

AERONAUTICS

TWELFTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE

FOR AERONAUTICS

1926

INCLUDING TECHNICAL REPORTS
Nos. 233 to 256



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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 twelfth annual report of the committee for the fiscal year ended June 30, 1926.

Attention is invited to Part V of the committee's report presenting a summary of the present status of aviation with special reference to technical development and to the aeronautical situation as affected by the constructive legislation enacted at the last session of Congress. Although it will take time to accomplish results under the air commerce act and the approved five-year aircraft-building programs of the Army and Navy, it is gratifying to note the committee's opinion that America leads the world in the private ownership and operation of aircraft, is keeping pace with other nations in the technical development of aircraft for military purposes, and has the technical knowledge necessary at least to equal the commercial developments abroad.

I concur in the committee's opinion that the development of commercial aviation on a sound business basis depends primarily upon the solution of the basic problems of reduction in cost and increase in safety, which are, in turn, in the last analysis largely dependent upon the continuous prosecution of scientific research on the fundamental problems of flight. I believe that the American aviation program is sound in principle and when carried into effect will go far toward making America first in the development of aircraft for military and civil purposes.

CALVIN COOLIDGE.

THE WHITE HOUSE,
December 9, 1926.

LETTER OF TRANSMITTAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., November 20, 1926.

Mr. PRESIDENT:

In compliance with the provisions of the act of Congress approved March 3, 1915 (Public, No. 271, 63d Cong.), I have the honor to transmit herewith the Twelfth Annual Report of the National Advisory Committee for Aeronautics for the fiscal year ended June 30, 1926.

Scientific study of the fundamental problems of flight has been continued, and the progress made has been reflected in a steady improvement in performance and reliability of aircraft for all purposes.

The recent enactment by Congress of constructive aeronautical legislation should promote the orderly development of military and naval aviation on a sound basis and should stabilize and encourage the aircraft industry and stimulate commercial aviation.

The present state of development is outlined in Part V of the committee's report. In this part the committee shows the relation of research to national defense and to aeronautical progress in general, and focuses attention on the basic problems of reduction in cost and increase in safety, on which substantial progress must be made in order that the American people may receive the benefits of the full possibilities of aviation.

The report concludes with a statement of the bright outlook for the future, and emphasizes the need for the continuous prosecution of scientific research as the most fundamental activity of the Government in connection with the development of aeronautics.

Respectfully submitted.

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*.

TWELFTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., November 17, 1926.

To the Congress:

In accordance with the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its twelfth annual report for the fiscal year 1926. Final approval of the committee was given to this report on November 9, 1926. In this report the committee has described its organization; its general activities during the past year; the progress made in the scientific study, under the cognizance of the various technical subcommittees, of the fundamental problems of aeronautics; the coordination of research work in general; the creation by law of the Aeronautical Patents and Design Board and the relations of the committee with that board in connection with the consideration of aeronautical inventions; the principles embodied in the air commerce act for the encouragement of commercial aviation and the committee's part in connection with the formulation thereof; and the collection, analysis and dissemination of scientific and technical data. This report also contains brief descriptions of the technical reports, and references to the technical notes, technical memorandums, and aircraft circulars issued by the committee during the past year.

A statement of expenditures for the fiscal year ended June 30, 1926, is also contained in the report.

In Part V of his report, the committee presents an outline of "The Present Status of Aviation," including references to the present state of technical development; aeronautical research in the United States and its relation to national defense; the general problem of aeronautical organization, with a summary of the legislative situation; the status of commercial aviation; references to the Air Mail Service, the aircraft industry, and to the relation of the work of the committee to aeronautical progress.

PART I

ORGANIZATION

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, and their investigation and application to practical questions of aeronautics. The act also authorized the committee to direct and conduct research and experimentation in aeronautics in such laboratory or laboratories, in whole or in part, as may be placed under its direction.

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

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

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

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

Fourth. The committee keeps itself advised of the progress made in research and experimental work in aeronautics in all parts of the world, particularly in England, France, Italy, Germany, 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.

During the past year the Congress made the first legislative change in the functions of the committee. In the act approved July 2, 1926, an Aeronautical Patents and Design Board was created, consisting of Assistant Secretaries of War, Navy, and Commerce. Section 10(r) of that act (Public, No. 446, 69th Cong.) provided that "upon the recommendation of the National Advisory Committee for Aeronautics" the Patents and Design Board shall determine questions as to the use and value to the Government of aeronautical inventions submitted to any branch of the Government.

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. The law further provides that all members as such shall serve without compensation.

No change has occurred during the past year in the membership of the committee.

During the last session of Congress a bill was passed by the Senate (S. 4529) providing for an increase in the membership of the National Advisory Committee for Aeronautics from 12 to 15 to include the new Assistant Secretaries of War, Navy, and Commerce. A similar bill was introduced in the House of Representatives and was favorably reported by the committee to which it was referred, but was not reached for consideration prior to the adjournment of Congress.

The entire committee meets twice a year, the annual meeting being held in October and the semiannual meeting in April. The present report includes the activities of the committee between the annual meeting held on October 22, 1925, and that held on October 21, 1926.

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

Charles D. Walcott, Sc. D., chairman.

David W. Taylor, D. Eng., secretary.

Joseph S. Ames, Ph. D.

George K. Burgess, Sc. D.

Maj. John F. Curry, United States Army.

William F. Durand, Ph. D.

Capt. Emory S. Land, United States Navy.

Charles F. Marvin, M. E.

Rear Admiral William A. Moffett, United States Navy.

Maj. Gen. Mason M. Patrick, United States Army.

S. W. Stratton, Sc. D.

Orville Wright, B. S.

MEETINGS OF THE ENTIRE COMMITTEE

The semiannual meeting of the entire committee was held at the Langley Memorial Aeronautical Laboratory, Langley Field, Hampton, Va., on April 22, 1926, and the annual meeting in Washington on October 21, 1926. At these meetings the general progress in aeronautical research was reviewed and the problems which should be experimentally attacked were discussed. Administrative reports were submitted by the Secretary and by the Director of the Office of Aeronautical Intelligence. Doctor Ames, chairman of the executive committee, made complete reports of the research work being conducted by the committee at the Langley Memorial Laboratory and reported briefly on the general activities of the committee.

In connection with the semiannual meeting at Langley Field on April 22, the committee made an inspection of the facilities and activities of its laboratory, the various investigations under way being explained in detail by members of the laboratory staff. On that occasion also the members of the committee were conducted by the commanding officer of Langley Field on a tour of inspection of the Army's flying facilities and airship hangar, where they saw the non-rigid airship *TC-4* and the recently developed tank car especially designed for the transportation of helium.

At the annual meeting in Washington on October 21, a motion-picture film was exhibited showing some of the tests being conducted at the Langley Memorial Aeronautical Laboratory on the problem of autorotation, or the flat spin. At this meeting also the committee had as its guests Hon. Edward P. Warner, Assistant Secretary of the Navy, and Hon. William P. MacCracken, jr., Assistant Secretary of Commerce. Assistant Secretary of War Davison, who had been invited as a guest, and General Patrick were absent from the city. Brig. Gen. William E. Gillmore, new chief of the matériel division of the Army Air Corps, was present on invitation as a representative of General Patrick.

The election of officers was the concluding feature of the annual meeting. The present officers of the committee were elected for another year, as follows: Chairman, Dr. Charles D. Walcott, secretary; Dr. David W. Taylor; chairman, executive committee, Dr. Joseph S. Ames.

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 in addition 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.
 Maj. John F. Curry, United States Army.
 Capt. Emory S. Land, United States Navy.
 Charles F. Marvin, M. E.
 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.

During the past year the executive committee, on invitation of General Patrick and Major Curry, held one of its regular meetings at McCook Field, Dayton, Ohio, in connection with which the members inspected the facilities and activities of the Engineering Division of the Army Air Corps. At its last meeting the executive committee accepted an invitation from Admiral Moffett for the members to visit the naval aircraft factory, at the Philadelphia Navy Yard, and become directly acquainted with the work in progress there.

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 research program in aeronautics approved by the executive committee is vested in the director of aeronautical research, 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. David W. Taylor.
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, technical memorandums, and aircraft circulars 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 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. David W. Taylor, vice chairman.
Prof. Charles F. Marvin.
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 services. The administrative office is also the headquarters of the various subcommittees and of the Office of Aeronautical Intelligence.

Field stations of the committee are the Langley Memorial Aeronautical Laboratory, at Langley Field, Hampton, Va., and the office of the technical assistant in Europe, located in Paris.

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 Corps, 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.

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

The laboratory consists of seven buildings: A research laboratory building, containing the administrative offices, the headquarters of the aerodynamics and power plants divisions, the technical library, the photographic laboratory, and a lunch room; two aerodynamical laboratories, one containing a wind tunnel of the open type and the other a variable-density 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; an airplane hangar equipped with a repair shop, dope room, and facilities for taking care of 16 or 18 airplanes used in flight research; and a service building, containing an instrument laboratory, drafting room, machine and woodworking shops, and storeroom.

On June 25, 1925, the committee authorized the construction of propeller research equipment large enough to investigate full-sized propellers. It is expected that the propeller research equipment will be completed and in operation before the end of this fiscal year. The test chamber will be of sufficient size to accommodate the fuselage of an airplane, on which the propeller will be mounted and operated by the airplane engine. The throat of the test chamber will be 20 feet in diameter and the air speed will be approximately 100 miles an hour.

Recognition by the Government of the necessity of satisfying the increasing demand for new and accurate knowledge on the fundamental problems of flight has made possible the development of the Langley Memorial Aeronautical Laboratory as an efficient research organization numbering 126 employees at the close of the fiscal year 1926.

THE OFFICE OF AERONAUTICAL INTELLIGENCE

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the committee's activities. Its functions are the collection, classification, and diffusion of technical knowledge on the subject of aeronautics to the military and naval air organizations 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 handle efficiently 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 visit personally the governmental and private laboratories, centers of aeronautical information, and private individuals in England, France, Italy, Germany, and other European countries, and endeavor to secure for America not only printed matter which would in the ordinary course of events become available in this country, but more especially 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. Mr. John Jay Ide, of New York, is the present incumbent.

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

Committee and subcommittee members.....	1, 010
Langley Memorial Aeronautical Laboratory.....	2, 074
Paris office of the committee.....	3, 581
Army Air Corps.....	2, 988
Naval air organization, including Marine Corps.....	3, 015
Manufacturers.....	4, 637
Educational institutions.....	5, 259
Bureau of Standards.....	444
Miscellaneous requests.....	16, 199
Total distribution.....	39, 207

The above figures include the distribution of 16,725 technical reports, 6,624 technical notes, 7,729 technical memorandums, and 984 aircraft circulars of the National Advisory Committee for Aeronautics. Five thousand six hundred and twenty-nine written requests for reports were received during the year in addition to innumerable telephone and personal requests, and 21,029 reports were forwarded upon request.

FINANCIAL REPORT

The appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1926, as carried in the independent offices appropriation act approved April 22, 1926, was \$522,000, under which the committee reports expenditures and obligations during the year amounting to \$516,709.27, itemized as follows:

Salaries (including engineering staff).....	\$192, 884. 43
Wages.....	109, 763. 96
Supplies and materials.....	22, 562. 11
Communication service.....	1, 059. 52
Travel.....	12, 826. 75
Transportation of things.....	4, 962. 26
Furnishing of electricity.....	10, 968. 60
Rent.....	634. 78
Repairs and alterations.....	3, 097. 29
Special investigations.....	33, 450. 00
Equipment.....	84, 507. 07
Laboratory Building.....	39, 992. 50
Expenditures.....	516, 709. 27
Reserve, "One Per Cent Club".....	5, 245. 00
Unexpended balance.....	45. 73
Total.....	522, 000. 00

In addition to the above, the committee had a separate appropriation of \$12,000 for printing and binding, of which \$11,518.19 was expended.

PART II

GENERAL ACTIVITIES

CONSIDERATION OF AERONAUTIC INVENTIONS

The President's Aircraft Board, known as the Morrow Board, in Section III (7) of its report submitted to the President November 30, 1925, recommended that "the functions of the National Advisory Committee for Aeronautics should be extended to cover the field of advice to inventors regarding aeronautic inventions." The executive committee at its meeting on February 5, 1926, went on record as being willing to assume definitely the duty of rendering such further assistance in this respect as the Congress may determine. This was followed on February 17, 1926, by a letter from The Adjutant General of the Army stating that all aeronautic inventions received by the War Department would be referred to the committee with the understanding that "these inventions will be investigated and such action will be taken as appears advisable in each case." By a prior agreement with the Navy Department dated April 12, 1921, the Navy had been referring to the committee "all inventions on aeronautics of a general character and not of a specific value to the Navy nor in reply to a request for designs."

The committee had first begun the consideration of aeronautic inventions during the war period at the request of War and Navy representatives on the committee. After the war the committee continued to receive inventions and to advise inventors and the military services upon all inventions submitted by individuals direct or through other governmental agencies. The difficulties with this method were:

1. That there was no agency with power on the part of the Government to reimburse an inventor for a valuable design.
2. The committee could only advise an inventor, and there was no governmental agency authorized to render a final decision on the merits of an invention.

The Congress met this situation by the creation of a patents and design board composed of Assistant Secretaries of War, Navy, and of Commerce. This legislation was contained in the Army Air Corps act (Public, No. 446, 69th Cong.), section 10(r) of which reads as follows:

A board to be known as the Patents and Design Board is hereby created, the three members of which shall be an Assistant Secretary of War, an Assistant Secretary of the Navy, and an Assistant Secretary of Commerce. To this board any individual, firm, or corporation may submit a design for aircraft, aircraft parts, or aeronautical accessories, and whether patented or unpatentable, the said board upon the recommendation of the National Advisory Committee for Aeronautics shall determine whether the use of such designs by the Government is desirable or necessary, and evaluate the designs so submitted and fix the worth to the United States of said design, not to exceed \$75,000. The said designer, individual, firm, or corporation, may then be offered the sum fixed by the board for the ownership or a nonexclusive right of the United States to the use of the design in aircraft, aircraft parts, or aeronautical accessories and upon the acceptance thereof shall execute complete assignment or nonexclusive license to the United States: *Provided*, That no sum in excess of \$75,000 shall be paid for any one design.

The Patents and Design Board held its first meeting on October 12, 1926, and was composed of the following:

Hon. F. Trubee Davison, Assistant Secretary of War for Aeronautics;
Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics;
Hon. William P. MacCracken, jr., Assistant Secretary of Commerce for Aeronautics.

Mr. Davison as representative of the ranking department presided, and Mr. Warner acted as recorder.

The Patents and Design Board decided at the outset that it would be a board of record and it was agreed in the interests of economy that the National Advisory Committee for Aeronautics would maintain the records of the board separate and distinct from its own records.

The board adopted an outline of procedure which provides among other things that all projects must be submitted in full and in writing; that they would be referred in the first instance to the National Advisory Committee for Aeronautics for consideration, preparation of an abstract, and recommendation to the board; that final action on each project so considered would be taken at meetings of the board to be held periodically; that personal interviews with inventors would not be granted by the board except after full consideration of the invention, provided that in cases offering prospect of favorable action, the inventor should be invited to appear before the board for its further information.

In the meantime, the National Advisory Committee for Aeronautics had appointed a special subcommittee to determine its procedure in discharging the additional duties devolving upon it under the act that created the Patents and Design Board. This subcommittee consisted of Dr. D. W. Taylor, chairman, Rear Admiral William A. Moffett, United States Navy, and Maj. Gen. Mason M. Patrick, United States Army.

On October 18, 1926, this subcommittee made a report recommending that the outline of procedure adopted by the Patents and Design Board in so far as it relates to the procedure of the committee, be approved as a governing policy of the committee. The subcommittee's report contained the following further recommendations which were made "in harmony with the above procedure or with the known views of the members of the board":

(1) That the National Advisory Committee for Aeronautics consider and report to the board on all aeronautical inventions received direct or referred to the committee by the board or by any other governmental agency.

(2) That in the consideration of an invention the committee will conduct with the inventor such direct correspondence as may be necessary to disclose clearly his idea and will then submit to the Board on Patents and Design the papers in the case together with an abstract of the invention and the committee's recommendation.

(3) That a technical committee on aeronautical patents and design be not organized at this time but that the Director of Aeronautical Research be authorized to act for the National Advisory Committee for Aeronautics in respect to the committee's functions as outlined in one and two above and in connection therewith to call upon any subcommittee or member thereof for advice or assistance, provided that in his discretion important or doubtful cases may be submitted to the executive committee for determination of the committee's recommendation to be submitted to the Board on Patents and Design.

(4) That in the interests of efficiency and economy the committee offer the use of its conference room for meetings of the Board on Patents and Design and agree so long as may be deemed necessary to provide the necessary personnel and facilities for the maintenance of the board's records separate and distinct from the records of the committee.

The report of the subcommittee was approved by the executive committee of the National Advisory Committee for Aeronautics on October 21, and became a governing policy of the committee. A satisfactory beginning has been made by the Patents and Design Board and the National Advisory Committee for Aeronautics acting in cooperation in the consideration of aeronautic inventions in full compliance with the spirit of the new law referred to.

THE AIR COMMERCE ACT

The year 1926 will be memorable in aeronautics as marking the year in which Congress enacted the air commerce act. (Public—No. 254—69th Cong.—S. 41.) This act provides the legislative cornerstone for the development of commercial aviation in America. It establishes certain fundamental principles to govern the relation of the Federal Government to the whole problem of aiding the development of commercial aviation in America on a sound basis. The act asserts the doctrine of Federal sovereignty in the air over the lands and waters of the United States to the exclusion of foreign nations. It asserts under the commerce clause of the Constitution the right of the Federal Government to regulate interstate air commerce. It authorizes the designation of airways by the Federal Government and compels adherence to a single set of Federal flying rules on the part of all who use such airways, regardless of whether they are engaged in interstate or intrastate air commerce or private flying. It authorizes Federal lighting systems along airways and the Federal establishment and maintenance of emergency landing fields. It authorizes the transfer of the postal airways, including emergency landing fields, to

the jurisdiction of the Department of Commerce and the transfer of the postal air ports or terminal facilities to the jurisdiction of the municipalities concerned under arrangements subject to approval by the President. It contemplates the establishment and maintenance of air ports by the municipalities or by private industries. It provides for the compulsory registration of aircraft engaged in interstate commerce and for the optional registration of other aircraft. It provides for the periodic examination and rating of airmen serving in connection with registered aircraft. It provides for the emergency use of existing governmental facilities, extends the application of existing laws to foreign air traffic, and, in short, imposes upon the administrative officer concerned—the Secretary of Commerce—the duty of fostering the development of air commerce in the United States.

Although there had been an almost universal desire among all aeronautical elements in this country for Federal legislation to regulate and encourage commercial aviation, there were conflicting schools of thought on the principles to be followed and the methods to be employed. After the bill had passed both the Senate and House of Representatives and while it was in conference there were differences as to fundamental principles which threatened for a time the enactment of the legislation into law. In this situation Senator Bingham, of Connecticut, the sponsor of the legislation in the Senate and one of the Senate conferees, called upon the National Advisory Committee for Aeronautics on April 15, 1926, for "a full report embodying such constructive criticisms and recommendations as your committee may deem advisable and necessary." At the semiannual meeting of the entire committee, held at Langley Field, Va., on April 22, a special subcommittee on the encouragement and regulation of aircraft in commerce was organized in response to Senator Bingham's letter, as follows:

William F. Durand, chairman.

Joseph S. Ames, Johns Hopkins University.

George K. Burgess, Director Bureau of Standards.

Maj. John F. Curry, United States Army, Chief Engineering Division, McCook Field.

Capt. Emory S. Land, United States Navy, Bureau of Aeronautics.

Rear Admiral William A. Moffett, United States Navy, Chief, Bureau of Aeronautics, Navy.

Maj. Gen. Mason M. Patrick, United States Army, Chief of Air Service, War Department.

S. W. Stratton, president Massachusetts Institute of Technology.

David W. Taylor, secretary National Advisory Committee for Aeronautics.

Orville Wright.

This special subcommittee considered the air bill carefully and submitted a unanimous report, which was approved by the National Advisory Committee for Aeronautics and transmitted to Senator Bingham on April 23. In its report the subcommittee enumerated a number of changes in important details deemed advisable, but focused its attention primarily on two principles involved which it characterized as "fundamentally unsound and prejudicial alike to the best interests of aviation and to the Government." These were the policies at that time contained in the bill providing for the Federal establishment and operation of airports and for the extension of Federal control to include all air navigation.

FEDERAL ESTABLISHMENT AND OPERATION OF AIRPORTS

After citing specific provisions of the bill authorizing the Federal establishment and operation of airports, the subcommittee in its report commented on this principle as follows:

The policy of the Federal Government regarding airports and the encouragement of air navigation should be analogous to its policy regarding seaports and the encouragement of water navigation. In the latter field the Government makes charts, establishes and maintains lighthouses, dredges channels, furnishes weather forecasts and storm warnings, and provides for inspection and licensing, but leaves to municipal authorities the control of port facilities. In aid of air navigation the Federal Government should chart airways, establish markers, including lights for night flying, establish and maintain emergency landing fields, furnish weather-report service, and provide for inspection and licensing, but leave to municipal authorities the control of airports.

Although it is not clearly stated in any one place, the bill does authorize the Secretary of Commerce to purchase, establish, maintain, and operate airports. If this measure should become a law in its present form, the effect would be to destroy the initiative of municipalities in providing their own airports and to bring about demands for large appropriations by Congress for the acquisition by the Secretary of Commerce of land in cities and towns in all parts of the country, and the preparation of such land for use as airports. The financial burden on the Federal Treasury would be so tremendous that it would take a great many years to carry the policy into effect, if, indeed, the responsibility thus assumed would ever be discharged. One result would be certain: Airports would not be established as needed, and the primary object of the bill—the encouragement of commercial aviation—would be defeated. On the other hand, if the municipalities desiring airports are given to understand that they must provide their own airports, the job can be accomplished simultaneously and without delay in all such cities and towns, and the cost involved would fall where it properly belongs.

As to the disposition of the postal airports, after the Post Office Department has placed the air transportation of the mails upon a contract basis and has gone out of the business of operating aircraft, it would be a mistake to transfer these airports to the Secretary of Commerce to be maintained and operated by the Federal Government. This would involve discrimination between the cities that had postal airports and those that had not. It would be the entering wedge for Federal operation of airports. It is considered of great importance as a matter of policy that the Secretary of Commerce should not at any time be engaged in the operation of postal airports, for, if the precedent were to be established, the bad effects might last a long time. The postal airports should be transferred to the municipalities concerned, upon arrangements to be made by the Postmaster General, subject to approval by the President, or if no satisfactory arrangements can be made they should be closed and the properties disposed of as are any other public properties no longer needed by the Federal Government.

The report then recommended specific changes in the bill to carry into effect the views expressed.

FEDERAL CONTROL OF ALL FLYING

Under the subject of Federal control of all flying, the subcommittee reported as follows:

The bill as it passed the Senate provided for Federal control of air navigation used in interstate or foreign commerce. The bill as it passed the House extends Federal control to intrastate commerce and to private flying, interstate and intrastate. This principle involves two major considerations—one of constitutionality, the other of policy. Although it appears to your committee that private flying can not be construed to constitute "commerce" in the legal sense and that its regulation by the Federal Government can not therefore be justified under the commerce clause of the Constitution, nevertheless your committee does not feel competent to do more than sound a note of warning as to the doubtful constitutionality of this feature of the bill, and will confine itself primarily to the matter of policy involved.

Assuming for the sake of argument that the regulation of intrastate air commerce and of all private flying is constitutional, is it advisable? The primary purpose of the whole bill is, or should be, to encourage commercial aviation, and as an incident to that encouragement to provide reasonable and needful regulations. The regulation of private flying is not necessary at this time to encourage the development of commercial aviation, nor is the regulation of intrastate air commerce necessary to the major purpose of the bill—encouragement of commercial aviation. In the judgment of your committee, the wisest policy to pursue at this time is to provide a maximum of encouragement with a minimum of regulation.

