

AERONAUTICS

NINTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1923

INCLUDING TECHNICAL REPORTS
NOS. 159 TO 185



WASHINGTON
GOVERNMENT PRINTING OFFICE
1924

Particular attention is invited to the four portions of this report summarized below:

The report on the fundamental principles of the Air Mail Service submitted to the late President Harding at his request—Development of night flying and the establishment of regular trans-continental mail service is urged. (See page 11.)

The statement of the need of Federal legislation for the regulation and licensing of aircraft, airdromes, and aviators, and for the encouragement of the development of commercial aviation generally. (See page 14.)

The explanation of the relation of aeronautical research to national defense—No limitation on the use of aircraft in warfare—Army and Navy defense programs influenced by the rapid development of the art of aviation—Aviation progress dependent upon scientific research—In this respect at least America is providing well against unpreparedness. (See page 54.)

The conclusion of the report, summarizing American achievements of popular interest during the past year—What is holding back commercial aviation—Necessity of greater appropriations to maintain adequate air services in Army and Navy. (See page 55.)

LETTER OF SUBMITTAL.

TO THE CONGRESS OF THE UNITED STATES:

In compliance with the provisions of the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics, I submit herewith the ninth annual report of the committee, for the fiscal year ended June 30, 1923.

The attention of the Congress is invited to the conclusion of the committee's report, which contains constructive recommendations for the advancement of aeronautics, civil and military. I wish especially to indorse the recommendation of the National Advisory Committee for Aeronautics for the establishment of a Bureau of Civil Aeronautics in the Department of Commerce. I concur in the committee's views as to the necessity of scientific research and the importance of providing for continued development of military and naval aviation if America is to keep abreast of other nations.

CALVIN COOLIDGE.

THE WHITE HOUSE,
December 10, 1923.

LETTER OF TRANSMITTAL.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., November 23, 1923.

Mr. PRESIDENT:

In compliance with the provisions of the act of Congress approved March 3, 1915 (Public No. 273, 63d Cong.), I have the honor to transmit herewith the ninth annual report of the National Advisory Committee for Aeronautics, including a statement of expenditures for the fiscal year ended June 30, 1923.

During the past year there has been remarkable progress in aeronautical development. A speed of $4\frac{1}{2}$ miles per minute has been attained and new records made for airplane endurance and economy of operation. The air mail service, by flying through the night on schedule, has demonstrated that, as soon as authorized, a regular transcontinental mail service within 36 hours can be given the American people. The cumulative evidence of aeronautical progress since the armistice would, if fully appreciated, stir the imagination of far-seeing people, especially American business men, for air navigation as an improved means of transportation is destined to become as revolutionary and as indispensable as the automobile.

The airplane, however, is also becoming a more vital implement of war. Aviation will be the first branch of either the Army or the Navy to come into action in the future, and supremacy in the air will be practically essential for ultimate success. With this in mind, and recognizing the need for retrenchment in governmental expenditures generally, it is the judgment of the National Advisory Committee for Aeronautics that it is unwise economy to withhold from the air services of the Army and the Navy the funds necessary for their development and for their adequate equipment and maintenance.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
CHARLES D. WALCOTT, *Chairman.*

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

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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JOHN F. VICTORY, *Assistant Secretary*.

NINTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

WASHINGTON, D. C., November 14, 1923.

To the Congress:

In accordance with the provision of the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its ninth annual report. In this report the committee has described its activities during the past year, the technical progress in the study of scientific problems relating to aeronautics, the assistance rendered by the committee in the formulation of policies for the general development of aviation, the regulation of air navigation, the coordination of research work in general, the examination of aeronautical inventions, and the collection, analysis, and distribution of scientific and technical data. This report also contains a statement of expenditures and recommendations for advancing the science and art of aeronautics.

FUNCTIONS OF THE COMMITTEE.

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915. The organic act charges 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, their investigation and application to practical questions of aeronautics. The act also authorizes the committee to direct and conduct research and experimentation in aeronautics in such laboratory or laboratories, in whole or in part, as may be placed under its direction.

Supplementing the prescribed duties of the committee, 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 problems in this field 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, particularly in England, France, Italy, Germany, Austria, and Canada.

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 services 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.

ORGANIZATION OF THE COMMITTEE.

The committee has 12 members, appointed by the President. The law provides that the personnel of the committee shall consist of two members from the War Department, from the office in charge of military aeronautics; two members from the Navy Department, from the office in charge of naval aeronautics; a representative each of the Smithsonian Institution, the United States Weather Bureau, and the United States Bureau of Standards; and not more than five additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences. All members as such serve without compensation.

During the past year Maj. Lawrence W. McIntosh, United States Army, was appointed by the President a member of the committee to succeed Maj. Thurman H. Bane, United States Army, who retired from active duty in the Army. The President has also appointed to membership on the committee Dr. George K. Burgess, who succeeded Dr. S. W. Stratton as Director of the Bureau of Standards. Dr. John F. Hayford, of Northwestern University, Evanston, Ill., resigned, and the vacancy thus caused, was filled by the President by the reappointment of Doctor Stratton from private life, because of his keen interest, as president of the Massachusetts Institute of Technology, in the fundamental problems of aeronautics.

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 19, 1922, and that held on October 18, 1923.

The organization of the committee at the close of the past year was as follows:

Charles D. Walcott, Sc. D., chairman.
 S. W. Stratton, Sc. D., secretary.
 Joseph S. Ames, Ph. D.
 George K. Burgess, Sc. D.
 William F. Durand, Ph. D.
 Commander Jerome C. Hunsaker, United States Navy.
 Charles F. Marvin, M. E.
 Maj. Lawrence W. McIntosh, United States Army.
 Rear Admiral William A. Moffett, United States Navy.
 Maj. Gen. Mason M. Patrick, United States Army.
 David W. Taylor, D. Eng.
 Orville Wright, B. S.

MEETINGS OF THE ENTIRE COMMITTEE.

The semiannual meeting of the entire committee was held in Washington on April 19, 1923, and the annual meeting on October 18, 1923. At these meetings the committee reviewed the general progress in aeronautical research and discussed the problems that should be attacked. Administrative reports were submitted by the secretary and by the Director of the Office of Aeronautical Intelligence.

At the semiannual meeting Doctor Taylor made a report on the research work in progress under the committee's direction at the Langley Memorial Aeronautical Laboratory at Langley Field, Va., and exhibited and explained relief models showing the distribution of pressure over the surfaces of an airplane in actual flight.

At the annual meeting Doctor Ames, chairman of the executive committee, made a complete report of the research work in progress at Langley Field, in the course of which he exhibited lantern slides showing the methods used and the results obtained. Doctor Ames also reported on the general progress and needs of the committee's laboratory at Langley Field.

Officers of the committee were elected for the ensuing year, as follows: Dr. Charles D. Walcott, chairman; Dr. David W. Taylor, secretary; Dr. Joseph S. Ames, chairman executive committee.

THE EXECUTIVE COMMITTEE.

For carrying out the work of the Advisory Committee the regulations provide for the election annually of an executive committee, to consist of seven members, and to include further any member of the Advisory Committee not otherwise a member of the executive committee but resident in or near Washington and giving his time wholly or chiefly to the special work of the committee. The present organization of the executive committee is as follows:

Joseph S. Ames, Ph. D., chairman.
 David W. Taylor, D. Eng., secretary.
 George K. Burgess, Sc. D.
 Commander Jerome C. Hunsaker, United States Navy.
 Charles F. Marvin, M. E.
 Maj. Lawrence W. McIntosh, United States Army.
 Rear Admiral William A. Moffett, United States Navy.
 Maj. Gen. Mason M. Patrick, United States Army.
 S. W. Stratton, Sc. D.
 Charles D. Walcott, Sc. D.
 Orville Wright, B. S.

The executive committee, in accordance with the general instructions of the Advisory Committee, exercises the functions prescribed by law for the whole committee, administers the affairs of the committee, and exercises general supervision over all its activities. The executive committee holds regular monthly meetings.

The executive committee has organized the necessary clerical and technical staffs for handling the work of the committee proper. General responsibility for the execution of the programs and policies approved by the executive committee is vested in the executive officer, Mr. George W. Lewis. In the subdivision of general duties 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 assistant secretary, Mr. John F. Victory, has charge of administration and personnel matters, property, and disbursements, under the direct control of the secretary of the committee, Dr. David W. Taylor.

SUBCOMMITTEES.

The executive committee has organized six standing subcommittees, divided into two classes, administrative and technical, as follows:

ADMINISTRATIVE.

Governmental relations.
 Publications and intelligence.
 Personnel, buildings, and equipment.

TECHNICAL.

Aerodynamics.
 Power plants for aircraft.
 Materials for aircraft.

The organization and work of the technical subcommittees are covered in the reports of those committees appearing in another part of this report. A statement of the organization and functions of the administrative subcommittees follows:

COMMITTEE ON GOVERNMENTAL RELATIONS.

FUNCTIONS.

1. Relations of the committee with executive departments and other branches of the Government.
2. Governmental relations with civil agencies.

ORGANIZATION.

Dr. Charles D. Walcott, chairman.
 Dr. S. W. Stratton.
 John F. Victory, secretary.

COMMITTEE ON PUBLICATIONS AND INTELLIGENCE.**FUNCTIONS.**

1. The collection, classification, and diffusion of technical knowledge on the subject of aeronautics, including the results of research and experimental work done in all parts of the world.
2. The encouragement of the study of the subject of aeronautics in institutions of learning.
3. Supervision of the Office of Aeronautical Intelligence.
4. Supervision of the committee's foreign office in Paris.
5. The collection and preparation for publication of the technical reports, technical notes, and annual report of the committee.

ORGANIZATION.

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

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT.**FUNCTIONS.**

1. To handle all matters relating to personnel, including the employment, promotion, discharge, and duties of all employees.
2. To consider questions referred to it and make recommendations regarding the initiation of projects concerning the erection or alteration of laboratories and the equipment of laboratories and offices.
3. To meet from time to time on the call of the chairman, and report its actions and recommendations to the executive committee.
4. To supervise such construction and equipment work as may be authorized by the executive committee.

ORGANIZATION.

Dr. Joseph S. Ames, chairman.
 Dr. S. W. Stratton, vice chairman.
 Prof. Charles F. Marvin.
 Dr. David W. Taylor.
 John F. Victory, secretary.

QUARTERS FOR COMMITTEE.

The headquarters of the National Advisory Committee for Aeronautics are located in the Navy Building, Seventeenth and B Streets NW., Washington, D. C., in close proximity to the Army and Navy Air Services. In April, 1923, the committee's offices were moved from the seventh wing, second floor, to the third wing, third floor, of the Navy Building, pursuant to assignment of office space by the Public Buildings Commission. The administrative office is also the headquarters of the various subcommittees.

The scientific investigations authorized by the committee are not all conducted at the Langley Memorial Aeronautical Laboratory, but the facilities of other governmental laboratories and shops are utilized, as well as the laboratories connected with institutions of learning whose cooperation in the scientific study of specific problems in aeronautics has been secured.

THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY.

The greater part of the research work of the committee is conducted at the Langley Memorial Aeronautical Laboratory, which is located at Langley Field, Va., on a plot of ground set aside by the War Department for the use of the committee when Langley Field was originally laid out. Langley Field is one of the most important and best equipped stations of the Army Air Service, occupying about 1,650 acres and having hangar and shop facilities for the accommodation of four bombing squadrons, a service squadron, a school squadron, and an airship squadron.

In the committee's laboratory and on the flying field used in connection therewith, the fundamental problems of scientific research recommended by the various subcommittees are investigated. The laboratory is organized with five subdivisions, as follows: Power plants division, wind tunnel division, flight test division, technical service division, and property and clerical division. The administration of the laboratory is under the immediate direction of the engineer in charge, under the general supervision of the officers of the committee.

The laboratory consists of six units: A research laboratory building, containing the administrative offices, the drafting room, the machine and woodworking shops, and the photographic and instrument laboratories; two aerodynamical laboratories, one containing a wind tunnel of the open type, and the other a compressed-air wind tunnel, each unit being complete in itself; two engine dynamometer laboratories of a semipermanent type, both equipped to carry on investigations in connection with power plants for aircraft; and an airplane hangar equipped with a repair shop, dope room, and facilities for taking care of 16 or 18 airplanes.

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 to the Military and Naval Air Services and civil agencies interested, including especially the results of research and experimental work conducted in all parts of the world. It is the officially designated Government depository for scientific and technical reports and data on aeronautics.

Promptly upon receipt, all reports are analyzed and 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 governmental channels.

To efficiently handle the work of securing and exchanging reports in foreign countries, the committee maintains a technical assistant in Europe, with headquarters in Paris. It is his duty to personally visit the Government and private laboratories, centers of aeronautical information, and private individuals in England, France, Italy, Germany and Austria, 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 to secure advance information as to work in progress, and any technical data not prepared in printed form, and which would otherwise not reach this country.

The records of the office show that during the past year copies of technical reports were distributed as follows:

Committee and subcommittee members.....	1, 676
Langley Memorial Aeronautical Laboratory.....	1, 835
Paris office of committee.....	4, 350
Army Air Service.....	2, 351
Naval Air Service, including Marine Corps.....	4, 381
Manufacturers.....	6, 171
Educational institutions.....	4, 778
Bureau of Standards.....	879
Miscellaneous.....	10, 499
Total distribution.....	36, 870

The above figures include the distribution of 15,262 technical reports, 10,036 technical notes, and 2,262 technical memorandums of the National Advisory Committee for Aeronautics. Two thousand nine hundred and fifty-six written requests for reports were received during the year in addition to innumerable telephone and personal requests, and 18,514 reports were forwarded upon request.

CONSIDERATION OF AERONAUTICAL INVENTIONS.

The committee examines and reports upon all aeronautical inventions which are submitted to it for consideration and recommendation.

By virtue of a formal agreement with the Navy Department, inventions of a general character relating to aeronautics which are received in the Navy Department are referred to the National Advisory Committee for Aeronautics for consideration and proper action. The committee examines such inventions, conducts the necessary further correspondence with the inventors, and where a given invention has prospective value the committee makes a report to the Navy Department, a copy of which is sent to the Army Air Service. In like manner, although without a formal agreement, the committee considers inventions referred to it by the Army Air Service, and if any such inventions appear to be promising, a copy of the committee's report to the Army is sent to the Navy in each case.

USE OF NONGOVERNMENTAL AGENCIES.

The various problems on the committee's approved research programs are as a rule assigned for study by governmental agencies. In cases where the proper study of a problem requires the use of facilities not available in any governmental establishment, or requires the talents of men outside the Government service, the committee contracts directly with the institution or individual best equipped for the study of each such problem to prepare a special report on the subject. In this way the committee has marshaled the facilities of educational institutions and the services of specialists in the scientific study of the problems of flight.

COOPERATION OF ARMY AND NAVY.

Through the personal contact of responsible officers of the Army and Navy serving on the three standing technical subcommittees, a knowledge of the aims, purposes, and needs of each service in the field of aeronautical research is made known to the other. The cordial relations that invariably flow from such personal contact are supplemented by the technical information service of the committee's Office of Aeronautical Intelligence, which makes available the latest technical information from all parts of the world. While a healthy rivalry exists in certain respects between the Army and Navy, there is at the same time a coordination of effort in experimental engineering and a mutual understanding that is productive of the best results.

The Army and Navy Air Services have aided whenever called upon in every practicable way in the conduct of scientific investigations by the committee. Each service has placed at the disposal of the committee airplanes and engines required by the committee for research purposes. The committee desires to record its appreciation of the cooperation given by the Army and Navy Air Services, for without this cooperation the committee could not have undertaken many of the investigations that have already made for substantial progress in aircraft development. The committee desires especially to acknowledge the many courtesies extended by the Army authorities at Langley Field, where the committee's laboratories are located.

INVESTIGATIONS UNDERTAKEN FOR THE ARMY AND THE NAVY.

As a rule, the technical subcommittees, including representatives of the Army and Navy Air Services, prepare programs of research work of general use or application, and these programs, when approved by the National Advisory Committee for Aeronautics, furnish the problems for solution by the Langley Memorial Aeronautical Laboratory. The cost of this work is borne by the committee out of its own appropriation. If, however, the Army Air Service or the Naval Bureau of Aeronautics, desires specific investigations to be undertaken by the committee for which the committee has not the necessary funds, the committee's regulations as approved by the President, provide that the committee may undertake the work at the expense of either the Army or the Navy.

The investigations thus undertaken by the committee during the past year may be outlined as follows:

FOR THE BUREAU OF AERONAUTICS OF THE NAVY DEPARTMENT.

Development of Roots type supercharger, including the design, construction, testing, and development of the Roots type supercharger for application to the TS and DT airplanes.

Investigation in free flight of the comparative stability, controllability, and maneuverability of several types of airplanes, including the VE-7, the SE-5, the Fokker D-VII, the Spad VII, and the MB-3.

Investigation in free flight of the effect of dihedral angle on lateral controllability.

Investigation and development of a solid-injection type of aeronautical engine.

Flight tests of BR-1 racer, including performance tests, with a view to obtaining information for making any changes in the aerodynamic properties of the airplane that may be found desirable.

Investigation of taking off and landing, including the determination of the air and water speed and the angle of attack, on landing, of various types of seaplanes.

Investigation of the pressure distribution over the C-7 airship, including flight tests to determine the pressure distribution over the envelope and the fins and rudders; tests in the compressed-air wind tunnel on a model of the C-7 to check the information obtained in free flight; and a study of the equipment and installation necessary for the determination of the pressure distribution over the control surfaces and envelope of the U. S. S. *Shenandoah*.

Investigation of landing on the U. S. S. *Langley*, including the development of instruments for the determination of the decelerations and speed of an airplane when landing on the *Langley*.

Flight tests of superchargers, including flight and performance tests of the DH-4 and DT airplanes equipped with Roots type superchargers, and of the TS airplane equipped with a supercharged Lawrence J-1 air-cooled engine.

FOR THE ENGINEERING DIVISION OF THE ARMY AIR SERVICE.

Full-scale investigation of different wings on the Sperry messenger airplane, including flight tests of six different sets of wings, each to be flown at about six air speeds;

Investigation of the efficiency of propellers when used in front of obstructions as found in bombing airplanes, including tests at Stanford University on models of bombardment airplanes tested with four different arrangements of propeller with thick wing section, engine housing, and radiator;

Report on the determination of the characteristics of the pressure distribution over the surfaces of the Thomas Morse airplane under various conditions of flight.

In addition to the investigations enumerated above, theoretical investigations were undertaken for the Army and the Navy, first on the design and calculations of the Navy rigid airship U. S. S. *Shenandoah*, formerly known as the ZR-1, and second, on the Army semirigid airship RS-1. These investigations are more fully described under separate headings.

SPECIAL COMMITTEE ON DESIGN OF NAVY RIGID AIRSHIP ZR-1.

A complete report prepared by the special subcommittee on design of Navy rigid airship ZR-1 has been submitted by the National Advisory Committee for Aeronautics to the Bureau of Aeronautics, Navy. The report contains a complete analysis of the methods of calculating stresses in airships; a discussion on the proper design for horizontal and vertical fins and control surfaces; analyses of maximum unit stresses and factors of safety in longitudinal girders, transverse frames, and shear wires. In all twenty-seven appendices were prepared in addition to the main report.

The special subcommittee on design of Navy rigid airship ZR-1 was appointed by the National Advisory Committee for Aeronautics at the request of the Bureau of Aeronautics, of the Navy Department. The committee was organized as follows:

Henry Goldmark, chairman.
W. Hovgaard.
L. B. Tuckerman.
Max M. Munk.
W. Watters Pagon, secretary.

The first meeting of the committee was held in Washington, June 19, 1922, and was called to order by Rear Admiral D. W. Taylor, United States Navy, a member of the National Advisory Committee for Aeronautics who outlined the purpose and scope of the special committee's work. Most of the meetings of the committee were held in Washington, the committee visiting the Naval Aircraft Factory, Philadelphia; the Naval Air Station, Lakehurst, N. J., and the Bureau of Standards.

The summary of conclusions contained in the report of the committee is as follows:

(1) The only wise policy was followed by the Bureau of Aeronautics in basing the design of the *ZR-1* on that of a successful airship while checking its strength by detailed computations.

(2) The German airship *L-49*, selected as the prototype, was more suitable than any other, as it embodied the most extended available experience with rigid airships.

(3) The modifications made in the details were based on sound considerations, and add materially to the strength of the *ZR-1*.

(4) The external loading assumed in the calculations is more nearly correct than that used in previous airships, especially the dynamic loads which were derived from special studies made in connection with this design.

(5) The stress analyses, given in the Design Memoranda, are founded on sound principles and form a more complete treatment of the stresses in rigid airships than any hitherto published.

(6) With the modifications described in the report, the "method of bending moments" is a satisfactory method for finding the primary stresses in the longitudinal girders.

(7) The calculations for determining the stresses due to gas pressure, and the secondary and other minor stresses are also correct within reasonable limits.

(8) The maximum unit stresses, while relatively higher than those used in steel structures, correspond to factors of safety, which have been found entirely permissible in successful aircraft.

(9) The fins, rudders and elevators are fully as strong as those in the *L-49* and similar airships.

(10) The gas valves are of proper size to prevent unduly high pressures under all operating conditions.

(11) Excessive differences in air pressure within and without the ship are fully guarded against by ample openings in the outer envelope, with automatic covers.

(12) Owing to the careful specifications and rigid inspection, the quality of the material and workmanship is of an unusually high standard of excellence.

(13) As shown by the specimen tensile tests, the duralumin used is of a very uniform grade and has the specified strength and ductility.

(14) The numerous full-sized girder tests indicate a very uniform and entirely satisfactory breaking strength.

(15) The program of trials and tests is well conceived and will give much valuable information. It should be fully carried out before the acceptance of the ship.

(16) The *ZR-1* is shown by comparative calculations to be measurably stronger than the British airship *R-38*, which failed on a trial trip, while other possible reasons for its failure, besides structural weakness, have been guarded against in the *ZR-1*.

(17) Judging the design of the *ZR-1* as a whole, the committee has been very favorably impressed by the thorough studies made by the engineers in charge and the good judgment shown throughout in applying their results and also the great care shown in executing the plans. It sees no reason whatever to doubt that the *ZR-1* will prove a complete success in service.

The success attending the early trial flights of the *ZR-1*, subsequently named the U. S. S. *Shenandoah*, led the National Advisory Committee for Aeronautics to extend its congratulations to the Navy. The committee stated that it was particularly gratified to know that every precaution was being taken to insure the success of the airship and to demonstrate its efficiency in a carefully arranged program of tests. The committee also stated that the performance of this airship would be watched and studied by the American people for the reason that it is

sure to have a very large effect on the future development of lighter-than-air craft in this country for commercial as well as military purposes.

The following reply was received from the Assistant Secretary of the Navy under date of September 22, 1923.

"SIR: Your letter of September 15, 1923, in which you extend the congratulations of the National Advisory Committee for Aeronautics on the completion and trial flights of the airship *ZR-1*, is gratefully acknowledged.

"I desire to express through you to the National Advisory Committee for Aeronautics my sincere appreciation of the courteous message which you have expressed in your recent letter. I am not unmindful of the very generous cooperation and valuable assistance which has been rendered by the National Advisory Committee for Aeronautics in connection with the building of the *ZR-1*, and your committee is entitled to a large share in any success which may be credited to the Navy Department.

"Will you please extend to the National Advisory Committee for Aeronautics my appreciation of their interest in this work that the Navy has undertaken and express to them my thanks for their counsel and help.

"Respectfully,

"THEODORE ROOSEVELT.

"Dr. JOSEPH S. AMES,

"National Advisory Committee for Aeronautics, Washington, D. C."

SPECIAL COMMITTEE ON DESIGN OF ARMY SEMIRIGID AIRSHIP RS-1.

At the request of the Army Air Service, the National Advisory Committee for Aeronautics appointed a special subcommittee to examine and report on the design and construction of the Army semirigid airship known as the *RS-1*. This special subcommittee was organized on February 15, 1923, as follows:

Mr. Henry Goldmark, New York City, chairman.

Prof. William Hovgaard, Boston.

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

Dr. Max M. Munk, National Advisory Committee for Aeronautics.

Mr. W. Watters Pagon, Baltimore, secretary.

The *RS-1* is a semirigid type airship, 300 feet in length, 71 feet in diameter, and has a capacity of 700,000 cubic feet. The contract for the design and construction of the airship was awarded by the Army Air Service to the Goodyear Tire & Rubber Co.

The special committee appointed by the National Advisory Committee is to pass upon the design and calculations as prepared by the Goodyear engineers working in conjunction with the engineers of the engineering division of the Army Air Service.

AMERICAN AERONAUTICAL SAFETY CODE.

During the year the project for formulating a safety code for aeronautics has made active progress. The work is being pursued according to the scheme of procedure of the American Engineering Standards Committee, which in 1920 recognized the United States Bureau of Standards and the Society of Automotive Engineers (Inc.) as joint sponsors for this project.

A sectional committee to handle the technical work was formed during 1921, and at a meeting held in New York, September 2, 1921, the permanent organization of this committee was effected, the officers being: Chairman, Mr. H. M. Crane, Society of Automotive Engineers; vice chairman, Dr. J. S. Ames, National Advisory Committee for Aeronautics; secretary, Dr. M. G. Lloyd, Bureau of Standards; assistant secretary, Mr. Arthur Halsted, Bureau of Standards.

The sectional committee consists of 36 members. The following organizations have representation on the sectional committee:

Aero Club of America.

Aeronautical Chamber of Commerce.

American Institute of Electrical Engineers.
 American Society of Mechanical Engineers.
 American Society for Testing Materials.
 American Society of Safety Engineers.
 Manufacturers Aircraft Association.
 National Aeronautic Association.
 National Aircraft Underwriters Association.
 National Advisory Committee for Aeronautics.
 National Safety Council.
 Rubber Association of America.
 Underwriters Laboratories.
 United States Coast Guard.
 United States Forest Service.
 United States Navy Department.
 United States Post Office Department.
 United States War Department.
 United States Weather Bureau.

The American Aeronautical Safety Code will include parts as follows:

Introductory Part.—Scope and Nomenclature.
 Part 1.—Airplane Structure.
 Part 2.—Power Plants.
 Part 3.—Equipment and Maintenance of Airplanes.
 Part 4.—Signals and Signaling Equipment.
 Part 5.—Airdromes and Airways.
 Part 6.—Traffic and Pilotage Rules.
 Part 7.—Qualifications for Pilots.
 Part 8.—Balloons.
 Part 9.—Airships.
 Part 10.—Parachutes.

