental policy that began with the act of Congress in 1915 when in establishing the National Advisory Committee for Aeronautics "to supervise and direct the scientific study of the problems of flight," the Congress laid the foundation for rapid and continuous progress in this new science. A part of recent governmental policy has been the maintenance of a nucleus of an aircraft industry capable of satisfactory expansion ot meet needs in an emergency. The volume of commercial sales of aircraft has been severely checked during the past three years, with the result that the Government is still the chief customer of the aircraft industry. With the completion of the 5-year aircraft procurement programs of the Army and Navy, a further legislative declaration of policy is necessary under present conditions to afford sufficient stability to maintain a satisfactory nucleus of an aircraft industry.

Research pays.—Although technical progress in the development of aircraft has been gratifying for a number of years, there is yet an urgent need for greater safety and greater economy. The major problems are to increase the aerodynamic efficiency of aircraft, the horsepower and operating efficiency of engines, and the control of airplanes at low speeds. The committee, in the exercise of its prescribed function under the law is investigating these and many other important problems which underlie progress in aeronautics. The committee's work not only leads directly to greater safety, efficiency, and reliability of aircraft, but its researches yield results annually of economic value alone in excess of the cost thereof.

In submitting this, its eighteenth annual report, the committee invites attention to Part II presenting reports of activities of the various technical subcommittees, and also to Part IV presenting a summary of technical development in aeronautics accomplished under the committee's direction during the past year.

PART I

ORGANIZATION AND GENERAL ACTIVITIES

FUNCTIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 151). The organic act charged the committee with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, the determination of problems which should be experimentally attacked, and their investigation and application to practical questions of aeronautics. The act also authorized the committee to direct and conduct research and experimentation in aeronautics in such laboratory or laboratories, in whole or in part, as might be placed under its direction.

Supplementing the prescribed duties of the committee under its organic act, its broad general functions may be stated as follows:

First. Under the law the committee holds itself at the service of any department or agency of the Government interested in aeronautics for the furnishing of information or assistance in regard to scientific or technical matters relating to aeronautics, and in particular for the investigation and study of fundamental problems submitted by the War, Navy, and Commerce Departments with a view to their practical solution.

Second. The committee may also exercise its functions for any individual, firm, association, or corporation within the United States, provided that such individual, firm, association, or corporation defray the actual cost involved.

Third. The committee institutes research, investigation, and study of problems which, in the judgment of its members or of the members of its various subcommittees, are needful and timely for the advance of the science and art of aeronautics in its various branches.

Fourth. The committee keeps itself advised of the progress made in research and experimental work in aeronautics in all parts of the world.

Fifth. The information thus gathered is brought to the attention of the various subcommittees for consideration in connection with the preparation of programs for research and experimental work in this country. This information is also made available promptly to the military and naval air organizations and other branches of the Government and such as is not confidential is immediately released to university laboratories and aircraft manufacturers interested in the study of specific problems, and also to the public.

Sixth. The committee holds itself at the service of the President, the Congress, and the executive departments of the Government for the consideration of special problems which may be referred to it.

The act of Congress approved July 2, 1926, and amended March 3, 1927 (U. S. C., Supp. V, title 10, sec. 310r), which created and specified the functions of an aeronautical patents and design board, consisting of an Assistant Secretary of War, an Assistant Secretary of the Navy, and an Assistant Secretary of Commerce, provided that upon favorable recommendation of the National Advisory Committee for Aeronautics the patents and design board should determine questions as to the use and value to the Government of aeronautical inventions submitted to any branch of the Government. The legislation provided that designs submitted to the board should be referred to the National Advisory Committee for Aeronautics for its recommendation, and this has served to impose upon the committee the additional duty of considering on behalf of the Government all aeronautical inventions and designs submitted.

ORGANIZATION

The act of Congress establishing the committee, as amended by act approved March 2, 1929 (U. S. C., Supp. V, title 50, sec. 151a), provides that the National Advisory Committee for Aeronautics shall consist of 15 members appointed by the President, as follows: Two members from the War Department, from the office in charge of military aeronautics; two members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, the United States Weather Bureau, and the United States Bureau of Standards; and not more than eight additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences. The law further provides that all members as such shall serve without compensation.

On December 19, 1931, Maj. Gen. James E. Fechet, United States Army, was relieved from membership on the committee because of his retirement from active duty in the Army and as Chief of the Air Corps. Under date of January 5, 1932, Maj. Gen. Benjamin D.

Foulois, United States Army, General Fechet's successor as Chief of the Air Corps, was appointed by the President to succeed him on the committee.

On July 2, 1932, the committee lost one of its most valuable and devoted members in the death of Dr. George K. Burgess, Director of the Bureau of Standards. Doctor Burgess was appointed to membership by the President on May 26, 1923, and was for nine years chairman of the important subcommittee on materials for aircraft and for five years chairman of the subcommittee on metals. He also served as chairman of the committee on aircraft accidents from its organization in 1928 until his resignation from the chairmanship in 1931. Doctor Burgess' successor on the committee has not yet been appointed.

The entire committee meets twice a year, the annual meeting being held in October and the semiannual meeting in April. The present report includes the activities of the committee between the annual meeting held on October 22, 1931, and that held on October 20, 1932.

The present organization of the committee is as follows:

- Joseph S. Ames, Ph. D., chairman, president of Johns Hopkins University, Baltimore, Md.
- David W. Taylor, D. Eng., vice chairman, Washington, D. C.
- Charles G. Abbot, Sc. D., secretary of the Smithsonian Institution.
- Capt. Arthur B. Cook, United States Navy, Assistant Chief of the Bureau of Aeronautics, Navy Department.
- William F. Durand, Ph. D., professor emeritus of mechanical engineering, Stanford University, California.
- Maj. Gen. Benjamin D. Foulois, United States Army, Chief of the Air Corps.
- Harry F. Guggenheim, M. A., American Ambassador to Cuba.
- Col. Charles A. Lindbergh, LL. D. New York City.
- William P. MacCracken, jr., Ph. B., Washington, D. C.
- Charles F. Marvin, Sc. D., Chief of the Weather Bureau.
- Rear Admiral William A. Moffett, United States Navy, Chief of the Bureau of Aeronautics, Navy Department.
- Brig. Gen. Henry C. Pratt, United States Army, Chief of the matériel division, Air Corps.
- Edward P. Warner, M. S., editor of Aviation.
- Orville Wright, Sc. D., Dayton, Ohio.

THE EXECUTIVE COMMITTEE

For the purpose of carrying out the work of the advisory committee the regulations provide for the election annually of an executive committee. The present membership of the executive committee includes all the members of the advisory committee with the exception of its two far-distant members, Doctor Durand and Mr. Guggenheim.

The executive committee has organized the necessary clerical and technical staffs for handling the work of the committee proper. The total paid personnel of the committee numbered 317 employees on June 30, 1931, comprising 44 in Washington, 270 at the Langley Memorial Aeronautical Laboratory, Langley Field, Va., and three at the office of the technical assistant in Europe, Paris, France. General responsibility for the execution of the policies and the direction of the activities approved by the executive committee is vested in the director of aeronautical research, Mr. George W. Lewis. He has immediate charge of the scientific and technical work of the committee, being directly responsible to the chairman of the executive committee, Dr. Joseph S. Ames. The secretary, Mr. John F. Victory, is ex officio secretary of the executive committee, directs the administrative work of the organization, and exercises general supervision over the expenditures of funds and the employment of personnel.

SUBCOMMITTEES

In order to facilitate the conduct of its work, the executive committee has organized a number of standing committees, with subcommittees in some instances to cover the general field more effectively.

The committees of the executive committee, with their subcommittees, are as follows:

- Aerodynamics—
  - Subcommittee on airships.
- Power plants for aircraft.
- Materials for aircraft—
  - Subcommittee on metals.
  - Subcommitte on aircraft structures—
    - Temporary subcommittee on research programs on monocoque design.
  - Subcommittee on miscellaneous materials.
  - Subcommittee on methods and devices for testing aircraft materials and structures.
- Problems of air navigation—
  - Subcommittee on instruments.
  - Subcommittee on meteorological problems.
- Aircraft accidents.
- Aeronautical inventions and designs.
- Publications and intelligence.
- Personnel, buildings, and equipment.

The organization and work of the technical committees on aerodynamics, power plants for aircraft, materials for aircraft, and problems of air navigation are covered in the reports of those committees in Part II of this report, while the activities of the committee on aircraft accidents and the committee on aeronautical inventions and designs are included under the subjects of the study of aircraft accidents and the consideration of aeronautical inventions, respectively.

The organization of the administrative committees on publications and intelligence, and personnel, buildings, and equipment is as follows:

COMMITTEE ON PUBLICATIONS AND INTELLIGENCE

Dr. Joseph S. Ames, chairman.
Dr. Charles F. Marvin, vice chairman.
Miss M. M. Muller, secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

Dr. Joseph S. Ames, chairman.
Dr. David W. Taylor, vice chairman.
John F. Victory, secretary.

In addition to its standing committees, the executive committee has established from time to time special work. On such conference, the special conference on aeronautical nomenclature, is at present engaged in the revision of the standard nomenclature for aeronautics, which was published by the committee in 1926 as Technical Report No. 240. On completion of this work the revised nomenclature will be issued by the committee to supersede the previous report.

THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY

The Langley Memorial Aeronautical Laboratory is operated under the direct control of the committee. It is located at Langley Field, Va., on a plot of ground set aside by the War Department for the committee's use. The laboratory was started in 1916 coincident with the establishment of Langley Field.

The laboratory is organized with six divisions, as follows: Aerodynamics division, power plants division, hydrodynamics division, physical research division, technical service division, and property and clerical division. The laboratory is under the immediate direction of an engineer-in-charge, Mr. Henry J. E. Reid, subject to the general supervision of the officers of the committee.

There are at present 11 structures comprising the Langley Memorial Aeronautical Laboratory, as follows:

1. A research laboratory building containing administrative offices, technical library, physics laboratory, photographic laboratory, and headquarters of the various divisions.

2. An atmospheric wind-tunnel building, in which are housed a modern closed-return tunnel with an open rectangular throat 7 by 10 feet and a vertical tunnel with closed return and an open throat 5 feet in diameter. These two pieces of equipment are used in a comprehensive study of the problems of control and spinning characteristics of an airplane. In addition to the above equipment the building houses a 6-inch open-throat wind tunnel for instrument and wind-tunnel studies and a 6-inch refrigerated tunnel for the study of ice formation on aircraft.

3. A variable-density wind-tunnel building, housing the variable-density wind tunnel and a jet-type high-speed wind tunnel which utilizes the waste air from the variable-density wind tunnel.

4 and 5. Two engine dynamometer laboratories of a semipermanent type equipped to carry on investigations in connection with power plants for aircraft. In addition to the usual dynamometer equipment and single-cylinder test engines for studying both carbureted and Diesel-oil engines, there is equipment suited to the study of superchargers and the cooling of engine cylinders, and special high-speed photographic equipment for the study of fuel sprays.

6. A service building containing an instrument laboratory, drafting room, machine shop, woodworking shop, and storeroom.

7. A propeller-research tunnel, in which tests may be made in a 20-foot air stream at 100 miles per hour. This equipment permits the full-scale testing of propellers, fuselages, and landing gears.

8. An airplane hangar, 240 feet long by 110 feet wide, including office space for the staff of the committee's flight research laboratory, and a repair shop and facilities for taking care of the airplanes used in flight research.

9. A combination heating plant, storehouse, and garage.

10. A full-scale wind tunnel, having an oval-shape throat 60 by 30 feet, large enough for the testing of full-size airplanes, and particularly suitable for the study of the problems of airplane resistance or drag, stability, and control at low speeds, and spinning characteristics. The tunnel is operated by two 4,000-horsepower electric motors, generating an air stream of 115 miles per hour.

11. The N. A. C. A. tank, 1,980 feet long, 24 feet wide, and 12 feet deep, for the testing of large models of seaplane floats and flying-boat hulls. The carriage for towing the models through the water may be operated at speeds up to about 60 miles per hour.

Items 1, 2, 3, 4, 5, 6, and 9 are located on plot 16. Items 7, 10, and 11 are located within two blocks of the laboratory headquarters, and item 8 is located on the flying field.

The committee's laboratory is well equipped and has the great advantage of being located on a flying field. The work of the laboratory is conducted without interference with military operations at the field. In fact, there is a splendid spirit of cooperation on the part of the military authorities, who by their helpfulness in many ways have aided the committee materially in its work.

THE OFFICE OF AERONAUTICAL INTELLIGENCE

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

Promptly upon receipt, all reports are analyzed, classified, and brought to the special attention of the subcommittees having cognizance and to the attention of other interested parties through the medium of public and confidential bulletins. Reports are duplicated where practicable and distributed upon request. Confidential bulletins and reports are not circulated outside of Government channels.

To handle efficiently the work of securing and exchanging reports in foreign countries, the committee maintains a technical assistant in Europe, with headquarters at the American Embassy in Paris. It is his duty to visit the governmental and private laboratories, centers of aeronautical information, and private individuals in European countries and endeavor to secure for America not only printed matter which would in the ordinary course of events become available in this country but more especially advance information as to work in progress and technical data not prepared in printed form, which would otherwise not reach this country. John Jay Ide, of New York, has served as the committee's technical assistant in Europe since April, 1921.

STUDY OF AIRCRAFT ACCIDENTS

A standard procedure for the analysis of aircraft accidents as recommended by the committee in Technical Report No. 357 is followed in the War, Navy, and Commerce Departments. Uniformity in interpretations of definitions and explanations has been secured through meetings of the committee on aircraft accidents, which includes representatives of the War, Navy, and Commerce air organizations.

The work of the committee was materially furthered by the cooperation of medical officers of the War, Navy, and Commerce Departments who met, not only with the committee, but with each other, with a view to evolving a plan for determining the effect of the physical, mental, and temperamental characteristics of pilots on the number and nature of accidents. Statistical information is needed on the underlying physiological and psychological causes of aircraft accidents. During the past year that committee cooperated with representatives of the Actuarial Society of America, the United States Aviation Underwriters (Inc.), and other insurance interests in connection with problems relating to the determination of a basis for rating pilots' risks.

The present membership of the committee on aircraft accidents is as follows:

Hon. Edward P. Warner, editor of Aviation, chairman.
Maj. J. W. Jones, United States Army, Air Corps.
George W. Lewis, National Advisory Committee for Aeronautics.
W. Fiske Marshall, Aeronautics Branch, Department of Commerce.
Lieut. Commander A. C. McFall, United States Navy, Bureau of Aeronautics.
Lieut. H. B. Temple, United States Navy, Bureau of Aeronautics.
Lieut. Lyman P. Whitten, United States Army, Air Corps.

The following are the medical officers of the Government who cooperated with the committee on aircraft accidents during the past year:

Col. Glen I. Jones (M. C.), United States Army.
Dr. R. F. Longacre, Aeronautics Branch, Department of Commerce.
Lieut. Commander John R. Poppen (M. C.), United States Navy.
Lieut. Commander Joel J. White (M. C.), United States Navy.

CONSIDERATION OF AERONAUTICAL INVENTIONS

In accordance with act of Congress approved July 2, 1926, as amended by act approved March 3, 1927, the National Advisory Committee for Aeronautics passes upon the merits of aeronautical inventions and designs submitted to any branch of the Government for an award. Under the law an aeronautical patents and design board, consisting of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce, is authorized, upon the favorable recommendation of the committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed $75,000."

During the past year the committee received approximately 800 new submissions, most of which, being addressed direct to the committee and not meriting favorable recommendation, were settled by direct correspondence, without reference to the aeronautical patents and design board. The committee, through its committee on aeronautical inventions and designs, submitted reports to the board on 91 cases during the past year.

COOPERATION WITH THE ARMY AND THE NAVY

Through the personal contact of the heads of the Army Air Corps and of the Bureau of Aeronautics of the Navy serving as members of the National Advisory Committee for Aeronautics and of their chief subordinates acting as members of the subcommittees, there is first-hand discussion of the technical problems of these organizations, and this has served as a most effective means of coordination of aeronautical research.

Many of the committee's fundamental researches have resulted from requests received from the Army and Navy for the study of particular problems.

The Army and Navy have placed at the committee's disposal airplanes and engines required for research purposes. The committee desires to give special recognition to the splendid spirit of cooperation shown by the Army and Navy, and to acknowledge in particular the many courtesies extended by the Army authorities at Langley Field, where the committee's laboratories are located, and by the naval authorities at the Hampton Roads Naval Air Station.

The investigations conducted by the committee during the past year for the Army and the Navy are as follows:

Study of loads on wings of military type airplanes.

Investigation of pressure distribution on bomber airplane in dives.

Calculation of pressure distribution for various airfoils.

Study of water-pressure distribution on seaplane floats and hulls.

Effect of variations in dimensions and form of hull on performance of flying boats during take-off.

Investigation of design of floats for racing seaplanes.

Determination of maximum negative thrust coefficients of propellers.

Effect of propeller pitch settings on dive speed and engine revolutions.

Study of design factors for metal propellers.

Investigation of unsatisfactory spinning characteristics of F4B-2 airplane.

Investigation of autorotation.

Investigation of flight path characteristics.

Investigation of methods of improving wing characteristics by control of the boundary layer.

Investigation of effect of sags in wing surface.

Investigation of aerodynamic loads on U. S. airship *Akron*.

Study of the forces on an airship at large angles of yaw.

Investigation of windshields and fairings for protection from air currents.

Development of cowling combining cooling, accessibility, and low drag, for radial air-cooled engine installed in nacelle.

Investigation of cowling and cooling of 2-row radial air-cooled engine.

Study of wing-fuselage interference in airplane of gull-wing type.

Investigation of pressure distribution on observation-type airplane.

Investigation of tail surface loads in maneuvers.

Investigation of means of silencing airplane propellers.

Investigation of effect of slipstream on airplane tail surfaces.

Determination of standard design characteristics for certain airfoils.

Pressure distribution on ring cowling.

Investigation of wing flutter.

Development of solid-injection type of aeronautical engine.

Investigation of application of compression ignition to air-cooled engine cylinders.

Performance of airship engine using hydrogenated safety fuels.

Effect of supercharging highly heated inlet air on performance of carburetor-type engine.

Study of effect of different degrees of supercharging with several compression ratios.

RELATIONS WITH THE AIRCRAFT INDUSTRY

The committee cooperates closely with representatives of the aircraft industry in planning research programs which are of particular interest and importance to commercial aeronautics. The general program of research as formulated by the committee for the cowling and cooling of radial air-cooled engines was circulated to engineers of the industry and their comments obtained, and the result of this investigation was the development of the N. A. C. A. cowling. During the past year the results obtained by the committee in the study of propeller efficiency and the interference drag of combinations of engine nacelle and wing, and made available to the airplane manufacturers, have been reflected in the improved performance of recent designs of airplanes, particularly the large transport types. The committee takes advantage of every opportunity to obtain the comments and suggestions of the industry in formulating its research program on problems of general interest, such as the cowling and cooling of air-cooled engines and the best location of engine nacelles for any wing arrangement.

One problem in connection with which there has been active cooperation with the industry is the study of load factors in flight due to atmospheric disturbances. A number of air transport companies have cooperated with the committee in this investigation. The N. A. C. A. accelerometer, which was developed by the committee for this study, is now being superseded by a new and improved instrument known as the N. A. C. A. V-G recorder. This instrument registers both applied load factors and corresponding air speeds, thus greatly facilitating the task of obtaining the information needed in the study of this problem. Records from these instruments have been or are being obtained for the committee's investigation by the Boeing Air Transport, American Airways, Ford

Motor Co., Pan American Airways, United Air Lines, and Varney Speed Lines, on airplanes in regular operation.

Annual research conference.—In 1926 the National Advisory Committee for Aeronautics established the policy of holding at its laboratory at Langley Field, the Langley Memorial Aeronautical Laboratory, annual conferences with representatives of the manufacturers and operators of aircraft. The purposes of these conferences are to give to the representatives of the industry an opportunity to become acquainted with the facilities for aeronautical research at the committee's laboratory and to afford them an opportunity to make suggestions to the committee as to aeronautical research problems of interest to the industry which in their opinion the committee is especially equipped to solve.

In accordance with this policy, the Seventh Annual Aircraft Engineering Research Conference was held at the committee's laboratory on May 25, 1932. The committee was represented by its officers, members of the main committee, and the members of its committees on aerodynamics and power plants for aircraft. The conference was presided over by Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics.

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.

At the close of the session the representatives of the industry were conducted on a tour of inspection of the committee's laboratories and the research equipment was shown in operation. On this occasion the committee exhibited for the first time a specially constructed smoke-flow wind tunnel which shows visually by means of smoke streamers the character of the air flow over wing models, streamline forms, and other shapes.

The afternoon session was devoted to the discussion of the problems of commercial aeronautics. Prior to the conference, the committee had requested the representatives of the industry to submit suggestions in writing, and a large number were received. In addition, several such suggestions were presented and discussed at the conference. Among these were the investigation of the interference effects of engine nacelles in various positions in relation to biplane wings; investigation of flying boat hulls at various displacements and with various assumed wing loadings; further study of interference effects, with particular reference to the effect of obstructions on airplane wings; study of the interference and of the cowling and cooling of in-line type air-cooled engines; further study of cooling fins on air-cooled engine cylinders; and further investigation of the two-stroke-cycle engine for aircraft use.

All the suggestions for investigation presented in connection with the conference, totaling 37, including both those presented in the discussion in the afternoon session and those submitted in correspondence, have been carefully studied and classified, and each has been considered by the committee on aerodynamics, the committee on power plants for aircraft, or the subcommittee on aircraft structures. Many of these problems were already a part of the committee's research program, and in a number of other cases the program has been modified to include the problems suggested.

FINANCIAL REPORT

The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1932, as carried in the independent offices appropriation act approved February 23, 1931, was $1,028,070. In response to the President's plea for economy, the committee early in the fiscal year pledged a definite saving of $53,500 and by sustained pressure managed to effect a saving of $68,552 leaving the amount expended and obligated $959,518, itemized as follows:

Personal services	$670, 858. 50
Supplies and materials	40, 433. 59
Communication service	1, 829. 05
Travel expenses	13, 972. 10
Transportation of things	1, 843. 20
Furnishing of electricity	23, 103. 07
Rent of office (Paris)	960. 00
Repairs and alterations	28, 210. 41
Special investigations and reports	49, 500. 00
Equipment	128, 808. 31
Expenditures	959, 518. 23
Unobligated balance	68, 551. 77
Total, general appropriation	1, 028, 070. 00

The appropriation for printing and binding for 1932 was $23,000, of which $22,963.59 was expended.

The appropriations for the current fiscal year 1933 total $920,000, of which approximately $51,500 will be impounded in the Treasury pursuant to the Economy Act approved June 30, 1932.

PART II

REPORTS OF TECHNICAL COMMITTEES

FUNCTIONS OF THE TECHNICAL COMMITTEES

To facilitate the conduct and coordination of the scientific study of the problems of aeronautics in its various phases the National Advisory Committee for Aeronautics has established under the executive committee four main technical committees, with subcommittees for certain specific subdivisions of the work. The main technical committees are the committee on aerodynamics, the committee on power plants for aircraft, the committee on materials for aircraft, and the committee on problems of air navigation.

The functions of the technical committees are as follows:

1. To determine what problems in their respective fields are the most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding investigations in their respective fields and developments in progress or proposed.
4. To direct and conduct research in their respective fields in such laboratory or laboratories as may be placed either in whole or in part under their direction.
5. To meet from time to time on call of their chairmen and report their actions and recommendations to the executive committee.

The technical committees, by reason of the representation of the various organizations interested in aeronautics, are in close contact with all research work in their respective fields being carried out in the United States. The current work of each organization is therefore made known to all, duplication of effort being thus prevented. Also all research work is stimulated by the prompt distribution of new ideas and new results, which add greatly to the efficient conduct of aeronautical research. The committees keep the research workers in this country supplied with information of European progress in aeronautics through the work of the foreign representative of the National Advisory Committee, who is in close touch with aeronautical activities in Europe. This direct information is supplemented by the translation and circulation of copies of the more important foreign reports and articles.

The committees on aerodynamics and power plants for aircraft have direct control of the aerodynamical and power plant research, respectively, conducted at Langley Field, and of a number of special investigations conducted at the Bureau of Standards. The major 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 Bureau of Standards, and other Government agencies are reported to the committees on aerodynamics, power plants for aircraft, materials for aircraft, and problems of air navigation, respectively.

REPORT OF COMMITTEE ON AERODYNAMICS

ORGANIZATION

The committee on aerodynamics is at present composed of the following members:

Dr. David W. Taylor, chairman.
Dr. L. J. Briggs, Bureau of Standards.
Lieut. Commander W. S. Diehl (C. C.), United States Navy.
Dr. H. L. Dryden, Bureau of Standards.
Capt. Albert C. Foulk, United States Army, matériel division, Air Corps, Wright Field.
Richard C. Gazley, Aeronautics Branch, Department of Commerce.
Maj. C. W. Howard, United States Army, matériel division, Air Corps, Wright Field.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Dr. Charles F. Marvin, Weather Bureau.
Hon. Edward P. Warner, editor of Aviation.
Commander W. W. Webster (C. C.), United States Navy.
Dr. A. F. Zahm, division of aeronautics, Library of Congress.

Under the committee on aerodynamics there has been organized one subcommittee, the subcommittee on airships, for the supervision and coordination of investigations in connection with lighter-than-air craft.

SUBCOMMITTEE ON AIRSHIPS

The present organization of the subcommittee on airships is as follows:

Hon. Edward P. Warner, editor of Aviation, chairman.
Starr Truscott, National Advisory Committee for Aeronautics, vice chairman.

Dr. Karl Arnstein, Goodyear-Zeppelin Corporation.

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

Maj. William E. Kepner, United States Army, matériel division, Air Corps, Wright Field.

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

Ralph H. Upson, Ann Arbor, Mich.

The subcommittee on airships has kept in close touch with the airship investigations under way during the past year at the Langley Memorial Aeronautical Laboratory. At a meeting of the subcommittee held on February 5, 1932, the results obtained in tests of a 1/40-scale model of the airship *Akron* in the propeller-research tunnel and in tests of the full-size airship in flight, conducted at the request of the Bureau of Aeronautics of the Navy Department, were discussed. At this meeting the subcommittee approved an investigation of airship forms to be conducted in the variable-density wind tunnel to determine the effect on the drag of variations in the nose fullness, tail fullness, and tail angle.

At a meeting held on October 10, 1932, a program of investigation of airship problems to be conducted by the Langley Memorial Aeronautical Laboratory was approved. This included model representation in the full-scale wind tunnel of ground handling of the *Akron*, as requested by the Bureau of Aeronautics of the Navy; an investigation in the N. A. C. A. tank of the drag of a model of the *Akron*, for comparison with the results obtained in wind-tunnel tests; further study in the 20-foot propeller-research tunnel of the boundary layer and of the pressure distribution on an airship model; and an investigation in the propeller-research tunnel of the effect of surface roughness on the drag of the airship model. At both these meetings there was general discussion of problems of airship development and operation.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

EQUIPMENT.—Improvements recently completed in the variable-density wind tunnel have been described in a report which incorporates also for ready reference the standard methods of reducing the airfoil data obtained in this tunnel. (Technical Report No. 416.) A report has also been prepared during the year describing the 7 by 10 foot tunnel; with its balance. (Technical Report No. 412.) The high-speed tunnel has been in operation for several months, and a report is in preparation describing the tunnel and presenting the results of tests of a number of airfoils at air speeds approaching the velocity of sound. The special spinning balance for the 5-foot vertical tunnel has been placed in operation, and a report is in preparation describing this balance and presenting the results of an investigation of the forces and moments on a model of an NY-1 airplane in spinning attitude.

The full-scale tunnel has been calibrated during the year, and after adjustment of the angular setting of some of the guide vanes a velocity distribution was obtained in which the variation over that portion of the jet occupied by an airplane under test is within plus or minus one-half per cent. A report describing the tunnel and the methods of operation is in preparation. The N. A. C. A. tank, for the study of hydrodynamic problems connected with aeronautics, is also in regular operation on a carefully considered program of research. Several new instruments have been developed during the year for use in flight investigations, and methods have been developed for the use of smoke to indicate the flow about the parts of an airplane in flight (Technical Note No. 425) and to show the flow about bodies in a small tunnel.

CONTROLLABILITY AND STABILITY.—The past year has seen a substantial improvement in safety on commercial airlines and in military flying. This improvement is largely the result of careful training of pilots and well-regulated flying. Satisfactory stability and controllability have not yet been attained throughout the entire range of speed or of angle of attack of conventional airplanes, and as indicated by the accident records for unorganized flying, there is great need for further research on control and stability.

During the past year considerable progress has been made in an extensive investigation on lateral controllability. In this investigation the relative merits of various forms of ailerons and other lateral control devices are tested and compared in regard to their effect on lateral controllability and lateral stability at high angles of attack, and also their effect on airplane performance. The comparisons are based on wind-tunnel test data, all the control devices being fitted to model wings having the same span, area, and airfoil section, and being subjected to the same series of force and rotation tests. The investigation is being carried out mainly in the 7 by 10 foot tunnel, but certain of the more interesting devices are also being tested in flight.