Commercial aviation has not been able to exist in European countries without direct subsidies that amount to from 50 to 95 per cent of the cost of the service rendered the public. Commercial aviation, on a sound commercial basis is nonexistent in Europe. Private flying, due largely to strict and unnecessary governmental regulation, is at a very low ebb in European countries. Although authentic statistics are not available, it is the judgment of your committee that there are in America to-day more privately owned and operated aircraft than in all Europe, and that the reason for this condition is that private flying in Europe has suffered from premature regulation as well as from overregulation, whereas private flying in America has had complete freedom of development. We believe that the effect of the bill in its present form on private flying in America will be to drive out of the air a major portion of the privately owned aircraft and private flyers, primarily because of the nuisance and inconvenience of unnecessary regulations. It is therefore recommended that the regulatory provisions of the bill be limited to the regulation of aircraft engaged in interstate or foreign commerce.

The subcommittee then proposed changes in the text deemed necessary to accomplish its recommendation in this respect, and in the conclusion of its report said:

We are strongly in favor of the enactment of legislation to encourage and regulate commercial aviation. We believe that the objections presented to the principle of Federal establishment of airports and to the principle of Federal regulation of private flying at this time and in the manner proposed in this bill are fundamental, and that it would be better that the bill should fail of enactment than that either of these principles should be retained.

In transmitting to Senator Bingham the report of the subcommittee, which was signed by each of the 10 members, Doctor Walcott, chairman of the National Advisory Committee for Aeronautics, concurred and invited particular attention to the concluding recommendation as above. The report of the subcommittee was presented to the conferees on the bill and the changes in principles recommended by the committee were accepted, and along with some other minor changes were incorporated into the conference report which was adopted soon after by the Senate and House of Representatives and the measure was approved by the President and became a law on May 20, 1926.

The act created the position of an additional Assistant Secretary of Commerce specifically to aid in the administration of the Federal air law and in the encouragement of commercial aviation.

Although the air commerce act may not be without fault in some details, it is the opinion of the committee that experience will show that it is sound in principle and that it will prove to be the legislative foundation for the air commerce of the future.

CONFERENCE WITH AIRCRAFT INDUSTRY

Up to the present time the greater part of the productive thought and energy of those interested in the development of aviation has been devoted to the interests of military and naval aviation. In this respect the problems of the manufacturers and of the Government were largely merged and came under regular consideration by the committee through its subcommittees. With the passage of the air commerce act of 1926, an impetus has been given to the growth of commercial aviation, and the committee is of the opinion that a new series of problems peculiar to commercial aviation will confront manufacturers and operators of aircraft.

In accordance with the policy announced in its last annual report, and in order to give the representatives of the industry an opportunity to present some of the new problems arising out of commercial aviation with a view to the incorporation of the same in the committee's research program, the committee held, on May 24, 1926, at the Langley Memorial Aeronautical Laboratory, Langley Field, Va., its first joint conference with representatives of aircraft manufacturers and operators. At this conference the committee was represented by its subcommittee on aerodynamics and members of the laboratory staff, Dr. Joseph S. Ames, chairman of the executive committee and of the subcommittee on aerodynamics, acting as chairman.

At a preliminary meeting held in the morning the history, functions, and work of the committee were briefly outlined, following which the representatives of the industry were shown the facilities of the laboratory and the character of the problems under investigation. In the afternoon the conference proper convened. After a brief statement by the chairman as to the purpose of the meeting, there was general discussion of the problems of commercial aviation, in which the representatives of the industry participated. Among the needs of commercial aviation as pointed out were the development of a small, light airplane for individual use, which would have the ability to take off and land in a much smaller space and which would be safer than present-type airplanes; further information as to the problem of control at low speeds; and greater consideration in airplane design for the comfort and convenience of passengers. One research problem proposed at the conference, the investigation of the M-6 and M-12 airfoils equipped with trailing edge flaps, was promptly incorporated in the committee's research program.

Following the conference an executive session of the committee on aerodynamics was held, while the representatives of the industry were conducted on an inspection of the Army facilities at Langley Field as the guests of the commanding officer and witnessed a special aerial demonstration which had been arranged in their honor.

THE DANIEL GUGGENHEIM FUND FOR THE PROMOTION OF AERONAUTICS

On January 16, 1926, Mr. Daniel Guggenheim announced the foundation of the Daniel Guggenheim Fund for the Promotion of Aeronautics and his intention to place at its disposal the sum of \$2,500,000. The fund is administered by a board of directors consisting of 15

members representatives of the highest type of commercial and scientific activities, and the whole fund, including principal and interest, is available for expenditure in the discretion of the board.

According to the statement of the founder, the general purposes to which the new fund will devote itself may be broadly defined as follows:

1. To promote aeronautical education both in institutions of learning and among the general public.
1. To assist in the extension of fundamental aeronautical science.
3. To assist in the development of commercial aircraft and aircraft equipment.
4. To further the application of aircraft in business, industry, and other economic and social activities of the Nation.

Two members of the National Advisory Committee for Aeronautics, Dr. W. F. Durand, past chairman, and Mr. Orville Wright, are members of the board of directors. From the statement of the purposes of the fund and the obviously high character of the members of the board of directors, it may be confidently expected that its activities will be carefully planned to produce a maximum of immediately practical and substantial assistance to aviation in its commercial, industrial, and scientific aspects, while at the same time avoiding duplication with existing agencies, governmental and private.

COOPERATION OF ARMY AND NAVY

Through the personal contact of the heads of the Army and Navy air organizations serving on the main committee and the frequent personal contact on the subcommittees of their chief subordinates who have to do with technical matters in aeronautics, there has been accomplished in fact not only a coordination of aeronautical research, which is the major function of the committee, but also a coordination of experimental engineering activities of the services and an exchange of first-hand information, comment, and suggestions that have had beneficial effects in both services. The needs of each service in the field of aeronautical research are discussed and agreements invariably reached that promote the public interests. The cordial relations that usually follow from frequent personal contact are supplemented by the technical information service of the committee's office of aeronautical intelligence, which makes available the latest scientific data and technical information secured from all parts of the world. Although there is a healthy rivalry between the Army and Navy air organizations, there is at the same time a spirit of cooperation and a mutual understanding of each other's problems that serve to prevent unnecessary duplication in technical developments in aeronautics.

Much of the fundamental research work of the committee has grown out of requests received from the Army and Navy for the study by the committee of particular problems encountered in the services, and in connection with this work the committee desires to give special recognition to the splendid spirit of cooperation of the two services with the committee. Each service has placed at the disposal of the committee airplanes and engines required for research purposes, and has otherwise aided in every practical way in the conduct of scientific investigations by the committee. Without this cooperation the committee could not have prosecuted successfully many of its investigations that have made for 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, and by the naval authorities at the Hampton Roads naval air station.

INVESTIGATIONS UNDERTAKEN FOR THE ARMY AND THE NAVY

As a rule research programs covering fundamental problems demanding solution are prepared by the technical subcommittees and recommended to the executive committee for approval. These programs supply the problems for investigation by the Langley Memorial Aeronautical Laboratory. When, however, the Army Air Corps or the naval Bureau of Aeronautics desires special investigations to be undertaken by the committee, such investigations, upon approval by the executive committee, are added to the current research programs.

The investigations thus under conduct by the committee during the past year for the Army and the Navy may be outlined as follows:

FOR THE AIR CORPS OF THE ARMY

Full-scale investigation of different wings on the Sperry messenger airplane.
 Investigation of the behavior of an airplane in landing and in taking off.
 Investigation of the flat spin of the Douglas O-2 airplane.
 Comparative wind-tunnel tests of the M-6, M-12, and Clark Y airfoils.
 Investigation of pressure distribution over the wing section of a VE-7 airplane.
 Investigation of pressure distribution and accelerations on a pursuit type airplane.
 Investigation of performance characteristics of the aeromarine variable-thickness and variable-camber wing.
 Acceleration readings on the PW-9 airplane.

FOR THE BUREAU OF AERONAUTICS OF THE NAVY DEPARTMENT

Investigation of the effect of fineness ratio on airship models.
 Investigation and development of a solid-injection type of aeronautical engine.
 Development of supercharger for aircraft engines.
 Distribution of loading between wings of biplanes and triplanes.
 Flight tests of superchargers.
 Effect of varying the aspect ratio and area of wings on the performance of a fighter airplane with a supercharged air-cooled engine.
 Investigation of aerodynamic loads on the U. S. S. *Los Angeles*.
 Investigation of spoiler aileron control for TS airplane.
 Investigation of performance characteristics of DT and CS seaplanes.
 Investigation in the variable-density wind tunnel of standard propeller sections with various camber ratios.
 Investigation of performance of five propellers in flight.
 Investigation of water-pressure distribution on seaplane hulls.
 Investigation of the forces on seaplane floats under landing conditions.
 Investigation of autorotation on the NB-1 airplane.
 Investigation of performance of model air propellers in a free air stream and in front of a VE-7 model.
 Propeller tests on an SC-1 airplane.
 Determination of the effect of polish on the surface of airfoil models.
 Determination of stresses in aircraft in flight.
 Effect of various forms of cowling on performance and engine operation of fighter airplane with supercharged air-cooled engine.

USE OF NONGOVERNMENTAL AGENCIES

The various problems on the committee's approved research programs are as a rule assigned to governmental agencies for study and investigation. 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. Such special reports are published the same as other technical reports of the committee. In this way the committee makes effective use of the facilities of educational institutions and the services of specialists in the scientific study of the problems of flight.

COOPERATION WITH BRITISH AERONAUTICAL RESEARCH COMMITTEE

Cordial relations have existed for the past several years between this committee and the British Aeronautical Research Committee. These have been greatly strengthened by the delivery on four different occasions of the annual Wilbur Wright memorial lecture before the Royal Aeronautical Society of Great Britain, by Americans closely affiliated with the work of this committee. Three members of the National Advisory Committee for Aeronautics—Dr. W. F. Durand, Dr. Joseph S. Ames, and Dr. David W. Taylor—and a member of our

subcommittees on aerodynamics and materials for aircraft who later became a member of the advisory committee—Commander J. C. Hunsaker, United States Navy—have had the honor of delivering this lecture. This led to a closer interchange of thought between those interested in aeronautical research in the two countries.

These cordial relations were further strengthened by the visit, in 1925, of the chairman of the British Aeronautical Research Committee to the Langley Memorial Aeronautical Laboratory and to other research laboratories in this country at which the work is coordinated by the National Advisory Committee for Aeronautics. This visit led directly to the request on the part of the British committee for the loan of certain instruments specially designed by this committee for aeronautical research work, which was granted. After completion of their tests of the instruments, the British authorities furnished this committee the information they had obtained, which proved to be very useful.

The research committees of the two countries have cooperated for several years in an attempt to bring about a standardization of wind tunnels so that the results of tests in various tunnels will be strictly comparable. For this purpose models of airships, airplanes, and wing sections first tested by the British committee were sent to this country and tested by this committee. The tests in the variable-density wind tunnel at Langley Field were especially valuable in giving results at values of Reynolds Number comparable with results obtained in full-scale flight tests.

STANDARDIZATION OF WIND-TUNNEL RESULTS

For the past several years a program of tests has been under way in various wind tunnels in this country and abroad on several series of standard models with a view to bringing about, a standardization of wind-tunnel results by a comparison of the results of these tests.

As part of this program, tests have been under way in various wind tunnels on three-cylinder models having a length ratio of 5:1 and four models of the U. S. A. 16 airfoil section having an aspect ratio of 6:1 and lengths varying from 18 to 36 inches. The tests on these models have not yet been completed.

During the past year the program of standardization tests for the wind tunnels of this country has been extended to include tests of three geometrically similar disks 4, 8, and 12 inches in diameter, respectively. These disks have been constructed and have been tested at the Langley Memorial Aeronautical Laboratory, and will later be tested in the wind tunnels at the Washington Navy Yard, the Bureau of Standards, the Massachusetts Institute of Technology, and McCook Field.

On request of the Aeronautical Research Committee of Great Britain, the committee is now testing in its variable-density wind tunnel at Langley Field a model of the R. A. F. 15 wing section on a Bristol fighter airplane, a model of the R. A. F. 19 wing section on a BE-2E airplane, and a model of the R. A. F. 30 section on a Bristol fighter airplane, for comparison with the results of wind-tunnel and full-scale tests conducted on these sections in England.

In response to suggestion of the Aeronautical Research Committee that valuable information might be obtained if a metal propeller model which had been tested in this country in an open-type wind tunnel could be sent to England and tested in one of the closed-type tunnels of the National Physical Laboratory, the committee forwarded to England for this purpose a metal propeller model which had previously been tested in the open-type wind tunnel at Stanford University.

STANDARDIZATION OF AERONAUTICAL SYMBOLS AND ABBREVIATIONS

During the past year the American Engineering Standards Committee has had under way a program for the simplification and standardization of symbols and abbreviations used in technical and scientific fields. This program is being carried out by a sectional committee on scientific and engineering symbols and abbreviations of the standards committee, the sponsors for which are the American Association for the Advancement of Science, the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Society of Mechanical Engineers, and the Society for the Promotion of Engineering Education.

The National Advisory Committee for Aeronautics has cooperated in this project in the preparation of the proposed standard symbols for aeronautics. Dr. Joseph S. Ames, chairman of the executive committee and of the subcommittee on aerodynamics of the National Advisory Committee, acted as chairman of the subcommittee on aeronautics of the sectional committee on scientific and engineering symbols and abbreviations. The following organizations were represented on this subcommittee in addition to the National Advisory Committee for Aeronautics: The Army Air Corps, the Naval Bureau of Aeronautics, the Bureau of Standards, the United States Weather Bureau, the Air Mail Service of the Post Office Department, the American Society of Mechanical Engineers, the Society of Automotive Engineers, and the Society for the Promotion of Engineering Education. A meeting of the subcommittee was held on April 23, 1926, and a list of aeronautical symbols was recommended for approval as American standard. This list is now being considered by the sectional committee.

EXHIBIT AT NATIONAL SESQUICENTENNIAL EXPOSITION

On invitation of the United States commissioner for the National Sesquicentennial Exposition in Philadelphia the committee installed an exhibit in the Transportation Building, where other Government exhibits were installed. The direct expenses involved were defrayed from allotments made by the United States commissioner. The committee's exhibit occupied a prominent position just inside the main entrance of the Transportation Building. It covered an area of approximately 450 square feet. The exhibit was composed mostly of working models illustrating facilities and methods employed in the conduct of aeronautical research in the committee's laboratories at Langley Field, Va. There was a scale model of the variable density wind tunnel; a model showing the working of the control system of an airplane; a model showing why an airplane flies, which illustrated graphically the dynamic reaction of the air upon the wings of an airplane in flight; a model showing the effect of a rotating cylinder in an air stream and illustrating the principle involved in the Flettner rotor ship; an airplane fuselage section showing special research instruments installed to record various flying characteristics of an airplane, and various models showing the distribution of pressure over the surfaces of airplane wings and airship envelopes and controls. There was also a comprehensive photographic display showing the work in progress and the methods and facilities used by the committee at the Langley Memorial Aeronautical Laboratory. Over the exhibit was an inflated spherical balloon 12 feet in diameter.

The exhibit was one of the first Government exhibits installed and opened for inspection, and because of the public interest in aeronautics and the fact that many of the models could be operated by the visitor himself by pressing buttons, the exhibit proved to be popular to such an extent that visitors kept the working models in nearly continuous operation.

The general message conveyed to the public by the committee's exhibit was that there is an agency in the Government devoted to the study of the fundamental problems of flight and that the National Advisory Committee for Aeronautics supervises and conducts scientific research in aeronautics.

PART III

REPORTS OF TECHNICAL COMMITTEES

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.
Capt. H. C. Richardson, United States Navy, vice chairman.
Dr. L. J. Briggs, Bureau of Standards.
Lieut. Ernest W. Dichman, United States Army, matériel division, Air Corps, McCook Field.
Lieut. W. S. Diehl, United States Navy.
Prof. Alexander Klemm, Department of Commerce.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Maj. Leslie MacDill, United States Army, matériel division, Air Corps, McCook Field.
Prof. Charles F. Marvin, Weather Bureau.
Dr. Max M. Munk, National Advisory Committee for Aeronautics.
Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics.
Dr. A. F. Zahm, construction department, Washington Navy Yard.

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. To 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. To meet from time to time on call of the chairman and report its actions 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 committee on aerodynamics has direct control of the aerodynamical research conducted at Langley Field, certain propeller research conducted at Stanford University under the supervision of Dr. W. F. Durand, and a number of special investigations conducted at the Bureau of Standards. The aerodynamical investigations undertaken at the Washington Navy Yard, the matériel division of the Army Air Corps at McCook Field, the Bureau of Standards, and the Massachusetts Institute of Technology are reported to the committee on aerodynamics.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

ATMOSPHERIC WIND TUNNEL.—Airfoils.—During the past year models of the N. A. C. A. 81, N. A. C. A. 81-J, Clark Y, M-6, and M-12 airfoils were tested for lift, drag, and pitching moments. In addition, two wing models of particular interest were tested. The first had a section developed by Professor Witoszynski to give a high lift. The second model had the U. S. A. 27 section with protuberances added to the upper surface. The purpose of the protuberances was to lower the induced drag by reducing the lateral flow of air, but the tests showed only a uniform increase in profile drag and no reduction of induced drag.

The results of the biplane-triplane tests made last year were reported for publication.

The magnitude and distribution of aerodynamic pressures was determined on a model of the upper wing of the Fokker D-VII airplane. This model was equipped with an aileron of the overhanging balanced type and unusually large pressures were observed on this overhanging portion, indicating that specifications for the sand loading of this type of aileron should be changed. The effect of a "spoiler" on the pressures over the wing was also investigated with this model. The results showed the spoiler flaps to be a very effective means of producing large rolling moments through the "spoiling" of the lift.

A model of a tapered and twisted thick wing (N. A. C. A. 81-J) was tested to determine the effect of twist on the distribution of lift along the span. This research is still in progress.

A model of the PW-9 wing cellule was designed and constructed for pressure distribution tests. These tests will be made in cooperation with the flight research section to compare with similar pressure-distribution tests on the full-scale airplane.

Investigation of spins.—A number of tests have been made during the past year on a model of the Boeing NB-1 airplane in an investigation of its spinning characteristics. These tests which were made at the request of the Bureau of Aeronautics, consisted chiefly of autorotation tests. In order to simulate as closely as practicable a true spin, it was necessary to construct a specially designed holder which allowed the model to rotate freely with a limited degree of freedom in pitch and yaw. Observations were made on the autorotation rates and angles for various model conditions, wind speeds, angles, etc. In particular, studies were made of the effects of changing the c. g. location, the gap, the size of the vertical tail surfaces, and the location of the vertical tail surfaces.

The tests on the NB-1 were followed by somewhat similar series of tests on a model of the Douglas O-2 airplane for the Army Air Corps. In the O-2 tests the investigation was extended to the effects of aileron settings, flap settings, and stagger on the autorotation rates and angles. It was found that a definite reduction in autorotation range and rate follows the use of differential ailerons, upturned flaps, or stagger in the form of sweepback of the lower wing.

It became increasingly evident during the NB-1 and O-2 tests that the restrictions necessarily imposed in this type of test are sufficient to prevent a duplication of the full-scale spin. Analyses of the wind-tunnel and the free-flight test data showed that precessional moments play a very important part. It was therefore concluded that the wind tunnel could best be used for quantitative determinations of the effects of given modifications on the autorotation rates and angles, while the spin itself could best be studied in a "dropping" test. For the dropping test a scale model is constructed of balsa wood in such a manner that its loading and mass distribution can be adjusted to correspond to any desired condition within reasonable limits. Such a model, when dropped in still air from a considerable altitude—in the present case from the top of an airship shed—very closely duplicates the motion of the full-scale airplane. The dropping tests which have been made to date have given very satisfactory results and appear to be an excellent method of extending the wind-tunnel investigations.

Miscellaneous.—The resistances of three geometrically similar disks were measured for the purpose of standardization of wind tunnels. The same disks are to be tested in other tunnels with a view to their standardization.

The investigation of the forces on rotating cylinders at large ratios of peripheral speed to air speed was concluded.

The results of the tests on flapping fabric have been completely analyzed.

As in the past, instruments for tunnel and flight research have been calibrated and checked in the wind tunnel.

VARIABLE-DENSITY WIND TUNNEL.—With the exception of one or two short periods of minor repair, this tunnel has been in operation through the entire year. Seventy tests, comprising 220 runs, were completed—43 tests on airfoils, 11 on airplane models, 4 on airship models, and 22 on air flow, calibration, and work of a similar nature.

Tunnel wall-interference tests.—Tests were made in the tunnel on five airfoils of the N. A. C. A. M-6 section having different aspect ratios to determine the effect of the tunnel walls on the airfoil characteristics. Further tests using the R. A. F. 19 airfoil section are being made to check the results of the above tests. A report covering the entire search will be published.

A transverse cross-sectional survey of the air flow at six pressures was made along three diameters at the test section. Particular attention was given to the dynamic pressures close to the wall. The results of this survey were then utilized in determining the theoretical effect of the flow structure. Further work on the theoretical effect is being done.

Sperry messenger airplane model.—Tests were completed on this model fully rigged, using six sets of wings of different section (U. S. A. 5, U. S. A. 27, U. S. A. 35B, R. A. F. 15, Clark Y, and Göttingen 387); the model was also tested with and without a propeller (to scale) at five different pressures ranging from 1 to 20 atmospheres. A report of this work is in preparation.

A. D. C. (Upson) airship model.—A series of tests was completed on this model through a complete pressure range (1 to 20 atmospheres) under the following conditions: Bare hull, hull with car and fins, and hull completely rigged as the MC-2, all at zero angle of pitch; and hull completely rigged at 10 degrees angle of pitch. The resistance of the bare hull was found to be only 40 per cent that of the fully rigged airship. At the maximum pressure the Reynolds Number was equivalent to that of the airship flying at one-quarter cruising speed.

U. S. N. propeller sections.—Six airfoils generated from sections of the United States Navy standard propeller form were tested at 1 and 20 atmospheres density. These sections occur at various radii of a propeller blade. The results obtained are of special interest because of the opportunity for the study of scale effect on a family of airfoil sections having different thickness ratios. A report on these tests has been completed.

N. A. C. A. M-6 and M-12 airfoils with flaps.—A series of tests is now under way to determine the lift, drag, and pitching moment of the N. A. C. A. M-6 and M-12 airfoils with flaps of various sizes and at various flap angles. On these tests the angle-of-attack range is being extended to $+48^\circ$ to determine the aerodynamic characteristics past the burble point. The tests on a 6 by 36 inch M-6 airfoil have been completed. The model was equipped with 20 per cent flaps and ailerons. These were set at seven angles and airfoil characteristics determined. The center of pressure travel was computed for the entire wing under these various conditions.

Miscellaneous.—Improvements in wind-tunnel technique are being continually made. Experiments in the use of plaster-of-Paris airfoils have been conducted. The effects of surface texture and of irregularities in models are being studied.

Several miscellaneous airfoil models have been tested and reported upon, as follows: Clark Y, Witoszynski B-47, N. A. C. A. M-12, N. A. C. A. CYH, R. A. F. 15, N. A. C. A. 81, N. A. C. A. 81-J, R. A. F. 19, and Göttingen 398.

PROPELLER RESEARCH EQUIPMENT.—The committee has under construction at the Langley Memorial Aeronautical Laboratory a new piece of equipment known as the propeller research equipment. Its purpose is to make tests on full-sized airplane propellers under flying conditions. It consists of a wind tunnel of the open-throat type large enough to permit the mounting of a full-sized airplane fuselage with its engine and propeller.

The throat diameter of this tunnel is 20 feet, and an air velocity of 100 miles per hour at the throat is expected. The experimental chamber is 50 feet by 60 feet in plan and 50 feet high. The driving propeller is to be 28 feet in diameter and to have eight cast-aluminum blades. It is to be driven by two Diesel engines of 1,000 rated horsepower each. The air-

plane to be tested will be mounted on a balance by which the torque and thrust may be measured. Lift, drag, and pitching moments may be measured also if desired. There is also to be a special test fuselage provided with a dynamometer for measuring engine torque. This is for checking results obtained on the regular balance.

It will be possible with this equipment to make tests which could not heretofore be made on engines, engine cowlings, and other full-sized airplane parts, as well as tests of propellers under actual flying conditions.

The main structure of this equipment has been completed. The power plant is now under construction. It is expected that the tunnel will be put in operation in a few months.