These various parts are being developed in working subcommittees. The procedure has been for the subcommittee to prepare and distribute to those interested a preliminary draft for discussion in mimeograph form. Later the preliminary draft is completely reconsidered together with all criticisms of it which may have been submitted. A revised draft is then reported for the consideration of the sectional committee.

The sectional committee has considered six such subcommittee reports and approved five of them for publication. Each is then published in pamphlet form as one of the various parts of the code listed above, and is made available for general distribution.

In this printed form the various parts of the code are subject to revision pending their adoption by the sectional committee and sponsor bodies when all parts of the code are ready for consideration together.

The stage of development of the various parts of the code is listed below:

The Introductory Part, Scope and Nomenclature; Part 1, Airplane Structure; Part 2, Power Plants; Part 6, Traffic and Pilotage Rules; Part 7, Qualifications for Pilots; and Part 10, Parachutes, are in the form of a preliminary draft. Plans are made for their revision in the near future.

Part 3, Equipment and Maintenance of Airplanes; and Part 4, Signals and Signaling Equipment, have been approved for publication by the sectional committee; and Part 5, Airdromes and Airways; Part 8, Balloons; and Part 9, Airships, are available for distribution in pamphlet form.

INTERNATIONAL STANDARDIZATION OF WIND-TUNNEL RESULTS.

The program outlined in last year's report for the testing of the National Physical Laboratory airship models has been carried out, and separate reports have been completed and submitted by the Langley Memorial Aeronautical Laboratory, the Massachusetts Institute of

Technology, the Bureau of Standards, and the aerodynamical laboratory of the Washington Navy Yard. The separate reports have been considered by a committee consisting of Dr. A. F. Zahm, Prof. Edward P. Warner, Dr. H. L. Dryden, and Mr. D. L. Bacon, and a joint report on the comparative tests of the two models by six American wind tunnels has been prepared. The airship models have been returned to the National Physical Laboratory.

Exact copies of the National Physical Laboratory airship models have been made and will be tested in the committee's compressed-air wind tunnel at Langley Field in the near future.

The committee has received from the National Physical Laboratory standard models of a R. A. F. 15 airfoil, which are now undergoing tests at the Langley Memorial Aeronautical Laboratory. These models have been tested both in England, at the National Physical Laboratory, and in France, at St. Cyr and Auteuil (Eiffel).

The standardization tests authorized by the National Advisory Committee for Aeronautics to be conducted in the United States have been partially completed. The models, consisting of three cylinders having length-diameter ratios of 5 to 1, and four models of U. S. A. 16 airfoil section each having an aspect ratio of 6 to 1 and a length varying from 18 to 36 inches, have been tested and a report submitted by the Langley Memorial Aeronautical Laboratory. The tests on both the cylinder models and the airfoil models were made over as wide a range of V/L as possible, and included determinations of lift, drag, and pitching moment every four degrees from -4° to $+20^\circ$. As a first step in a program of further tests, the models have been sent to the aerodynamical laboratory of the Washington Navy Yard.

FUNDAMENTAL PURPOSES OF THE AIR MAIL SERVICE.

In December, 1922, the late President Harding wrote to the National Advisory Committee for Aeronautics requesting the recommendations of the committee as to the most promising program to be followed by the Air Mail Service in the expenditure of its limited funds. The reply of the committee, as transmitted under date of December 20, 1922, was as follows:

"DEAR MR. PRESIDENT: In response to your letter of December 4, I have the honor to submit herewith the advice and recommendations of the National Advisory Committee for Aeronautics as to the most promising program for the Post Office Department to follow in connection with the Air Mail Service.

"This report contains the views of the committee developed at two special meetings held on December 12 and 20, 1922, grouped under the following topics:

- "1. The fundamental purpose of the Air Mail Service.
- "2. The accomplishments of the Air Mail Service to date.
- "3. What remains to be accomplished.
- "4. Comparison of an operating with a development program.
- "5. Recommendations of the committee.

"1. THE FUNDAMENTAL PURPOSE OF THE AIR MAIL SERVICE.

"The fundamental purpose of the Air Mail Service is to demonstrate the safety, reliability, and practicability of air transportation of the mails, and incidentally of air transportation in general. In particular, it should—

"(a) Develop a reliable 36-hour service between New York and San Francisco, and make that service self-supporting by creating the necessary demand for it and charging a rate between ordinary postage rates and night-letter telegraph rates.

"(b) Keep strict records of the cost of the service and strive in every way to reduce such costs to a minimum, thereby demonstrating the value of air transportation from an economic point of view, and in particular making it possible for private enterprise eventually to contract for the carrying of mails by airplane at a rate which not only would not exceed the income from such a service but would permit the Post Office Department to provide other postal airways to meet the demands of the people for the more rapid transportation of mail. In the present undeveloped state of the art, it would be wholly impracticable to operate an air mail service by contract.

"2. THE ACCOMPLISHMENTS OF THE AIR MAIL SERVICE TO DATE.

"The Air Mail Service was established in 1918, flying between New York and Washington. It is now operating between New York and San Francisco, in a system of train-and-airplane relays, for night and day travel, respectively. The safety and practicability of air navigation in the daytime have been well demonstrated by the performance during the past year, when more than 2,000,000 miles were flown in the Air Mail Service without a fatality. This performance over the longest regularly traveled route in the world is unique for safety and regularity. Data have been produced as to cost of operation, but this cost is higher than necessary, because airplanes not specially designed for, nor entirely suitable to, the service have of necessity been used.

"3. WHAT REMAINS TO BE ACCOMPLISHED.

"The following very important objects remain to be accomplished by the Air Mail Service:

"(a) Demonstrate that night flying is practicable over a regular route and schedule. This includes development of a chain of emergency landing fields, adequate lighting for night flying, improved methods of navigation through fog, storm, and darkness, and a specially trained personnel.

"(b) Bring about the development of an efficient type of airplane for this special purpose, as distinct from military purposes, and perfect methods for protecting the mail from damage by fire or crash.

"4. COMPARISON OF AN OPERATING WITH A DEVELOPMENT PROGRAM.

"The present daytime air mail service from New York to San Francisco, alternating with trains at night, will require an appropriation of about \$1,500,000 a year. The appropriation for the current fiscal year is \$1,900,000, of which about \$400,000 is being devoted to preliminary preparation for night flying. With an appropriation limited to \$1,500,000, the development of night flying on the transcontinental route will be impossible. If the Air Mail Service were to concentrate on the development of night flying between Chicago and Cheyenne, which is the part of the transcontinental route where this should be first attempted, night flying might be developed with an appropriation of \$1,500,000, but the present airplane service from Chicago to New York and from Cheyenne to San Francisco would have to be abandoned for lack of funds. This would be a step backward, would waste the present investment in organization and equipment east of Chicago and west of Cheyenne, and would alienate public interest and support.

"On the other hand, the development of the Air Mail Service over the one authorized transcontinental route, with facilities for night flying between Chicago and Cheyenne, will, it is estimated, require an appropriation of \$2,500,000 for the next fiscal year. In order that facilities for night flying may be extended over the eastern and western portions of the transcontinental route, the sum of approximately \$2,500,000 should be appropriated for the Air Mail Service for each of the two fiscal years next following.

"5. RECOMMENDATIONS OF THE COMMITTEE.

"The National Advisory Committee for Aeronautics submits the following recommendations:

"A. That the Air Mail Service under the Post Office Department be continued until it has—

"(1) Demonstrated the practicability of night flying in the mail service, and actually established a regular service between New York and San Francisco in 36 hours or less.

"(2) Met the popular demand for a fast transcontinental service and made such service self-supporting by means of appropriate rates;

"(3) Demonstrated the exact cost and economic value of air transportation, using the most appropriate equipment, including airplanes specially designed for efficient performance.

"B. That when the above program is once accomplished the further application of aircraft to the carrying of mail be effected by contracts with private enterprise.

"C. That, as the development of night flying can not be undertaken on any section of the New York to San Francisco route with an appropriation limited to \$1,500,000, an appropriation of between \$2,300,000 and \$2,500,000 be granted for the fiscal year 1924 for the Air Mail Service.

"D. That if the appropriation for the next fiscal year is limited to \$1,500,000, the only thing that can be done is to continue the present plan of flying by day and alternating with trains at night. To so limit the appropriation as to prevent the inauguration of night flying on the New York to San Francisco route will render the value of the Air Mail Service relatively small as compared to the great value it would otherwise have.

"Respectfully submitted,

"NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
"CHARLES D. WALCOTT, *Chairman.*"

Congress appropriated \$1,500,000 for the fiscal year 1924, which was insufficient to provide for regular night flying of the mails. The Post Office Department, however, did manage, with its limited appropriation, to make a five-day test demonstration of the practicability of night flying between Chicago and Cheyenne, in which the mail was carried across the continent in each direction in from 27 to 30 hours. In the judgment of the National Advisory Committee for Aeronautics, that demonstration was the most significant forward step made in aviation in a year marked by substantial progress in many respects. The committee, under date of September 13, 1923, addressed the following letter to the Postmaster General:

"SIR: The executive committee of the National Advisory Committee for Aeronautics, at a regular meeting held on September 13, 1923, had under consideration the significance of the recent five-day test demonstration of night flying between Chicago and Cheyenne by the Air Mail Service. Our members were very much gratified with this important initial success, and adopted a resolution which I have the honor to transmit, as follows:

"Whereas in a statement dealing with the fundamental purposes and the most promising program of the Air Mail Service, submitted to the late President Harding on December 20, 1922, the National Advisory Committee for Aeronautics stated that one of the important objects to be accomplished by the Air Mail Service was to "demonstrate that night flying is practicable over a regular route and schedule"; and

"Whereas in a recent five-day test demonstration of the practicability of night flying, mails were successfully carried across the continent in both directions in less than 30 hours: Now, therefore be it

"Resolved, That the National Advisory Committee for Aeronautics recognizes that the night flying of the mails between Chicago and Cheyenne on a regular schedule for five days is in itself an epoch-making performance, and a splendid start toward the accomplishment of one of the fundamental purposes of the Air Mail Service—the development of a regular and reliable mail service between the Atlantic and the Pacific in thirty-six hours or less; and be it further

"Resolved, That the National Advisory Committee for Aeronautics extends its congratulations to the Postmaster General and to all officials and employees of the Postal Service on this significant achievement that will have far-reaching results, not only in assuring the more rapid transportation of the mails, but also in stimulating the development of aviation for civil and commercial purposes; in lessening the handicap of natural barriers of distance between different sections of the United States, and in promoting the unity of the American people.'

"Respectfully,

"NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
"JOSEPH S. AMES,
"Chairman, Executive Committee."

The National Advisory Committee for Aeronautics at this time reiterates its faith in the value to the Nation of the Air Mail Service as a practical means for aiding the development of commercial aviation, as well as a means for expediting the transportation of the mail. We can not shut our eyes to the future. Mail is bound to be carried eventually by the fastest means available, and it is safe to say that in this age of progress the American people will demand a more or less general use of aircraft in the near future for carrying the mails.

The National Advisory Committee for Aeronautics strongly recommends the granting by Congress of liberal appropriations to the Air Mail Service, sufficient to enable it to—

(a) Demonstrate that night flying is practicable over a regular route and schedule. This includes development of a chain of emergency landing fields, adequate lighting for night flying, improved methods of navigation through fog, storm, and darkness, and a specially trained personnel.

(b) Bring about the development of an efficient type of airplane for this special purpose, as distinct from military purposes, and perfect methods for protecting the mail from damage by fire or crash.

THE NEED OF FEDERAL LEGISLATION.

The committee again recommends the creation by law of a Bureau of Civil Aeronautics in the Department of Commerce for the regulation and licensing of aircraft, airdromes, and aviators, and the general control and encouragement of commercial flying.

The increasing relative importance of aircraft in warfare is alone sufficient to justify the Federal Government in taking proper cognizance of the problem of commercial aviation and aiding its development. It has been the history of civilized nations that governments have found it necessary and advantageous to aid in the development of means of transportation. The wonderful growth of transcontinental railroads in America was greatly aided by land grants from our Government. Progressive European nations are spending public funds through direct and indirect subsidies for the promotion of civil and commercial aviation. It is essential to the practical development of aviation in America that the Federal Government give intelligent support and effective aid, through Federal legislation outlined above, and by cooperation with the States in the establishment of airways and landing fields.

CANADA'S CONTINUED COURTESY TO AMERICAN AIR PILOTS.

In May, 1920, Canada promulgated regulations permitting United States qualified aircraft and pilots to fly in Canada for a period of six months on the same basis as if the United States had established its regulations as contemplated under the Convention for the Regulation of International Air Navigation. The Government of the United States has not as yet ratified this convention. Canada, however, has from time to time extended for periods of six months or a year the regulations favoring American air pilots, the latest extension expiring May 1, 1924. The Government of the United States has expressed appreciation to the Government of Canada for these repeated courtesies. The proper remedy for the resulting unsatisfactory situation is either for the United States to ratify the Convention for the Regulation of International Air Navigation or to negotiate a separate treaty with Canada. Neither of these remedies, however, could be effective in the absence of an agency for the regulation of civil air navigation in the United States. The annual recurrence of diplomatic negotiations with Canada on this subject serves to emphasize the need for the enactment of Federal legislation for the regulation of air navigation, which is one of the recommendations contained in the conclusion of this report.

INTERNATIONAL AIR CONGRESS.

An International Air Congress, unofficial in character, was held in London in June, 1923, attended by representatives of nations interested in aeronautical development, including the United States. Without going into the details of the transactions of the congress, the committee deems it of interest to present a digest of the resolutions which were adopted.

The most important resolutions confirmed were those dealing with international air lines and the demands made by flying on the human frame. The first, put forward by Spain, Rumania, Holland, Norway, Italy, and Belgium, at a meeting under the presidency of France, urged "That in the interests of aerial navigation the Governments be asked to unite in subsidizing the transcontinental air services as speedily as possible."

The second resolution was that "From the evidence now accumulated of the physical condition of pilots who have flown for years the medical section of the International Air Congress affirm that, given reasonable flying hours, they have no evidence to show that pilots deteriorate

more rapidly than in other employments, and the data and curves already available indicate that these pilots maintain a condition above the normal for their age."

The remaining resolutions confirmed were as follows:

"The International Air Congress of Aerial Navigation urges the International Commission for Air Navigation to evolve some uniform scheme of posting the weather forecasts in all air stations, and of compiling a leaflet of essential advices to be handed to pilots.

"That as soon as possible an International Conference be held, with delegates appointed by their respective Governments, to study and define the general principles of private international law relating to the air, and to submit propositions of law for ratification by the various nations concerned.

"That this International Air Congress invite the International Commission for Air Navigation to consider the advisability of setting up a permanent international commission for the standardization of aircraft materials and component parts, and for this purpose to invite delegates from the various national standards organizations to report on the matter.

"That the International Air Traffic Association should be invited to approach the postal authorities of the various European Governments with a view to discovering the air transport time-tables which would best suit them for the carriage of mails, and this body should then communicate this information to the various air transport companies concerned."

REPORT OF COMMITTEE ON AERODYNAMICS.

ORGANIZATION.

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

Dr. Joseph S. Ames, Johns Hopkins University, chairman.

Mr. D. L. Bacon, Langley Memorial Aeronautical Laboratory.

Dr. L. J. Briggs, Bureau of Standards.

Mr. H. N. Eaton, Bureau of Standards.

Commander J. C. Hunsaker, United States Navy.

Maj. Leslie MacDill, United States Army, engineering division, McCook Field.

Lt. C. N. Monteith, United States Army.

Prof. Charles F. Marvin, Chief, Weather Bureau.

Prof. Edward P. Warner, Massachusetts Institute of Technology, secretary.

Dr. A. F. Zahm, United States Navy.

FUNCTIONS.

The functions of the committee on aerodynamics are as follows:

1. To determine what problems in theoretical and experimental aerodynamics 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 aerodynamic investigations and developments in progress or proposed.

4. The committee may direct and conduct research in experimental aerodynamics in such laboratory or laboratories as may be placed either in whole or in part under its direction.

5. The committee shall meet from time to time on the call of the chairman and report its action and recommendations to the executive committee.

The committee on aerodynamics by reason of the representation of the various organizations interested in aeronautics is in close contact with all aerodynamical work being carried out in the United States. In this way the current work of each organization is made known to all, thus preventing duplication of effort. Also all research work is stimulated by the prompt distribution of new ideas and new results, which add greatly to the efficient conduction of aerodynamic research. The committee keeps the research workers in this country supplied with information on all European progress in aerodynamics by means of a foreign representative who is in close touch with all 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 aerodynamic committee has direct control of the aerodynamical research conducted at Langley Field, the propeller research conducted at Leland Stanford University under the supervision of Dr. W. F. Durand, and some special investigations conducted at the Bureau of Standards and at a number of the universities. The investigations undertaken at the Washington Navy Yard aerodynamical laboratory, the engineering division, Army Air Service, the Bureau of Standards, and the Massachusetts Institute of Technology are reported to the committee on aerodynamics.

THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY.

Wind tunnel research—Standardization.—Following a policy unanimously subscribed to by the aeronautical laboratories of the world, the committee is sponsoring a series of tests in the chief wind tunnels of this country, with the object of standardizing apparatus to a point which will permit the intercomparison of data. To this end several groups of models, comprising wings, circular cylinders, and airship models, have been tested in the atmospheric wind tunnel and are now being circulated among the other important wind tunnels of this country. This program has been combined with that of the British Aeronautical Research Committee to the extent of substituting the British airship models for the American, and by circulating the single British airfoil, together with the four American ones. In conjunction with the standard tests, certain special investigations of turbulence effect and of model support interferences have been made which, it is expected, will be of use in interpreting the collected data resulting from tests of the standard models in numerous laboratories.

Airfoils.—Routine tests have been made of a number of propeller airfoils at the request of Stanford University. These airfoils had previously been tested in another laboratory in which the speed was limited to 30 m. p. h. Our low speed results were in substantial agreement with these, but the influence of scale on these particular models was so great as to show an entirely different set of characteristics at 67 m. p. h. and provided another example of the extreme desirability of high scale testing.

The division of load between the individual wings of biplane and triplane combinations is being elaborately studied at the request of the Bureau of Aeronautics, in order to permit of more intelligent design of wing structures, particularly those intended for large airplanes carrying heavy loads. The very large number of possible wing arrangements considered in the program of tests have required the exclusive services of the atmospheric wind tunnel and its staff on this work for many months.

The previous determinations of pressure distribution over airfoils are being extended by measurement on a new series of thick tapered wings proposed by the Air Service, models for which are in preparation. In order to expedite the test work, and thus minimize the monopoly of the tunnel by this one investigation, a method has been devised whereby all necessary pressure measurements on any one model may be made in an hour, instead of the day or more which was formerly required. This method involves the connection of a large number of pressure openings on the model surface through a system of hypodermic tubes, embedded in the model, to a multiple manometer, where the pressures are simultaneously recorded. The saving of time required to make the tests more than offsets the extra cost of the construction of the models.

Model airplanes.—A complete model of a thick wing biplane, the Fokker D-VII, has been subjected to tests in the atmospheric and variable density tunnels. The former tests were limited, of necessity, to one-tenth of full dynamic scale, while the latter were carried to more than five times that value by increasing the density of the air. These experiments, in conjunction with flight tests, demonstrate that whereas the atmospheric tunnel gives a good index of full scale performance with airplanes using thin wings, it can not be considered to give a reliable indication of the full scale drag of thick-winged airplanes. In this particular case the atmospheric tunnel shows a maximum lift/drag ratio about 20 per cent lower than does the variable density tunnel in agreement with flight tests.

A model of a multiplane pursuit airplane was tested in the atmospheric tunnel at the request of the Air Service. This test was of interest chiefly because the extremely low scale of test, necessitated in any ordinary tunnel by the wing chord of 0.8 inch, made the result not directly applicable for design purposes and demonstrated that the only way to acquire usable experimental data on such a model will be by means of the variable density wind tunnel.

Flight research—Airships.—To permit a rational basis for stress analysis, and at the request of the Bureau of Aeronautics, an extensive study is being made of the air forces which act upon the hull and control surfaces of a nonrigid airship in flight. After some preliminary tests with instruments already on hand, new measuring instruments were designed and constructed which permit the simultaneous measurement at frequent intervals of 240 different pressures. Some rough preliminary estimates of forces on the control surfaces were communicated to the Navy before the first flights of the *ZR-1* (rechristened U. S. S. *Shenandoah*). Since then a tremendous amount of data has been accumulated from these tests, the computation and analysis of which will occupy all available personnel for several months to come. The experience gained during the progress of this work is now being applied in a careful analysis of the larger problem of determining the loads on the U. S. S. *Shenandoah*.

Airplanes.—Pressure measurements on airplane wings have usually been limited to model tests, or to measurements over a very small portion of an airplane wing in flight. The laboratory has recently completed an elaborate series of measurements over the entire wing surface of a high-speed pursuit biplane in normal flight and during violent maneuvers for the engineering division Army Air Service. The results of this research throw a new light on the constructional desiderata of fast airplanes, as several small areas were found on which the air suction was many times greater than that usually assumed for the design of the structure. This information gives an explanation of the cause of several accidents to racing and pursuit airplanes which could not be explained before.

The previous investigations of dynamic stability have been extended by determination of the period of longitudinal oscillation and the longitudinal damping characteristics of two airplanes, using both free and locked controls. Only one instance of dynamic instability was observed and it is concluded that the study of this characteristic need not be performed on models of new airplanes but may safely be postponed until these airplanes are available for flight tests.

Preliminary experiments have been made on several airplanes to determine the maximum lift coefficient which those airplanes can be made to develop, how nearly this lift coefficient can be approached in level flight, and what margin of control is available under these conditions.

At the request of the Navy, the laboratory is investigating the planing characteristics of seaplanes moving on the surface of the water, in order to acquire data previously obtainable only from the model basin.

Propellers.—The committee is conducting, this year for the first time, flight tests of propellers. The usual assumptions for the computation of slipstream velocities in performance estimation have been verified in flight and, from the velocities so measured, an approximation of the effective thrust has been developed which is in close agreement with the figures obtainable from known rates of glide and climb. Preparations are in progress for flight tests, in conjunction with complete model tests at Stanford University, of two families of propellers having varying pitch ratio and aspect ratio, respectively. No flight researches on systematically varied propellers have ever been made in parallel with wind tunnel tests of the same propellers, and this research is expected to fill a long-felt need.

Air structure.—The theory of dynamic similitude as applied to aircraft is based on the assumption that an airplane and its model prototype both move in fluids having equivalent initial disturbances. Experiments performed at the laboratory with large spheres falling from a great height in calm air have shown that the air resistance coefficient of a blunt body in the free atmosphere may be quite different from that of the same body in any known form of wind tunnel and that this disagreement is apparently chargeable to "air structure." While the flow about blunt bodies is undoubtedly dependent upon the nature of the initial air structure

to a much greater degree than is that about thin airfoils, we have reason to believe that airship hulls and some of the thicker airfoils have resistance coefficients which, for small Reynolds numbers, depend fully as much on initial air structure as they do on the dynamic scale of motion. These experiments, begun on spheres, are to be continued with other bodies in order to gain additional information on this important matter.

Performance tests.—In addition to its regular research work and because of the accurate special instruments and the experienced personnel available, the laboratory has been requested to make an accurate measurement of the performance of several airplanes. This has involved a study of the comparative merits of different means of measurement and methods of reducing flight data for comparison. A proper application of the approved method serves to obtain more consistent data than that usually resulting directly from the performance tests.

Further progress has been made on the investigation started several years ago, to compare the merits of a series of airfoils, as determined in the wind tunnel and in actual flight. These experiments were started on the thin-wing JN-4th and continued on the thick-wing Fokker D-VII, but the engineering division of the Army Air Service is now furnishing the committee with a Messenger airplane having six sets of interchangeable wings of different profiles, and with an exact model of the airplane. The scale intermediate between the conventional wind tunnel and flight testing is now bridged by means of the variable density tunnel, thus permitting direct comparison between tunnel and flight tests, so far as the influence of the viscosity is concerned.

Wind tunnel and flight equipment.—The atmospheric wind tunnel has been in continuous operation throughout the year, and all difficulties with both the electrical installation and the aerodynamic characteristics of the tunnel, which had at one time or another caused interruptions to the regular routine of work during previous years, have now been overcome entirely. A minor improvement has been effected by the provision of air vents or "bleeder" holes communicating between the operating chamber and the tunnel proper at a point well down stream from the model. These prevent disturbances near the model due to the inevitable air leak which must occur through the walls of the operating chamber.

The N. A. C. A. variable density wind tunnel has been continuously developed during the year and is now sufficiently refined and accurate. This tunnel was the first one of its kind to be constructed and required many details in design where no precedent was available. Many minor details of the operating and observing devices were therefore installed merely in a temporary manner until they should prove their usefulness or satisfactory operation under test. After actual operating experience with the tunnel these devices have either been made permanent, or have been so changed as to permit sufficient convenience in operation.

The air flow has been greatly improved by installing deflector plates at both ends of the air tank and a honeycomb at the entrance to the throat and is now satisfactorily uniform.

At the time of the first tests the provisions for mechanically changing the attitude of the model were not yet completed and experiments were hampered by the necessity of deflating the tank between successive measurements. The mechanism to avoid these troublesome delays has now been installed and the instrumental equipment has been augmented by remote control micro-manometers and air pressure distributing valves which permit of measuring successively a number of pressures on a single instrument.

The electric-power transmission line from Hampton to Langley Field, which has until the present time been of insufficient capacity to permit the simultaneous operation of both wind tunnels, is now being replaced by one of larger capacity and no further inconvenience from this source is anticipated.

Instrument research and development.—During the past year the standard recording instruments have been improved in many respects and have been applied to new uses. In addition, several new types have been developed and put into successful operation. The three component and single component accelerometers have undergone changes making for easier adjustment of sensitivity and damping. The single component turn meter has been redesigned, using a standard commercial gyroscope, and its sensitivity range has been increased. A speed

change mechanism has been built for use in the recording instruments, which provides six film speeds ranging from one revolution of the drum in one-half minute to one in two hours and thus covers the range from rapid maneuvers to ceiling tests of airplanes. A new constant speed motor has been developed for general instrument application, which is both lighter and smaller than the older type, and is also more efficient. Considerable work on sensitive pressure capsules has been done in the laboratory and several very small and efficient capsules produced, some of which are especially well adapted for the accurate recording of small pressures such as those encountered on the surface of an airship.