The wind-tunnel tests have been completed for the following arrangements: (1) Ordinary ailerons of three different proportions, all mounted in the usual position at the trailing edge of the wing, the ailerons being tested both locked to the wing and arranged to float with respect to the wing (Technical Report No. 419); (2) slotted ailerons and Frise ailerons (Technical Report No. 422); (3) ordinary ailerons rigged up 10° when neutral, to eliminate the adverse yawing-moment characteristics of the ailerons with the usual rigging in line with the wing (Technical Report No. 423); (4) full-chord floating tip ailerons on rectangular wings (Technical Report No. 424); (5) spoilers and combinations of spoilers and ailerons on rectangular wings (Technical Report No. 439); (6) skewed ailerons on rectangular wings (Technical Report No. 444); (7) Handley Page tip slots and full-span slots with ailerons and spoilers (Technical Report No. 448); (8) ordinary ailerons on wings with rounded tips; (9) ordinary ailerons on tapered wings. Technical reports are in preparation covering items (8) and (9).

Square tips.—On rectangular wings with ordinary or skewed ailerons the direct rolling control at high angles of attack was best with short, wide ailerons rigged up 10° when neutral and having an extreme differential movement from the rigged-up position, but the control forces required were exceptionally high. With the ailerons neutral, the autorotational tendency was found to be less with the ailerons rigged up 10° than when they were rigged even with the wing.

Rounded tips.—On wings with rounded tips reasonably satisfactory rolling moments at all angles of attack that can be maintained by average airplanes were obtained by short, wide ailerons, and particularly by short wide skewed ailerons on a wing with a long and slender tip. In general, the yawing moments were somewhat smaller for the ailerons on the wings with rounded tips than for the corresponding ailerons on rectangular wings.

Tapered wings.—Two wings tapered in plan, one tapered 5:3 and the other 5:1, were tested with ordinary ailerons. The ailerons on tapered wings gave better lateral control below the stall in regard to all three of the important factors, rolling, yawing, and hinge moments, than corresponding ailerons on rectangular wings, but with the 5:1 taper the rolling moments fell off almost completely just above the stall and adverse yawing moments of great magnitude occurred.

Floating tip ailerons.—Full-chord floating tip ailerons on rectangular wings gave definitely poorer general performance, particularly in regard to speed range and climb, than that for a wing with the same over-all dimensions and ordinary ailerons. At the higher angles of attack well above the stall, the control with the wing-tip ailerons was found to be greater than the assumed satisfactory value, whereas the ordinary ailerons failed almost completely. The floating tip ailerons gave no appreciable adverse yawing moments (body axes), but gave large favorable ones at high angles of attack. The autorotative tendency was not as bad as for the wings with ordinary ailerons.

Spoilers.—The investigation of spoilers showed that when spoilers and ailerons are used together, the full effect of both is not obtained if the spoilers are located directly in front of the ailerons. With the proper combination of spoiler and aileron, however, it is possible to obtain satisfactory rolling control up to high angles of attack (several degrees above the stall), together with favorable yawing moments and small control forces. A moderate amount of rolling control with favorable yawing moments and small control forces was obtained with a large spoiler alone. The results of these tests indicated that the spoilers might give improved lateral control over that obtained by means of ordinary ailerons, and they are therefore being tested also in flight, both as the sole means of lateral control, and coupled with short, wide ailerons. The flight tests are being carried out on a small parasol monoplane.

Wing slots.—Wind-tunnel experiments were made on a wing with various lengths of Handley Page tip slot to find the best length of slot for the prevention of autorotation. (Technical Note No. 423.) The best length was found to be 50 per cent of the semispan, or slightly greater, for the particular arrangement tested. Control tests were then made on a wing model with tip slots of this length, and also on a model with full-span slots. The model with the tip slots and certain combinations of ailerons and properly located spoilers was found to have satisfactory damping in roll and satisfactory rolling control with no adverse yawing moments at all angles of attack up to 30°. With the full-span slot, the conventional ailerons alone did not give rolling control of the assumed satisfactory amount at angles of attack above 10° (maximum lift occurred at 26°), but when combined with spoilers satisfactory rolling moments were obtained with no adverse yawing moments. Large spoilers tested as the sole means of lateral control on both the wing with tip slots and that with the full-span slot gave a moderate amount of rolling control at all angles of attack, together with favorable yawing moments which were extremely large, possibly too large.

Flight tests have also been made on an airplane equipped with Handley Page slots and flaps, to determine the effect of those devices on the lateral control, on the lift and drag, and on take-off time and distance. (Technical Note No. 398.) The airplane used was a low-wing monoplane having full-span automatic slots divided in such a manner that they could be used as tip slots only, if desired, and trailing-edge flaps which were confined to the portion of the span inboard of the ailerons. A tentative analysis of the results of the tests indicates that there is an approximately lineal variation of rolling moment with lift coefficient for the unstalled portion of the range of angle of attack, the moments decreasing with increased lift coefficient. The full-span slots merely extend the unstalled range without altering the rolling moments in the range covered by the normal wing. This condition is in accordance with what would be expected from the wind-tunnel tests with Handley Page slots. With only the tip portions slotted, however, the rolling control is definitely decreased, indicating an increased damping in roll. A report covering this work is in preparation.

Separate airfoils as ailerons.—Wind-tunnel tests are now under way on ailerons consisting of small symmetrical airfoils separated from the main wing. They are being tried in a large number of positions with respect to the main wing. In each location the aileron airfoils are deflected for control in the usual manner, and also when allowed to float.

Full-scale stability tests.—Flight tests on longitudinal stability have been carried out with a small parasol monoplane. The results of these tests showed that the dynamic stability theory, based on small deviations from the steady state, is satisfactory for the conditions encountered in flight. (Technical Report No. 442.) In an attempt to calculate the stability of the airplane from the type of basic data that are available at the outset of a new design, it was found that very satisfactory results could be obtained for the power-off condition but that more data are required concerning slipstream effects for the power-on condition.

LANDING.—One obvious means of increasing the safety of aircraft is to reduce the minimum flying speed and increase the angle of glide, making possible landing and taking off in smaller areas. A report has been published covering the investigation on modifications to conventional airplanes giving nonstalling and short-landing characteristics. (Technical Report No. 418.) Such landings require that the landing gear be able to absorb a greater shock than the conventional gear would withstand. Some measurements have been made of glide landings with an airplane equipped with long-stroke shock-absorber struts. Further tests will include a study of the behavior of the airplane during glide landings in gusty air. A method has been perfected for an accurate detailed study of the motion of an airplane for an approach in landing. A motion-picture camera on the ground is employed to record the various items of interest in connection with the study of landings and flight close to the ground. The results of an investigation made at the request of the Bureau of Aeronautics on the relative shock-absorbing properties of rubber-cord and oleo landing gears have been published. (Technical Report No. 406.)

There have also been conducted investigations of the air conditions that an airplane must encounter in landing. For this purpose measurements have been obtained with a device that indicates the approximate magnitude and direction of the wind simultaneously at velocities from the ground up to 50 feet. These measurements have extended over a period of about six months so as to include various representative air conditions.

In connection with the general study of landings, an analysis of the directional stability while taxying (with particular reference to ground looping) has been made and a report is in preparation.

LANDING SPEED AND SPEED RANGE.—In an effort to provide means for obtaining lower landing speeds and greater speed ranges, many devices have been developed for increasing the maximum lift without excessive increase of the minimum drag. These devices include pilot planes, slots, flaps, etc., most of which have movable parts entailing a certain amount of complication. In this field, wind-tunnel investigations have been made recently on Clark Y basic airfoils with various of these devices. In addition, to avoid the obvious objection to movable parts, tests were made on fixed slots and fixed auxiliary airfoils.

Fixed slots.—Aerodyamic force tests were made in the 5-foot vertical tunnel on a Clark Y wing equipped with several forms of fixed slot (Technical Report No. 407), and with four fixed slots and a trailing-edge flap. The slots were arranged to act singly and in combination to determine the optimum combination with the flap neutral and also with it deflected. (Technical Report No. 427.) On the basis of the maximum lift coefficient and the speed-range ratio $C_{L_{max}}/C_{D_{min}}$ with the flap neutral no appreciable improvement was found with the use of more than a single slot at the leading edge. On the same basis but with the flap down 45° the optimum combination was obtained with only the two rearmost slots, the maximum lift coefficient in that case being 2.44 as compared with 1.29 for the plain Clark Y.

Flap modifications.—An investigation was made in the 7 by 10 foot wind tunnel on a model wing with split trailing-edge flaps of three different sizes. (Technical Note No. 422.) The flaps were formed of the lower rear portion of the wing, and were rotated downward about the axes at their front edges. The axes could be moved back in even steps to the trailing edge of the main wing, giving in effect an increase in area. The split flaps when deflected about their original axis locations gave slightly higher maximum lift coefficients than conventional trailing-edge flaps, and the lift coefficients were increased still further by moving the axes toward the rear. The highest value of $C_{L_{max}}$, which was obtained with the largest flap hinged at 90 per cent of the main wing chord from the leading edge, was 2.52 as compared with 1.27 for the basic wing.

Another high-lift device tested in the 7 by 10 foot tunnel was the Hall high-lift wing, which is essentially an airfoil having a split flap and also an internal air passage. (Technical Note No. 417.) The air enters the passage through an opening in the lower surface somewhat back of and parallel to the leading edge, and flows out through an opening made by deflecting the rear portions of the under surface downward as a flap. For ordinary flight conditions, the front opening and the rear flap can be closed, providing in effect a conventional airfoil. The tests were made with various flap settings and with the entrance to the passage both open and closed. The highest lift coefficient found, $C_L=2.08$, was obtained with the passage closed.

Wind-tunnel tests were also made on a model of the Fowler variable-area wing (Technical Note No. 419), which consists of a combination of a main wing and an extension surface, also of airfoil section. The extension surface can be entirely retracted within the lower rear portion of the main wing, or it can be moved to the rear and downward. The tests were made with the nose of the extension airfoil in various positions near the trailing edge of the main wing, and with the surface at various angular deflections. The highest lift coefficient obtained was 3.17, as compared with 1.27 for the main wing alone.

Airfoils of low aspect ratio.—Because of the interesting high-lift characteristics of flat plates of very low aspect ratio, tests were made in the 7 by 10 foot wind tunnel on Clark Y airfoils having aspect ratios varying from 0.5 to 3, the force, moment, and autorotational characteristics being determined. The tests revealed a marked delay of the stall and a decided increase in the values of maximum lift coefficient and maximum resultant force coefficient for aspect ratios of the order of 1, as compared with the values for aspect ratios of 2 and 3, and higher. The results, when reduced to infinite aspect ratio by conventional formulas, indicate that such formulas are not applicable for aspect ratios of less than 1.5. The plan form and tip shape were found to be of major importance among the factors affecting airfoil characteristics at aspect ratios of 1.5 and smaller. (Technical Report No. 431.)

Fixed auxiliary airfoil.—Another investigation made in the vertical wind tunnel consisted of a series of tests on a Clark Y wing fitted with a narrow fixed auxiliary airfoil. (Technical Report No. 428.) The results of the wind-tunnel tests were so favorable that flight tests were also made with a similar auxiliary airfoil mounted on a small parasol monoplane. The addition of the auxiliary airfoil increased the lift capacity of the airplane 45 per cent, and the drag for the high-speed condition only 4 per cent. The minimum gliding speed was decreased 19 per cent, and the minimum gliding angle was unaffected. The maximum gliding angle at low speed, however, was increased from 8.6° to 16.8°, a change that tends to facilitate landing in restricted areas. The flight tests are in good agreement with the results predicted from the wind-tunnel tests. A report of this work is in preparation.

This investigation of fixed auxiliary airfoils is now being continued in the vertical tunnel to determine the best size and section of the auxiliary airfoil when combined with a main wing of Clark Y section. The original auxiliary airfoil used in both the wind-tunnel and flight tests was a highly cambered section (N. A. C. A. 22) and had a chord about 15 per cent that of the main wing. At present, auxiliary airfoils with this section and also with a symmetrical section (N. A. C. A. 0012), and with the Clark Y section, are being tested in several different sizes each. The results obtained so far (N. A. C. A. 22 section only) indicate that the chord of the auxiliary airfoil has little effect on the characteristics of the combination except that when the chord of the auxiliary is increased to 25 per cent of the wing chord the characteristics are slightly inferior. The optimum locations of the auxiliary airfoils, however, are considerably different for the different sizes. The effect of the auxiliary airfoil on the main wing appears to be due to the "scrubbing" action of the air over the upper surface of the main wing and the resultant suppression of the boundary layer, and not to the downwash from the auxiliary wing.

ROTATING-WING AIRCRAFT.—One obvious disadvantage of the conventional airplane with respect to safety is the comparatively high minimum flying speed, making necessary large smooth areas for landing and taking off. The rotating-wing type of aircraft is attractive in this respect, as it makes possible the maintenance of lift with little, if any, motion of the body supported by the wings. With a view to studying the real advantages offered by the autogiro and accumulating knowledge regarding similar types, the committee has in progress investigations on three types of rotating-wing aircraft.

Glide tests have been completed and lift and drag characteristics determined on an autogiro. (Technical Report No. 434.) Preparations have been made to determine the distribution of load between the fixed and moving wings of the autogiro by means of pressure-distribution measurements in flight. The results will be of importance in providing quantitative confirmation of the present theory of the autogiro. The theory of each of the other types of rotating-wing systems mentioned above has also been studied.

SPINNING.—Investigations are being continued in flight and in the wind tunnel to add to the present knowledge of spinning and to make it possible to design airplanes that will spin satisfactorily and recover quickly and surely. The results of full-scale spin tests with an airplane in which the mass distribution and several items pertaining to the geometric arrangement of the airplane were varied have been published. (Technical Report No. 441.) In conjunction with the flight results, there is also given a strip-method analysis of data obtained with a wind-tunnel model of the airplane. The comparison between the predicted and actual conditions of spinning equilibrium for that airplane has indicated that the method of analysis gives fairly satisfactory qualitative results. The method has consequently been applied to a study of the effect of various factors that enter into the equilibrium conditions, and a paper on the results of this study is now being prepared.

With another airplane the effects of control position and the effects of mass distribution have been investigated. Also, owing to the reports of success with sharp leading edges in the prevention of bad spins, tests were made with the wings of the airplane modified to form sharp leading edges. This modification resulted in a marked and probably favorable effect on the spin, but caused objectionable decreases in the maximum speed and the maximum lift coefficient. A paper on the results of the tests with the sharp leading edges is being prepared.

Several factors have recently tended to focus attention on the yawing moments developed in spins as exerting a very important influence on the character of the spins. Analysis has indicated that the resultant yawing moment in spins is relatively small, and smoke-flow pictures obtained during the last year in steady spins demonstrate that the vertical tail surfaces are blanketed to a large extent. (Technical Note No. 421.) The tests have shown, however, that recovery is effected largely through the use of the rudder. It seems evident, therefore, that the conditions for equilibrium are upset by a small variation in the resultant yawing moment. Some recent tests have shown that a small change in the alignment of the very small vertical fin on the airplane used in the previous investigation changes the character of the spin to a marked extent.

At the present time, flight tests are being made with an airplane possessing reputedly vicious spinning characteristics, the primary purpose of which is to find if possible a simple means of improving the character of the spin of this particular airplane. The method developed for measuring in flight the motion of, and forces acting on, an airplane during a steady spin is now used regularly in all flight tests. A study is now in progress with a view to extending this method to include the measurement of the same elements during the accelerated portion of the spin, the entry, and the recovery.

The construction of a spinning balance for the 5-foot vertical tunnel has been completed. Preliminary calibration tests indicated that considerable damping was required on the balance arms, and after this was applied satisfactory operation was obtained. This balance measures all six components of the air forces and moments about the center of gravity of a model airplane when it is being turned at the particular rate, radius, and attitude corresponding to an actual steady spin as measured in flight. Variations from the actual spin can also be made as desired. The first series of tests has been completed on a model of the NY–1 airplane mounted on the spinning balance. The results agree with flight tests in showing that the rudder is much more effective in giving a moment opposing the spin when the elevator is up than when it is down. In addition, the results indicate that nothing would be gained with the particular airplane tested by putting the elevator below neutral in coming out of a spin, and that the elevator is most effective in producing a diving moment when the rudder is neutral. A report describing these tests is in preparation.

Structural Loading.—The rapid strides made in airplane performance in the past year and the broadened scope and increased severity of the tactical maneuvers of military and naval airplanes have pointed to the necessity of placing the structural design of airplanes on a sound and rational basis. Studies by the flight research section of the basic problem of the structural loads occurring on the various types of airplanes have been extended along several lines.

Load factors.—Special investigations of the applied load factors, or total loads, on military and naval airplanes during tactical maneuvers have been made and the information obtained has furnished, in large part, the basis of extensive revisions to structural design procedure for the types of airplanes involved. Further investigations of this type are in progress, including a study of the relation between the control force and the applied load factor in pulling out of a fast dive. Statistical data have been accumulated on the applied load factors experienced by transport airplanes on several routes during all seasons of the year. Although these data are not yet considered complete, enough information has been obtained to establish fairly reliable indications of the load factors to be expected during transport operations.

Inasmuch as these data have been obtained on several types of airplanes under a variety of conditions of speed and loading, the results have been reduced to corresponding "effective" gust velocities on the basis of the assumptions of sharp-edge gusts and no pitching displacement. This procedure makes possible the plotting of curves of gust probability which show the expectancy of encountering "effective" gusts of given intensity during unit flying time. It has been found from data obtained in several thousand hours of flying that effective gusts of the order of 25 to 30 feet per second occur about three times per 100 hours of flying, and that they may act either upward or downward with equal expectancy. Effective gusts of greater intensity than 30 feet per second have not yet been encountered.

A special type of instrument which records the acceleration and air speed has been devised to aid in the accumulation of statistical data on load factors for airplanes. An advantage of this instrument is that it can be left unattended in an airplane for any desired period of time, and for this period it yields, in directly usable form, the desired data. Several such instruments are now in service.

The use of the vertical dive as a bombing maneuver has required that special consideration be given to the applied load factors involved in pulling out of dives at terminal velocity and to means for reducing the terminal velocities. An investigation of the influence of the propeller on the diving speed has been completed, the results indicating that an adjustable-pitch propeller can be used to great advantage in controlling diving speeds for special purposes.

Load distribution.—In addition to investigations of the applied load factor or total load, studies have been continued on problems of load distribution. A report presenting a method of calculating the design load for the leading-edge portion of the wing has been published (Technical Report No. 413) and the method has been incorporated in Navy design specifications. The theoretical basis of this method has been extended and practical methods have been devised therefrom for convenient application of accurately simulated aerodynamic loads to wing-rib tests for any desired condition of load. These methods are shortly to be incorporated in design specifications.

A study of the lift distribution between biplane wings has been made and a report is in process of publication. (Technical Report No. 445.) The working charts presented in this report are based partly on theoretical considerations but largely on empirical data, and make possible the rapid determination of the lift distribution for the principal combinations of the important biplane variables.

An investigation of the load distribution on wing tips has been completed, and results have been published from time to time during the progress of the tests. (Technical Notes Nos. 347, 360, 379, 387, and 433.) A comparison of the results on all tips tested, which range from slender elliptical to square in plan form, indicates that the distribution of lift coefficient and moment coefficient along the span is independent of the plan form. It is believed that these results will enable a simple and exact method to be devised for applying wing-tip loads to any particular design.

Further work on structural loading is in progress, the most important of which is a complete series of measurements of the total load, load distribution, structural deformations, and stresses on a Navy diving bomber. This work is of a highly specialized character, but should provide some information of general interest regarding the true interrelations of structural loads, stresses, and deformations as compared with calculated relations from present design methods.

Tail loads.—Studies of tail loads have been continued on an Army observation-type airplane and several new aspects of the problem have come to light. In conjunction with the study of tail loads, some tests have been made in the variable-density wind tunnel to determine the influence of airfoil thickness and camber and slight amounts of decalage such as might inadvertently be present on the moment coefficient of biplane cellules of varying stagger. The results indicate a negligible influence of the airfoil thickness and camber, but show that a slight amount of accidental decalage, particularly at the large staggers, influences the pitching moment of the cellule, and hence the tail load, so greatly that a precise predetermination of the tail load for such cases is probably not possible.

Prevention of Ice Formation.—The study of a method of prevention of ice formation on aircraft was completed and reported. (Technical Report No. 403.) This report shows that there is ample heat in the exhaust of an airplane engine to prevent ice from forming on the wings of the airplane. The report presents information for the design of such equipment and outlines the results obtained with one device for utilizing heat from the engine exhaust in heating the leading edge of an airplane wing. The study of the formation of ice on gasoline-tank vents has been reported (Technical Note No. 394), and shows that with a vent tube of suitable size pointing downstream the danger of stoppage by ice formation is eliminated.

Aerodynamic Interference and Drag.—The mutual aerodynamic effects of the component parts of aircraft have become increasingly important as the parts have been refined and as flying speeds have been increased. For example, the arrangement of a projecting gasoline filler cap was of relatively little importance when it projected from a fuselage of crude form over which the flow of air had been thoroughly disturbed by an uncowled air-cooled engine. The turbulence set up by the same object and the drag associated with it demand consideration, however, when it projects from a modern fuselage of fine aerodynamic form, particularly if the engine in front is fitted with a cowling. To insure continued increases in the speed and efficiency of aircraft, it becomes necessary to give more consideration to the subject of aerodynamic interference.

The committee has in progress in the variable-density wind tunnel a series of investigations dealing with the aerodynamic interference between simple bodies including fuselage-wing combinations. A new piece of equipment, known as a smoke tunnel, has been added during the past year to assist in the interference investigations. It permits the flow of air about interfering bodies to be observed directly and photographed. Investigation of the interference effects between engine nacelles and wings arranged in different ways, including the effects of the propeller slipstream, has been continued throughout the year in the propeller-research tunnel. The arrangements investigated include variously cowled nacelles with tractor propellers in combination with monoplane wings and biplanes; tandem propellers with monoplane wings; and pusher propeller nacelles with monoplane wings.

Interference of small protuberances.—The interference investigations that have been carried out in the variable-density tunnel during the past year have dealt largely with the interference and drag of small objects protruding from the surfaces of bodies. An examination of present-day airplanes, both military and commercial, indicates that a considerable part of their drag arises from small projecting objects such as fittings, tubes, wires, rivet heads, lap joints, butt straps, filler caps, and many other objects projecting from the main surfaces that may be classed together as protuberances. A systematic investigation of protuberances differently formed and variously located on both streamline bodies of revolution and on airfoils was therefore undertaken.

The additional drag resulting from a small flat plate protruding at various positions on the surface of a streamline body of revolution was measured over a wide range of values of Reynolds Number. The results showed that the variation of the drag with the position of the protuberance could be entirely accounted for by considering the velocity variations near the bare hull at the protuberance positions as determined from boundary-layer surveys made in the propeller-research tunnel on a 1/40-scale model of the U. S. airship *Akron*. Protuberances of streamline form faired into the body surface were shown to cause only slight increases in drag at large values of Reynolds Number. A report is in preparation giving the results of this investigation.

The effects on the aerodynamic characteristics of an airfoil of variations of the position of a protuberance, and in the height and shape of the protuberance extending along the entire span of the airfoil, were measured. The results indicate that the forward portion of the upper surface of the airfoil is most sensitive to the addition of protuberances. (Technical Report No. 446.) The drag of any bluff object protruding from the airfoil surface should, however, in no case be considered negligible, inasmuch as rectangular protuberances from any part of the airfoil surface caused drag increases of the order of the product of the protuberance frontal area and the dynamic pressure. Rectangular protuberances having a height exceeding one-half of 1 per cent of the airfoil chord produced marked interference effects when located on the forward portion of the upper surface. Such protuberances should, of course, be particularly avoided unless an increased drag is sought.

The characteristics of wings as affected by protuberances of short span were also investigated. These protuberances were of one height and located at one position on the airfoil profile but of various lengths and variously distributed along the span.

The results indicate that the central sections of a rectangular wing are more sensitive to the addition of protuberances than the outer sections and that a very short protuberance in the midspan position may cause a disproportionately large reduction in maximum lift. Consideration is given in the analysis of the results to induced interference effects that may cause disproportionately large drag increases at the higher lift coefficients. At lift coefficients corresponding to high-speed flight the drag due to the protuberances is shown to increase approximately as the total length of the protuberances. The adverse effects are shown to be greatly reduced by the application of simple fairings over the protuberances. A technical report on this work is in process of publication. The investigation of interference is being continued in the variable-density tunnel to include the effects of a wing in various positions with reference to the fuselage.

Wing-nacelle-propeller effects.—The results from the investigation of the relative merits of various arrangements of nacelles with tractor propellers in the propeller-research tunnel have been published during the year. (Technical Reports Nos. 415 and 436.) The effects of idling and locked propellers and of nacelle cowlings on the landing speed of tractor monoplanes have also been studied in connection with this investigation, and the results published. (Technical Note No. 420.)

An investigation of the net efficiency of a nacelle with tractor propeller located in various positions with reference to the wings of a biplane indicated that if the nacelle were placed in the leading edge of the upper wing the net efficiency was practically the same as in the case of the monoplane wing, and when located in the leading edge of the lower wing the results were only slightly inferior. Positions other than in the leading edge of one of the wings proved to be decidedly inferior and a position between the wings, commonly used in practice, gave a net efficiency of 66 per cent, as compared with 75 per cent for the optimum position.

An investigation of tandem arrangements of engines in connection with a monoplane wing revealed that the tandem type in all cases gave lower net efficiencies than the tractor type, and that the highest efficiency was obtained when the nacelles were located below the wing with the forward propeller some distance back of the leading edge. The tandem arrangement in its best position gave a net efficiency of 68 per cent as compared with 75 per cent for the tractor. Increasing the distance between the tandem propellers had a negligible effect on the net efficiency. A report covering the results of this investigation is now in preparation.

A third series of tests on a nacelle with pusher propeller on a monoplane wing is now in progress. With the completion of the present investigation it is thought that the question of wing-nacelle-propeller interference will have been answered in a very comprehensive manner. The large scale of the models (4-foot propellers) and the careful reproduction of the actual airplane parts are particularly noteworthy. The suggestions of manufacturers have been of great help in the preparation of the research programs with a view to practical application of the results.

AIRSHIPS.—At the request of the Bureau of Aeronautics, Navy Department, tests were made in the propeller-research tunnel on a 1/40-scale model of the U. S. airship *Akron*, and various measurements were taken on the airship itself during the performance trials. The wind-tunnel tests included not only the lift, drag, and moment measurements, but also the elevator hinge moments (Technical Report No. 432) and pressure-distribution measurements over the entire hull and control surfaces (Technical Report No. 443). A survey of the boundary layer over the hull was also made, and theoretical computations based on the data thus obtained show very good agreement with force measurements of the drag. (Technical Report No. 430.) Predictions from the results of the wind-tunnel measurements of the hinge moments of the tail surfaces were borne out in the flight tests of the full-scale airship.

The flight tests included pressure-distribution measurements, deceleration tests, turning trials, and the rates of ascent and descent, and were made at the request of the Navy Department and in cooperation with the Goodyear-Zeppelin Corporation. The results of the pressure-distribution measurements and other data have been evaluated and forwarded to the Bureau of Aeronautics. The drag coefficient for the airship deduced from deceleration tests was found to be slightly less than any previously obtained. The longitudinal distribution of pressure along the hull at zero pitch in steady flight was found to be in fair agreement with the measurements made on the model in the propeller-research tunnel. The results also agree fairly well with the theoretical distribution for the hull without the fins.

MANEUVERABILITY.—An investigation of maneuverability of airplanes, requested by the Bureau of Aeronautics, Navy Department, has been continued. The purpose of this investigation is to study the factors that influence maneuverability and to develop a satisfactory criterion of maneuverability. The quantitative data previously obtained have been augmented by the completion of tests with a Navy observation-type airplane. During these tests the pilot performed various selected maneuvers designed to show the separate and combined effects of the factors that contribute to maneuverability. A report on these tests is now being prepared.

PROPELLERS.—A large number of model tests of propellers have been made in connection with the wing-nacelle-propeller investigation, a 4-foot propeller being used. The results of these tests are included in the various reports on the efficiency of the various wing-nacelle-propeller combinations. In some cases the measurements have been extended to low pitch settings and to values of $\frac{V}{nD}$ beyond zero thrust and power to obtain data on negative thrust characteristics, which are of some importance in estimating the landing speeds of airplanes and the speeds of airplanes in dives. As mentioned in the discussion of structural loading, it has been found possible to reduce the speeds of airplanes in vertical dives by adjusting the propeller pitch. The results of a number of tests have been assembled in a report now in preparation, which will provide data on metal propellers at negative thrust analagous to those of Durand and Lesley on wooden propellers published some years ago.

During an investigation of propeller efficiencies at various tip speeds, data were obtained on the direction and velocity of the air leaving the propeller. From these data the distribution of thrust and torque along the blade was computed, and a report giving the results has been published. (Technical Report No. 421.)

AIRFOILS—*Tests in the variable-density tunnel.*—The investigation of a wide variety of related airfoils in the variable-density wind tunnel has been completed, and the results published in preliminary form as Technical Notes Nos. 385, 391, 392, 401, and 404. Meanwhile, all the data have been assembled and the results correlated to show the trend of aerodynamic characteristics with changes of airfoil shape. This information will be made available in a technical report now in preparation.

