AERONAUTICS

FIFTEENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1929

INCLUDING TECHNICAL REPORTS NOS. 309 TO 336

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FOURTH ANNUAL AIRCRAFT ENGINEERING RESEARCH CONFERENCE

UNDER THE AUSPICES OF

THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

LANGLEY FIELD, VIRGINIA, MAY 14, 1929

Seated, front row, left to right: DR. GEORGE W. LEWIS, Director of Aeronautical Research; *DR. ORVILLE WRIGHT; *DR. D. W. TAYLOR, Vice Chairman; *DR. CHARLES F. MARVIN; *CAPT. E. S. LAND, U. S. N.; *BRIG. GEN. W. E. GILLMORE, U. S. A.; *MAJ. GEN. JAMES E. FECHET, U. S. A.; *DR. JOSEPH S. AMES, Chairman; *REAR ADMIRAL WILLIAM A. MOFFETT, U. S. N.; *Assistant Secretary of Commerce, WILLIAM P. MACCRACKEN; HON. W. H. NEWTON, Secretary to the President; *HON. EDWARD P. WARNER; *HARRY F. GUGGENHEIM; SENATOR HIRAM BINGHAM; Assistant Secretary of the Navy, DAVID S. INGALLS; *DR. GEORGE K. BURGESS

(Those marked with an asterisk are members of the National Advisory Committee for Aeronautics)

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 Fifteenth Annual Report of the committee for the fiscal year ended June 30, 1929.

It is evident from the committee's report that, although material progress has been made in aeronautics during the past year, the best efforts of America are needed to keep pace with other progressive nations in the rapidly developing science of aeronautics. Attention is invited to Part V of the committee's report presenting a summary of the progress in aircraft development, and especially to the conclusion, wherein the committee expresses certain opinions with reference to the relative position of the United States and other nations that are active in the development of aeronautics.

I concur in the committee's opinion that progress on the two outstanding problems of increased safety and decreased costs necessitates continuous scientific research on the fundamental problems of flight. To this end enlarged facilities are being provided at the committee's laboratories at Langley Field, Va.

It is gratifying to note the committee's opinion that the efforts of all agencies, governmental and private, concerned with the technical development of aircraft are effectively coordinated in prosecuting the research programs of the committee.

HERBERT HOOVER.

THE WHITE HOUSE,
December 5, 1929.

LETTER OF TRANSMITTAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C, November 19, 1929.

MR. PRESIDENT: In compliance with the provisions of the act of Congress approved March 3, 1915 (U. S. C., p. 1698, sec. 153), I have the honor to transmit herewith the Fifteenth Annual Report of the National Advisory Committee for Aeronautics for the fiscal year ended June 30, 1929.

Substantial progress has been made during the past year in the scientific investigation of the fundamental problems of flight. The Army, Navy, and Department of Commerce air organizations, the Weather Bureau, and the Bureau of Standards have continued to cooperate effectively for the general development of American aeronautics. The efforts of governmental agencies, of the aircraft industry, of universities teaching aeronautical engineering, and of individuals active in the field of technical development have been largely coordinated through the technical subcommittees of the National Advisory Committee for Aeronautics, with the result that the aeronautical research programs of the committee have been prosecuted efficiently and without duplication, and existing facilities throughout the country have been utilized to good advantage. The net result has been continuous improvement in the design and performance of aircraft.

Attention is invited to Part V of the committee's report presenting a summary of progress in aircraft development. The committee has taken note of constant improvement in foreign types of aircraft, especially in military aircraft, and believes that our best efforts are necessary to keep pace with foreign progress in this rapidly advancing art. Developments in military aircraft continue to find application in the improvement of commercial aircraft. The most vital problems confronting aeronautics at this time are the needs for greater safety and for lower costs. On these basic problems the committee is concentrating its major effort.

The committee is grateful to the President and to the Congress for the liberal support of scientific research in aeronautics and firmly believes that the continuous prosecution of fundamental research is the most effective guarantee of continuous progress.

Respectfully submitted.

JOSEPH S. AMES,
Chairman.

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

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FIFTEENTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 12, 1929.*

To the Congress of the United States:

In accordance with the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its fifteenth annual report for the fiscal year 1929.

The most significant fact in the progress of aeronautics during the past year is that the airplane has found a place in the transportation needs of the country. Its accelerated development as a military weapon during the great war gave promise of its ultimate successful use for purposes of business and of pleasure. An ensuing decade of scientific research, of military experimentation, and of earnest study and application of fundamental principles of aerodynamics, and we now witness the airplane used regularly with increasing safety and efficiency, on a growing network of airways, carrying more and more passengers, mail, and merchandise at steadily decreasing costs.

The airplane as an improved means of transportation may be expected not only to bring our own people closer together but to bring the nations of the world closer to us. The peoples of all progressive nations are taking an interest in aeronautics. The present generation of Americans is learning how to see America from the air. The great interest of the youth of our land indicates that the rising generation may use the airplane as naturally, although perhaps not as generally, as we use motor cars to-day.

It is difficult accurately to appraise the significance of the present period of transition through which we are passing. The rapid advancement of technical science and increased economic pressure are bringing results steadily in improving the safety and efficiency of aircraft. The Federal Government has followed a wise constructive policy for the development and encouragement of the civil uses of aircraft upon a sound economic basis. The temporary overexpansion in certain phases of the aircraft industry is but characteristic of new and promising industries in America. The groundwork for commercial aeronautics has been well laid. The important figures that indicate the growth of American aeronautics, according to official estimates of the Department of Commerce obtained November 1, 1929, show, for example: That operating companies in the United States have developed scheduled air transport services which fly approximately 82,000 miles daily; that there are 170 different types of airplanes licensed by the Department of Commerce, including 12 types having two or more engines; that there are approximately 9,300 licensed or identified civil aircraft in the United States; that there are 35,000 miles of airways of which approximately 12,500 miles are lighted for night flying; that mail carried by aircraft has increased tenfold since 1926 to an estimated total for 1929 of 8,000,000 pounds; that paying passengers have increased from 8,000 in 1926 to 85,000 in 1929; that there are now 1,520 airports and landing fields and over 1,200 proposed; that 8,900 civilian pilots' licenses and 28,000 pilot student permits have been issued.

These are evidences of the present growth in the use of aircraft and reflect the progress made in the design, construction, and performance of aircraft. The factor that has contributed the most to the improvement in the airplane itself has been the direct assistance of the Federal Government during the past 10 years. During most of this time the major stress was laid on improving the characteristics of airplanes for the national defense. The demands upon military aircraft are much more exacting and much more difficult to meet than in the case of commercial aircraft, and hardly a single military improvement has failed to find an application in commercial aircraft. In more recent years the Federal Government, through the activities of the Aeronautics Branch of the Department of Commerce and the extended weather-report service provided by the Weather Bureau, has provided those essential aids to air navigation that are properly the function of the Government. These factors, combined with the fundamental scientific research conducted by the National Advisory Committee for Aeronautics, the results of which are applicable alike to military and commercial aircraft, and the engineering and experimental development work of the Army and Navy, have served largely to pave the way for a greater development in commercial aviation in America, uninfluenced either in nature or extent by direct cash subsidies.

All of the experience with aircraft, governmental and private, emphasizes the need for greater safety and greater efficiency, for despite the wonderful record of progress and accomplishment there are accidents, and aviation is still expensive.