The pressure instruments, such as the air-speed recorder, have been adapted to other uses. One of these new applications is the recording of small changes in altitude, for which purpose a combined air-speed meter and statoscope using two small sensitive capsules has been developed. An air-speed recorder having a very stiff diaphragm has been used with a water Pitot for measuring the water speed of seaplanes. The air-speed recorder has also been used for measuring the ground speed of an airplane in taking off and landing, by recording the pressure impulses produced by a piston and cylinder operated by a cam on one of the airplane wheels.

A new trailing bomb-shaped instrument has been developed to replace the bomb kymograph. The case contains a pendulum whose position with respect to the axis of the bomb is determined by means of a rolling contact and resistance, the records being made in the cockpit of the airplane instead of in the suspended instrument. The advantages of this type are greater ease of handling and independence of sunlight for recording, permitting test flights on dull days and in any direction.

A combined air-speed and altitude recorder was developed primarily for the supercharger flight work but has proved valuable for other flight work as well. It is a standard type of recorder, having an air-speed capsule and a barometric cell, both giving a continuous trace on the film. An automatic observer has been constructed for the high altitude supercharger flight work, which consists of a box carrying an electrically operated multiple camera and lights at one end and a panel of indicating instruments at the other end. With this apparatus a picture of 8 or 10 indicating instrument dials is made every 20 seconds, standard moving-picture film being used.

A combined air-speed and inclination recorder has been built for use in glide tests and other investigations requiring a record of the airplane's inclination. The inclinometer consists of an oil-damped pendulum carrying a mirror which controls the recording light beam.

A motor driven micromanometer with a capacity of 40 inches of pressure head has been designed especially for use in the variable density wind tunnel. This manometer, however, will also be of considerable value for the accurate and rapid calibration of pressure instruments in the laboratory.

A new suspension type oil-damped galvanometer has been built for use with the electrical recording instruments. It has a period of approximately one-hundredth of a second and will eliminate the various difficulties encountered with the commercial movements formerly employed.

In addition to the above major items a considerable number of the simpler instruments and accessories have been built, such as yaw heads, Pitot tubes, swiveling air-speed heads, manometers, and various indicating devices.

AERODYNAMIC THEORY.

During the past year additional improvements have been made in the theory of air forces, bringing the general theory to a point where additional research work appears necessary before further important progress can be made. In particular, that part of the theory which pertains to wings and wing sections in a nonviscous fluid has been very much elaborated and the methods of study reduced to formulæ as simple as those employed in other branches of technical science.

A notable advance was made in the theory of air forces on the hulls of rigid airships as worked out by Dr. Max M. Munk in connection with the report of the *ZR-1* committee. Preliminary experiments have verified this theory in a satisfactory manner. It is proposed to

improve and extend the theory to make it applicable to semirigid and nonrigid airships which, in consequence of their small fineness ratios, present considerable difficulty in the exact calculations of the air forces involved.

Doctor Munk recently devised a new method for use in computing propeller characteristics and assisting in the choice of the proper propeller. An important innovation suggested by this method is the use of certain new coefficients which bear simple and direct relations to the principal propeller characteristics, so that the design work is considerably simplified. The new method has been checked by analysis of more than 150 tests on models and in free flight.

STANFORD UNIVERSITY.

The propeller investigation, mentioned in last year's report, to determine the thrust and torque coefficients and the efficiency with obstructions placed in the air stream, has been completed and a report submitted. In this investigation simple geometrical forms were selected for the obstructions, such forms offering the advantage of easy, exact reproduction at another time or in other laboratories. An extension of the investigation of propeller interference is being conducted, using obstructions of various forms as encountered in actual airplane design, especially such designs where the propeller is mounted in front of the fuselage or nacelle.

The propeller investigation now being conducted at Stanford University for the committee is on the coefficients of propellers of standard type. In determining coefficients of propellers of standard type an arbitrary standard propeller, designated as propeller C, was selected, the propeller type being one of standard use and found satisfactory. The investigation will include tests of 13 model propellers, comprising three series of tests. In the first series the pitch will be varied, being changed in steps from 0.5D to 1.1D; in the second series, propeller C will be modified by changes in thickness of the blade section; and in the third series, modification will be in blade width. The program covering the investigation was prepared under the direction of the subcommittee on aerodynamics and in conjunction with the Bureau of Aeronautics, Navy Department; engineering division, Army Air Service; Langley Memorial Aeronautical Laboratory; and Stanford University.

WASHINGTON NAVY YARD.

Wind tunnels.—The aerodynamical laboratory at the Washington Navy Yard is operated by the Bureau of Construction and Repair for the Bureau of Aeronautics. All technical details connected with the tests and reports are under the direction and immediate supervision of Doctor A. F. Zahm.

The equipment consists of two wind tunnels, one closed circuit type 8 by 8 feet in cross section at the testing plane, and one open circuit N. P. L. type 4 by 4 feet in cross section. The larger tunnel is fitted with a special six-component balance designed by Doctor Zahm and his assistants and constructed in the Washington Navy Yard. As described in N. A. C. A. Technical Report No. 146, this balance is equipped with automatic weighing beams which enable readings to be taken with great rapidity. The smaller tunnel is equipped with a modified N. P. L. type of balance, also having automatic weighing beams.

The testing program is formulated for the greater part in the Bureau of Aeronautics and necessarily follows rather closely the design needs of the bureau. It is the policy, however, to make all tests as general as possible and to make available for general use all data which appear to justify publication. Such data are published from time to time as Technical Reports by the National Advisory Committee for Aeronautics, or, in special cases, by some scientific publication.

Airfoils and wings.—A comparatively large number of airfoils have been tested during the past year. The most important series of tests were those on the Handley Page wing. This investigation, continued from 1922, represents a large amount of experimental work covering detailed tests on five models. The second investigation in importance was the completion of a research on variable cambered airfoils, during which 12 models were tested. A third investigation, on lateral control, required a similar amount of testing.

In addition to the airfoil and wing investigation, a number of individual models were tested from time to time. Among these were two variable angle-variable camber models supplied by inventors, 10 Göttingen sections, 2 modified Sloane airfoils, and 13 other sections.

Tests on the RAF-15 and Sloane models were carried to large negative angles in order to secure design data for the upside down condition of flight. Tests were also made on the biplane wing arrangement used in the TS airplane, and on the monoplane wings used in the NW and CT airplanes.

Several of the new airfoils appear to have unusually good characteristics and are to be given further tests. The best section in this class is the N-9, a modification of the Göttingen No. 398. Another section of some promise is a thickened Sloane which has characteristics practically identical with the original section.

Airplanes.—During the past year 15 model airplanes have been given routine tests for lift, drag, and moments under various conditions. The usual routine test at the Washington Navy Yard is arranged to supply data on control, stability, and performance. In many cases, however, additional information, such as the resistance of some part or the effect of a modification in the general arrangement, is also obtained. As an example, one model seaplane was tested with two types of tail surfaces, and another with five types of tail surfaces, in order to obtain certain design data. Another model was tested to determine the effect of the slipstream caused by a model propeller mounted in front of the engine housing and driven by an air turbine.

It was formerly considered that wind tunnel test data was unreliable except for predicting stalling speed, controllability, and balance. However, the methods of correcting test data have recently been improved to the point where the complete performance may be accurately predicted.

Airplane parts.—A series of eight representative seaplane floats have been given thorough tests for air forces and moments, including the variation of drag with wind velocity. Two other seaplane floats and two boat seaplane hulls have been tested for lift and drag only.

Tests have been made on two model bodies, one being for the TS seaplane and the other a model which was constructed during some shop experiments. It is proposed to extend these tests in the near future to include models representative of current design. The proposed tests are to parallel the tests on seaplane floats and may be expected to supply valuable information for the designer.

Lighter-than-air.—Check tests have been made on two streamline models supplied by the National Physical Laboratory in connection with the "standardization" tests being carried out at various wind tunnels here and abroad.

A model power car for the *ZR-1* was tested to determine the effect on the resistance of closing a visor hood. The data obtained checked very well with that calculated on the assumption that the interior exposed parts would be subjected to a wind speed approximately proportional to the hood opening.

A model of the A. P. kite balloon was tested in yaw to obtain data for comparison with other types, such as the NU, having radically different fin arrangements.

The velocity distribution around a model hull of the *ZR-1* was obtained from soundings in six transverse planes. The results, which have direct application in propeller design, are of interest in showing the nature of the airflow around a streamline body.

General.—Several notable additions have been made in the equipment at the Washington Navy Yard. Automatic weighing beams have been installed on the balance of the 4 by 4 foot tunnel and prove to be a great improvement. An automatic speed control has also been fitted to this tunnel with very satisfactory results.

A very interesting manometer has recently been designed by Doctor Zahm. The tubes in this manometer are bent along the curve of a tractrix so that there is a constant precision in the reading at any speed.

BUREAU OF STANDARDS.

Wind tunnel investigations.—The work in aerodynamics has been carried out in three wind tunnels, one 3 feet in diameter with a speed range of 11 to 180 miles per hour; one $4\frac{1}{2}$ feet in

diameter with a speed range of 17 to 90 miles per hour, and one 10 feet in diameter with a speed range of 15 to 70 miles per hour. Most of the work during the past year has been in cooperation with the engineering division of the Air Service, McCook Field, War Department, the Ordnance Department, United States Army, and the National Advisory Committee for Aeronautics.

A continuous program of testing and research has been carried on for the engineering division of the Air Service in connection with the design of the *RS-1* semirigid airship. Four proposed hull models were tested, measurements of drag, cross-wind force, torque, and center of pressure being made. In conference, the aerodynamic characteristics were considered in connection with structural advantages and disadvantages and one of the hulls was selected. The pressure distribution over this hull was measured and the distribution of force computed for various attitudes of the model, the data serving as a partial basis for the keel design. Forces and moments on the hull were measured with 22 suggested designs of fins, the control surfaces being in the neutral position. Damping coefficients were measured for the same surfaces on the Washington Navy Yard oscillator, which was loaned to the bureau through the courtesy of Doctor Zahm. Two of the best designs were selected by the engineering division for further tests with the control surfaces at angles. One of these designs was selected for use, and a study made of the pressure distribution over the after part of the hull with the fins in place. Measurements of the pressure over the fins are now in progress.

At the beginning of the year, complete studies were made of the aerodynamical characteristics of the military airship and the type A. P. high altitude observation balloon.

In the field of bomb ballistics further measurements of the damping coefficients of bomb models have been made. An investigation of the validity of an empirical rule now used for the design of fin surface for bombs is in progress. The present rule relates the center of area of the meridian section of the bomb to the center of gravity. The correspondence between the center of area position and the center of pressure position is being studied experimentally.

A comparison of tests on a 4-inch model in the 4½-foot tunnel with tests of a full scale bomb in the 10-foot tunnel yielded very satisfactory results.

Measurements in the high speed wind stream, obtained by discharging air from a compressor through an orifice, have been continued. Many of the measurements were made in cooperation with the Ordnance Department on projectile and bomb models, but during the past year spheres have been included. A balance has been constructed and is now being installed for measurements on airfoils of the same sections as those used in the high speed wind tunnel at McCook Field. Lift, drag, and center of pressure will be measured. All of this work is made possible through the courtesy of the General Electric Co. The work on airfoils is in cooperation with the National Advisory Committee for Aeronautics.

The determination of the speed of wind tunnel streams, independent of the use of the Pitot tube, has been continued for the National Advisory Committee with certain refinements in the methods. No improvement in precision was obtained. The mean ratio of the speed determined by floating balloons to that determined by the Pitot tube is unity within 0.2 per cent, the mean deviation of about 40 determinations being of the order of 1 per cent.

Studies of the steadiness of wind tunnel air streams have been made for the National Advisory Committee. The principal result of the investigation is the demonstration of the existence of pressure waves of a frequency roughly equal to the natural frequency of stationary sound waves in the tunnel. The importance of short large-diameter connections to the recording mechanism has also been shown, long connections producing resonance effects, small-diameter connections giving large damping.

Aeronautic instruments section.—The outstanding feature of the work of the aeronautic instruments section of the Bureau of Standards during the past year has been the development of a variety of special instruments for use on the United States Navy rigid airship *Shenandoah*. The importance of having accurate instruments to aid in the navigation of this ship has been appreciated by those responsible for its construction and operation, and this has brought about the adoption of a comprehensive program of instrument development at the Bureau of Standards by the Navy Department. Among the instruments which have already

been completed for the *Shenandoah* are a temperature-compensated altimeter, a sensitive landing altimeter, a rate-of-climb indicator, and electric turn meter, two suspended head electric airspeed meters, an electric thermometer, and a fabric tension meter.

In addition, the usual program of research and development work on aeronautic instruments has been continued in cooperation with the National Advisory Committee for Aeronautics, the Army and Navy Air Services, and other Government departments. A considerable amount of routine testing has also been done.

The investigation of all types of instrument diaphragms for the National Advisory Committee for Aeronautics has been continued. Reports on several phases of this work have been brought nearly to completion. The theory of the deflection of slack diaphragms has been formulated and has been verified experimentally in numerous widely different cases with an accuracy of 5 per cent or less. It is now possible by using this theory to design slack diaphragm pressure elements to meet specified conditions and to give almost any desired load-deflection curve. The drift and recovery curves obtained from the tension tests referred to in last year's report have been investigated in the light of Boltzmann's theory of elastic time effects. With this theory it has been found possible to predict the recovery curves, once an expression has been found which fits the drift curves accurately. Using the expression representing the drift, it is possible to predict the time hysteresis. Making use of the drift curves obtained from tests of Bourdon tubes to compute the time hysteresis curves, then comparing these with the experimentally determined hysteresis curves, it has been found that the time hysteresis comprises approximately half of the total hysteresis loop, directional hysteresis (i. e., the German "elastische hysteresis") accounting for the remainder. By subtracting the time hysteresis from the total hysteresis it has been possible, therefore, to determine the shape and magnitude of the directional hysteresis loop. A new theory of the deflection of Bourdon tubes has been developed and has been tested experimentally. This theory has been found to agree with experimental results much more closely than any of the theories previously formulated.

A report on aerial navigation and one on night and cloud flying have been prepared and are nearly ready for publication.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

Equipment.—The most notable addition to the equipment of the aeronautical laboratory during the past year is the large wind tunnel, 7½ feet in diameter, which is now in full operation. As the result of the suppression of all honeycombs in the throat of the tunnel, the only straightening device being placed well out toward the mouth of the entrance cone, the efficiency proved somewhat higher than had been anticipated, a wind speed of 90 miles an hour being attained with an expenditure of 125 horsepower. The flow is satisfactorily steady, the wind speed being kept very closely at any desired value by an automatic regulator, similar to that already in use on the small tunnel but with the addition of a magnetic vibrator to keep the regulator arm oscillating continuously and to counteract any time lag and resultant tendency to "hunt" which might arise from the large inertia of the armatures of the electrical machines on which the regulation ultimately acts. The turbulence in the new tunnel seems to be exceptionally low, presumably because of the distance between the honeycomb and the model and the change of diameter between the two, and the effect of low turbulence is, as usual, to decrease the maximum lift of airfoils. The maximum lifts recorded for typical sections are somewhat less than those found for the same sections by most other American tunnels, but somewhat more than have been recorded at Gottingen.

The balance used supports the model in the tunnel only by wires. The drag is taken through a 45° linkage, as at Gottingen, but the points of attachment of the wires are not the same as those used at Gottingen, and the balance itself is quite different from the German design in mechanical detail. As two sets of drag wires are used, with independent attachment to the balance, yawing and rolling moments, as well as lift, drag, and pitching moments, can be measured, all five readings being taken without disturbing the model or readjusting the balance.

Wind tunnel flow investigations.—In addition to the usual routine studies of the flow in the large tunnel, including the making of transverses, the use of recording airspeed and yaw meters, etc., a detailed investigation of the effect of turbulence has been undertaken. Measurements of the lift and drag of several airfoils, as well as of the drag of a number of other objects, have been made in the small tunnel with screens of various degrees of closeness of mesh placed across the stream in front of the model, and the indication has been that the scale of the disturbances which constitute turbulence is at least as important a factor as the total extent of the disturbance. The larger the mesh of the screen, within the limits to which the experiments were carried, the larger was the effect on aerodynamic forces.

Airfoil tests.—The testing of airfoils has been carried on in both wind tunnels, about 30 sections having been tried in all. For the purpose of providing airplane designers with data which would certainly be directly comparable a series of standard tests have been undertaken, about 20 sections having been selected from among the best produced in any of the laboratories of the world. Models of these sections have been made up in a uniform size of 36 by 6 inches on the Nichols wing machine and have been tested at uniform speed of 40 miles an hour. A similar series of tests is later to be made at higher speeds. The sections tested up to the present time include nine of American, one of British, one of French, and four of German origin.

Airplane model tests.—The practice of making an extended series of wind tunnel tests on the new airplanes designed for the Army Air Service has continued, and about a dozen complete models have been tested during the year. Very interesting conclusions with regard to downwash and its effect on the balance of the airplane, as well as to the way in which balance depends on the aspect ratio of the tail, have been arrived at, and further light has been gained on the difference between real and "apparent" or "calculated" downwash and on the factors which control the relation between those quantities.

Control.—The investigation of controllability and maneuverability characteristics has been continued, and the completion of the rolling and yawing moment balances have made it possible to add a study of aileron behavior to the work previously done in determining the effectiveness of the elevator and rudder on each model tested. The most important general conclusion has been that an aileron on the lower wing of a biplane is superior to one on the upper wing from every point of view. It further appears that the action of the ailerons depends very largely on the section of the wing to which they are attached, and that it is unsafe to consider the results of model tests made with a single section as of general application.

The prediction of maneuverability characteristics from wind tunnel tests is still being studied, and a theoretical minimum turning radius is now calculated for all models. Only the results of an elevator control test are needed to make this prediction if a vertical bank is assumed.

Miscellaneous.—A number of short researches, not falling directly in any of the classes enumerated above, have been carried to completion. Among the most interesting were a determination of the effect on airfoil performance of corrugations and striations of various forms on the surfaces, and a series of experiments on the pressures arising from the impact when a flat or curved surface, corresponding to the bottom of a seaplane float, is suddenly dropped onto smooth water.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT.

ORGANIZATION.

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

- Dr. S. W. Stratton, Massachusetts Institute of Technology, chairman.
- Henry M. Crane, Society of Automotive Engineers.
- Harvey N. Davis, Harvard University.
- Dr. H. C. Dickinson, Bureau of Standards.
- Leigh M. Griffith, Langley Memorial Aeronautical Laboratory.

W. S. James, Bureau of Standards.

Edward T. Jones, engineering division, Army Air Service.

Lieut. Commander B. G. Leighton, United States Navy.

George W. Lewis, National Advisory Committee for Aeronautics, vice chairman.

FUNCTIONS.

The functions of the committee on power plants for aircraft are as follows:

1. To determine which problems in the field of aeronautic power-plant research 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 aeronautic power-plant research in progress or proposed.
4. To direct and conduct research on aeronautic power-plant problems in such laboratories as may be placed either in whole or in part under its direction.
5. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

By reason of the representation of the Army, the Navy, the Bureau of Standards, and the industry upon this subcommittee, it is possible to maintain close contact with the research work being carried on in this country and to exert an influence toward the expenditure of energy on those problems whose solution appears to be of the greatest importance, as well as to avoid waste of effort due to unnecessary duplication of research.

The committee on power plants for aircraft has direct control of the power plants research conducted at Langley Field and also of special investigations authorized by the committee and conducted at the Bureau of Standards. Other power-plant investigations undertaken by the Army Air Service of the Bureau of Aeronautics are reported upon at the meetings of the committee of power plants for aircraft.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY.

Fuel injection engine—Spray photography.—The fuel injection spray photography research was prosecuted according to the plan presented in the report for last year, the development being carried on at the request of the Bureau of Aeronautics, Navy. The difficulty of obtaining prompt delivery of the special apparatus required and the necessity of designing and building in our own shops such apparatus as could not be obtained to advantage from commercial establishments, has caused frequent and extended delays. These delays together with the pressure of other work and the lack of personnel have considerably retarded the prosecution of this work.

The original scheme of the apparatus has been changed considerably in order that light flashes of the desired intensity and frequency might be obtained. The electrical relief valve method of controlling the frequency of the light flashes, using a water resistance as described in the report for 1922, did not produce the exact results desired, because the large current required in producing the proper illumination at the spark gap caused a prohibitive energy loss. The water resistance has been replaced by several inductance coils and a special synchronous interrupter switch, placed in series with the spark gap. In this case the valvular action is produced by the large inductance of the coils preventing sudden changes in current flow. While this system is somewhat more complicated, it is, nevertheless, very much more efficient.

The dark field method of spray illumination was retained. The spark gap was located at one focus of an elliptical mirror and the spray chamber was arranged to take the indirect light at a point slightly beyond the other focus. The electrical discharge across the gap caused a deposit to be formed on the mirror which became so corroded as to be unsatisfactory. The necessity of finding a suitable remedy for this action and the difficulty of obtaining a good mirror surface led to the trial of a system employing a parabolic mirror to reflect the light from the gap in parallel rays through the spray chamber, placed at an angle with the light beam. This system produced an even illumination which can be increased to the desired amount by

the addition of more reflectors. It is expected that satisfactory photographs will be obtained with this arrangement without very much difficulty.

Fuel characteristics.—A research has been undertaken to determine the vapor pressures of various fuels and liquids at high temperatures. It is hoped that information will be obtained which will assist materially in the solution of the fuel injection engine problem. Little work has been done on this subject heretofore, water being the only liquid for which this relation seems to have been definitely established at temperatures pertaining to the fuel injection engine. Consequently the vapor pressure of water was determined first in order to connect the present work with that done previously. This is being followed by determinations upon alcohol, benzol, Diesel fuel oils, gasoline, and kerosene.

Another phase of the general research is directed to the determination of the coefficients of discharge for orifices suitable for use in injection nozzles. Orifices of 0.004 inch to 0.025 inch diameter and of various lengths are being used. Diesel fuel oil has been tested exclusively thus far but these tests will be followed by others using such other liquids as are of pertinent interest.

Injection valves and pumps.—The study of fuel injection engine fuel pumps and injection valves has been continued in the laboratory both on actual engines and on the bench. The cam-operated, spring-loaded pump constructed for the preliminary work with the single cylinder Liberty has been refined in design and another pump constructed which is more compact and stronger than the original one. A pump employing sleeves around the plunger for timing the starting and ending of injection was constructed and a more elaborate design of the same general type has been studied on the drawing board. A large number of designs using the pump suction valve as a means of timing the injection have been studied and the most promising of these designs is being constructed and will be subjected to bench and engine tests. The relative merits of both packed and lapped plungers have been studied, as a result of which this pump is to be first constructed with a packed plunger, although provision is made for the substitution of a lapped plunger construction. The pump plunger and suction valve control will be operated by an eccentric and the rod connecting the eccentric to the valve control will act against adjustable cam blocks so that the injection may be timed to occur at various portions of the plunger stroke, thus taking advantage of the velocity change of the plunger to obtain different rates of fuel discharge.

A complete study was made of the deflection of solid and orifice diaphragms with both concentrated and distributed load, using small single and multiple diaphragms of various thicknesses and of sizes suitable for use in injection valves. A number of injection valves employing different combinations and arrangements of these diaphragms have been studied and several of the more promising have been constructed and subjected to laboratory test. Excellent atomization is obtained with this type and sufficient experience has been secured to permit rational design to meet specified conditions.

Apparatus is being constructed which will enable the characteristics of a given injection system, consisting of fuel pump, injection valve and connecting tube, to be more carefully and more completely studied. The pump will be driven by an adjustable speed motor belted to the jack shaft upon which the pump is mounted. A large disk also mounted on the jack shaft and rotating with it will provide for the determination of the timing of the actual discharge in relation to the pump setting, and of the distribution of the quantity discharged over the period of injection. Consequently, the effect of changes in the setting and construction of the pumps and valves, and the effect of changes of size and length of the connecting tube, may be rationally evaluated.

Engine test work.—The study of fuel injection engine problems with the single cylinder engines has been continued throughout the year. The limitations of the Liberty engine cylinder as adapted for direct fuel injection and compression ignition have been approximately determined. At the same time information has been obtained that will guide the improvement of that performance by design modifications. Tests were made with both external and internal injection, combined with spark ignition, using a number of pistons giving various ratios of

compression and fuels consisting of different proportions of gasoline and benzol. This work enabled a direct comparison to be made with the carburetion engine as regards capacity and fuel economy, and with the compression ignition engine as regards capacity.

Using compression ignition and a compression ratio of 11, an I. M. E. P. of 119 pounds has been obtained at 1,800 r. p. m. with Diesel fuel oil containing 3 per cent of tetraethyl lead. With spark ignition, internal injection, and a compression ratio of 5.4, an I. M. E. P. of 138 pounds was obtained at 1,735 r. p. m. with a 25/75 benzol-aviation gasoline mixture, while with spark ignition, external injection, and the same compression ratio, an I. M. E. P. of 148 pounds was obtained at 1,750 r. p. m. and an I. M. E. P. of 150 pounds at 1,900 r. p. m. using a 50/50 benzol-aviation gasoline mixture.

Thus it is seen that with internal injection and spark ignition results comparable to Liberty 12 cylinder practice are obtained, but that external injection and spark ignition yield appreciably greater power. The power with compression ignition has so far been less than with any of the other arrangements. These tests, however, can not of themselves be taken as conclusive for all compression ignition work, since the form of the Liberty cylinder is very poor for such a high compression ratio and internal injection. A cylinder barrel arranged for detachable heads, together with two types of cylinder heads to fit, have been constructed for use in connection with single cylinder test work. The combustion chamber forms of these heads are more favorable for a number of types of fuel sprays.

A Liberty cylinder has been modified for the study of two cycle fuel injection electric ignition operation by cutting ports in the bottom of the cylinder and adding suitable scavenging air ducts, changing the water jacketing, and by providing special cam shafts to operate both the inlet and exhaust valves as exhaust valves. In this application a separate blower forces scavenging air through the cylinder ports and out the exhaust valves, driving the exhaust gases before it. The work to date has been with pistons giving 5.4 and 5 compression ratios and 115 pounds I. M. E. P. obtained. With the present apparatus it is expected to approximately determine the air pressure necessary to secure satisfactory scavenging and, in a general way, the limitations of two cycle application.