The main investigation has been extended to include studies of the effects of certain additional changes in the airfoil shape. One series of tests was made to determine the relation between nose shape and the shape of the lift curve at maximum lift. For this purpose, five airfoils were developed from the N. A. C. A. 2412 section by reducing the thickness of the airfoil forward of the maximum-thickness station. A technical note is in preparation giving these results. Another series of tests dealt with the effect of major changes of shape aft of the maximum ordinate. The N. A. C. A. 2412 section was again used as the basic airfoil and the trailing edge was upturned various amounts to produce a stable center of pressure. The results will be incorporated in the report on the main investigation mentioned above.

Several other airfoil studies have been conducted in the variable-density tunnel. Two airfoils of Göttingen 398 section modified by the addition of sharp leading edges were tested in connection with a study of the spinning characteristics of the wings, as described more in detail in the discussion of spinning. The results were published as Technical Note No. 416. Another investigation was made to determine the effects of fabric sag on the aerodynamic characteristics of airplane wings. Two airfoils simulating wings with sagged fabric between the ribs were tested and the characteristics compared with those of the wing without sag. It was concluded that the usual sagging of the wing covering has for practical purposes a negligible effect on the aerodynamic characteristics of the wing. (Technical Note No. 428.) The effect of surface texture on airfoil characteristics has also been further investigated during the year. These data are now being analyzed for publication. They indicate that varying surface conditions have marked effects, and that certain of these effects are not likely to be predicted from low-scale tests.

Several routine tests of nonrelated airfoils have been made at the request of the Army and Navy to provide data for immediate application to practical problems. Tests of a series of well-known airfoils have been carried out through the range of angles of attack from negative maximum lift to positive maximum lift, to provide data needed in the structural design of certain types of airplanes. The results have been published. (Technical Notes Nos. 397 and 412.)

Tests in high-speed wind tunnel.—The results of preliminary investigations in the high-speed wind tunnel have indicated that airfoils of 2-inch chord may be satisfactorily tested and may be considered as of infinite aspect ratio. The airfoils are built of steel for adequate stiffness and the tests are carried through air velocities up to 96 per cent of the velocity of sound. Tests of a series of six commonly used propeller sections are now in progress, and the results thus far have indicated large detrimental effects at speeds well below the velocity of sound. A technical report giving the description of the tunnel and an account of this work is in preparation. One result of this investigation that may find immediate application outside the field of propeller design is the indication of an important compressibility effect on the airfoil pitching moment. Pitching moments considerably greater than those for which an airplane is designed may act on the wings in a dive of high velocity. A related series of symmetrical airfoils having systematic changes in their geometrical characteristics is now under construction as part of a more comprehensive study of the compressibility phenomena, to make possible the correlation of aerodynamic characteristics with changes of airfoil shape.

Theory of wing sections.—A report has been prepared (Technical Report No. 411) on the theory of wing sections of arbitrary shape. This work is being continued and a report is now being prepared which presents an exact treatment of the problem of determining the 2-dimensional potential flow around the wing sections of any shape. The problem is condensed into the compact form of an integral equation capable of yielding numerical solutions by a direct process. An attempt has also been made in this paper to analyze and coordinate the results of earlier studies relating to properties of wing sections. The existing approximate theory of thin wing sections and the Joukowsky theory with its numerous generalizations are reduced to special cases of the general theory of arbitrary sections, permitting a clearer perspective of the entire field. The method not only permits the determination of the velocity at any point of an arbitrary section and the associated lift and moments, but furnishes also a scheme for developing new shapes of predetermined aerodynamical properties. The theory applies also to bodies that are not airfoils, and is of importance in other branches of physics involving potential theory.

Wind-Tunnel Wall Interference.—A theoretical study of the wind-tunnel wall interference has been reported in Technical Report No. 410. This work has been carried on further to check experimentally this theoretical study by tests in the model of the full-scale tunnel, and the results of this work are found to be of considerable interest to wind-tunnel investigators. Not only was the maximum lift found to depend on the nearness to the adjacent wall, but it was also discovered that in some cases the true tunnel axis did not remain entirely fixed. A report on this work is in progress.

Sources of Noise in Aircraft.—During the past year the laboratory has continued its investigation of the sources of noise in aircraft. One phase of the work has been the study of the propeller noise, the research being almost exclusively concentrated on problems of a fundamental nature. Efforts are being made to create a satisfactory and consistent theory of propeller sound capable of explaining the real origin and nature of the very complex disturbances produced by a revolving propeller. In this study the new type of sound analyzer developed last year is being used.

Another phase of the research on sources of noise has been the study of the vibration of aircraft structures. In this work an airplane was suspended in a floating position and excited by a sinusoidal force applied in the plane of the cylinder bank. Test results indicated that the airplane wing system possessed three critical frequencies in which the response became excessively large. Two of these frequencies were within the operating range of the engine speed. Flight tests confirmed the fact that an unusually large vibration amplitude existed. The objects of this research are to accumulate knowledge regarding the essential causes of vibration and noise, to devise efficient methods by which the manufacturer may detect the nature of the difficulty, and to determine means of prevention and elimination.

Work in the Full-Scale Wind Tunnel.—A number of investigations have been made in the full-scale wind tunnel during the year. The aerodynamic characteristics of four different types of airplanes were investigated and compared with the results obtained in flight tests. Satisfactory agreement was obtained, a correction factor for the jet boundary previously determined from tests of a series of airfoils in a model of the full-scale tunnel being used. Several other airplanes were tested at the request of the Army or Navy to answer specific questions of design. Tests of a series of airfoils are in progress at the present time.

Several projects may be mentioned as showing the usefulness of the full-scale wind tunnel in answering questions of practical design that have arisen in connection with the work of the military and naval services. At the request of the Army Air Corps the committee investigated the effect on the take-off characteristics of wheel wells in the wing of a Lockheed Altair airplane. The airplane was installed in the full-scale tunnel and the lift and drag measured with the landing gear retracted and extended and with the wheel wells both open and closed when the wheels were extended. The cockpit was covered on one of the tests to ascertain whether the open cockpit affected the drag appreciably. It was found that neither the open wheel wells nor the open cockpit had an appreciable influence on the drag or take-off characteristics.

In connection with the design of a large flying boat (the P3M–1), the committee was requested by the Bureau of Aeronautics, Navy Department, to investigate the cooling characteristics of the engines located in nacelles between the biplane wings and to recommend, if possible, means for reducing the drag of the nacelle. For these tests a complete engine assembly with a stub wing of 14-foot span was furnished. By an alteration of the tail of the nacelle and the choice of a suitable engine cowling, the drag of the nacelle was appreciably reduced and at the same time satisfactory cooling was obtained.

The Bureau of Aeronautics, Navy Department, also requested an investigation on a Fairchild F–22 airplane to determine the comparative advantages of two wing sections, the N–22 and the N. A. C. A. 2412. It was found that there was practically no difference between the two sections, the principal difference being that the N. A. C. A. 2412 section showed a sharper break in the lift curve at the stall than the N–22.

At the request of the Department of Justice, an investigation was made to test the validity of the claims of Mr. Esnault Pelterie in connection with his suit for infringement of patents on the stick control for airplanes. A Vought Corsair airplane was fitted with the ring and bird type tail surfaces and measurements made to determine the resulting pitching and yawing moments for each.

As a final determination of the jet-boundary corrections for this tunnel, a series of airfoils of the same profile and aspect ratio but of different spans is being tested at air speeds chosen to give the same Reynolds Number for all. The airfoils are of Clark Y section and have spans of 12, 24, 36, and 48 feet. To obtain data on scale effect the tests are being extended to cover a range of Reynolds Numbers from 350,000 to 5,600,000. A marked scale effect on maximum lift is indicated thus far by the tests.

The optimum position of a wing with reference to a fuselage has never been determined for high Reynolds Numbers. At the request of the Army Air Corps, an investigation of this question has been started. A YO–31A airplane with gull wing has been chosen for the investigation. The airplane has been tested, and a mock-up fuselage of the same airplane is under construction to permit testing with the wings in different positions. For some of the tests the gull-wing roots are replaced by a straight center section, permitting the position of the wing to be changed. The program includes also a thick cantilever wing at the bottom of the fuselage. In addition to the force measurements, pressure-distribution measurements will be made on the wings for each of the various wing positions and also a survey will be made to determine the direction and velocity of the air at all points about the tail surfaces.

SEAPLANES.—The N. A. C. A. tank, or seaplane channel, for the study of hydrodynamic problems connected with aeronautics is now in regular operation. The program for the tank includes several items of direct interest to the aircraft industry, a number of investigations specifically requested by the Bureau of Aeronautics, Navy Department, and also certain items which may be classed as fundamental information.

Effects of variations in dimensions and form of hull on the take-off of flying boats.—The forms given to the hulls of flying boats differ radically according to the designer and the country. It seems hardly possible that all of the five distinct types, which can be easily recognized, can be of equal merit. The determination of the effect of the form and the dimensions of the hull on the take-off of a flying boat is therefore of immediate interest. In this problem are included not only the resistance to propulsion along the water, but also the attitude assumed and the spray thrown.

The effects of variations in dimensions are being studied by tests of a series of models derived from a common form by systematic variations in dimensions. The effects of variations in fundamental form are being studied by tests of models representing several of the distinct types.

The nature and amount of spray thrown out during the take-off is of special interest. If it is heavy and is thrown into the propellers these may be damaged. If it strikes the wings or other surfaces damage may be done or resistance increased. One of the simpler methods of reducing the spray and changing its direction is to fit narrow strips along the side of the hull, usually projecting from the chine at an angle, which will deflect the rising sheets of water.

A model of a hull which was known to have good performance was selected, and to it were applied successively spray strips having various angles and various widths. Tests of these showed that the wider strips at sharper downward angles gave the better suppression of the spray and that the resistance was affected but little. A technical note describing these tests is being prepared.

Floats for seaplanes.—At the request of the Bureau of Aeronautics, the committee is investigating the manner in which variations in the form and dimensions of the twin floats used in high-speed seaplanes affect the performance during take-off. This investigation is conducted with model floats which are varied in dimensions and form much as in the case of the flying-boat hulls.

Fundamental information regarding planing surfaces.—For a large part of the take-off run of a seaplane that part of the weight of the craft not supported by the wings is supported by the hydrodynamic reaction of the water on the bottom of the float or boat. In the actual craft, or complete model, the various phenomena connected with this stage are so entangled that the effects from the bottom alone can not be studied separately. However, by testing surfaces that skim along the top of the water simulating only the bottom of a float, much valuable fundamental information can be obtained, and by its use it will be possible to understand more perfectly what happens under the bottoms of actual floats.

Surfaces for such tests have been procured and tests are planned to begin shortly.

Frictional resistance of boat surfaces.—The frictional resistance of those surfaces of a boat hull which are exposed to the passing water has been determined quite accurately for speeds up to about 15 miles per hour. For speeds of from 30 to 60 miles per hour, or higher, the frictional resistance can only be estimated. Furthermore, the effect on this resistance of slight structural roughnesses produced by rivet heads, plate butts, etc., is practically unknown.

Friction plates which are to be towed at relatively high speeds to determine the frictional resistance and the effect of roughnesses have been procured and are being prepared for testing. The information obtained from these tests should make possible a decision as to how smooth a boat bottom need be or how large an increase in resistance must be accepted if rivet heads project. It should also help in the more accurate estimation of the resistance of model and full-size hulls.

BUREAU OF STANDARDS

WIND-TUNNEL INVESTIGATIONS—The aerodynamic activities of the Bureau of Standards have been conducted as heretofore in cooperation with the Aeronautics Branch of the Department of Commerce and the National Advisory Committee for Aeronautics. The work completed and in progress may be summarized under the following heads:

Improved apparatus for measuring turbulence.—A report has been submitted for publication describing recent improvements in the design of the equipment associated with the hot-wire anemometer for the measurement of fluctuating air speeds in turbulent air flow. The design of amplifiers and compensating circuits is discussed in some detail and a description is given of attempts to measure the distribution of the energy of the fluctuations with respect to frequency. With the improved equipment, fluctuations of air speed with frequencies up to 5,000 cycles per second may be studied.

Increasing the aerodynamic efficiency of jets.—A report has been completed on the studies of the effects of deflectors, guide vanes, ring-shape airfoils, and Venturi tubes on the thrust reaction of free jets. The augmentation of the thrust obtained was not sufficient to make jet-propulsion practical at ordinary airplane speeds.

Computation of boundary-layer flow.—The air flow in the boundary layer of a plate subjected to sinusoidal variations of pressure along the length of the plate has been computed by an approximate method for the case of laminar flow. If one imagines the sinusoidal pressure variation to move slowly along the plate, the computed fluctuation of the air speed at a fixed point varies with the distance of the point from the plate in a manner similar to that measured experimentally by the hot-wire anemometer. The mean velocity is nearly the same as it would be if there were no pressure fluctuations present. It has thus been concluded that the large speed fluctuations in that part of the boundary layer which is inferred to be laminar from the character of the distribution of mean speed are forced by the turbulence of the external stream. The amplitude of the fluctuations within the layer is much greater than the amplitude in the external stream.

Aerodynamic characteristics of conventional control surfaces.—Measurements of the yawing moments due to rudders of several spans and chords have been described in Technical Report No. 437, "The Effect of Area and Aspect Ratio on the Yawing Moments of Rudders at Large Angles of Pitch on Three Fuselages."

Two short papers have been prepared dealing with ailerons, in which questions raised in the discussion of Technical Reports Nos. 298, 343, and 370 have been answered. These papers deal with the mutual interference between ailerons on opposite wings and the effect of aileron displacement on wing characteristics.

REDUCTION OF AIRPLANE NOISE.—Measurements have been completed on the reduction of noise and of engine horsepower due to several mufflers intended for use on airplane engines. It was concluded that it is not profitable to use mufflers unless the propeller noise is less than the noise of the unmuffled engine, which means in general that the propeller tip speed must be as low as 650 to 700 feet per second; that the use of a manifold system in itself gives a considerable muffling effect; that it is possible to reduce the noise of the unsilenced engine (open-port condition) in the absence of the propeller by 15 to 20 decibels by means of a muffler with an added weight of 30 or 40 pounds and a reduction in engine horsepower of less than 3 per cent. The detailed results will be published in an aeronautics bulletin of the Aeronautics Branch of the Department of Commerce.

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 development of particular instruments outlined below:

Temperature coefficient of elastic moduli.—The experimental work has been completed on the determination of the temperature coefficient of the elastic moduli of elastic materials for aircraft instruments. The temperature coefficient was measured in the temperature range $-50°$ to $+50°$ C. and data were obtained on the effect of heat treatment, strain hardening, and external stress. It was found that, except for tungsten, the temperature coefficients of two elastic moduli are practically the same, and are independent of external stress within the range applied. The coefficients generally increase with increase in temperature and vary considerably with the heat treatment or cold work of a given material. A report has been prepared on the investigation, and is now being edited.

Reports on aircraft instruments.—A report on current methods of measuring air speed and ground speed, emphasizing descriptions of, and performance data on, the instruments, was completed and has been published as Technical Report No. 420. A second draft of a report on power plant instruments was practically completed. Considerable progress was made on reports similar in scope on altitude instruments and on compasses.

Friction of pivots.—Attention was given to improving the apparatus for making the measurements, modification of which has been completed.

Airship thermometers.—Four electrical resistance thermometers of the type previously developed for use in the flight testing of airplanes were constructed for use on airships in measuring the free-air temperature. The instruments are of the unbalanced Wheatstone-bridge type. The temperature-sensitive resistance element is mounted on the airship so as to be in the free air, and the indicator and other parts are installed in the control car. This type of instrument has the advantage that it can be built to have a much smaller time lag in indication than liquid-in-glass thermometers.

Strut thermometer.—Distant-indicating thermometers now available are far from satisfactory for service use in airplanes to measure free-air temperature. An experimental thermometer of the bimetal type, which was designed to be mounted as a unit on a strut of the airplane, was constructed. The thermometer indicates on a dial sufficiently large so as to be easily read from the cockpit.

WASHINGTON NAVY YARD

The wind-tunnel equipment at the Washington Navy Yard consists of an 8 by 8 foot closed-circuit type, built in 1913, and a new 6-foot closed-circuit type, recently completed. The 6-foot tunnel has been continuously employed on current design and related problems during the past year. The early completion of the balance for the 6-foot tunnel will enable such testing to be made under more favorable conditions. Testing to date in the 6-foot tunnel has been confined to air-flow and simple drag measurements. Some vibration difficulties due to the type of construction were found and eliminated in the preliminary tests.

The Washington Navy Yard tests are concerned largely with complete model airplanes, the routine tests covering the measurement of lift, drag, pitching moments, and yawing moments, and the moments being obtained for a series of control positions. Rolling moments are not considered a part of routine tests, although measured on unconventional designs. The nonroutine tests for the greater part consist in studies of fairing and slight changes for drag reduction and in tests for improvement of control and stability.

In accordance with established policy the wind-tunnel work of the Washington Navy Yard is confined to problems relating directly to the design of naval aircraft. All research investigations of a fundamental aerodynamic nature are requested from the National Advisory Committee for Aeronautics.

MATÉRIEL DIVISION, ARMY AIR CORPS

The present wind-tunnel equipment at Wright Field consists of two wind tunnels, a 5-foot tunnel, and a high-speed tunnel 14 inches in diameter, both of the N. P. L. type.

The work in the 5-foot wind tunnel is concerned largely with design problems and routine tests on airplane models of designs submitted to the Air Corps. Models of the XP-936, XP-900, XP-25, and YO-31 airplanes were tested for lift, drag, and stability.

Special wind-tunnel tests.—Tests were made to determine the aerodynamic effects of various changes in fairings, cowlings, wing shapes, tail shapes, cockpit enclosures, and landing-gear designs. Airplane accessories such as Venturis, impellers, radiators, and tail wheels were tested also.

Wing location and root shape.—A study based on wind-tunnel tests was made of the effects of the vertical location of a monoplane wing. Several methods of attaching and fairing the wing into the fuselage were employed.

Tail design.—It has been necessary to make a large number of wind-tunnel tests of models with modified tail assemblies. The necessity for changes in tail design has usually arisen from changes which have been made in the cockpit enclosures, engine nacelles, or wing center sections.

Performance estimates.—Estimates of the performance of many of the existing and proposed airplanes with alternative power-plant installations were made. Consideration was given to engines under development as well as to standard types.

Autogiro.—An autogiro was tested in flight and the data thus obtained formed the basis for a study which was made to determine the practicability of adapting such a machine to the military service.

Controllable propellers.—Considerable progress has been made in the development of mechanisms for controlling the pitch setting of propellers while in flight.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

ORGANIZATION

The present organization of the committee on power plants for aircraft is as follows:

Hon. William P. MacCracken, jr., chairman.
George W. Lewis, National Advisory Committee for Aeronautics, vice chairman.
Henry M. Crane, Society of Automotive Engineers.
Prof. Harvey N. Davis, Stevens Institute of Technology.
Dr. H. C. Dickinson, Bureau of Standards.
Carlton Kemper, National Advisory Committee for Aeronautics.
Capt. Clements McMullen, United States Army, matériel division, Air Corps, Wright Field.
Commander C. A. Pownall, United States Navy.
Prof. C. Fayette Taylor, Massachusetts Institute of Technology.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

Compression-Ignition Engines.—The continued improvement in the safety and performance of aircraft is dependent upon a continued increase in the reliability, power output, efficiency, and safety of aircraft power plants. The low specific fuel consumption obtained with the compression-ignition engine for a wide range of propeller loads and the reduced fire hazard when Diesel fuel oil is used are the two outstanding advantages of this type of engine which warrant its continued development as a power plant for aircraft. These advantages are of such importance for commercial rigid airships that compression-ignition engines are already being used as power plants for airships in spite of their decreased power output per cubic inch of displacement, which makes them unsuitable at present as power plants for airplanes. The researches of the committee on the compression-ignition engine have been directed toward increasing the specific power output of this type of engine by the use of improved fuels and by the accumulation of new knowledge concerning the injection and combustion characteristics of fuel sprays.

Fuel spray characteristics.—The design of suitable combustion chambers for compression-ignition engines is influenced by the distribution of fuel sprays. Research has been conducted to determine the relative distribution of the fuel throughout the spray during injection. The methods employed at the start of this investigation consisted of injecting the fuel against targets of Plasticine and of directing normal to the fuel spray a jet of air of small diameter having an extremely high velocity. The targets showed that the greater part of the fuel in the spray was concentrated in the spray core. The spray core could not be disrupted by the air flow unless the velocity of the fuel jet was considerably less than that usually employed in compression-ignition engines. Further tests in which fuel sprays were directed counter to each other showed that the core was discontinuous, since the two sprays would apparently penetrate through each other with little interference if the point of impingement was at least 1 inch from the nozzle.

The process by which a solid jet of fuel issuing from an orifice is disintegrated to form a fuel spray has been determined from photomicrographs, made at a magnification of 10 diameters, of various sections of fuel sprays during injection. The photomicrographs showed clearly the progress of the jet disintegration under varying conditions of jet velocity, air density, fuel viscosity, and discharge-orifice diameter. A comparison of the results obtained with fuel sprays injected into a vacuum with those of sprays injected into dense air showed that, although the turbulence of the fuel flow assisted the disintegration of the fuel jet, the greater effect was obtained from the interaction of the liquid fuel with the air into which the fuel was sprayed. The results showed that the rate of jet disintegration could be increased by increasing the relative velocity between the fuel and the air, by increasing the air density, or by decreasing the fuel viscosity and the orifice diameter. The results of the research on spray distribution have been published as Technical Report No. 438.

The research on the hydraulics of fuel-pump injection systems has been extended to include the determination of the rates of fuel injection when a cam-operated fuel-injection pump and an automatic injection valve are used. The data showed that the rate of fuel discharge from a given pump injection system could be varied considerably by variations in the length and diameter of the injection tube, the injection valve-opening pressure, and the discharge-orifice diameter. The data also showed that in the design of a fuel-injection system, the system from the pump to the discharge orifice should be considered a unit. The results of this investigation are described in Technical Report No. 433.

Combustion in compression-ignition engines.—The necessary improvement in the performance of compression-ignition engines that will warrant their use in airplanes is dependent upon increased knowledge concerning the various stages in the combustion process. Outstanding progress has been made with the N. A. C. A. fuel-spray combustion apparatus in determining the rates at which present fuels vaporize under conditions of air density, temperature, and air flow comparable to those occurring in the engines during the injection period. A description of the apparatus and the results of preliminary tests have been published in Technical Report No. 429.

An investigation to determine the effect of air flow velocities from 0 to 800 feet per second when directed counter to and normal to fuel sprays has been made with the combustion apparatus. The tests showed that although the air flow has considerable effect on the spray envelope and on the whole spray after injection is completed, the main core of the spray is only slightly deflected during injection.

A series of five fuels covering a range of boiling points as measured under atmospheric conditions from 150° to 375° F. has been used in investigating the effect of engine speed, temperature of the combustion-chamber walls, injection advance angle, and fuel quantity on the vaporization of fuel sprays. During injection the fuel vaporized at a rate that far exceeded the rates at which the fuel had previously been thought to vaporize. The results showed that the vaporization was materially affected by the boiling temperature of the fuel and by the temperature of the combustion-chamber and cylinder walls. The flame records showed that unless combustion by auto-ignition was forced to take place before all of the fuel was injected, the burning started almost simultaneously throughout the combustion chamber and was accompanied by violent combustion shock. The diffusion of the fuel vapors was found to be more rapid and uniform than the diffusion of the atomized fuel spray. Technical Report No. 435 has been published giving the results of this investigation.

The increasing interest in the development of fuels for high-speed compression-ignition engines and the differences in the combustion characteristics of several fuels indicated that it would be desirable to have a method of determining by simple engine tests the suitability of a fuel for the operating conditions of an individual engine, and which one of several fuels is most suitable. Tests made with an engine having no effective air flow in the combustion chamber were found to be of more value in rating fuels than those made with combustion chambers having effective air flow.

The engine tests led to the conclusion that a fuel that will allow injection to be advanced beyond the optimum injection advance angle without encountering excessive knock or excessive cylinder pressures is a satisfactory fuel for that particular engine and its operating conditions. A comparative rating of several fuels may be obtained by determining the consistent operating range of the injection advance angle. This range is directly dependent upon the ignitibility of the fuel, but involves no question of the method of measuring ignition lag. Fuels with longer consistent operating ranges are more satisfactory for engine operation. The results of these tests have been published in Technical Note No. 418.

The reduction of combustion shock in compression-ignition engines depends to a great extent on the reduction of the time interval between the injection of fuel into the engine cylinder and the start of combustion. During this time interval the fuel absorbs sufficient heat from the high-temperature air to raise it to its auto-ignition temperature. The addition of heat to the fuel before its injection into the combustion chamber should reduce this time interval. Tests have been made to determine the effect on ignition lag and combustion of preheating Diesel fuel oil before injecting it into the combustion chamber. As the addition of heat to the fuel results in decreased spray penetration, the tests were conducted with engines having precombustion and quiescent-combustion chamber shapes. The results showed that preheating the fuel to 330° F. reduced the ignition lag and combustion shock. The greater reduction in ignition lag was obtained with the combustion-chamber shape having high-velocity air flow.

The process of combustion in the engine cylinder can be followed by a chemical analysis of the gases taken from the engine cylinder. A stroboscopic valve has been designed and constructed so that samples of the charge in the combustion chamber may be removed for chemical analysis at any point in the cycle. This gas-sampling valve is inertia-operated and the mechanism is driven through a flexible shaft. The effective opening period is less than 0.0003 second, although the valve stem leaves the seat for slightly more than 0.0004 second. These values are independent of operating speed.

The valve has been used in the integral combustion chamber to determine whether its contents remain in a quiescent state during combustion. Gas samples taken during the combustion period with the fuel injected through a standard 6-orifice nozzle showed the increase in carbon dioxide content of the gases almost coincident with the rise of pressure in the cylinder. When a 2-orifice nozzle was used with the gas-sampling valve located in a part of the combustion chamber not served with fuel, no carbon dioxide could be detected in the samples obtained, indicating that combustion does not materially affect the quiescent condition of the combustion chamber.

The accumulation of engine exhaust gases in the unventilated cockpits of airplanes powered with carburetor engines is dangerous, because of the percentage of carbon monoxide contained in the exhaust. An investigation was made to determine the quantity of carbon monoxide in the exhaust gases from spark-ignition and compression-ignition engines for a range of operating conditions. An analysis of the samples of exhaust gas taken at the exhaust valves of a single-cylinder universal test engine operating with aviation gasoline at two-thirds and full load and with both a carburetor and a fuel-injection system showed 5 per cent by volume of carbon monoxide in the exhaust. A 500-horsepower multicylinder radial engine operating under service conditions showed an average of 7 per cent carbon monoxide in the exhaust. When the compression-ignition engine was operated with a clear exhaust, the carbon-monoxide content of the exhaust gases varied from 0.03 to 0.50 per cent. With excessive smoke and flame in the exhaust the percentage of carbon monoxide increased to 0.75 per cent. The results indicate that the use of compression-ignition engines will considerably reduce the danger of carbon-monoxide poisoning.

Combustion-chamber investigation—Integral type.—The basic requirements for injection-valve nozzles for quiescent combustion chambers as formulated last year assumed that the effective pressure on each individual orifice was the same. As the total discharge area was increased to take care of the increased fuel required for supercharged operation, it became apparent that the required equal pressures were not being maintained. A method was devised for catching and weighing the discharges of the individual orifices and increasing the size of orifices where necessary to maintain the proper proportional distribution throughout the combustion chamber.

The engine performance tests of a quiescent combustion chamber with supercharging have been continued and have included an investigation of the effect of scavenging the combustion space by using valve overlap. The results of this investigation have shown that an increase in power from the additional air available for combustion is obtained and that the removal of the residual products of combustion has a beneficial effect on the combustion of the fuel and allows greater quantities of fuel to be burned without smoke or flame appearing in the exhaust. The brake mean effective pressure obtainable with clear exhaust increases repidly with increase of inlet pressure up to 3 inches of mercury above atmospheric pressure, indicating that this pressure will effect the complete scavenging of the combustion space. The increase in performance with clear exhaust under these conditions is 33 per cent greater power and 16 per cent less specific fuel consumption. The results of these tests have been prepared for publication.

Combustion chamber investigation—Auxiliary-chamber type.—The engine performance tests of the auxiliary chambers containing 20, 35, 50, and 70 per cent of the total clearance volume have been completed and an analysis of the results showed that variation of clearance distribution had little effect on control of combustion, although maximum pressures and rates of pressure rise were least with the 35 per cent chamber. A slight gain in performance was obtainable with the larger chambers, but it was not commensurate with the increase in maximum pressures and rates of pressure rise. The results of these tests have been published in Technical Note No. 435.

The work on this type of combustion chamber has included an investigation of the effect of variation of the diameter of the connecting passage between the cylinder and the auxiliary chamber. This change was in effect a variation in the velocity of the air entering the auxiliary chamber. The results of this investigation showed that a passage size determined for maximum engine speed would permit satisfactory performance at lower speeds. Passage sizes so small as to cause large pressure differences between cylinder and chamber were too small to allow good performance and were responsible for large throttling losses as evidenced by high friction mean effective pressure. With the larger sizes the air velocity was so reduced that the mixing of the fuel and air was not effective, and the engine performance suffered from incomplete and delayed combustion. Between these two extremes there was a satisfactory operating range in which the passage size was not very critical. Technical Note No. 436 presents the results of this investigation.

Fire Hazard in Aircraft—*Carburetor intake-system backfires.*—The investigation on confining carburetor intake-system backfires has been completed. The results are reported in Technical Report No. 409.