The War, Navy, and Commerce Departments are keeping systematic records of the causes of accidents in accordance with a plan proposed by the committee, and these records are given intensive study by the subcommittee on aircraft accidents. Wherever this study indicates the need for the scientific investigation of any particular problem, the matter is referred to the appropriate technical subcommittee to initiate the necessary item of research. It is the duty of the technical subcommittees to outline the specific problems to be attacked and prepare programs of research, which embody the allocation of the problems recommended to various agencies, public and private, that are best equipped to undertake given investigations. Most of the fundamental investigations conducted by the committee have a bearing alike on the improvement of military and commercial airplanes, and the results are brought to the attention of the governmental agencies concerned, of the manufacturers of aircraft, and of others interested, through the committee's Office of Aeronautical Intelligence. That office serves as the Government depository for scientific and technical data on aeronautics, and collects, analyzes, classifies, and disseminates such data originating both at home and abroad.

The airplane must be made safer and less costly. On these major problems the committee is concentrating most of the efforts of the Langley Memorial Aeronautical Laboratory at Langley Field, Va., the facilities of which are being expanded under appropriations made for the purpose. In this connection the committee wishes to express its appreciation to the President and to the Congress for the liberal support by the Government of scientific research in aeronautics. Money expended in this direction is constantly yielding new knowledge obtainable in no other way. The members of the National Advisory Committee for Aeronautics are enthusiastic over the prospects for the future of aeronautics in America, and, while not making prophecies, nevertheless firmly believe that with the continued support of coordinated scientific research, there will be continued progress in the solution of the basic problems of increased safety and of increased efficiency in aviation. It is primarily in this manner that the airplane will ultimately be enabled to render its fullest service to mankind as an agency of transportation that is destined to contribute much to the advancement of civilization.

This annual report is submitted in five parts. Part I describes the organization of the committee, states its functions, outlines the facilities available under the committee's direction for the conduct of scientific research in aeronautics, explains the activities and growth of the Office of Aeronautical Intelligence in the collection, analysis, and dissemination of scientific and technical data, and presents a financial report of expenditures during the fiscal year ended June 30, 1929.

In Part II of this report the committee describes its miscellaneous activities, including the study of aircraft accidents, the consideration of aeronautical inventions and designs, the relations with the aircraft industry, and the cooperation with other governmental agencies.

In Part III the committee presents reports on the major results of its fundamental work in the form of reports of its standing technical subcommittees on aerodynamics, power plants for aircraft, materials for aircraft, and problems of air navigation, which include statements of the organization and the functions of each and of the progress of investigations conducted under their general cognizance in governmental and private laboratories.

In Part IV the committee presents summaries of the Technical Reports published during the past year, and enumerates by title the Technical Notes, Technical Memorandums, and Aircraft Circulars issued.

In Part V the committee presents a summary of progress in the technical development of aircraft. The report closes with a reference to the factors that have contributed to the advancement of American aeronautics.

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 charged the committee with the supervision and direction of the scientific study of the problems of flight with a view to their practical solution, the determination of problems which should be experimentally attacked, and their investigation and application to practical questions of aeronautics. The act also authorized the committee to direct and conduct research and experimentation in aeronautics in such laboratory or laboratories, in whole or in part, as 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 organizations and other branches of the Government and such as is not confidential is immediately released to university laboratories and aircraft manufacturers interested in the study of specific problems, and also to the public.

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

By act of Congress approved July 2, 1926 (Public, No. 446, 69th Cong.), and amended March 3, 1927 (Public, No. 748, 69th Cong.), the committee was given an additional function. This legislation created and specified the functions of an Aeronautical Patents and Design Board, consisting of an Assistant Secretary of War, an Assistant Secretary of the Navy, and an Assistant Secretary of Commerce, and provided that upon favorable 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. The legislation provided that designs submitted to the board should be referred to the National Advisory Committee for Aeronautics for its recommendation and this has served to impose upon the committee the additional duty of considering on behalf of the Government all aeronautical inventions and designs submitted.

ORGANIZATION OF THE COMMITTEE

The membership of the National Advisory Committee for Aeronautics was increased from 12 to 15 members by the act of Congress approved March 2, 1929 (Public, No. 908, 70th Cong.), which reads as follows:

An Act to increase the membership of the National Advisory Committee for Aeronautics

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the membership of the National Advisory Committee for Aeronautics is hereby increased from twelve members to fifteen members: *Provided,* That the three additional members to be appointed by the President shall be acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences, and shall serve as such without compensation.

The qualifications prescribed for the three additional members are identical with the qualifications prescribed for the five members from private life authorized in the organic act.

The organic act of 1915, as amended by the above-quoted act, provides for the appointment by the President of 15 members of the committee, as follows: 2 members from the War Department, from the office in charge of military aeronautics; 2 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 8 additional persons acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences. The law further provides that all members as such shall serve without compensation.

On April 5, 1929, the President appointed the three additional members authorized by the act approved March 2, 1929, as follows: Hon. Harry F. Guggenheim, president of the Daniel Guggenheim Fund for the Promotion of Aeronautics; Hon. William P. MacCracken, jr., Assistant Secretary of Commerce for Aeronautics; and Hon. Edward P. Warner, editor of Aviation.

On June 13, 1929, Capt. Emory S. Land (C. C.), United States Navy, submitted his resignation as a member of the committee on account of his extended leave of absence from active duty in the Navy, and under date of July 6, the President appointed Commander John H. Towers, United States Navy, Assistant Chief of the Bureau of Aeronautics of the Navy, to succeed Captain Land as a member of the committee. Commander Towers executed the oath of office on July 18, 1929. He had previously served as a naval representative on the committee from January 10, 1917, to August 16, 1919.

Under date of July 2, 1929, Brig. Gen. William E. Gillmore, United States Army, submitted his resignation as a member of the committee on his relief from duty as chief of the matériel division of the Air Corps, and under date of August 5, Brig. Gen. Benjamin D. Foulois, General Gillmore's successor as chief of the matériel division, was appointed to succeed him as a member of the committee. General Foulois executed the oath of office on August 14, 1929.

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 18, 1928, and that held on October 24, 1929.

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

Joseph S. Ames, Ph. D., chairman, president of Johns Hopkins University, Baltimore, Md.

David W. Taylor, D. Eng., vice chairman, Washington, D. C.

Charles G. Abbot, Sc. D., Secretary of the Smithsonian Institution.

George K. Burgess, Sc. D., Director of the Bureau of Standards.

William F. Durand, Ph. D., professor emeritus of mechanical engineering, Stanford University, California.

Maj. Gen. James E. Fechet, United States Army, Chief of the Air Corps.

Brig. Gen. Benjamin D. Foulois, United States Army, chief of the matériel division. Air Corps.

Harry F. Guggenheim, M. A., president of the Daniel Guggenheim Fund for the Promotion of Aeronautics.
William P. MacCracken, jr., Ph. B., Chicago, Ill.
Charles F. Marvin, M. E., Chief of the Weather Bureau.
Rear Admiral William A. Moffett, United States Navy, Chief of the Bureau of Aeronautics, Navy Department.
S. W. Stratton, Sc. D., president of the Massachusetts Institute of Technology, Cambridge, Mass.
Commander John H. Towers, United States Navy, Assistant Chief of the Bureau of Aeronautics, Navy Department.
Edward P. Warner, M. S., editor of Aviation.
Orville Wright, Sc. D., Dayton, Ohio.

MEETINGS OF THE ENTIRE COMMITTEE

The semiannual meeting of the entire committee was held on April 18, 1929, at the committee's headquarters in Washington, and the annual meeting on October 24, 1929, also at the committee's headquarters. At these meetings the recent progress in aeronautical research was reviewed and some of the principal problems of aeronautics were discussed. Administrative reports were submitted by the secretary, Mr. John F. Victory, and by the Director of the Office of Aeronautical Intelligence, Dr. Joseph S. Ames.