The universal single cylinder test engine mentioned in the report of last year was set up in the laboratory for dynamometer operation and was subjected to a series of calibration tests. Considerable delay was experienced due to the difficulty of obtaining satisfactory cylinder head castings. Several modifications in the rather complicated valve operating mechanism have been necessary, but the functions of variable compression, variable valve lift, and variable valve opening and closing have thus far been satisfactory. This engine has been operated as a carburetion engine to date, but it is planned to change to fuel injection as soon as the required pump and injection nozzle are available.

Supercharging compressor—Roots type.—The problem of the Roots type compressor for supercharging aircraft engines has been continuously studied throughout the year. Flight tests in the modified DH-4 were continued with the original supercharger until its performance to 20,000 feet was established. It has been possible to repeatedly climb to an aneroid altitude of 20,000 feet in 20 minutes. The best climb of this same airplane with plain engine was 12,000 feet in 20 minutes, or to a ceiling of 14,500 feet in 36 minutes. The standard radiator installation proved inadequate for the increased quantity of heat to be dissipated when full supercharging was applied, so that it was necessary to provide an auxiliary radiator. This undoubtedly affected the performance of the airplane adversely. Lack of suitable oxygen equipment prevented flights to higher altitudes at that time.

Following the above series of flight tests, the original supercharger was modified by changing the ratio of impeller to engine speeds from 1.5 to 1.94, thus obtaining greater supercharger capacity and consequently better engine performance at the higher altitudes. Flight tests of the modified supercharger showed that the time of climb to 20,000 feet was somewhat greater than with the original gear ratio. It has been possible, however, to maintain ground level pressure at the carburetor to slightly over 20,000 feet, as compared with 13,000 feet with the

1.5 gear ratio. Oxygen equipment was installed and flights approaching the absolute ceiling were made, attaining an aneroid altitude of approximately 30,000 feet.

At the time the gear ratio was increased impellers made of magnesium alloy were substituted for those of aluminum alloy previously used. In the laboratory tests made before the installation of the modified supercharger in the airplane this metal proved to be better than the aluminum alloy, especially as regards the manner in which it withstood contacting between the impellers. The aluminum alloy impellers tended to abrade or gall badly upon contacting, whereas the magnesium alloy surface hardened at the point of contact and thus increased its ability to withstand further contacting.

Another Roots type supercharger of the same design was constructed and installed in a DT-2 airplane with a Liberty engine at the request of the Bureau of Aeronautics of the Navy Department. This supercharger proper is of the same capacity and design as the original, although some minor design changes were made in the connections. The air-duct system connecting the supercharger and carburetors was modified somewhat in order to provide greater adaptability to temporary alterations to determine the optimum air-duct arrangement. Flights to 20,000 feet have been made, but difficulties with details and accessories have prevented any very conclusive data from being obtained to date.

Numerous design details have been made for an improved Roots type supercharger, based upon experience with the original supercharger. It is hoped to complete and test a sample of this improved design during the coming year. Further study has also been made of the general problem of supercharging aircraft engines and of the different types of compressors that may be used for this work.

Other supercharging problems.—A research to determine the adaptability of air-cooled engines to supercharging has been undertaken at the request of the Bureau of Aeronautics. Construction of special apparatus has been started and plans have been practically completed for initiating the actual test work. It is planned to use a Lawrance J-1 engine installed in a TS airplane, making a temporary installation of one of the present oversize superchargers in order to quickly obtain some information as to the limit imposed on air cooling.

The high-speed fan type compressor mentioned in the report for 1922 has had almost no attention, owing to lack of personnel and the desirability of concentrating on the type of supercharger of greatest immediate promise. The fan type has been studied to some extent, however, and a promising form of very light rotor constructed. As soon as possible it will be set up in the laboratory and dynamometer tests will be made to determine its characteristics. The rotor design employed is quite a departure from usual commercial practice and seems to have considerable promise.

Power plant laboratory equipment.—A new 100 h. p. electric dynamometer has been installed in the second unit of the power-plant laboratory and will be used primarily for fuel injection engine research. A number of changes have been made in the 75 h. p. dynamometer and an exhaust disposal system is being installed to connect that machine with the system on the 400 h. p. dynamometer in the same building.

Much time has been spent in the periodic overhaul of the two gasoline engine driven electric generating sets used for the operation of the dynamometers. This has involved a considerable expense and the frequent failure of these units has caused the loss of many tests. It is hoped to replace them with a 100 h. p. motor-generator set drawing from the service power lines.

The instrument work in connection with the power-plant research is described in the report of the committee on aerodynamics.

BUREAU OF STANDARDS.

The aeronautic power-plant work at the Bureau of Standards during 1922 and 1923 has been carried on in cooperation with the National Advisory Committee for Aeronautics, the Bureau of Aeronautics of the Navy Department, and the engineering division of the Air Service.

Aircraft-engine performance.—Reports have been submitted to the Bureau of Aeronautics covering very complete performance tests of two aircraft engines, the Packard 1551 and the

Wright H-3. These engines had been subjected to a program of altitude chamber tests of broad scope. The Bureau of Aeronautics has requested that other engines be given similar tests during the coming year.

For several years the relation between the power developed by an engine and the intake-air temperature has been under investigation. This work has been supported by the Air Service and the National Advisory Committee for Aeronautics and a report has been submitted to the latter for publication.

A report on the effect of changes in compression ratio upon engine performance is now in preparation. This subject also has been under investigation for several years.

A report entitled "The Relation of Fuel-Air Ratio to Engine Performance" has been prepared for publication by the National Advisory Committee for Aeronautics. This report is based on an analysis of a very large number of engine tests and contains information of material value to engine designers and users.

Ignition.—The relation between character of the ignition spark and flame velocity has been investigated for several explosive gas mixtures, including those of gasoline vapor and air. Velocities have been measured by firing a quantity of gas inclosed in a soap bubble or in a thin-walled glass bulb and recording the flame spread photographically. For this work the development of much special apparatus has been necessary. This, together with the results obtained, is described in a report entitled "Effect of Spark Characteristics of Flame Velocity," which has been prepared for publication by the National Advisory Committee for Aeronautics.

Spark gaps are used extensively in testing ignition apparatus, and at the request of the Air Service the behavior of various spark gaps has been investigated with a view to standardizing the type which should prove to be most suitable for such testing work. The difficulty of obtaining regular sparking voltage was found to be greater than had been anticipated and although much valuable information on the characteristics of spark gaps has been obtained an entirely satisfactory form of gap has not been developed.

A comparative study of 10 radically different types of magnetos and spark coils has been pursued, with the object of obtaining more definite knowledge of the electrical phenomena involved in the functioning of an ignition system and their relation to design. Tests are being made to investigate various empirical and theoretical relations between the voltage developed and the conditions of speed, current, etc., under which the system operates. Such knowledge should permit drafting suitable specifications and methods of test for ignition systems and should assist manufacturers in improving their product.

Carburetion.—Under authorization from the Bureau of Aeronautics of the Navy Department a rather complete investigation has been made of the characteristics of two types of carburetors as mounted on a Lawrance engine. For this investigation the engine was installed in the altitude chamber and fuel-air measurements made under conditions typical of those encountered in service. A report of this work is being prepared for the Bureau of Aeronautics.

In conjunction with the altitude chamber tests of the Packard 1551 and the Wright H-3 engines, special tests of five carburetors were made. The performance of these carburetors is discussed in the reports of these engine tests which have been submitted to the Bureau of Aeronautics.

A report of an investigation of several carburetors with regard to the relation between their metering characteristics under steady and pulsating air flow has been submitted to the engineering division of the Air Service.

The investigation of the factors controlling the formation of liquid drops from jets issuing from orifices of various types and the transportation of such drops in air streams has been continued.

Fuels.—Special fuels for aircraft engines, chiefly benzol-gasoline and alcohol-gasoline blends have been investigated under authorization from the Bureau of Aeronautics of the Navy Department in parallel with a general investigation of fuels for high-compression engines authorized by the National Advisory Committee for Aeronautics. As a part of this investigation an engine having a compression ratio of 14 to 1 has been operated satisfactorily. This

ratio is believed to be higher than any previously employed in an internal-combustion engine operating on the Otto cycle. Some of the outstanding results of these tests were presented at the January, 1923, meeting of the Society of Automotive Engineers.

Physical and chemical characteristics of fuels have been studied with special reference to the separation temperatures of blended fuels and the relative tendencies of the various fuels to cause corrosion.

Progress reports covering the above work have been submitted to the Bureau of Aeronautics, and a report summarizing the work done to date is in preparation for publication by the National Advisory Committee for Aeronautics.

A method has been developed for measuring the minimum temperature at which the fuel in a mixture of fuel and air will remain in the vapor state. This method has been applied to a number of gasolines and a report of the results of this work is in preparation.

Internal-combustion engine lubrication.—The major portion of the lubrication work specifically relating to internal-combustion engine problems has been requested and supported by the engineering division of the Air Service.

One of the problems most actively investigated has been that of developing a method for the determination of the relative resistance of oils to partial oxidation similar to that proposed by Waters but more suitable for routine tests. Many methods have been investigated and it is confidently expected that a satisfactory method will be developed during the ensuing year.

Engine tests have been carried on throughout the year with the twofold purpose of (1) ascertaining the conditions of engine operation which are of primary importance in controlling the formation of solids in the combustion chambers and crank cases of engines, and (2) selecting the program of tests most suitable for a comparative study of oils with reference to their tendencies to form solids in combustion chambers and crank cases of engines. Qualitative information as to the effect of the temperature of a metal surface upon the rate at which "carbon" is formed upon it has been obtained and made available to automotive engineers through the trade press.

The operation of the specially designed apparatus for the investigation of journal bearing lubrication has been materially improved and satisfactory readings considerably below the region of the minimum coefficient of friction have been obtained.

Apparatus has been designed and constructed both for measuring the plasticity of oils at low temperatures and for investigating the significance of the pour test in estimating the relative ease with which oils will be drawn into aircraft engine oil pumps under winter conditions.

Cooling problems.—For the past three years, an investigation under the title "Ballast Recovery for Airships" has been in progress. At the request of the Air Service this work has been considered confidential up to the present time and hence has not been mentioned in previous reports. The original request of the Army Air Service was for an investigation of the possibilities of compensating for the loss in load, due to the fuel consumed, by the condensation of the water vapor in the engine exhaust. A study of the problem indicated it to be feasible and subsequently two water condensing units, each for a 300-horsepower engine, were designed and constructed. To date, one of these units has been given a 50-hour ground test and the other a 100-hour test and a flight test of 25 hours. The performance of both units has been so satisfactory as to demonstrate beyond any doubt that ample ballast for the purpose desired can be recovered with an apparatus of practicable weight. A complete report entitled "History, Design, and Theory Relating to Ballast Recovery Project" has been submitted to the engineering division of the Air Service.

An investigation of the air flow through radiators mounted in other than free air streams has been conducted under authorization from the National Advisory Committee for Aeronautics. The air flow measurements have been made in flight, the flight work being made possible by the cooperation of the flying personnel of the Bureau of Aeronautics of the Navy Department. Information derived from this investigation should greatly increase the value of the published results of the bureau's comprehensive laboratory tests of the characteristics of aircraft radia-

tors by making possible their application to problems involving radiators mounted in other than free air streams.

At the request of the National Advisory Committee for Aeronautics the work on aircraft radiator characteristics is being extended to higher air speeds. With the wind tunnel equipment now available at the bureau it will be possible to obtain measurements at an air speed of 150 miles per hour. It is believed possible to complete this investigation during the coming year.

A critical study of the behavior of Pitot tubes as used to measure air flow through the cells of aircraft radiators has also been undertaken at the request of the National Advisory Committee for Aeronautics. The problem has been investigated from both theoretical and experimental standpoints with concordant results and a report of the work is being prepared.

Phenomena of combustion.—This work, which has for its chief aim an investigation of the kinetics of explosive gaseous reactions, has been supported as in previous years by the National Advisory Committee for Aeronautics. A description of the device and method developed for this investigation has been submitted to that committee for publication. This device makes it possible to determine not only the rate of flame movement in space, but also the rate of flame penetration relative to the reacting gases. Since the device permits the reaction to run its course at constant pressure, and since the mixture ratio of the gases may be expressed in terms of concentration (partial pressure), it becomes possible to express the relation between the rate of flame penetration (reaction rate) and concentration. In this way the interesting relation has been revealed that the rate of flame movement relative to the mixture is proportional to the product of the concentrations of the reacting components.

The effect of inert gases on the reaction rate is also indicated by the above relation and has been satisfactorily checked by many measurements. The method also permits the determination, from the observed velocities, of the number of molecules taking part in the reaction in much the same way that this important fact is revealed in ordinary flameless reactions. This indication should prove useful in dealing with fuels of indefinite composition.

The effect of pressure upon concentration and hence upon reaction rate should be a function of the molecular number of the reaction. This important relation has never been qualitatively investigated over the range of conditions met with in engine practice. Provision has been made and apparatus devised for a thorough study of the effect of this factor on flame velocity.

NEW ENGINE TYPES.

The new types of engines under development by both the Bureau of Aeronautics of the Navy Department and the engineering division of the Army Air Service, and described in the eighth annual report, have been completed during the past year, and many of the engines have undergone preliminary tests.

One of the outstanding results of the past year's work was the decision of the Bureau of Aeronautics, Navy, to abandon definitely the use, in future naval aircraft construction, of water-cooled engines of less than 300 H. P. The development of direct air-cooled engines, and particularly of the Lawrance model J-1, 200 H. P. engine, has progressed rapidly during the past year, and engines of this type are taking their place in service.

Development of the direct air-cooled engine to a point where in dependability and in all-round serviceability it compares favorably with the more commonly used water-cooled types, is an accomplishment of the greatest importance to aircraft operations, because it permits the complete elimination of the weight and complication entailed in the water, radiator piping, fittings, and accessories required in the cooling system of the water-cooled engine. The weight of the cooling system of the water-cooled engine is usually in excess of 25 per cent of the weight of the engine itself.

An air-cooled engine development for the Navy is being carried on by the Kinney Manufacturing Co., who are producing a 60 H. P. five-cylinder radial engine. Single-cylinder tests of this engine have been completed, and the first engine is being assembled and will be tested before the end of the present year.

A large number of Wright (Lawrance) J-1, 200 H. P. air-cooled engines have been in flight service and have definitely proved their serviceability. A number of defects have been uncovered and a new model known as the Wright J-3 is being produced. This engine has incorporated in it the modifications found necessary as a result of the block and flight testing. The first of these engines is expected prior to the end of the present year.

A nine-cylinder 6 by 6½ radial engine known as the model P-1 is being developed for the Bureau of Aeronautics of the Navy by the Wright Aeronautical Corporation. This engine is rated at 400 h. p. and 1,650 r. p. m. A large number of single-cylinder tests have been conducted, and it is hoped that the first experimentally complete engine will be available for test during the early part of 1924.

The Engineering Division of the Army Air Service has developed two very successful air-cooled cylinders, the first of which is known as type K. The design was primarily intended for engines of 200 h. p., and can be adapted to a Lawrence J-1 engine. A similar cylinder design, known as type J cylinder, has been developed for engines developing 400 h. p., and can be adapted to the Wright radial nine-cylinder air-cooled engine.

The Army Air Service has been concerned chiefly with the final development of the W 700 h. p. engine, and the continuation of the development of the Almen barrel-type engine in collaboration with Almen Motors (Inc.). The new model of the Almen engine has been received, is now being tested, and shows great promise. The weight per horsepower compares favorably with the best type of water-cooled engine now in service.

The supercharger development at McCook Field has brought out the side-type turbine supercharger, which has made possible a much cleaner installation, reducing the head resistance and eliminating the heating difficulties. The development of the turbine-type supercharger with a gear drive is also under way.

Last year the Bureau of Aeronautics adopted test specifications requiring 300 hours' full-throttle operation as a goal to be obtained in engine durability. The Aeromarine U 8 D, the Wright model E-4, the Packard model 1551, the Curtiss model D-12, and the Lawrence model J-1 engines were subjected to these tests, and as a result many inherent weaknesses were discovered and steps taken to remedy them.

The special cylinder blocks and valve gear designed for the Liberty engine have been tested and the parts released for production. The Aeromarine Plane & Motor Co. will complete a number of these cylinder blocks during the current year. The use of these cylinder blocks has increased the power and economy of the Liberty engine materially above that of the original machine.

The Packard model 1300, 12-cylinder, 375 h. p. engine, has successfully completed the 50-hour acceptance test. Several engines of this type are being produced and will be placed in flight service. The characteristics of this engine are extreme compactness and low weight per horsepower.

The Curtiss model D-12, 375 h. p. engine has been equipped with oversized cylinders and high compression ratio pistons and operated at high rotative speed. Under these conditions the engine has developed 500 h. p. at 2,300 r. p. m. When the excessive power output of this engine is considered, the durability obtained is to be commended. Several engines of this type have been purchased and have completed a number of hours' running, both on the test stand and in the air.

The Bureau of Aeronautics has placed approximately 40 Wright model T-2 engines in service. This engine has shown exceptional durability and is very satisfactory, one installation in a DT airplane operating for a period of approximately 250 hours. Tests are under way with T-2 engines varying the compression ratio from 5.5 to 7.1. At a compression ratio of 7.1 the engine has developed 780 h. p. at 2,250 r. p. m. A design of a Wright model T-2 engine has been completed providing for the use of reduction gears. The reduction gears have been completed and have successfully passed preliminary tests and are awaiting installation in the engine.

The Aeromarine Plane & Motor Co. is developing for the Bureau of Aeronautics a 12-cylinder engine of unique design. The design is such as to permit of a very short engine base and crank

shaft. Single-cylinder tests have been completed and the engine is being assembled. It is expected that the first engine will be ready for test within two or three months. The engine is rated at 620 h. p. at 1,650 r. p. m., and will weigh about 1.7 pounds per horsepower. The over all dimensions are approximately the same as the dimensions of the Wright model H-3.

REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT.

Prof. Charles F. Marvin served as chairman of the committee during the period covered by this report. He was succeeded by Dr. George K. Burgess on October 18, 1923.

Following is a statement of the organization and functions of the committee on materials for aircraft:

ORGANIZATION.

Dr. G. K. Burgess, Bureau of Standards, chairman.
Mr. S. K. Colby, American Magnesium Corporation.
Mr. Henry A. Gardner, Institute of Industrial Research.
Prof. George B. Haven, Massachusetts Institute of Technology.
Commander J. C. Hunsaker, United States Navy.
Mr. Zay Jeffries, Aluminum Company of America.
Mr. J. B. Johnson, engineering division, Air Service.
Prof. E. P. Warner, Massachusetts Institute of Technology.
Dr. Carlile P. Winslow, Forest Service.
Prof. H. L. Whittemore, Bureau of Standards, acting chairman.

FUNCTIONS.

1. To aid in determining the problems relating to materials for aircraft to be experimentally attacked by governmental and private agencies.
2. To endeavor to coordinate, by counsel and suggestion, the research and experimental work involved in the investigation of such problems.
3. To act as a medium for the interchange of information regarding investigations of materials for aircraft, in progress or proposed.
4. The committee may direct and conduct research and experiment on materials for aircraft in such laboratory or laboratories, either in whole or in part, as may be placed under its direction.
5. The committee shall meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

The committee on materials for aircraft, through its personnel acting as a medium for the interchange of information regarding investigations on materials for aircraft, is enabled to keep in close touch with research in this field of aircraft development.

Much of the research, especially in the development of light alloys, must necessarily be conducted by the industries interested in the particular development and both the Aluminum Co. of America and the American Magnesium Corporation are represented on the committee. In order to cover effectively the large and varied field of research on materials for aircraft three subcommittees were formed, as follows:

- Subcommittee on metals (Dr. G. K. Burgess, chairman).
- Subcommittee on woods and glues (Prof. H. L. Whittemore, chairman).
- Subcommittee on coverings, dopes, and protective coatings (Mr. Henry A. Gardner, chairman).

Most of the research in connection with the development of materials for aircraft is financed directly by the Bureau of Aeronautics of the Navy Department and the engineering division of the Army Air Service.

The Bureau of Aeronautics and the engineering division of the Army Air Service in connection with the operation of tests in their own laboratories apportion and finance research problems on materials for aircraft to the Bureau of Standards, the Institute of Industrial Research, and the Forest Products Laboratory.

SUBCOMMITTEE ON METALS.

LIGHT ALLOYS—DURALUMIN.

Flexural fatigue tests.—The flexural fatigue machines for the testing of sheet duralumin described in the report for 1922 have been in continuous and satisfactory operation through the past year at the Bureau of Standards, for the Bureau of Aeronautics of the Navy Department. Ninety-one specimens of seven different thicknesses (0.02 to 0.120 inch) and from two manufacturers have been tested. The number of specimens tested is smaller than was anticipated because it was found necessary to run tests up to two hundred million alternations of stress instead of from ten to twenty million, which had been found sufficient for steels. The fatigue machines have been very free from disturbances. One machine has just been stopped after a 389-day nonstop run of two hundred million alternations. The check calibration of the machine on November 2, 1923, gave the same result as the original calibration on October 5, 1922.

Sufficient information has been obtained to give a good idea of the fatigue characteristics of this material up to one hundred million alternations of stress. Within that range no indication of an endurance limit has been found. This is consistent with published results secured with machined materials on rotating-beam machines at McCook Field and elsewhere.

Impact fatigue tests.—The impact fatigue machines were, after several preliminary machines had been designed and built, found to work satisfactorily. The specimen subject to tensile stresses was bent at an angle of about 90° and clamped to the anvil. The tup struck the middle of the specimen where it was bent. The portion of the specimen between the middle and the ends was reduced to a width of one-half inch, the thickness being in all cases that of the original sheet as for the flexural fatigue tests.

As in the preliminary trials, it was found that the specimens broke where they were struck by the tup, although the width there was one inch, and a metal protector was bolted to the middle of the specimen. When these protectors were used, failure occurred in the reduced portion for over 90 per cent of the specimens.

The cast-iron anvil is supported on a block of concrete. It is usual in machines of this kind to support the anvil on springs, and unless this is done comparable results will not be obtained on machines built from the same drawings but supported on foundations offering different resistances. It was found, however, experimentally, that the three machines used for this work and placed side by side on the same floor did give comparable results. Tests of thin sheet steel such as is used in aircraft work will be made to compare with the results on duralumin.

Theoretically, the stress in the reduced portion of the specimen is given by the formula.

$$S = \sqrt{2 \frac{E W H}{l a}}$$

in which

E = modulus of elasticity—pounds per square inch.

W = weight of tup — pounds.

H = height of fall — inches.

l = length of specimen between clamps — inches.

a = area of reduced portion — square inch.

In this formula, it is of course assumed that the specimen is one-half inch wide for its whole length, which is not the case. Some of the energy is dissipated in the floor and in other ways.

Experiments showed that about 25 per cent of the energy is lost if the specimens are thin (0.020 inch), and about 50 per cent if they are thick (0.120 inch).

Allowing for this loss and computing the stress in the specimens shows that a large number of blows are required to cause failure if the stress is about 15,000 pounds per square inch.

Graphs plotted from test results show that the number of blows is increased as the energy of the tup, and therefore the stress in the specimen, is decreased. The curves through these values show that a single blow causing a stress of about 42,500 pounds per square inch would

rupture the specimen. This agrees with the results of tensile tests, as practically this same value was found for the yield point of the material.

The resistance to impact fatigue seems to be higher for specimens cut in the direction of rolling than for those cut perpendicular to that direction.

On some of the specimens tested in these impact machines, over one million blows were struck.

Other physical properties.—To determine the other physical properties of the sheet duralumin, the tensile strength longitudinally and across the rolling direction, the Ericksen value, and the hardness (Brinell, Rockwell, and scleroscope) were measured. An apparatus was built to wrap the specimen, under a constant tension, first around one cylinder, then in the opposite direction around another cylinder.

The results of these tests were consistent and showed differences in the specimens that were more marked than those found by other tests.

A tensile impact test was also used which measured properties of the material that could not be found in any other way. It is evident that the usual notched bar impact test can not be made on this thin sheet material. This impact test showed that the energy absorbed was proportional to the thickness, and the same for longitudinal and crosswise specimens.

Tests on structural parts for rigid airships.—The tests described in the report for 1922, on the girders of the recently completed airship, U. S. S. *Shenandoah* (ZR-1), have led to a comprehensive series of tests on the duralumin channels and angles from which the girders are manufactured. The tests will comprise compression tests on various shapes, thickness, and lengths, with controlled failure simulating the conditions occurring in the girders. These will be correlated, through tests on short sections of the girders, with the results already obtained on the full-sized girders. It is expected that these tests will make it possible to design for future airships lighter girders of equal or greater strength.

Tests of steel tubing as columns and beams.—A special investigation to determine the strength of steel tubing struts when subjected to combined transverse and column loading was made for the Bureau of Aeronautics, Navy Department. The purpose of the investigation was to determine whether experimental data confirmed the approximate theory of struts subjected to these stresses.

The physical properties of every section of tubing used was determined and a large number of tests were made on struts of different lengths with different intensities of transverse loading, varying from that of a column with no transverse loading to that of a beam with no column load.

A study of the conditions contributing to the strength of steel tubing struts show that eccentricities resulting from—

1. variations in wall thickness,
2. deviation from straightness,

are very important factors in determining the strength. These eccentricities were accurately determined in this investigation by special measurements.

The results of the investigation showed that experimental data does not corroborate the theory that a strut subjected to transverse loadings will fail when the stress $\frac{M_o}{I} \times \frac{P}{A}$ approximates $\frac{C}{C}$

the yield point where M_o is determined by either of the commonly used formulas

$$-M_o = \frac{WEI}{P} \left(\sec \frac{\pi}{2} \sqrt{\frac{P}{P_e}} - 1 \right) \text{ or } -M_o = \frac{1}{8} w l^2 \left(\frac{P_e}{P_e - P} \right)$$

(See Morley, Theory of Structures, p. 309.) These formulas do not represent actual strut conditions, the results indicating that their use for short struts or struts with small side loads may give dangerously high results.

A modified rational formula based upon the consideration of the effect of eccentricity—

$$-M_o = P_e \sec \frac{\pi}{2} \sqrt{\frac{P}{P_e}} + \frac{WEI}{P} \left(\sec \frac{\pi}{2} \sqrt{\frac{P}{P_e}} - 1 \right)$$

where "e" is the eccentricity, was found to give remarkable accurate results. The experimental data checks very closely with computations by the modified formula and shows that it should be used when accuracy and safety are essential.