FLIGHT RESEARCH.—*Airships*.—The most extensive research conducted at the Langley Memorial Aeronautical Laboratory during the last year, and probably the most complete of its kind, was the series of tests conducted on the U. S. S. *Los Angeles* to find the stresses and loads experienced by a rigid-type airship in maneuvering flight and in flight in gusty air. The loads were determined from pressure measurements made simultaneously at approximately 300 points on the tail surfaces, hull, and car, together with acceleration tests and turning trials. At the same time stress measurements were made by the Bureau of Aeronautics of the stresses in a number of the main structural members of the airship. By means of instruments recording other measurements, such as air speed, angle of yaw, angular velocity, and control position, the motion of the airship was determined. Since all the measurements were simultaneous and continuous for a period of time, the result is a history of the motion of the airship through the air, the pressures and loads experienced during this motion, and the stresses imposed in the structure by the loads experienced. The large amount of data obtained has not as yet been arranged in the form of a report, but such results as have been worked up show definitely that the loadings and stresses experienced in gusts greatly exceed those in maneuvers.

Airplanes.—Within the year a research has been completed in which a study was made of the effect of the proximity of the ground upon the aerodynamic characteristics of a full-scale airplane. The tests conducted consisted in the determination of the lift and drag characteristics of an airplane close to the ground and at an altitude sufficient to avoid any possibility of "ground effect." It was found that the drag of the airplane was materially reduced upon approaching the ground and that the reduction might be satisfactorily calculated according to theoretical formulæ. In continuation of this work, smoke-flow photographs and pressure-distribution measurements were made to study the type of air flow over the wings when the drag was reduced, but because of excessive experimental difficulties the work was discontinued for the time being.

The information obtained last year on the landing and take-off characteristics of nine of the service type airplanes in use by the Army Air Corps has been studied and analyzed, and formulæ derived for determining the distance required for the ground run of an airplane in wind of any velocity. By use of the formulæ the ground run of any airplane of normal design can be calculated to a reasonably close approximation, thus enabling the estimating of this characteristic in a proposed design, and also providing data for estimation of the requisite size of proposed landing fields.

The aerodynamic characteristics of an airplane equipped with several different sets of wings has been determined. The tests were conducted on a Sperry messenger airplane equipped successively with R. A. F. 15, U. S. A. 5, U. S. A. 27, and Göttingen-387 wings, and the lift and drag characteristics of the airplane with each set of wings determined throughout the flight range of angle of attack. The results establish the comparative characteristics of these airfoils free from scale effect, and furthermore provide a standard for comparison with wind-tunnel tests.

A complete investigation is in progress of the air-pressure distribution over the wings and tail surfaces of a high-speed pursuit airplane. Together with the pressure measurements, accelerometer readings are made of the accelerations of the wing tips, tail surfaces, and center of gravity of the airplane, in order to determine the occurrence of the inertia loads at these places with respect to air loads and also the correlation of the inertia loads at the wing tips and

tail surfaces with those at the center of gravity. Since the investigation is being conducted to provide the data necessary for a revision of the methods of load computations and loading specifications, the investigation includes violent maneuvers to make certain the obtaining of the most critical loadings.

The work on seaplanes during the year has been on the problem of measuring the pressures and forces experienced by a seaplane hull or pontoon at landing or while taxiing. For this type of research an apparatus has been developed and constructed with which it is possible to measure the water pressures over the bottom of a pontoon. The apparatus is of the recording type and is capable of recording continuously over a period of time the pressures that occur as a result of the impact at landing and the impact of waves striking the hull. Since these pressures exist for only a very short time it has been necessary to construct the apparatus to record pressures one one-hundredth of a second in duration.

In addition to the water-pressure distribution tests the investigation includes the determination of the magnitude and direction of the resultant force on the seaplane. This is accomplished by means of three 3-component accelerometers mounted, respectively, in the pontoon nose, pontoon tail, and fuselage of the seaplane which measure the magnitude and direction of the forces experienced at each place. A knowledge of this resultant force is required for use in the design of the pontoon bracing. Both researches are in progress at present.

A study of the possible increase in lateral control by the use of spoiler flaps acting in conjunction with ailerons has been completed. The angular velocities and accelerations in roll and in yaw of a TS airplane fitted with spoiler gear were measured and the change of altitude was determined when the spoiler gear was employed and when the ailerons alone were used. The results showed that this particular type of gear offered little if any improvement over the usual aileron control.

A knowledge of the character of gusts and the velocity of the air in them is of importance in studying the behavior of airplanes in landing, but is of even greater importance in the study of the forces on airships encountering gusts. As a preliminary step in the study of gusts an apparatus has been installed at the laboratory to measure the velocity of air in gusty and stormy weather. With the apparatus a series of measurements are taken over a period of time when the weather is stormy or the air particularly bumpy and the resulting information studied to determine the possibility of forecasting the nature of gusts to be expected in different conditions of weather.

For the better study of the maneuverability of airplanes, particularly in spins, experiments were conducted with a specially constructed camera obscura with which the maneuvers were photographed from the ground. As yet the development is in a preliminary stage, but the results obtained indicate the practicability of this method of studying maneuvers.

Propellers.—The flight tests of four experimental propellers on the VE-7 airplane, mentioned in last year's report, are practically completed. Wind-tunnel tests of similar model propellers are being conducted and the results will be compared with flight results to establish the applicability of the former to full-scale use and if possible determine the correction necessary.

Several propellers are being calibrated to be used in determining the torque characteristics of supercharged engines in flight.

Performance.—The performance tests mentioned in last year's report are still in progress on the DT and CS airplanes to determine the possible improvement in the performance of these airplanes equipped with Wright T-2 and T-3 engines when the use of (a) overcompression, (b) superchargers, (c) gears, or (d) combination of gears with overcompression or supercharging, is resorted to. A series of performance tests of a DH-9 airplane equipped with a hub-type engine dynamometer has been completed. These tests were conducted for the dual purpose of testing the practicability of the dynamometer and of obtaining data on the variation of engine power with altitude.

ANALYTICAL SECTION.—During the past year the following investigations were undertaken.

Pressure loss in tubes.—This research, which had been begun during the previous year, was concluded. Experiments in the laboratory and tests on an airplane in flight showed that the pressure loss is negligible in apparatus as now installed for pressure-distribution tests.

Simple formulæ for determining the error caused by mass forces in connecting tubes as used in tests on large aircraft such as airships were worked out and the limits wherein friction and elasticity cause no appreciable error of the pressure reading were laid down from experimental curves. However, considerable mathematical analysis failed to reveal any formulæ for computing the pressure errors, if any exist.

Influence of the wind-tunnel flow structure on the wing air forces.—This investigation deals with the modification of the air forces on an airfoil in a wind tunnel caused by an uneven distribution of the flow velocity over the throat cross section.

An analytical method suitable for the investigation of this and other problems was developed and was applied to the study of flow structure in the variable-density wind tunnel. The research will be completed by combining the analytical and experimental results.

Study of orifices.—A study has been begun of the relation between the size of the orifice used in pressure-distribution measurements and the size and form of the surface over which the pressure is being measured. A wind tunnel with a 6-inch throat diameter was built and put in operation to supplement the analytical work by researches of a physical character. Although it has been in operation only a part of the year, there has been completed an investigation of one phase of the more general problem of the measurement of air pressures. This consisted in the determination of the effect of orifice size on the pressure distribution around a circular cylinder. The results show that orifices now being used on aircraft and models in making pressure-distribution measurements do not introduce appreciable errors in the pressure readings.

INSTRUMENT RESEARCH AND DEVELOPMENT.—A considerable amount of work has been done during the year in adapting instruments previously constructed to meet the more exacting requirements of the tests recently undertaken by this laboratory. The changes made in the design and operation of the instruments have made the procurement of valuable test data possible.

An example of work of this nature is the instruments which were prepared for a series of flight tests with the U. S. S. *Los Angeles*. Here the physical measurements taken were extremely small and changed in value slowly, the pressures being of the order of 1 inch of water. The pressure-recording instruments used on this test included three multiple recording manometers. Each manometer contained 60 complete differential pressure gauges, which simultaneously recorded upon a sensitized film pressures at various points on the airship. The pressure records were synchronized with other records by electrically operated chronometers. The same recording instruments have been modified for a somewhat similar test on the Boeing PW-9 airplane, in which the pressures measured will probably be one hundred times greater than on the lighter-than-air craft and will change very rapidly in value. Such wide changes of characteristics illustrate the adaptability of these special research instruments.

The adaptation of two 30-capsule type recording manometers to record impact pressures on seaplane pontoons in landing was carried out successfully by converting the pressure capsules to electric recording instruments. There are 15 complete electrical units on each recorder, each unit consisting of a solenoid-operated optical system, connected electrically to a pressure-operated step-by-step rheostat secured to the pontoon being tested. Impact pressures of one one-hundred-and-fiftieth second duration can be recorded.

During the past year a number of the standard recording instruments were duplicated, such as recording altimeters, automatic observers, flight path recorders, and recording accelerometers. The optical and damping systems of the three-component type recording accelerometer were redesigned to permit of easier adjustment. The opportunity was taken on each instrument duplicated to incorporate improvements that would increase its reliability and usefulness.

A fixture for calibrating accelerometers and turn recorders was constructed and placed in service. Through its use the time required to make routine calibrations of these instruments is materially reduced and at the same time accurate calibrations may be made throughout the entire range of accelerations and angular velocities encountered by aircraft in free flight. In addition, the apparatus has been used to investigate the time lag and damping of accelerometers and it is intended to extend this investigation to turn recorders.

A large liquid manometer having 30 glass tubes was constructed for use in connection with wind-tunnel work. With this instrument permanent records of pressures are obtained on photostat paper. A second manometer of this type having 116 glass tubes is now under construction. An automatic yaw observer, a new continuous recording film drum, and special control reduction apparatus for use in recording position of airship controls were developed for use on the test of the U. S. S. *Los Angeles*.

Much valuable work was done on the elimination of temperature effect on recording instruments by the use of the altitude chamber which was constructed last year. Investigations of temperature and pressure effects have been made on practically all of the recording research instruments now in use at this laboratory. Changes have been made, where possible, in instrument construction to minimize this effect. However, in nearly all tests the temperature correction is determined before the instrument is installed, and a check is made after the test. In connection with this work a study of the change in viscosity with temperature of a number of oils suitable for instrument damping is under way. It is expected that an oil or a combination of oils will be found that will be satisfactory at the low temperatures encountered in some of the flight tests. More work remains to be done on this investigation before any definite conclusions can be drawn. The altitude chamber has been valuable in the investigation, at reduced pressure and temperature, of the performance of magnetos and spark plugs before their installation in airplanes for high-altitude tests.

An investigation is now in progress to determine the practicability of the use of carbon disks in conjunction with a cathode-ray oscillograph as an engine indicator for high-speed aircraft engines. Such an indicator would eliminate the inertia errors now present in the majority of such indicators and would be a means of obtaining the much-needed information as to the true pressures encountered in high-speed internal-combustion engines.

Considerable study has been given to the design and construction of a fuel-flow recorder for power-plant use. The work was undertaken for the purpose of making an instrument that would record the rate of fuel consumption of an aircraft engine during flight, thereby giving information needed in the investigation of engine characteristics. A Venturi type, a vane type, and a diaphragm type meter have so far been investigated. The latter type has proved the most satisfactory. It consists of a metal case which is divided into two compartments of different volume by a metal diaphragm. The fuel is directed through both compartments in its flow, thereby creating a difference in pressure which deflects the diaphragm. An optical system is provided to record the diaphragm deflection upon a moving film. However, more work remains to be done on this type of meter with a view to eliminating the effect of vibration.

At the request of the Bureau of Aeronautics a recording accelerometer was prepared and a series of tests made at the naval aircraft factory to instruct their personnel in taking records of catapult acceleration and deceleration.

STANFORD UNIVERSITY

The following investigations have been completed during the past year at the Stanford University aerodynamic laboratory:

(1) Tests of three model propellers in a free wind stream and in combination with a model VE-7 airplane. Two of the model propellers were of duralumin, one two-bladed and the other three-bladed, the driving face of the blades being concave or cambered somewhat more than the conventional design. The third model was of pressed steel (two-bladed) and provided with cloth fairing.

(2) Tests of a model propeller with symmetrical blade sections. The sections used in these tests were Göttingen airfoil No. 409.

(3) Tests of five metal model propellers of adjustable pitch. These models consisted of a single steel hub and five pairs of duralumin blades. Each set of blades was carried through complete tests with six separate angular settings, thus making in all 30 models.

Aeronautical activities at Stanford University, both in research and instruction, will be increased as a result of a grant received from the Daniel Guggenheim fund for the promotion of aeronautics. The wind tunnel will be moved from its present situation in a temporary building to a permanent location, and additional facilities and apparatus provided for research, including a wire aerodynamic balance in addition to the special propeller balance which has been in use for several years in the present laboratory. The grant will also provide for two new professorships—one in aerodynamics and one in design and construction. These two new chairs, together with the strengthened and improved laboratory facilities, are expected to lay a foundation for a well-balanced and thorough course of training in aeronautical engineering, as well as secure considerable extension in the amount and scope of the research work carried on.

WASHINGTON NAVY YARD

Airplane models.—During the past year the 8-foot wind tunnel at the Washington Navy Yard has been employed largely in testing airplane models. In all, 31 complete tests in pitch and yaw were made on 18 different designs. Eleven of these models accounting for 20 of the tests were Bureau of Aeronautics design studies. The remaining seven models were chiefly made up of service types which were tested for particular requirements.

In continuance of past practice four design studies were tested in both the landplane and the seaplane arrangement, while two models were tested with two wing sections and one model was tested with three wing sections. These tests have supplied data of considerable interest and value to the bureau, the most important feature probably being the high efficiency of the Göttingen-398 wing section and its modifications in biplane arrangements. The magnitude of the improvement as shown by thoroughly checked wind-tunnel tests is approximately 10 per cent in L/D at all normal angles. Flight tests are to be made at an early date to verify the wind-tunnel indications. Analyses of the tests on landplane and seaplane arrangements, which are now under way, indicate a remarkably uniform difference in parasite area, running from 1 to $1\frac{1}{2}$ square feet greater for the seaplane than for the landplane.

Another series of tests of great interest was made on the PN-9 model, in which wing incidences of 2° , 4° , and 6° to the thrust line were used. It was found that increasing the incidence from the original value of 2° to 4° (the value adopted for the PN-10) gave a marked improvement in take-off and cruising characteristics, with an unexpected increase in static stability.

Other tests included a study of the effect of flaps on the OL-1, tests on the UO-1 model through 360° in pitch, and the test of a biplane in which the lower wing had considerable taper and dihedral, so that its outer tip was attached to the upper wing.

Airfoils and wings.—Owing to the press of urgent airplane model tests, only four airfoils and one wing model have been tested during the past year. However, a number of airfoil tests have been projected and the models are now awaiting tests at a convenient opportunity. As explained in the previous report, these sections have been developed from standard sections with a view to producing desirable structural characteristics while retaining desirable aerodynamic characteristics.

Miscellaneous tests.—Tests have been made in pitch and yaw and at various speeds on 14 seaplane float models. These tests were made in the 4 by 4 foot wind tunnel and cover, in connection with previous tests, about every type of float now used or proposed for use. A report of the tests will be submitted later to the National Advisory Committee for publication.

The tests on fuselages have also been extended along the lines followed previously. A total of 12 models have now been tested and a report of these tests will also be submitted for publication later.

Three models of a special Heinrich wing radiator for racing airplanes were given the usual radiator tests while mounted on a dummy full-scale wing. Additional tests on the wing alone gave the resistance added by the radiator and indicate that while this type of radiator has much less resistance than the cellular type, it probably has considerably more resistance than the true wing type. Tests were to be made on a section of a wing radiator to determine this resistance, but it has not been practicable to obtain a satisfactory model.

Tests have been started on a series of 12 struts, using the Navy No. 1 section. These tests will cover the effect of fineness ratio, scale, and trailing-edge radius.

Two models of the *MC-2* airship were given tests in pitch and yaw and for damping moments. It was originally intended to make the complete series of tests on the first model, but a very large scale effect was found in the damping tests, necessitating the construction of a second and larger model from which satisfactory data were secured.

Wind-tunnel equipment.—Only one important change has been made to the wind tunnels during the past year. The chain drive for the 4 by 4 foot tunnel has been replaced by a direct drive, which eliminates considerable vibration while giving steadier operation at higher speeds.

During the tests on fuselages and floats a new type of stream-line spindle was used with very satisfactory results. This spindle replaces the conventional tapered cylindrical spindle and not only reduces the correction to a very low figure but also practically eliminates mutual interference.

BUREAU OF STANDARDS

Wind-tunnel investigations.—As mentioned in the last annual report of the committee, measurements have been made at Edgewood Arsenal of the pressure distribution over six airfoils ranging in camber ratio from 0.10 to 0.20 at speeds from 0.5 to 1.08 times the speed of sound. During the past year the necessary computations have been made and the results have been presented to the committee and accepted for publication as a technical report. An interesting result of the tests was a limiting value of the decrease in pressure on the upper surface of any airfoil of about one-half to one atmosphere.

Apparatus is now being installed at the Bureau of Standards of capacity comparable to that at Edgewood Arsenal for conducting investigations at high speeds. It is expected to continue work on the design of expanding nozzles to give speeds much greater than the speed of sound and a stream free from standing pressure waves. Work will also be carried out on airfoils, especially force measurements on thin airfoils.

Measurements have been made of the aerodynamical characteristics of several aircraft bombs for the Ordnance Department of the Army. The bomb fins were designed by the method developed at the bureau, and in all cases the observed center of pressure was the same as the computed center of pressure within about 3 per cent of the bomb length. A study was made of the comparative effectiveness of 4, 6, and 8 fins. Four fins are most favorable when the dimensions are kept within a prism containing the bomb body.

The investigation of turbulence in wind tunnels has been continued in cooperation with the National Advisory Committee for Aeronautics. Various experiments have been carried out with hot wire instruments for measuring variations in air speed and with small direction vanes for measuring variations in wind direction. Neither of the instruments has yet been developed to give satisfactory measurements of variations the frequency of which is greater than about 10 per second.

The measurements of the distribution of pressure over the surface of a square base prism, 8 by 8 by 24 inches, have been published as Scientific Paper 523 of the Bureau of Standards. During the past year measurements have been made of the total forces on square-base prisms of several heights in continuation of the work on wind pressures on structures. Measurements of the distribution of pressure over two cylinders, one 8 inches in diameter and 60 inches long, the other 12.6 inches in diameter and 60 inches long, have been completed and the results are now being prepared for publication.

A large number of measurements have been made on an airplane model submitted by Mr. Charles Ward Hall. The measurements included pitching, rolling, and yawing moments with various control settings on the original model and on several modifications of the original model.

Aeronautic instrument investigations.—The research and development work of the aeronautic instruments section of the Bureau of Standards has, as in other years, been largely in cooperation with the National Advisory Committee for Aeronautics, the Bureau of Aeronautics of the Navy, the Air Corps of the Army, and other Government departments.

The instruments constructed for the National Advisory Committee for Aeronautics include three electric resistance thermometers and two galvanometer units each containing three galvanometers. The electric thermometers are for measuring the free air temperatures in flight to an accuracy of less than 1° F. in the range -40° to $+90^{\circ}$ F. The galvanometer units contain small, highly sensitive galvanometers of the type developed during the previous year. Rubber diaphragms of unusually good aging characteristics have been inserted in six Ogilvie air-speed meters which are now being given service tests at the Langley Memorial Aeronautical Laboratory.

An electric type air-speed meter of the frequency type has been developed and constructed for the Army Air Corps. The output of an alternating current generator, driven by a propeller in the air stream, is measured by an induction type indicator which is calibrated in air speed.

A superheat meter and a gas-pressure alarm, both for use on the U. S. S. *Los Angeles*, were constructed for the Bureau of Aeronautics. The gas-pressure alarm is an improvement of an earlier model constructed at this bureau. Considerable work of an experimental nature has been under way on earth inductor compasses which has resulted, among other things, in reducing greatly the trouble inherent in the use of brushes. Rattling tests have been conducted on specimens of duralumin containing patches riveted in the same manner as for the proposed all-metal airship.

The equipment of an altitude chamber in which both the temperature and pressure can be reduced has been in progress. The chamber is of such size as to admit two observers and the instruments under test.

Altitude-pressure tables based on the United States standard atmosphere have been prepared with especial reference for use in determining altitudes. These supplement the tables given in Technical Report No. 218 and are being issued as Technical Report No. 246.

A summary of the current experimental work on the friction of instrument bearings and pivots has been prepared for the Army Air Corps. A report on the theory of the deflection, temperature errors, and lag of capillary type rate-of-climb indicators has been under preparation during the past year for the Bureau of Aeronautics.

Assistance has been given the Army Air Corps and the Bureau of Aeronautics of the Navy in standardizing the specifications for aircraft instruments. About 20 specifications were rewritten and submitted to the air services. The revisions related largely to the tests and tolerances.

The theoretical and experimental work on statistical hysteresis has been summarized in a report now in press as a Bureau of Standards scientific paper. A new property of materials, the static hysteresis modulus, is proposed and evaluated for Armco iron. An extension of this work promises data important to designers of precision instruments.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Wind tunnels and equipment.—No radical changes have been made in the wind tunnels or equipment. A new wire balance with automatic beams of light construction has been designed for the 4-foot wind tunnel. The beams have been built.

Propeller interference tests.—The tests commenced during 1925 in the $7\frac{1}{2}$ -foot wind tunnel to find propeller effects on a one-fourth scale DH-4B model have been continued throughout the year. Complete measurements have been made at angles of attack from 0° to 20° of the forces and moments on the model due to various slip streams, the effect of the model on the propeller, the increase in control moments due to slip stream, the downwash caused by the propeller, and the slip-stream velocity in so far as it affects the force on the horizontal tail. Following the tests with the regular DH-4B fuselage, some investigation has been carried on of the effect of rounding the fuselage with and without a spinner on the propeller.

Miscellaneous tests.—A few complete models of airplanes have been tested in the 4-foot tunnel. Other researches in the tunnel include an investigation of wing locations in multiplanes, air-flow tests of several radiator cores, and some work on the cooling capacity of a radiator unit. Student researches included ground effect on control moments, the air force on bridge trusses, and the effect of hinge gap on control forces.

McCOOK FIELD

General.—Only about 50 routine tests were made in the McCook Field 5-foot wind tunnel last year. The work done has been largely of the nature of improvements in apparatus and technique.

High-force tests.—Use of the wire balance has been inaugurated for routine work on 6 by 36 inch airfoils at 120 miles per hour, and on model airplanes at whatever velocity the model will stand. The high forces obtained, reaching 250 pounds, have introduced novel problems, for example, some metal airfoils bow up in the middle; in one case the steel "skid" carrying the pitching moment force deflected sufficiently to take a permanent set. It has been necessary to adopt optical methods of aligning the model during tests, since wire stretch becomes large at high velocities, and ordinary mechanical methods are insufficient. By means of telescopic model alignment, the use of self-balancing scales has been justified, especially for the higher velocities. Travel of the scale pans is taken care of simultaneously with wire stretch by raising and lowering the platforms on which the scales rest. The motion is derived from electric motors under control, by means of push buttons, of the telescope operator.

Low-force tests.—The N. P. L. type balance is retained for low-speed tests under 60 miles per hour, since at these lower speeds the wire balance is less accurate and less convenient.

It has been necessary to reopen the question of "spindle and guard corrections," and new values have been determined which seem to be more satisfactory than the conventional values originated at the National Physical Laboratory. The correction was found sufficient to jeopardize one series of tests made to determine the effect of size of airfoil; in this series models from 1 by 6 inches to 6 by 36 inches were under examination and ultimately required the adoption of a stream-line wire in lieu of a spindle.

Pressure drops through Goodyear-Zeppelin radiator.—In order to predict the energy loss in a tunnel-type radiator proposed by the Goodyear-Zeppelin Corporation for airship use, a dummy section representing the radiator was connected to the 14-inch wind tunnel, air was caused to flow through the section, and the pressure drop under various conditions was observed. The purpose of the data was to predict the amount of flow to be expected through the radiator, rather than to measure resistance or heat transmission.