At both the annual and semiannual meetings Doctor Ames, as chairman of the executive committee, presented detailed reports of the research work being conducted by the committee at the Langley Memorial Aeronautical Laboratory, Langley Field, Hampton, Va., and exhibited charts and photographs showing the methods used and the results obtained in the more important investigations.

The election of officers was the concluding feature of the annual meeting. The officers of the committee were reelected for the ensuing year, as follows: Chairman, Dr. Joseph S. Ames; vice chairman, Dr. David W. Taylor; chairman executive committee, Dr. Joseph S. Ames; vice chairman executive committee, Dr. David W. Taylor.

THE EXECUTIVE COMMITTEE

For the purpose of carrying out the work of the Advisory Committee the regulations provide for the election annually of an executive committee, 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.

As a result of the appointment of three additional members to the Advisory Committee during the past year, the executive committee has been increased from 11 to 13 members. Its present organization is as follows:

Joseph S. Ames, Ph. D., chairman.
David W. Taylor, D. Eng., vice chairman.
Charles G. Abbot, Sc. D.
George K. Burgess, Sc. D.
Maj. Gen. James E. Fechet, United States Army.
Brig. Gen. Benjamin D. Foulois, United States Army.
William P. MacCracken, jr.
Charles F. Marvin, M. E.
Rear Admiral William A. Moffett, United States Navy.
S. W. Stratton, Sc. D.
Commander John H. Towers, United States Navy.
Edward P. Warner, M. S.
Orville Wright, Sc. D.

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

The executive committee has organized the necessary clerical and technical staffs for handling the work of the committee proper. General responsibility for the execution of the policies and the direction of the activities as approved by the executive committee is vested in the Director of Aeronautical Research, Mr. George W. Lewis. He has immediate charge of the scientific and technical work of the committee, being directly responsible to the chairman of the executive committee, Dr. Joseph S. Ames. The secretary, Mr. John F. Victory, is ex officio secretary of the executive committee, directs the administrative work of the organization, and exercises general supervision over the expenditures of funds and the employment of personnel.

SUBCOMMITTEES

In order to facilitate the conduct of its work the executive committee has organized the following standing committees with subcommittees as indicated:

- Aerodynamics—
  - Subcommittee on airships.
  - Subcommittee on aeronautical research in universities.
- Power plants for aircraft.
- Materials for aircraft—
  - Subcommittee on metals.
  - Subcommittee on woods and glues.
  - Subcommittee on coverings, dopes, and protective coatings.
  - Subcommittee on aircraft structures.
- Problems of air navigation—
  - Subcommittee on problems of communication.
  - Subcommittee on instruments.
  - Subcommittee on meteorological problems.
- Aircraft accidents.
- Aeronautical inventions and designs.
- Publications and intelligence.
- Personnel, buildings, and equipment.
- Governmental relations.

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

Statements of the organization and functions of the administrative committees on publications and intelligence; personnel, buildings, and equipment; and governmental relations, follow:

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.

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

Prof. Charles F. Marvin, chairman.
Dr. David W. Taylor.
John F. Victory, secretary.

QUARTERS FOR COMMITTEE

The headquarters of the National Advisory Committee for Aeronautics are located in the rear of the eighth wing, third floor, of the Navy Building, Eighteenth and B Streets NW., Washington, D. C., in close proximity to the Army and Navy air organizations. This space has been officially assigned for the use of the committee by the Public Buildings Commission. The administrative office is also the headquarters of the various subcommittees and of the Office of Aeronautical Intelligence.

The committee has been seriously handicapped in its ability to discharge its functions most effectively by the lack of sufficient office space. The committee's needs have been presented from time to time to the Public Buildings Commission, and although that commission has appeared fully appreciative of the situation only partial relief could be granted. During the past year the committee has obtained 400 additional square feet of office space, making the total office space in Washington 7,394 square feet. The committee regrets that it has been prevented by lack of quarters from rendering the fullest possible measure of useful service to the public and to the aircraft industry. It appears that substantial relief must await progress in the prosecution of the Federal building program in Washington.

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

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

During the past year authority of law was obtained for the construction of a full-scale wind tunnel at an estimated cost of $900,000, a seaplane channel at an estimated cost of $208,000, and a combination heating plant, storehouse, and garage at an estimated cost of $30,000. The latter structure was erected on plot 16 during the summer of 1929 at a cost of $27,055. It is a brick structure 102 by 52 feet by 29 feet high, with an outside brick smokestack 64 feet high.

The War Department has assigned to the committee additional space on a suitable part of Langley Field for the erection of the full-scale wind tunnel and for the construction of the seaplane channel. It is expected that these structures will be in operation during the fiscal year 1931. In its estimates for the fiscal year 1931 the committee has requested authority for the erection of a permanent new brick hangar to replace the present steel hangar which must be removed to make way for extensive military improvements at Langley Field.

There are nine structures at present comprising the Langley Memorial Aeronautical Laboratory, housing activities as follows:

1. A research laboratory building containing administrative offices, technical library, photographic laboratory, and headquarters of the various divisions.
2. An atmospheric wind tunnel building containing a 5-foot wind tunnel of standard type with a closed throat, and a refrigerated wind tunnel with an open-throat diameter of 6 inches for the investigation of ice formation on aircraft.
3. A variable-density wind tunnel building, housing the variable-density wind tunnel. A research balance of an entirely new design intended to insure greater reliability, accuracy, and adaptability for model tests has been installed and this equipment is again in full operation after the fire which destroyed the mechanism on August 1, 1927. In rebuilding the tunnel after the fire the design was changed to an open-throat type with the same throat diameter of 5 feet. In rebuilding the tunnel features were incorporated which resulted in greater efficiency and ease of operation, better accessibility of apparatus, improved quality of air flow, and the elimination of all combustible material. This building also houses the new jet-type wind tunnel for investigations at approximately the velocity of sound in air, or in excess of 750 miles per hour. Waste air from the variable-density wind tunnel is utilized by means of the injector principle to create a flow of air through a test chamber 12 inches in diameter at speeds up to 800 miles per hour.
4. Two engine dynamometer laboratories of a semipermanent type equipped to carry on investigations in connection with power plants for aircraft.
5. A service building containing an instrument laboratory, drafting room, machine shop, woodworking shop, and storeroom.
6. A propeller research tunnel in which tests may be made in a 20-foot air stream at 100 miles per hour. This equipment permits the full-scale testing of propellers, fuselages, and landing gears.

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7. An airplane hangar with a repair shop and facilities for taking care of airplanes used in flight research.

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

Items 1, 2, 3, 4, 5, and 8 above are located on plot 16. Item 6, the propeller research tunnel, is located within 2 blocks of the laboratory headquarters and is near the site of the proposed full-scale wind tunnel and seaplane channel. Item 7, the airplane hangar, is located on the flying field.

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 181 employees at the close of the fiscal year 1929. The work of the laboratory is conducted without interference with military operations at the field. In fact, there is a splendid spirit of cooperation on the part of the military authorities, who by their helpfulness in many ways have aided the committee materially in its work.

THE OFFICE OF AERONAUTICAL INTELLIGENCE

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the committee's activities. Its functions are the collection, classification, and diffusion of technical knowledge on the subject of aeronautics to the military and naval air organizations, aircraft manufacturers, educational institutions, and others interested, including 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, classified, and brought to the special attention of the subcommittees having cognizance and to the attention of other interested parties through the medium of public and confidential bulletins. Reports are duplicated where practicable, and distributed upon request. Confidential bulletins and reports are not circulated outside of Government channels.

The records of the committee show that during the past year there has been an increase of 47 per cent over the previous year in the distribution of technical publications. A total of 16,923 written requests for reports were received during the year in addition to innumerable telephone and personal requests and 77,729 reports were distributed upon request, which represents an increase of 28,189 over last year.