The above modified rational formula reduces to the secant column formula

$$f_c = \frac{P}{A} \left(1 + \frac{ec}{r^2} \sec \frac{\pi}{2} \sqrt{\frac{P}{P_e}} \right)$$

for struts with no side load, i. e., pure columns. The results of the column tests for which the eccentricities were accurately determined indicate that the column will fail when the extreme fiber stress, as determined by the secant column formula is equal to the yield point of the material. An empirical formula based on this formula in which the eccentricity "e" is taken as an average of the eccentricities in commercial tubing can probably be developed and used with reasonable accuracy and safety for determining the strength of columns.

SUBCOMMITTEE ON COVERING DOPES AND PROTECTIVE COATINGS.

During the past year rather extensive investigations have been carried on for the Navy Department in the development of fabrics, dopes, and protective coatings, at the laboratory of Mr. Henry A. Gardner. These investigations include the continuation of the work of past years on suitable fabrics for gas cells of rigid airships, very satisfactory results having been obtained during the past summer on exposure tests of experimental fabrics of low weight. These have remained very flexible and of almost constant low diffusion. Investigations have also been conducted on the development of fuels of the absolute alcohol-gasoline type. These studies also included an investigation of the effect of various fuels upon corrosion. A great many tests have also been made upon the relative air and water corrosion of aluminum alloys, and methods of preventing such corrosion, together with the development of protective coatings for aluminum sheets and aluminum alloy parts. Studies have also been included on the determination of the most suitable types of antifouling paints for bottoms of floats of aircraft that may remain moored for some considerable period of time in barnacle-infested waters.

At the Bureau of Standards extensive investigations have also been made during the past year in the development of experimental gas cell fabrics for rigid airships, most promising initial results having been obtained with certain new types that have recently been exposed. The Bureau of Standards is also at the present time making extensive investigation of the effects of different ways of preparing the rubber and of the addition of various materials to rubber that is used in the manufacture of airship fabrics, to determine the effect upon the lowering of permeability, etc. The bureau is also cooperating in the various work being done in the production of various coatings. It has been examining various types of fabrics submitted by the Navy Department for permeability and strength tests. It has also been active in the examination of dopes.

A multicross system of dead-weight loading was employed by the textile section of the Bureau of Standards to test the load-deformation characteristics of the doped outer cover cloth specified for use on the *ZR-1*. These tests required several thousand observations and were conducted under standard humidity conditions. The purpose was to supply data to be used in calculations on the contribution of the outer cover cloth to the structural strength of the airship. The data showed further that this type of doped fabric under load changes continuously in physical characteristics with time; however, two weeks' loading is generally sufficient to obtain a fairly constant modulus. A preliminary report on general characteristics and a final report covering changes occurring during one week were made. The tests were continued for five weeks.

SUBCOMMITTEE ON WOODS AND GLUES.

The Forest Products Laboratory of the Department of Agriculture conducts practically all investigations on the application of woods and glues to aircraft construction. Most of the investigations are undertaken at the request of the Bureau of Aeronautics, Navy, or the engineering division of the Army Air Service. The following are some of the more important investigations.

Causes of brashness of wood.—The Forest Products Laboratory have tested over 500 specimens in the toughness machine of ash, spruce, oak, and black walnut, some of which were normal and some of which were brash, i. e., broke at low loads with little deformation. The data on the oak and walnut have not been fully analyzed.

The information so far obtained shows that brashness, at least in the ash and spruce tested, does not depend on the obvious structural characteristics of the wood, such as width of annual rings, proportion of summer wood, thickness of fiber walls, number of medullary rays, etc., but is apparently due to something more obscure, such as the physical or chemical structure of the cell walls.

Development of waterproof glues.—The investigation of waterproof glues has been continued during the year by the Forest Products Laboratory. Knowledge on this subject has been considerably increased by a study of some natural and artificial gums and resins which may be suitable for use as adhesives. A blood albumin glue has been developed which can be used without hot pressing and this on a laboratory scale has proved practically waterproof. Before recommending it for general use, it will be necessary to find the best method of using it for heavy stock. The cost of the glue is, at present, higher than commercial glues but it is probable that further investigation will develop a composition which will replace other glues.

Use of plywood in wing beams.—The investigations of the Forest Products Laboratory, during the past year, on the shearing strength of plywood, shows the desirability of using the plywood with the face grain at an angle of about 45° with the length of the beam to obtain the greatest strength in the structure.

A series of tests was made on beams, approximating the upper front BS-1 wing beam section, to determine the best way to use plywood in beams of this size. These tests together with observations on numerous other types of beams, led to the conclusion that in the design of either plywood box or I beams a web thickness 25 per cent greater than that calculated to give equal likelihood of failure by shear or compression, will give the best results. The results further demonstrated that in three-ply webs with the grain at 45° to the length of the beam the two face plies should be of equal thickness and their combined thickness should equal that of the core in order to prevent side buckling of the beam under load. This affords symmetry of construction and avoids the unequal distribution of stresses and greater tendency to lateral buckling which accompanies a lack of balance between core and faces. Reports have been issued on both series of tests.

Influence of stains, molds, and decay on properties of wood.—This study should furnish data on the effect of stains, molds, and decay on the principal woods used in the airplane industry. Means for diagnosing early stages of decay should be worked out. Methods for preventing or controlling decay in airplane timber should be formulated.

Previous to June 30, 1922, this project has been almost entirely supported by the Bureau of Plant Industry. Approximately 1,200 tests had been run of Sitka spruce and 800 tests on Douglas fir. These tests included static bending, impact bending, compression parallel, shear and hardness tests on both green and dry sticks. The project is now being carried largely by the Army and Navy Air Services with certain assistance from the Bureau of Plant Industry. Some 1,400 toughness tests have been run on green Douglas fir infected with fungi which are common to both Douglas fir and Sitka spruce. In the course of this year 8,500 cultures have been run to determine which of the tested sticks were sound and which were infected. Correlation of the results of the mechanical tests has been started for the Douglas fir. The results so far show a marked difference in the effect produced by the different fungi. The conditions under which the yellowing of oak airplane lumber occurs have been studied in a set of experiments in which the boards were yellowed by artificial inoculation.

Form factors for wing beams.—The Forest Products Laboratory have completed the fundamental study of form factors and stresses in bending which has resulted in the development of formulas for accurately computing the form factors of various sections.

The fundamental work undertaken on the influence of form on the strength and stiffness of wooden beams has been completed during the present year. A report covering Part I of

this study, entitled "Deflection of Beams with Special Reference to Shear Deformations," and Part II, "Form Factors of Beams Subjected to Transverse Loading Only," has been prepared. The work has also been completed on Part III of this study entitled "Stresses in Wood Members Subjected to Combined Column and Beam Action." In the light of the data covered in Part II, definite conclusions have been arrived at regarding the maximum stress in members subjected to combined column and beam action for various ratios of compressive to total stress. The tests which have been made are conclusive regarding the variation of stress at maximum load for various ratios of compressive to total stress, and these data are now being correlated with the theoretical considerations involved. The above mentioned report in three parts, will be published as Technical Reports of the National Advisory Committee for Aeronautics.

Toughness tests of airplane woods.—In connection with the inspection of wood for airplanes, particularly those species used for propeller construction, a need has been felt for a simple test which could be applied to each piece of wood to determine its acceptability. To meet this need a machine, utilizing the pendulum principle but applying the load by means of a strap operating over a drum, was developed for testing relatively small specimens with a single swing of the pendulum. This test gives a good indication of the toughness of a specimen, and the character of the failure is of further value in estimating the quality of the wood. It would appear that this test is more practicable than the specific gravity limitation now adopted as standard acceptance for aircraft wood, and at the same time affords a more reliable criterion of the strength.

Torsion in box and other beam sections.—This investigation was undertaken by the Forest Products Laboratory at the request of the Bureau of Aeronautics, Navy, as very little data were available on the torsional strength of beams of various cross sections and no torsional formulas which could be used in designing members of other than solid circular sections with any degree of accuracy. These tests that have been made fully support the conclusions drawn from a consideration of the principles of mechanics to the effect that the most efficient torsion member is a tube of circular section whose walls consist of several thicknesses of thin veneer wound in alternating spirals. However, there are two principal objections to the use of such sections, viz: (1) the difficulty of building them, and (2) the difficulty of attaching other members to them. While these difficulties are not insurmountable, it is considered preferable from the standpoint of convenience, rapidity, and cost of production, to use torsion members of box section of rectangular or at least quadrilateral outline.

During the present and preceding fiscal years a number of tests have been made in an attempt to determine how to proportion the various parts of box beams for maximum efficiency and to derive rules or formulas for the construction of beams to meet a given strength requirement. These tests have indicated that sections now used are probably not the most efficient and that the formulas and factors used in design are of uncertain applicability. A report of this work will be written during the present fiscal year.

Effect of isolated factors on seasoning.—This investigation has been continued by the Forest Products Laboratory and during the present fiscal year the experimental work on birch was completed and the final report on ash prepared. Work was also started on another species. A fundamental equation has been developed showing the relation between the moisture content and drying rate. This is an important basic formula and its development will aid very materially in the perfection of drying methods and schedules for aircraft.

TECHNICAL PUBLICATIONS OF THE COMMITTEE.

On recommendation of the committee on publications and intelligence, the National Advisory Committee for Aeronautics has authorized the publication of 27 technical reports during the past year. The reports cover a wide range of subjects on which research has been conducted under the cognizance of the various subcommittees, each report having been approved by the subcommittee concerned and recommended to the executive committee for publication. The technical reports presented represent fundamental research in aeronautics carried on at different aeronautical laboratories in this country including the Langley Memorial Aeronautical

Laboratory, the aeronautical laboratory at the Washington Navy Yard, the Bureau of Standards, the Forest Products Laboratory, the Stanford University, and the Massachusetts Institute of Technology.

To make immediately available technical information on experimental and research problems, the National Advisory Committee for Aeronautics has authorized the issuance in mimeographed form of another series known as "Technical Notes," of which 45 have been issued during the past year. A list of the technical notes issued during the fiscal year follows the summary of technical reports.

The office of aeronautical intelligence, in addition to issuing technical reports and technical notes, has issued translations and reproductions of important technical articles of a miscellaneous character. These have been issued in mimeographed form, and the number of requests for and the importance of these papers resulted in an action of the executive committee authorizing the committee on publications and intelligence to issue translations and technical articles to be known as "Technical Memorandums" of the National Advisory Committee for Aeronautics. In accordance with this authorization, the committee has issued 91 technical memorandums on subjects that were of immediate interest not only to research laboratories but also to airplane manufacturers. A list of technical memorandums issued during the year follows the list of technical notes.

Summaries of the 27 technical reports issued during the past year, and lists of the technical notes and technical memorandums issued during the past year follow.

SUMMARY OF TECHNICAL REPORTS.

The first annual report of the National Advisory Committee for Aeronautics 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; and since the preparation of the eighth annual report the committee has issued the following technical reports, Nos. 159 to 185:

Report No. 159, entitled "Jet Propulsion for Airplanes," by Edgar Buckingham, Bureau of Standards.—This report is a description of a method of propelling airplanes by the reaction of jet propulsion.

Air is compressed and mixed with fuel in a combustion chamber, where the mixture burns at constant pressure. The combustion products issue through a nozzle, and the reaction of the jet constitutes the thrust.

Data are available for an approximate comparison of the performance of such a device with that of the motor-driven air screw. The computations are outlined and the results given by tables and curves.

The relative fuel consumption and weight of machinery for the jet, decrease as the flying speed increases; but at 250 miles per hour the jet would still take about four times as much fuel per thrust horsepower-hour as the air screw, and the power plant would be heavier and much more complicated.

Propulsion by the reaction of a simple jet can not compete, in any respect, with air screw propulsion at such flying speeds as are now in prospect.

Report No. 160, entitled "An Airship Slide Rule," by E. R. Weaver and S. F. Pickering, Bureau of Standards.—This report describes an airship slide rule developed by the gas-chemistry section of the Bureau of Standards at the request of the Bureau of Engineering of the Navy Department. The development of this slide rule was requested by the Navy because of the successful results which had been reported by the Scott-Tweed rule which had been developed and used by the British naval air service. It is intended primarily to give rapid solutions of a few problems of frequent occurrence in airship navigation, but it can be used to advantage in solving a great variety of problems, involving volumes, lifting powers, temperatures, pressures, altitudes, and the purity of the balloon gas.

The rule is graduated to read directly in the units actually used in making observations, constants and conversion factors being taken care of by the length and locations of the scales. In order to simplify as much as possible the manipulation of the rule, absolute accuracy has in some cases been sacrificed to convenience. Generally this has been necessary only in those cases in which the data upon which the computations will be based are not subject to accurate observation.

It is thought that with this rule practically any problem likely to arise in this class of work can be readily solved after the user has become familiar with the operation of the rule, and that the solution will, in most cases, be as accurate as the data warrant.

Report No. 161, entitled "The Distribution of Lift over Wing Tips and Ailerons," by David L. Bacon, Langley Memorial Aeronautical Laboratory.—This investigation was carried out in the 5-foot wind tunnel of the Langley Memorial Aeronautical Laboratory for the purpose of obtaining more complete information than was heretofore available on the distribution of lift between the ends of wing spars, the stresses in ailerons and the general subject of airflow near the tip of a wing.

It includes one series of tests on four models without ailerons, having square, elliptical, and raked tips respectively, and a second series, positively and negatively raked wings, with ailerons adjusted to different settings.

The results show that negatively raked tips give a more uniform distribution of air pressure than any of the other three arrangements, because the tip vortex does not disturb the flow at the trailing edge. Aileron loads are found to be decidedly less severe on wings with negative rake than on those with positive rake. The data are presented in such form as to permit direct application to the calculation of aileron and wing stresses and also to facilitate the proper distribution of load in sand testing. Contour charts show in great detail the complex distribution of lift over the wing.

Report No. 162, entitled "Complete Study of the Longitudinal Oscillation of a VE-7 Airplane," by F. H. Norton and W. G. Brown, Langley Memorial Aeronautical Laboratory.—This investigation was carried out in order to study as closely as possible the behavior of an airplane when it was making a longitudinal oscillation. The air speed, the altitude, the angle with the horizontal and the angle of attack were all recorded simultaneously and the resulting curves plotted to the same time scale. The results show that all the curves are very close to damped sine curves, with the curves for height and angle of attack in phase, that for angle with the horizon leading them by 18 per cent and that for path angle leading them by 25 per cent.

Report No. 163, entitled "The Vertical, Longitudinal, and Lateral Accelerations Experienced by an S. E. 5A Airplane While Maneuvering," by F. H. Norton and T. Carroll, Langley Memorial Aeronautical Laboratory.—This investigation was undertaken for the purpose of measuring the accelerations along the three principal axes of an airplane while it was maneuvering. The airplane selected for this purpose was the fairly maneuverable S. E. 5A and the instruments used were the N. A. C. A. three component accelerometer and the N. A. C. A. recording air speed meter. The results showed that the normal accelerations did not exceed 4.00 g., while the lateral and longitudinal accelerations did not exceed 0.60 g.

Report No. 164, entitled "The Inertia Coefficients of an Airship in a Frictionless Fluid," by H. Bateman, California Institute of Technology.—This report deals with the investigation of the apparent inertia of an airship hull. The exact solution of the aerodynamical problem has been studied for hulls of various shapes and special attention has been given to the case of an ellipsoidal hull. In order that the results for this last case may be readily adapted to other cases, they are expressed in terms of the area and perimeter of the largest cross section perpendicular to the direction of motion by means of a formula involving a coefficient K which varies only slowly when the shape of the hull is changed, being 0.637 for a circular or elliptic disk, 0.5 for a sphere, and about 0.25 for a spheroid of fineness ratio 7. For rough purposes it is sufficient to employ the coefficients, originally found for ellipsoids, for hulls otherwise shaped. When more exact values of the inertia are needed, estimates may be based on a study of the way in which K varies with different characteristics and for such a study the new coefficient possesses some advantages over one which is defined with reference to the volume of fluid displaced.

The case of rotation of an airship hull has been investigated also and a coefficient has been defined with the same advantages as the corresponding coefficient for rectilinear motion.

Report No. 165, entitled "Diaphragms for Aeronautic Instruments," by Mayo D. Hersey, Bureau of Standards.—This investigation was carried out at the request of the National Advisory Committee for Aeronautics and comprises an outline of historical developments and theoretical principles, together with a discussion of expedients for making the most effective use of existing diaphragms, and a summary of experimental research problems.

Flexible diaphragms actuated by hydrostatic pressure form an essential element of a great variety of instruments for aeronautic and other technical purposes. The various physical data needed as a foundation for rational methods of diaphragm design have not, however, been available hitherto except in the most fragmentary form.

Report No. 166, entitled "The Aerodynamic Plane Table," by A. F. Zahm, Bureau of Construction and Repair, Navy Department.—This report gives a description and the use of a specially designed aerodynamic plane table. For the accurate and expeditious geometrical measurement of models in an aerodynamic laboratory, and for miscellaneous truing operations, there is frequent need for a specially equipped plane table. For example, one may have to measure truly to 0.001 inch the offsets of an airfoil at many parts of its surface. Or the offsets of a strut, airship hull, or other carefully formed figure may require exact calipering. Again, a complete airplane model may have to be adjusted for correct incidence at all parts of its surfaces or verified in those parts for conformance to specifications. Such work, if but occasional, may be done on a planing or milling machine; but if frequent, justifies the provision of a special table. For this reason it was found desirable in 1918 to make the table described in this report and to equip it with such gauges and measures as the work should require.

Report No. 167, entitled "The Measurement of the Damping in Roll on a JN4h in Flight," by F. H. Norton, Langley Memorial Aeronautical Laboratory.—This investigation was carried out by the National Advisory Committee for Aeronautics for the purpose of measuring the value of L_p in flight. The method consisted in flying with heavy weights on each wing tip, suddenly releasing one of them, and allowing the airplane to roll up to 90° with controls held in neutral while a record was being taken of the air speed and angular velocity about the X axis. The results are of interest, as they show that the damping found in the wind tunnel by the method of small oscillations is in general 40 per cent higher than the damping in flight. At 50 m. p. h. the flight curve of L_p has a high peak, which is not indicated in the model results. It is also shown that at this speed the lateral maneuverability is low.

Report No. 168, entitled "The General Efficiency Curve for Air Propellers," by Walter S. Diehl, Bureau of Aeronautics, United States Navy.—This report is a study of propeller efficiency based on the equation

$$\pi = \left(\frac{V}{\pi ND} \right) \cot (\phi + \gamma)$$

where V = speed of advance.

N = revolutions per unit of time.

D = diameter of the helix described by the particular element under consideration.

$$\phi = \tan^{-1} \left(\frac{V}{\pi ND} \right)$$

$$\gamma = \tan^{-1} \left(\frac{D}{L} \right)$$

It is shown that this formula may be used to obtain a "general efficiency curve" in addition to the well-known maximum efficiency curve. These two curves, when modified somewhat by experimental data, enable performance calculations to be made without detailed knowledge of the propeller. The curves may also be used to estimate the improvement in efficiency due to reduction gearing, or to judge the performance of a new propeller design.

Report No. 169, entitled "The Effect of Airfoil Thickness and Plan Form on Lateral Control," by H. I. Hoot, Langley Memorial Aeronautical Laboratory.—This investigation was carried

out for the purpose of determining the effectiveness of ailerons and tests were made on six model airfoils in the No. 1 wind tunnel of the National Advisory Committee for Aeronautics. The method consisted in measuring the rolling moments and aileron moments in the ordinary way. In addition to this the wing was allowed to spin freely about an axis in the direction of the air flow and the angular velocity measured.

The results show that the thickness of the airfoil has very little effect on either the rolling moment or the hinge moment, but that the tapering in plan form somewhat decreases the rolling moment and hinge moment, although the resulting efficiency is somewhat higher for the tapered wings. The airfoil tapered in plan form, however, shows practically no falling off in the rolling moment at the critical angle of attack, whereas the wings of rectangular plan form show a marked dropping off in the rolling moment at this point. This indicates that it is possible to obtain good lateral control with small ailerons at low speeds if the plan form is tapered. The rotational speed of the different airfoils is practically the same for all of the sections tested.

Report No. 170, entitled "A Study of Longitudinal Dynamic Stability in Flight," by F. H. Norton, Langley Memorial Aeronautical Laboratory.—This investigation was carried out by the aerodynamic staff of the National Advisory Committee for Aeronautics for the purpose of studying experimentally the longitudinal dynamic stability of airplanes in flight. The airplanes selected for this purpose were a standard rigged VE-7 advanced training airplane and a JN4h with special tail surfaces. The airplanes were caused to oscillate by means of the elevator; then the longitudinal control was either locked or kept free while the oscillation died out. The magnitude of the oscillation was recorded either by a kymograph or an airspeed meter. The results show that the engine speed has as much effect on the period and damping as the airspeed, and that, contrary to theory as developed for small oscillations, the damping decreased at the higher airspeeds with closed throttle.

Report No. 171, entitled "Engine Performance and the Determination of Absolute Ceiling," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.—This report was prepared for the National Advisory Committee for Aeronautics and contains a brief study of the variation of engine power with temperature and pressure. It is shown that for the conventional engines

$$\text{BHP} \propto \left(\frac{P}{P_0} \right)^{1.15}$$

when temperature and R. P. M. are held constant and that

$$\text{BHP} \propto \left(\frac{T}{T_0} \right)^{-0.50}$$

when pressure and R. P. M. are held constant. Combining these in the standard atmosphere (N. A. C. A. Report No. 147 and Technical Note No. 99) gives.

$$\text{BHP} \propto \left(\frac{P}{P_0} \right)^{1.055}$$

for constant R. P. M.

The variation of R. P. M. with altitude is then found from the flight tests reports of the United States Army Air Service to be

$$N \propto \left(\frac{P}{P_0} \right)^{0.10}$$

for the usual case, or constant in certain special cases where the engine is provided with adequate throttle control. These relations are sufficient to determine the variation of BHP in standard atmosphere.

The variation of propeller efficiency in standard atmosphere is obtained from the general efficiency curve which is developed in N. A. C. A. Report No. 168. The variation of both power available and power required are then determined and curves plotted, so that the absolute ceiling may be read directly for any known sea-level value of the ratio of power available to power required.

Report No. 172, entitled "Dynamic Stability as Affected by the Longitudinal Moment of Inertia," by Edwin B. Wilson, Harvard University.—In a recent Technical Note (No. 115, October, 1922) of the National Advisory Committee for Aeronautics, Norton and Carroll have reported experiments showing that a relatively large (15 per cent) increase in longitudinal moment of inertia made no noticeable difference in the stability of a standard S. E. 5A airplane. They point out that G. P. Thomson, "Applied Aeronautics," page 208, stated that an increase in longitudinal moment of inertia would decrease the stability. Neither he nor they make any theoretical forecast of the amount of decrease. Although it is difficult, on account of the complications of the theory of stability of the airplane, to make any accurate forecast, it may be worth while to attempt a discussion of the matter theoretically with reference to finding a rough quantitative estimate.

Report No. 173, entitled "Reliable Formulae for Estimating Airplane Performance and the Effects of Changes in Weight, Wing Area, or Power," by Walter S. Diehl, Bureau of Aeronautics, United States Navy.—This paper, which was prepared for publication by the National Advisory Committee for Aeronautics, contains the derivation and the verification of formulae for predicting the speed range ratio, the initial rate of climb, and the absolute ceiling of an airplane. It is shown that the ratio of the maximum speed V_x to the minimum speed V_s is given by

$$\frac{V_x}{V_s} = \frac{K_1 \eta_m^{1/3}}{\left(V_s \cdot \frac{W}{HP} \right)^{1/3}}$$

where η_m is the maximum propeller efficiency and K_1 is a constant with an average value of 20.30 when V is in M. P. H. and $\frac{W}{HP}$ is in lb./BHP.

The rate of climb at sea level, C_0 , is given by

$$C_0 = 33000 \left(\frac{K_2 \eta_m}{\frac{W}{HP}} - \frac{(2V_s + V_x)}{1125 \left(\frac{L}{D} \right)} \right)$$

where $\left(\frac{L}{D} \right)$ is the overall value for the airplane at the angle for best climb (maximum value of $\frac{L}{D}$ is to be used) and K_2 is a constant found to be

$$K_2 = \left(\frac{V_x}{V_s} \right)^{-0.27}.$$

The absolute ceiling is given indirectly by

$$\frac{HP_{ao}}{HP_{ro}} = \frac{K_4 \left(\frac{L}{D} \right)}{\left(\frac{1}{\eta_m} \cdot V_s \cdot \frac{W}{HP} \right)^{.80}}$$

K_4 having an average value of 61.7 when V_s is in M. P. H. and $\frac{W}{HP}$ is in lb./BHP. The absolute ceiling is obtained by reference to the usual curves of absolute ceiling against the ratio $\frac{HP_{ao}}{HP_{ro}}$.

These curves are given in National Advisory Committee for Aeronautics Report No. 171.

Standard formulae for service ceiling, time of climb, cruising range, and endurance are also given in the conventional forms.

Report No. 174, entitled "The Small Angular Oscillations of Airplanes in Steady Flight," by F. H. Norton, Langley Memorial Aeronautical Laboratory.—This investigation was carried out by the National Advisory Committee for Aeronautics at the request of the Army Air Service to provide data concerning the small angular oscillations of several types of airplanes in steady flight under various atmospheric conditions. The data are of use in the design of bomb sights and other aircraft instruments. The method used consisted in flying the airplane steadily in

one direction for at least one minute, while recording the angle of the airplane with the sun by means of a kymograph. The results show that the oscillations differ but little for airplanes of various types, but that the condition of the atmosphere is an important factor. The average angular excursion from the mean in smooth air is 0.8° in pitch, 1.4° in roll, and 0.9° in yaw without special instruments to aid the pilot in holding steady conditions. In bumpy air the values given above are increased about 50 per cent.

Report No. 175, entitled "Analysis of W. F. Durand's and E. P. Lesley's Propeller Tests," by Max M. Munk, National Advisory Committee for Aeronautics.—This paper is a critical study of the results of propeller model tests with the view of obtaining a clear insight into the mechanism of the propeller action and of examining the soundness of the physical explanation generally given. The nominal slip-stream velocity is plotted against the propeller tip-velocity, both measured by the velocity of flight as a unit. Within the range corresponding to conditions of flight, the curve thus obtained is a straight line. Its inclination depends chiefly on the effective blade width, its position on the effective pitch. These two quantities can therefore be determined from the result of each propeller test. Both can easily be estimated therefrom for new propellers of similar type. Thus, a simple method for the computation of propellers suggests itself.