Hydrogenated safety fuels.—The use of fuels of low volatility having flash points at atmospheric conditions of 105° F. in conventional spark-ignition engines continues to be an attractive method for reducing the fire hazard in aircraft. The antiknock characteristics of these fuels have been improved by the manufacturer, so that they can now be used at a maximum compression ratio of 8.5 without the addition of tetraethyl lead or other fuel dope. The investigation of the engine performance obtained with these safety fuels injected into the engine cylinder has been continued Progress has been made in reducing the specific fuel consumption with safety fuels by improving the distribution of the fuel spray and by increasing the temperature of the engine coolant from 150° to 250° F. With direct fuel injection a brake mean effective pressure of 144 pounds per square inch and a specific fuel consumption of 0.49 pound per brake horsepower per hour have been obtained at a compression ratio of 7.5 and an engine speed of 1,500 revolutions per minute.

The performance characteristics of these safety fuels at higher speeds and compression ratios are being determined for the Bureau of Aeronautics of the Navy Department. Alterations have been made to an N. A. C. A. universal test engine to permit the maximum rotative speed of the engine to be increased from 1,800 to 2,400 revolutions per minute.

The increase in the buoyancy of rigid airships as the fuel supply is consumed is counteracted by the condensation of water vapor from the engine exhaust. Because of the lower hydrogen content of the safety fuel as compared with gasoline, the airship industry is interested in knowing the quantity of water recoverable from the exhaust of an engine using safety fuels. The results obtained from a single-cylinder test engine operated with a carburetor and gasoline and with a fuel-injection system and safety fuel indicated that the water recovered from the exhaust when the safety fuel was used was 80 per cent of that obtained when gasoline was used.

INCREASE IN ENGINE POWER—*Two-stroke-cycle investigation.*—The use of the 2-stroke cycle instead of the 4-stroke cycle with internal-combustion engines is a method of obtaining increased power output per unit of weight and displacement. The committee is conducting investigations to determine the effect of the various factors influencing the performance of an engine of this type having gasoline injection and electric ignition. A new water-cooled cylinder and cylinder head have been constructed to continue this investigation at higher speeds and power outputs than were possible with the air-cooled 2-stroke-cycle engine. The new engine can be operated at a maximum speed of 2,000 revolutions per minute. Preliminary tests have been conducted at a compression ratio of 5.0, which indicate exceptional promise for this type of engine on the basis of increased horsepower per cubic inch of displacement.

Large valve overlap.—An appreciable gain in engine performance can be obtained by completely scavenging the clearance volume of a 4-stroke-cycle engine. This improved scavenging can be obtained efficiently by using a large valve overlap and a low boost pressure in the inlet manifold. With a fuel-injection system the time of fuel injection can be controlled to prevent the loss of fuel with the scavenging air. The results of tests made with a single-cylinder engine for a range of compression ratios from 5.5 to 8.5, a valve overlap of 112°, and an engine speed of 1,500 revolutions per minute, showed that complete scavenging of the clearance volume could be obtained with a pressure difference of 2 to 5 inches of mercury across the intake and exhaust valves. The results showed that with a compression ratio of 6.5, a boost pressure of 2 inches of mercury, and a fuel quantity giving 98 per cent of maximum power, the brake mean effective pressure developed was 182 pounds per square inch and the corresponding fuel consumption 0.44 pound per brake horsepower per hour. A comparison of the brake mean effective pressure obtained in operation with valve overlap and fuel injection as compared with that obtained in operation with normal valve timing showed a gain of 18 per cent in brake mean effective pressure obtained by improved scavenging.

Hub dynamometer.—The flight testing of airplanes is handicapped because there are no means available for measuring the power delivered by an engine in flight. The committee has developed a hydraulic dynamometer that may be attached to the hub of a propeller and that records photographically the torque developed by an engine. The power developed may be calculated from the known torque and engine speed. During the year the dynamometer has been adapted to permit measuring the torque developed by engines equipped with steel propellers. The necessary temperature corrections for the variation in volume of the liquid in the dynamometer with change in air temperature have been determined. The dynamometer has been flight-tested in a Vought O3U-1 airplane for 20 hours and found to operate satisfactorily. The precision of the propeller-hub dynamometer will be determined by tests to be made in the full-scale wind tunnel with a liquid-cooled engine mounted in a special test fuselage fitted with a torque dynamometer.

COWLING AND COOLING OF AIRCRAFT ENGINES—*Cooling properties of finned surfaces.*—The development of air-cooled engines having increased power output is dependent upon an improvement in the efficiency with which the waste heat from the engine cylinder can be dissipated to the cooling air. The effect of fin pitch, width, thickness, and shape on the quantity of heat dissipated by finned cylinders has been determined from tests made with a constant heat input and a range of air speeds from 30 to 150 miles per hour. The results of these tests indicate that for tapered fins having widths of 1 inch or less there is no interference with the air flow between the fins providing the fin pitch is greater than 0.15 inch.

Patterns of the air flow around a cylinder mounted in the wind tunnel showed that approximately one-half the cooling area of the cylinder does not come in contact with the cooling air stream, because of the breakaway of the air stream from the cylinder. To determine the temperature distribution when the entire cooling area was used, a finned cylinder was enclosed with a cowling and the cooling air forced past the cylinder by a Roots blower. This method of cooling resulted in a greater quantity of heat being dissipated and more uniform temperature distribution around the cylinder being obtained for the same tunnel air speed. An investigation to determine the minimum quantity of air required to cool present air-cooled engines under operating conditions is being conducted with a single-cylinder air-cooled test engine.

Cowling of engine nacelles.—Comparative drag and cooling tests were made for the Bureau of Aeronautics, Navy Department, with a P3M-1 engine nacelle. Three antidrag rings of various shapes were tested in combination with modifications made to the nose and tail of the nacelle to improve the cooling at air speeds of 60, 80, and 100 miles per hour. A substantial reduction in cylinder and oil temperatures was obtained by the use of deflectors between the cylinders and an oil cooler placed in the inlet manifold between the carburetor and the engine.

BUREAU OF STANDARDS

Altitude tests of aircraft engines.—A report is in preparation on the distribution of fuel heat in the Curtiss D-12 engine, supercharged and unsupercharged, under a variety of controlled operating conditions and at various altitudes. Study of formulas proposed for estimating the altitude performance of aircraft engines from sea-level tests indicates the need of additional experimental data (1) on the variation of horsepower with carburetor air temperature when there is a supercharger between the carburetor and the engine, (2) on the influence of initial temperature and pressure conditions upon the compression ratio of a supercharger and upon the power required to drive it, and (3) on the effect of engine compression ratio upon the variation of horsepower with exhaust pressure.

Phenomena of combustion.—A comprehensive investigation of the effect of inert diluents (argon, helium, and nitrogen) on the gaseous explosive reaction between equivalent amounts of carbon monoxide and oxygen has been completed. The gases in each case were saturated with water vapor. The preparation of a report on this work for publication by the National Advisory Committee for Aeronautics was interrupted by the sudden death of Doctor Stevens on May 17. It is now almost ready for release, after revision by his successor in accordance with the suggestions of Doctors Kassel, Lewis, Von Elbe, and Tolman. The immediate program contemplates a similar study in the presence of smaller quantities of water vapor.

Combustion in an engine cylinder.—The effect of combustion-chamber shape and number and location of ignition points on flame movement and pressure development in an engine cylinder are being studied with 4 different combustion chambers, 7 different locations of a single ignition spark, and 2 different arrangements of twin ignition. A small camera is used in photographing, through the stroboscope, the many small windows symmetrically distributed over the engine head. The protographs check satisfactorily with visual observations and provide a permanent record of the progress of the flame.

Improved equipment has been developed for measuring infra-red radiation from the explosion in the engine cylinder. The apparatus is sufficiently sensitive to permit observations with a stroboscope opening of only 1° or 2° of engine crank-angle while using a selected series of filters to indicate roughly the spectral distribution of the radiant energy over the region from the visible to about 11μ. Studies are being made to determine to what extent such data can be interpreted in terms of charge temperature and chemical composition.

Pressures and temperatures in aircraft engines.—A special engine head was prepared and used for direct comparisons of diaphragm-type indicators, and for studying the effect of indicator location and of adapters which interpose a passage between the engine and the pressure element. Experiments indicated that, in the absence of detonation, pressure readings were independent of the location of the indicator in the cylinder head, but that long, narrow connecting passages caused a marked increase in the measured pressures during explosion, and magnified greatly the variations from cycle to cycle. These errors introduced by the connecting passage become more prominent as maximum explosion pressures increase.

Mechanism of atomization.—A review of available data, both theoretical and experimental, on the atomization accompanying solid injection indicates quite definitely that such atomization, like air-stream atomization, is a surface phenomenon. Both can be explained by the formation of ligaments at the liquid-gas interface, under the influence of the relative motion of gas and liquid, followed by the collapse of these ligaments under the influence of surface tension. The results of this study are being published as Technical Report No. 440.

Effect of spark character on ignition ability.—The use of the cathode-ray oscillograph to measure the voltage and current in the spark discharge without appreciably altering the character of the spark presented unexpected difficulty, owing to the low inductance and capacitance of the ignition circuit. A report on the Theory of Voltage Dividers and Their Use With Cathode-Ray Oscillographs will be found in the Bureau of Standards Journal of Research for July, 1932 (RP 460). A report on the measurement of current in the spark discharge is in preparation. Further study of the effectiveness of ignition sparks, as measured by the amount of chemical reaction occurring when different sparks are passed through lean mixtures of oxygen and hydrogen at atmospheric pressure, was made necessary by the discovery that changes in the length and location of the high-tension leads may alter the character of the spark.

The ignition laboratory is studying also the reliability of spark ignition and the phenomena of autoignition at the request of the Bureau of Aeronautics. In connection with the latter problem, the effects of pressure and temperature on the ultra-violet absorption spectra of various hydrocarbon vapors with and without air have been determined with a quartz spectrograph. Preliminary attempts to detect preflame oxidation of fuel-air mixtures in the engine have been made by passing light from an iron arc through a pair of quartz windows in the combustion chamber and through a stroboscope to the spectrograph. In order to isolate the effect of temperature, fuels which show no change in absorption with pressure have been employed in the engine tests.

Radio-shielded ignition equipment.—As a basis for preparing Army-Navy specifications on shielded ignition harnesses, tests were conducted jointly at the Naval Aircraft Factory in Philadelphia and at the Bureau of Standards on available commercial types of shielded harnesses applicable to radial aircraft engines. The five types tested were found equally satisfactory from the standpoint of radio-interference shielding but they differed with respect to accessibility, strength, shielding efficiency, and waterproofing. Tests of the Curtiss D–12 engine with and without a radio-shielded ignition system were made in the altitude laboratory at pressures corresponding to altitudes from sea level to 20,000 feet. No significant effect of the shielding on the altitude performance of the engine was found.

Effect of air humidity on engine performance.—As a result of the tests reported in Technical Note No. 309 and Technical Report No. 426 of the National Advisory Committee for Aeronautics, the National Advisory Committee has adopted standard dry-air pressures as a basis for correcting sea-level and altitude tests of aircraft engines. A corresponding revision of the power-correction formula in the S. A. E. Handbook has been proposed. Preliminary work on the injection of water spray into the combustion chamber of a variable-compression engine at compression ratios from 4:1 to 10:1 verified earlier results, but funds were not available for completing the test program.

Tests at subfreezing temperatures on the modified psychrometer developed during this research showed that it functioned satisfactorily when supercooled water was used. It was also found that, for low air temperatures, humidity determinations with a psychrometer in which a thermometer covered with a thin film of ice replaced the wet bulb were more reliable than those obtained with the customary frozen-wick wet bulb.

Gumming characteristics of gasolines.—The investigation of the gumming characteristics of gasolines, undertaken at the request of the Air Corps, deals with the determination of the gum contents of gasolines and the evaluation of their tendency to form gum during storage. It is obviously necessary to have a significant method for the determination of gum content before any limit can be set on the permissible gum content for satisfactory engine operation and before the increase in gum content in storage can be followed. Since evaporation in the engine manifold takes place in a current of air, work in the laboratory was concentrated on an evaporation method using an air jet. Each of the variables affecting evaporation in the manifold was investigated over a wide range in connection with the laboratory evaporation method. It was found that changes in the conditions during evaporation affected the absolute values for gum content, but that the relative gum contents of a series of gasolines were independent of the particular conditions used in the evaporation, so long as these conditions were held constant during the series. Accordingly, any convenient and reproducible air-jet method is equally significant for the determination of gum content, and evaporation from a bath maintained at 200° C. was found to be the most convenient.

The investigation of gum stability presents considerable difficulty, for it is desirable to develop a method which will tell in advance how much gum a gasoline will contain when stored for periods of six months to two years. Preliminary work has shown that the gum stability of gasolines decreases very rapidly as the temperature is increased. Accordingly, storage experiments are being made with several gasolines over a wide range of elevated temperatures with the idea of extrapolating to the stability at ordinary storage temperatures. It is hoped that this work will lead to a test method in which the measurement of stability at about 100° C. will permit an accurate prediction of stability at ordinary temperatures.

Type testing of commercial aircraft engines.—During the year, 27 type tests and 4 calibration tests were undertaken at the Arlington laboratory, involving 18 engine types submitted by 11 manufacturers. As a result, 14 engines passed, 14 failed, and 3 were withdrawn. Only 3 of the 14 engines which failed ran more than halfway through the 50-hour endurance test and 6 failed to complete the first 5-hour period. Four engine types failed two or three times each during the year, whereas five improved types passed on retest. Valves were the most common source of major failure, four cases being noted. Piston seizure, crankshaft breakage, and cylinder-head cracks were responsible for two failures each. The following parts each caused one major failure: Cylinder-head studs, thrust-bearing-plate studs, connecting-rod lock rings, and knuckle pin. At the end of June, 84 engines had received approved-type certificates from the Department of Commerce.

The department's revised aircraft-engine requirements (to be effective January 1, 1933) call for a 50-hour preliminary test by the manufacturer at the proposed rated speed and increase the severity but not the duration of the present type test. The revised regulations include special requirements for altitude engines, i. e., engines which are not designed for operation at full throttle below a specified altitude. In the case of such engines, the rated altitude and the maximum altitude power to be assigned to the engine will be based on an approximate altitude test. Equipment for making dynamometer calibrations and approximate altitude tests of air-cooled aircraft engines is being installed at the bureau.

REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT

ORGANIZATION

During the past year the committee on materials for aircraft has suffered the loss of its chairman, Dr. George K. Burgess, by his death in Washington on July 2, 1932. Doctor Burgess had served as chairman of the committee on materials for aircraft since 1923 and had been a member of that committee since 1917. He rendered invaluable assistance in the coordination of the activities of the Army Air Corps, the Bureau of Aeronautics of the Navy, the National Advisory Committee for Aeronautics, and other agencies, especially in connection with the investigation of problems relating to aircraft materials. Both the committee on materials for aircraft and the executive committee at their meetings following the death of Doctor Burgess recorded their sorrow at his death and their sincere appreciation of his long and faithful service.

The vacancy in the chairmanship of the committee on materials for aircraft has not yet been filled, and in the meantime the activities of the committee are being conducted under the leadership of the vice chairman, Prof. H. L. Whittemore.

The committee on materials for aircraft is at present composed of the following members:

Prof. H. L. Whittemore, Bureau of Standards, vice chairman and acting secretary.
Lieut. Commander R. S. Barnaby (C. C.), United States Navy.
S. K. Colby, American Magnesium Corporation.
Warren E. Emley, 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, Aluminum Company of America.
J. B. Johnson, matériel division, Army Air Corps, Wright Field.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Capt. Alfred J. Lyon, United States Army, matériel division, Air Corps, Wright Field.
H. S. Rawdon, Bureau of Standards.
E. C. Smith, Republic Steel Corporation.
G. W. Trayer, Forest Products Laboratory, Forest Service.
Starr Truscott, National Advisory Committee for Aeronautics.
Hon. Edward P. Warner, editor of Aviation.

In order to cover effectively the large and varied field of research on aircraft materials the following subcommittees have been established under the committee on materials for aircraft:

Subcommittee on metals.
Subcommittee on aircraft structures—temporary subcommittee on research program on Monocoque design.
Subcommittee on miscellaneous materials.
Subcommittee on methods and devices for testing aircraft materials and structures.

SUBCOMMITTEE ON METALS

The present organization of the subcommittee on metals is as follows:

H. S. Rawdon, Bureau of Standards, chairman.
Dr. H. W. Gillette, Battelle Memorial Institute.
Dr. Zay Jeffries, Aluminum Company of America.
J. B. Johnson, matériel division, Army Air Corps, Wright Field.
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, Bureau of Standards.

A number of investigations on metals and the factors which may limit their usefulness in aircraft have been conducted at the Bureau of Standards with the cooperation of the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, and the National Advisory Committee for Aeronautics.

Intercrystalline embrittlement of sheet duralumin.—This investigation has been of several years' duration. In 1927 an extensive series of light alloys available in sheet form were exposed to the weather. Triplicate exposure test panels were set up at the naval air stations at Coco Solo, Canal Zone; Hampton Roads, Va.; and at the Bureau of Standards. At stated intervals, twice a year, specimens have been brought into the laboratory to determine the change in properties resulting from the corrosive influences to which the metal had been subjected. The experimental part of this program has been completed. As mentioned in previous reports, a number of important facts have been established concerning the intercrystalline type of corrosion of duralumin and related aluminum alloys; its inherent nature, the rate at which the deterioration may occur, methods for overcoming the attack by proper treatment of the alloy and by surface protective coatings. A full report of the investigation is in preparation. The salient features as set forth in last year's report have not been changed in any important respect by the results of the past year.

Because of the marked advances and changes in the light-alloy industry during the past few years, a continuation of the program appeared extremely desirable and a series of tests of recently developed materials will be undertaken. Manufacturers have cooperated in furnishing typical new commercial materials, both aluminum-base and magnesium-base alloys, and the assembled exposure panels are being exposed to the weather at the same three locations as in the first tests. The exposed specimens are in two forms, bars machined to size and strips from which test specimens can be machined after corrosion. New and promising coating methods are also represented in the test program. The list of materials includes 19 aluminum-base alloys and 9 magnesium-base alloys. Over 7,000 individual test specimens are included in the program.

Protection of duralumin, anodic oxidation.—A technical note was issued during the year summarizing the results of the study made of the anodic oxidation process as a preliminary basic treatment of aluminum alloys before coating them in any other way. It is entitled "Advantages of Oxide Films as Bases for Aluminum-Pigmented Coatings for Aluminum Alloys."

Further work has been carried out on the various methods used for anodic treatment. One of the methods studied appears very promising and a patent to protect the Government's interest is being considered. A study is being made of the various factors which may contribute to the limited life of the electrolytic baths used in the commercial process of anodic treatment. The progressively increasing inferior character of the treated surfaces resulting from changes in composition which tend to "build up" in the solution used in the process constitute a serious drawback to the use of this very important method for the protection of aluminum alloys.

Exposure tests of magnesium and magnesium alloys.—Thirty-six months' continuous exposure to the weather at the Bureau of Standards has resulted in no marked decrease in tensile properties of a series of magnesium alloys, although none of the coatings remained intact on the specimens for as long as 24 months. These results for these materials in this location are in striking contrast to those obtained in the tropical location and it was considered especially desirable to include magnesium alloys in the new series of exposure tests for aluminum alloys.

High-frequency endurance tests of light alloy sheet materials.—Experimental work on this subject was completed during the year. The results given in the last annual report for the materials in this investigation may be accepted with confidence as the endurance limit of the various aluminum and magnesium alloys reported for the test conditions employed, that is, the high-frequency vibration of a strip maintained free from any constraint due to mechanical supports. No difference was found in the endurance limit of heat-treated duralumin sheet tested in the plain condition and after being given the anodic oxidation treatment. The value of 15,000 pounds per square inch was found in each case.

There is some indication that slight atmospheric corrosive attack in this method of testing occurs simultaneously with the stressing. This factor, however, influences all service results in like manner. This should be borne in mind in the interpretation and use of the values determined. A full report of the investigation is nearly ready.

Identification of chromium-molybdenum steel.—A technical note entitled "Rapid Chemical Test for the Identification of Chromium-Molybdenum Aircraft Tubing" was issued during the year. The chemical test for molybdenum described is relatively simple and rapid and though not so simple as a "spot test" is the closest approach to this that has yet been developed.

SUBCOMMITTEE ON AIRCRAFT STRUCTURES

The subcommittee on aircraft structures is at present organized as follows:

Starr Truscott, National Advisory Committee for Aeronautics, chairman.
Lieut. C. E. Archer, United States Army.
Capt. Howard Z. Bogert, United States Army, matériel division, Air Corps, Wright Field.
C. P. Burgess, Bureau of Aeronautics, Navy Department.
Richard C. Gazley, Aeronautics Branch, Department of Commerce.
Charles Ward Hall, Hall-Aluminum Aircraft Corporation.
Lieut. Lloyd Harrison (C. C.), United States Navy.
George W. Lewis (ex officio member).
Lieut. Commander R. D. MacCart (C. C.), United States Navy.
Charles J. McCarthy, Chance Vought Corporation.
Prof. J. S. Newell, Massachusetts Institute of Technology.
Dr. L. B. Tuckerman, Bureau of Standards.

Airship girders and airship structural members.—The tests on small preformed wire terminal loops, made by the Goodyear-Zeppelin Corporation by the same method as was employed in making the loops for the *ZRS-4* and *ZRS-5*, have been continued. The bending stresses have been measured on loops formed from wire of 0.092-inch diameter. Over 3,000 measurements of curvature were made on specimens up to loads of 800 pounds, in which they were bent around pins equal in diameter to the forming pin to a grommet of the largest diameter which could be inserted in the loop. When the loops were much larger than the largest grommet or were unsymmetrical, tests were also made about a pin of as large size as could be inserted in the loop without deforming it. For these loops maximum-stress differences, calculated according to the Winkler curved-beam theory, of over 900,000 and 1,500,000 pounds per square inch corresponding to 450 and 800 pounds load or 28 and 50 per cent of the specified breaking load of the wire, respectively, have been found in bending a loop nominally 0.4-inch diameter about a pin 0.312-inch diameter.

The investigation is proceeding in an attempt to confirm the existence of these high-computed stresses by independent methods. X-ray studies have been made of the wire by the Naval Research Laboratory. Stress-strain curves of the wire have been made by means of the Tuckerman optical strain gage. The residual stresses in the wire are being studied by successively removing segments of the wire and computing the residual stress from measurements of change in curvature. As these high-computed bending stresses suggest the possibility of failure in fatigue at relatively low loads, flexural fatigue tests are being made to determine a Goodman diagram which may furnish some criterion as to the extent of the extreme fiber stress which can be safely used.

Specimens of the original German duralumin lattices and channels from the U. S. airship *Los Angeles* have been submitted at intervals throughout the year.

The results of the tensile tests on the channel material do not suggest that there has been any appreciable progress in corrosion in the chord members of the airship during the year. No specimen was found which had a tensile strength below design values.

The samplings from the thin lattice material seem to indicate a definite but slow progress of the corrosive attack since the last sampling. However, no specimen was found in which the strength had diminished sufficiently to lessen the strength of the girders.

A number of specimens of thin sheet Alclad, cut from the hull plating of the metal-clad airship *MC-2*, have been tested in tension. The specimens from the hull plating do not show a measurable deterioration as a result of corrosion. No hull specimens showed ultimate strengths of less than 54,800 pounds per square inch or elongations less than 15.5 per cent.

Flat plates under normal pressure.—Forty-one rectangular plates of 17 ST aluminum alloy have been tested under normal pressure, ranging in size from 2.5 by 2.5 to 7.5 by 7.5 inches and in thickness from 0.01 to 0.10 inch. Only six of the plates were tested with supported edges while the rest had fixed edges, the second condition of edge restraint being preferred because it is more clearly defined and is also closer to that actually prevailing in the bottom sheeting of seaplane floats.

Both the total deflection of the plates at the center and the permanent set at the center were plotted against the pressure for each plate, and it was observed that both curves approached straight lines for high pressure in all cases except those in which it was not possible to avoid slipping at the edges in spite of the use of knurled bars to hold down the plate. The intersection of the straight-line asymptote of the permanent-set curve with the pressure axis was taken as a measure of the beginning of plastic yielding in the plate.

A plot of this yielding pressure versus the ratio of thickness to width, $\frac{h}{2a}$, for square plates results in a single curve for the 2.5 by 2.5 and 5 by 5 inch plates; the points for the 7.5 by 7.5 inch plates fall on this curve except for the very thin plates, which show lower yielding pressures, possibly because of slipping at the edges. The yielding pressure reaches a minimum value of about 20 pounds per square inch for a ratio $\frac{h}{2a}=0.006$; yielding begins at a higher pressure for both thicker and thinner plates of the same size. It seems possible, therefore, to increase the strength of such a plate and at the same time save weight by decreasing its $\frac{h}{2a}$ ratio from 0.006 to, say, 0.003. This peculiar property of the square plate with fixed edges was found in qualitative agreement with calculations based on Foeppl's theory of the plate of medium thickness. The quantitative agreement was poor, however.

A detailed survey of the state of deformation in a 5 by 5 by 0.02 inch duralumin plate with fixed edges has been made, a special device being used to measure deflections at points 0.05 inch apart and a 1-inch Tuckerman optical strain gage to measure the surface strains at various points on the plate as the pressure was increased from 0 to 60 pounds per square inch. The empirical data thus obtained will enable us to compute both the bending stresses and the median-plane tensile stresses developed in the plate, and may provide an empirical basis for testing the assumptions made in Foeppl's theory and for interpreting the curves of permanent set versus pressure so far obtained.

Similar tests on rectangular plates of 18-8 stainless steel are being prepared. The tensile properties of

14 specimens, ranging in thickness from 0.011 to 0.039 inch have already been obtained with a 2-inch Tuckerman optical strain gage.

Strength of welded joints in tubular members for aircraft.—The welded joints of the second series of tests in this investigation have been completed and are now being tested.

All the tubes and joints were inspected by passing a magnetic flux through the specimens and dusting them with a specially prepared iron powder, the technique developed by A. V. DeForest being used. The accumulation of the powder which clung to the edges of flaws and cracks showed defects which were not otherwise visible under careful visual inspection even with a hand lens.

No difficulty was encountered in welding the joints made in chromium-molybdenum tubing of 1.5-inch outside diameter by 0.058-inch wall. It was not found possible to avoid heat cracks in the thin-wall chromium-molybdenum tubing of 1.5-inch outside diameter by 0.020-inch wall in welding this tubing by the ordinary method using low-carbon welding rod. Numerous expedients were tried but without success. Finally a special technique which has recently been developed was used. This involves the use of a reducing flame and a special welding rod melting at a lower temperature than the base metal. No cracks could be found in any of the thin-wall tubes welded by this method.

Inelastic behavior of duralumin and alloy steels in tension and compression.—The compression tests on short lengths of thin-wall channel and tubing have been continued. Even when buckling has been restrained in the free length of the material, difficulty is still found in restraining the secondary buckling of the ends of the specimen adjacent to the heads of the testing machine. A large number of experiments have been carried out in an endeavor to prevent this, so far with only partial success. The compressive stress-strain curves so far obtained on these thin-wall shapes are therefore definitely affected by secondary stresses. Additional refinement in the technique of testing is expected to reduce these further.

End fixation of struts.—The investigation has been continued with the testing of duralumin, of stainless steel, and of two more sizes of chromium-molybdenum tubes. A series of duralumin tubes 1.5 inches in diameter by 0.058 inch thick, covering the range from "short" columns to "long" columns, was tested, and check tests were made with tubes 2 inches in diameter by 0.058 inch thick and tubes 1 inch in diameter by 0.035 inch thick. Stainless-steel tubes having five different sizes of cross section and covering the range from "short" to "long" columns were tested. Check tests were made of chromium-molybdenum tubes 1.125 inches in diameter by 0.049 inch thick and 1 inch in diameter by 0.035 inch thick.

In view of the applicability of the Considère-Engesser theory to struts with elastically restrained ends, as found experimentally last year, the main body of the tests this year has been carried on with freely supported ends. In all cases, however, check tests have been made with restrained ends. It appears now that for practical purposes the strength of chromium-molybdenum steel and duralumin columns can be predicted by means of the Johnson parabola and the Euler hyperbola when the yield points, the moduli of elasticity, and the conditions at the ends are known. For some specimens of chromium-molybdenum tubing somewhat higher values have been previously found for columns in the transition region but the type of stress-strain curve which gives these higher values is not found in all the chromium-molybdenum tubing meeting present specifications. The work has not proceeded far enough to draw definite conclusions with respect to stainless-steel columns.

Torsional strength of tubing.—Torsion tests have been completed on 60 chromium-molybdenum steel tubes, ranging in length from 19 to 60 inches, in outside diameter from 0.75 to 2.5 inches, in thickness from 0.03 to 0.125 inch, and in diameter-thickness ratio from 12 to 74.

There was a large scatter of values for the critical shearing stress, i. e., the shearing stress at which the tube failed by buckling. This scatter seemed to be related to the equally large scatter in the yield-point stress and ultimate strength in tension, as determined from tests on tensile specimens cut from the tubes. The results were therefore replotted in terms of the three dimensionless variables σ, μ, A involving these properties. σ, μ, A are defined as

$$\sigma=\sqrt{3}\sigma\gamma/\sigma_{Y.P.};\ \mu=D/t;\ A=\sigma_{ult}/\sigma_{Y.P.}$$

where $\sigma\gamma$ = critical shearing stress;
$\sigma_{Y.P.}$ = yield-point stress in tension;
σ_{ult} = ultimate strength in tension;
D = outside diameter of tube;
t = wall thickness of tube.