The technical publications were distributed as follows:

Committee and subcommittee members	1,739
Langley Memorial Aeronautical Laboratory	2,518
Paris office of the committee	5,222
Army Air Corps	2,352
Naval Air Service, including Marine Corps	3,499
Manufacturers	15,619
Educational institutions	9,515
Bureau of Standards	670
Miscellaneous	62,942
Total distribution	104,076

The above figures include the distribution of 33,259 Technical Reports, 17,763 Technical Notes, 29,554 Technical Memorandums, and 14,093 Aircraft Circulars of the National Advisory Committee for Aeronautics. Part IV of this report presents the titles of the publications issued during the past year the distribution of which is included in the foregoing figures.

To handle efficiently the work of securing and exchanging reports in foreign countries, the committee maintains a technical assistant in Europe, with headquarters at the American Embassy in Paris. It is his duty to visit the government 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, which would otherwise not reach this country. John Jay Ide, of New York, has served as the committee's technical assistant in Europe since April, 1921.

FINANCIAL REPORT

The appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1929, as carried in the independent offices appropriation act approved May 16, 1928, was $615,770, under which the committee reports expenditures and obligations during the year amounting to $611,633.27, itemized as follows:

Personal services	$448, 771. 16
Supplies and materials	32, 714. 07
Communication service	1, 267. 63
Travel expenses	14, 620. 46
Transportation of things	977. 44
Furnishing of electricity	7, 511. 30
Rent of office (Paris)	960. 00
Repairs and alterations	3, 779. 51
Special investigations and reports	47, 222. 15
Equipment	53, 809. 55
Expenditures	611, 633. 27
Personnel reserve	3, 300. 00
Unobligated balance	836. 73
Total	615, 770. 00

In addition to the above, the committee had a separate appropriation of $13,000 for printing and binding, of which $12,925.61 was expended.

The appropriations for the fiscal year 1930 total $1,300,000, which includes $525,000 toward the construction of a full-scale wind tunnel at an authorized cost of $900,000; and $30,000 for the construction of a combined heating plant, storehouse, and garage. In addition there is an appropriation for the fiscal years 1929 and 1930 of $208,000 for the construction of a seaplane channel which, in effect, when added to the regular appropriation for 1930, makes the total appropriation for 1930, $1,508,000.

PART II

GENERAL ACTIVITIES

STUDY OF AIRCRAFT ACCIDENTS

In response to request of the Air Coordination Committee, consisting of the Assistant Secretaries for Aeronautics in the Departments of War, Navy, and Commerce, the National Advisory Committee for Aeronautics organized, in March, 1928, a special committee on the nomenclature, subdivision, and classification of aircraft accidents, to prepare a basis for the classification and comparison of aircraft accidents, both civil and military. This committee made a detailed study of the problem, and as a result drew up a chart for the analysis of accidents, combining consideration of the immediate causes, underlying causes, and results of accidents. This chart, together with a detailed explanation, was published in October, 1928, as Technical Report No. 308 of the National Advisory Committee for Aeronautics, entitled "Aircraft Accidents—Methods of Analysis," and was officially adopted for use by the War, Navy, and Commerce Departments.

On completion of this report, the special committee on the nomenclature, subdivision, and classification of aircraft accidents was discharged, and, as it was thought probable that the introduction of the proposed chart would result in questions as to interpretation and suggestions as to changes, and that a study of the information obtained from the application of the method of analysis would indicate that certain features in aircraft operation or construction should be given more detailed study or consideration, a new standing committee on aircraft accidents was appointed with the same personnel as the special committee, to consider from time to time such new questions regarding aircraft accidents as might appear desirable or as might be brought before it.

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

- Dr. George K. Burgess, Bureau of Standards, chairman.
- Lieut. Harold Brand, United States Army, Air Corps, War Department.
- Edward P. Howard, Aeronautics Branch, Department of Commerce.
- George W. Lewis, National Advisory Committee for Aeronautics.
- Lieut. Commander L. C. Stevens, United States Navy, Bureau of Aeronautics, Navy Department.
- Hon. Edward P. Warner, editor of Aviation.

The committee when first organized included in its membership the following Army and Navy officers who have supplied valuable information regarding the study of accidents in their respective services, and who have since been relieved from membership upon their transfer to duty outside of Washington:

- Lieut. J. D. Barker, United States Army.
- Lieut. Charles R. Brown, United States Navy.
- Lieut. D. B. Phillips, United States Army.

Doctor Burgess has expressed a desire to be relieved as chairman of this committee, and it is therefore contemplated that when the revision now being made of the report on methods of accident analysis has been completed, he will be succeeded in the chairmanship by Mr. Warner.

The committee has been aided from time to time in the study of its problems by a number of invited representatives from the Government organizations concerned, among whom were the following:

- Dr. L. H. Bauer, Aeronautics Branch, Department of Commerce.
- Dr. H. J. Cooper, Aeronautics Branch, Department of Commerce.

Commander R. G. Davis (M. C.), United States Navy.
P. Edgar, Aeronautics Branch, Department of Commerce.
Lieut. Col. L. M. Hathaway (M. C.), United States Army.
F. J. Martel, Aeronautics Branch, Department of Commerce.
Lieut. Commander John R. Poppen (M. C.), United States Navy.
Lieut. Stanhope C. Ring, United States Navy.
E. R. Strong, Aeronautics Branch, Department of Commerce.
Starr Truscott, National Advisory Committee for Aeronautics.

The analysis of aircraft accidents by the Army, Navy, and Department of Commerce in accordance with the standard method confirmed the conclusion previously reached, that a large percentage of aircraft accidents are due to pilots' errors. The need for the study and analysis of the defects or shortcomings of pilots which account for this fact was brought to the attention of the committee on aircraft accidents by Lieutenant Phillips, at that time a member of the committee. The initial meeting of the accidents committee was held on March 16, 1929, to consider this problem, and meetings have been held at frequent intervals since that date. Consideration has been given not only to problems affecting the personnel element in accident causes, but to a number of other aspects of the subject as well.

In the period which has elapsed since the adoption of the chart as a standard method of accident analysis, its value has been definitely demonstrated. The analysis of accidents in accordance with the prescribed standard has enabled the three services to learn important facts as to causes of accidents, and to take appropriate steps toward remedying these causes. It has made it possible for the Aeronautics Branch of the Department of Commerce to reorganize its inspection service on a more effective basis.

Some doubt has been expressed as to the possibility of actually standardizing accident statistics on account of the probable lack of consistency in analyses made by different individuals or groups of individuals. In this connection it is of interest to note that the results obtained in the analysis of a large number of accidents by different individuals and groups showed excellent agreement.

In view of the large percentage of accidents due to pilots' errors, the prompt and thorough study of accident statistics is of great importance, particularly in connection with the issuance of licenses to pilots of civil aircraft by the Department of Commerce. A study has been made by the committee on aircraft accidents of some of the more important influences contributing to pilots' errors. The importance of adequate flight training, especially for pilots in commercial service, including a reasonable amount of actual piloting experience, is evident, and during the past year Congress has authorized the Secretary of Commerce to provide for the examination and rating of civilian schools giving instruction in flying.

Some of the more important mental and physical characteristics of pilots which affect their ability to operate aircraft safely were given consideration by the committee on aircraft accidents. It was found that a large percentage of the pilot's accident responsibility had been ascribed in the accident analysis to "poor reaction." Important information as to this phase of the problem was presented to the committee by medical authorities from the War, Navy, and Commerce Departments, and in these discussions suggestions were presented which were of benefit to the members in connection with the work of their respective departments in the prevention of accidents.