Surface-flow pictures.—Many photographs have been taken of the air flow at the surface of various models, using a method borrowed from the General Electric steam turbine laboratories and developed for use at low velocities. This method involves painting the model with a mixture of lampblack and kerosene; the air flow then records its direction by scouring fine channels in the pigment; "surface lines" result and may be photographed at leisure. A study has been made of the divergence between this "surface" flow and the adjacent flow outside the boundary layer.

Officers' school.—The usual period required by the McCook Field officers' school was devoted to instructing 13 officers in wind-tunnel procedure.

Removal to Wright Field.—In anticipation of moving the 5-foot and 14-inch tunnels to Wright Field in 1927, new construction has been discontinued. The propeller dynamometer, though completed, has not been put into use, and various other development projects have been postponed.

Test of model of engine-dynamometer stand.—To facilitate design of ventilation apparatus for the engine test laboratory proposed for Wright Field, two models have been tested in the 14-inch tunnel. One was an exhaust flue actuated by an air jet; the other was a cooling-blast system.

Service tests.—Service tests have included the following:

- 1/24-scale model, long distance reconnaissance (on wire balance at 100 miles per hour).
- 1/50-scale model, Huff-Daland XHB-1 heavy bombardment (on N. P. L. balance at 40 miles per hour).
- 1/36-scale model, Huff-Daland XLB-1 light bombardment.
- 1/36-scale model, Douglas C-1 transport.
- 1/30-scale model, Douglas XNO-1 night observation.
- Twenty 3 by 18 inch propeller airfoils at speeds from 30 to 250 miles per hour (N. P. L. and wire balances).
- Six 6 by 36 inch air foils on wire balance at 40 to 140 miles per hour, as follows:

STAE-27A.

Clark Y-.

Clark Y-15.

Clark Y-18.

Clark Y-21.

Göttingen-398.

Model of Gligorin rotor wing.

Hinge moments on $\frac{1}{16}$ -scale model XHB-1 rudder.

Hinge moments on model of a balanced elevator.

Various instrument calibrations, including rate-of-climb indicators, yaw meters, anemometers, experimental Pitot-static tubes, etc., and a Nipher static-head orifice.

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.

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

Henry M. Crane, Society of Automotive Engineers.

Prof. Harvey N. Davis, Harvard University.

Dr. H. C. Dickinson Bureau of Standards.

Prof. C. Fayette Taylor, Massachusetts Institute of Technology.

Capt. T. E. Tillinghast, United States Army, matériel division, Air Corps, McCook Field.

Commander E. E. Wilson, United States Navy.

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 plant 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 Corps or the Bureau of Aeronautics are reported upon at the meetings of the committee on power plants for aircraft.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

FUEL INJECTION ENGINE.—The performance requirements of aircraft engines are exacting. Maximum power per pound engine weight, minimum fuel consumption per horsepower per hour, and maximum reliability are required. The application of hydraulic injection and compression ignition of fuel oils to aircraft engines not only involves all the problems of the usual heavy, slow-speed oil engine but considerably intensifies them and introduces many new problems because of the combination of high speeds, high mean effective pressures, low fuel consumption, and light weight with reliability required.

The major fundamental problems involved in building a successful fuel-injection engine for aircraft service are, first, the efficient physical and thermal preparation of the fuel to obtain its practically instantaneous autoignition at injection into the engine cylinder; second, the efficient and complete distribution of the fuel throughout the combustion chamber by the use of proper oil spray shapes, atomization, and energies, combustion chamber shapes, and turbulence to obtain its complete uniform mixing, and therefore combustion, with the air in the cylinder early in the power stroke; third, the determination of the effects of a number of engine variables, such as compression ratio, speed, temperatures of the air, water, and oil, and engine design details upon mechanical, volumetric, and thermal efficiencies.

The solutions to these fundamental problems are obtained by conducting systematic investigations in injection hydraulics, on the characteristics of fuels, on the characteristics of oil sprays in dense gases by means of ultra high-speed motion-picture photography, on the bench and engine performance of injection valves, pumps, and miscellaneous oil injection equipment, on the engine performance of cylinders, cylinder heads, and oil injection systems on single-cylinder test engines for various test conditions and engine design details, and by theoretical analyses.

Engine performance—Combustion chamber design.—The study of the effects of combustion chamber design, chiefly as regards shape and turbulence, on engine performance has been continued. This work has been carried on with a single-cylinder Liberty engine base fitted with a special steel cylinder to which the several cylinder heads to be tested are bolted. The effects of compression ratio may be investigated by inserting metal gaskets between the engine base and cylinder or between the cylinder and cylinder head. The cylinder bore is 5 inches and the stroke 7 inches. Standard aircraft engine pistons, connecting rods, and valves are used.

The performance of a flat disk-shaped combustion chamber having one inlet and one exhaust valve in the head, and the injection valve located at the circumference of the combustion chamber, has been determined for speeds up to 1,800 revolutions per minute, various injection rates and injection pressures, and various powers with a compression ratio of 12.7 to 1, and a controlled maximum cylinder pressure of 800 pounds per square inch. The fuel pump used was of the impact type, cam-actuated and fitted with means for timing the injection of the fuel. The injection valve was of the automatic spring-loaded stem type, with an impact surface to direct and atomize the fuel. The performance of this cylinder head with and without directed flow of the inlet air was determined for a speed of 1,500 revolutions per minute. The best results were obtained with an injection valve opening pressure of 1,400 pounds per square inch, a high rate of fuel injection, and with the flow of the inlet air directed to produce turbulence in the cylinder. For full-load conditions, i. e., a fuel weight per cycle giving 15 per cent excess air, and 1,500 revolutions per minute, the indicated mean effective pressure was 82 pounds per square inch and the fuel consumption 0.65 pound per indicated horsepower per hour with the flow of inlet air not directed. With directed flow of the inlet air the indicated mean effective pressure was 99 pounds per square inch and the fuel consumption 0.53 pound per indicated horsepower per hour. At two-thirds load, i. e., two-thirds the fuel weight per cycle at full load, the indicated mean effective pressure was 82 pounds per square inch and the fuel consumption 0.41 pound per indicated horsepower per hour.

The performance of a precombustion or bulb-type cylinder head with the greater part of the clearance volume in the bulb was completed from the previous year for speeds up to 1,800 revolutions per minute, and various powers with a compression ratio of 9.9 and a controlled

maximum cylinder pressure of 1,000 pounds per square inch. The orifice between the cylinder and bulb produced moderate turbulence. An eccentric-operated fuel pump and an automatic diaphragm type injection valve were used. A high rate of fuel injection and injection pressures up to 10,000 pounds per square inch were investigated. The indicated mean effective pressure obtained at full load and 1,800 revolutions per minute was 106 pounds per square inch, and the fuel consumption 0.48 pound per indicated horsepower per hour. At two-thirds load, the indicated mean effective pressure was 99 pounds per square inch and the fuel consumption 0.35 pound per indicated horsepower per hour.

The construction of the second bulb-type cylinder head, arranged to permit the investigation of compression ratios up to 15 to 1, and providing for various precombustion chamber volumes and shapes and degrees of turbulence has been completed. The performance of this cylinder head has been determined for a compression ratio of 13.5 to 1, a precombustion chamber volume equal to one-half the clearance volume, speeds from 600 to 1,800 revolutions per minute, maximum cylinder pressures from 500 to 750 pounds per square inch, and a high degree of turbulence. The effects of extending the fuel valve nozzle various distances into the precombustion chamber have been determined. Power performance characteristics have been determined for progressive alterations in the orifice between the cylinder and precombustion chamber. A cam-operated fuel pump and an automatic injection valve having special discharge characteristics and producing extremely fine fuel atomization were used. The best results thus far have been obtained at 1,300 revolutions per minute with the injection valve nozzle extended one-quarter inch into the precombustion chamber, and with the orifice flared to discharge the burning gases from the precombustion chamber so as to produce uniform fuel distribution and a high rate of gas rotation in the cylinder. At full load and 1,600 revolutions per minute, the indicated mean effective pressure was 119 pounds per square inch and the fuel consumption 0.44 pound per indicated horsepower per hour, with 740 pounds per square inch maximum cylinder pressure. The indicated mean effective pressure at two-thirds load was 107 pounds per square inch and the fuel consumption 0.32 pound per indicated horsepower per hour, with 690 pounds per square inch maximum cylinder pressure. At one-third load the indicated mean effective pressure was 65 pounds per square inch and the fuel consumption 0.26 pound per indicated horsepower per hour, with 610 pounds per square inch maximum cylinder pressure.

Engine performance—Engine variables.—The investigation of the effects of a number of engine variables, chiefly compression pressure, injection timing, injection valve opening pressure, and maximum injection pressure or engine power performance, mechanical, volumetric, and thermal efficiencies, is nearly completed for a wide range of conditions. This work has been carried on with the N. A. C. A. Universal test engine which is constructed so that the compression ratio, injection timing, and inlet and exhaust valve timing and lift may be readily varied while the engine is running. The present combustion chamber of this engine is well adapted for and has been used extensively in carburetor engine work. It is pent-roof shaped, however, and no definite turbulence is provided so that complete mixing of the fuel and air in oil engine research is not obtained. A special fuel preheating and atomizing injection valve has been developed and used with an eccentric-operated fuel pump adjusted to give a high rate of fuel injection.

The performance of this cylinder head has been determined for various powers at 1,500 and 1,750 revolutions per minute, with a compression pressure of 360 pounds per square inch and a maximum cylinder pressure of 800 pounds per square inch. The indicated mean effective pressure at full load and 1,750 revolutions per minute was 116 pounds per square inch and the fuel consumption 0.45 pounds per indicated horsepower per hour. At two-thirds load the indicated mean effective pressure was 96 pounds per square inch and the fuel consumption 0.35 pound per indicated horsepower per hour.

The performance of this cylinder head and injection system, for a constant quantity of fuel injected per cycle equal to 83 per cent full load, at 1,500 revolutions per minute, and for compression pressures ranging from 325 to 560 pounds per square inch and a wide range of injection timing and maximum cylinder pressures, has been completed. With a compression

pressure of 345 pounds per square inch and the fuel entering the cylinder 2 degrees before top center, the indicated mean effective pressure was 81 pounds per square inch, the fuel consumption 0.54 pounds per indicated horsepower per hour, the maximum cylinder pressure 590 pounds per square inch, and the mechanical efficiency 65 per cent. When the injection timing was advanced to start injection of the fuel 20 degrees before top center the indicated mean effective pressure was 112 pounds per square inch, the fuel consumption 0.39 pounds per indicated horsepower per hour, and the mechanical efficiency 76 per cent. When the fuel was injected 31.5 degrees before top center, the indicated mean effective pressure was 132 pounds per square inch, the fuel consumption 0.33 pounds per indicated horsepower per hour, and the mechanical efficiency 81 per cent. The maximum cylinder pressures for the last-quoted performance were excessive and not permissible in a service engine.

Starting tests, made when the engine was cold, show that, starting from rest, only one revolution is necessary to obtain invariable starting with compression pressures of 420 pounds per square inch.

The engine idles continuously without load at 150 revolutions per minute, and at lower speeds until the inertia of the rotating parts fail to carry the piston through the compression stroke.

Two cylinder heads have been designed and are being constructed for use with the Universal test engine, in which special provisions have been made for varying the compression ratio, testing various types of injection valves, and investigating the effects of various kinds and degrees of turbulence.

The design of a piston for high-speed oil engine operation, incorporating fundamental methods for minimizing mechanical and thermal distortion and friction, chiefly by small, pressure-lubricated bearing surfaces and special autoseal piston rings, is practically completed.

A complete analysis of the cycle efficiencies that may be obtained in practice for various combinations of compression ratio, maximum cylinder pressure, and point of fuel cut-off has been undertaken. A considerable amount of test data, taken with the Universal test engine, has been used to establish approximate pressures, temperatures, and efficiencies for use in this investigation.

Fuel injection pumps and valves.—Further investigations on the performance of an eccentric-operated injection pump have been made for various speeds, pump adjustments, injection valve opening pressures, and maximum injection pressures. This work has been done with the special bench testing equipment, by means of which the effects of the several variables in an injection system on the lag of the appearance of the spray behind the pump cycle, the duration of injection, the weight of fuel discharged per cycle, and the maximum injection pressure have been determined. A critical point in the lag of the spray, at which the first part of the injection changed from that caused by a pressure wave to that caused by normal pressure rise in the system, was found when investigating the effects of the opening pressure of an injection valve over a range from 600 pounds per square inch to 5,000 pounds per square inch. The information obtained has been used in connection with engine tests with the same injection apparatus.

The fuel-injection bench testing equipment has been equipped with a light-tight chamber fitted with a small blower to remove oil vapor, and an Elverson oscilloscope. This apparatus has been used to observe the start, development, and cut-off of fuel sprays under operating conditions, and has aided in obtaining a knowledge of the action of different injection valves.

A new type of automatic injection valve, having only four parts and constructed without springs or sliding parts, has been developed for use with disk or conical shaped combustion chambers. The valve preheats the fuel and produces highly atomized sprays. The seats are constructed for continuous operation at temperatures up to 2,000° F. The performance reported for the Universal test engine was obtained for a small amount of fuel preheating with this injection valve.

A design of a similar injection valve, involving several modifications and fitted with thermocouples for temperature measurements, has been undertaken.

An automatic spring-loaded stem injection valve has been altered to give highly atomized fuel sprays with relatively high penetration. The valve has a high opening pressure, with

injection and fuel cut-off at pressures approximately of the same value as the opening pressure. The performance reported for the second bulb-type cylinder head was obtained with this injection valve.

An automatic diaphragm-type injection valve has been constructed, the design of which permits easy adjustment of the valve opening pressures, positive control of the maximum deflection of the moving parts, a wide variation in the stiffness of the diaphragm spring unit, and interchangeability and alteration of different types of valve stems and nozzles. This injection valve has been used in connection with several investigations on the characteristics of oil sprays in dense gases, carried on with the committee's spray photography apparatus.

Fuel spray characteristics.—Several investigations on the characteristics of fuel sprays have been completed during the past year. The work was carried out with the fuel-spray photography apparatus constructed and developed by the staff of the committee. This apparatus is constructed to permit determination of the performance of various types of mechanically operated and automatic injection valves for injection pressures up to 10,000 pounds per square inch and spray-chamber pressures up to 600 pounds per square inch. Records of the start, development, cut-off, and distribution of the fuel sprays are obtained by photographing them on a moving film at intervals of from 0.00025 to 0.0005 second during the period of injection. The spray photography apparatus has been described in previous reports of the committee.

An investigation was made of the hydraulic and design factors influencing and controlling the exact reproducibility of fuel sprays, and the phenomena of secondary discharges from automatic injection valves. The reproducibility was found to be controlled by the initial pressure in the injection valve and tube, and the secondary discharges by pressure waves produced by the rapid opening of the fuel cut-off valve, in connection with the dimensions of the various parts of the apparatus.

The effects of altering the spray-controlling parts of centrifugal injection valves on the characteristics of fuel sprays have been determined. The investigation also included studies of a noncentrifugal valve. For this work the angle of the helical fuel grooves that produced the rotation of the fuel jet was varied from 90 degrees, i. e., axial grooves, to 23 degrees; the ratio of the orifice area to the total cross-section area of the helical grooves was varied from 0.19 to 2.05; the ratio of the orifice length to the orifice diameter was varied from 0.20 to 2.50; and the location of the seat changed from a position before the helical grooves and orifice to a position between the helical grooves and the orifice. It was found that a considerable change in the characteristics of the sprays was caused by the first three variables. The results are for an injection pressure of 8,000 pounds per square inch and chamber pressures up to 600 pounds per square inch, and are given in terms of spray penetration, velocity, volume, cone angle, and effective distribution, i. e., ratio of spray volume to oil volume. The effects of the four variables investigated are too numerous and interdependent to be summarized in this report.

An investigation of the effects of fuel and spray-chamber gas density and viscosity on the characteristics of fuel sprays has been completed. A standardized injection valve and standardized injection and spray-chamber pressures were used. Gasoline, kerosene, Diesel engine fuel oil, and a furnace fuel oil were compared when injected into compressed air. Diesel engine fuel oil sprays were studied when injected into air, nitrogen, carbon dioxide, and helium at pressures ranging from atmospheric pressure up to 600 pounds per square inch. The results of major importance were the increase of penetration and decrease in spray cone-angle and distribution with increase in fuel density; the negligible effect of gas viscosity on the spray characteristics; and the fact that the density of the gases controlled the penetration and other characteristics of fuel sprays at room temperatures.

An investigation of the performance of several types of injection valves for various injection and spray chamber pressures and a wide range of related conditions is under way.

It has been decided to extend the present spray photography equipment to permit the study of the effects of air pressure, temperature, turbulence, and dilution with exhaust gases, upon the lag of autoignition, source of ignition, and combustion of atomized fuels for oil engines. Conditions comparable to those existing within engine cylinders will be sought, but the apparatus will be designed to permit the fundamental investigation of each variable over a wide

range of conditions independently of the other variables. Active work on this project has been started.

Fuel vapor pressures.—The data obtained in the investigation of the vapor pressures of six fuels, various mixtures of three of the fuels, a lubricating oil, and water are being prepared for publication. Temperatures up to 900° F. and pressures up to 5,000 pounds per square inch were recorded. The results indicate the stability and instability of the liquids tested and give the temperatures required to force the rapid vaporization of the fuels in an engine cylinder.

SUPERCHARGING—Adaptability of supercharged air-cooled engines to flight conditions.—Further study has been made of the adaptability of air-cooled engines to supercharging, using a Wright J-4A engine and a Roots type supercharger in a UO-1 airplane, in which the amount of supercharging was increased above that previously employed; that is, the supercharger capacity was increased to enable the maintenance of full supercharging to 28,000 feet, as compared to 18,000 feet, in order to determine the possibilities of utilizing the extra amount of supercharging with this type of engine. During this investigation considerable engine trouble was experienced from preignition caused by overheated spark plugs, the bronze bushings of which had become loosened in service, causing poor thermal conductivity and consequently poor spark-plug cooling. Extremely high cylinder temperatures accompanied this preignition condition both in flight and when operating at full throttle without supercharging on the ground. After the cylinders were fitted with new bushings this trouble was partially remedied, and several flights to 27,000 feet were made using varying amounts of benzol in the fuel mixture. In these flights the climb performance to 18,000 feet obtained with the lesser amount of supercharging was duplicated, but above that altitude cylinder temperatures increased somewhat above the maximum of 530° F. observed previously and, as no air cooler was employed, carburetor air temperatures increased from 160° to 200° F. Under these conditions there was a loss in engine speed and very little, if any, improvement, in the climb performance above 18,000 feet; in fact, the climb performance in some cases was considerably inferior.

From these results it was concluded that the extra amount of supercharging was not practical with this engine, owing in part to insufficient cylinder cooling capacity, poor spark plug cooling, and existence of high carburetor air temperatures, all of which combined to minimize the improvement in airplane performance to be expected from the additional supercharging. These conclusions must be qualified, however, as an engine having better spark-plug cooling might very probably have given better results.

In view of the success met with in employing the lesser amount of supercharging with the Wright J type air-cooled engines, a supercharger of more suitable proportions for use with 200 horsepower engines has been constructed. This supercharger has a displacement of 0.19 cubic foot per revolution and is designed to operate at rotor speeds from two to three times crankshaft speed. Tests of this supercharger in the laboratory have indicated a reduction of only 8 to 10 per cent in volumetric efficiency at a rotor speed of 6,000 revolutions per minute.

Characteristics of Roots superchargers.—Three superchargers suitable for use with 400 horsepower engines, having 25 per cent less displacement than the original supercharger designed for the Liberty engine and being geared to operate at increased rotor speeds to offset the reduced displacement, have been constructed. One of these machines has been tested in the laboratory to determine the characteristics of this type supercharger at the higher rotor speeds. It was found that the volumetric efficiencies at a rotor speed of 5,300 revolutions per minute ranged from 95 per cent with no compression to 90 per cent with 12 inches of mercury pressure difference across the rotors. At this speed and pressure difference, about 63 horsepower was required to handle 1.4 pounds of air per second with 75° F. intake-air temperature. The power required for a given air weight and pressure difference was slightly higher than for the original supercharger, owing to the increase in rotor speed necessary. The power required to drive the supercharger with free intake and discharge was 7.5 horsepower at 5,300 revolutions per minute, the power at lower speeds following an approximate cubic relation. At a given speed the power was proportional to the pressure difference, but at a given pressure difference the power increased with speed somewhat more rapidly than proportionally.

These tests have shown that the higher rotor speeds are practicable, thus enabling the advantages of reduction in size of the unit to be realized.

The effect of supercharger capacity on airplane performance.—One of the new type Roots superchargers has been mounted in a modified DH-4 airplane and flight tests started to determine the effect on airplane and engine performance of varying the supercharger capacity by changing the rotor speed. The present supercharger is geared to operate at 1.97 times crankshaft speed, giving a critical altitude of about 13,000 feet; and it is planned to use three additional drive ratios, giving critical altitudes from 9,000 feet to 22,000 feet.—Engine power will be obtained by using calibrated propellers.

Problems incidental to supercharging.—In connection with the problem of determining directly the altitude performance of supercharged engines, and thus establishing the relation between theoretical and actual performance, the full-scale propellers used in supercharger research with the DH-4 airplane are being calibrated in flight to obtain power and torque coefficients. A Bendemann hub type dynamometer used in obtaining these calibrations has proved suitable for this purpose. A report on the results obtained during preliminary flight tests of this dynamometer apparatus has been issued.

An investigation is also being undertaken to determine the relative specific fuel consumption of normal and supercharged engines in flight. In this connection, fuel-flow meters suitable for flight use are being investigated, but so far no instrument suitable in all respects has been developed.

BUREAU OF STANDARDS

Supercharging of aircraft engines.—The purpose of this investigation has been to determine the maximum improvement in engine performance to be expected as a result of supercharging. By means of the altitude-laboratory equipment it was possible to maintain sea-level pressure at the entrance to the carburetor and the pressure of the desired altitude at the exhaust ports. During the past year a Liberty-12 engine has been tested over a wide range of temperatures and pressures, and the results of this test, together with results of a previously made test of a Curtiss D-12 engine, are to be incorporated in a report to be published by the National Advisory Committee for Aeronautics.

Friction of aviation engines.—A report of this investigation has been completed. It discusses the influence of certain factors upon engine friction, among which are temperature of the air entering the engine, atmospheric pressure, throttle opening, engine speed, jacket-water temperature, compression ratio, and piston design.

Phenomena of combustion.—This investigation has been in progress several years. It is primarily a study of the factors which are of fundamental importance in governing the rates of explosive gaseous reactions and the nature of the physical and chemical phenomena involved, the ultimate object being more complete data on the explosive gas reaction in engine cylinders. During the year velocities of the carbon-monoxide-oxygen reaction have been measured for pressures of 1,400, 1,520, 1,700, and 1,900 millimeters of mercury. Several hundred measurements have also been made for pressures less than atmospheric.

Tests of fuel volatility.—Atmospheric distillations are at present generally used as the basis for judging the volatility characteristics of fuels. The results of such distillations are not, however, readily translatable into expected performance in the engine nor do they permit of direct quantitative comparison of fuels. For these reasons other methods of measuring fuel volatility have been investigated and a method which gives promise of being very useful has been developed. This method consists essentially of an atmospheric distillation in the presence of air.

Fuels for high-compression engines.—A considerable number of cracked gasolines have been tested in the single-cylinder engine during the past year. These gasolines in general are superior to straight-run products as regards antiknock characteristics. In that respect, therefore, they are particularly adapted for use in high-compression engines.

Investigation of bearing friction.—By means of a simple friction machine, comparisons have been made between the friction of a bearing when a light mineral oil is used and when the same

oil containing 1 per cent of diatomaceous earth is used. The results suggest the desirability of high viscosity from the standpoint of reducing wear, but the work has not been carried far enough to show whether or not, in a given type of equipment, the advantages of a high viscosity would outweigh the added difficulty of supplying an adequate amount of lubricant to the bearing surface and the increase in friction due to the higher viscosity.

Measurements of "break-away" torque.—A study has been made of the relation between oil viscosity and the torque required to start an engine in rotation. Results indicate that while the viscosity of the oil does have a pronounced effect upon the power required to rotate the engine at speeds of 100 revolutions per minute and higher, it does not affect appreciably the power required to start the engine nor to rotate it very slowly. In the light of these results it appears probable that when an engine starts or is operating very slowly practically all of the oil is squeezed out from between the rubbing surfaces and lubrication is dependent upon the so-called "oiliness" film.