The method of least squares was then used to fit an empirical relation as closely as possible to the observed points. The empirical formula

$$\sigma=15.27\,\frac{A-1}{\mu}+0.981$$

obtained in this way reduced the scatter from about 30 per cent to around 10 per cent. From it a set of curves of critical torque T divided by $\sigma_{Y.P.}D^3$ versus D/t was computed for different values of A. From these curves it is easy to calculate the size of chromium-molybdenum steel required to transmit a given torque provided the yield point of the material and the ratio A of its ultimate strength to its yield point are known and provided the tube falls within the range of dimensions and of properties of those tested.

A report of this work has been written and will soon be ready for publication.

Strength of riveted joints in aluminum alloy.—This investigation was undertaken in cooperation with the National Advisory Committee for Aeronautics for the purpose of providing more fundamental and detailed data on the strength of riveted joints in thin aluminum-alloy sheet than are now available.

A program has been worked out for this investigation, sheet and rivets have been purchased for making test specimens, and a number of testing fixtures are under construction in the shop. It is expected that tests will be started in a short time.

The first part of the investigation will be confined to static tests on single rivets. Later on it is hoped to extend the investigation to multiriveted joints and to joints under alternating stress. Plate thickness ranging from 0.010 inch to 0.125 inch and rivets from 0.0625 inch to ⅜ inch in diameter in six head types will be used.

The present program includes tests to determine the proper driving pressures, amount of upsetting produced by driving, effect of amount of upsetting on the strength, allowable bearing and shearing stress in single shear and in double shear for a complete range of plate thickness and rivet diameters, effect of marginal distances on the strength of riveted and pinned joints, and tensile strength and frictional resistance of various head types.

TEMPORARY SUBCOMMITTEE ON RESEARCH PROGRAM ON MONOCOQUE DESIGN

The temporary subcommittee on research program on monocoque design is at present composed of the following members:

- George W. Lewis, National Advisory Committee for Aeronautics, chairman.
- Capt. Howard Z. Bogert, United States Army, matériel division, Air Corps, Wright Field.
- Richard C. Gazley, Aeronautics Branch, Department of Commerce.
- Eugene E. Lundquist, National Advisory Committee for Aeronautics.
- Lieut. Commander R. D. MacCart (C. C.), United States Navy.
- Dr. L. B. Tuckerman, Bureau of Standards.

STRESSED-SKIN STRUCTURES.—As a result of the present trend toward all-metal airplane construction the strength of stressed-skin, or monocoque, structures is being given, perhaps, more consideration and study by aeronautical engineers than any other single aircraft structural problem. Early studies made of the strength of stressed skins indicated that the highest strength-weight ratios would probably be obtained with corrugated material. Accordingly, a relatively large amount of test data were obtained on the strength of corrugated sheet by the Army Air Corps and others. However, the difficulties encountered in the fabrication of complete structures of corrugated material, the fact that corrugations stiffen the skin in one direction only, and the possibility of adverse aerodynamic effects from the use of corrugated skins have caused designers who wish to employ the stressed-skin, or monocoque, type of construction to use, in many cases, smooth skin reinforced by longitudinal and transverse stiffeners. The efforts of the temporary subcommittee on research program on monocoque design have therefore been directed toward studies which, it is hoped, will lead to rational methods of strength calculation for this type of structure.

Research on thin-wall duralumin cylinders.—An investigation at the Langley Memorial Aeronautical Laboratory on thin-wall cylinders of duralumin has been completed, including tests on cylinders of different radii and tests on elliptic cylinders in practically all of the conditions of loading, compression, torsion, bending, and combined loading. Approximately 400 specimens have been tested during the past year and the data are now being summarized in both curve and equation form by nondimensional coefficients which should apply to all materials in the range of elastic failure. A preliminary report on the strength of thin-wall cylinders in torsion (pure shear) has been published (Technical Note No. 427) and other reports are in preparation.

Besides providing data on the strength of true monocoque fuselage specimens, perhaps the most valuable results of the investigation on thin-wall cylinders are the data being obtained on the type of failure which occurs in unreinforced skin. The wrinkles form in regular patterns, diagonal folds for shear and "diamonds" spaced in longitudinal and circumferential rows for compression and bending. As one of the objects of reinforcement is to prevent failure in the skin, the data obtained on the wrinkles should be of great value in connection with the spacing of longitudinal and transverse reinforcement to provide maximum stiffening of the skin.

Some of the general conclusions which have been drawn from the results of this investigation are that the length-radius ratio, in addition to the radius-thickness ratio, is a very important factor in the determination of the shear strength of true monocoque fuselage specimens, but that it is not an important factor in the determination of the compressive or bending strength; that workmanship in fabrication, concentrations of stress, and eccentricity in the elements of the skin are all factors which affect the compressive and bending strength very appreciably; that the stress developed on the extreme fiber in bending as calculated by the ordinary theory of bending is definitely greater than the stress developed in direct compression; and that the bending strength of an elliptic cylinder is very nearly equal to the bending strength of the circumscribed cylinder of circular section with the same skin thickness.

Research on reinforced skin.—As a first study of the strength of skin in combination with stiffeners, a report is being prepared in which three methods of calculating the compressive strength of flat sheet and stiffeners are compared. In this report it is concluded that a method based upon a mutual action of skin and stiffener gives the best general agreement between observed and predicted loads. Methods based on the assumption of only partial action of sheet and stiffener as a unit do not always give predicted loads that agree with loads observed in tests. Accordingly, restrictions are given in the report which define the range of conditions over which these methods may be applied.

Coordination of research on stressed-skin structures.—One of the duties of the subcommittee on research program on monocoque design is to suggest problems and keep informed regarding research on stressed-skin structures in other than Government laboratories so that no unnecessary duplication of effort will result and to insure that all organizations will be working progressively toward the development of methods for designing, rationally if possible, stressed-skin, or monocoque, structures for aircraft. In this connection several problems were recommended by the committee during the past year for study in other laboratories and close contact has been maintained with these organizations.

However, in an effort to insure that the data being obtained will be of fundamental and lasting value a memorandum is being prepared for circulation to these organizations in which special attention is called to the presentation of structural test data in nondimensional form correlated with the shape of the stress-strain curve for the material as well as with the usual material properties. Unless the shape of the stress-strain curve is taken into account and the results of tests reduced to nondimensional form, independent of the materials used, there is little hope of reducing the large number of structural tests now required when a new material is adopted.

SUBCOMMITTEE ON METHODS AND DEVICES FOR TESTING AIRCRAFT MATERIALS AND STRUCTURES

The subcommittee on methods and devices for testing aircraft materials and structures is at present organized as follows:

- Henry J. E. Reid, Langley Memorial Aeronautical Laboratory, chairman.
- Capt. Howard Z. Bogert, United States Army, matériel division, Air Corps, Wright Field.
- Lieut. Lloyd Harrison (C. C.), United States Navy.
- George W. Lewis (ex officio member).
- Eugene E. Lundquist, Langley Memorial Aeronautical Laboratory.
- R. L. Templin, Aluminum Company of America.
- Dr. L. B. Tuckerman, Bureau of Standards.

In the construction of aircraft of proved types and in the development of new types of construction, a large amount of testing is required to obtain quantitative data on the properties of materials and structures, both for inspection and research purposes. The testing of aircraft materials and structures is therefore a subject of great importance. The accurate testing of materials and the study of the strength properties of structures require great care and an accurate knowledge of testing machines, devices, and methods. Many tests are worthless because the operator has used methods and equipment incapable of measuring the stress or strain accurately and oftentimes other factors unknown to the operator have existed and very seriously affected the results. While there are a great number of devices for use in testing materials and structures, many must be used with special precautions and others are actually unsuited to the study of aircraft materials and structures.

Because of this difficulty the subcommittee on methods and devices for testing aircraft materials and structures was established. Under the auspices of this new subcommittee, a survey has been made of the methods and devices now in use, including those used by the Army, Navy, Bureau of Standards, and a number of aircraft manufacturers. It also includes information obtained from various European sources through the Paris office of the committee. A number of manufacturers of testing machines have been visited and the devices available studied and correlated with respect to their use in testing aircraft materials. The subcommittee has had one meeting to study this survey and especially to discuss the causes of errors in testing. The survey is now being organized with a view to the publication of the information by the committee as a report or a series of reports dealing with certain phases of the testing of aircraft materials and structures.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS

The present organization of the subcommittee on miscellaneous materials is as follows:

- Charles H. Helms, National Advisory Committee for Aeronautics, chairman.
- Dr. W. Blum, Bureau of Standards.
- C. J. Cleary, matériel division, Army Air Corps, Wright Field.
- Warren E. Emley, Bureau of Standards.
- George W. Lewis (ex officio member).
- J. E. Sullivan, Bureau of Aeronautics, Navy Department.
- G. W. Trayer, Forest Products Laboratory.
- P. H. Walker, Bureau of Standards.
- G. P. Young, matériel division, Army Air Corps, Wright Field.

Mercerization of cotton for aeronautical uses.—A systematic study of the mercerization of cotton yarn for aeronautical uses, where maximum strength for a given weight is important, has been completed. This study demonstrated that the optimum conditions of mercerization for increasing the strength of yarns are different from those of ordinary commercial mercerization, where improvement in luster is the primary object. The elongation of yarn mercerized for maximum strength is usually low. It was found that the elongation can be increased by a second mercerization without tension. An increase of 50 per cent in strength with an elongation of 10 per cent at break was found to be possible. A detailed report has been prepared for publication.

Substitute for silk cloth for parachutes.—The two cotton cloths of different construction which were finished commercially were not made into parachutes because the properties of the laboratory-finished cloths could not be duplicated satisfactorily on the commercial scale.

In view of the promising performance of the parachute made from K K cloth and in view of the objection to the bulkiness of a parachute made from a 2-ounce cotton cloth, experiments were undertaken to develop a cotton cloth for parachutes which would weigh 1.5 ounces per square yard and meet the air-permeability requirement, the strength and tear resistance to be as great as possible. Considerable progress has already been made. Sufficient cloth will be woven for a parachute which will be given performance tests in comparison with the standard parachute made from silk.

Gas-cell fabric of high tear resistance and outer-cover cloth for airships.—The experimental weaving of fabrics of high tear resistance has been completed. A 2-ounce cloth was developed with a tear resistance twenty times that of the 2-ounce H H balloon cloth. Sufficient material of this and of three other cloths was woven for large-scale tests. It was submitted to the Bureau of Aeronautics, Navy Department, which is having it tested by the Goodyear-Zeppelin Corporation.

REPORT OF COMMITTEE ON PROBLEMS OF AIR NAVIGATION

ORGANIZATION

The committee on problems of air navigation is at present organized as follows:

Hon. William P. MacCracken, jr., chairman.
Dr. L. J. Briggs, Bureau of Standards.
Lloyd Espenschied, American Telephone & Telegraph Co.
Maj. Gen. B. D. Foulois, United States Army, Air Corps, War Department.
Paul Henderson, National Air Transport (Inc.).
Capt. S. C. Hooper, United States Navy, director of naval communications, Navy Department.
Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Col. Charles A. Lindbergh.
Dr. Charles F. Marvin, Weather Bureau.
Lieut. J. P. W. Vest, United States Navy, Hydrographic Office, Navy Department.
Hon. C. M. Young, Assistant Secretary of Commerce for Aeronautics.

Under the committee on problems of air navigation there are organized two subcommittees, as follows:

Subcommittee on instruments.
Subcommittee on meteorological problems.

SUBCOMMITTEE ON INSTRUMENTS

The membership of the subcommittee on instruments is as follows:

Dr. L. J. Briggs, Bureau of Standards, chairman.
Marshall S. Boggs, Aeronautics Branch, Department of Commerce.
Dr. W. G. Brombacher, Bureau of Standards.
C. H. Colvin, Society of Automotive Engineers.
Capt. A. F. Hegenberger, United States Army, matériel division, Air Corps, Wright Field.
Dr. A. W. Hull, General Electric Co.
Carl W. Keuffel, Keuffel & Esser.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Lieut. C. D. McAllister, United States Army, matériel division, Air Corps, Wright Field.
H. J. E. Reid, National Advisory Committee for Aeronautics.
Lieut. L. D. Webb, United States Navy, Bureau of Aeronautics, Navy Department.

Investigations relating to the development of instruments for air navigation conducted under the cognizance of the committee on aerodynamics are outlined in the report of that committee. The work of other organizations, which are in the main represented on the subcommittee on instruments, covers a wide field, but emphasis appears to have been upon the following:

"Blind" flying instruments.—Blind or instrument flying appears to have definitely passed from the experimental to the routine stage, marked by the adoption of regulations by the Aeronautics Branch of the Department of Commerce requiring pilots flying airplanes engaged in scheduled operation of interstate transport service to be proficient in blind flying and further requiring airplanes in that service to be equipped with suitable instruments for such flying. The airplanes must as a consequence be now equipped with the following navigation instruments in addition to the magnetic compass: Gyroscopic artificial horizon, directional gyro, sensitive altimeter, turn and bank indicator, air-speed meter, and rate-of-climb indicator.

Of these instruments the artificial horizon, the directional gyro, and the sensitive altimeter have been improved during the past year in details rather than in fundamental design. Outstanding problems not yet entirely solved in connection with the operation of the artificial horizon and the directional gyro are those of a more suitable source of operating suction than the Venturi tube and an indicator of the proper speed of the gyroscope rotor. A number of organizations have developed vacuum pumps specifically for aircraft use, but the flow of air required for satisfactory operation under all conditions of use is not known. A number of tests have been made at the Bureau of Standards on the directional gyro with the main object of determining the air flow required at various altitudes and temperatures. At a constant speed of the gyroscope rotor it was found that both the suction required and the mass flow of air increased linearly with the air pressure (decreased with altitude). The rates of change with air pressure are of large magnitude. Fortunately, however, constant speed is obtained with a constant-volume flow of air through the instrument, which flow is given by vane-type vacuum pumps driven at constant speed. As might readily be predicted, tests in the range from $+30°$ to $-5°$ C. show that the mass flow and the suction increase as the temperature decreases. Similar tests appear to be required on the artificial horizon before the capacity of the vacuum pumps can be properly specified.

An ideal indicator which shows whether or not the gyroscopic instrument is functioning properly has not as yet been devised. Knowledge of the suction appears to be of doubtful value since it appears that in general the speed of the gyroscope rotor can not be maintained even approximately constant by maintaining a constant suction.

"Blind" landing instruments.—The blind landing of aircraft is still in the experimental stage. The matériel division of the Army and the Aeronautics Branch of the Department of Commerce have further developed their respective methods. Each involves the use of certain instruments essential in blind flying together with special radio equipment.

Determination of position.—Progress continues to be made on the instruments and methods for determining the position of aircraft by dead reckoning and astronomical observations. The Hydrographic Office of the Navy has issued a volume entitled, "Dead Reckoning, Altitude, and Azimuth Table" (H. O. No. 211), in a further effort to simplify the method of position finding.

The drift and ground-speed meter developed by Gatty has aroused interest in the development of such instruments. The following features have been stressed in most of the proposed instruments: (*a*) The ground must be viewed from the inside of the airplane; (*b*) the design must be simple. In each case the ground-speed indicators have been of the type in which a surface moving or rotating at constant or variable speed is used to neutralize the apparent motion of the ground below the aircraft. Devices with a constant speed, of which Gatty's instrument is an example, appear to be favored. It is, however, still debatable whether this type of instrument is superior to the wind-star method of determining ground speed.

Publications.—Three reports on instruments are being prepared at the Bureau of Standards for the National Advisory Committee for Aeronautics. These include (1) the present status of development of blind flying instruments, (2) altitude instruments, and (3) power-plant instruments.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The subcommittee on meteorological problems is at present organized as follows:

- Dr. Charles F. Marvin, Weather Bureau, chairman.
- W. R. Gregg, Weather Bureau.
- Dr. W. J. Humphreys, Weather Bureau.
- Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation.
- George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
- Lieut. F. W. Reichelderfer, United States Navy, naval air station, Lakehurst.
- Dr. C. G. Rossby, Massachusetts Institute of Technology.
- Eugene Sibley, Aeronautics Branch, Department of Commerce.
- Capt. Alfred H. Thiessen, United States Army, Signal Corps, War Department.

The subcommittee on meteorological problems has, during the past year, continued its investigations of wind gustiness and ice formation on aircraft.

Wind gustiness.—Continuous records are being obtained with a magneto anemograph at the Weather Bureau's station at Akron, Ohio. During periods of unusual activity or special interest an open time scale is employed, in order that the structure of the wind may be studied in more detail than is possible with the standard slow time scale. It is planned, as opportunity offers and after a sufficient amount of data is available, to analyze the records and issue a report thereon.

Important work on this subject is also being carried out by the department of engineering research of the University of Michigan, under the direction of Prof. R. H. Sherlock. The purpose of this investigation is to determine the wind forces acting against the poles and conductors of an electric line under storm conditions. Preliminary reports embodying some of the results have already appeared. The work is being continued, and more complete reports will be published later.

At the Langley Memorial Aeronautical Laboratory two researches having a bearing on the study of the structure of the atmosphere have been in progress during the past year. One of these investigations concerns the effect of gusts on an airplane while landing. As a preliminary step, measurements of the wind have been made to determine the magnitude and direction of the velocity at several altitudes up to 50 feet. These variables have been recorded simultaneously and continuously over periods of time representing the time required for an airplane to pass through the last 50 feet of altitude before the landing. The measurements have now been carried out over a period of six months and include various representative wind conditions.

The second investigation relates to the effect of gusts on the structural loads imposed on airplanes in flight. Accelerometers have been installed in a number of transport airplanes operated on various airlines throughout the country. Records obtained from these instruments, which have been in use through all seasons of the year, have provided a considerable fund of statistical data on the magnitude of the loads imposed by gusts and the prevalence of gusty conditions in various localities. On the assumption that the acceleration recorded is that resulting from a vertical current and that there is no velocity gradient between the air moving vertically and the still air, the information collected makes it possible to compute an "effective" velocity of the vertical current that is responsible for the acceleration recorded. Although the data thus far obtained are not considered complete, a probability curve of the "effective" velocity of vertical currents likely to be encountered in gusty air has been derived. This curve shows that vertical currents of a velocity of the order of 10 feet per second are likely to be encountered three hundred times in 100 hours of flying, and those of the order of 30 feet per second, which are the highest obtained, three times per hundred hours. It shows, also, that the vertical current is likely to have a downward direction as often as an upward direction.

Ice formation on aircraft.—A considerable amount of information on this subject has been secured in connection with the Weather Bureau's program of meteorological observations during airplane flights. The data have been summarized and useful conclusions have been drawn regarding the different types of deposit and the conditions most favorable for their formation. It is expected that this summary will be published by the committee in the near future.

PART III

TECHNICAL PUBLICATIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics has issued technical publications during the past year covering a wide range of subjects. There are 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 carried on in various laboratories in this country, public and private. In all cases the reports were recommended for publication by the technical subcommittees having cognizance of the investigations. During the past year 40 technical reports were submitted for publication.

Technical notes present the results of short research investigations and the results of studies of specific detail problems which form parts of long investigations. The committee has issued during the past year, in mimeographed form, 38 technical notes.

Technical memorandums contain translations and reproductions of important foreign aeronautical articles of a miscellaneous character. A total of 47 technical memorandums was issued during the past year.

Aircraft circulars contain translations of reproductions of articles descriptive of new types of foreign aircraft. During the past year 20 aircraft circulars were issued.

The committee recently issued a bibliography of aeronautics for the year 1930. It had previously issued bibliographies for the years since 1909. The bibliography for 1931 has been prepared but its printing has been postponed in the interest of economy. All issues of the Bibliography of Aeronautics to date were prepared by Paul Brockett.

Summaries of the 40 technical reports and lists of the technical notes, technical memorandums, and aircraft circulars follow:

SUMMARIES OF TECHNICAL REPORTS

The first annual report of the National Advisory Committee for Aeronautics for the fiscal year 1915 contained Technical Reports Nos. 1 to 7; the second annual report, Nos. 8 to 12; the third annual report, Nos. 13 to 23; the fourth annual report, Nos. 24 to 50; the fifth annual report, Nos. 51 to 82; the sixth annual report, Nos. 83 to 110; the seventh annual report, Nos. 111 to 132; the eighth annual report, Nos. 133 to 158; the ninth annual report, Nos. 159 to 185; the tenth annual report, Nos. 186 to 209; the eleventh annual report, Nos. 210 to 232; the twelfth annual report, Nos. 233 to 256; the thirteenth annual report, Nos. 257 to 282; the fourteenth annual report, Nos. 283 to 308; the fifteenth annual report, Nos. 309 to 336; the sixteenth annual report, Nos. 337 to 364; the seventeenth annual report, Nos. 365 to 400; and since the preparation of the seventeenth annual report for the year 1931 the committee has authorized the publication of the following technical reports, Nos. 401 to 440:

Report No. 401, entitled "Combustion in a High-Speed Compression-Ignition Engine," by A. M. Rothrock, National Advisory Committee for Aeronautics.

This investigation was undertaken to determine the factors which control the combustion in a high-speed compression-ignition engine. Indicator cards were taken with the Farnboro indicator and analyzed according to the tangent method devised by Schweitzer. The analysis shows that in a quiescent combustion chamber increasing the time lag of auto-ignition increases the combustion efficiency of the engine and also increases the maximum rate of combustion. Increasing the maximum rate of combustion increases the tendency for detonation to occur. The results show that by increasing the air temperature during injection the start of combustion can be forced to take place during injection and so prevent detonation from occurring. It is shown that the rate of fuel injection does not in itself control the rate of combustion.

Report No. 402, entitled "Effect of Orifice Length-Diameter Ratio on Fuel Sprays for Compression-Ignition Engines," by A. G. Gelalles, National Advisory Committee for Aeronautics.

Experimental results on the effect of the length-diameter ratio of the orifice on the spray characteristics, together with a brief analysis of the factors affecting these characteristics, are presented in this report. The length-diameter ratios tested ranged from 0.5 to 10; the orifice diameters from 0.008 to 0.040 inch; and the injection pressures from 2,000 to 8,000 pounds per square inch. The density of the air into which the fuel was discharged was varied from 0.38 to 1.35 pounds per cubic foot.

When a plain stem was used in the injection valve and the length-diameter ratio of the orifice was increased from 0.5 to 10, the rate of spray-tip penetration at first decreased and reached a minimum between the ratios of 1.5 and 2.5; then reached a maximum between the ratios of 4 and 6; and decreased again as the ratio was increased to 10. The exact position of the maximum and minimum points depended upon the orifice diameter. The spray cone angle was affected very little by the variation of either the diameter of the orifice or the length-diameter ratio tested at ratios greater than 4.

With a helically grooved stem in the injection valve the ratios at which the highest penetration occurred varied between 5 and 7. The spray cone angle increased with the ratio of the orifice area to groove area.

Report No. 403, entitled "Ice Prevention on Aircraft by Means of Engine Exhaust Heat and a Technical Study of Heat Transmission from a Clark Y Airfoil," by Theodore Theodorsen and William C. Clay, National Advisory Committee for Aeronautics.

This investigation was conducted to study the practicability of employing heat as a means of preventing the formation of ice on airplane wings. The report relates essentially to technical problems regarding the extraction of heat from the exhaust gases and its proper distribution over the exposed surfaces. In this connection a separate study has been made to determine the variation of the coefficient of heat transmission along the chord of a Clark Y airfoil.

A study of the heat transmission from the airfoil reveals that the local transmission is very high at the leading edge and that it decreases rapidly to a minimum value at a point located about 30 per cent back along the chord.

Experiments on ice prevention both in the laboratory and in flight show conclusively that it is necessary to heat only the front portion of the wing surface to effect complete prevention.

The marked variation in the heat transmission over the front portion of the wing makes the problem of an efficient heat-distributing system a matter of some technical difficulty. The actual quantity of heat needed for ice prevention is, however, surprisingly small, being in the order of one-tenth of that available in the engine exhaust gases.

The relative merits of various methods of ice prevention by means of heat are analyzed with the result that a vapor system is found to offer the most satisfactory solution, especially for airplanes which are not constructed entirely of metal. In "all metal" designs it may be entirely practicable to employ a direct exhaust-heating system.

Experiments in flight show that a vapor-heating system which extracts heat from the exhaust and distributes it to the wings is an entirely practical and efficient method for preventing ice formation.

A narrow slot on the upper surface located about one-tenth of the chord length from the leading edge is employed in these tests for the purpose of collecting the water which would otherwise blow back and freeze aft of the heated leading edge. The tests seem to indicate, however, that this slot may not be essential.

Report No. 404, entitled "The Effect of Increased Carburetor Pressure on Engine Performance at Several Compression Ratios," by Oscar W. Schey and Vern G. Rollin, National Advisory Committee for Aeronautics.

The object of this investigation was to determine the effect of increasing the carburetor pressures from 30 to 40 inches of mercury, at compression ratios from 3.5 to 7.5, on the power, on the maximum cylinder pressures, on the fuel consumption, and on the other performance characteristics of an engine. The tests were conducted on the N. A. C. A. single-cylinder universal test engine. A Roots-type aircraft-engine supercharger was used to maintain the desired carburetor pressure.

The results of these tests show: That the decrease in brake thermal efficiency with boosting is negligible; that the power increases with boosting much more than the losses to the cooling water increase; that a large increase in power can be obtained with comparatively small increase in maximum cylinder pressures; and that it is advisable to supercharge an engine of highest practicable compression ratio consistent with the degree of supercharging desired and the nondetonating quality of the fuel used because the power increase will be greater, the exhaust gas temperatures will be lower, and the power required by the supercharger to maintain the same pressure at the carburetor will be less.

Report No. 405, entitled "Application of Practical Hydrodynamics to Airship Design," by Ralph H. Upson, University of Michigan, and W. A. Klikoff, Aircraft Development Corporation.

The design of a large high-speed airship is primarily a structural problem, in which the most important stresses are those due, directly or indirectly, to aerodynamic forces on the surface of the hull. The force on any small element of the surface is most conveniently divided into two components, respectively tangent and normal to the surface. The tangent or skin-friction forces are so small per unit area that they are structurally almost negligible compared with the normal forces; yet their total integrated resultant is responsible for almost the entire drag of the hull, whereas the normal components of pressure are so nearly balanced over a good hull that their net resultant is practically zero. The interreaction of these very substantial forces is, of course, through the medium of stresses in the hull, and in combination with fin and inertia forces they are essential not only from a structural standpoint but also in the consideration of stability and control. The distribution of velocity and skin friction can also be indirectly determined from the normal force distribution. An accurate determination of the latter and its effects is therefore of the very first importance.

The pressure on ellipsoidal shapes is presented first in Part I as a foundation for more generalized formulas. Although any ellipsoid is susceptible of accurate mathematical treatment, only the case of a prolate spheroid with circular cross section is investigated here because of its approximation to airship hulls.

Part II deals with important adaptations of the ellipsoidal formulas, and other hydrodynamic relations to any airship hull, with particular reference to structural requirements.

In Part III the theoretical results are applied to the practical computation of airship stability, and relations established which can be evaluated from simple wind-tunnel tests.

In Part IV the same fundamentals are used in the determination of viscous forces, leading to an improved classification of airship drag, and a new outlook on drag generally.

Examples of practical airship characteristics are employed throughout.

Report No. 406, entitled "Drop and Flight Tests on NY-2 Landing Gears Including Measurements of Vertical Velocities at Landing," by W. C. Peck and A. P. Beard, National Advisory Committee for Aeronautics.

This investigation was conducted to obtain quantitative information on the effectiveness of three landing gears for the NY-2 (Consolidated training) airplane. The investigation consisted of static, drop, and flight tests on landing gears of the oleo-rubber-disk and the mercury rubber-cord types, and flight tests only on a landing gear of the conventional split-axle rubber-cord type.

The results show that the oleo gear is the most effective of the three landing gears in minimizing impact forces and in dissipating the energy taken. The flight results indicate that in pancake landings with a vertical velocity at contact of 8 feet per second the maximum accelerations experienced are approximately 3.2g, 4.9g, and 4.4g with the oleo, the mercury, and the split-axle rubber-cord gears, respectively.

The results show also that, in the good landings, larger impact forces were experienced subsequent to contact (generally less than 2.8g) than experienced at contact (generally less than 2.0g).

The oleo landing gear permitted severe landings to be made without violent rebound, but the mercury and the split-axle rubber-cord gears caused very violent and dangerous rebounds.

A comparison of the results of the drop tests, based upon equal heights of free drops, does not show the relative merits of the landing gears as realized in flight tests. However, a comparison made upon a basis of equal heights of total drop (free drop plus vertical movement of the load during the initial stroke of the landing gear) is indicative of them.

Report No. 407, entitled "The Characteristics of a Clark Y Wing Model Equipped with Several Forms of Low-Drag Fixed Slots," by Fred E. Weick and Carl J. Wenzinger, National Advisory Committee for Aeronautics.

This investigation was undertaken to develop a low-drag fixed slot for an airplane wing which would avoid the complications and maintenance difficulties of the present movable-type Handley Page slot. Tests were conducted on a series of fixed slots in an attempt to reduce the minimum drag coefficient without decreasing the maximum lift coefficient or the stalling angle of the slotted wing. The tests were made in the N. A. C. A. 5-foot vertical wind tunnel on a Clark Y basic section having a 10-inch chord.