Other physiological factors entering into the accident problem were discussed, including sight, hearing, general health, effect of worry, etc. The influence of these factors on the efficiency of the pilot is evidence of the value of specialized medical supervision over flying personnel.

The accidents committee is now engaged in a revision of Technical Report No. 308, Aircraft Accidents—Methods of Analysis, clarifying the definitions in the light of the experience gained in the analysis of accidents by the three Government services, and including some of the suggestions presented in the discussions in the meetings of the committee. This revision when completed will be published as a Technical Report of the National Advisory Committee for Aeronautics.

CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, a Patents and Design Board was created, and it was provided that upon recommendation of the National Advisory Committee for Aeronautics the board should determine questions as to the use and value to the Government of aeronautical inventions submitted to the Government. By act of Congress approved March 3, 1927, the act of July 2, 1926, was amended in such a manner as to limit the board to the consideration of such cases as were favorably recommended to it by the National Advisory Committee for Aeronautics. This relieved the board of the burden of considering cases which were unfavorably recommended by the committee, but at the same time it made the National Advisory Committee for Aeronautics responsible for the final disapproval of the large majority of the devices submitted as applications for awards.

In order to discharge the duties devolving upon the committee under this legislation, a committee on aeronautical inventions and designs was created, the present membership of which is as follows:

Dr. D. W. Taylor, chairman.
Dr. George K. Burgess, vice chairman.
Prof. Charles F. Marvin.
Commander John H. Towers, United States Navy.
J. F. Victory, secretary.

Inventions and designs submitted are considered by the Director of Aeronautical Research. The committee on aeronautical inventions and designs considers in committee only such inventions or designs as are presented by the Director of Aeronautical Research or are recommended for committee consideration by any other member of the National Advisory Committee. The Director of Aeronautical Research is authorized to submit his unfavorable recommendations direct to the Aeronautical Patents and Design Board, but any favorable recommendations must be considered and made by the committee on aeronautical inventions and designs.

Under the present procedure careful consideration is given to all inventions and designs submitted. The Aeronautical Patents and Design Board and the National Advisory Committee for Aeronautics are working in harmony and the burden of considering large numbers of inventions is placed so as to reduce the demands on the time of the members of the committee on aeronautical inventions and designs and of the members of the Aeronautical Patents and Design Board to the consideration of submissions which have received competent preliminary examination and are deemed worthy of further consideration.

In the past year, which was the third year of the operation of the Aeronautical Patents and Design Board, the committee received about 2,400 letters relating to inventions. Fifty per cent of these represented wholly new submissions. This number includes 150 inventions and designs submitted to the Aeronautical Patents and Design Board. In each of these cases the committee made a report to the board as to the merits of the device. The remaining cases, being addressed to the committee, were acted on by direct correspondence with the submitters. Two cases were sufficiently meritorious to warrant favorable recommendation.

RELATIONS WITH THE AIRCRAFT INDUSTRY

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

In accordance with this policy, the Fourth Annual Aircraft Engineering Research Conference was held at the Langley Memorial Aeronautical Laboratory on May 14, 1929. In addition to the representatives of the industry, the conference was attended by representatives of aeronautical journals and of educational institutions engaged in the teaching of aeronautical engineering. The committee was represented by its officers, members of the main committee, and the members of its committees on aerodynamics and power plants for aircraft. The conference was presided over by Dr. Joseph S. Ames, chairman of the National Advisory Committee for Aeronautics.

At the morning session the principal investigations under way at the laboratory were explained by the engineers in charge of the work, and charts were exhibited showing some of the results obtained. Some of the more important investigations outlined were the study of pressure distribution over the wings and tail surfaces of pursuit airplanes; the study of water pressure distribution on seaplane floats and hulls; the determination of the stresses on the oleo type landing gear in landing; the effect of mass distribution on the spinning characteristics of airplanes; the effect of slots and flaps on the performance of aircraft; the effect on airplane performance of the N. A. C. A. low-drag cowling for radial air-cooled engines; the study of cooling with the N. A. C. A. cowling; interference effects between wing and propeller; the effect of high tip speeds on propellers; the development of the Roots type supercharger; and the development of a high-speed heavy-oil fuel-injection engine. At the close of the session, the representatives of the industry were conducted on a tour of inspection of the committee's laboratories, and the research equipment was shown in operation.

The afternoon session was devoted to the discussion of the problems of commercial aeronautics, and 24 suggestions were made, chiefly by representatives of the industry. A number of these problems were already a part of the committee's research program. Among the problems discussed were the causes of abnormal spins of airplanes; the reduction of airplane resistance and the study of interference effects; the interaction between engine nacelle, propeller, and wing; and the study of take-off and landing characteristics. The need for the thorough study of the characteristics of seaplanes and flying boats was pointed out, and it was announced that the committee had obtained authority from Congress and was proceeding with plans for the construction at Langley Field of a model tank for the testing of models of seaplanes and flying boats.

The 24 suggestions presented at the conference have since been carefully considered by the committee on aerodynamics, and two of them—the determination of load and load distribution on commercial type airplanes, and the wind-tunnel investigation of the placing of nacelles with biplane structures, including the measurement of propeller efficiencies—have been incorporated in the committee's research program.

Following the conference, demonstration flights were made by the Pitcairn Autogiro, through the courtesy of Mr. Harold F. Pitcairn, and by the Stinson Detroiter with the Packard Diesel heavy-oil engine, through the courtesy of Mr. L. M. Woolson and the Packard Motor Car Co.

RIGID AIRSHIPS

The round-the-world flight of the German rigid airship *Graf Zeppelin* in August and September, 1929, was an epochal achievement that challenged the admiration of the world. It served to focus attention on the possibilities of long-distance air navigation by the use of rigid airships and to prompt a review of the American airship development program. In order clearly to grasp the situation in America, the following brief chronology of events is presented:

1917.—Appointment of a joint Army and Navy airship board.

1918.—The sending of a commission abroad by that board to investigate the rigid airship situation.

1918.—Appropriations made by Congress for the construction of one or more rigid airships.

1918.—Decision to build a duplicate of the *L-49*, plans of which were secured from the French (later the *ZR-1*, *Shenandoah*).

1918.—Preliminary work begun on the *Shenandoah*.

1918.—Joint Army and Navy board recommended that the development of rigid airships be assigned to the Navy. Approved by the Secretary of War and the Secretary of the Navy.

November 11, 1918.—The armistice. After the armistice work continued on the *Shenandoah*. Plans made for the hangar at Lakehurst, N. J.

1919.—British rigid airship *R-34* made round-trip flight between England and the United States.

1919.—Rigid airships *Bodensee* and *Nordstern* constructed in Germany and flown successfully as passenger carriers for nine months, when they were taken over by the Allies and allotted one to France and one to Italy.

1919.—Airship board recommended purchase of British airship *R-38*, then 80 per cent complete. Contract was executed with British Government and the airship designated by the United States, *ZR-2*.

1919-21.—Diplomatic negotiations under way to secure an airship from Germany as a result of an armistice agreement under which the United States was entitled either to an airship or a cash payment in lieu of an airship destroyed by the Germans at the time of the armistice.

1919-21.—*R-36* was flown in England. Great Britain, except for operating this airship, virtually abandoned airship development.

August, 1921.—*R-38* (*ZR-2*) destroyed in England on trial flight, with loss of 46 lives.

October, 1921.—Council of ambassadors at Paris agreed to permit the United States to have a modern rigid airship constructed in Germany.

1921.—Erection of *ZR-1*, *Shenandoah*, just getting under way.

February-June, 1922.—Contract negotiated with Zeppelin Co. for building the *ZR-3*, later the *Los Angeles*, against the account of the German Government.