Antifreezing solutions.—The past year has witnessed unusual activity in the development of antifreezing solutions for the cooling systems of internal-combustion engines. The freezing point of many of these solutions has been measured by the Bureau of Standards and their corrosive properties investigated.

NEW ENGINE TYPES

The Army Air Corps has discontinued for the present the development of the Almen engine upon which it has been working for some time. While this engine has interesting possibilities as compared with other water-cooled types, it suffers by comparison with the new air-cooled engines when power-plant weight is taken into consideration. The cam engine on which the preliminary work was done by the Army Air Corps has now been taken over by the Fairchild company and is being flight tested and further developed. It appears to have interesting possibilities from the standpoint of cheapness of construction. The Attendu heavy-oil engine under development by the Bureau of Aeronautics has shown sufficient promise to warrant the consideration of the next step in the development of such an engine, namely, a multicylinder engine for service use. It is expected that by utilizing the interesting results of the fundamental research conducted by the Langley Memorial Aeronautical Laboratory of this committee, substantial progress can be made in heavy-oil engines for aircraft.

In the water-cooled engine field but one new type of engine has been initiated. The Army Air Corps and the Curtiss Aeroplane & Motor Co. have brought out the new Curtiss V-1550, an engine incorporating the excellent features of its predecessors, the Curtiss D-12 and V-1400 engines. The new engine is conservatively rated at 500 horsepower at 2,100 revolutions per minute, and is being built with direct and with geared drive. The gears are of Curtiss design and construction and have successfully passed their endurance tests. The two Packard engines, the 1,500 and 2,500 cubic-inch models, have gone into quantity production for the Navy. Through refinements and improvements they have been advanced from the 1A-1500 and 1A-2500 to the 3A models of both engines. The Navy is using the 1,500-cubic-inch engine as direct drive, inverted, and geared types, the direct-drive engine being used in the aircraft-carrier pursuit or fighting type airplanes, the inverted engines in the aircraft-carrier and battleship amphibian spotting-type airplanes, and the geared engines in the long-range patrol airplanes of the PN-10 type. The Army Air Corps is using the Packard 2,500-cubic-inch geared engine in a number of single-engined bombers. The Navy has on order 150 Packard 3A-2500 direct-drive engines for its aircraft-carrier type of bomber.

The most striking development of the year is the advance made in air-cooled engine types. The Wright model J-4 has advanced to the J-5 type, of which type the Navy has ordered over 300. This engine includes among its improvements a greatly improved cylinder construction, fully inclosed valve gear, the new Eclipse concentric-impulse or flywheel starter, and a three-barreled carburetor. The new cylinder construction permits full throttle operation at fuel consumptions 10 per cent less than that usually obtained in engines using water-cooled cylinders. The J-5 engine has been supercharged at sea level to an unusually high mean effective pressure. Its cooling is excellent. The Wright P-2 radial air-cooled engine which has been

under development for some time has been superseded by newer types which are far more promising.

Two new types of radial air-cooled engines are being developed for the Navy by the Pratt & Whitney Aircraft Co. The first of these engines, the "Wasp," has a displacement a little over 1,300 cubic inches. On this capacity it develops a normal horsepower of 425 on a dry weight of 650 pounds, including the propeller hub but excluding the Eclipse starter. This engine, the development of which began with the organization of the Pratt & Whitney Co. August 1, 1925, has proved most successful. The "Wasp" has been thoroughly flight-tested in various types of fighter airplanes and has been adopted by the Navy as the standard type engine for pursuit or fighting airplanes. A contract has recently been let for 200 of these engines, which are required to meet the Navy's building program for this year.

Simultaneously with this development, the Pratt & Whitney Co. has been developing a larger radial air-cooled engine for the Navy, to be known as the "Hornet." The engine conforms in general to the "Wasp" design but has a displacement of 1,690 cubic inches and is expected to develop 500 horsepower at 1,800 revolutions per minute. This engine is designed for use in heavy-duty types of aircraft, such as scouting, bombing, and torpedo seaplanes, either single or twin engined.

In competition with the "Hornet" the Wright Aeronautical Corporation is building a large radial air-cooled engine (the R-1750 "Cyclone"), which is being tested. This engine also is designed to meet the Navy's requirements for a heavy-duty engine. It incorporates all the results of the Wright Co.'s previous wide experience in the radial air-cooled engine field. From these two engines the Navy expects to be able to choose an excellent power plant for its aircraft-carrier bombers.

The Army Air Corps has continued the development of its air-cooled Liberty with a view to conducting flight tests and determining the possibilities of the V-type air-cooled engine. The results to date have been encouraging. The success of both the radial and V type air-cooled engines in pursuit or fighting types of airplanes is one of the striking events of the year. At present the trend in practically all new types of aircraft engines is away from water cooling and toward air cooling.

REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT

ORGANIZATION

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

Dr. George K. Burgess, Bureau of Standards, chairman.
 H. L. Whittemore, Bureau of Standards, vice chairman and acting secretary.
 S. K. Colby, American Magnesium Corporation.
 Henry A. Gardner, Institute of Paint and Varnish Research.
 Dr. H. W. Gillett, Bureau of Standards.
 Prof. George B. Haven, Massachusetts Institute of Technology.
 Zay Jeffries, Aluminum Co. of America.
 J. B. Johnson, matériel division, Army Air Corps, McCook Field.
 George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
 Capt. H. C. Richardson, United States Navy.
 G. W. Trayer, Forest Products Laboratory, Forest Service.
 Starr Truscott, National Advisory Committee for Aeronautics.
 Hon. Edward P. Warner, Assistant Secretary of the Navy for Aeronautics.

FUNCTIONS

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

1. To aid in determining the problems relating to materials for aircraft to be solved experimentally 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. To 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. To 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 manufacturers interested in the particular problems, 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 have been formed, as follows:

Subcommittee on metals:

Dr. H. W. Gillett, Bureau of Standards, chairman.

Zay Jeffries, Aluminum Co. of America.

J. B. Johnson, matériel division, Army Air Corps, McCook Field.

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

Starr Truscott, National Advisory Committee for Aeronautics.

H. L. Whittemore, Bureau of Standards.

Subcommittee on woods and glues:

G. W. Trayer, Forest Products Laboratory, Forest Service, chairman.

H. S. Betts, Forest Service.

George W. Lewis (ex officio member).

H. L. Whittemore, Bureau of Standards.

Subcommittee on coverings, dopes, and protective coatings:

Henry A. Gardner, Institute of Paint and Varnish Research, chairman.

Dr. W. Blum, Bureau of Standards.

Warren E. Emley, Bureau of Standards.

Prof. George B. Haven, Massachusetts Institute of Technology.

Isadore M. Jacobsohn, Bureau of Standards.

George W. Lewis (ex officio member).

P. H. Walker, Bureau of Standards.

E. R. Weaver, Bureau of Standards.

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, the matériel division of the Army Air Corps, and the National Advisory Committee for Aeronautics.

The Bureau of Aeronautics and the matériel division of the Air Corps, 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 Forest Products Laboratory, and the Industrial Research Laboratories.

MEETINGS OF THE COMMITTEE

The committee held several meetings during the year. The corrosion of the light alloys having received considerable attention in both the technical and the lay press as a result of the loss of the *Shenandoah* and the subsequent investigations, this subject was discussed at each meeting. At a meeting held at the Langley Memorial Aeronautical Laboratory, Langley Field, Mr. J. A. Boyer, chief chemist of the American Magnesium Corporation, discussed the corrosion of magnesium and the magnesium aluminum alloys containing manganese in a most illuminating manner. This paper will be published by the committee as a technical report. After this meeting the committee inspected the laboratory and later visited the naval air station at Hampton Roads, Va. In the course of this visit an all-metal airplane about 6 years old,

which had been exposed for three years, was inspected and samples of the parts of the structure were taken. Much interest was shown in the all-metal floats of certain seaplanes which had just returned from the Tropics. The personnel of the station discussed the behavior of these floats in considerable detail.

SUBSTITUTE FOR SILK PARACHUTE CLOTH

The general increase in the use of parachutes makes it desirable to develop American-made substitutes for the silk cloth used in their manufacture. At present this is practically all imported as cloth. Very good success has been obtained in the development of American-woven silk cloths to be substituted for the imported.

The committee has also had under way for some time an investigation intended to develop a cloth acceptable for use in the manufacture of parachutes which might be made in this country from materials produced here. After preliminary investigation the problem has resolved itself into the finding of a method of treating cotton yarns which will impart to these yarns the added strength and elasticity required to make them equal silk yarns.

A very careful study has been made of the physical properties of silk parachute cloth and its constituent yarns and these have been compared with cotton yarns. In order to produce the necessary increase in the strength and elasticity it has been found necessary to subject the yarns from which the cloth is to be woven first to a process of mercerization and then to a coating with a special dope. It has been demonstrated that it is possible to increase the strength of cotton yarns very considerably by the special dope, and this phase of the problem is fairly well along. However, the stretch is little affected by the doping, and the treatment which promises most improvement here is mercerization.

A very careful study has been given to the general subject of mercerization, especially as applied to fine cotton yarns, and processes which appear to give the desired results have been developed.

The question of the origin of the yarns has also been studied and yarns made from Egyptian (probably Sakellaridis), Indian Sea Island, Egyptian, and Sea Island cottons have been experimented with. Incidentally this work has required a lengthy study of the effect of twist in the yarns on their properties.

So far the work has been done on a laboratory scale and it has proved difficult to produce any large quantities of treated yarns having generally the same characteristics. However, several pieces of experimental cloth have been woven to determine whether the woven cloth would develop the properties expected from the yarns. In order to economize on treated yarn, the cloths were woven using a warp of normal yarn and filling of treated yarn. When tested for tensile strength, stretch, and resistance to tear, these cloths have given fairly satisfactory results, but not what was anticipated. Certain difficulties due to the scale on which the work is being carried on must be overcome, probably by working on a somewhat enlarged scale.

Although the progress is not as great as was hoped for the past year it has been material, and in view of the information which has been obtained it is believed it will not be long before an acceptable substitute can be supplied to replace the imported silk parachute cloth.

SUBCOMMITTEE ON METALS

Intercrystalline embrittlement of duralumin.—During the past year this subcommittee has worked on the program for investigating intercrystalline embrittlement of duralumin, which was approved by the committee on materials for aircraft last year.

Sheet duralumin had previously been found to be subject to a peculiar deterioration resulting from corrosion. Without any marked surface evidence of the change, the metal may become very brittle as a result of the weakening of the intercrystalline "bonds" by corrosion. The change begins at the surface and gradually penetrates inward.

Considerable progress on this investigation has been made and it is believed that satisfactory solutions for many phases of the problem are in sight. Much time necessarily has been spent, however, on examination of materials from the U. S. S. *Shenandoah* and U. S. S. *Los Angeles*.

This work has considerably delayed the completion of the program on embrittlement. This examination of different material from the airships which had seen considerable service showed that both the lattice and the channel sections were more susceptible to corrosion if the metal had been worked after heat treatment.

An encouraging fact which should not be overlooked is that almost all the duralumin which has been used for airship construction in this country has given satisfactory service until the airship was taken out of commission. It is realized, however, that the design for future airships may impose conditions for which any corrosion of the duralumin might reduce the structural strength of the airship. This is particularly true if the duralumin is to be used in very thin sections. Slight corrosion, which in more massive sections would be of little importance, in these very thin sheets would be very dangerous.

The purpose of the investigation has therefore been twofold:

First. To study those factors in duralumin (composition, heat treatment, mechanical treatment, etc.) which are favorable to this type of corrosion with the aim of making the alloy more resistant to corrosive attack.

Second. To study means for protecting or modifying the surface of duralumin.

Dependable methods of producing intercrystalline corrosion have been developed. Tension test bars are used as specimens throughout and are pulled in tension after a definite exposure to corrosive attack by a solution of sodium chloride and hydrogen peroxide. Materials from several different sources have been used in the investigation. These have been tested plain and coated in a variety of ways.

All the duralumins examined were corroded by the method used. Usually this produced a combination of pitting and intercrystalline penetration. Proper heat treatment appeared to reduce the severity of the attack but cold working after heat treatment increased it. However, it seems improbable that complete immunity to intercrystalline attack can be had in the Cu-Mg-Si type of alloy, which gives the highest physical properties, since the present indications are that susceptibility to attack is connected with the presence of copper.

Although laboratory tests can not truly reproduce service conditions, it is believed that protection by spraying with pure aluminum, followed by heat treatment, and the coating with bitumastic enamel are probably the two surest methods. Other methods, of varying qualities, are, however, available.

Exposure panels protected by various methods have been paralleled with tension bars similarly coated. These will be tested at intervals to determine the change in physical properties with exposure.

If the laboratory tests can be taken as criteria of service, properly protected duralumin is a thoroughly dependable material of construction.

From its work so far the committee is convinced that—

(1) Although the corrosion of duralumin is a serious matter, especially because the attack may be almost completely hidden, it is not more serious than the corrosion of ferrous metals.

(2) The corrosion of duralumin can be prevented for all practical purposes.

Structures for airships.—Tests of girders duplicating those used in the *Shenandoah*—made while that airship was under construction—showed that the strength of such girders was determined by the elastic properties of the channels and the type of restraint offered by the lattices. The principal elastic constants of the channels are their flexural stiffnesses (moments of inertia \times Young's modulus) in the directions of the two principal axes of inertia and their torsional stiffness (torsion constant \times shear modulus).

An investigation is being conducted to determine by tests the relative importance of these three constants in determining the strength of the girders. For this purpose it has been necessary to study accurately and in detail the deformation of the channels in the girders under compressive loads, first unconstrained and then with outside constraints applied to prevent particular types of deformation. This has been done in the large Emery testing machine at the Bureau of Standards, using a technique especially developed for the purpose of securing the proper loading conditions and accurate determination of the deformations.

Because of the large amount of testing made necessary by the work in connection with the investigation of the loss of the *Shenandoah*, not as much progress has been made as was anticipated. However, complete tests have been made on two girders differing radically in their lattice arrangement, a special girder with opposite latticing and a standard girder with spiral latticing.

These tests included runs with no restraint, restraint of the twist of 1, 2, and 3 chord members, respectively, and restraint of spread of the channel lips. Over 14,000 individual measurements were made.

The characteristic wavy flexure of these girders was shown to be almost wholly a twist of the channel section. Restraining the twist of the chord members without in any way restraining the lateral deflection or spread of the flanges increased the carrying capacity of the girders by over 40 per cent. The torsional stiffness of the channels is then the major controlling factor in determining the strength of these girders.

The strength of this type of girder can be materially increased, without increase in weight, only by increasing the resistance of their chord members to twist, either (a) by increasing their torsional stiffness, or (b) by altering the manner of their lattice support. Restraining the spread of the outstanding flanges or increasing the moments of inertia of the section without increasing the torsional stiffness will not appreciably increase the strength.

It is planned to see if these results will be confirmed by repeating the tests upon a sufficiently wide range of girders to establish the range of application of these conclusions. The completion of the tests promise to make it possible—

(1) To determine the strength of a full-length latticed girder of the Zeppelin type from tests on short sections;

(2) To predict the strength of a girder of this type from tests on the chord members alone; and

(3) To predict the strength of girders of this type from a knowledge of the three elastic constants of the chord members and the dimensions of the girders alone.

The full or even the partial working out of these results in a definite form would provide the basis for a rational (as contrasted with a purely empirical) development of improved designs which would furnish stronger girders of equal weight or lighter girders of equal strength than are at present possible.

New experimental chord-member sections have been fabricated. These are designed to eliminate the eccentric application of the lattice restraints which tests have shown contribute to the torsional failure of the girders. It is planned to test these sections to see how far they accomplish the desired result.

As a result of a careful and extended investigation of wreckage from the *Shenandoah*, made for the court of inquiry on the loss of that airship, the conclusion was drawn, "No single specimen was found which had deteriorated sufficiently to lower the resistance of the structure of the ship to static or aerodynamic loads, nor was any evidence found that fatigue failure had contributed to the wreck of the ship." The basis for this statement lay in the fact that the original tests of girders made for the Bureau of Aeronautics during the construction of the airship had shown that "they would fail by flexure within the elastic limits of the material without producing tensile stresses in any case of more than 36,050 lbs./sq. in. as found by tests."

It was, however, thought desirable to confirm these conclusions by tests of full-sized girders comparable with the tests made while the airship was building. Two 5-meter girders were salvaged from the wreckage in which only small twisting of the channels had been produced by the crash, although several of the lattices were badly bent and broken. These were reconditioned in the following manner. The broken and damaged lattices were removed, the channels were straightened, and the lattices then replaced by other undamaged lattices salvaged from the wreck. There was therefore no new material in the girders tested, as it all came from the *Shenandoah* wreckage.

Test fixtures taken from the original girder tests were used and the tests repeated, reproducing the conditions and methods of the original tests with one exception. Since there were only two girders, it was desired to use each girder for both a column test and a beam test. Con-

sequently, steps were taken to prevent the complete collapse of the girder, when tested as a column, after the maximum load was passed. Limiting stops were placed so that the increase in lateral deflection after the column became unstable could not exceed a few tenths of an inch.

In the column tests the columns were loaded to beyond the maximum axial load. They then suddenly became unstable and came to rest against the stops, producing some deformation of the channels and destroying one or two lattices. They were reconditioned as before and again tested, this time as beams and to destruction, under the same conditions as in the original tests.

The test loads carried, both as columns and as beams, were as high as the corresponding girders had carried in the original tests, thus confirming fully the conclusions quoted.

High-speed fatigue testing.—A decision was reached to adopt the type of high-speed fatigue testing machine in which the specimen is loaded by means of compressed air. The specimen is set into flexural vibration which produces pure bending without shear. After the construction of a single experimental machine a battery of machines has been completed and these are now available for operation. For the present all the test specimens used are made of duralumin. However, material for magnesium test specimens is now available and it is planned to extend the series to steel specimens if this proves feasible.

The results so far obtained appear to be comparable very closely with those obtained from the mechanical fatigue machines which were developed for determining the fatigue resistance of metal used in the *Shenandoah*. A tendency to develop lower fatigue values has been traced to the existence of corrosion in some sheet material which had been on hand for a considerable period.

SUBCOMMITTEE ON WOODS AND GLUES

The Forest Products Laboratory of the Department of Agriculture conducts practically all the investigations on the application of woods and glues to aircraft construction. These investigations are undertaken at the request of the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, or the National Advisory Committee for Aeronautics. Some of the more important investigations now in progress are outlined below.

Continuous beams.—From a previous study of the stress distribution in continuous beams under transverse load only, there were obtained simplified methods of calculation which led to greater accuracy in design. The theoretical foundations for these methods were checked by tests.

The methods of calculation developed for transverse loading seemed to apply quite well, with slight modifications, to continuous beams under combined transverse and axial loadings. However, the Bureau of Aeronautics wished additional tests to corroborate this idea. Accordingly, 32 I and box beams of conventional type were tested for this purpose. The results demonstrated that essentially the same principles were involved as in the previous work and justified the extension of the method.

Design of plywood webs for box beams.—Until quite recently practically all plywood for web material of box beams was made in three plies. Now two-ply material is commonly used for such purposes. The purpose of this study was to compare the two types and to determine working stresses for both. It was found that when similarly constructed, two-ply web material was equally as efficient as three-ply. Allowable shear stresses for the two types were set up for conventional box beams without diaphragms and for beams with various diaphragm spacings.

Bearing strength of bolts in wood.—This is the subject of a series of investigations on the strength of bolted fastenings. The first report of the series dealt with solid bolts and a condition of loading where the pull on the bolt was parallel to the grain of the wood, and the second dealt with hollow bolts under the same conditions of loading. The third report covers the case where the pull is at an angle to the grain and in the plane determined by the grain of the wood and the axis of the bolt.

The analysis of the test data of the third report shows that—

- (1) The end pull on the bolt must be taken care of by ample washers or plates.

(2) The line of action of the pull must meet the surface of the timber between the bolts or within the polygon joining the bolts.

(3) Under the condition of loading of this report the strength of a joint is dependent upon the component of the force parallel to the grain of the wood and may be calculated from the curves of the former reports by using the component of the stress parallel to the grain of the wood.

Determination of acceptance-test values.—In the inspection of wood for airplanes, the need has been felt for a simple and expeditious mechanical test which could be applied to each piece to determine its acceptability. To meet this need the Forest Products Laboratory toughness-testing machine was developed.

Studies were made to obtain data enabling the use of this machine for the inspection and selection of suitable airplane woods, and were completed on white oak, black walnut, yellow birch, white ash, and Sitka spruce.

This year data for Douglas fir (coast type) have been added to the list. It is now possible by the use of this machine to inspect and select woods of high quality of the six species for which minimum values have been established.

Seasoning practice at naval aircraft establishments and contractors' plants.—At the request of the Bureau of Aeronautics, Navy Department, an inspection was made of the lumber-seasoning practice at a number of naval aircraft establishments and contractors' plants. Individual inspection reports on the various plants visited and a final summary and report were submitted. Many specific recommendations and suggestions were made as well as a number of general recommendations.

Preparation of publication on gluing.—A manuscript on gluing woods for aircraft purposes has been prepared and is now ready for editing for publication. It is based on the results of various investigations on glues and gluing and, in the light of these and other data, outlines methods and procedure with particular reference to aircraft requirements. It deals specifically with glues for aircraft, preparation of glues for use, preparation of wood for gluing, application of glue to the wood, pressing, drying, and conditioning glued stock; and other subjects.

Testing of commercial water-resistant glues.—Fourteen different brands of commercial water-resistant glues were tested by the block and plywood-joint test methods and observations were made as to their mixing characteristics, working life, and hardness. Tests were also made on samples of casein glues in stock since 1918.

The casein glues tested were not extraordinary, although some of them should be classed among the better grades of this class of adhesives.

Hot-press glues made in England tested high in water resistance, although equally high results have been obtained with the cold-press blood glue formula developed by the Forest Products Laboratory.

The soya-bean glue, which came into use within the past few years, has been improved until it is equal in water resistance to some of the medium grades of casein glues. In dry strength generally speaking, it is still somewhat below the casein glues.

Manufacture of casein water-resistant plywood.—As a result of this investigation it has been concluded that the requirements for grade A plywood are so severe in some respects that they can not at present be complied with consistently by plywood glued with casein glue. It was found further that plywood test values, obtained under present testing methods, are variable for different combinations of ply thicknesses, and curves expressing the relation of face and core thicknesses to test values have been worked out. Based upon this relation of test values to ply thicknesses, it has been shown that a specification value suited to the easy combinations, such as allowed in one-sixteenth and three thirty-seconds inch panels, may not be just for difficult combinations as required at present in one-eighth and three-sixteenths inch panels. The working out of this relationship has explained why it has been possible to meet the requirements of grade A plywood in some cases and not in others with the same care gluing.

Development of water-resistant glues.—The work on the development of water-resistant glues has resulted in a formula for making animal glue water resistant through the addition of paraformaldehyde. In the past the drawback to mixtures of animal glue and formaldehyde has been their quick setting, which has made their use impractical in commercial operations. By the addition of a small amount of acid, the working life of an animal-glue-paraformaldehyde mixture has been extended to several hours. Oxalic acid was one of the most effective acids used, yielding a glue of a suitable working life and at the same time of high water resistance. The treated animal glue compares well in water resistance to the better casein glues and there is a possibility that it may be more durable under prolonged exposure to damp conditions.

SUBCOMMITTEE ON COVERINGS, DOPES, AND PROTECTIVE COATINGS

Gas-cell fabrics.—Work on the further development of experimental gas-cell fabrics has gradually eliminated many of the compounds which were considered to afford possible solutions of this problem, and has led to concentration on two types. The one uses sheets of commercial cellophane as a substitute for the sheets of goldbeater's skins and has been developed sufficiently to enable the construction of a full-sized gas cell. The fabric of this cell has been subjected to unusually severe conditions of handling during the period of manufacture and to the further unfortunate circumstance that it was necessary to stop all work on it for a period of some months while more urgent repairs to other gas cells were being carried on by the naval aircraft factory. In spite of these difficulties, the fabric first made appears to be in splendid condition. An experiment intended to improve the fabric by impregnation of the cellophane of certain areas with glycerine resulted unfortunately, as the glycerine caused the material to take up water and the cellophane separated from the foundation fabric. These defects will be remedied by the use of cellophane in which the glycerine is compounded initially. It is anticipated that this cell will be placed in the *Los Angeles* for test in a very short time.