The best combination of wing and fixed slot that was developed had a maximum lift coefficient of 1.751, which was 34.6 per cent higher than that of the plain wing. The angle of attack for maximum lift was raised 9°, from 15° for the plain wing to 24° for the slotted wing. The minimum drag of the wing with fixed slot was increased 52.6 per cent above that of the plain wing, or a value about 38.8 per cent above that for a slotted wing with the movable slot closed. Fixed slots might also be used at the tips of the wings only, in which case the total drag of an average airplane would be increased very slightly, causing a loss in high speed of only 1 or 2 miles per hour.

Report No. 408, entitled "General Formulas and Charts for the Calculation of Airplane Performance," by W. Bailey Oswald, California Institute of Technology.

In this report the general formulas for the determination of all major airplane performance characteristics are developed. A rigorous analysis is used, making no assumption regarding the attitude of the airplane at which maximum rate of climb occurs, but finding the attitude at which the excess thrust horsepower is maximum.

The characteristics of performance are given in terms of the three fundamental parameters λ_p, λ_s, and λ_t, or their engineering alternatives l_p, l_s, and l_t, where

$\lambda_p \propto l_p$ = parasite loading.
$\lambda_s \propto l_s$ = effective span loading.
$\lambda_t \propto l_t$ = thrust horsepower loading.

These combine into a new parameter of fundamental importance which has the alternative forms:

$$\Lambda' \propto \Lambda = \frac{l_s\, l_t^{4/3}}{l_p^{1/3}}$$

A correction is made for the variation of parasite resistance with angle of attack and for the nonelliptical wing loading by including in the induced drag term a factor e, called the "airplane efficiency factor." The correction is thus assumed proportional to C_L^2.

A comprehensive study of full-scale data for use in the formulas is made. Using the results of this investigation, a series of performance charts is drawn for airplanes equipped with modern unsupercharged engines and fixed-pitch metal propellers.

Equations and charts are developed which show the variation of performance due to a change in any of the customary design parameters.

Performance determination by use of the formulas and charts is rapid and explicit. The results obtained by this performance method have been found to give agreement with flight test that is, in general, equal or superior to results obtained by present commonly used methods.

Report No. 409, entitled "The Elimination of Fire Hazard Due to Back Fires," by Theodore Theodorsen and Ira M. Freeman, National Advisory Committee for Aeronautics.

A critical study was made of the operation of a type of back-fire arrestor used to reduce the fire hazard in aircraft engines.

A flame arrestor consisting of a pack or plug of alternate flat and corrugated plates of thin metal was installed in the intake pipe of a gasoline engine; an auxiliary spark plug inserted in the intake manifold permitted the production of artificial back fires at will.

It was found possible to design a plug which prevented all back fires from reaching the carburetor.

Analysis of the heat-transfer phenomena in the arrestor shows (*a*) that the length-diameter ratio of the individual passages is of first importance in determining the effectiveness of the device, (*b*) that the plug need not be heavy, and (*c*) that the thermal conductivity of the material of which it is made is only of secondary influence.

Measurements of the pressure drop across the adopted model show that the increase of engine-pumping loss caused by the presence of the arrestor is quite negligible; the reduction in volumetric efficiency amounts to a few per cent.

Report No. 410, entitled "The Theory of Wind-Tunnel Wall Interference," by Theodore Theodorsen, National Advisory Committee for Aeronautics.

This report outlines the development of a general theory for the calculation of the effect of the boundaries of the air stream on the flow past an airfoil. An analytical treatment of the conventional closed and open jet types of rectangular wind tunnels disclosed the possibility of devising three distinctly new types: Tunnels with horizontal boundaries only, with vertical boundaries only, and with a bottom boundary only. Formulas are developed for the tunnel-wall interference in each case for an airfoil located at the center of the tunnel. The correction is given as a function of the width to height ratio of the tunnel. The formulas are exact for infinitely small airfoils only, but give good approximations for spans up to about three-quarters of the tunnel width.

The surprising result is obtained that the three last-mentioned nonconventional types of wind tunnels all are superior to the conventional open or closed tunnels as regards wall interference. It is possible to design two distinct types of semiclosed wind tunnels having no wall interference; namely, a square tunnel with horizontal boundaries and no side walls, and a rectangular type of a width to height ratio of slightly less than 2 :1 equipped with vertical boundaries only.

The author goes on to show that instabilities in the flow may occur for the free-jet and the open-bottom type tunnels, impairing the predictability of the tunnel-wall corrections. A tunnel with a jet free on three sides and restricted only by a lower horizontal boundary extending along the test section from the entrance to the exit cone, is finally recommended as the most promising choice. The correction for this type is from five to eight times smaller than that of the corresponding free-jet type.

Report No. 411, entitled "Theory of Wing Sections of Arbitrary Shape," by Theodore Theodorsen, National Advisory Committee for Aeronautics.

This report presents a solution of the problem of the theoretical flow of a frictionless incompressible fluid past airfoils of arbitrary forms. The velocity of the 2-dimensional flow is explicitly expressed for any point at the surface, and for any orientation, by an exact expression containing a number of parameters which are functions of the form only and which may be evaluated by convenient graphical methods. The method is particularly simple and convenient for bodies of stream-line form. The results have been applied to typical airfoils and compared with experimental data.

Report No. 412, entitled "The 7 by 10 Foot Wind Tunnel of the National Advisory Committee for Aeronautics," by Thomas A. Harris, National Advisory Committee for Aeronautics.

This report described the committee's 7 by 10 foot wind tunnel and associated apparatus. Included also are calibration-test results and characteristic test data of both static force tests and autorotation tests made in the tunnel.

The tunnel air flow is satisfactory. The velocity, at the model location, is uniform within ± 0.2 per cent and the air flow direction is parallel to the axis of the jet within $\pm 0.3°$.

The tunnel is equipped with a 6-component indicating balance, on which the three forces and three moments may be measured directly and independently. All tests are made at the same dynamic pressure on models having the same area and aspect ratio. By this arrangement, the results are obtained in coefficient form and very little time is required to reduce the test data.

The balance may also be used for making stable autorotation tests or for measuring the rolling moment due to roll. In such cases the force-test model support is replaced by one designed for rotation tests.

Report No. 413, entitled "A Method for Computing Leading-Edge Loads," by Richard V. Rhode and Henry A. Pearson, National Advisory Committee for Aeronautics.

In this report a formula is developed that enables the determination of the proper design load for the portion of the wing forward of the front spar. The formula is inherently rational in concept, as it takes into account the most important variables that affect the leading-edge load, although theoretical rigor has been sacrificed for simplicity and ease of application. Some empirical corrections, based on pressure distribution measurements on the PW–9 and M–3 airplanes, have been introduced to provide properly for biplanes.

Results from the formula check experimental values in a variety of cases with good accuracy in the critical loading conditions. The use of the method for design purposes is therefore felt to be justified and is recommended.

Report No. 414, entitled "The Effect on Airplane Performance of the Factors That Must Be Considered in Applying Low-Drag Cowling to Radial Engines," by William H. McAvoy, Oscar W. Schey, and Alfred W. Young, National Advisory Committee for Aeronautics.

This report presents the results of flight tests with three different airplanes using several types of low-drag cowling for radial air-cooled engines. The greater part of the tests were made with a Curtiss XF7C–1 (Sea Hawk) with a 410-horsepower Wasp engine, using three fuselage nose shapes and six types of outer cowling. The six cowlings were: A narrow ring, a wide ring, a wide cowling similar to the original N. A. C. A. cowling, a thick ring incorporating an exhaust collector, a single-surface cowling shaped like the outer surface of the exhaust-collector cowling, and a polygon-ring cowling, of which the angle of the straight sections with the thrust line could be varied over a wide range.

The high speed in level flight was determined by means of timed runs over a measured course. Ten-minute full-throttle climbs were made for several of the cowling conditions. Temperatures at 18 points on the engine cylinders were measured for a large number of climbs and level flights. Photographs showing the pilot's field of vision were taken for several cowling conditions.

The addition of outer cowlings to the XF7C–1 resulted in speed increases of from 6 to 20 miles per hour, depending upon the type of cowling and the fuselage shape. The narrow-ring cowling gave the least increase in speed and the single-surface cowling the greatest. A reasonably wide cowling with its leading edge behind the front plane of the engine cylinders gave the best performance of the plain-ring types of cowling. The optimum range for the angle of the cowling section with the thrust line was only 3° or 4°; the position of the range was dependent upon the shape of the fuselage and the shape and location of the cowling section. In general the engine temperatures increased as the high speed was increased, both of these effects being directly contributed to by reductions in the amount of air flowing past the cylinders. The use of cowlings had very little effect upon the performance in climb.

Less extensive tests were made on a Vought O2U–1 (Corsair) and a Fairchild FC2W–2 with some of the same cowlings used on the XF7C–1. Only the high speed of these airplanes was determined, to furnish a check on the effect of cowlings with different types of airplanes.

Report No. 415, entitled "Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. Part I. Thick Wing—N. A. C. A. Cowled Nacelle—Tractor Propeller," by Donald H. Wood, National Advisory Committee for Aeronautics.

This report gives the results obtained in the committee's 20-foot propeller-research tunnel on the interference drag and propulsive efficiency of a nacelle-propeller combination located in 21 positions with reference to a thick wing.

The wing had a 5-foot chord, a 15-foot span, and a maximum thickness of 20 per cent of the chord. The engine was a 4/9-scale model of a Wright J–5 radial air-cooled engine and was installed in a nacelle with a cowling of the N. A. C. A. type. The propeller was a 4-foot-diameter model of the standard Navy adjustable-pitch metal propeller No. 4412.

The lift, drag, and propulsive efficiency were obtained at several angles of attack for each of the 21 locations. A net efficiency was derived for determining the over-all effectiveness of each nacelle location.

Best results were obtained with the propeller about 25 per cent of the chord directly ahead of the leading edge. A location immediately above or below the wing near the leading edge was very poor.

Report No. 416, entitled "The N. A. C. A. Variable-Density Wind Tunnel," by Eastman N. Jacobs and Ira H. Abbott, National Advisory Committee for Aeronautics.

This report describes the committee's redesigned variable-density wind tunnel; it supersedes a previous report that described the original tunnel. The operation of the balance and the method of testing are explained and the method of correcting and presenting airfoil data is described. A summary of the formulas for predicting the characteristics of finite wings from the airfoil section data as they are usually presented is also given.

Report No. 417, entitled "Pressure Distribution Tests on a Series of Clark Y Biplane Cellules with Special Reference to Stability," by Richard W. Noyes, National Advisory Committee for Aeronautics.

The pressure-distribution data discussed in this report represent the results of part of an investigation on the factors affecting the aerodynamic safety of airplanes. These tests were made on semispan, circular-tip Clark Y airfoil models mounted in the conventional manner on a separation plane. Pressure readings were made simultaneously at all test orifices at each of 20 angles of attack between $-8°$ and $+90°$.

The results of the tests on each wing arrangement are compared on the bases of maximum normal force coefficient, lateral stability at a low rate of roll, and relative longitudinal stability. Tabular data are also presented giving the center-of-pressure location of each wing.

The principal conclusions drawn from the results of these tests may be summarized as follows:

1. No biplane arrangement investigated has as high a value of maximum normal force coefficient as the monoplane, although the value for the cellule having 50 per cent positive stagger and 3° positive decalage (the lower wing at a higher angle of attack than the upper) is only 3 per cent less.

2. Unstable rolling moments due to a low rate of roll are generally decreased by the use of a gap-chord ratio of less than 1.0 positive stagger alone, or positive stagger and negative decalage.

3. Combined positive stagger and negative decalage show the greatest relative longitudinal stability below the stall.

Report No. 418, entitled "Preliminary Investigation of Modifications to Conventional Airplanes to Give Nonstalling and Short-Landing Characteristics," by Fred E. Weick, National Advisory Committee for Aeronautics.

This report describes flight and landing tests made on a group of conventional airplanes at the committee's laboratory. The upward deflection of the elevators was limited to the point where the airplanes could not be made to spin without the aid of power. With the elevator travel thus limited, the airplane in every case had good lateral stability and good aileron effectiveness up to the highest angles of attack which could be obtained in a glide, although this was not true in any case without the limited control. All ordinary flight maneuvers could be performed with the elevator displacement limited, but usually there was not sufficient control to get the tail down for a normal 3-point landing.

In order to investigate the feasibility of making landings by gliding straight to the ground with the full but limited amount of tail-depressing longitudinal control in use, glides were made and the vertical velocities measured. These were found to range from 12 to 24 feet per second for the various airplanes tested; and since the lateral stability and control in the glides with the control sticks full back to the limited positions were satisfactory, it seemed that landings could be satisfactorily made in this manner if reasonably long-stroke shock-absorbing landing gears were provided. In addition, a comparison was made between the computed distance required to glide in this manner over an average obstruction and alight upon the ground and the distance required for the shortest conventional type landing. For this purpose both medium and short conventional landings were measured with all the airplanes tested, and the comparisons indicated that much shorter landings could be made by gliding straight in with the stick full back to the limited position.

As this type of landing seemed to have several advantages, one of the airplanes (the Verville AT) was fitted with long-travel shock-absorber struts and actual landing tests were made in which the distances, as well as the accelerations upon contact with the ground, were measured. The glide landings with the control stick full back to the limited position were satisfactory, the landing runs as well as the air distances being substantially shorter than the shortest present-day conventional landings. Other landings made by gliding straight in at higher air speeds, and landings in which the flight paths were somewhat leveled off just before contact were also satisfactorily performed. The various landing tests showed that with the airplane as modified a safe landing is made in smooth air almost regardless of the manner in which the airplane is brought to the ground, as long as the air speed is held to within about 15 miles per hour of the minimum, the wings are held level laterally, and the controls are not used violently. In gusty air other factors are encountered which complicate the problem, and this condition is being studied further.

After it had been determined that satisfactory landings could be made, more detailed flight tests were made on this airplane with the elevator deflection limited. These showed that the control limitation did not appreciably affect the ability to perform acrobatic or ordinary maneuvers in flight, and that the airplane could be satisfactorily maneuvered in turns during glides with the stick full back to the limited position.

Report No. 419, entitled "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. I—Ordinary Ailerons on Rectangular Wings," by Fred E. Weick and Carl J. Wenzinger, National Advisory Committee for Aeronautics.

This report is the first of a series in which it is intended to compare the relative merits of all ordinary and some special forms of ailerons and other lateral control devices in regard to their effect on lateral controllability, lateral stability, and airplane performance. The comparisons are based on wind-tunnel test data, all the control devices being fitted to model wings having the same span, area, and airfoil section, and being subjected to the same series of force and rotation tests.

In this particular report the results are given for ordinary ailerons of three different sizes. The medium-size ailerons, which with equal upward and downward deflection are used as a standard for comparison, had a chord 25 per cent of the wing chord and a span 40 per cent of the semispan of the wing. Of the other two sizes, one was long and narrow and the other short and wide. The results are given for 5 different aileron movements: 1 with equal up-and-down deflection, 1 with average and 1 with extreme differential motion, 1 with upward deflection only, and 1 with the ailerons arranged to float with respect to the wing.

The results showed that although the ailerons of medium size with either the equal up-and-down or the commonly used differential motions gave very unsatisfactory control above the stall, satisfactory control was obtained with the short, wide ailerons with upward deflection only, and was closely approached by the same ailerons with extreme differential motion. The short, wide and the medium ailerons with upward deflection only also gave powerful yawing moments which at all angles of attack would aid the rolling, although with small deflections above the stall slight adverse yawing moments occurred. The only ailerons which gave no adverse yawing moments at any deflection or angle of attack were the short, wide ones arranged to float.

Report No. 420, entitled "Aircraft Speed Instruments," by K. Hilding Beij, Bureau of Standards.

This report presents a concise survey of the measurement of air speed and ground speed on board aircraft. Special attention is paid to the Pitot-static air-speed meter which is the standard in the United States for airplanes. Air-speed meters of the rotating-vane type are also discussed in considerable detail on account of their value as flight-test instruments and as service instruments for airships. Methods of ground-speed measurement are treated briefly, with references to thd more important instruments. A bibliography on air-speed measurement concludes the report.

Report No. 421, entitled "Measurement of the Differential and Total Thrust and Torque of Six Full-Scale Adjustable-Pitch Propellers," by George W. Stickle, National Advisory Committee for Aeronautics.

Force measurements giving total thrust and torque, and propeller slipstream surveys giving differential thrust and torque were simultaneously made on each of six full-scale propellers in the committee's 20-foot propeller-research tunnel. They were adjustable-pitch metal propellers 9.5 feet in diameter; three had modified Clark Y blade sections and three had modified R. A. F. 6 blade sections. This report gives the differential thrust and torque and the variation caused by changing the propeller tip speed *V/nD*, and the pitch setting. The total thrust and torque obtained from integration of the thrust and torque distribution curves are compared with those obtained by direct force measurements.

In the above comparison the torques measured by the two methods were directly comparable but the thrusts derived from the slipstream survey differed from those obtained from the force measurements by two factors, the drag of the hub and the increase of body drag due to the slipstream. Since single values of two coefficients used to obtain the factors brought all the thrust curves measured by the two methods into very good agreement, it is believed that the factors represent accurately the drag of the hub and the increase of body drag due to the slipstream.

Report No. 422, entitled "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. II—Slotted Ailerons and Frise Ailerons," by Fred E. Weick and Richard W. Noyes, National Advisory Committee for Aeronautics.

Three model wings, two with typical slotted ailerons and one with typical Frise ailerons, have been tested as part of a general investigation on lateral control devices, with particular reference to their effectiveness at high angles of attack, in the committee's 7 by 10 foot wind tunnel. Force tests, free-autorotation tests, and forced-rotation tests were made which show the effect of the various ailerons on the general performance of the wing, on the lateral controllability, and on the lateral stability. In general, the slotted and Frise ailerons tested were inferior in rolling control at 20° angle of attack to plain ailerons of the same size. The adverse yawing moments obtained with the slotted and Frise ailerons were, in most cases, slightly smaller than those obtained with plain ailerons of the same size and deflection. However, this improvement was small as compared to the improvement obtainable by the use of suitable differential movements with any of the ailerons, including the plain.

Report No. 423, entitled "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. III—Ordinary Ailerons Rigged up 10° When Neutral," by Fred E. Weick and Carl J. Wenzinger, National Advisory Committee for Aeronautics.

Wind-tunnel tests have been made on three model wings having different sizes of ordinary ailerons rigged up 10° when neutral, the same models having previously been tested with the ailerons rigged even with the wings in the usual manner. One of the wings had ailerons of medium size, 25 per cent of the wing chord by 40 per cent of the semispan, one had long, narrow ailerons, and one had short, wide ones. These tests are part of a general investigation on lateral control devices, with particular reference to the control at high angles of attack, in which all the devices are being subjected to the same series of tests in the committee's 7 by 10 foot wind tunnel. Force tests of the usual type, free-autorotation tests, and forced-rotation tests were made showing the effect of the ailerons on the general performance of the wing, on the lateral controllability, and on the lateral stability.

With the ailerons rigged up 10° when neutral, negligibly small yawing moments (body axis), at all angles of attack which can be maintained by conventional airplanes, were given by the medium-size ailerons with equal up-and-down deflection. Large favorable yawing moments, and no adverse ones with any portion of the total deflection, were given at all angles of attack by each of the three sizes of ailerons with up-only movement, by the short, wide ailerons with a medium differential movement, and by the medium-size ailerons with an extreme differential movement. The direct rolling control was best at high angles of attack with the short, wide ailerons with an extreme differential movement, but this combination required exceptionally high control forces. For neutral setting the lateral instability was found to be less with the ailerons rigged up 10° than with them rigged even with the wing.

Report No. 424, entitled "Wind-Tunnel Research Comparing Lateral ontrol Devices, Particularly at High Angles of Attack. IV—Floating Tip Ailerons on Rectangular Wings," by Fred E. Weick and Thomas A. Harris, National Advisory Committee for Aeronautics.

This report is the fourth of a series on systematic tests conducted by the committee, which compare lateral control devices with particular reference to their effectiveness at high angles of attack. This report covers tests with floating tip ailerons on rectangular Clark Y wings. Ailerons of two profiles were tested, symmetrical and Clark Y, both with adjustable trailing-edge flaps. Each form was tested at three hinge-axis locations, both with and without vertical end plates between the ailerons and the wing proper. The results from these tests are compared with the results from tests on a wing of the same over-all size equipped with average-size ordinary ailerons.

All the wing-tip floating ailerons tested had about the same characteristics throughout except for their effect on the general performance of the wing. The general performance was found to be definitely poorer for all of the rectangular wings with floating-tip ailerons than with a wing having the same over-all dimensions and ordinary ailerons. At the stall and just above, the rolling control was less than an assumed satisfactory value, but was appreciably better than with the standard wing with ordinary ailerons. At angles of attack above 22° the control with the wing-tip ailerons was found to be greater than the assumed satisfactory value, whereas the ordinary ailerons on the standard wing failed almost completely. The wings with floating tip ailerons gave no appreciable adverse yawing moments (body axis), but gave large favorable ones at high angles of attack. The instability in rolling was not as bad as for the wing with ordinary ailerons.

Report No. 425, entitled "The Effect of Nozzle Design and Operating Conditions on the Atomization and Distribution of Fuel Sprays," by Dana W. Lee, National Advisory Committee for Aeronautics.

The atomization and distribution characteristics of fuel sprays from automatic injection valves for compression-ignition engines were determined by catching the fuel drops on smoked-glass plates, and then measuring and counting the impressions made in the lampblack. The experiments were made in an air-tight chamber in which the air density was raised to values corresponding to engine conditions.

The effects of the jet velocity, chamber-air density, orifice diameter, and the orifice length-diameter ratio on the fineness and uniformity of the atomization and on the distribution of the fuel in sprays from plain cylindrical nozzles were determined. The atomization and distribution characteristics of sprays from valves having spirally grooved stems, of sprays produced by the impinging of two fuel jets, and of sprays produced by a fuel jet striking a metal lip were also measured and compared with those of sprays from the plain nozzles.

It was found that each spray is composed of several million drops whose diameters range from less than 0.00025 inch to 0.005 inch, and sometimes to 0.010 inch. The experiments indicated that with a given fuel the fineness and uniformity of the atomization increase with an increase in the jet velocity, and with a decrease in the orifice diameter. Orifice length-diameter ratio and chamber-air density had no decided effect on the spray atomization. Centrifugal-type sprays, impinging-jet sprays, and sprays formed by a jet striking a metal lip were found to have no better atomization than sprays from plain nozzles, provided that the jet velocity was the same, but the distribution of the fuel within these sprays was found to be much better than for plain sprays.

Report No. 426, entitled "The Effect of Humidity on Engine Power at Altitude," by D. B. Brooks and E. A. Garlock, Bureau of Standards.

From tests made in the bureau's altitude chamber, it was found that the effect of humidity on engine power is the same at altitudes up to 25,000 feet as at sea level. Earlier tests on automotive engines, made under sea-level conditions, showed that water vapor acts as an inert diluent, reducing engine power in proportion to the amount of vapor present.

By combining the effects of atmospheric pressure, temperature, and humidity, it is shown that the indicated power obtainable from an engine is proportional to its mass rate of consumption of oxygen. This has led the National Advisory Committee for Aeronautics to adopt a standard basis for the correction of engine performance, in which the effect of humidity is included.

Report No. 427, entitled "The Effect of Multiple Fixed Slots and a Trailing-Edge Flap on the Lift and Drag of a Clark Y Airfoil," by Fred E. Weick and Joseph A. Shortal, National Advisory Committee for Aeronautics.

Lift and drag tests were made on a Clark Y wing equipped with four fixed slots and a trailing-edge flap in the committee's 5-foot vertical wind tunnel. All possible combinations of the four slots were tested with the flap neutral and the most promising combinations were tested with the flap down 45°. Considering both the maximum lift coefficient and the speed-range ratio $C_{L_{max}}/C_{D_{min}}$, with the flap neutral no appreciable improvement was found with the use of more than the single leading-edge slot. With the flap down 45° a maximum lift coefficient of 2.60 was obtained but the particular slot combination used had a rather large minimum drag coefficient with the flap neutral. With the flap down 45° the optimum combination, considering both the maximum lift coefficient and the speed-range ratio, was obtained with only the two rearmost slots in use. For this arrangement the maximum lift coefficient was 2.44.

Report No. 428, entitled "Wind-Tunnel Tests of a Clark Y Wing with a Narrow Auxiliary Airfoil in Different Positions," by Fred E. Weick and Millard J. Bamber, National Advisory Committee for Aeronautics.

Aerodynamic force tests were made on a combination of a Clark Y wing and a narrow auxiliary airfoil to find the best location of the auxiliary airfoil with respect to the main wing. The auxiliary was a highly cambered airfoil of medium thickness having a chord 14.5 per cent that of the main wing. It was tested in 141 different positions ahead of, above, and behind the nose portion of the main wing, the range of the test points being extended until the best aerodynamic conditions were covered.

A range of positions was found in which the combination of main wing and auxiliary gave substantially greater aerodynamic efficiency and higher maximum lift coefficients (based on total area) than the main Clark Y wing alone. In the optimum position tested, considering both the maximum lift and the speed-range ratio, the combination of main wing and auxiliary gave an increase in the maximum lift coefficient of 32 per cent together with an increase in the ratio $C_{L_{max}}/C_{D_{min}}$ of 21 per cent of the respective values for the main Clark Y wing alone.

Report No. 429, entitled "The N. A. C. A. Apparatus for Studying the Formation and Combustion of Fuel Sprays and the Results from Preliminary Tests," by A. M. Rothrock, National Advisory Committee for Aeronautics.

This report describes the apparatus, as designed and constructed at the committee's laboratory, for studying the formation and combustion of fuel sprays under conditions closely simulating those occurring in a high-speed compression-ignition engine. The apparatus consists of a single-cylinder modified test engine, a fuel-injection system so designed that a single charge of fuel can be injected into the combustion chamber of the engine, an electric driving motor, and a high-speed photographic apparatus. The cylinder head of the engine has a vertical-disk form of combustion chamber whose sides are glass windows. When the fuel is injected into the combustion chamber, motion pictures at the rate of 2,000 per second are taken of the spray formation by means of spark discharges. When combustion takes place the light of the combustion is recorded on the same photographic film as the spray photographs.

The report includes the results of some tests to determine the effect of air temperature, air flow, and nozzle design on the spray formation. The results show that the compression temperature has little effect on the penetration of the fuel spray but does affect the dispersion, that air velocities of about 300 feet per second are necessary to destroy the core of the spray, and that the effect of air flow on the spray is controlled to a certain extent by the design of the injection nozzle. The results on the combustion of the spray show that when ignition does not take place until after spray cut-off the ignition may start almost simultaneously throughout the combustion chamber or at different points throughout the chamber. When ignition takes place before spray cut-off the combustion starts around the edge of the spray and then spreads throughout the chamber.

Report No. 430, entitled "Measurements of Flow in the Boundary Layer of a 1/40-Scale Model of the U. S. Airship *Akron*," by Hugh B. Freeman, National Advisory Committee for Aeronautics.

This report presents the results of measurements of flow in the boundary layer of a 1/40-Scale model of the U. S. airship *Akron* (*ZRS-4*) made with the object of determining the boundary-layer thickness, the point of transition from laminar to turbulent flow, and the velocity distribution in the boundary layer.

The boundary-layer thickness was found to vary along the 19.62-foot hull from 0.08 inch at the most forward station, about 15 inches from the nose, to approximately 10 inches at the tail. A marked increase in the rate of thickening of the boundary layer was found at the transition from laminar to turbulent flow which occurred at a Reynolds Number $\left(\frac{Va}{v}\right)$ of about 814,000, where (a) is the axial distance from the nose. The velocity distribution over the greater part of the turbulent portion of the boundary layer was found to be fairly well approximated by the seventh-power law. The frictional drag, computed from the loss of momentum in the boundary layer and also from Clark Millikan's equations, was in good agreement with the measured drag.

Report No. 431, entitled "Characteristics of Clark Y Airfoils of Small Aspect Ratios," by C. H. Zimmerman, National Advisory Committee for Aeronautics.

This report presents the results of a series of wind-tunnel tests showing the force, moment, and autorotational characteristics of Clark Y airfoils having aspect ratios varying from 0.5 to 3.

An airfoil of rectangular plan form was tested with rectangular tips, faired tips, and semicircular tips. Tests were also made on one airfoil of circular plan form and two airfoils of elliptical plan form.

The tests revealed a marked delay of the stall and a decided increase in values of maximum lift coefficient and maximum resultant force coefficient for aspect ratios of the order of 1 as compared with the values for aspect ratios of 2 and 3. The largest value of $C_{R_{max}}$ was 2.17 with a wing of circular plan form and an aspect ratio of 1.27. The same wing gave a $C_{L_{max}}$ of 1.85 and an L/D ratio of 1.63 at 45° angle of attack.

Wings having aspect ratios of about 1 were found to have moment characteristics more favorable to stability than those having larger aspect ratios. Decreasing the aspect ratio greatly reduced ranges and rates of autorotation based on a given span and air speed. Results, when reduced to infinite aspect ratio by conventional formulas, indicate that such formulas are not applicable for aspect ratios less than 1.5. It is apparent that the plan form and tip shape of the wing are of major importance among the factors affecting airfoil characteristics at aspect ratios of 1.5 and smaller.