July, 1922.—Construction of the *ZR-3* started.

July, 1923.—The *Shenandoah* made her first flight.

1923.—Great Britain planned for two large rigid airships—*R-100* and *R-101*—ready for flight in 1929.

October, 1924.—The *ZR-3*, *Los Angeles*, delivered in America by Doctor Eckener.

September, 1925.—*Shenandoah* was wrecked in a storm over Ohio, with a loss of 14 lives.

October, 1925.—Steps taken in Navy Department toward replacement of *Shenandoah* and establishment of a definite rigid airship construction program.

December, 1925.—The National Advisory Committee for Aeronautics, after analysis of the situation as developed by the loss of the *Shenandoah*, definitely recommended that the development of rigid airships be continued.

1926.—Restrictions on airship construction in Germany removed. Construction of *Graf Zeppelin* started by the Zeppelin Co. largely under public subscription.

1926.—Contract executed by the Navy for first metal-clad airship, which was successfully flown in the fall of 1929.

1926.—Five-year Navy aircraft building program authorized construction of two rigid airships.

1928.—No appropriation having been made for construction of the two airships, and certain inquiries having been presented to the committee, the National Advisory Committee for Aeronautics adopted the following resolution:

"*Resolved*, That it is the opinion of the National Advisory Committee for Aeronautics that the present state of the art of constructing and operating large rigid airships has progressed to the point where we are justified in believing that large rigid airships can be constructed and operated successfully.

"*Resolved further*, That it is the opinion of the National Advisory Committee for Aeronautics that the most practical step to be taken at the present time to encourage the development of an airship industry in the United States is to begin the construction of the airships authorized under the 5-year building program. The construction of these airships will foster the development of an airship industry, and this, with the knowledge to be acquired from experience in the operation of airships, will be necessary in order to enable the United States to meet the needs for commercial airship construction and operation when they arise."

Funds were appropriated for the construction of two rigid airships of 6,500,000-cubic-foot capacity each, and contracts were entered into with the Goodyear-Zeppelin Corporation of Akron, Ohio. The keel ring of the first of the two airships was laid on November 7, 1929. These airships are at present designated the *ZRS-4* and *ZRS-5*. This step marks the beginning of a rigid airship industry in the United States, as the only rigid airship heretofore built in America was the *Shenandoah*, which was fabricated at the Philadelphia Navy Yard and assembled at Lakehurst. The present American rigid airship program as authorized by law also includes the maintenance of an airship base on the east coast at Lakehurst and the construction of an additional airship base on the west coast.

The present airship program also brings into existence a new helium industry, all helium for airships having heretofore been produced by the Government. Additional helium fields have been located in the United States, and it is the present belief of authorities on the subject that the present known supply of helium is much more than ample to meet any requirments for the next generation. The United States continues to enjoy an apparent monoply in the possession and production of helium in quantities sufficient for use in airships. As helium is noninflammable and noncombustible, its use contributes materially to the safety of rigid airships, although its lifting capacity is approximately 8 per cent less than hydrogen per unit of volume.

A consideration of the economic possibilities in the use of various types of aircraft for long flights leads the committee to express the belief that the most useful field for rigid airships is for flights of over 1,000 miles over the water; that for flights under 1,000 miles over the water large seaplanes will prove more efficient; and for long flights over the land airplanes of the land type will be used, with stops for refueling every 400 or 500 miles.

Rigid airships have great potential value for military purposes, the present primary military field being that of naval scouts. There are great possibilities in the use of rigid airships for commercial purposes which were strikingly demonstrated by the round-the-world flight of the *Graf Zeppelin*. If the United States is to take full advantage of the possibilities of air transportation, especially in the field of transoceanic air travel, the importance of the development of rigid airships can not be overemphasized, as in transportation by air over long distances, and especially over the water, rigid airships have marked advantages over airplanes. In order to develop their naval uses and in order more especially to assist and hasten the development of rigid airships in America for commercial purposes, the committee recommends firm support by the President and by the Congress of the present Navy rigid airship development program.

THE DANIEL GUGGENHEIM FUND FOR THE PROMOTION OF AERONAUTICS

The cordial relations which already existed between this committee and the Daniel Guggenheim Fund for the Promotion of Aeronautics were strengthened by the appointment, in April of this year, of Mr. Harry F. Guggenheim, president of the fund, as one of the three additional members of the committee as authorized by act of Congress approved March 2, 1929.

During the current year the fund has been able to round out some of its activities, and as a result of a progress in aviation which has exceeded its expectations, its work will terminate about the end of this year. Since the fund was founded in January, 1926, its existence will cover a 4-year period, during which the character of the fund's work has changed as aviation has advanced. By the middle of 1928 public support of aviation was assured, and the fund, therefore, began to concentrate particularly upon the problem of safe flying and landing through fog.

During the present year the Daniel Guggenheim Fund has continued its activities in providing practical and substantial assistance to aeronautics in its commercial, industrial, and scientific aspects. The fund has extended its financial support of educational institutions. It has given appropriations totaling over $1,200,000 to five engineering universities as follows:

California Institute of Technology.
Massachusetts Institute of Technology.
Stanford University.
University of Michigan.
University of Washington.

It announced this fall it would undertake a survey for the purpose of making a similar grant to some university in the South.

In addition to these appropriations among higher institutions the fund established a committee on elementary and secondary aeronautic education so as to carry this work into the schools as well. The fund has itself published from time to time documents of both a popular and a technical nature on various aeronautical problems.

Among its new projects the fund recently announced an appropriation of $250,000, made to the city of Akron and the California Institute of Technology for the establishment of an airship institute; an appropriation of $140,000 for a chair at the Library of Congress for the purpose of organizing a complete aeronautical library for research purposes; and a large number of smaller grants to other institutions.

On September 24, 1929, at Mitchel Field, the Daniel Guggenheim Fund made a demonstration of a method of safe flying and landing through fog. This experiment established the principle of safe fog flying which must, however, be eventually perfected for commercial use. It points the way to the elimination of one of the greatest hazards to the reliability of airplane travel. This demonstration was realized through the aid of only three instruments which are not already the standard equipment of an airplane, and of these three instruments two will replace two instruments now in use.

Another important activity recently undertaken by the Guggenheim Fund is the preparation of an encyclopedia of aerodynamic theory. This work is to be international in character and will present a fairly complete statement of the present condition of aerodynamic theory, the various portions being written by authors who have especial and first-hand knowledge of their subjects. This project is now under way under the direction and supervision of Dr. W. F. Durand.

The safe-airplane competition inaugurated by the fund has been continued. This competition was initiated for the purpose of promoting safety in flying and has led to efforts on the part of manufacturers and designers to make safer airplanes.

The fund has also included in its activities the study of the problem of regulation of civil aeronautics and has called attention to the desirability of uniform State legislation to provide regulations for intrastate flying identical with the Federal regulations for interstate flying.

COOPERATION WITH STATE DEPARTMENT ABROAD

The committee has cooperated with the Department of State by making available the services of its technical assistant in Europe, Mr. John J. Ide, for attendance as unofficial observer or technical adviser on behalf of the United States at several international air conferences abroad. The Department of State accepted the committee's offer. In accordance with action by the State Department Mr. Ide represented the United States unofficially at the following conferences: Meeting in Paris on May 6, 1929, of the International Technical Committee of Aerial Juridical Experts; meeting in Paris beginning on June 10, 1929, of the International Commission for Air Navigation; and the Second International Diplomatic Conference on Private Aeronautical Law, held at Warsaw, Poland, beginning on October 4, 1929.