The slip curve mentioned is not a straight line along its entire length. At a small relative tip velocity it is bent up, because the lift curve of the blade sections used is bent up that way at small lift coefficients. At a certain high relative tip velocity the slip curve shows a break and runs then straight again but at a different slope. The slope is increased so that at progress zero the propeller develops a larger thrust than could be expected from the magnitude of the thrust in flight.

Report No. 176, entitled "A Constant Pressure Bomb," by F. W. Stevens, Bureau of Standards.—This report, prepared for publication by the National Advisory Committee for Aeronautics, describes a new optical method of unusual simplicity and of good accuracy suitable to study of the kinetics of gaseous reactions.

The device is the complement of the spherical bomb of constant volume, and extends the applicability of the relationship, $pV = RT$ for gaseous equilibrium conditions, to the use of both factors p and v .

The method substitutes for the mechanical complications of a manometer placed at some distance from the seat of reaction the possibility of allowing the radiant effects of the reaction to record themselves directly upon a sensitive film.

It is possible the device may be of use in the study of the photoelectric effects of radiation.

The method makes possible a greater precision in the measurement of normal flame velocities than was previously possible.

An application of the method in the investigation of the relationship between the flame velocity and the concentration of the reacting components, for the simple reaction of $2CO + O_2 = 2CO_2$, shows that the equation

$$k = \frac{s}{C_{CO}^2 C_{O_2}}$$

describes the reaction.

An approximate analysis shows that the increase of pressure and density ahead of the flame is negligible until the velocity of the flame approaches that of sound.

Report No. 177, entitled "The Effect of Slip Stream Obstructions on Air Propellers," by E. P. Lesley and B. M. Woods, Stanford University.—The screw propeller on airplanes is usually placed near other objects, and hence its performance may be modified by them. Results of tests on propellers free from slip stream obstructions, both fore and aft, are therefore subject to correction, for the effect of such obstructions and the purpose of the investigation was to determine the effect upon the thrust and torque coefficients and efficiency, for previously tested air propellers, of obstructions placed in the slip stream, it being realized that such previous tests had been conducted under somewhat ideal conditions that are impracticable of realization in flight.

At the start of this investigation, it was planned to use obstructions representative of the nose of the fuselage, of radiators, or of other parts of an airplane structure, but a consideration of the wide variety of forms thus defined led to the selection of simple geometrical forms for the initial investigation. Such forms offered the advantage of easy, exact reproduction at another time or in other laboratories, and it was believed that the effects of obstructions usually encountered might be deduced or surmised from those chosen.

Report No. 178, entitled "Relative Efficiency of Direct and Geared Drive Propellers," by Walter S. Diehl, Bureau of Aeronautics, United States Navy.—This report is an extension of the National Advisory Committee for Aeronautics Report No. 168 and has been prepared for the National Advisory Committee for Aeronautics to show the relative values of various direct and geared drives. It has been assumed that the speed V and the crankshaft revolutions are held constant at each value of $\left(\frac{V}{ND}\right)_2$, corresponding to the maximum efficiency for a two-bladed, direct-drive propeller, so that the corresponding $\left(\frac{V}{ND}\right)$ and maximum efficiency for any other propeller arrangement depends only on N and D , which are easily calculated. The net efficiencies are obtained by allowing 98 per cent for the gears and 95 per cent for the efficiency of a four-bladed propeller relative to a two-bladed propeller.

The net efficiencies so found are given in terms of the efficiency for the two bladed, direct-drive case, and plotted against $\left(\frac{V}{ND}\right)_2$, so that having given the $\left(\frac{V}{ND}\right)$ corresponding to maximum efficiency for a two-bladed, direct-drive propeller, the relative gain or loss due to any ordinary arrangement may be readily estimated. The conclusion is reached that when $\left(\frac{V}{ND}\right)_2$ is greater than 0.70, gearing is not advisable.

Report No. 179, entitled "The Effect of Electrode Temperature on the Sparking Voltage of Short Spark Gaps," by F. B. Silsbee, Bureau of Standards.—This paper presents the results of an investigation carried on at the Bureau of Standards under the auspices of the National Advisory Committee for Aeronautics to determine what effect the temperature of spark-plug electrodes might have on the voltage at which a spark occurred. A spark gap was set up so that one electrode could be heated to temperatures up to 700°C, while the other electrode and the air in the gap were maintained at room temperature. The sparking voltages were measured both with direct voltage and with voltage impulse from an ignition coil. It was found that the sparking voltage of the gap decreased materially with increase of temperature. This change was more marked when the hot electrode was of negative polarity. The phenomena observed can be explained by the ionic theory of gaseous conduction, and serve to account for certain hitherto unexplained actions in the operation of internal-combustion engines.

Report No. 180, entitled "The Influence of the Form of a Wooden Beam on Its Stiffness and Strength, I—Deflection of Beams with Special Reference to Shear Deformations," by J. A. Newlin and G. W. Trayer, Forest Products Laboratory.—The purpose of the investigation described in this report was to determine to what extent ordinary deflection formulas, which neglect shear deformations, are in error when applied to beams of various sections, and to develop reasonably accurate yet comparatively simple formulas which take into account such deformations.

A great many tests were made to determine the amount of shear deformation for beams of various sections tested over many different spans. As the span over which the beam is tested is increased the error introduced by neglecting shear deformations becomes less, and the values obtained by substituting measured deflections in the ordinary formulas approach more nearly the modulus of elasticity in tension and compression. For short spans, however, the error is considerable, and increases rapidly as the span is reduced.

Two formulas were developed for estimating the magnitude of shear deformations, both of which have been verified by tests. The first assumes the parabolic distribution of shear on a cross section of a beam and, starting with a differential volume, the distortion due to shear is

determined by the ordinary methods of summarizing the work. The second assumes that the deflections due to shear in any two beams of the same length, height, and moment of inertia, which are similarly loaded, are proportional to the summations of the shear stresses on their respective vertical sections. Both formulas check experimental results very closely when the calculations are made with great refinement.

Report No. 181, entitled "The Influence of the Form of a Wooden Beam on Its Stiffness and Strength, II—Form Factors and Beams Subjected to Transverse Loading Only," by J. A. Newlin and G. W. Trayer, Forest Products Laboratory.—The general aim of the investigation described in this report is the achievement of efficient design in wing beams. The purpose of the tests was to determine factors to apply to the usual beam formula in order that the properties of wood based on tests of rectangular sections might be used as a basis of design for beams of any sections and if practical to develop formulas for determining such factors and to verify them by experiment.

Such factors for various sections have been determined from test by comparing properties of the beam in question to similar properties of matched beams 2 by 2 inches in section. Furthermore, formulas were worked out, more or less empirical in character, which check all of these test values remarkably well.

Report No. 182, entitled "Aerodynamic Characteristics of Airfoils, III," Continuation of Report No. 124, by National Advisory Committee for Aeronautics.—This collection of data on airfoils has been made from the published reports of a number of the leading aerodynamic laboratories of this country and Europe. The information which was originally expressed according to the different customs of the several laboratories is here presented in a uniform series of charts and tables suitable for the use of designing engineers and for purposes of general reference.

It is a well-known fact that the results obtained in different laboratories, because of their individual methods of testing, are not strictly comparable even if proper scale corrections for size of model and speed of test are supplied. It is, therefore, unwise to compare too closely the coefficients of two wing sections tested in different laboratories. Tests of different wing sections from the same source, however, may be relied on to give true relative values.

The absolute system of coefficients has been used, since it is thought by the National Advisory Committee for Aeronautics that this system is the one most suited for international use and yet is one for which a desired transformation can be easily made. For this purpose a set of transformation constants is included in this report.

Each airfoil section is given a reference number, and the test data are presented in the form of curves from which the coefficients can be read with sufficient accuracy for design purposes. The dimensions of the profile of each section are given at various stations along the chord in per cent of the chord, the latter also serving as the datum line. When two sets of ordinates are necessary on account of taper in chord or ordinate, those for the maximum section (at center of span) are given on the individual characteristic sheets, while those for the tip (dotted) section are given in separate tables. Where the ratio of ordinate to chord remains constant, the one set of ordinates applies to both center and tip sections. The shape of the section is also shown with reasonable accuracy to enable one to more clearly visualize the section under consideration, together with its characteristics.

The authority for the results here presented is given as the name of the laboratory at which the experiments were conducted, with the size of model, wind velocity, and date of test.

Report No. 183, entitled "The Analysis of Free Flight Propeller Tests and Its Application to Design," by Max M. Munk, National Advisory Committee for Aeronautics.—This paper contains a description of a new and useful method suitable for the design of propellers and for the interpretation of tests with propellers. The fictitious slipstream velocity, computed from the absorbed horsepower, is plotted against the relative slip velocity. It is discussed in detail how this velocity is obtained, interpreted, and used. The methods are then illustrated by applying them to model tests and to free flight tests with actual propellers.

Report No. 184, entitled "The Aerodynamic Forces on Airship Hulls," by Max M. Munk, National Advisory Committee for Aeronautics.—This report describes the new method for making

computations in connection with the study of rigid airships, which was used in the investigation of the Navy's *ZR-1* by the special subcommittee of the National Advisory Committee for Aeronautics appointed for this purpose. It presents the general theory of the air forces on airship hulls of the type mentioned, and an attempt has been made to develop the results from the very fundamentals of mechanics without reference to some of the modern highly developed conceptions, which may not yet be thoroughly known to readers uninitiated into modern aerodynamics, and which may, perhaps, for all time remain restricted to a small number of specialists.

Report No. 185, entitled "The Resistance of Spheres in Wind Tunnels and in Air," by David L. Bacon and Elliott G. Reid, Langley Memorial Aeronautical Laboratory.—To supplement the standardization tests now in progress at several laboratories, a broad investigation of the resistance of spheres in wind tunnels and free air has been carried out by the National Advisory Committee for Aeronautics.

The subject has been classic in aerodynamic research, and in consequence there is available a great mass of data from previous investigations. This material was given careful consideration in laying out the research, and explanation of practically all the disagreement between former experiments has resulted. A satisfactory confirmation of Reynolds law has been accomplished, the effect of means of support determined, the range of experiment greatly extended by work in the new variable density wind tunnel, and the effects of turbulence investigated by work in the tunnels and by towing and dropping tests in free air.

It is concluded that the erratic nature of most of the previous work is due to support interference and differing turbulence conditions. While the question of support has been investigated thoroughly, a systematic and comprehensive study of the effects of scale and quality of turbulence will be necessary to complete the problem, as this phase was given only general treatment.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR.

- No.
115. The Effect of Longitudinal Moment of Inertia upon Dynamic Stability. By F. H. Norton and T. Carroll, N. A. C. A.
 116. F-5-L Boat Seaplane—Comparative Performance with Direct Drive and Geared Engines. By W. S. Diehl, Bureau of Aeronautics, Navy Department.
 117. The Synchronization of N. A. C. A. Flight Records. By W. G. Brown, N. A. C. A.
 118. F-5-L Boat Seaplane—Performance Characteristics. By W. S. Diehl, Bureau of Aeronautics, Navy Department.
 119. The Elimination of Dead Center in the Controls of Airplanes with Thick Sections. By T. Carroll, N. A. C. A.
 120. A Preliminary Study of Airplane Performance. By F. H. Norton and W. G. Brown, N. A. C. A.
 121. Further Information on the Laws of Fluid Resistance. By C. Wieselsberger. Translated from *Physikalische Zeitschrift*, Vol. 23, 1922.
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 124. Downwash of Airplane Wings. By Max M. Munk and Gunther Cario. Translated from *Technische Berichte*, Vol. III, No. 1 (1918).
 125. Results of Experimental Flights at High Altitudes with Daimler, Benz, and Maybach Engines to Determine Mixture Formation and Heat Utilization of Fuel. By K. Kutzbach. Translated from *Technische Berichte*, Vol. III, No. 1 (1918).
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 134. Standardization and Aerodynamics. By Wm. Knight, L. Prandtl, v. Karman, G. Costanzi, W. Margoulis, R. Verduzio, R. Katzmayer, E. B. Wolff, and A. F. Zahm. Taken from Aerial Age, June 20 and Oct. 3, 1921; Jan. 2, Feb. 20, Mar. 6, Apr. 3, May 8, June 19, Sept. and Dec., 1922.
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 140. General Theory of Stresses in Rigid Airship ZR-1. By W. Watters Pagon.
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163. Comparison of Nonrigid and Semirigid Airships. By Stapfer. Translated from Premier Congres International de la Navigation Aerienne, Nov., 1921. Vol. IV.

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BIBLIOGRAPHY OF AERONAUTICS.

During the past year the committee issued a bibliography of aeronautics covering the years 1917, 1918, and 1919 in one volume. It had previously issued the bibliography covering the years 1910 to 1916 in one volume. The bibliography for the years 1920 and 1921 in one volume will be ready for distribution in 1924. The bibliography for 1922 is in the hands of the printer, and should also be issued during the coming year. It is the policy of the committee to prepare and publish thereafter an annual bibliography.

Citations of the publications of all nations are included in the language in which the publications originally appeared. The arrangement is in dictionary form, with author and subject entry, and one alphabetical arrangement. Detail in the matter of subject reference has been omitted on account of cost of presentation, but an attempt has been made to give sufficient cross-reference to make possible the finding of items in special lines of research.

FINANCIAL REPORT.

The appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1923, as carried in the sundry civil appropriation act approved February 13, 1922, was \$210,000, under which the committee reports expenditures and obligations during the year amounting to \$209,591.53, itemized as follows:

Salaries (including engineering staff).....	\$70,488.47
Wages.....	25,044.27
Supplies and materials.....	12,438.61
Communication service.....	716.91
Travel.....	9,103.84
Transportation of things.....	1,790.52
Furnishing of electricity.....	1,465.58
Repairs and alterations.....	17,271.27
Equipment.....	10,032.23
Structures and parts.....	14,480.96
Special investigations.....	35,700.00
Printing and binding.....	11,058.87
Expenditures.....	209,591.53
Unexpended balance.....	408.47
	210,000.00

In addition to the above, the committee had a separate appropriation of \$15,600 for "Increase of compensation" to employees at the rate of \$240 per annum. Under this appropriation the committee expended \$15,460.10.

HELIUM A NATIONAL ASSET.

During the past year, for the first time, service airships have actually been inflated with helium. The Navy rigid airship U. S. S. *Shenandoah*, and a number of Army nonrigid airships are now using helium. The improvement in the method of its extraction, referred to in the committee's report of last year, has materialized, and when further perfected will permit the production of helium at a much lower cost.

Gases carrying helium in amounts adequate for quantity extraction are found only in the United States. This exclusive possession constitutes a unique national asset which should not be dissipated. Even if any large-scale production of helium be not undertaken at this time, America should conserve this existing natural resource. The National Advisory Committee for Aeronautics, therefore, strongly recommends that Congress provide for the acquisition and sealing by the Government of the largest and best helium fields.

RELATION BETWEEN AERONAUTIC RESEARCH AND AIRCRAFT DESIGN.

On May 31, 1923, Dr. Joseph S. Ames, chairman of the executive committee of the National Advisory Committee for Aeronautics, delivered the eleventh annual Wilbur Wright Memorial Lecture before the Royal Aeronautical Society in London, the topic being "Relation Between Aeronautic Research and Aircraft Design." The information presented in that lecture dealt entirely with the research work of the committee conducted at the Langley Memorial Aeronautical Laboratory. The story of aeronautical research as presented in that lecture evoked many complimentary expressions from Englishmen and favorable comment from the British press. As indicating the manner in which the lecture was received in England, the following paragraphs are quoted from the comment appearing in the June issue of the British magazine, *Aeronautical Engineering*:

"The lecture should undoubtedly have the effect of opening the eyes of British aeronautical engineers to the very valuable and extensive nature of the research work which has already been carried out in the United States of America, and to the probability of rapid advance in that country.

"If Doctor Ames's lecture has the effect of galvanizing our own aeronautical research committee into a state of a little greater liveliness it will be of enormous value. If it fails of this effect, it will at least direct the attention of British designers to the very large store of useful information which is to be found in the reports of the American Advisory Committee."

In view of the fact that Doctor Ames's lecture related only to the official work of the National Advisory Committee for Aeronautics, the committee has authorized its publication as an appendix to this its ninth annual report. A copy of the appendix may be obtained upon application.

ADVANTAGES OF THE AMERICAN SYSTEM FOR AERONAUTICAL RESEARCH.

The National Advisory Committee for Aeronautics is by law specifically authorized to supervise and direct aeronautical research in the United States. England, France, and Japan have technical committees to either direct or advise in the conduct of scientific research in aeronautics. Our committee has naturally been always interested in the work of the foreign committees. For several years there has been an exchange of technical information, partly by personal contact, but principally through the mails. During the past year, however, three members of the National Advisory Committee for Aeronautics, at different times, visited Europe, namely: Dr. Joseph S. Ames, chairman of the executive committee, who went abroad to deliver the Wilbur Wright Memorial Lecture before the Royal Aeronautical Society of Great Britain in May, 1923, and to gather information on which to base recommendations for next year's research program in this country; Dr. S. W. Stratton, who went abroad primarily to participate in the International Conference on Weights and Measures, but who took advantage of his

presence in Europe to investigate aeronautical progress; and Commander Jerome C. Hunsaker, United States Navy, in charge of the design section of the Naval Bureau of Aeronautics, who went abroad on Navy business. Each of these members on his return to America reported his observations and recommendations to the committee, and in this way the committee, in preparing its own research programs, has had the benefit of first-hand information as to the progress and plans for aeronautical research in other countries.

England has probably devoted more attention to aeronautical research, and in the past has contributed more to the development of the science of aeronautics, than any other country. At the present time, however, America is probably making greater progress in aeronautical development, and is rapidly overcoming the advantage that England and France possessed at the signing of the armistice.

Doctor Ames, chairman of the executive committee, in his report to the entire committee, stated that English officials appeared to be much interested in how America had made such substantial progress as it was now making with younger and less experienced men conducting aeronautical research, and with the expenditure of only a fraction of the sum spent on aeronautical development in England. Doctor Ames stated that, in response to frank and direct questions from officials of the British Air Ministry, he had stated that there were four reasons why America was making such progress in aeronautical research, namely:

1. That the members of the National Advisory Committee and of its standing subcommittees serve without compensation.

2. That our committee is an independent Government establishment, reporting directly to the President, receiving its own appropriation from Congress, and, by virtue of such status, is enabled to conduct any investigation it desires to undertake, limited only by the funds available.

3. That our research laboratories are located on a flying field where all phases of the work, including flight operations, are controlled and actually performed by the committee's own employees.

4. That there is splendid cooperation and coordination of effort in America, not only between the Army and the Navy themselves, but also between both the Army and the Navy and the National Advisory Committee for Aeronautics, and that our committee can and does obtain from the Army and the Navy all aircraft, equipment, and accessories needed in connection with any investigation.

RELATION OF AERONAUTICAL RESEARCH TO NATIONAL DEFENSE.

Despite the progress that has been made in aeronautics, no one at this time can safely predict its future or its limitations, either for purposes of war or commerce. As to our national defense, the programs of the Army and Navy are subject to change from year to year and are dependent in large part upon the progress of aviation. And the progress in aviation is in turn dependent upon aeronautical research. The fact that the limitation of armaments conference placed no limitation on the development of aeronautics for military purposes assures its greater relative importance in future warfare, whether over land or sea.

With the increase in expenditure in the maintenance of the military and naval air services, especially in view of the aggregate cost of new types of aircraft, it is more than ever necessary that fundamental information should be available on which proper design of new aircraft is based. The Army and Navy rely upon the National Advisory Committee for Aeronautics for the fundamental aerodynamic information requisite for the design of military and naval aircraft.

To keep pace with military developments abroad as well as to hasten the day of practical commercial aviation in this country, more knowledge is necessary on the fundamental problems of flight. The committee from year to year has carefully prepared its research programs, but has invariably had to modify or delay their execution for lack of funds. The committee feels that the curtailment and postponement of its research programs mean the denial to the American people of knowledge necessary for the substantial development of aviation, civil and military, even though liberal appropriations be made, as they should be, for the Army, Navy, and Postal Air Services.

The committee appreciates the need for economy in Government expenditures at the present time, but the continuous advancement of aeronautics places heavy demands upon the committee for new knowledge, which can be obtained only by the conduct of scientific research. The committee believes that the development of aeronautics will promote our national welfare, increase our national prosperity, and make secure our national defense. When considering the costs involved, it should be considered that scientific research is the best insurance obtainable to prevent waste of funds through the design and construction of aircraft which are not suitable for the purposes intended. The air services of our Army and Navy are not so large as those of other world powers, but we are gradually forging ahead of other nations in our knowledge of the scientific principles underlying the design and construction of aircraft, and in this important respect at least we are providing against unpreparedness in the air.

CONCLUSION.

During the past year there has been a gratifying increase in knowledge of the science of aeronautics, as fully described in the reports of the technical subcommittees and in the various publications of the National Advisory Committee for Aeronautics. A year or more must usually elapse before the results of fundamental research become evident in the construction of better aircraft. Justification of the policy of continuous prosecution of scientific research is reflected in American achievements of more popular interest during the past year, among which may be mentioned the following:

(a) The five-day test demonstration by the Air Mail Service of the practicability of night flying of the mails, resulting in the transportation of mails across the continent in both directions in from 27 to 30 hours.

(b) The completion of the first rigid airship to be built in America, the Navy fleet airship U. S. S. *Shenandoah*, formerly known as the *ZR-1*, which has successfully passed the preliminary tests and which promises, under careful handling, to furnish reliable information as to the safety and practicability of airships in warfare using helium instead of hydrogen, and which may serve to open up a new era in air transportation and establish a new industry in America.

(c) The winning by the American Navy, in international competition, of the Schneider cup for naval seaplanes, when an American naval seaplane made a speed of 177 miles per hour, which was 20 miles per hour faster than the nearest competitor of any other nation, and 31 miles per hour faster than the speed of the winning British seaplane the year before.

(d) The nonstop flight by the Army Air Service across the continent from coast to coast, or 2,520 miles, in 27 hours, in a T-2 airplane in which the Army had previously established the endurance record of 36 hours.

(e) The establishment by the Navy in the Pulitzer trophy contest of a new official world's airplane speed record of 243.67 miles per hour over a four-lap triangular course of 200 kilometers, an increase of 37.87 miles per hour over the winning speed of the year before; and the subsequent establishment of a record of 266.6 miles per hour over a straightaway course of 3 kilometers.

(f) The remarkable demonstration of popular interest in aeronautics on the occasion of the annual air races held in St. Louis, October 4 to 6, 1923, when, according to reliable reports, 150,000 people attended and 300,000 miles were flown in connection with the meet without casualty.

These visible evidences of progress during one year compel recognition of the fact that America, although spending less money on aviation and maintaining smaller air services in the Army and Navy, is nevertheless abreast of other nations in the physical development of aircraft. There has, however, been but little application of existing knowledge of aircraft, or air navigation, to commercial purposes. Broadly speaking, the situation with reference to the lack of commercial flying may be summarized as follows:

(a) Only when reliable service at reasonable cost can be given will American business men be ready for commercial aviation. Progress must be gradual. It must rest upon a sound economic basis. Despite the remarkable physical development of aircraft, the present high

cost factor, combined with the absence of improved national airways, constitutes an economic barrier to the general application of aviation to commercial purposes.

(b) There has been no Federal legislation and but little State legislation to encourage the development of commercial aviation.

The continuous prosecution of scientific research on the fundamental problems of flight by the National Advisory Committee for Aeronautics, and the systematic collection and dissemination of technical information from all parts of the world, assure progress in the development of aircraft. Although necessary, these activities alone are not sufficient to assure the early introduction of aviation into commercial pursuits generally.

Costs must be reduced, but to accomplish this the development of commercial aviation should be given greater encouragement than it now receives from the Government. The present 10-year aircraft building program of the Army Air Service and the 5-year program of the Navy will, if carried out, meet the absolute needs of the two services, and possibly serve to keep in existence a nucleus of an industry until a strong, self-supporting commercial aircraft industry develops.

While there is serious question as to whether commercial aviation can or should be permanently maintained by the Federal Government, it is certain that it can not get an early start without assistance. The practical development of aviation in America will not be realized until the Government gives intelligent support and effective aid, principally by regulating and licensing and by cooperation with the States in the establishment of airways and landing fields. The Committee accordingly reaffirms its oft-repeated recommendation for the establishment of a Bureau of Civil Aeronautics in the Department of Commerce.

The committee also strongly recommends liberal appropriations for the development of aviation in the Army and in the Navy. At the present time the Army Air Service is equipped largely with obsolete war-time airplanes and engines. These aircraft are being rapidly exhausted, and at the present rate of appropriations the supply of equipment will become more inadequate each year. The Navy is also confronted with a serious shortage of aircraft. Bombing exercises have taught the lesson that aircraft are absolutely necessary for mobile coast defense, and that a navy without adequate aircraft will be at a hopeless disadvantage in future warfare. Major warships are being equipped with aircraft, but at the present rate of appropriations, after making due allowance for necessary replacements, the fleet will not be equipped with the proper proportion of aircraft.

Whatever may be the demands of economy, serious consideration must be given to the increasing relative importance of aircraft in warfare and funds appropriated to equip and maintain adequately the air services of the Army and Navy. Progress in aeronautics is being made at so rapid a rate that the only way to keep abreast of other nations *is actually to keep abreast, year by year, never falling behind.*

Respectfully submitted.

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

APPENDIX TO ADMINISTRATIVE REPORT

RELATION BETWEEN AERONAUTIC RESEARCH AND
AIRCRAFT DESIGN

By JOSEPH S. AMES
Chairman, Executive Committee
National Advisory Committee for Aeronautics

APPENDIX TO ADMINISTRATIVE REPORT.

RELATION BETWEEN AERONAUTIC RESEARCH AND
AIRCRAFT DESIGN.¹

By JOSEPH S. AMES,

Chairman, Executive Committee, National Advisory Committee for Aeronautics.

INTRODUCTION.