The other type of fabric is believed to contain even more promise than the cellophane fabric. In this case the gas-containing compound is spread on the foundation fabric instead of being cemented on as in the case of goldbeater's skin fabric or the cellophane fabric. An experimental production order for about 1,500 yards of this type of material has been placed and preliminary results indicate that the shop production will be, if anything, superior to the laboratory production and that the quality of the resulting fabric will correspond. As this fabric has shown a permeability much lower than that of goldbeater's skin fabric and weighs even less, it is being watched most carefully.

Although other types of fabric are being examined, the great promise offered by the two types which have just been described has led to a slowing down in the search for new types and a concentration of effort on the development of the two which seem to have the most promise. Most of the work connected with the experimental study of the fabrics has been done at the Bureau of Standards. The construction of the experimental gas cell has been done at the Naval Aircraft Factory. If the results from the experimental production order for the second type of fabric prove to be as good as anticipated, there will be a similar experimental gas cell constructed of that fabric.

Coatings for duralumin to prevent corrosion.—Experiments with the anodic treatment have continued. In contrast to the good results reported by the British, this process has not been as satisfactory in this country as was expected. It has been found desirable to paint or varnish over the anodic coating in order to improve the protection.

Paint and varnish of conventional type have been found to be of short life as a protective coating, particularly in salt water. Apparently the water penetrates the paint and the coating quickly separates from the metal.

A process has been developed by means of which a thin layer of gum rubber can be built up on a duralumin surface with the adhesion between the rubber and the metal of a very high order. This protection has been applied to a seaplane float and also to a number of test samples. The information received so far indicates that the protection is very good. Bituminous paints still

remain the most certain protection where they are not exposed to sunlight. When exposed to sunlight they break down and dust off unless given a light color by means of some added pigment.

The application of a thin coat of pure aluminum by means of the metal-spray gun seems to give a very high degree of protection. This may be combined with additional painting or coating, as may be desired. On account of its recent introduction the life of this type of coating can be judged only by its behavior in accelerated corrosion tests. It will probably be necessary to await the results of a series of exposure tests which are now under way at Hampton Roads on about 250 specimens before definite conclusions can be reached. In these exposure tests all manner of coatings are being tested, both qualitatively and quantitatively. The quantitative test is obtained by applying the coatings under examination to standard test bars and breaking these bars at intervals in a tension machine. The reductions in tensile strength and elongation afford a very accurate measure of the degree to which the protective coating has failed to do its work.

The introduction of the nitrocellulose lacquers for the protection of small types of metal fittings was attended by the difficulty that such lacquers were applied practically uniformly by spray. During the past year methods have been developed for the application of these lacquers by hand brush, thus making it possible to use them for the painting of small parts of airplanes. The quick drying of these lacquers—from 5 to 20 minutes—makes them highly desirable under some conditions.

Airplane dopes and paints.—A rather comprehensive study was made during the past year of the durability obtained from various schemes of airplane doping and varnishing. This includes a study of the use of cellulose acetate and cellulose nitrate dopes and other schemes for airplane fabric surfaces. The tests were made in Washington at the Institute of Paint and Varnish Research, and at the United States naval air station, Pensacola, Fla. The effects of various colors and plasticising agents were studied.

The weight of the fabric, its tensile strength and tautness were determined both before and after exposure. The tautness tests were made both by striking the dope panels and by an apparatus devised by Barnaby and Freymoyer. The two methods checked up very well. Very comprehensive tables of results were obtained and it was finally recommended that one type of dope, namely, nitrate dope, should be used exclusively for airplane surfaces and that it should be pigmented at the time of application by the addition of approximately 10 per cent of aluminum powder. As a result of the adoption of the standard recommended from these tests, one type of dope can be carried in stock with a small amount of aluminum powder and used for all doping. The use of clear varnish over the doped surfaces for the purpose of keeping the fabric clean was also suggested.

PART IV

TECHNICAL PUBLICATIONS OF THE COMMITTEE

During the past year the committee added a new series of publications known as Aircraft Circulars, making a total of four series of technical publications issued regularly by the committee. Only one series is printed, that known as Technical Reports, the other three series being mimeographed.

On recommendation of the committee on publications and intelligence, the National Advisory Committee for Aeronautics has authorized the printing of 24 Technical Reports during the past year covering a wide range of subjects on which research had 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 represent fundamental research in aeronautics carried on in different laboratories in this country, including the Langley Memorial Aeronautical Laboratory, the aerodynamical laboratory at the Washington Navy Yard, the Bureau of Standards, the Weather Bureau, Stanford University, and the Massachusetts Institute of Technology.

To make available immediately technical information on experimental and research problems, and to present the results of small research investigations and the results of studies of specific detail problems which form parts of long investigations, the committee has during the past year issued in mimeograph form 20 Technical Notes.

The third series of publications, known as Technical Memorandums, contain translations and reproductions of important aeronautical articles of a miscellaneous character. A total of 50 Technical Memorandums were issued during the past year.

The new series, known as Aircraft Circulars, contain translations or reproductions of articles descriptive of types of aircraft. This series was inaugurated in May, 1926, and up to the end of September 16 circulars were issued.

Summaries of the 24 Technical Reports and lists of the Technical Notes, Technical Memorandums, and Aircraft Circulars issued during the past year follow.

SUMMARIES 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; the ninth annual report, Nos. 159 to 185; the tenth annual report, Nos. 186 to 209; the eleventh annual report, Nos. 210 to 232; and since the preparation of the eleventh annual report the committee has authorized the publication of the following Technical Reports, Nos. 233 to 256.

Report No. 233, entitled "The Aerodynamic Characteristics of Seven Frequently Used Wing Sections at Full Reynolds Number," by Max M. Munk and Elton W. Miller, National Advisory Committee for Aeronautics.—This report contains the aerodynamic properties of the wing sections U. S. A. 5, U. S. A. 27, U. S. A. 35A, U. S. A. 35B, Clark Y, R. A. F. 15, and Göttingen 387, as determined at various Reynolds Numbers up to an approximately full scale value in the variable density wind tunnel of the National Advisory Committee for Aeronautics.

It is shown that the characteristics of the wings investigated are affected greatly and in a somewhat erratic manner by variation of the Reynolds Number. In general there is a small increase in maximum lift and an appreciable decrease in drag at all lifts.

Report No. 234, entitled "Three Methods of Calculating Range and Endurance of Airplanes," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.—This report, which was prepared for the National Advisory Committee for Aeronautics, develops new equations

which give the range and endurance of airplanes with an accuracy equal to that obtained from a step-by-step integration of the flight. A method of obtaining equally satisfactory results from Breguet's equations, is also given in detail. A third method of calculating range and endurance, derived by the writer for use in routine estimating in the Bureau of Aeronautics, is also given in full.

The report contains tables and curves arranged for convenient use and illustrates the three methods by comparative estimates.

Report No. 235, entitled "Interaction between Air Propellers and Airplane Structures," by W. F. Durand, Stanford University.—The purpose of the investigation, the results of which are presented in this report, was the determination of the character and amount of interaction between air propellers as usually mounted on airplanes and the adjacent parts of the airplane structure—or, more specifically, those parts of the airplane structure within the wash of the propeller and capable of producing any significant effect on propeller performance.

In report No. 177, by Messrs. Lesley and Woods, such interaction between air propellers and certain simple geometrical forms was made the subject of investigation and report. The present investigation aims to carry this general study one stage further by substituting actual airplane structures for the simple geometrical forms.

From the point of view of the present investigation, the airplane structures, viewed as an obstruction in the wake of the propeller, must also be viewed as a necessary part of the airplane and not as an appendage which might be installed or removed at will.

Report No. 236, entitled "Tests on Airplane Fuselages, Floats, and Hulls," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.—This report is a compilation of test data on airplane fuselages, nacelles, airship cars, seaplane floats, and seaplane hulls, prepared by the Bureau of Aeronautics, at the request of the National Advisory Committee for Aeronautics. The discussion of the data includes the derivation of a scale correction curve to be used in obtaining the full scale drag. Composite curves of drag and L/D for floats and hulls are also given.

Report No. 237, entitled "Tests of Thirteen Navy Type Model Propellers," by W. F. Durand, Stanford University.—The tests on these model propellers were conducted at Stanford University under research authorization of the National Advisory Committee for Aeronautics, and were undertaken for the purpose of determining the performance, coefficients, and characteristics for certain selected series of propellers of form and type as commonly used in recent Navy designs.

The first series includes seven propellers of pitch ratio varying by 0.10 from 0.50 to 1.10, the area, form of blade, thickness, etc., representing an arbitrary standard propeller which had shown good results.

The second series covers changes in thickness of blade section, other things equal, and the third series, changes in blade area, other things equal.

These models are all of the standard 36-inch diameter employed in this laboratory.

The dimensions of these model forms are as shown in Figs. 1 to 14.

It will be noticed that propellers A to G form the series on pitch ratio, C, N, I, J the series on thickness of section, and K, M, C, L the series on area.

Report No. 238, entitled "The Effect of Flight Path Inclination on Airplane Velocity," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.—This report was prepared at the request of the National Advisory Committee for Aeronautics in order to supply a systematic study of the relations between the flight velocity V and its horizontal component V_H , in power glides. Curves of V and V_H plotted against the inclination of the flight path θ are given, together with curves, which show the maximum values of V_H and the corresponding values of θ . Curves are also given showing the effect of small departures from the horizontal in high speed performance testing.

Report No. 239, entitled "Power Output and Air Requirements of a Two-Stroke Cycle Engine for Aeronautical Use," by C. R. Paton and Carlton Kemper, National Advisory Committee for Aeronautics.—The investigation herein reported was undertaken by the National

Advisory Committee for Aeronautics at its research laboratory, Langley Field, Va., in order to determine the pressure and amount of air necessary for satisfactory high-speed, two-stroke cycle operation and thus permit the power requirements of the air pump or blower to be determined. Assembly and development of the apparatus and preliminary work in connection with the fuel-injection system were done under the direction of Mr. Robertson Matthews.

The object of this investigation was to determine the pressure and amount of air necessary for satisfactory scavenging and operation of a high-speed, two-stroke cycle engine for aeronautical use, a 5 by 7 inch single-cylinder Liberty test engine being adapted for the purpose. The fuel and scavenging system consisted of a fuel-injection pump and injection valve, used in conjunction with a separately driven Roots type blower. Tests were conducted at speeds of 1,000, 1,200, and 1,300 revolutions per minute, with air-supply pressures from 2 to 6 lb./sq. in. gauge, and results show, that 53 brake horsepower could be developed at 1,300 revolutions per minute, with a scavenging air pressure of 5.5 lb./sq. in., a specific air consumption of 9 lb./B.H.P./hr., and a specific fuel consumption of 0.61 lb./B.H.P./hr. Under these conditions 3 horsepower was required to supply the air, resulting in a net power output of 50 brake horsepower. A minimum specific air consumption of 8.4 lb./B.H.P. was obtained at this speed with an air-supply pressure of approximately 3.5 lb./sq. in. when developing 41 brake horsepower. Chattering of cam-operated exhaust valves prevented higher speeds.

Based on power output and air requirement here obtained the two-stroke cycle engine would seem to be favorable for aeronautical use. No attempts were made to secure satisfactory operation at idling speeds.

Report No. 240, entitled "Nomenclature for Aeronautics," by the National Advisory Committee for Aeronautics.—This report was prepared by a special conference on aeronautical nomenclature authorized by the executive committee of the National Advisory Committee for Aeronautics at a meeting held on August 19, 1924, at which meeting Dr. Joseph S. Ames was appointed chairman of said conference. The conference was composed of representatives of the National Advisory Committee for Aeronautics and, in response to the committee's invitation, specially appointed representatives officially designated by the Army Air Service, the Bureau of Aeronautics of the Navy Department, the Bureau of Standards, the American Society of Mechanical Engineers, the Society of Automotive Engineers, and the Aeronautical Chamber of Commerce.

This report supersedes all previous publications of the committee on this subject. It is published for the purpose of securing greater uniformity and accuracy in the use of terms relating to aeronautics in official documents of the Government and, as far as possible, in technical and other commercial publications.

Report No. 241, entitled "Electrical Characteristics of Spark Generators for Automotive Ignition," by R. B. Brode, D. W. Randolph, and F. B. Silsbee, Bureau of Standards.—This paper reports the results of an extensive program of measurements on 11 ignition systems differing widely in type. The results serve primarily to give representative data on the electric and magnetic constants of such systems, and on the secondary voltage produced by them under various conditions of speed, timing, shunting resistance, etc. They also serve to confirm certain of the theoretical formulas which have been proposed to connect the performance of such systems with their electrical constants, and to indicate the extent to which certain simplified model circuits duplicate the performance of the actual apparatus.

Report No. 242, entitled "Characteristics of a Twin-Float Seaplane During Take-Off," by John W. Crowley, jr., and K. M. Ronan, National Advisory Committee for Aeronautics.—At the request of the Bureau of Aeronautics, Navy Department, an investigation has been made by the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics of the planing and get-away characteristics of three representative types of seaplanes, namely, single float, boat, and twin float. The experiments carried out on the single float and boat types have been reported on previously. This report covers the investigation conducted on the twin-float seaplane, the *DT-2*, and includes as an appendix, a brief summary of the results obtained on all three tests.

The fundamental take-off characteristics of the *DT-2* seaplane (twin float) are similar to those of the *N-9H* (single float) and the *F-5L* (boat type). At low-water speeds, 20 to 25 miles per hour, the seaplane trims by the stern and has a high resistance. Above these speeds the longitudinal control becomes increasingly effective until, with a gross load of 6,000 pounds, it is possible to get away at angles of attack of 8° to 14° with corresponding speeds of 56 to 46 miles per hour. It was further determined that an increase in the load caused little if any change in the water speed at which the maximum angle and resistance occurred, but that it did produce an increase in the maximum angle.

Report No. 243, entitled "A Preliminary Study of Fuel Injection and Compression Ignition as Applied to an Aircraft Engine Cylinder," by Arthur W. Gardiner, National Advisory Committee for Aeronautics.—This report summarizes some results obtained with a single-cylinder test engine at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics, during a preliminary investigation of the problem of applying fuel injection and compression ignition to aircraft engines. For this work a standard Liberty engine cylinder was fitted with a high compression, 11.4 : 1 compression ratio, piston, and equipped with an airless injection system, including a primary fuel pump, an injection pump, and an automatic injection valve.

The results obtained during this investigation have indicated the possibility of applying airless injection and compression ignition to a cylinder of this size, 5-inch bore by 7-inch stroke, when operating at engine speeds as high as 1,850 revolutions per minute, although the unsuitability of the Liberty cylinder form of combustion chamber for compression ignition research probably accentuated the difficulties to be overcome. No difficulty was experienced in metering and injecting the small quantities of fuel required. A minimum specific fuel consumption with Diesel engine fuel oil of 0.30 pound per indicated horsepower hour was obtained when developing about 16 brake horsepower at 1,730 revolutions per minute. Specific fuel consumption increased for higher loads at these speeds. A maximum power output of 29.7 brake horsepower at 1,700 revolutions per minute was obtained, but could not be maintained for more than one-half minute due to piston failure. Mean effective pressures approaching standard aircraft engine practice could not be obtained, due in part, it was attributed, to the unsuitable form of the Liberty cylinder combustion chamber. Excessive maximum combustion pressures were encountered when developing only about 60 pounds B. M. E. P. at 1,700 revolutions per minute, and piston life was very short. The engine could be idled with regular firing at 400 revolutions per minute, but acceleration under load was not satisfactory, due probably to the fixed timing of injection during any particular run.

Report No. 244, entitled "Aerodynamic Characteristics of Airfoils—IV," 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 series of airfoils designated N. A. C. A.-M1 to N. A. C. A.-M27 were tested in the variable density wind tunnel of the National Advisory Committee for Aeronautics at a pressure of approximately 20 atmospheres.

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 it is one from which a desired transformation can be easily made. For this purpose a set of transformation constants is given.

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 designing 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 section. 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 year of test.

Report No. 245, entitled "Meteorological Conditions along Airways," by W. R. Gregg, Weather Bureau.—This report was prepared at the suggestion of and for publication by the National Advisory Committee for Aeronautics, and is an attempt to show the kind of meteorological information that is needed, and is in part available, for the purpose of determining operating conditions along airways. In general, the same factors affect these operating conditions along all airways though in varying degree, depending upon their topographic, geographic, and other characteristics; but in order to bring out as clearly as possible the nature of the data available, a specific example is taken, that of the Chicago-Fort Worth airway, on which regular flying begins this year.

Report No. 246, entitled "Tables for Calibrating Altimeters and Computing Altitudes Based on the Standard Atmosphere," by W. G. Brombacher, Bureau of Standards.—During 1925 the assumption of an isothermal atmosphere which was in general use as the standard for the calibration of altimeters in the United States was replaced by a standard atmosphere which assumes an altitude-temperature relation closely corresponding to the average of upper air observations at latitude 40° in this country. The same standard atmosphere had already been adopted somewhat earlier in the United States as the aircraft performance standard.

National Advisory Committee for Aeronautics Technical Reports Nos. 147 and 218 give necessary constants, tables, and information. However, neither of these reports includes all of the tables required for the computation of actual altitudes nor those readily suitable for use in calibrating altimeters, since the altitude intervals for which data are given are not sufficiently small. The present report has been prepared specifically for these purposes.

The formulas which define the standard atmosphere are given in this report, together with other formulas giving the corrections to be applied to the standard altitude in order to obtain the actual altitude when the necessary observations of pressure and temperature are available.

The tables necessary for the use of this standard atmosphere in calibrating altimeters and in computing altitudes form the principal part of this report. In Table I are given the standard altitudes at pressure intervals of 0.1 millimeter of mercury in the range 87 to 200 millimeters of mercury and at intervals of 0.2 millimeter of mercury in the range 200 to 790 millimeters of mercury. In Table II standard altitudes are given at intervals of 0.01 inch of mercury in the range 3.4 to 31.09 inches of mercury. In Table III are given the pressure in inches and millimeters of mercury, the temperature, the mean temperature, and the corresponding isothermal altitude at every 500-foot interval of standard altitude in the range -1,000 to +50,000 feet. Temperature corrections for use in computing altitudes from observed pressures and temperatures are given in Table IV.

An example of the computation of actual altitude from the necessary observations of pressure and temperature is also included.

Report No. 247, entitled "Pressure of Air on Coming to Rest from Various Speeds," by A. F. Zahm, Construction Department, Washington Navy Yard.—The text gives theoretical formulas from which is computed a table for the pressure of air on coming to rest from various speeds, such as those of aircraft and propeller blades. Pressure graphs are given for speeds from 1 centimeter-second up to those of swift projectiles.

The present treatment slightly modified was prepared for the Bureau of Aeronautics, Navy Department, February 17, 1926, and by it was submitted for publication to the National Advisory Committee for Aeronautics.

Report No. 248, entitled "The Corrosion of Magnesium and the Magnesium Aluminum Alloys Containing Manganese," by J. A. Boyer, American Magnesium Corporation.—The tentative conclusions drawn from the experimental facts of this investigation are as follows:

The overvoltage of pure magnesium is quite high. On immersion in salt water the metal corrodes with the liberation of hydrogen until the film of corrosion product lowers the potential to a critical value. When the potential reaches this value it no longer exceeds the theoretical hydrogen potential plus the overvoltage of the metal. Rapid corrosion consequently ceases. When aluminum is added, especially when in large amounts, the overvoltage is decreased and hydrogen plates out at a much lower potential than with pure magnesium. The addition of a small amount of manganese raises the overvoltage back to practically that of pure metal, and the film is again protective.

Report No. 249, entitled "A Comparison of the Take-Off and Landing Characteristics of a Number of Service Airplanes," by Thomas Carroll, National Advisory Committee for Aeronautics.—This investigation, which is a continuation of Technical Report No. 154, "A Study of Taking Off and Landing an Airplane," follows very closely the earlier methods and covers a number of service airplanes, whereas the previous report covered but one, the JN-4h.

In addition to the air speed, acceleration, and control positions as given in report No. 154, information is here given regarding the distance run and the ground speed for the various airplanes during the two maneuvers.

Report No. 250, entitled "Description of the N. A. C. A. Universal Test Engine and Some Test Results," by Marsden Ware, National Advisory Committee for Aeronautics.—This report describes the 5-inch bore by 7-inch stroke single-cylinder test engine used at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics, in laboratory research on internal-combustion engine problems and presents some results of tests made therewith.

The engine is arranged for variation over wide ranges of the compression ratio and lift and timing of both inlet and exhaust valves while the engine is in operation. Provision is also made for the connection of a number of auxiliaries. These features tend to make the engine universal in character and especially suited for the study of certain problems involving change in compression ratio, valve timing and lift.

Incidental to investigations of carburetor and fuel-injection engine problems, considerable data have been obtained which indicate the effect of changes of compression ratio on friction horsepower and volumetric efficiency. From this and some other work, it appears that with a change in compression ratio from 5 to 13, the friction horsepower obtained by motoring the engine increases by about 15 per cent, while the volumetric efficiency taken during power runs is practically unchanged.

The results of some tests are presented also that show the power obtained when operating as a carburetor engine on aviation gasoline at compression ratios in excess of that which will permit full throttle as a normal engine and controlling detonation by throttling the intake charge and by varying the inlet valve timing. For fixed compression ratios in these tests throttling gave the least power while variation of the inlet valve closing time with the opening time kept fixed gave the greatest power for the conditions tried.

Report No. 251, entitled "Approximations for Column Effect in Airplane Wing Spars," by Edward P. Warner and Mac Short, Massachusetts Institute of Technology.—The significance attaching to "column effect" in airplane wing spars has been increasingly realized with the passage of time, but exact computations of the corrections to bending moment grooves resulting from the existence of end lobes are frequently omitted because of the additional labor involved in an analysis by rigorously correct methods. The present report, submitted for publication by the National Advisory Committee for Aeronautics, represents an attempt to provide for approximate column effect corrections that can be graphically or otherwise expressed so as to

be applied with a minimum of labor. Curves are plotted giving approximate values of the correction factors for single and two bay trusses of varying proportions and with various relationships between axial and lateral loads. It is further shown from an analysis of those curves that rough but useful approximations can be obtained from Perry's formula for corrected bending moment, with the assumed distance between points of inflection arbitrarily modified in accordance with rules given in the report.

The discussion of general rules of variation of bending stress with axial load is accompanied by a study of the best distribution of the points of support along a spar for various conditions of loading.

Report No. 252, entitled "The Direct Measurement of Engine Power on an Airplane in Flight with a Hub Type Dynamometer," by W. D. Gobe and M. W. Green, National Advisory Committee for Aeronautics.—This report describes tests made at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics, to obtain direct measurements of engine power in flight. Tests were made with a Bendemann hub dynamometer installed on a modified DH-4 airplane, Liberty 12 engine, to determine the suitability of this apparatus.

This dynamometer unit, which was designed specially for use with a Liberty 12 engine, is a special propeller hub in which is incorporated a system of pistons and cylinders interposed between the propeller and the engine crank shaft. The torque and thrust forces are balanced by fluid pressures, which are recorded by instruments in the cockpit.

These tests have shown the suitability of this type of hub dynamometer for measurement of power in flight and for the determination of the torque and power coefficients of the propeller.

Report No. 253, entitled "Drag and Pressure-Drag of Simple Quadrics," by A. F. Zahm, construction department, Washington Navy Yard.—In this text are given the pressure distribution and resistance found by theory and experiment for simple quadrics fixed in an infinite uniform stream of practically incompressible fluid. The experimental values pertain to air and some fluids, especially water; the theoretical refers sometimes to perfect, again to viscid fluids. For the cases treated the concordance of theory and measurement is so close as to make a summary of results desirable. Incidentally formulas for the velocity at all points of the flow field are given, some being new forms for ready use derived in a previous paper and given in Table I.