COOPERATION WITH BRITISH AERONAUTICAL RESEARCH COMMITTEE

It is a great pleasure to this committee to offer its congratulations to the Aeronautical Research Committee of Great Britain on the completion, in April of this year, of 20 years of aeronautical research under the direction of that committee and its predecessor, the Advisory Committee for Aeronautics. Our own committee, established in 1915, was organized along similar lines to those of the British committee. Aeronautics throughout the world owes a debt of gratitude to the British organization for its accomplishments in scientific research during the past two decades.

The officers and members of our committee were most pleased to receive during the past year a visit from Mr. H. E. Wimperis, director of scientific research of the British Air Ministry, and Mr. R. McKinnon Wood, head of the aerodynamics section of the Royal Aircraft Establishment.

This visit presented an opportunity for the informal discussion of a number of problems of aeronautical research and development which are of special interest to the two committees.

Comparative tests by the two committees, initiated several years ago with a view to standardizing the results of wind-tunnel tests, have been continued. These tests have been extended to include the comparison of flight test results obtained in England with results obtained on models of the same airplanes in the variable-density wind tunnel, and have yielded valuable information on the subject of scale effect. Tests are being made in the variable-density tunnel on a British model of a Hawker Hornbill airplane with A. D. 1 wing section, and it is hoped that useful information relating to the problems of stability and control at or near the stalling angle will be obtained from these tests. Tests in the variable-density tunnel of a British model of an R. A. F. airfoil are also contemplated.

An exchange of flight test instruments has been made for comparative study, this committee receiving a force recording rudder bar and a force recording control stick, and lending to the British committee in return a 3-component accelerometer.

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. Both services have placed at the disposal of the committee airplanes and engines required for research purposes, and have 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, the Naval Bureau of Aeronautics, or the Aeronautics Branch of the Department of Commerce 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, the Navy, and the Department of Commerce may be outlined as follows:

FOR THE AIR CORPS OF THE ARMY

Investigation of cowling for protection of gunners and pilots from air currents.
Wind-tunnel investigation of biplane cellules.
Investigation of pressure distribution on observation-type airplane.
Study of comparative performance with various types of superchargers.
Study of mutual interference of propeller and fuselage, with geared engine.
Study of ice formation.
Determination of moment coefficients and hinge moment coefficients for different tail surfaces.
Determination of aileron hinge moments versus rolling moments for various types of ailerons and wings.
Investigation of wing flutter.
Investigation of the flat spin.
Investigation of pressure distribution and accelerations on pursuit type airplane.
Acceleration readings on the PW-9 airplane.

FOR THE BUREAU OF AERONAUTICS OF THE NAVY DEPARTMENT

Investigation of flight path characteristics.
Ice formation on aircraft.
Comparative tests of rubber and oleo type landing gears.
Investigation of windshields and fairings for protection from air currents.
Study of design factors for metal propellers.
Investigation of autorotation and spinning characteristics of airplanes.
Determination of radii of gyration of airplanes.
Investigation of comparative aerodynamic resistance of riveted and bolted construction.
Investigation of parasite resistance and propeller efficiencies of PB-2.
Investigation of methods of improving wing characteristics by control of the boundary layer.
Investigation of the forces on seaplane floats under landing conditions.
Investigation of water-pressure distribution on seaplane hulls.
Development of solid-injection type of aeronautical engine.
Investigation of application of compression ignition to air-cooled engine cylinders.
Effect of varying the aspect ratio and area of wings on performance of fighter airplane with supercharged air-cooled engine.
Investigation of aerodynamic loads on the U. S. S. *Los Angeles*.
Development of aircraft engine supercharger.
Effect of various forms of cowling on performance and engine operation of fighter airplane with supercharged air-cooled engine.

FOR THE AERONAUTICS BRANCH OF THE DEPARTMENT OF COMMERCE

Study of high-speed cowling as ignition shielding of air-cooled engines to aid radio reception.

EXHIBIT AT SEVILLE INTERNATIONAL EXPOSITION

On invitation of the Commissioner General of the United States for the International Exposition at Seville, Spain, the committee prepared an exhibit and selected Chester W. Hicks, a member of the engineering staff at Langley Field, to install and maintain it. The installation was completed March 18, 1929, and the exhibit was among the first ready for public inspection. The expenses involved were defrayed from the allotment of $5,000 made by the commission for this purpose. The unexpended balance of $782.50 was returned to the State Department.

A room of 480 square feet in one of the United States Government buildings was made available for the committee's exhibit. The hexagonal shape of the room is ideally adapted to the arrangement of the models to the best possible advantage. It is the most prominent space in the United States buildings. The exhibit is composed of 5 working models, 1 show case containing airplane models and instruments, 2 tables on which are shown the results of pressure distribution investigations on the surfaces of an airplane and airship, and 18 charts illustrating the facilities and methods employed in the conduct of aeronautical research in the committee's laboratories at Langley Field, Va. The five working models consist of scale models of the propeller research tunnel and of the variable-density wind tunnel; a model showing the operation of the control system of an airplane; a model showing why an airplane flies, which illustrates graphically the dynamic reaction of the air upon an airplane in flight; and a model showing the effect of a rotating cylinder in an air stream and illustrating the principle involved in the Flettner rotor ship. Mr. Hicks has reported that visitors appreciate and praise this method of demonstration.

A band of blue satin with the name of the committee inscribed in gold letters, around the walls near the ceiling, with blue and white streamers symbolic of the national colors, contributes to the appearance of the exhibit.

The daily attendance varies from 800 on week days to 2,000 on Sundays and holidays. The reports made by Mr. Hicks indicate that the Spanish public and visitors to Seville from many nations are interested in aeronautics and that the committee's exhibit is proving popular.

Sufficient data are included to make the exhibit of interest also to the technically trained visitors and particularly to those connected with aeronautical activities. The committee's exhibit is part of a comprehensive exhibit entered by the Government of the United States.

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. David W. Taylor, chairman.
Dr. L. J. Briggs, Bureau of Standards.
G. G. Budwig, Aeronautics Branch, Department of Commerce.
Lieut. W. S. Diehl (C. C.), United States Navy.
Lieut. Grandison Gardner, United States Army, matériel division, Air Corps, Wright Field.
Maj. C. W. Howard, United States Army, matériel division, Air Corps, Wright Field.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Prof. Charles F. Marvin, Weather Bureau.
Lieut. Commander A. C. Miles (C. C.), United States Navy.
Hon. Edward P. Warner, editor, Aviation.
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. The current work of each organization is therefore made known to all, duplication of effort being thus prevented. Also all research work is stimulated by the prompt distribution of new ideas and new results, which add greatly to the efficient conduct of aerodynamic research. The committee keeps the research workers in this country supplied with information on European progress in aerodynamics by means of a foreign representative who is in close touch with aeronautical activities in Europe. This direct information is supplemented by the translation and circulation of copies of the more important foreign reports and articles.

The committee on aerodynamics has direct control of the aerodynamical research conducted at Langley Field and of 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 Wright Field, and the Bureau of Standards are reported to the committee on aerodynamics.

SUBCOMMITTEE ON AIRSHIPS

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

Hon. Edward P. Warner, editor of Aviation, chairman.
Starr Truscott, National Advisory Committee for Aeronautics, vice chairman.
Dr. Karl Arnstein, Goodyear-Zeppelin Corporation.
Commander Garland Fulton (C. C.), United States Navy.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Capt. Edgar P. Sorenson, United States Army, matériel division, Air Corps, Wright Field.
Ralph H. Upson, Red Bank, N. J.