It is a great honor to be invited to give the Wilbur Wright lecture on aeronautics, especially so for a fellow citizen of the Wright brothers. I think that I appreciate the honor all the more because of personal relationships with Mr. Orville Wright and because, since the day of their first successful cross-country flight, I have had the opportunity of realizing the truly unique qualities of these great men. The fact can not be emphasized too often that, from the very beginning of their work, their point of view was that of the scientific investigator. Empirical methods, engineering development did not satisfy them; they wished to know the underlying scientific facts and to build on them. They had, in reality, the true concept of the purpose of the great aerodynamic laboratories of to-day.

The selection of a subject for the Wilbur Wright lecture is not an easy matter, especially when the selection must be made months in advance and when, as in this case, the request was made to send the title by cable. I confess my title is commonplace, but it was the best I could think of which would be sufficiently indefinite to allow me to include in the lecture the results of several investigations then in progress. For there is always a grave uncertainty in any physical investigation as to the day when the results obtained will have sufficient value to be reported.

THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY.

The aerodynamic laboratory with which I am connected is the Langley Memorial Aeronautical Laboratory, not far from Old Point Comfort, Va., which has been developed since 1915 by the National Advisory Committee for Aeronautics of the United States. This committee is an independent Government agency, not under any of the departments, but reporting directly to the President. We have a laboratory for power-plant investigations; a large wind tunnel of the type developed by the N. P. L.; another tunnel in which the air may be compressed to 20 atmospheres or more; excellent facilities for the design and construction of instruments; and a large fleet of airplanes, equipped for scientific purposes. In addition we are able to engage the services of competent mathematical physicists familiar with aerodynamics. What we would like to do would be to give free scope to these latter, and to conduct the laboratory tests under their direction, so that theory and knowledge of facts could make progress together. But this is not possible in an establishment whose primary purpose is to give advice to other governmental services, especially advice concerning questions raised by these services. It is true that we can often inspire these questions, and we can always, in the process of obtaining the answers, learn more than is required for the specific purpose. It follows, that while we are conducting practical tests we are also doing fundamental scientific work continuously, exactly as a justice of a high court expresses his deepest thoughts as *obiter dicta*.

¹ The eleventh annual Wilbur Wright memorial lecture, delivered in London before the Royal Aeronautical Society of Great Britain, May 31, 1923, by Dr. Joseph S. Ames

THE DISTRIBUTION OF FORCES ON AIRPLANE PARTS.

As it has happened, two problems of a general nature have come to us this year from both the Army and the Navy, which, while not new at all, have led to new methods and to new knowledge. Both have an immediate bearing upon the design of aircraft; and it was for these reasons that I selected my rather indefinite title for this lecture.

The first problem stated generally was to learn more about the distribution of forces on the parts of aircraft. It came to us in three questions:

(a) How is the distribution of load over a wing tip and aileron modified by changing the plan form of the wing of an airplane? (b) Why are high-speed pursuit airplanes subject to certain types of accident, such as the ripping off of the linen envelope of the wings? (c) What are the forces to which the fixed and movable surfaces and the envelope of an airship are subjected when it is making maneuvers?

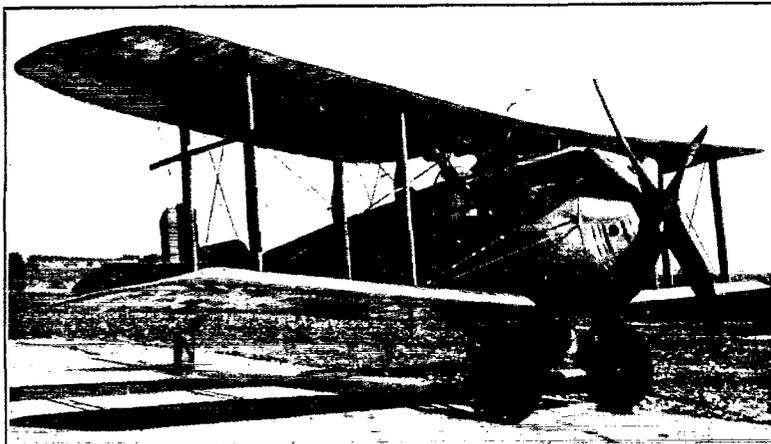


FIG. 1.—The rebuilt Thomas Morse MB-3 airplane ready for wing and aileron pressure distribution tests.

The first of these led to an extensive investigation in the standard wind tunnel. One series of tests was on four model airfoils without ailerons, having square, elliptical, and positively and negatively raked tips; the second series was on wings having raked tips with ailerons adjusted to different settings. The models had a chord of 6 inches and a mean semispan of 18 inches, and the method of images recommended in one of the British R. and M. reports was adopted in the investigation. A large number of series of openings were made in the surfaces of the airfoil and each was connected to a liquid manometer. The results give a great deal of what is apparently new information concerning the air flow near the tip of a wing. They will soon be published both in tabular and in graphical form, so that designers can calculate with ease the distribution of lift between the ends of the wing spars, the shears and bending moments, and the aileron efficiency. Further, with the knowledge obtained, proper distribution of load in sand testing is facilitated. The most important general conclusions are that tips with a positive rake give an erratic distribution of lift near the tip of the aileron and that this may be avoided by the use of a negative rake. Considerable new light is also thrown upon the question of aileron balance.

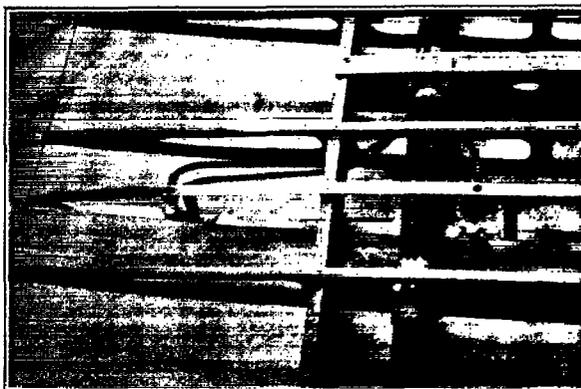


FIG. 2.—Enlarged view of portion of wing skeleton, showing tubes and surface connections for pressure distribution tests on MB-3.

In order to study the air flow about a high-speed pursuit airplane, a Thomas Morse MB-3 airplane was rebuilt and suitably prepared for experimentation, Fig. 1. This has a maximum air-speed of 145 M. P. H. A large number of holes were made in the two surfaces of both the upper and lower wings; these were connected by rubber tubes (Fig. 2) to recording multiple manometers mounted in the fuselage; so in this way 60 records could be made simultaneously. The manometer, which has been described in published reports of the committee, consists of a series of metal capsules, across the middle of each of which is stretched a metal diaphragm. In most of the tests the two holes facing each other on opposite sides of the wing were connected to the opposite sides of the capsule; but in some cases only one hole was so connected, the other side

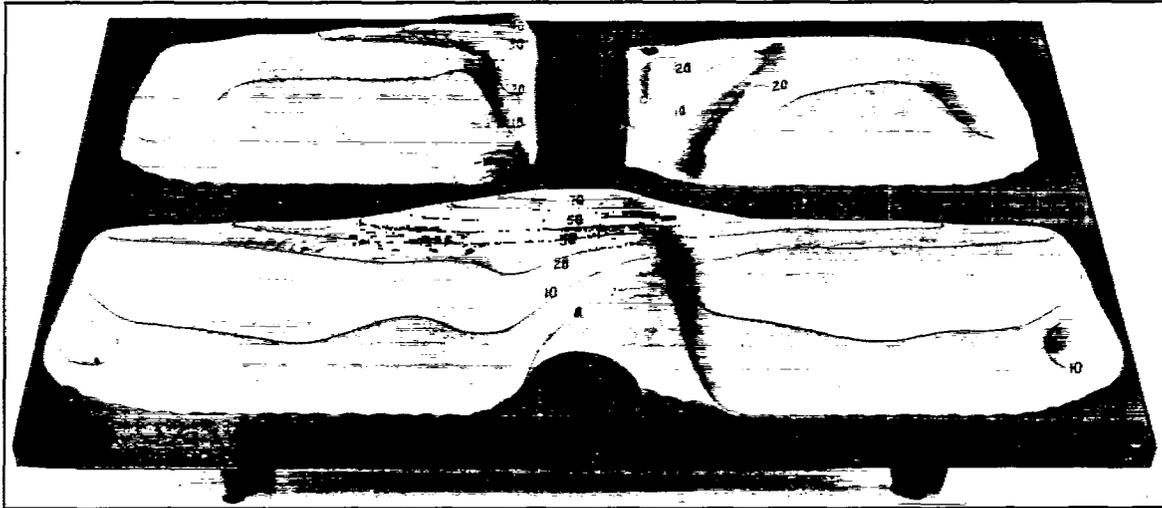


FIG. 3.—Model in relief, showing lift of MB-3 in steady flight at 70 M. P. H. and 1,600 R. P. M.

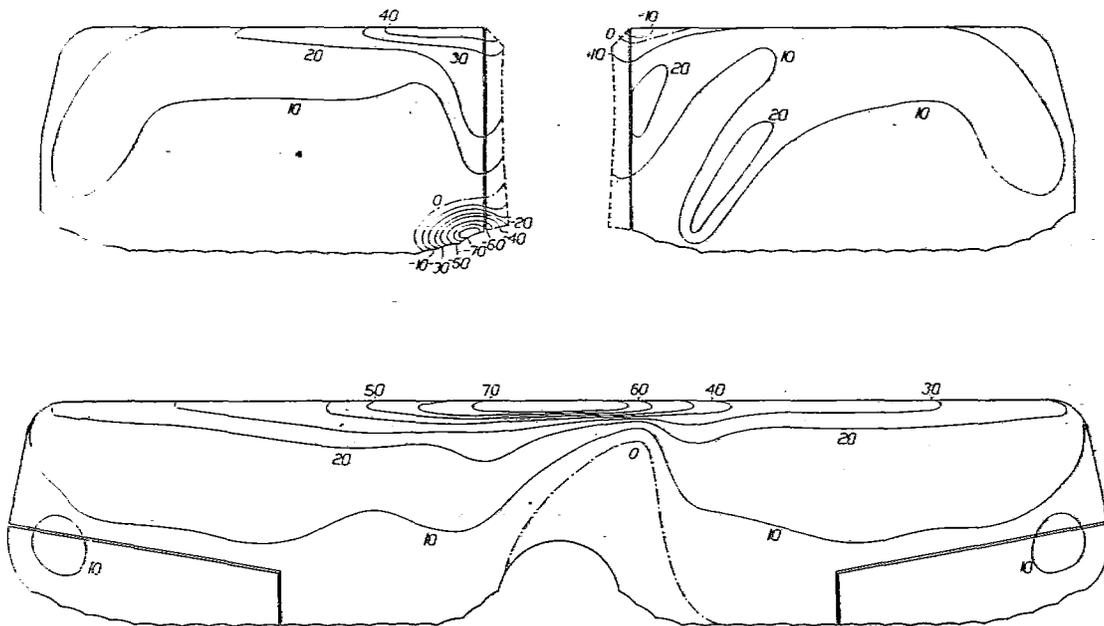


FIG. 4.—Lift of wings in steady flight at 70 M. P. H. and 1,600 R. P. M.

of the capsule being joined to a reservoir in the cockpit communicating with a static tube whose opening was in the interior of the wing. Special attention was paid to the distribution of pressure in the slipstream and near the leading and trailing edges. Since there is such a great variation in pressure over a wing, each capsule was adjusted separately, so as to have the proper sensibility corresponding to the opening with which it was connected. At the leading edge pressures as high as 200 lb./sq. ft. had to be measured, while farther back the pressure often did not exceed 30 lb./sq. ft. An accelerometer, a recording airspeed meter, a control position recorder, and an electric chronometer were also installed in the airplane.

The information specially desired was the distribution of lift over the portions of wings in the slipstream during steady flight and that over the entire wings during violent maneuvers. Measurements were made at air speeds of 70, 115, and 145 miles per hour, at closed, medium, and full throttle, under conditions of steady flight, and also during three maneuvers, a roll, a flattening out of a dive, and a vertical bank at 150 M. P. H. (Figs. 3, 4, 5, 6, and 7.)

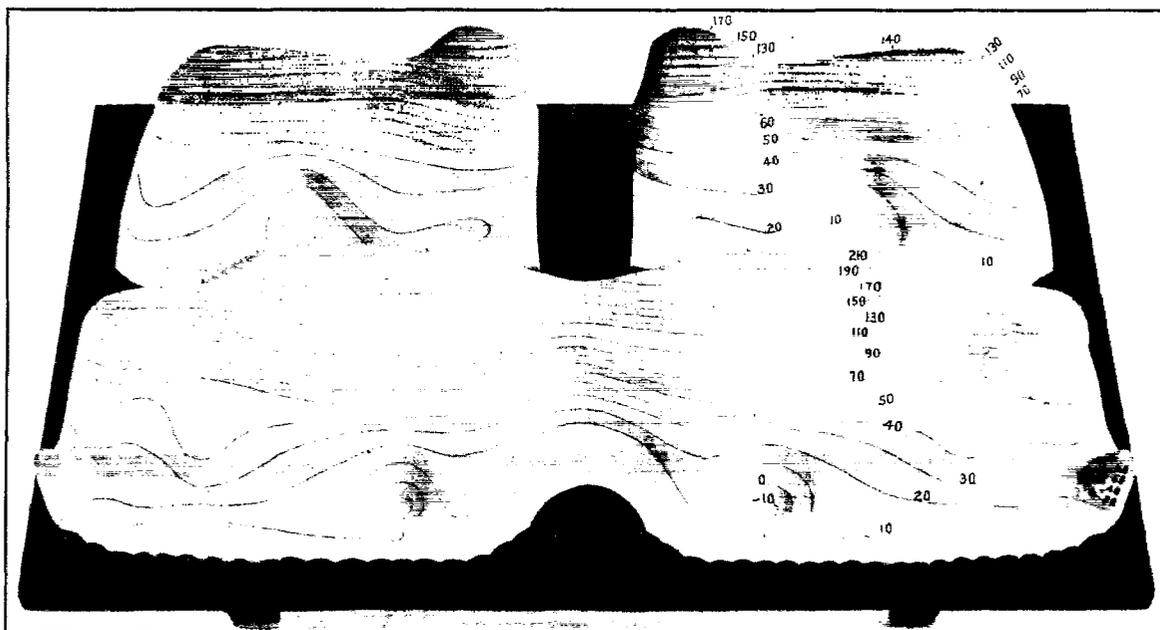


FIG. 5.—Model in relief, showing lift of MB-3 wings in a vertical bank at 150 M. P. H. and 1,900 R. P. M. Acceleration 4.2 g. Elevator pulled up 12°.

The results can be understood most easily by the use of graphical methods. Contour lines of pressure may be drawn on a model of the wings; or, what is far more striking, three dimensional models may be constructed. Both these methods are illustrated. The numbers adjacent to any contour line indicate the total pressure upward in pounds per square foot, i. e., the combination of the effects on the two sides of the wing. The relief maps also give the combined effects.

Some of the most striking facts observed are:

1. The lift in the slipstream during steady flight is far from uniform on this airplane; at high airspeed and high engine speed a lift of 100 lb./sq. ft. was observed on the leading edge of the upper wing, while on the leading edge of the lower right wing there was an area of down pressure of 60 lb./sq. ft.
2. At low airspeed and high engine speed—that is, while climbing—there was at the trailing edge of the lower left wing, near the fuselage, a down pressure of 70 lb./sq. ft.
3. When the suction on the upper surface of a wing was measured with reference to the air inside the wing it was found to amount to as much as 76 lb./sq. ft. in steady flight, whereas in one isolated point an inward pressure of as much as 24 lb./sq. ft. was observed.

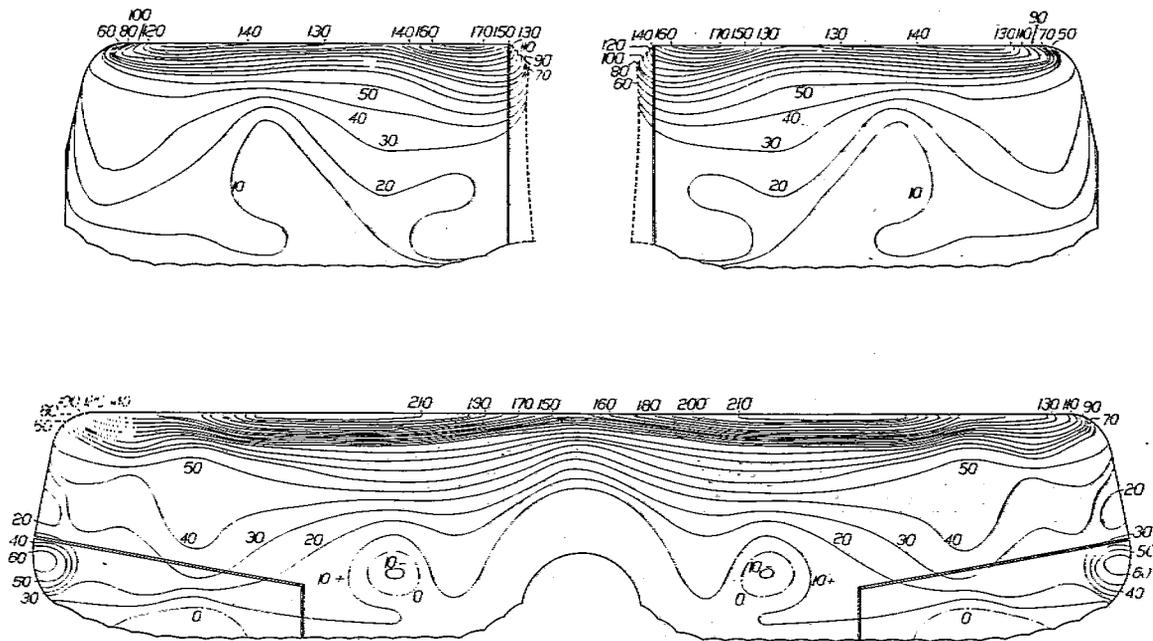


FIG. 6.—Lift of wings in a vertical bank at 150 M. P. H. and 1,900 R. P. M. Acceleration 4.2 g. Elevator pulled up 12°.

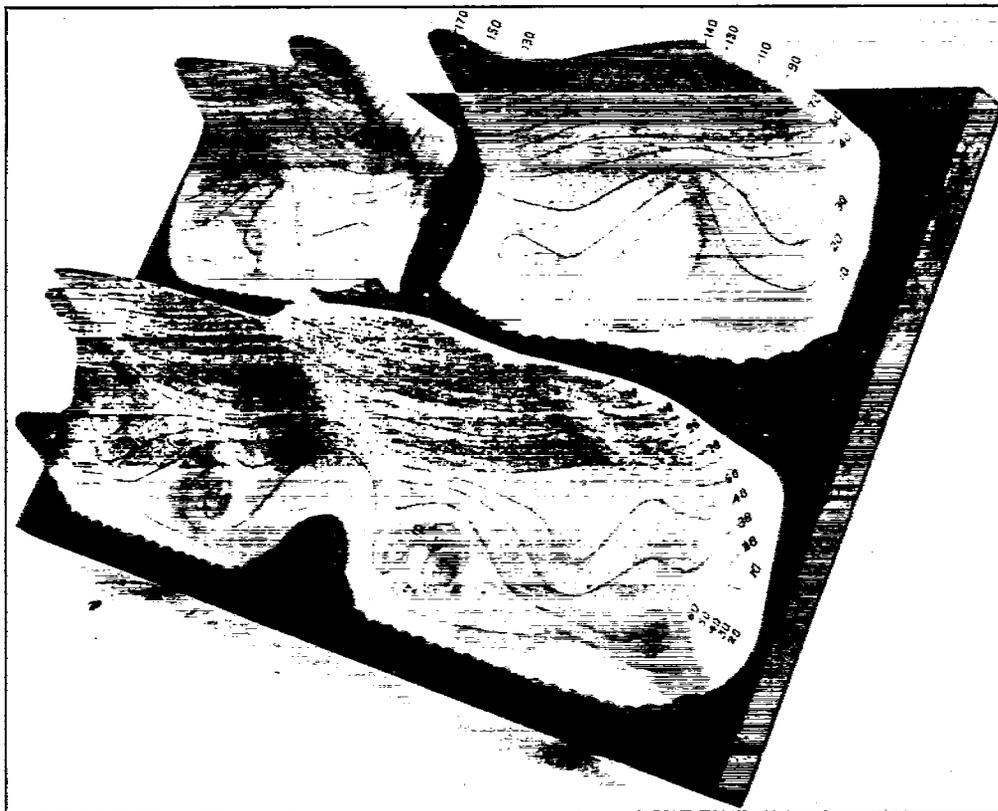


FIG. 7.—Model in relief, perspective view, showing lift of MB-3 wings in a vertical bank at 150 M. P. H. and 1,900 R. P. M. Acceleration 4.2 g. Elevator pulled up 12°.

4. In flattening out of a dive the wings support only 80 per cent of the total load on the airplane, whereas in a vertically banked turn at 150 M. P. H. where the acceleration rose to 4.2 g. the wings carried 90 per cent of the load, the remainder being borne by the fuselage and tail surfaces.

5. In steady flight at 145 M. P. H. the lift per square foot of the upper wing is twice that of the lower; the total lift of both wings being about 400 lb. greater than the weight of the airplane, balancing the down load on the fuselage and tail. This fact is, no doubt, due to the rigging of this particular airplane; i. e., to the angular difference between the wings and to the lower wing being almost at zero lift.

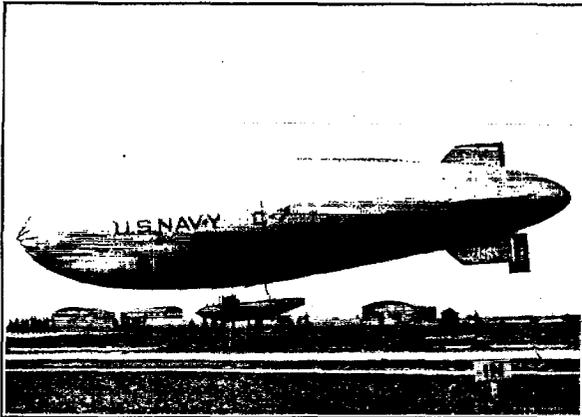


Fig. 8.—“C” class airship on which the pressure distribution work was done.

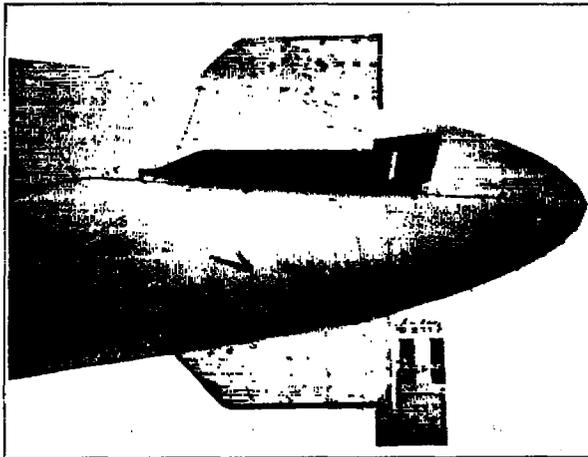


Fig. 10.—Control surfaces of airship, showing location of pressure pads.

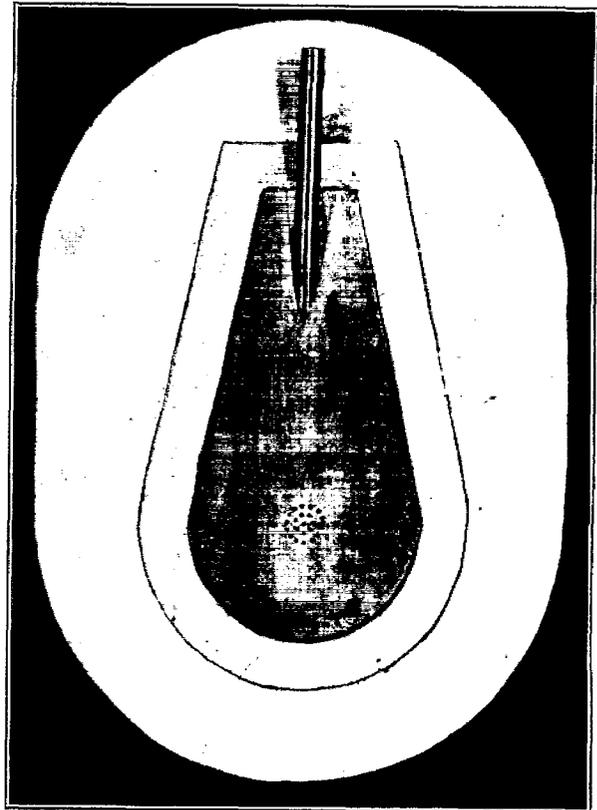


Fig. 9.—Pressure pad used on airships.

It is important to add that this MB-3 airplane is a single-seater, so that the pilot has to control the airplane and press the button which starts all the automatic recording devices. This investigation of the MB-3 proved so interesting and offered so many suggestions that further studies of pursuit airplanes have been called for. The plans are now perfected for similar investigations of the latest types of military fighting airplanes. One problem in this connection is to compare the inherent advantages and disadvantages of monoplanes and biplanes.

MEASURING THE PRESSURES OVER AIRSHIP SURFACES.

As is well known, the United States is interested in the construction of airships. The Navy has practically finished a large rigid, and the Army has well under way a semirigid. As is equally well known, the actual scientific knowledge of the aerodynamics of airships is not extensive. At the request first of the Navy and later of the Army, our National Advisory Committee undertook to study and report upon the airship designs made by these two services.