Report No. 254, entitled "Distribution of Pressure Over a Model of the Upper Wing and Aileron of a Fokker D-VII Airplane," by A. J. Fairbanks, National Advisory Committee for Aeronautics.—This report describes tests made in the atmospheric wind tunnel of the National Advisory Committee for Aeronautics, for the purpose of determining the distribution of pressure over a model of the tapered portion of the upper wing and the aileron of a Fokker D-VII airplane. Normal pressures were measured simultaneously at 74 points distributed over the wing and ailerons. Tests were made throughout the useful range of angles of attack with aileron settings ranging from -20° to $+20^\circ$. The results are presented graphically.

It was found that the pressure distribution along the chord is in general similar to that of thick tapered airfoils previously tested. The maximum resultant pressure recorded, was five times the dynamic pressure. The distribution of the air load along the span may be assumed to be uniform for design purposes.

Aileron displacements affect the pressures forward to the leading edge of the wing and may increase the air load on the outer portion of the wing by a considerable amount. With the wing at large angles of attack, the overhanging portion of the aileron creates usually a burbled flow and therefore a large drag. The balance reduces the control stick forces at small angles of attack for all aileron displacements. At large angles of attack it does this for small displacements only. With the airplane at its maximum speed, an angle of attack of 18° , and a down aileron displacement of 20° , the bending moment tending to break off the overhanging portion of the aileron will be greater than that caused by a uniform static load of 35 pounds per square foot.

Report No. 255, entitled "Pressure Distribution Over Airfoils at High Speeds," by L. J. Briggs and H. L. Dryden, Bureau of Standards.—This report deals with the pressure distribu-

tion over airfoils at high speeds, and describes an extension of an investigation of the aerodynamic characteristics of certain airfoils which was presented in N. A. C. A. Technical Report No. 207.

The results presented in report No. 207 have been confirmed and extended to higher speeds through a more extensive and systematic series of tests. Observations were also made of the air flow near the surface of the airfoils, and the large changes in lift coefficients were shown to be associated with a sudden breaking away of the flow from the upper surface.

The tests were made on models of 1-inch chord and comparison with the earlier measurements on models of 3-inch chord shows that the sudden change in the lift coefficient is due to compressibility and not to a change in the Reynolds number. The Reynolds number still has a large effect, however, on the drag coefficient.

The pressure distribution observations furnish the propeller designer with data on the load distribution at high speeds, and also give a better picture of the airflow changes.

Report No. 256, entitled "The Air Forces on a Systematic Series of Biplane and Triplane Cellule Models," by Max M. Munk, National Advisory Committee for Aeronautics.—The air forces on the largest systematic series of biplane and triplane cellule models ever published, measured in the atmospheric density tunnel of the Langley Memorial Aeronautical Laboratory, are the subject of this report. The tests consist in the determination of the lift, drag, and moment of each individual airfoil in each cellule, mostly with the same wing section.

The magnitude of the gap and of the stagger is systematically varied; not, however, the decalage, which is zero throughout the tests. Certain check tests with a second wing section make the tests more complete and the conclusions more convincing.

The results give evidence that the present Army and Navy specifications for the relative lifts of biplanes are good. They furnish material for improving such specifications for the relative lifts of triplanes. A larger number of factors can now be prescribed to take care of different cases.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

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| 229. | An Altitude Chamber for the Study and Calibration of Aeronautical Instruments. By H. J. E. Reid and Otto E. Kirchner. |
| 230. | The Spacing of Orifices for the Measurement of Pressure Distributions. By Max M. Munk. |
| 231. | The Resistance to the Steady Motion of Small Spheres in Fluids. By R. A. Castleman. |
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| 235. | Propeller Design. By Fred E. Weick. Part I. Practical Application of the Blade Element Theory. |
| 236. | Propeller Design. By Fred E. Weick. Part II. Extension of Test Data on a Family of Model Propellers by Means of the Modified Blade Element Theory. |
| 237. | Propeller Design. By Fred E. Weick. Part III. A Simple System Based on Model Propeller Test Data. |
| 238. | Propeller Design. By Fred E. Weick. Part IV. A Simple Method for Determining the Strength of Propellers. |
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 243. The Characteristics of the N. A. C. A. M-12 Airfoil Section. By George J. Higgins.
 244. Navy Propeller Section Characteristics as Used in Propeller Design. By Fred E. Weick.
 245. Report on Tests of Metal Model Propellers in Combination with a Model VE-7 Airplane. By E. P. Lesley.
 246. Test of a Model Propeller with Symmetrical Blade Sections. By E. P. Lesley.
 247. The Drag of Airships—Part I. By Clinton H. Havill.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

- No.
 332. Concrete Airship Sheds at Orly, France. By Freyssinet. Part I. General Aspect of the Problem; Basic Principles of the Final Project; Principal Structural Elements. Translation from "Le Genie Civil," September 22 and 29, 1923.
 333. Concrete Airship Sheds at Orly, France. By Freyssinet. Part II. Supporting Structure and Method of Moving; Mechanism for Moving and Centering; Apparatus for Handling the Materials; Remarks on Construction Details.
 334. Theory of Flapping Flight. By Alexander Lippisch. Translation from "Flugsport," June 17, 1925.
 335. Schütte-Lanz Airship Projects after the War. By Georg Weiss. Translation from "Schiffbau," May 27, 1925.
 336. Pressure Distribution on Joukowski Wings. By Otto Blumenthal.
 Graphic Construction of Joukowski Wings. By E. Trefftz. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," May 31, 1913.
 337. A Method for the Direct Determination of Wing-Section Drag. By A. Betz. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," February 14, 1925.
 338. Recent Progress in the Theoretical Deduction of Airplane Wings. By M. Panetti. Translation from "Rivista Aeronautica," July, 1925.
 339. Aerodynamic Characteristics of Aircraft with Reference to their Use. By M. Panetti. Translation from "L'Ala d'Italia," April, 1925.
 340. An Introduction to the Helicopter. By Alexander Klemin. From "Mechanical Engineering," Mid-November, 1924.
 341. Strength Calculations on Airplanes. By A. Baumann. Translation from "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," July, 1925.
 342. Wire Suspensions in Wind Tunnel Experiments. By Jean Kerneis. Translation from "L'Aerophile," September 1-15, 1925.
 343. Potential Flow in Engine Valves. By Bruno Eck. Translation from "Zeitschrift für angewandte Mathematik und Mechanik," Vol. IV, 1924.
 344. Calculation of Tubular Radiators of the Automobile Type. By L. Richter. Translation from "Zeitschrift für angewandte Mathematik und Mechanik," August, 1925.
 345. Photographic Time Studies of Airplane Paths. By A. G. Von Baumhauer. Translation of Report V 79, from "Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart," Vol. III, 1925.
 346. Behm Acoustic Sounder for Aircraft. Translation from "Flugsport," November 11, 1925.
 347. Two-Stroke-Cycle Engines for Airplanes. By J. Jalbert. Translation from "L'Aeronautique," July and August, 1925.
 348. Protection of Wooden Airplane Parts against Moisture by Means of Varnish. By E. B. Wolff and L. J. G. Van Ewijk. Translation of Report M 14 A from "Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart," Vol. III, 1925.
 349. The Metal Construction of Airplanes—Its Advantages—Its Present State—Its Future. By M. De Woitine. Paper read before the Institution of Aeronautical Engineers, December 15, 1925.
 350. Change of 180° in the Direction of a Uniform Current of Air. Prepared for publication by J. Bonder.
 351. Kirsten-Boeing Propeller. By H. Sachse. Translation from "Zeitschrift für Flugtechnik und Motorluftschiffahrt," January 14, 1926.

- No.
352. Functioning of Reduction Gears on Airplane Engines. By Raffaelli Matteucci. Translation from "Notiziario Tecnico," December, 1925.
 353. Recent Experiments with Large Seaplanes. By Adolf Rohrbach. Translation from "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt," July 1925.
 354. Tests for Determining the Effect of a Rotating Cylinder Fitted into the Leading Edge of an Airplane Wing. By E. B. Wolff and C. Koning. Translation of Report A. 105 of the "Rijks-Studiedienst voor de Luchtvaart," Amsterdam.
 355. Slip Stream Effect. By Charles N. Montieth. From "Slipstream," December, 1925.
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- No.
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 2. The Pander Light Biplane—A School Two-Seater with 45 Horsepower Anzani Engine. From "Flight," April 1, 1926.
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BIBLIOGRAPHY OF AERONAUTICS

During the year 1926 the committee issued a bibliography of aeronautics for the year 1923. It had previously issued bibliographies for the years 1909 to 1916, 1917 to 1919, 1920 to 1921, and 1922. A bibliography for the year 1924 is now in the hands of the printer and should be ready for distribution during the coming year.

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.

PART V

THE PRESENT STATUS OF AVIATION

THE PRESENT STATE OF TECHNICAL DEVELOPMENT

AERODYNAMICS

Reviewers of the progress in aerodynamics in the past have usually found that the theory had advanced at a greater rate than its practical application. This is a natural phase in the development of a new science. However, it is apparent that the time has now arrived when the main theoretical foundation has been laid and we may expect in the future to find extensions of and additions to existing theory rather than new fundamental conceptions. We are therefore entering into a phase of refined and applied theory, as shown by the developments during the past year. This phase demands that theory be developed in detail to fit particular requirements or to explain unusual phenomena.

Considering first the general theories of air flow and their practical application, it is found that satisfactory progress has been made. One of the most important contributions made by theory to practice in recent years is the "wall effect" correction, by means of which the interference between a model and the wind-tunnel walls can be calculated. During the past year these corrections have been proved valid not only by check calculations based on more refined assumptions and methods but also by numerous practical applications whereby the test results from different wind tunnels were brought into excellent agreement. Outstanding applications of theory to practice are to be found in the reports of the British Aeronautical Research Committee, while considerable work has also been done along similar lines at the Langley Memorial Aeronautical Laboratory, where numerous checks on the wing theory have been made.

WIND TUNNELS.—As more data are accumulated on wind tunnels and their limitations, additional justification is found for reliance on them as an invaluable adjunct to design. The failure to recognize the existence of large scale effect and the failure to make proper allowance therefor in the interpretation of test results has frequently led to conclusions very much in error. For example, it has been shown conclusively during the past year that the variable-density wind tunnel gave data at high Reynolds numbers which were correct only when the model was a true geometrical scale reproduction, this feature extending even to the surface finish on airfoil or wing models. Along similar lines it has been shown that tests on airplane models in atmospheric wind tunnels are of little value unless scale corrections or the equivalent of scale corrections are made. This matter is now being satisfactorily handled in some wind tunnels by the elimination, through special tests, of the scale effect on struts, wires, and fittings.

FREE-FLIGHT TEST—Investigation of spinning.—An increasing interest is being shown in free-flight research. This is due in part to the excellent results which have been obtained by the use of new and improved recording instruments and devices and in part to the stimulus brought about by the general discussions which have followed the discovery that certain types of airplanes could be put into spins from which recovery was very difficult. These spins, which are characterized by an unusually rapid rotation at a high angle of attack, have been under investigation in this country and in England for almost two years and the solution now seems well in hand. Analyses of this type of spin from wind-tunnel and flight-test data indicate that equilibrium in the unusual flat attitude is due to precessional moments brought about by an excessively rapid rotation and that the cure should be found either in a reduction of the rate of rotation or in a new mass distribution giving the proper relations between the moments of inertia about the principal axes. The correctness of these deductions has been demonstrated by tests in which models of the airplanes have been dropped from a height in such a manner as to fall into spins. The motion is studied from standard and ultrarapid moving pictures.

These models were constructed of balsa wood in such a manner that the mass distribution was the same as in the full-sized airplane. Provision was also made for changing the mass distribution. This method of studying the behavior of airplanes in maneuvers has apparently opened an entirely new field in aerodynamic research.

Pressure distribution and loading.—The questions of loading, such as the distribution of loads between the wings of a biplane, distribution of load along the span, local loadings, and loads on control surfaces, have always received considerable attention, but as a general rule no more than was demanded for immediate design requirements. With the demand for refinements in design it is inevitable that more free-flight tests along these lines will be required. It is gratifying to record that the testing program at the Langley Memorial Aeronautical Laboratory contains a number of important pressure-distribution studies and that considerable data are now available for design use.

In this connection, attention is invited to the fact that pressure-distribution measurements have long been known to yield data not obtainable by other means, but the difficulties involved have prevented this field of testing from developing to a degree commensurate with its worth. With the advent of the special photographic recording instruments designed and built at the Langley Memorial Aeronautical Laboratory it became possible to secure a continuous and simultaneous pressure record for any desired number of points on the airplane and for any desired length of time. These instruments enable an almost unlimited amount of data to be obtained on a single flight, with the obvious result that the only limit now imposed is that of labor involved in tabulating and analyzing the test data. It is the opinion of many who are in touch with these developments that pressure-distribution studies made with the new equipment offer the most logical and most promising method of increasing the knowledge of design requirements, particularly since it has been demonstrated that in no case does the recorded pressure vary more than a few per cent from the true pressure.

Supplementing the free-flight pressure-distribution data, a very important wind-tunnel research on the distribution of loading between the wings of biplanes and triplanes has been completed during the past year. This research covers systematically the effect of gap, stagger, and wing section on the load distribution, and, in connection with the excellent work previously done along similar lines in Germany and England, it is believed that present needs will be fully met.

Control at low speeds.—Control at low speeds has now been under investigation for several years in England and real progress has been made through the demonstration of several methods of securing control in stalled flight. This investigation has been so thorough and complete that any extensive work in this country would be largely a duplication of effort. The National Advisory Committee for Aeronautics has therefore adopted the general policy of limiting low-speed-control tests as far as practicable to features not covered in the British tests, or to flight tests on special devices. In accordance with this policy tests have been made by the Army and Navy on the Savage-Bramson antistall gear, the Frise aileron, and differential ailerons of various types, with and without the "spoiler" gear. The British tests on the Hill tailless airplane and the La Cierva autogiro have been watched with great interest, in view of the potential value of these types for special purposes.

During the past year flight tests have been made at the Langley Memorial Aeronautical Laboratory to determine landing and take-off runs, ground effect, and the effect of supercharging on performance. The preliminary reports of these tests, which are now available are of considerable general interest as well as technical value.

SCALE EFFECT.—The investigation and comparison of model and full-scale data have continued both here and abroad. In this country tests, both model and full scale, have been under way for some time on the Sperry messenger airplane fitted with different wings, while the Army and Navy have conducted a number of design studies along similar lines. The same problem has been under investigation in England to an even greater extent and a number of reports have been issued by the British Aeronautical Research Committee.

The variable-density wind tunnel is now supplying data of great importance in design and design analysis. During the past year several features demanding further attention have been brought out. For example, the tests have shown that the scale effect in atmospheric tunnels may be very favorable for certain wing sections and unfavorable for others. This tendency had previously been noted, but its magnitude was greater than expected. It has also been shown conclusively that the characteristics of certain wing sections are extremely sensitive to slight alterations in camber or surface conditions, thus explaining the poor performance of certain designs and the decrease in performance after a long period of service. It is believed that a fruitful field for research lies in the determination of those sections which have a stable flow with good aerodynamic properties.

LIGHTER-THAN-AIR CRAFT.—Among the lighter-than-air investigations, the determination of pressure distribution on the *Los Angeles* is by far the most important. The data from these tests are expected to supply a large part of the background for the design of rigid airships in the future. Tests are now under way in the variable-density wind tunnel on a series of airship models in which the ratio of length to diameter is varied over a wide range in order to determine the best ratios for various volumes.

METAL PROPELLERS.—One of the most pronounced tendencies noted during the past year is the general adoption of metal propellers. Continued testing in service has proved that the thin-section metal propellers not only give higher efficiencies than the conventional wooden designs but that the higher efficiency is accompanied by greater economy. The problems involved in propeller design, however, have become more numerous and more difficult, for the metal propeller shows a decided tendency to flutter and the deformations under load are large. These defects have been remedied for the time being by cut-and-try methods pending the completion and operation of the propeller research equipment of this committee.

TESTS OF MODEL PROPELLERS.—Additional model data on propeller characteristics and interference effects have been made available during the year, but there is almost universal agreement among designers that the differences in deformation between model and full scale are so great that only full-scale tests will bring out the improvements which may be expected in the future. It should be noted in this connection, however, that those comparisons between model and full scale which have been completed show excellent agreement in most cases and lead to the conclusion that model data obtained under proper conditions may be used with confidence.

FIELDS FOR FUTURE RESEARCH.—In concluding this review of aerodynamical progress, it is desired to emphasize the fact that all indications now point to a stabilized progress, in which improvements are restricted largely to refinement of design. The possibilities in refinement of design are very great, since there is no part of an airplane which is not subject to improvement structurally and aerodynamically. For example, the subject of slots and flaps has long been under investigation and excellent airplanes have been built incorporating them, but these devices alone can not convert a poor airplane into a good one, since they merely give a moderate improvement. The most promising fields for future research are: First, along the lines which increase our knowledge of forces and force distributions, thus leading to more efficient structures and greater safety through better control; second, in the development of better wing sections free from unstable flow characteristics; and third, in the adaptation of special devices, such as slots, flaps and other devices to the improved wing sections.

AIRPLANE STRUCTURES

TREND OF DESIGN—Standardization of types.—The tendency toward standardization of types for particular services has continued. For commercial service where air speeds are low and efficiency is the primary requirement, the tendency is toward the use of monoplanes. In the lighter and faster types of commercial airplanes, the biplane is used, as it has in general the advantages of maneuverability and compactness of form.

For military airplanes, particularly of the lighter types using semiinternally braced, moderately thick wings, the biplane combinations predominate. This type of wing cellule is used not only in the best types of pursuit airplanes but also in observation and bombing types.

Number and location of engines.—Last year there appeared to be a tendency toward the use of single engines of 800 horsepower or more in large bombing airplanes. Of late there seems to be a change and it is probable that any large bombers built in the near future by the Army Air Corps will have more than one engine. The Navy recognizes some advantages in the multiple-engine arrangement and is investigating the possibility of its adaptation to meet the peculiar requirements of operation from shipboard. In commercial types the tendency is definitely toward a design using three engines.

Amphibian airplanes.—The further development of the amphibian airplane has been especially successful during the last year, and this type has now been adopted by the Army, Navy, and Coast Guard as a service airplane.

Differences between military and commercial types.—There is increased appreciation of the differences in the fundamentals of design of military and commercial types of airplanes. In the military types the design must be such as to enable the airplane to be catapulted, landed in an arresting gear, to carry bombs, torpedoes, and other armament, and in the lighter types to be highly maneuverable. This results in a structure which is highly specialized as compared with airplanes of commercial types.

Shock absorbers.—Shock absorbers of the hydraulic type have given such successful results in the landing gear of service airplanes that similar gear is being fitted to all service types. Future production orders will probably specify the use of this type of gear on all airplanes. This gear is also beginning to be used quite widely on commercial airplanes.

Brakes.—As a result of the successful development and use of brakes on the landing wheels of airplanes by the Army Air Corps, many commercial airplanes are now being fitted with wheel brakes. These are used not only to reduce the run after landing but also to increase the maneuverability of the airplane on the ground.

STRUCTURAL MATERIALS—Metal construction.—With the practically complete adoption of metal construction for the fuselage, attention has been transferred to the use of metal construction in the wings. Interest in this development is greatest in those cases where it appears possible to accomplish a saving in weight by the substitution of metal for wood. Extensive tests have been made on experimental metal wing beams by the engineering division, Air Corps, United States Army. Spars for these tests were designed by practically all of the important aircraft manufacturers.

It is particularly gratifying to note the extensive use of metal construction in many successful types of commercial aircraft developed in the last year. In addition to the metal fuselage, several manufacturers have introduced metal spars with metal ribs, others use metal spars and wooden ribs, while at least one manufacturer uses wooden spars with metal ribs. As a rule all-metal airplanes are original in design as well as in detail of construction, but one manufacturer has taken successful and standard types of military design in wood, or wood and metal, and reproduced them in all-metal construction.

Steel tubing.—Alloy steels, nickel and chrome molybdenum, are being used increasingly in place of mild steels for making the tubing used in welded fuselages. This type of fuselage is bound to profit from the race for improved welding methods which is now on. The new electrical methods in particular seem most promising of clean, high-strength welds.

Duralumin tubing.—Duralumin tubing also is superseding the mild-steel tubing. Manufacturers are successfully producing round and square tubing as well as structural shapes. They are being extensively used in the construction of fuselages and built-up spars.

Floats.—Metal construction has extended from the flying-boat hull to the smaller seaplane float of advanced design. Such floats have the double advantage of light weight to begin with and practical freedom from increase of weight caused by soakage while moored out. The uncertainty regarding the ability of duralumin to withstand corrosion, particularly under adverse circumstances, has retarded progress along these lines. With the development of a satisfactory method of protection against corrosion progress will certainly be accelerated.

Rubber "lumber."—An alternative material for metal, recently developed, is a variety of hard sponge rubber which is supplied in sheet form. This has been used in place of wood for

the decks, bottoms, and bulkheads of floats of wooden type of construction. It is being employed in production orders and if as successful in service as preliminary tests indicate, it may replace wood very widely.

Rubber protective coatings.—A rubber coating which can be applied directly to wood and which is very difficult to remove has also been developed as a protection against soakage in the wooden floats. This appears to have possibilities, and in particular might be of use as a protection for existing wooden floats.

A rubber coating similar to that used for wood has also been applied to duralumin with a view to protecting it against corrosion. Service tests on both wood and metal floats protected in this manner are in progress.

AIRCRAFT ENGINES

ENGINES AVAILABLE.—The present status of aircraft engine development is most satisfactory. In the water-cooled types we have proved engines of 200, 400, 500, 600, and 800 horsepower. In the air-cooled types we have highly developed engines of 200 and 400 horsepower. These engines meet most of our requirements. The air-cooled engines have been developed primarily for the Navy, which announced some time ago its policy of standardizing on air-cooled engines of three sizes—200, 400, and 500 horsepower. The 200-horsepower engine meets the needs of the primary training airplanes. The 400-horsepower engine is especially designed for high-performance aircraft, such as the observation and fighter types. The 500-horsepower engine is adapted to use in single or twin engine bombing, scouting, torpedo, and patrol airplanes. Upon the satisfactory completion of the 500-horsepower development, a line of three air-cooled engines will be available and new types of airplanes are being built around them to meet most of the needs of the Navy.

PRINCIPAL REQUIREMENTS.—The principal requirements for aircraft engines may be listed as follows: (1) Minimum weight per horsepower; (2) minimum fuel consumption; (3) maximum dependability; (4) maximum durability; (5) minimum first cost; (6) minimum maintenance cost. In so far as weight per horsepower is concerned, the new air-cooled radial engines weigh much less than 2 pounds per horsepower installed and ready to run as against more than 3 pounds per horsepower for the war-time Liberty engine. In so far as fuel economy is concerned, the new air-cooled radials show an improvement over the water-cooled engines.

In the matter of dependability, great strides have been made. Both the water-cooled and the air-cooled engines have been improved and refined to the point where only reasonable care is required to insure dependability of the engine itself. The chief difficulties are with gasoline, oil, and water systems, which do not always receive proper attention either in installation or maintenance.

The durability of aircraft engines is greatly increased. Many modern engines are running well over 300 hours without major overhaul, while the average life between such overhauls is at least twice that of earlier engines. The latest of the modern engines have been designed with particular reference to low first cost and low maintenance cost. The radial type air-cooled engine lends itself singularly well to this end.

In general, the aircraft engine situation is satisfactory from most viewpoints, and progress is being made. The developments so far are the result of excellent cooperation between the Army Air Corps, the Bureau of Aeronautics, and the industry. Thus in the development of the three sizes of air-cooled radial engines for the Navy, the industry has had a definite plan on which to work and has, under the guidance of the Navy Department, produced highly satisfactory engines. The 200-horsepower engine has already been widely adopted by the builders and operators of commercial aircraft. No doubt the other two types will prove of equal interest to the rapidly expanding commercial field. The 200-horsepower engine is now being redesigned from the standpoint of cost reduction, which should prove a further boon to commercial development.

AIRSHIPS

TECHNICAL DEVELOPMENT—Present situation.—The technical development of airships still lags behind that of airplanes. This may be expected to continue until airships are built in larger numbers and the correspondingly increased opportunities for the development of new ideas are available.