Report No. 432, entitled "Force Measurements on a 1/40-Scale Model of the U. S. Airship *Akron*," by Hugh B. Freeman, National Advisory Committee for Aeronautics.

This report describes a series of tests made on a 1/40-Scale model of the U. S. airship *Akron* (*ZRS-4*) for the purpose of determining the drag, lift, and pitching moments of the bare hull and of the hull equipped with two different sets of fins. Measurements were also made of the elevator forces and hinge moments.

The results of the drag measurements are in fair agreement with those of previous tests on smaller models of the *Akron* conducted in the committee's variable-density tunnel. The type of tail surface designated Mark II, a short, wide surface, was found to have more favorable control characteristics than the long, narrow type, Mark I. The results of the measurements of the elevator hinge moments showed that the elevators for both types of fins were overbalanced for a large range of elevator angles, indicating that the area of the balancing vanes, for the Mark II elevators at least, was excessive.

Report No. 433, entitled "Rates of Fuel Discharge as Affected by the Design of Fuel-Injection Systems for Internal-Combustion Engines," by A. G. Gelalles and E. T. Marsh, National Advisory Committee for Aeronautics.

Using the method of weighing fuel collected in a receiver during a definite interval of the injection period, rates of discharge were determined, and the effects noted, when various changes were made in a fuel-injection system. The injection system consisted primarily of a by-pass controlled fuel pump and an automatic injection valve. The variables of the system studied were the pump speed, pump-throttle setting, discharge-orifice diameter, injection-valve opening and closing pressures, and injection-tube length and diameter.

The results show that, for the same orifice diameter, the rate of discharge increased with the pump speed and injection-valve opening and closing pressures. For the same pump speed, the throttle setting had little effect upon the rate of discharge up to the point of cut-off. The rates of discharge conformed approximately to the contour of the cam only with the larger-size orifices; with the smaller orifices, because of the excess energy supplied by the pump over that utilized for discharge, the higher intensity reflections and reenforcements altered the discharge to a different conformation. The tube length was found to have little effect on either the rate of discharge, injection period, or injection lag. The data show that the pressure before the injection valve is affected substantially if injection-tube diameters are used that are below the critical diameter.

Report No. 434, entitled "Lift and Drag Characteristics and Gliding Performance of an Autogiro as Determined in Flight," by John B. Wheatley, National Advisory Committee for Aeronautics.

The results of flight tests on a Pitcairn PCA-2 autogiro are presented in this report. Lift and drag coefficients with the propeller stopped have been determined over approximately a 90° range of angles of attack. Based on the sum of fixed-wing and swept-disk areas, the maximum lift coefficient is 0.895, the minimum drag coefficient with propeller stopped is 0.015, and the maximum L/D with propeller stopped is 4.8. Lift coefficients were found also with the propeller delivering positive thrust and did not differ consistently from those found with propeller stopped. Curves of gliding performance included in this report show a minimum vertical velocity of 15 feet per second at an air speed of 36 miles per hour and a flight-path angle of $-17°$. In vertical descent the vertical velocity is 35 feet per second.

Report No. 435, entitled "Fuel Vaporization and Its Effect on Combustion in a High-Speed Compression-Ignition Engine," by A. M. Rothrock and C. D. Waldron, National Advisory Committee for Aeronautics.

The tests discussed in this report were conducted to determine whether or not there is appreciable vaporization of the fuel injected into a high-speed compression-ignition engine during the time available for injection and combustion. The effects of injection advance angle, fuel boiling temperatures, fuel quantity, engine speed, and engine temperature were investigated. The results show that an appreciable amount of the fuel is vaporized during injection even though the temperature and pressure conditions in the engine are not sufficient to cause ignition either during or after injection, and that when the conditions are such as to cause ignition the vaporization process affects the combustion. The results are compared with those of several other investigators in the same field. The tests were conducted with the committee's combustion apparatus.

Report No. 436, entitled "Tests of Nacelle-Propeller Combinations in Various Positions with Reference to Wings. II.—Thick Wing—Various Radial-Engine Cowlings—Tractor Propeller," by Donald H. Wood, National Advisory Committee for Aeronautics.

This report is the second of a series giving the results obtained in the committee's 20-foot wind tunnel on the interference drag and propulsive efficiency of nacelle-propeller-wing combinations. The first report gave the results of the tests of an N. A. C. A. cowled air-cooled engine nacelle located in 21 positions with reference to a thick wing. This report gives results of tests of a normal engine nacelle with several types of cowling and fairings in four of the positions with reference to the same wing.

The wing had a 5-foot chord, a 15-foot span, and a maximum thickness of 20 per cent of the chord. The engine was a 4/9-scale model of a Wright J-5 radial air-cooled engine, and was installed in a small nacelle of the same scale. Tests were made with no engine cowling, with a narrow variable-angle ring, two wide thin rings with different chord angles, and the hood previously used on the N. A. C. A. cowled nacelle. The propeller was a 4-foot diameter model of the standard Navy adjustable-pitch metal propeller No. 4412.

In two of the nacelle positions tests were made in two conditions—with the nacelle supported on struts and with the space between the nacelle and wing filled by fairing. The effects of fairing the N. A. C. A. hood into the wing and of side brackets on the nacelle when located ahead of the wing were also investigated.

The lift, drag, and propulsive efficiency were determined at several angles of attack for each cowling and fairing condition in each of the four nacelle locations. The net efficiency was computed by the method of Report No. 415 and compared with the results therein reported.

Although the propulsive efficiency of the small uncowled nacelle is higher than that of the nacelle with any of the cowlings, the drag and interference are also higher, and the highest net efficiency is obtained with the N. A. C. A. cowled nacelle. Fairing the nacelle into the wing is an advantage when the cowled nacelles are located near the wing but is of little value when the nacelles are not cowled. Fairing the N. A. C. A. hood into the wing is detrimental. Side brackets on the nacelle when it is located ahead of the wing are to be avoided. The N. A. C. A. cowled nacelle located about 25 per cent of the chord ahead of the wing is the best tractor-nacelle arrangement. If the cowling is omitted with nacelle in this position, a loss of lift results, especially at high angles of attack. The proper location of nacelles and careful cowling are important in the high-speed range of flight, but in the lower speed ranges there is little advantage of one nacelle position or cowling over another.

Report No. 437, entitled "The Effect of Area and Aspect Ratio on the Yawing Moments of Rudders at Large Angles of Pitch on Three Fuselages," by Hugh L. Dryden and B. H. Monish, Bureau of Standards.

In view of the paucity of data on the effect of systematic changes in the vertical tail surfaces, measurements have been made of the yawing moments produced by rudder displacement for seven rudders mounted on each of three fuselages at angles of pitch of 0°, 8°, 12°, 20°, 30°, and 40°. The dimensions of the rudders were selected to cover the range of areas and aspect ratios commonly used, while the ratios of rudder area to fin area and of rudder chord to fin chord were kept approximately constant.

An important result of the measurements is to show that increased aspect ratio gives increased yawing moments for a given area, provided the maximum rudder displacement does not exceed, say, 25°. If large rudder displacements are used, the effect of aspect ratio is not so great.

Report No. 438, entitled "Experiments on the Distribution of Fuel in Fuel Sprays," by Dana W. Lee, National Advisory Committee for Aeronautics.

The distribution of the fuel in sprays for compression-ignition engines was investigated by taking high-speed spark photographs of fuel sprays produced under a wide variety of conditions and also by injecting them against pieces of Plasticine. A photographic study was made of sprays injected into evacuated chambers, into the atmosphere, into compressed air, and into transparent liquids. Pairs of identical sprays were injected counter to each other and their behavior analyzed. Small high-velocity air jets were directed normally to the axes of fuel sprays, with the result that the envelope of spray which usually obscures the core was blown aside, leaving the core exposed on one side.

The results showed that the distribution of the fuel within the sprays was very uneven. Under engine-operating conditions the fuel was subdivided into many small particles by the time it had penetrated 0.75 inch. In the cores of the sprays, these particles had a high velocity relative to the air in their immediate vicinity, but as their velocity was reduced, they were forced out of the core and formed the spray envelope. The shape of the central core varied with the density of the chamber air, becoming shorter and thicker with increasing air density.

Report No. 439, entitled "Wind-Tunnel Research Comparing Lateral Control Devices, Particularly at High Angles of Attack. V—Spoilers and Ailerons on Rectangular Wings," by Fred E. Weick and Joseph A. Shortal, National Advisory Committee for Aeronautics.

This report covers the fifth of a series of systematic investigations in which lateral control devices are compared with particular reference to their effectiveness at high angles of attack. This report deals with tests of spoilers and ordinary ailerons on rectangular Clark Y wing models. In an effort to obtain satisfactory control throughout the entire angle-of-attack range that can be maintained in flight, various spoilers were tested in combination with two sizes of previously tested ordinary ailerons—one of average proportions and the other short and wide. In addition, one large spoiler was tested alone.

It was found that when ailerons and spoilers are used together the full effect of both is not obtained if the spoilers are located directly in front of the ailerons. With the proper combination of spoiler and aileron, however, it is possible to obtain satisfactory rolling control up to high angles of attack (15° to 20°), together with favorable yawing moments and small control forces. A moderate amount of rolling control with favorable yawing moments and small control forces was obtained with the large spoiler alone.

Report No. 440, entitled "The Mechanism of Atomization Accompanying Solid Injection," by R. A. Castleman, jr., Bureau of Standards.

A brief historical and descriptive account of solid injection is followed by a detailed review of the available theoretical and experimental data that seem to throw light on the mechanism of this form of atomization. It is concluded that this evidence indicates (1) that the atomization accompanying solid injection occurs at the surface of the liquid after it issues as a solid stream from the orifice; and (2) that such atomization has a mechanism physically identical with the atomization which takes place in an air stream, both being due merely to the formation at the gas-liquid interface of fine ligaments under the influence of the relative motion of gas and liquid, and to their collapse, under the influence of surface tension, to form the drops in the spray. This simple theory, previously proposed by the author, is the most satisfactory and fits the observations the best of any yet advanced. It is recommended that use of the term "atomization" be restricted to a certain definite range, in which its use is sound, etymologically and physically.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

No.

394. The Prevention of Ice Formation on Gasoline Tank Vents. By Theodore Theodorsen and William C. Clay.
395. Penetration and Duration of Fuel Sprays from a Pump Injection System. By A. M. Rothrock and E. T. Marsh.
396. Performance of a Compression-Ignition Engine with a Precombustion Chamber Having High-Velocity Air Flow. By J. A. Spanogle and C. S. Moore.
397. The Aerodynamic Characteristics of Six Commonly Used Airfoils Over a Large Range of Positive and Negative Angles of Attack. By Raymond F. Anderson.

No.

398. The Effect of Slots and Flaps on the Lift and Drag of the McDonnell Airplane as Determined in Flight. By Hartley A. Soulé.
399. Some Characteristics of Fuel Sprays at Low-Injection Pressures. By A. M. Rothrock and C. D. Waldron.
400. Advantages of Oxide Films as Bases for Aluminum Pigmented Surface Coatings for Aluminum Alloys. By R. W. Buzzard and W. H. Mutchler.
401. Tests of N. A. C. A. Airfoils in the Variable Density Wind Tunnel. Series 44 and 64. By Eastman N. Jacobs and Robert M. Pinkerton.
402. The Effectiveness of a Double-Stem Injection Valve in Controlling Combustion in a Compression-Ignition Engine. By J. A. Spanogle and E. G. Whitney.
403. The Interference Effects on an Airfoil of a Flat Plate at Mid-Span Position. By Kenneth E. Ward.
404. Tests of N. A. C. A. Airfoils in the Variable-Density Wind Tunnel. Series 24. By Eastman N. Jacobs and Kenneth E. Ward.
405. Valve Timing of Engines Having Intake Pressures Higher Than Exhaust. By Edward S. Taylor.
406. The Use of Large Valve Overlap in Scavenging a Supercharged Spark-Ignition Engine Using Fuel Injection. By Oscar W. Schey and Alfred W. Young.
407. Effect of the Reservoir Volume on the Discharge Pressures in the Injection System of the N. A. C. A. Spray Photography Equipment. By A. M. Rothrock and D. W. Lee.
408. Preliminary Tests on the Vaporization of Fuel Sprays. By A. M. Rothrock.
409. Effect of Aging on Taut Rubber Diaphragms. By D. H. Strother and H. B. Henrickson.
410. Experiments on the Distribution of Fuel in Fuel Sprays. By Dana W. Lee.
411. Rapid Chemical Test for the Identification of Chromium-Molybdenum Steel Aircraft Tubing. By John C. Redmond.
412. The Aerodynamic Characteristics of Airfoils at Negative Angles of Attack. By Raymond F. Anderson.
413. The Compressive Strength of Duralumin Columns of Equal Angle Section. By Eugene E. Lundquist.
414. Considerations of Air Flow in Combustion Chambers of High-Speed Compression-Ignition Engines. By J. A. Spanogle and C. S. Moore.
415. Preliminary Investigation of Rolling Moments Obtained with Spoilers on Both Slotted and Plain Wings. By Fred E. Weick and Carl J. Wenzinger.
416. Characteristics of Two Sharp-Nosed Airfoils Having Reduced Spinning Tendencies. By Eastman N. Jacobs.
417. Wind-Tunnel Tests of a Hall High-Lift Wing. By Fred E. Weick and Robert Sanders.
418. Compression-Ignition Engine Tests of Several Fuels. By J. A. Spanogle.
419. Wind-Tunnel Tests of the Fowler Variable-Area Wing. By Fred E. Weick and Robert C. Platt.
420. The Effect of Propellers and Nacelles on the Landing Speeds of Tractor Monoplanes. By Ray Windler.
421. The Nature of Air Flow About the Tail of an Airplane in a Spin. By N. F. Scudder and M. P. Miller.
422. The Aerodynamic Characteristics of a Model Wing Having a Split Flap Deflected Downward and Moved to the Rear. By Fred E. Weick and Thomas A. Harris.
423. Effect of Length of Handley Page Tip Slots on the Lateral-Stability Factor, Damping in Roll. By Fred E. Weick and Carl J. Wenzinger.
424. Preliminary Photomicrographic Studies of Fuel Sprays. By Dana W. Lee and Robert C. Spencer.
425. Methods of Visually Determining the Air Flow Around Airplanes. By Melvin N. Gough and Ernest Johnson.
426. Comparative Performance of a Powerplus Vane-Type Supercharger and an N. A. C. A. Roots-Type Supercharger. By Oscar W. Schey and Herman H. Ellerbrock, jr.
427. Strength Tests on Thin-Walled Duralumin Cylinders in Torsion. By Eugene E. Lundquist.
428. Characteristics of an Airfoil as Affected by Fabric Sag. By Kenneth E. Ward.
429. Heat Dissipation from a Finned Cylinder at Different Fin-Plane/Air-Stream Angles. By Oscar W. Schey and Arnold E. Biermann.
430. Effect of Engine Operating Conditions on the Vaporization of Safety Fuels. By A. M. Rothrock and C. D. Waldron.
431. Tests on Thrust Augmentors for Jet Propulsion. By Eastman N. Jacobs and James M. Shoemaker.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

No.

640. The New "Charlestop" Remote Brake Transmission and Control. By Pierre Léglise. From L'Aéronautique, July, 1931.
641. Lift Distribution and Longitudinal Stability of an Airplane. By Carl Töpfer. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, June 29, 1931.

No.

642. Flutter in Propeller Blades. By Friedrich Seewald. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, June 29, 1931.
643. Load Assumptions for the Landing Impact of Seaplanes. By Josef Taub. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, July 28, 1931.
644. On Atomization in Carburetors. By F. N. Scheubel. From Jahrbuch der Wissenschaftlichen Gesellschaft für Luftfahrt, 1927.
645. Relations between Ship Design and Seaplane Design. By Georg Schnadel. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Aug. 14, 1931.
646. Measurement of Visibility from the Pilot's Cockpit on Different Airplane Types. By Gerhard Kurz. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, March 28, 1931.
647. Spatial Buckling of Various Types of Airplane Strut Systems. By Alfred Teichmann. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Sept. 14, 1931.
648. Measurements of Vertical Air Currents in the Atmosphere. By K. O. Lange. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Sept. 14, 1931.
649. Liquid Cooling of Aircraft Engines. By Hanns Weidinger. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Sept. 28, 1931.
650. Development of a Non-Autorotative Airplane Capable of Steep Landing. By Wilhelm Schmidt. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Sept. 28 and Oct. 14, 1931.
651. Wind Tunnel of the Bucharest Polytechnic Institute. Data received from Paris Office.
652. Goldstein's Solution of the Problem of the Aircraft Propeller with a Finite Number of Blades. By H. B. Helmbold. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, July 28, 1931.
653. Turbulence and Mechanism of Resistance on Spheres and Cylinders. By Fr. Ahlborn. From Zeitschrift für Technische Physik, Vol. XII, No. 10, 1931.
654. Stresses Produced in Airplane Wings by Gusts. By Hans Georg Küssner. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Oct. 14 and Oct. 28, 1931.
655. Experiments with Intubed Propellers. By L. Stipa. From L'Aerotecnica, Aug., 1931.
656. Dynamic Testing of Airplane Shock-Absorbing Struts. By P. Langer and W. Thome. From Zeitschrift des Vereines Deutscher Ingenieure, Nov. 7, 1931.

No.

657. Resonance Vibrations of Aircraft Propellers. By Fritz Liebers. From Luftfahrtforschung, May 16, 1930.
658. Problems Involved in the Choice and Use of Materials in Airplane Construction. By Paul Brenner. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Nov. 14, 1931.
659. Disintegration of a Liquid Jet. By A. Haenlein. From Forschung auf dem Gebiete des Ingenieurwesens, April, 1931.
660. Airplane Flight in the Stratosphere. By Ugo de Caria. From Aeronautica, Dec., 1931.
661. Experiments with Planing Surfaces. By W. Sottorf. From Werft-Reederei-Hafen, Nov. 7, 1929.
662. Accurate Calculation of Multispar Cantilever and Semicantilever Wings with Parallel Webs Under Direct and Indirect Loading. By Eugen Sänger. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Oct. 28, 1931.
663. Problems Concerning the Stability and Maneuverability of Airplanes. By Jean Biche. From Revue de la Société Générale Aéronautique, Jan., 1932.
664. German Aircraft Accident Statistics, 1930. By Ludwig Weitzmann. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Jan. 15, 1932.
665. The Mutual Action of Airplane Body and Power Plant. By Martin Schrenk. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Dec. 14, and Dec. 28, 1931.
666. Development of Tailless and All-Wing Gliders and Airplanes. By Robert W. E. Lademann. From Die Luftwacht, Feb., 1932.
667. Application of the Theory of Free Jets. By A. Betz and E. Petersohn. From Ingenieur-Archiv, May, 1931.
668. Combustion Velocity of Benzine-Benzol-Air Mixtures in High-Speed Internal-Combustion Engines. By Kurt Schnauffer. From Zeitschrift des Vereines Deutscher Ingenieure, 1931.
669. The German Investigation of the Accident at Meopham (England). By Hermann Blenk, Heinrich Hertel, and Karl Thalau. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Feb. 15, 1932.
670. Determination of Stresses and Deformation of Aircraft Propellers. By Friedrich Seewald. From Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt, Dec., 1926 (supplement to Z. F. M.).
671. Twelfth Rhön Soaring Contest, 1931. By Walter Georgii. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Feb. 29, and March 14, 1932.

No.

672. Torsional Vibration of Aircraft Engines. By Karl Lürenbaum. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, Feb. 29, 1932.

673. Vertical Descent of the Autogiro. By J. A. J. Bennett. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, April 28, 1932.

674. Effect of the Ground on an Airplane Flying Close to It. By E. Tonnies. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, March 29, 1932.

675. Calculation of Potential Flow Past Airship Bodies in Yaw. By I. Lotz. From Ingenieur-Archiv, Vol. II, 1931.

676. Towing Tests of Models as an Aid in the Design of Seaplanes. By P. Schröder. From Werft-Reederei-Hafen, Aug. 22, 1930.

677. Stresses Developed in Seaplanes While Taking off and Landing. By Rudolfo Verduzio. From L'Aerotecnica, Nov., 1931.

678. Increase in the Maximum Lift of an Airplane Wing Due to a Sudden Increase in Its Effective Angle of Attack Resulting from a Gust. By Max Kramer. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, April 14, 1932.

679. Experimental Determination of the Thickness of the Boundary Layer Along a Wing Section. By Otto Cuno. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, April 14, 1932.

680. Approximate Calculation of Multispar Cantilever and Semicantilever Wings with Parallel Ribs Under Direct and Indirect Loading. By Eugen Sänger. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, May 14, 1932.

681. Reduction of Wing Lift by the Drag. By A. Betz and J. Lotz. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, May 28, 1932.

682. Airplane Stability in Taxying. By E. Anderlik. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, May 28, 1932.

683. Propeller Tip Flutter. By Fritz Liebers. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, May 14, 1932.

684. The Aerodynamic Safety of Airplanes. By Louis Kahn. From Bulletin Technique du Bureau Veritas, Feb., 1932.

685. The Controls at Low Hinge Moments. By M. Pris. From Bulletin de la Chambre Syndicale des Industries Aéronautiques, Nov.-Dec., 1931.

686. Further Flight Tests on the Effectiveness of Handley Page Automatic Control Slots. By Wilhelm Pleines. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, May 28, 1932.

LIST OF AIRCRAFT CIRCULARS ISSUED DURING THE PAST YEAR

No.

153. The Guillemin J. G. 10 (French). A Two-Place Touring Low-Wing Monoplane. From L'Aeronautique, Sept., 1931.

154. The Supermarine S. 6 B. Racing Seaplane (British). A Low-Wing Twin-Float Monoplane. From Aircraft Engineering, Oct., 1931, a pamphlet issued by Supermarine Aviation Works (Ltd.), and The Aeroplane, Sept. 30, 1931.

154. (Sup.) Supplement to the Supermarine S. 6 B. Racing Seaplane (British). A Low-Wing Twin-Float Monoplane. How the Supermarine S. 6 B. Was Built. From The Aeroplane, Dec. 16, 1931.

155. The Dornier Do K Commercial Airplane (German). A High-Wing Cantilever Monoplane. By Edwin P. A. Heinze. From Flight, Oct. 9 and Oct. 30, 1931.

156. The Armstrong-Whitworth A. W. XVI Military Airplane (British). A Single-Seat Biplane. From The Aeroplane, Oct. 14, 1931; from Flight, Oct. 16 and Oct. 23, 1931.

157. The Loire 11 Colonial Military Airplane (French). A High-Wing Semicantilever All-Metal Monoplane. By P. Loyer. From L'Aeronautique, Jan., 1932.

158. The C. A. M. S. 80 Amphibian (French). An Observation Monoplane. From data furnished by the manufacturers and L'Aeronautique, Dec., 1931.

159. The Dreieck I Tailless Airplane (German). A Low-Wing Cantilever Monoplane. By Edwin P. A. Heinze. From Flight, Oct. 9, 1931; Aircraft Engineering, Nov., 1931; and Rivista Aeronautica, Jan., 1932.

160. The S. A. B. C. A. S. XI Commercial Airplane (Belgian). A High-Wing Semicantilever Monoplane. By André Frachet. From Les Ailes, Sept. 17, 1931.

161. The Avro 631 Training Airplane (British). A Two-Seat Light Biplane. From The Aeroplane, March 23, 1932.

162. The D. H. 83 Fox Moth Commercial Airplane (British). A Three-Passenger Light Cabin Biplane. From The Aeroplane, March 16, 1932.

163. The Breguet 410 and 411 Military Airplanes (French). Multiplace Sesquiplane Fighters. By Pierre Léglise. From L'Aeronautique, March, 1932, and Aircraft Engineering, May, 1932.

No.

164. The Stieger ST. 4 Light Airplane (British). A Twin-Engine Four-Seat Low-Wing Cabin Monoplane. From Flight, April 22, 1932, and Aircraft Engineering, May, 1932.
165. The Farman Night Bombers 211 and 212 (French). Four-Engine High-Wing Monoplanes. From L'Air, May 1, 1932.
166. The Breda 32 Commercial Airplane (Italian). A Three-Engine All-Metal Low-Wing Monoplane. From information furnished by the manufacturers, the Societa Italiana Ernesto Breda, Milan, Italy.
167. Armstrong-Whitworth A. W. XV Atalanta Airplane (British). A Commercial Multiplace Cantilever Monoplane. From Flight, July 8 and July 15, 1932.
168. Spartan Cruiser Commercial Airplane (British). A Six-Seat Low-Wing Cantilever Monoplane. From Flight, July 22, 1932.
169. The Bleriot 137 Military Airplane (French). A Twin-Engine Multiplace Monoplane. From L'Aeronautique, July, 1932.
170. The Latecoere 501 Commercial Seaplane (French). A Three-Engine Metal Sesquiplane. From data furnished by the manufacturers and L'Aeronautique, August, 1932.
171. The S. P. C. A. M. 4 Military Airplane (French). A Multiplace Low-Wing Monoplane. From data furnished by the manufacturers and L'Aeronautique, August, 1932.

PART IV

SUMMARY OF PROGRESS IN AERONAUTICAL RESEARCH

AERODYNAMICS

There has been continued progress in aerodynamic development. Many major problems have been studied and valuable results have been obtained from investigations made with the new equipment especially designed for the study of full-scale problems. In general, the major problems investigated have related to improvement in aerodynamic efficiency, safety in flight, and improvements in design and operation.

Considerable work has been accomplished during the year in connection with safety in flight, especially with reference to the improvement of lateral control at or near stalling speed. This investigation was conducted both in the wind tunnel and in free flight. The free-flight investigations also included an accurate study of the landing characteristics of airplanes.

Coupled with the investigation of lateral control, a thorough investigation has been made of high-lift wing devices, both fixed and movable, their effect on lift and drag characteristics, and also their effect on control characteristics. As a result of the investigation, the committee feels that the solution of the problem of improving the airplane safety factor, especially in the design of small airplanes for the private owner, is now much nearer.

Valuable information has been obtained by the committee as a result of investigations conducted in the variable-density wind tunnel and in the propeller-research tunnel on the aerodynamic efficiency of the airplane wing and the propulsive efficiency and drag components of the engine-nacelle unit.

The results of the study of the effect of protuberances on airplane wings conducted in the variable-density wind tunnel have aroused a keener appreciation of the value of cleanness in aircraft design.

In the field of design and operation the committee's new V–G recorder described elsewhere enables the designer for the first time to calculate accurately the maximum loads on the structural members of any particular type of airplane and thus to break away from arbitrary design rules. Additional information has been obtained on loads in flight and the effect of slight structural modifications on such loads.

The results obtained in the propeller-research tunnel in the investigation of the propulsive efficiency and drag components of engine nacelles have been far-reaching. For the first time the optimum location of an engine nacelle of a multiengine airplane, either for a monoplane or biplane arrangement, with single engines or tandem engines, has been definitely determined. The results further indicate that the positions recommended by the committee are not the positions that have long been used.

At the request of the War, Navy, and Commerce Departments, the committee devotes the facilities of its research laboratory largely to the study of problems in which they are particularly interested. These specific problems are usually of an urgent nature, and it is the committee's policy to include these studies as part of a general investigation whenever possible, and to extend the work in all cases to obtain as much fundamental information as practical.

The general research program of the committee is formulated under the direct supervision of the committee on aerodynamics, with a view to answering the needs of the governmental agencies and the aircraft industry.

With the placing in operation of the newer items of equipment at the Langley Memorial Aeronautical Laboratory it has been possible to carry out more fully than has heretofore been possible those methods of procedure most desirable in a research laboratory: (1) Cooperative work between different sections in order to attack a given problem from somewhat different points of view and by the use of different equipment and personnel, and (2) more systematic investigation of each particular problem. As examples of the first method may be mentioned the study of scale effect through tests of airfoils in the variable-density tunnel, the 7 by 10 foot tunnel, and the full-scale tunnel, and measurements of the lift and drag of airplanes by glide tests in flight and force tests in the full-scale tunnel. As examples of the more systematic investigation of certain problems, it may be mentioned that in studying control and stability no less than 526 control devices and modifications of them have been investigated in the 7 by 10 foot tunnel, and in the investigation of high-lift devices in the same tunnel 688 different devices and modifications have been tested. In the investigation of wing-nacelle-propeller interference in the propeller-research tunnel, between 70 and 80 different wing-nacelle arrangements have been covered, and if the different cowlings were included the number would be further increased.

The volume of research work conducted by the laboratory has been greatly increased during the year.

The value of the full-scale wind tunnel in solving quickly and accurately specific problems of design for the Army and Navy has been demonstrated.

Structural loading.—In accordance with the well-established premise that structural safety and efficiency require exact and comprehensive information on the nature of the external loads, the committee has continued its investigations of the aerodynamic loads and load distribution on airplanes. Definite progress has been made in several phases of the problem.

Investigations of the total load, or load factor, on several types of airplanes have led to more complete understanding of this most important basis of structural design. Statistical data on load factors in gusts have been accumulated and are now sufficiently complete to justify the assertion that gust intensities up to 30 feet per second are quite commonly experienced although gust intensities above 30 feet per second are rarely encountered.

A study of the distribution of load between biplane wings has led to the development of a set of working charts for the determination of the load distribution. These charts are an improvement over methods heretofore used. Advances in theoretical aerodynamics combined with experimental data have been utilized in the formulation of simple and precise methods for the determination of the load distribution at any lift coefficient over the ribs of airfoils having any profile. An investigation of the load distribution over wing tips of various forms has been completed and has led to the important conclusion that the distribution of lift coefficient and moment coefficient along the span is independent of the tip plan form. Further results of this investigation indicate that the influence of changes in airfoil sections and incidence near the tip can be satisfactorily estimated. Investigations of tail loads have been continued and have furnished important new information concerning this problem.