In connection with this work one of the technical staff of the committee, Doctor Munk, elaborated a certain theory of the airship which was distinctly novel but led to results at variance with accepted practice. It was evident that real knowledge could be obtained only by extensive experimentation on actual airships. What was needed primarily was a series of measurements of pressures over the envelope and surfaces of an airship when in steady flight and when making

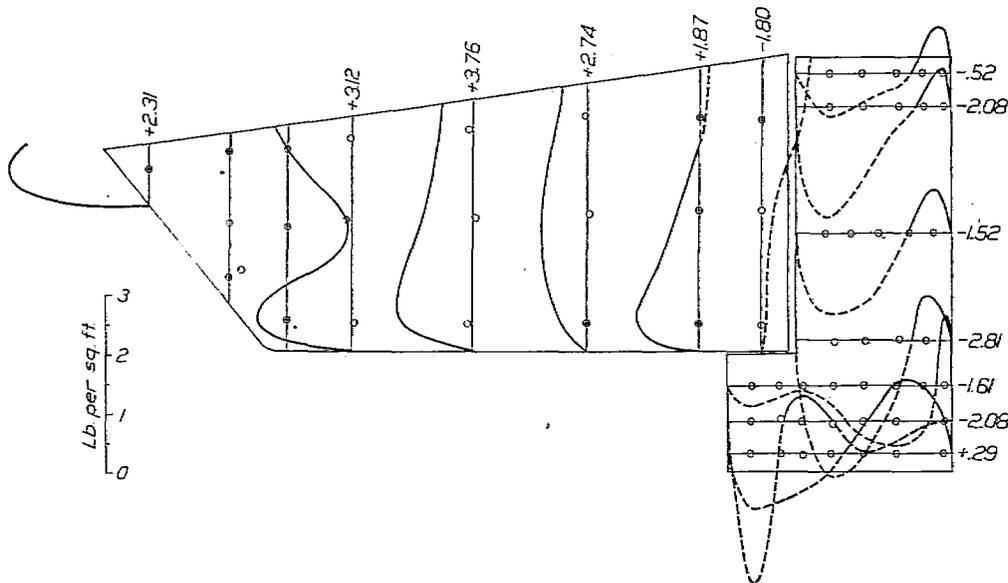


FIG. 11.—Pressure distribution over bottom fin and rudder. Circling flight.

maneuvers. For this purpose a nonrigid airship, Navy type C (Fig. 8), was placed at the disposal of the committee. It is 200 feet long, 40 feet in diameter, and has 200,000 cubic feet capacity. Pads were specially designed for the measurement of pressure (Fig. 9). These lie practically flush with the envelope of the airship, and each consists essentially of a metal

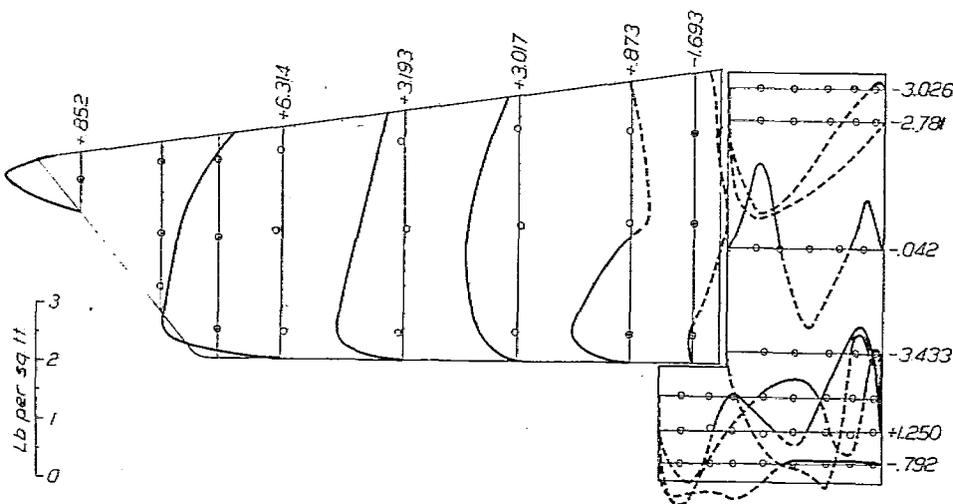


FIG. 12.—Pressure distribution over bottom fin and rudder. Beginning of circling flight.

box whose top and bottom surfaces are pear-shaped, roughly 2 inches by 4 inches, and held a distance of one one-hundredth of an inch apart by means of studs; in the top plate there are grouped in a comparatively small circle 22 holes, each three one-hundredths of an inch in diameter; a brass tube one-quarter of an inch in diameter serves as an outlet from the box. This is connected by rubber or aluminum tubing to a liquid manometer in the car of the airship.

There are about 400 of these pads on the envelope and surfaces of the airship, 36 being in the bottom fin and rudder (Fig. 10). Simultaneous readings of 260 manometers may be made photographically.

This investigation of the aerodynamics of an airship is not yet completed, but I can show you certain observations which indicate the importance and novel character of the results being obtained. One illustration (Fig. 11) shows the pressure distribution over the bottom fin and rudder in circling flight; and the other when the airship, while in steady flight, has its helm put hard down.

The drawings do not require much explanation, but emphasis may be placed upon the results shown when circling flight is begun (Fig. 12). When the helm is suddenly applied, and before the airship attains an appreciable angular velocity, the angular acceleration creates such a large force on the vertical fins in the opposite direction to the force on the rudder that the net force on the stern of the airship is much smaller than has been supposed hitherto. It follows that the condition of the sudden application of the rudder is not a serious one from the point of view of the stresses in the hull of the airship. Presumably the reversal of the helm, when the airship is in a steady turn, does not cause a large increase of the bending moments beyond those already existing in that condition.

These are the three problems referred to at the beginning of this paper as requiring an elaboration of the methods for the study of pressure distribution; and no one can question the importance of the results obtained in the proper design of aircraft.

INVESTIGATION OF SCALE EFFECT.

Quite a different set of questions has been asked our committee, which lead in the end to an investigation of the so-called scale effect. Certain questions can, of course, be answered on theoretical grounds, and answered definitely; but the great majority can not. Any aircraft is a complicated mechanism, made up of many parts; all of these have definite aerodynamical characteristics; but from a knowledge of these we can not pass to that of the machine as a whole. The question as to the changes in forces and moments with scale, especially in maneuvers, is exceedingly difficult. The first investigation which should be made on scale effect is to determine which aerodynamic properties are most susceptible to the effect; after that, the number of problems to be undertaken is practically infinite.

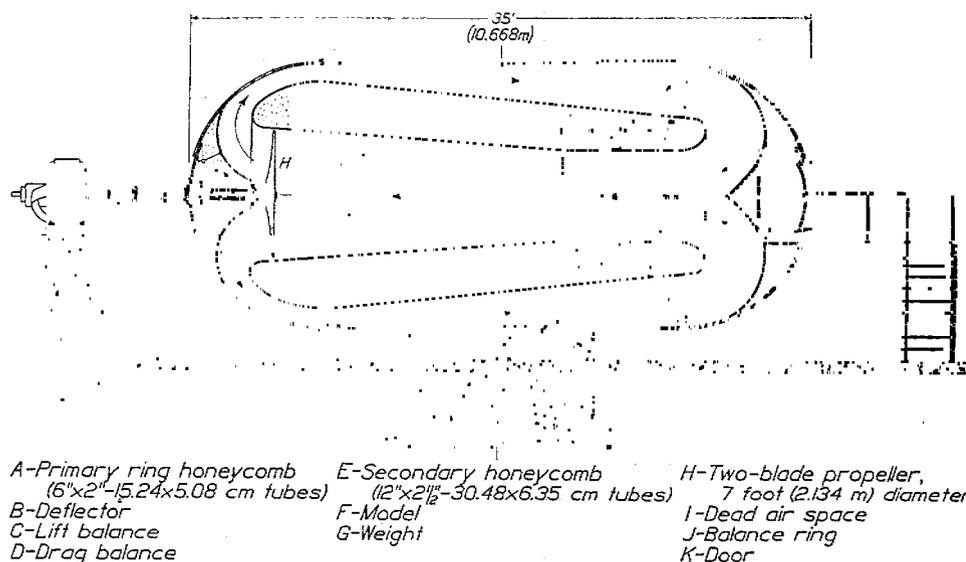


FIG. 13.—The N. A. C. A. variable density No. 2 wind tunnel.

THE VARIABLE DENSITY WIND TUNNEL.

At Langley Field our committee has facilities for studying scale effect by four different methods, two of which are, I believe, unique. We have an ordinary wind tunnel, having a 5-foot throat, and fitted with fans, so that an airspeed of 100 M. P. H. (147 feet per second) may be used; this gives a certain Reynolds number, not very large. A larger number may be obtained by a free flight method in which a large model is suspended below an airplane in steady flight; we have perfected methods for suspension and measurement, and the results are, on the whole, satisfactory. To secure a still larger Reynolds number, the committee has had constructed during the past year a wind tunnel to operate with air compressed to 20 atmospheres or more. The tunnel proper is 5 feet in diameter at the experimental chamber and is inclosed in a cylindrical tank with hemispherical ends (Fig. 13). The walls of the tunnel are hollow, providing an annular dead-air space in which the balance mechanism is installed. This may be controlled automatically, or settings may be made by small electric motors, operated from outside, which attach or release heavy balancing weights by means of cams, or shift lighter weights along balance arms. The model is attached to the balance (Fig. 14) by wires, there being three balance arms for measuring lift, drag, and pitching movements. The tank is 35 feet long and 15 feet in diameter and weighs 83 tons. It is mounted on a concrete foundation and is partially surrounded by a working platform (Fig. 15). An observer on this makes settings and readings by looking into the tank through small glass windows.

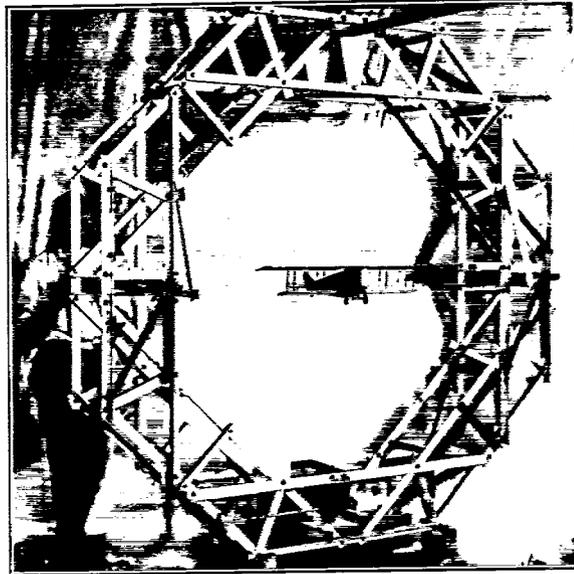


FIG. 14.—Balance ring for wind tunnel No. 2.

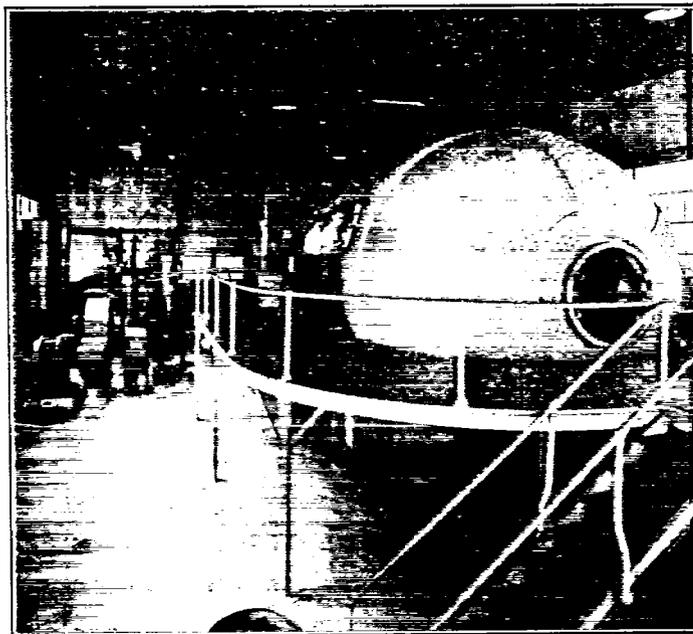


FIG. 15.—Variable density wind tunnel with observation platform and compressor.

of the operation of this tunnel as well as of the other tunnels in the committee's laboratory.

It may be of interest to note that when the tunnel is operating at its greatest density it is equivalent in scale to a tunnel 100 feet in diameter running at 60 miles per hour. It takes about an hour and a half to "inflate" the tank fully.

The density of the air in the tank is controlled by two compressors driven by electric motors (Fig. 16). Continuous stages may be secured from one-tenth of an atmosphere to 20 atmospheres. Circulation of air is effected by a two-blade propeller, of special design, 7 feet in diameter, and driven at 900 R. P. M. by a 250-HP. synchronous motor mounted on a separate foundation outside the tank. The drive shaft is made tight against air leakage where it passes through the head of the tank by a loosely packed gland through which oil is circulated.

The concept of such a tunnel was originated by Dr. Max M. Munk and this particular one was designed by him; and the mechanical equipment was designed and installed by Mr. D. L. Bacon, both members of the staff of the committee. The latter is in charge

Another method for obtaining a large Reynolds number, which is used by the committee, involves the accurate measurements of the motion of an actual airplane in flight. To this end the staff of the committee have perfected a large number of recording instruments. Among these may be mentioned a single-component accelerometer, a three-component accelerometer,

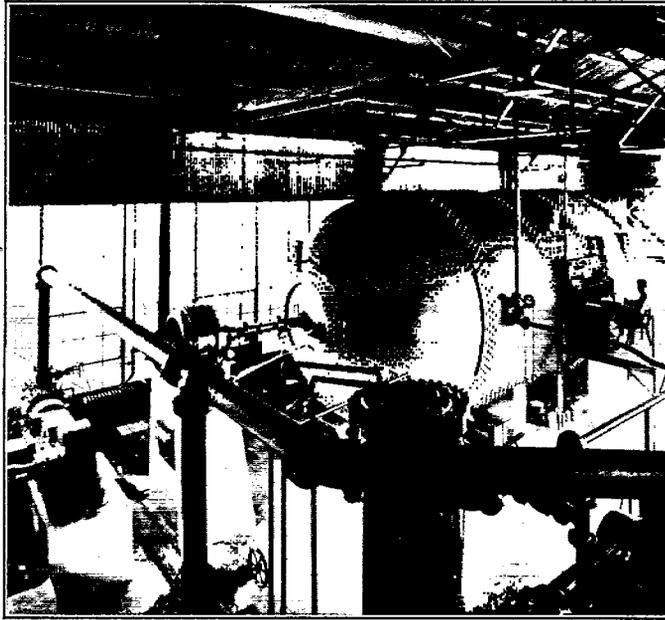


FIG. 16.—View of variable density wind tunnel showing fan motor and air pipes.

a three-component angular velocity recorder, a control-position recorder, a control-force recorder, an airspeed meter, an angle of attack recorder, and an electric chronometer. The committee owes the design of these instruments to the exceptional ability of two of its staff, Mr. F. H. Norton and Mr. H. J. E. Reid.

THE BOMB KYMOGRAPH.

The latest instrument developed and one used in work about which I shall speak later is a form of kymograph (Fig. 17). It consists of a streamlined body, from the front end of which projects a N. P. L. Pitot tube and which has a tail appendage to render the whole directionally and longitudinally stable. There is a transverse shaft through the center of mass, to the two ends of which are

attached suspension wires leading to winches in the cockpit of the airplane, so that when the latter is in flight the kymograph may be lowered to a distance of 25 feet, so as to be in undisturbed air. In the upper forward surface of the "bomb" there is an opening closed with a cylindrical lens, outside of which is a small vertical mirror, so that the rays of light from

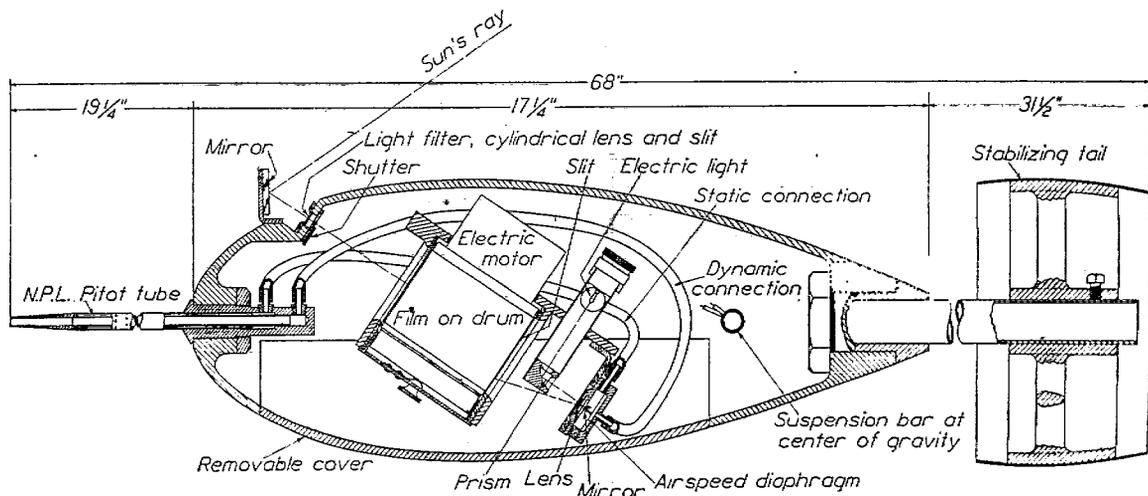


FIG. 17.—N. A. C. A. trailing kymograph-airspeed meter.

the sun may be reflected through the lens and then through two crossed slits onto a photographic film. The Pitot tube is connected to a capsule manometer, whose motions are recorded on the same film. This is wound on a drum, inside of which is a constant speed electric motor, driven by a current led in through the suspension wires of the instrument. An actual photograph of the records on the drum is given (Fig. 18).

When the airplane is flown in a direction away from the sun the kymograph takes a position along the direction of the relative wind, and a continuous record will be made of the angular position of the sun with reference to this direction. An observer on the ground observes simultaneously the altitude of the sun, and so one obtains a record of the angle between the flight path with reference to the air and a horizontal line. The airspeed is measured at the

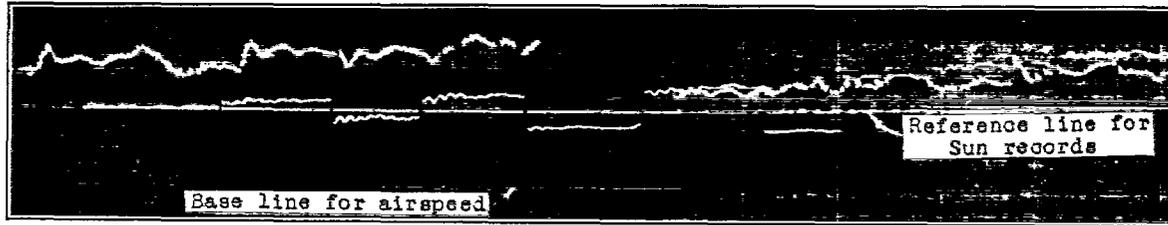


FIG. 18.—Kymograph record. Airspeed records are the sharp curves. Sun records are broadened.

same time, as is also the angle of attack of the airplane itself. Therefore, if gliding flights are taken, values of the ratio of lift to drag may be measured at various angles of attack at known airspeeds. This method is obviously independent of vertical air currents. As an illustration of its accuracy, a chart is shown (Fig. 19) giving the values of angle of glide with reference to airspeed at different values of $\frac{V}{ND}$, in which V is the airspeed, N is the number of revolutions per second of the propeller, and D its diameter. By a preliminary model investigation it was found that the value of $\frac{V}{ND}$ was 1.02 for the condition of zero torque. These and all other "free flight" tests under the direction of the committee have been carried out by Mr. F. H. Norton and Mr. W. G. Brown with the aid of the committee's most skillful test pilot, Mr. Thomas Carroll.

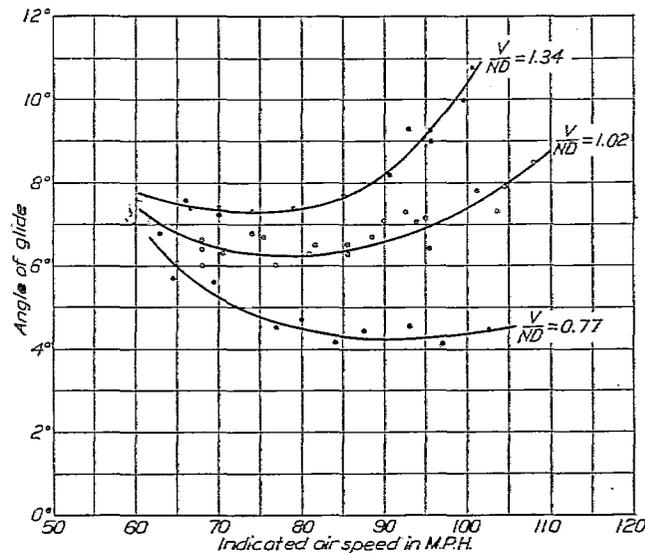


FIG. 19.—Indicated airspeed in M. P. H. Glide test of Fokker D-VII.

With these facilities at the Langley Memorial Aeronautical Laboratory, it is hoped that rapid progress will be made in the elucidation of the scale-effect problem.

Unfortunately for the purposes of this paper, the variable density tunnel was actually put into daily operation for observation purposes only about the first week in April, and so I can report the results of only two series of tests. For this reason, although I have no cause to question their accuracy, they should, I think, be regarded as provisional.

The first scale effect measurements undertaken were on spheres. There is nothing novel in this problem, but some of the results are interesting. Spheres of various sizes were studied in the two tunnels, with their supporting spindles in the direction of the air stream and at various angles to it (Fig. 20); other spheres were towed, suspended at a considerable distance below an airplane,

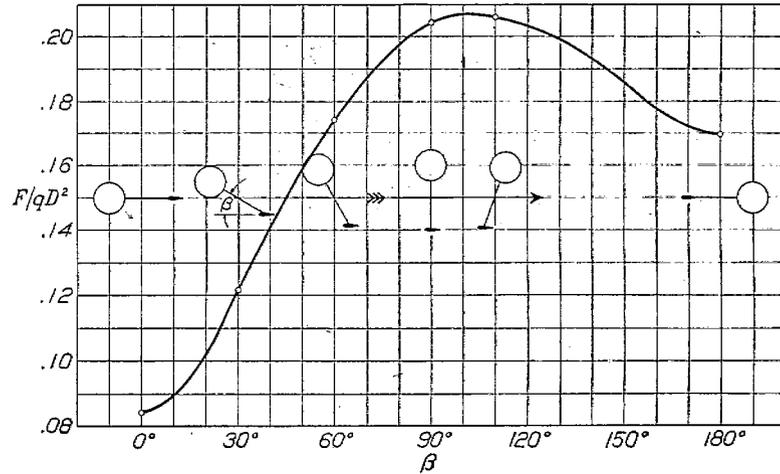


FIG. 20.—Effect on resistance of sphere of direction of support with reference to air stream. Reynolds number is 2.5×10^5 .

in flight; and finally certain spheres were taken aloft by an airplane on particularly quiet days and allowed to drop, their motion being determined by theodolite observations from the ground. The results of all of these methods are given on the accompanying diagram (Fig. 21). This test was undertaken both to obtain large Reynolds numbers and to investigate the condition of turbulence in the new wind tunnel. If time were available, I would call attention to several interesting features of these curves.

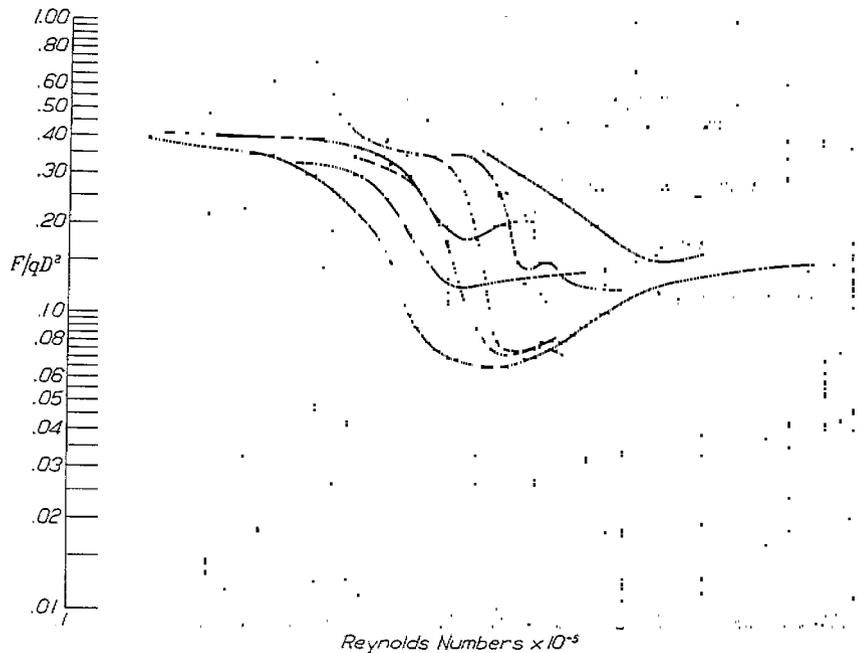


FIG. 21.—Curves giving resistance of a sphere at different Reynolds numbers.

The second test on the subject of scale effect was made with reference to a type of airplane using thick wings and having small parasite resistance. A Fokker D-VII was selected for this purpose. An airplane was equipped with suitable apparatus; and a model of one-fifteenth scale was made, which was fitted with its proper propeller. Series of measurements on models and

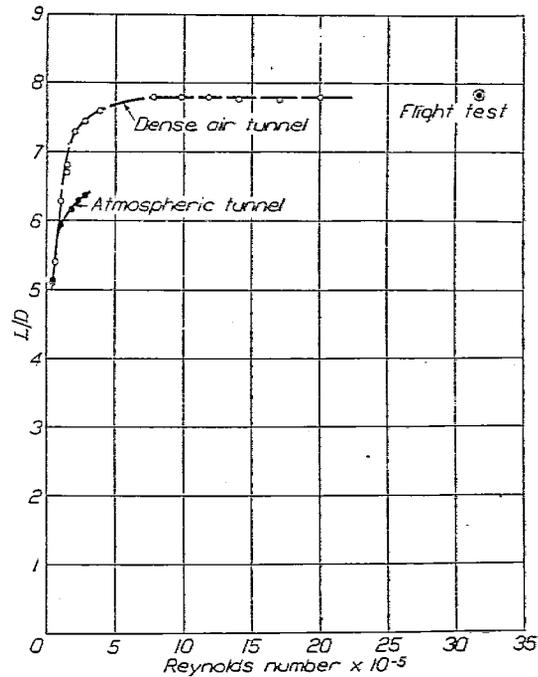


FIG. 22.—Scale effect on lift-drag ratio using Fokker D-VII airplane. Propeller at zero torque.

in full flight have been made; the aerodynamic characteristics of lift and drag were measured at different attitudes, and the results obtained are shown in the accompanying diagram (Fig. 22).

If the use of these scale-effect methods justifies our present hopes, we shall be able in a comparatively short time to place at the disposal of the designer of aircraft a wealth of information which should increase markedly the accuracy of his work.