Aside from the erection of practically standardized small nonrigid airships by the Army and Navy, there has been no new airship construction begun in the United States. Experimental investigations and research have continued for the dual purpose of improving the existing airships and of providing improved materials and methods of construction for new airships when they are begun. Along this line considerable progress has been made. The corrosion of duralumin has been studied intensively and satisfactory methods for its protection are in sight. Satisfactory substitutes for the gold-beater's skin fabric used in earlier airships have been developed and are now being used in the construction of gas cells. Methods for the design of new girders of the Zeppelin type are being derived from tests of these girders. Continued study has been given to the development of methods for analyzing the distribution of loads in the structure of rigid airships, and such methods have been brought to better form.

Work with *Los Angeles*.—The *Los Angeles*, which has now been in the United States about two years, still remains a most useful and active airship and is regularly used in research on problems connected with the design and operation of rigid airships. A series of pressure-distribution experiments made simultaneously with the study of strain distribution has been carried out on this airship and the results generally conform to those obtained from the earlier experiments on the *C-7*. The measurement of pressures was confined primarily to the fins and rudders; and the measurement of strains, to the principal girders in certain selected locations. It was found that flying in rough air produced stresses much greater than those produced by maneuvering in still air. This airship was also used to determine by means of observations in a camera obscura the behavior of an airship while turning.

The operating personnel of the *Los Angeles* have been active in the development of improved methods for handling airships on the ground and in and out of the sheds and have developed apparatus which has already given good promise of success. They have also made modifications in the methods of mooring to the *Patoka*, which have reduced the time required for this maneuver very considerably below that which prevailed in the past.

The Navy has utilized the *Los Angeles* very effectively in the calibration of the inshore sectors of the various radiocompass stations along the Atlantic coast from Maine to North Carolina. In this work the airship has accomplished things which could not be done by any other means in such a short time. A notable operation was a flight to Detroit where the airship was moored to the new Ford mooring mast. This is the first time the mast was used for a rigid airship and the first time that a naval airship was moored to a privately owned mast.

Work with *RS-1*.—The large Army semirigid *RS-1* was completed early in the year and given a series of tests similar to those applied to the *Los Angeles* in order to determine the agreement between stresses in the structure of the keel as determined by computation and from model tests. The strain-gauge readings made in flights during April check the proportion of bending load carried by the keel with that indicated by computations and the model. The breathing stresses were found to be greater than computed. However, the stresses in the keel while in flight in rough weather were less than the breathing stresses alone.

This airship had the distinction of being the first airship to moor to the new Ford mooring mast. The operation was successful in every way.

Metal-clad airship.—An airship of novel design is under construction for the Navy Department by the Aircraft Development Corporation, of Detroit. In this design the flexible fabric envelope is replaced by a thin metal shell reinforced by transverse and longitudinal girders. Many novel constructions and new features are introduced in this design and its completion and tests will be watched with great interest.

New mooring masts.—A large mooring mast generally similar to the one at the naval air station, Lakehurst, N. J., has been completed at the Ford Airport, near Detroit, and, as noted, has been used by the *RS-1* and the *Los Angeles*. A second mooring mast differing radically from any previously constructed is being built at Scott Field, Belleville, Ill. In this case the mast is being designed as a circular tower of steel plate very much like a smokestack.

Helium.—Helium tank cars have been delivered to the Army and Navy. These cars have already shown the anticipated savings and the Army Air Corps has ordered a second car. There has been a disheartening fall in the production of helium owing to the exhaustion of the Petrolia gas field. New sources of supply will have to be found in the near future if the operation of airships with helium is to be continued.

Progress in Great Britain.—In spite of the progress noted above, the world leadership in the design and construction of rigid airships has passed from the United States to Europe. Great Britain now has under construction, after an extensive series of tests, two rigid airships each having a volume of not less than 5,000,000 cubic feet. One of the airships is built of members constructed of duralumin which are very similar to those used in the *Shenandoah* and the *Los Angeles*. The structure of the other is made of stainless steel. The construction of these two airships, practically sisters, will afford a very fine opportunity for the determination of the real merits of the two materials.

The beginning of final construction of these airships was preceded by a very thorough-going series of pressure-distribution tests made on the old British airship *R-33*. Results so far made available from these tests indicate that they gave very useful information to the designers. Full-size tests of sections of the structure to be used in these airships have also been made with very gratifying results.

Mooring masts having a structure of novel type have been erected at Ismailia, Egypt, as well as in Great Britain, while an airship shed has been built at Karachi, India. These masts have eight vertical members in place of three, as in the case of the Lakehurst and Ford masts.

Progress in Germany.—The limitation of the size of airships which might be built in Germany having been removed, that country is now engaged in the construction of a new rigid airship of about 3,500,000 cubic feet. This was originally proposed in connection with the flight to the North Pole and subscriptions to the amount of about one-half the cost were obtained for that purpose. Its completion is now being urged to demonstrate the practicability of transatlantic airship traffic.

An important development proposed for this new airship is carrying in special cells, comparable to ballonets, fuel gas instead of gasoline for use in the engines. The purpose is to increase the range and reduce the loss of buoyant gas during operation. This accomplishes the same end as the water-recovery apparatus used in America but with lighter weight. However, it introduces an inflammable gas which nullifies the advantages of helium. This development appears to have very good possibilities and will be followed with interest.

Progress in Italy.—The flight of the *Norge* from Rome across the North Pole was a triumph for the semirigid type of airship which has been under development for a number of years in Italy. The technical excellence of this type of airship could be demonstrated in no more striking form.

It is understood that the Italian Airship Works is preparing to construct a semirigid airship of 53,000 cubic meters volume, very nearly the size of the *Shenandoah*, which is to be ready in 1928. This airship is intended for flights to South America.

In further testimony of the high opinion which is held of the Italian semirigid airships, it is reported that Russia has purchased a semirigid airship of the same size as the *Norge* and that Japan has purchased two in succession. The second of these is to be erected very shortly.

AERONAUTICAL LEGISLATION AND GOVERNMENTAL ORGANIZATION

During the past year notable progress was made in clarifying the aeronautical atmosphere, which had been more or less beclouded for several years. The principal factor was the enactment by Congress of a program of constructive legislation based largely upon the recommenda-

tions of the President's Aircraft Board, of which Mr. Dwight W. Morrow was chairman, and the House Select Committee of Inquiry into Operations of the United States Air Services, of which Representative Florian Lampert was chairman. The reports of these two investigating bodies were made in November and December of 1925. The immediate effect was reflected in the enactment of:

1. The air commerce act (Public No. 254, 69th Cong.), approved May 20, 1926.
2. The Navy five-year aircraft program act (Public No. 422, 69th Cong.), approved June 24, 1926.
3. The Army five-year aircraft program act (Public No. 446, 69th Cong.), approved July 2, 1926.

Following is a brief analysis of the three measures referred to:

The Air Commerce Act.—The air commerce act represents the culmination of years of effort to secure legislation providing for the Federal regulation and encouragement of commercial aviation. It asserts for the first time in American history the doctrine of Federal sovereignty in the air space over the lands and waters of the United States to the exclusion of foreign nations, and the right of the Federal Government to regulate interstate air commerce and to prescribe air traffic rules governing private as well as commercial aircraft engaged in intrastate as well as interstate air navigation. It authorizes the Secretary of Commerce to establish airways, to light the same for night flying, to establish and maintain emergency landing fields, and leaves to the municipalities and to private industry the establishment and maintenance of airports. It provides for the Federal inspection and registration of aircraft, the examination and licensing of airmen, the furnishing of weather report service along airways, and the application of existing laws to foreign air commerce. It provides civil penalties for violations and makes the aircraft involved subject to liens for such penalties. It also authorizes the use of Government airports or landing fields by private citizens or corporations, and the furnishing of supplies and repairs in cases of necessity. It authorizes the transfer of the postal airways to the jurisdiction of the Secretary of Commerce and the transfer of the postal air terminals or airports to the municipalities concerned under arrangements subject to approval by the President. It creates an additional Assistant Secretary of Commerce for the sole purpose of assisting in the administration of the air commerce act.

Subsequently an appropriation of \$250,000 was made for the administration of the act during the fiscal year 1927, and an additional appropriation of \$300,000 for the furnishing of aids to air navigation along airways.

The Navy Five-Year Aircraft Program Act.—The Navy five-year aircraft program act provides legislative authority for the procurement over a period of five years of a total of not to exceed 1,614 airplanes for naval purposes at a cost, including spare parts and equipment, of not to exceed \$85,078,750, and authorizes the annual procurement, after the fiscal year 1931, of not to exceed 333 airplanes, with spare parts and equipment, to cost not to exceed \$17,476,250. It contemplates the constant maintenance of 1,000 useful airplanes in the naval service. The act provides legislative authority for the construction of two rigid airships of approximately 6,000,000-cubic-foot volume each at a total cost of not to exceed \$8,000,000 for both, and also authorizes the purchase of an experimental metal-clad airship of approximately 200,000-cubic-foot volume at a cost of not to exceed \$300,000.

The act clarifies the status of air personnel in the Navy and provides that Navy and Marine Corps air activities, including the operation of aircraft carriers and tenders, shall be commanded, respectively, by naval and Marine Corps flying personnel.

The act creates an additional Assistant Secretary of the Navy primarily to aid the Secretary of the Navy in fostering naval aeronautics.

The Army Five-Year Aircraft Program Act.—The Army five-year aircraft program act is a companion measure to the Navy five-year program act. It provides for the reorganization of the Army Air Service into an Air Corps and increases its strength to 1,650 officers and 15,000 enlisted men, authorizes the transfer to the Air Corps of officers of other branches of the Army, provides temporary advanced rank to commanding officers under certain limitations,

provides for an investigation and study by the Secretary of War of alleged injustices in the promotion list of the Army and for the submission of recommendations to Congress to correct the same, creates for a period of three years an air section in each of the divisions of the General Staff, and clarifies the situation regarding flying pay.

The act authorizes a five-year air personnel expansion and aircraft procurement program, the latter being limited to the maintenance of 1,800 serviceable airplanes and such number of airships and free and captive balloons as may be necessary for training purposes.

The act creates an additional Assistant Secretary of War primarily to aid in fostering military aeronautics.

The act provides a method of procedure to be followed by the Army and the Navy in the procurement of aircraft, which involves design competitions and the recognition of proprietary rights for aircraft designs. The act creates a Patents and Design Board consisting of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce and provides that "to this board any individual, firm, or corporation may submit a design for aircraft, aircraft parts, or aeronautical accessories, and whether patented or unpatentable, the said board upon the recommendation of the National Advisory Committee for Aeronautics shall determine whether the use of such designs by the Government is desirable or necessary, and evaluate the designs so submitted and fix the worth to the United States of said design, not to exceed \$75,000. The said designer, individual, firm, or corporation may then be offered the sum fixed by the board for the ownership or a nonexclusive right of the United States to the use of the design in aircraft, aircraft parts, or aeronautical accessories and upon the acceptance thereof shall execute complete assignment or nonexclusive license to the United States: *Provided*, That no sum in excess of \$75,000 shall be paid for any one design."

The act further provides for the award of a soldier's medal and distinguished flying cross and certain increased emoluments for enlisted men of the Army who distinguish themselves in time of peace.

Contract Air-Mail Legislation.—The previous Congress had enacted an important measure known as the Kelly Act (Public No. 359, 68th Cong.), approved February 2, 1925, which authorized the Postmaster General to contract for air-mail service on a basis that promised successful commercial operation provided sufficient business could be secured. This measure led directly to the inauguration of contract air-mail service, which, in accordance with the Government's policy, will be increased until all air mail is carried under contracts and the Post Office Department is no longer engaged directly in the operation of aircraft. All air-mail contractors have not been successful financially, owing principally to lack of sufficient volume of business. The brief experience to date seems to indicate that contractors who depend for revenue on air mail alone can not succeed, and that they should extend their activities to include the transportation of passengers and goods.

Further Legislation Recommended.—To round out the program of constructive aeronautical legislation recently enacted into law, the National Advisory Committee for Aeronautics recommends further action by Congress along the following lines:

1. That the membership of the National Advisory Committee for Aeronautics be increased from 12 to 15 to provide for the appointment of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce. A bill to this effect (S. 4529) introduced by Senator Bingham passed the Senate at the last session of Congress, and a similar measure (H. R. 13115), introduced by Mr. James, was favorably reported to the House by the Committee on Military Affairs.
2. That the five-year aircraft construction programs of the Army and Navy approved at the last session of Congress be carried into effect.

In addition, there is the matter of "alleged injustices which exist in the promotion list of the Army," as to which Congress, in section 4 of the Army five-year aircraft program act, authorized the Secretary of War to make an investigation and study and to submit a report to the Congress.

The Present Government Aeronautical Organization.—In view of recent legislation, the committee deems it of timely interest to present briefly an outline of the present aeronautical organization of the Government:

1. Under the War Department there is an Army Air Corps functioning as a coordinate, combatant arm of the Army, with an authorized strength of 1,650 officers, 15,000 enlisted men, and 1,800 serviceable airplanes, and with an actual strength, as of June 30, 1926, of 919 officers, 8,720 enlisted men, and 1,254 serviceable airplanes, and under the immediate control of an Assistant Secretary of War for Aeronautics.

2. Under the Navy Department there is a Bureau of Aeronautics, functioning largely as a matériel bureau for the supply and development of naval aircraft and the training of flying personnel; a naval air organization serving as an integral part of the fleet, having no legal limitation on the number of personnel, but with an actual strength, as of October 1, 1926, of 715 officers and 3,600 enlisted men, and with an authorized complement of 1,000 serviceable airplanes, but a present strength of 639 serviceable airplanes; and with all aeronautical activities under the general cognizance of an Assistant Secretary of the Navy for Aeronautics.

3. Under the Department of Commerce, authority is vested in the Secretary of Commerce to regulate and encourage commercial aviation, with an Assistant Secretary of Commerce for Aeronautics in immediate charge of the work.

4. The National Advisory Committee for Aeronautics is the governmental agency that supervises and conducts scientific researches in aeronautics.

In addition to the above there are (a) the Air-Mail Service, the actual operation of which is gradually being turned over to private contractors; (b) the Weather Bureau, which has recently been authorized to furnish special weather report service along airways; (c) the Patents and Design Board, consisting of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce, to pass upon aeronautical inventions and designs submitted to the Government; and (d) the Aeronautical Board, composed of Army and Navy air officers, to effect coordination of military and naval air plans.

COMMERCIAL AVIATION

With the enactment of the air commerce act of 1926, the Congress has laid the legislative corner stone for the development of civil and commercial aviation in America on a practical basis. Under this act the Secretary of Commerce will establish airways and emergency landing fields, inspect and register aircraft and facilities, and examine and license airmen. He will encourage the establishment of airports, recommend the necessary meteorological service to be provided by the Weather Bureau, study the possibilities for the development of air commerce and disseminate information relative thereto, provide for the development of air navigation facilities, investigate and report upon causes of accidents in civil air navigation, and in general foster the development of air commerce. A significant feature of the law is that the establishment of airports or air terminals is left to the municipalities or to private industry, the Federal Government providing the connecting airways and facilities between terminals.

The act is comprehensive in scope and meets a fundamental need that has been the subject of annual recommendations of the committee for several years past. The committee does not propose to report on commercial aviation as such, as this matter, in accordance with the air commerce act, will be dealt with in the future by the Secretary of Commerce. The committee wishes at this time to record its gratification with the enactment of this legislation and to express its belief that it is fundamentally sound, and will, without direct subsidies, lead to the development of commercial aviation in America on a sound basis.

AERONAUTICAL RESEARCH IN THE UNITED STATES

Under the law the supervision and direction of the scientific study of the problems of flight are intrusted to the National Advisory Committee for Aeronautics, which is also authorized to conduct researches in its own laboratories provided by governmental appropriations, and in any other laboratories which may be placed at its disposal. The committee is composed in

part of representatives of governmental agencies concerned with the use of aeronautics—namely, the Army and Navy air organizations; of certain governmental scientific agencies interested in aeronautical problems—namely, the Smithsonian Institution, the Weather Bureau, and the Bureau of Standards; and of members appointed from private life. These latter, five in number, are not connected with aeronautics as a business but are men of science who have been appointed by the President because of their knowledge of aeronautical science. Membership on the committee is, therefore, both an honor, being a recognition of scientific ability, and an opportunity for patriotic service. It has never been refused by anyone who has been invited to serve either as a member of the main committee or on one of its subcommittees.

Because of this feature of its organization, the committee is able to obtain the services of men eminent in science, whose services on a compensation basis would be practically unobtainable. This applies equally to the subcommittees, which are organized along much the same lines as the main committee and which are composed of technical representatives of the Army and Navy air organizations, and civilian experts appointed from private life. Through the committee and its subcommittees the research activities of the country are coordinated and guided for the purpose of advancing the science of aeronautics in America.

Aeronautical research in the United States is supported by the Government both for the purpose of advancing the science and art of aeronautics as such, and because of the recognition of the direct bearing of aeronautical development upon national defense.

Each year shows improvements in the performance of aircraft, and consequently the relative military importance of aviation in war increases. Because of this continuous development, it has become more and more desirable to achieve and maintain leadership.

Leadership in the operation of commercial air lines will probably remain in European hands for some years, owing to the European policies of direct subsidies. Ultimate leadership will depend upon the solution of the basic problems of reduced cost and greater safety. These problems will be most effectively met through the encouragement and support of a comprehensive program of aeronautical research.

For ultimate leadership in the development of aeronautics, whether for military purposes or for commercial purposes, the United States depends primarily on the results of continuous research and development. The National Advisory Committee for Aeronautics therefore believes it to be its duty to emphasize the importance of scientific research as the most fundamental activity of the Government in connection with the development of aeronautics.

Aeronautical research programs are initiated by the various technical subcommittees as a result of frequent meetings and discussions of the need for development in their respective spheres. The research programs usually indicate the laboratory, public or private, in which each investigation recommended can be conducted to the best advantage. The executive committee considers the recommendations of the various subcommittees, determines the investigations to be undertaken, and allots funds when necessary.

The more fundamental investigations are undertaken by the committee in its own laboratory known as the Langley Memorial Aeronautical Laboratory, located at Langley Field, Va., on a plot of ground set aside for the purpose by the War Department and on which necessary buildings and equipment have been erected by the committee from appropriations made by the Congress. Special investigations for which adequate facilities are available elsewhere are referred to other organizations, such as the Army and Navy air organizations, the Bureau of Standards, the Weather Bureau, the Forest Products Laboratory, and educational institutions.

In the allocation of problems, the executive committee is guided by two main purposes: First, to have each investigation undertaken by an organization having proper equipment and personnel to handle the problem expeditiously and economically; and second, to distribute problems to educational institutions in such a manner as to encourage the development of trained investigators in the field of aeronautical science.

In this connection, as well as along other lines, the Daniel Guggenheim Fund for the Promotion of Aeronautics promises to be of much help, as it has made allotments of funds to universities to provide needed equipment and to maintain facilities for instruction of students in

aeronautics. There is close cooperation between the committee and the management of the Guggenheim fund. Two members of the committee, Dr. W. F. Durand, a past chairman, and Mr. Orville Wright, are also members of the Guggenheim fund.

It is evident from the statement of the governing principles of the Guggenheim fund and the caliber of its personnel that its activities will be carefully planned to produce a maximum of beneficial results and at the same time will avoid duplication with existing agencies, governmental and private.

The aeronautical research work of the committee does not relate exclusively to the development of military and naval aircraft but also includes the fundamental problems in aeronautics which relate to commercial aviation. The committee's organization for the conduct of aeronautical research as described is such as to enable it to work effectively with such agencies as the Guggenheim fund, as well as with educational institutions and the other governmental agencies concerned. This makes it possible to obtain results with a maximum of economy and efficiency.

The fundamental factors which have made for the success of the committee may be briefly stated as follows:

1. Its members serve without compensation, which enables the Government to obtain the services of men who would not otherwise be available for Government service.
2. The committee reports direct to the President and receives its appropriations direct from the Congress and by virtue of its status is enabled to initiate and conduct investigations of a truly scientific character, limited only by the funds available.
3. The research laboratories of the committee are located on an adequate flying field where all phases of the work, including the flight operations involved, are controlled and actually performed by the committee's own technical staff, thus bringing theory and practice together under ideal conditions.
4. The committee has the confidence and support of the Army and the Navy air organizations and is able at all times to obtain any cooperation desired.

SUMMARY

Progress in technical development has been continuous and has been reflected in improved performance of aircraft for both military and commercial purposes. In the matter of technical development for military purposes America has fully kept pace with foreign developments. The commercial use of airplanes is much further developed in Europe than in America. There large airplanes have been extensively developed for commercial and passenger-carrying services. This has been made possible largely by reason of direct governmental subsidies. In America since the war there have been intermittent attempts to establish passenger-carrying services. These have usually not been financially successful. Aviation in the United States must largely pay its own way, the Government merely doing what it should properly do in the way of establishing and maintaining airways and otherwise encouraging the development of commercial aviation without resorting to the European policy of direct subsidies.

Before commercial aviation can be extensively developed in the United States on a self-supporting basis, there must be substantial reductions in cost of construction, maintenance, and operation of aircraft, and substantial improvement in the safety of aerial navigation. For military purposes the problems are not so acute but are basically the same. The probability is remote that a revolutionary principle will be discovered that will contribute any great or sudden improvement to aircraft. It follows that the development of aviation will be limited to a gradual progress from year to year that is based largely on the fruits of scientific study and investigation of the basic problems of flight. This is the prescribed function of the National Advisory Committee for Aeronautics and in the last analysis is necessarily the most fundamental activity of the Government in connection with the development of aeronautics for civil and military purposes. The fact is emphasized that the problems which confront us are greater safety and lower cost of structure.

The enactment by Congress in 1926 of a constructive program of aeronautical legislation affecting military, naval, and commercial aviation in America promises great improvement in the aeronautical situation from the point of view of organization, personnel, and matériel. The creation by Congress of an aeronautical Patents and Design Board, consisting of assistant secretaries for aeronautics in the Departments of War, Navy, and Commerce, takes care of the problem of considering aeronautical inventions offered to the Government. The enactment of the air commerce act gives an important measure of stability to commercial aviation as a business proposition and in its direct effects will go far toward encouraging the development of civil and commercial aviation. The condition of the aircraft industry has continued to improve and the enactment into law of five-year aircraft building programs for the Army and the Navy, when carried into effect, will assure sufficient Government business to maintain a healthy nucleus of an aircraft industry that in time should find its principal support in meeting the needs of commercial aviation.

A BRIGHT OUTLOOK.—With the governmental agencies organized on a sound and logical basis and functioning in cooperation; with the regulation of commercial aviation under Federal supervision; with the impetus given to aeronautical education by the Daniel Guggenheim Fund for the Promotion of Aeronautics; with the continuous development of military and naval aeronautics assured under the approved five-year programs of the Army and Navy; and with the aircraft industry in a healthy condition, we have, for the first time in our history, a well-rounded aeronautical organization in the Government and a bright outlook for the advancement of aeronautics, civil and military. With the concerted effort of all the agencies concerned, governmental and private, we can reasonably expect greater progress than we have had in the past. There remain, however, the fundamental problems of increasing the safety and economy of aircraft and of interesting the people in their use and in the establishment by the municipalities or by private industry of their own airports and air terminal facilities. Federal pressure can not properly be exerted in this direction, but it is thought that those private organizations which concern themselves with the civic, national, and scientific development of the country have a field of great potential usefulness in educating the business men of every city as to the need for airports and in educating the public generally as to the possibilities of aviation as a means of transportation and of pleasure that is destined ultimately to prove as revolutionary in the economic life of the Nation as was the development of the automobile.

CONCLUSION

America leads the world in the private ownership and operation of aircraft; is at least abreast of other progressive nations in the technical development of aircraft for military purposes; and has the technical knowledge necessary to equal or excel the commercial airplanes of other nations. It is the opinion of the National Advisory Committee for Aeronautics that, without following the European policy of direct subsidies, American commercial aviation will surpass European developments when, but not until, the construction and operation of aircraft can meet the economic demands of lower cost and greater safety. Gradual improvement along these lines would result from trial-and-error methods, but substantial and rapid progress will necessitate, and depend mainly upon, the continuous prosecution of scientific research on the fundamental problems of flight.

Respectfully submitted.

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