In addition to advances made in the more general problems of total load and load distribution, investigations have been made that contribute information of value toward highly specialized problems of a military nature.

Control.—The present conventional control surfaces for airplanes are reasonably satisfactory except for the rolling control given by ailerons at high angles of attack and low speeds. The ailerons have been developed to a point where they are reasonably satisfactory for high-speed and cruising-speed flight through the use of differential motions and balances of the Frise type. At low speeds and high angles of attack, however, a condition of particular importance in forced landings, the conventional ailerons do not give sufficient rolling moment. With the low rolling moment they produce an adverse yawing moment which is often greater than can be overcome with an average rudder, and which has a secondary effect tending to make the airplane roll against the ailerons.

An investigation in the 7 by 10 foot wind tunnel on various lateral control devices with particular reference to the high angles of attack, where the present ailerons are ineffective, has been continued during the past year with interesting results. Tests on wings with various tip forms have shown that although ailerons of normal proportions give poor control at the high angles of attack, wide-chord ailerons (40 per cent of wing chord) will give reasonably satisfactory rolling moments at angles of attack definitely above the stall. Although the wide-chord ailerons could be given a smaller span, the hinge moments and therefore the control force required to operate the ailerons are rather high, and it is likely that with most airplanes an effective balancing device such as a Flettner type flap would have to be used. Ailerons of the short, wide form are now being fitted to the wing of a small parasol monoplane for flight tests.

Another interesting development of the control tests in the 7 by 10 foot tunnel has been on simple flat-type spoilers hinged to the upper surface of the wing somewhat back of the wing nose. With the proper combinations of spoilers and ailerons, satisfactory control, including rolling, yawing, and hinge moments, can, according to the wind-tunnel tests, be obtained up to angles of attack well above the stall. With larger spoilers as the sole means of lateral control, moderate-size rolling moments can be obtained up to angles of attack above the stall, together with very low control forces and very high yawing moments in a favorable direction, i. e., in a direction tending to retard the low wing in a turn. Spoilers are also being fitted to the above-mentioned parasol monoplane for flight tests to show their practicability.

Stability.—The mechanics of airplane stability was worked out many years ago, but because of its complexity it has been applied to airplane design in a very limited manner. This condition is reflected in the unsatisfactory flying characteristics of many airplanes as first designed and built, due to the difficulty of knowing in advance the flying and handling characteristics to be expected of a new design. A study of the entire stability problem is now being made at the committee's laboratory for the purpose of preparing the data in easily usable form so that a designer may readily compute in advance both the longitudinal and lateral stability characteristics to be expected in his airplane.

Flight tests on a commercial parasol monoplane have been completed and reported in which measurements were made of the oscillations in pitch in order to give data on the dynamic longitudinal stability. The results satisfactorily checked the dynamic-stability theory, based on small deviations, for the condition of gliding flight, but more data are required for satisfactory computations of dynamic stability with power on.

Wind-tunnel experiments have been continued on wing-tip slots to improve the lateral stability factor, damping in roll, at high angles of attack. Rotation tests on wings fitted with Handley Page tip slots of various lengths showed that for the design tested the optimum slot was slightly greater than 50 per cent of the semispan. With this length no autorotation occurred at angles of attack below 32°, which is well above the angle that can be maintained with conventional airplanes.

Spinning.—The spinning balance for the 5-foot vertical wind tunnel has been completed and testing has started. This balance measures all six components of air forces and moments acting on the model airplane while it is being rotated with an attitude and radius corresponding to an actual spin as measured in flight. The first series of tests corroborated the results of flight tests in showing that the rudder is much more effective in giving a moment opposing the spin if the elevator is up than if it is down. With this equipment in operation to measure the forces and moments on spinning models, it is expected that wind-tunnel investigations on spinning phenomena will progress more rapidly and productively than heretofore.

Flight tests in which spins have been measured by means of recording instruments have been continued and have indicated that modifying a conventional wing to have a sharp leading edge has a marked effect on the spin.

Speed range.—One of the interesting wind-tunnel investigations of the past year has resulted in a combination of wing and fixed auxiliary airfoil which gives a greater speed range than the main wing alone and also gives a higher maximum lift coefficient, improved pitching moments, and a much larger range of gliding angles. The auxiliary airfoil has a chord about one-seventh that of the main wing and is located ahead of and approximately parallel to the main wing. As the angle of attack of the combination is raised, the auxiliary airfoil stalls well before the main wing and the turbulent wake from the auxiliary has a scouring action on the air passing over the upper surface of the main wing, which retards the formation of the boundary layer with the result that a higher angle of attack and therefore a higher lift coefficient is reached before the main wing stalls.

Flights tests on a parasol monoplane equipped with a fixed auxiliary airfoil in the optimum position as found from the wind-tunnel investigation, showed that the addition of the auxiliary airfoil decreased the maximum speed 2 per cent and the minimum gliding speed 19 per cent. The flattest gliding angle was 6.5° both with and without the auxiliary airfoil, but the steepest unstalled gliding angle was increased from 8.6° to 16.8° by the auxiliary airfoil, a change that greatly improves the ability to land in restricted areas.

The wind-tunnel investigation of fixed auxiliary airfoils is now being continued to include auxiliaries having various sizes and various airfoil sections, the optimum position being found for each.

Several high-lift devices with movable parts have also been investigated during the past year. The one which gave the highest lift was the Fowler variable-area and variable-camber wing, for which the maximum lift coefficient was 3.17 as compared with 1.27 for the plain basic wing.

Landing.—A motion-picture method has been perfected for making an accurate detailed study of the motion of an airplane while landing. With this equipment the effect of gusty air conditions on landings, particularly on glide landings, will be studied.

Rotating-wing systems.—The problem of safety in flight has been largely resolved into the problem of flying at low speeds with adequate control. One of the most promising methods of realizing such performance is the application of rotating wings to aircraft so that the relative speed of wing and air is independent of the speed of the aircraft. The most highly developed and widely publicized example of this type of machine is the autogiro, which employs a rotor rotating freely in the air stream and maintaining practically a constant angular velocity regardless of the air speed.

A series of flight tests to determine the aerodynamic characteristics and the gliding performance of an autogiro has been completed by the committee, and the results have been published. Flight tests are now being made to study the rotor in accelerated flight, with the object of improving such characteristics of the aircraft as prove undesirable.

Although the major portion of the research on rotating-wing systems has so far been confined to the autogiro, other types have been investigated. A rotorplane, called the gyroplane, in which opposite blades are rigidly interconnected and are free to rotate about the span axis, has been the subject of a thorough analysis. This rotor manifests interesting possibilities and its study will be continued.

Boundary-layer investigation.—The possibility of reducing the various drag components of an aircraft to their minimum values offers the greatest opportunity of improvement in efficiency. With the continued improvement in engine cowlings and with the elimination of destructive interference the component of the drag that is contributed by the surface friction becomes of ever-increasing importance. Since the surface friction is directly related to the type of flow that prevails in the boundary layer a knowledge of this condition is vital for continued improvement in the performance of aircraft.

The frictional drag is also known to be directly responsible for the separation of flow from the upper surface of airfoils at the high angles of attack which results in a loss of lift and the consequent stalling of the airplane. Hence, boundary-layer investigations are of importance in this field in order to show how the flow over the wing may best be controlled in order to delay the stall and increase the lift of airfoils.

An investigation of the boundary layer of a 1/40-scale model of the U. S. airship *Akron* was carried out in the propeller-research tunnel and very interesting results obtained. These results indicated that the boundary-layer thickness and the frictional drag of a streamline body may be predicted with a surprising degree of accuracy by means of the boundary-layer theory, provided the pressure distribution about the body and the location of the transition region are known. The consistency of these test results was very convincing and demonstrated the advantage of conducting tests on large-scale models. Further tests are contemplated on this model to study the effect of surface roughness on the various boundary-layer characteristics.

Reduction of drag.—Large drag reductions even for the most efficient existing airplanes still appear to be possible. Engineers of the industry, by their eagerness to receive and use new information, have shown that they appreciate the value of this phase of the committee's research. Drag reductions may be accomplished by reducing the drag of all the component parts of an airplane to a minimum. The most important of these component parts, the wing, has been investigated in the greatest detail. Further investigation is needed, however, on the relation between the shape and drag of other component parts such as the fuselage, tail surfaces, landing gear, and miscellaneous small parts. Ideal forms for these parts are known approximately but in most instances, because of practical considerations, the ideal form can not be employed. Further research directed toward the reduction of the drag of these component parts is therefore required. An investigation of the drag of landing gears is now in progress, and in connection with a general interference investigation in the variable-density wind tunnel important information in regard to the drag of fuselages will be made available.

The problem of reducing the drag of a complete airplane is not solved by merely reducing the drag of each of its component parts to a minimum. In fact, it has been shown in some instances that reducing the drag of a component part may increase the drag component of the whole because of aerodynamic interference. The possibilities of obtaining favorable interference should also be considered. For example, in connection with an investigation now under way in the variable-density tunnel dealing with interference between the wing and fuselage, the possibility of securing favorable interference has been demonstrated. In other words, the drag of a wing-fuselage combination in some cases may be less than the sum of the wing drag and the fuselage drag.

Aerodynamic interference has been the subject of a number of investigations, in addition to a general investigation of interference that has been in progress during the past year in the variable-density wind tunnel. In the propeller-research tunnel further work has been carried out on the problem of determining the best location of an engine nacelle in relation to the wing. The investigation has been extended to include pusher and tandem nacelles and biplane wings. Later the study of landing-gear drag will be carried out in the propeller-research tunnel, but in the meantime, in connection with this problem, the interference and drag of a number of component parts of landing gears are being investigated in the 7 by 10 foot tunnel. To assist in the interference investigations another piece of equipment, known as the smoke tunnel, has been added during the past year. In it the flow of air past interfering bodies may be observed directly and photographed.

The parts of the general interference investigations that have been carried out in the variable-density wind tunnel during the past year dealt largely with the interference and drag of small objects protruding from the surfaces of bodies. An examination of existing airplanes, both military and commercial, leads to the belief that a considerable part of their drag arises from small projecting objects, such as fittings, tubes, wires, rivet heads, lap joints, filler caps, and many other objects protruding from the main surfaces that may be classed together as protuberances. A systematic investigation of protuberances, differently formed and variously located, on both streamline bodies of revolution and on airfoils, was therefore undertaken. Reports presenting the results of this investigation have been prepared, and the next phase of the general investigation, dealing with interference between the wing and fuselage, has been started

AIRCRAFT ENGINES

Research—Increase in engine power.—Research conducted with the object of increasing the power output of aircraft engines by increasing the weight of charge taken into the engine cylinder has shown that the removal of the exhaust gases from the clearance volume of a 4-stroke-cycle engine results in a gain in power output proportional to the weight of exhaust gases removed. The clearance volume can be efficiently scavenged by overlapping the timing of the inlet and exhaust valves and maintaining a slight boost pressure in the inlet manifold. The loss of fuel with the scavenging air can be avoided by replacing the carburetor with a fuel-injection system and timing the injection of fuel into the engine cylinder. The results of tests conducted with a single-cylinder test engine showed that the power obtained when operating with valve overlap and a fuel-injection system was 18 per cent greater than that obtained with normal valve timing and a carburetor. The specific fuel consumption for the two conditions was approximately the same.

The investigation of the factors influencing the performance of high-speed engines operating on the 2-stroke cycle instead of the 4-stroke cycle has been continued. The single-cylinder air-cooled engine has been replaced with a water-cooled engine, which will permit the extension of the investigation to include higher power outputs and a maximum engine speed of 2,000 revolutions per minute. Preliminary tests have indicated exceptional promise for this type of engine on the basis of increased horsepower per cubic inch of displacement.

The phenomenon of detonation in aircraft engines has continued to receive intensive study. Information regarding the effect of combustion-chamber shape and location and number of ignition points on the rate of propagation of the combustion zone in gaseous mixtures has been obtained. The rate of flame propagation has been determined from photographic records taken at 2° intervals of a large number of quartz windows of small diameter distributed over the combustion chamber. Equipment has also been assembled for measuring the infra-red radiation from the explosion in the engine cylinder.

Fire hazard in aircraft.—The use of a fuel having a flash point of 105° F. under atmospheric conditions is an effective means of reducing the fire hazard in aircraft. The investigation of the engine performance obtained when hydrogenated "safety fuels" are injected into the cylinder of a conventional spark-ignition engine has been continued. A reduction in fuel consumption has been obtained by improving the distribution of the fuel spray and by increasing the temperature of the engine coolant. Since the manufacturers have improved the antidetonating qualities of these fuels the investigation has been extended to include the determination of the engine performance at a maximum compression ratio of 8.5 and a speed of 2,400 revolutions per minute.

Cowling and cooling of aircraft engines.—The phenomenal increase in the power output per cubic inch of displacement of boosted radial air-cooled engines has intensified the problem of efficiently dissipating the waste heat from the engine to the cooling air stream. The data obtained regarding the effect of fin pitch, fin width, fin shape, and fin thickness on the quantity of heat dissipated by finned cylinders mounted in a wind tunnel have been augmented by tests in which the finned specimens are completely cowled and a blower used to force the air past the cooling fins. Patterns of the air flow around the cylinder mounted in a wind tunnel indicate that about one-half the cooling area of the cylinder does not come in contact with the cooling air because of the breakaway of the air stream from the cylinder. For the same air speed a more uniform temperature distribution can be obtained and a greater quantity of heat can be dissipated by the use of forced air cooling. The determination of the minimum quantity of air required to cool aircraft engines satisfactorily is being investigated with a single-cylinder air-cooled test engine and a calibrated Roots blower.

Compression-ignition engines.—Research has been concentrated on the investigation of problems influencing the performance of high-speed compression-ignition engines. The reduced fire hazard and low specific fuel consumption obtained for a wide range of throttle settings make this type of engine attractive as a power plant for aircraft. Investigations conducted to determine the process by which a solid jet of fuel issuing from an orifice is disrupted to form a fuel spray have resulted in the development of a technique for taking photomicrographs 10 diameters of the fuel spray. A large number of photomicrographs taken of sections of fuel sprays under varying conditions of jet velocity, air density, fuel viscosity, and discharge-orifice diameter indicates that the process of atomization in fuel sprays is quite similar to that occurring in carburetors.

The combustion of fuel sprays under conditions closely approximating those occurring in a high-speed compression-ignition engine has been studied with the N. A. C. A. fuel-spray combustion apparatus. The influence on fuel sprays of the boiling point of the fuel, engine speed, temperature of the combustion-chamber walls, injection-advance angle, and fuel quantity has been investigated. The results showed that during injection the fuel vaporized at a rate which far exceeded the rates at which the fuel had been previously thought to vaporize. The diffusion of the fuel vapors was found to be more rapid and uniform than the diffusion of the atomized fuel spray.

The progress of combustion in an engine cylinder has been studied by analyzing samples of the cylinder gases withdrawn at definite points in the engine cycle. A stroboscopic valve having an effective opening period of 0.0003 second irrespective of engine speed has been designed for withdrawing the gas samples. Samples of the exhaust gases from carburetor and compression-ignition engines for comparable operating conditions indicate that the percentage of carbon monoxide in the exhaust gases of a compression-ignition engine is so small that the use of this type of engine will considerably reduce the danger of carbon-monoxide poisoning.

The removal of all exhaust gases from the cylinder of a 4-stroke-cycle compression-ignition engine by the use of a large valve overlap and a slight boost pressure in the inlet manifold has been found to give a decided improvement in the combustion of the injected fuel.

The maximum power output of a single-cylinder test engine with a clear exhaust was increased 33 per cent, and the specific fuel consumption reduced 18 per cent by the complete removal of the exhaust gases from the cylinder. A specific fuel consumption of 0.44 pound per brake horsepower per hour has been obtained for a range of engine speeds from 800 to 1,700 revolutions per minute with a valve overlap of 146 crank degrees.

Development—Improvement in aircraft performance.—The cruising speeds of both military and civil aircraft have been greatly increased. A percentage of this increase in speed can be attributed to increase in engine power, but a greater percentage is due to more efficient location of the power plants in relation to the airplane wings and to improved engine cowling.

The progressive increase in the antiknock value of fuels manufactured for aircraft engines permits operation at higher compression ratios with an attendant gain in power and fuel economy. An appreciable reduction in the fuel consumption of aircraft engines operating at altitudes has been obtained by fitting the carburetor with an automatic control which insures that the engines operate with the most efficient fuel-air ratio at all altitudes.

The use of a fuel-injection system for gasoline instead of the conventional carburetor results in better fuel distribution, more rapid acceleration, and decreased fuel consumption. Engines equipped with fuel-injection systems are in use on the airways and have given satisfactory performance. The use of fuel-injection systems on aircraft engines is believed to be one of the most promising methods of obtaining decreased fuel consumption.

The problem of decreased fuel consumption is of such vital importance in the operation of commercial airships that four different types of high-speed compression-ignition engines are now being developed for airship use in this country and in Europe.

Increase in engine power.—An important engine development is that of the two-row radial air-cooled engine. The advantages of this type of power plant are small over-all diameter, greater freedom from vibration, and increased power output obtained with cylinders of relatively small diameter. The decreased over-all diameter of the engine has necessitated a new design of the auxiliaries mounted at the rear of the engine in order to obtain improved cooling.

The use of geared centrifugal blowers driven from an extension of the engine crankshaft still continues to be the most satisfactory method for increasing the power output of radial air-cooled engines. The gear ratio of these blowers has been limited to 14:1 because of the increase in fuel consumption obtained with higher gear ratios.

Engine reliability.—The radial air-cooled engines developed in this country are believed to be the most reliable engines in the world. The greatest single factor tending to increase the reliability of these engines is the progressive increase in the period of full-throttle operation required for acceptance by the military services. Beginning with a 50-hour test in 1917 the requirements have been gradually increased until at present new engine types are submitted to 100 hours of running before acceptance. The fact that improvements in specific weight and power output have been obtained at the same time the reliability has been increased is a tribute to the engine designers.

This increase in engine reliability is reflected in the revised aircraft-engine requirements of the Department of Commerce effective January 1, 1933. The department requires a 50-hour preliminary test by the engine manufacturer at the proposed rated speed and increases the severity but not the duration of the type test.

Engine design details.—The use of aircraft engines operating with a high-temperature coolant such as ethylene glycol in multiengine airplanes has required further research in order to determine the most efficient location of the engine and radiators in relation to the airplane wing. Investigations are being made to develop a low-drag cowling for this type of engine when mounted in the wing. Methods for reducing the drag of the engine radiator and the oil and gasoline radiators are also being investigated.

MATERIALS AND STRUCTURES

Materials.—During the past several years a great amount of work has been done on light-weight alloys for aircraft use. Many of these researches, although showing considerable promise, must await further experience and application before their true worth can be appraised. Some of the work, however, has resulted in new and improved metals which have already been adopted in aircraft and aircraft-engine construction. Two types of aluminum alloys have been especially investigated. These are the aluminum-silicon alloys and the aluminum-magnesium alloys.

The aluminum-silicon alloys have been utilized to a considerable extent in the past in the casting field, principally because of their excellent casting characteristics. These alloys possessed, however, some disadvantages, such as relatively low strength and elastic properties and relatively poor machinability. The silicon alloys have been developed to a degree that these characteristics have improved materially. The corrosion resistance of this type of alloy, which has always been considered one of its advantages, has been augmented by the careful control of impurities and by heat treatment.

Of particular interest is the development of a silicon alloy for the production of forged engine pistons. This alloy has a tensile strength of 52,000 pounds per square inch, 5 per cent elongation, and 115 Brinnell hardness. The use of the forging process in the fabrication of pistons enables the attainment of an integrity of metal and a freedom from porosity which can not be obtained by a casting process. This type of piston has been so successful that it is being adopted as standard by several aircraft-engine manufacturers.

The aluminum-magnesium alloys have long been recognized as possessing potentially valuable characteristics. Difficulties, however, incident to their fabrication have greatly retarded their application. Methods have been developed whereby sound castings may be obtained with practically any concentration of magnesium and these alloys possess many characteristics of interest for aircraft purposes.

In the field of magnesium alloys the greatest developments have been in the consolidation of information and the gradually increasing use of this material in aircraft. The adoption of the acid dip, both for cleaning the surface of the castings and to make them more resistant to corrosion, has met with such success that these alloys are finding considerable favor with aircraft-engine manufacturers. Unlike aluminum alloys, these alloys do not appear to be susceptible to the intergranular type of corrosion and when they do corrode it is immediately evident on the surface in an apparently magnified form. This feature facilitates their inspection and maintenance.

The use of stainless steel in aircraft construction continues to show progress. Its service tests in exhaust manifolds, wing ribs, seaplane floats, control and anchor cables, struts, and streamline wire have demonstrated its practicability in general and in particular its ability to resist corrosion under the extreme conditions of weather exposure. The difficulties early experienced with machining and welding of this steel have been largely overcome by improved chemical composition and by limiting the carbon constituent to a maximum of 0.07.

Although metals hold the greatest attention along the lines of research and refinement, other materials, such as plywood, glues, textiles, and protective coatings have not been overlooked, and gradual improvement in their physical properties has been made, especially in connection with those properties which are directly useful in their aircraft application. A development in protective coatings which appears from exposure and experimental service tests to be of outstanding merit is the bakelite varnish pigmented with 300-mesh aluminum powder. The results so far obtained indicate that it will supersede other types of coatings. It is especially applicable to aircraft parts which are subject to corrosion and which will experience severe exposure conditions, as, for example, the interior and exterior surfaces of aluminum-alloy seaplane floats.

Monocoque structures.—Progress in research on the strength of stressed-skin, or monocoque, structures for aircraft has been marked largely by fundamental studies of the strength and behavior of skin, reinforcement, and connections when tested separately.

An experimental report on the compressive strength of flat sheet has been published and an extensive series of tests on thin-wall cylinders and truncated cones of circular and elliptic section has been made to obtain basic information with regard to the strength and behavior of curved skins subjected to shear and compression. The first of a series of reports presenting the results of these latter tests has been published and the others are in preparation.

A study has been made of the available information on the compressive strength of corrugated sheet with both straight and curved pitch lines and a report presenting the results of this study is in progress.

A study of the available data on the compressive strength of stiffeners of various forms used as reinforcement in stressed-skin structures resulted in a column chart for duralumin angles. This chart has been published and the study is being continued for the purpose of deriving additional charts for other commonly used sections.

An investigation of the strength of riveted joints is in progress. The strength corresponding to each type of failure is being determined experimentally and is being correlated with the properties of the material so that the results will be applicable to any material. The strength of riveted joints with various types of rivet heads is being investigated and the strength which results from enlargement of the rivet and pressure between the heads is being studied.

A study of the available data on the compressive strength of flat sheet and stiffeners has been made and a report is in progress which presents a comparison of three methods for calculating the compressive strength of flat sheet and stiffeners in combination.

As the monocoque fuselage is perhaps more often elliptical than circular in section, a study has been made of the stresses in elliptic rings of uniform cross section and a series of working charts for the stress analysis of elliptic rings has been developed. A report presenting these charts as applied to the design of the main frames is now in progress.

AIRSHIPS

Research with full-size airships has been confined largely to the evaluation and study of data obtained in the trial flights with the U. S. airship *Akron*. These data have furnished much valuable and interesting information concerning the behavior of and forces on large airships under varied flight conditions. The measurements of over-all drag and local pressures on the hull and tail surfaces not only provide data of direct importance in connection with this particular airship but they also serve the general purpose of providing a basis for determining the applicability of data obtained with models.

Through research with models, considerable progress has been made in studies concerning two major aspects of the problem of airship drag. Theories regarding the laws of frictional resistance on streamline shapes have been correlated with the results of an investigation of the boundary layer on a 1/40-scale model of the U. S. airship *Akron* and have been found to be in good agreement with fact for the range of scales attainable in the wind tunnel used in the investigation. Interference drag caused by protuberances in contact with airship shapes has been studied in the variable-density wind tunnel. In this wind tunnel the large scales attainable give fair assurance that the comparative results are free from the effect of critical changes in the nature of the boundary layer on the model and, consequently, are believed to be applicable to full-size airships. This wind tunnel is now engaged in a research concerning the effect of shape on airship drag.

The four-in-line tandem arrangement of propellers in the *Akron* has brought to light a number of problems connected with this propulsive system. Owing to wandering of the propeller slipstreams as they flow aft because of gusts and undulations of the airship, widely differing over-all propulsive efficiencies are obtained when different combinations of propellers are operating. This makes it difficult to provide a type of propeller that will be efficient over the wide range of airship speeds. The present wooden propellers on the *Akron* are to be replaced by metal propellers of changeable pitch, and the expectation is that with these propellers more efficient propulsion at normal cruising speeds will be obtained.

A satisfactory apparatus for recovering water ballast from the engine exhaust, thus permitting helium-filled airships to maintain equilibrium in flight without valving gas, continues to prove a baffling problem. The problem is one peculiar to helium-filled airships. In the *Akron* the difficulties of the problem have been accentuated by the necessity for using tetraethyl lead in the fuel which engenders corrosion in parts of the recovery apparatus. A new type of light and compact water-ballast-recovery apparatus has been developed at Lakehurst and applied experimentally to the *Akron*. Fundamentally, it is similar to a large honeycomb radiator. The cooling air passes through the tubes, and the exhaust gases flow around them within a streamline casing. The drag of this type will be somewhat higher than previous types, but its weight will be materially less and its maintenance simpler.

The power plant of an airship and its installation present a number of problems for which various solutions can be obtained, and upon the solution adopted will depend the efficiency, economy, safety, and reliability of the airship operation. It is desirable, therefore, that research along various lines connected with improvements in airship power plants be prosecuted vigorously, both in laboratories and under flight conditions. Various improvements in airship power plants are under development in the United States and elsewhere.

The *Akron* is the first airship in the world to be equipped with a hangar for carrying airplanes. Hitherto airplanes have been attached to or dropped from an external trapeze on an airship, but the operation of airplanes to and from the *Akron* has become routine. Four airplanes may be stowed in the hangar and a fifth one, carried on the trapeze, may also be lifted into the hangar. New developments are under way to decrease the time interval between launching or picking up successive airplanes.

The U. S. airship *Los Angeles* has been laid up as a matter of economy, but her material condition is still good, after nearly eight years' service, and she could be recommissioned on short notice.

The experimental metal-clad airship *ZMC-2* continues in successful operation. She has been deflated and reinflated only once during three years of service.

In the field of mechanical handling of airships, the Navy Department has continued to make good progress. The stern handling beam described in last year's report has been found invaluable in taking the U. S. airship *Akron* in and out of the hangar at Lakehurst. A special wind-tunnel investigation into the forces acting on an airship when being handled near the ground has been planned for early conduct by the committee at Langley Field.

SUMMARY

Material and gratifying improvements in aircraft operation, performance, and reliability were made during the past year. In this progress scientific research was the most fundamental factor. The great development of aviation since the war has demonstrated the value and vital necessity of research.

Under the law the National Advisory Committee for Aeronautics is the governmental agency to plan and coordinate research programs for the development of aircraft. This is done in cooperation with the War Navy, and Commerce Departments, and the suggestions of the aircraft industry are obtained.

The Army, the Navy, and the industry necessarily conduct engineering experimentation and apply the results of research to aircraft, but this should not be confused with scientific investigation of fundamental problems which, for all branches of aviation, is conducted in one well-equipped laboratory. This laboratory, known as the Langley Memorial Aeronautical Laboratory, is located at Langley Field, Va., and is operated under the single and direct control of the committee. Its facilities are available to all governmental agencies, and upon payment of cost may also be used for special investigations desired by the industry.

This policy not only assures results of the greatest scientific and practical value to aeronautics, but at the same time prevents duplication and waste in the field of research. Were it not for the efficient and effective work of the committee, aeronautical research could not be as well planned to serve broadly the best interests of aviation, but each governmental agency concerned, in order to answer its own problems, would independently conduct the necessary research, with inevitable duplication, loss of efficiency, and increased cost to the Government.

The continuous prosecution of organized scientific research on fundamental problems is the most essential activity of the Government in the continued development of aeronautics, underlying as it does to a substantial degree technical progress in improving the performance, reliability, safety, and efficiency of aircraft for all purposes.

Under the present organization aeronautical research receives a high caliber of scientific direction that is necessary for the best results, and receives it at the least possible expense to the Government because the members of the committee and of the various technical subcommittees serve as such without compensation.

The continued development of aviation is vital to our national security and defense. Aviation is becoming an increasingly important factor as an agency of transportation. Its continued development holds possibilities for the growth of a large industry, creating new sources of wealth, new fields of employment, and new outlets for the energies of the American people.

Aviation is bringing the people of the United States closer together and is bringing this country closer to the other nations in the Western Hemisphere. Eventually there will be regular air-transportation service across the seas, first by rigid airships and later supplemented by large seaplanes. The history of the human race shows that man's progress has kept pace with improvements in transportation. In the judgment of the committee, aeronautics is destined to play an increasingly important rôle in the further progress of civilization.

As affording the best assurance of continued progress in developing the possibilities of aviation, the committee recommends continued support of its programs of organized scientific research on the fundamental problems of flight.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

JOSEPH S. AMES, *Chairman.*