During the past year the subcommittee on airships presented recommendations for two investigations on airship models to be conducted in the propeller research tunnel at the Langley Memorial Aeronautical Laboratory, both of which have been added to the committee's program. These two investigations were the study of the effect of appendages on airship hulls, including tests of an airship model about 40 inches in diameter with different protrusions, such as water-recovery apparatus, cars, propeller mountings, fins, and rudders of different contours; and the study of the forces on an airship entering a hangar, including the construction of models of two types of hangars and the measurement of the forces and moments on an airship model in various positions with respect to the hangar and the direction of the wind stream.

The subcommittee has continued the consideration of problems of atmospheric structure as affecting airship operation, particularly vertical air currents and gustiness, and is cooperating with the subcommittee on meteorological problems of the committee on problems of air navigation in the study of this subject.

SUBCOMMITTEE ON AERONAUTICAL RESEARCH IN UNIVERSITIES

In order to coordinate the aerodynamic research work undertaken by the various institutions of learning and to aid in improving the courses in aeronautical engineering and in promoting the study of aeronautics, a subcommittee on aeronautical research in universities has been organized under the committee on aerodynamics.

The membership of this subcommittee is as follows:

Prof. Charles F. Marvin, Weather Bureau, chairman.
Hon. Harry F. Guggenheim, president of Daniel Guggenheim Fund for the Promotion of Aeronautics.
Prof. Alexander Klemin, New York University.
Prof. E. P. Lesley, Stanford University.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Prof. Clark B. Millikan, California Institute of Technology.
Prof. F. W. Pawlowski, University of Michigan.

The functions of the subcommittee on aeronautical research in universities are as follows:

1. To consider aeronautical problems with a view to the initiation and conduct of aeronautical research by educational institutions; and in connection therewith to prepare programs of suggested lines of research intended to supplement existing research programs and to develop and train personnel for the conduct of scientific research in aeronautics along original lines.

2. To seek through interchange of ideas to improve the courses in aeronautical engineering and to promote the study of aeronautics and aerology in educational institutions.

3. To meet from time to time on call of the chairman and to report its actions and recommendations to the committee on aerodynamics.

The subcommittee on aeronautical research in universities held its initial meeting at the Langley Memorial Aeronautical Laboratory on June 21, 1929. The topics under discussion at this meeting included the equipment for aerodynamics departments at educational institutions, courses of study, and aerodynamic problems suitable for investigation by universities. In connection with the meeting the members of the subcommittee made a tour of inspection of the facilities and activities of the laboratory. On recommendation of the subcommittee, the standard wind-tunnel models on which comparative tests have been conducted during the past few years in the principal wind tunnels of this country are being made available for test in the wind tunnels of the various educational institutions, and in accordance with this plan the standard airship models are now being tested by the California Institute of Technology.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

Aerodynamic Safety.—As commercial aeronautics develops, the problem of safety in flight continues to be one of increasing importance, affecting more and more the general public, as well as the aircraft operators and manufacturers. Improvement in the accuracy of aircraft accident reports has made possible a more detailed analysis of the relative seriousness, as well as the underlying causes, of accidents. The air-accident statistics of the Department of Commerce for 1928 indicate that the pilot was at fault in nearly half the accidents occurring in that year. As analyzed from the standpoint of the nature of each accident, these data show that two-thirds were due to spins and forced or bad landings. Thus, we are brought to the conclusion that the airplane of to-day is too easy to spin and too difficult to land and, consequently, that too much is expected of the pilot and not enough of the designer. In other words, the airplane still possesses certain undesirable aerodynamic characteristics which should be definitely recognized, investigated, and ultimately removed.

The National Advisory Committee for Aeronautics has always recognized the importance of the problem of safety in flight, and a large part of the work of the laboratory has been devoted to its various phases, such as spinning, stability, controllability, maneuverability, ice formation on aircraft, structural safety, landing, and piloting under adverse weather conditions.

Spinning.—Most fatal air accidents are due to the tendency of an airplane when stalled to dive or to roll sharply contrary to the desire and the efforts of the pilot, resulting in a spin and if the airplane is near the ground, in a crash. Since there is no need for the spin as a customary maneuver for civil aircraft, it is desirable that the tendency to spin should be eliminated. If an airplane wing is stalled, it will have, among other things, a tendency to roll about an axis approximately parallel to the direction of flight, and this rolling will in itself produce a torque tending to build up the motion. If at the same time the wing is sideslipping, an additional torque acting in the same direction is produced. The resulting rolling motion is termed autorotation. These two torques are of the same order of magnitude, in general, and appear to be important factors in starting and maintaining the spin.

An investigation of autorotation was inaugurated about three years ago in the atmospheric wind tunnel. The test program included force, pressure distribution, and autorotation torque tests up to 90° angle of attack on models of a wide variety of wing systems. The force and pressure distribution tests have been completed and the results published. The first of the autorotation tests are now being made on an autorotation dynamometer in the wind tunnel. It is proposed to extend these tests at a later date by modifying the dynamometer so that pitching and yawing, as well as rolling moments, may be measured.

The problem involved with military airplanes is somewhat different since the airplane is required to spin as a military maneuver. The problem then is one of safe recovery from a spin.

An important factor in the recovery of airplanes from spins is the effect of the distribution of the mass of the airplane, and the flight research section of the laboratory has concentrated chiefly on this factor. Apparatus of great accuracy for measuring the mass distribution of an airplane has been developed, and the moments of inertia and ellipsoids of inertia of a number of airplanes have been determined. A study has been made of these inertia data, together with such information as is available on the type of spin executed by each airplane, and a definite relation between mass distribution and the type of spin appears to exist. The chief difficulty in this study has been the lack of accurate knowledge of the magnitude of the variables that enter into the dynamics of the spin, such as the radius and rate of rotation. Methods of measuring these variables in flight have been perfected, and complete data on one airplane have been obtained, from which the dynamic forces producing and maintaining these spins have been determined. The investigation is to be continued on other airplanes, and in particular on one normally spinning airplane in which the mass distribution is to be changed in an attempt to produce a flat spin.

Stability.—Safety depends to a great extent upon stability. Departure from a desired flight direction or attitude should be but momentary and loss of altitude small, whether the controls are being held by the pilot or left free. Many airplanes possess satisfactory stability below the angle of attack of maximum lift, but very few, if any, are as satisfactory in stalled flight. An investigation of stability in stalled flight is being carried on in the atmospheric wind tunnel. Tests have recently been made to determine the effect on stability of twisting a wing, and at the same time the effect of change in profile along the span. Both methods were found to give improved stability, and the report on the work is in preparation.

Controllability.—Safety also depends on controllability. The pilot must have at his command means for changing the path of the airplane with sufficient rapidity to avoid collisions, or to enter and recover from maneuvers, but not so rapidly as to stress unduly the airplane structure. Moreover, it is highly desirable that the change of direction should be smooth and constant without sudden or unexpected accelerations. Most airplanes have satisfactory controllability in normal flight, but when stalled many of them exhibit an anomalous behavior when the controls are operated. This is particularly true of airplanes equipped with the conventional type of ailerons, for in stalled flight operation of these ailerons produces at first a sluggish roll in the desired direction, followed shortly by a reversal of direction, while the ailerons are still held in the initial position. Obviously, this effect is confusing and likely to result in disaster. Considerable interest also centers around the fact that some military and many civil types of airplanes have been found to resist attempts at recovery from the steady spin, particularly when the spin has been allowed to develop for several turns. During such spins, either the controls have been practically ineffective or the force required to operate them has been too great for the pilot to exert.

A study has been made in the atmospheric wind tunnel of the effectiveness of various types of ailerons, particularly from the standpoint of stalled flight and the spin, and it is planned in the near future to conduct flight tests on a special monoplane arranged for convenient changing of the wings, ailerons, and tail surfaces. In these tests, every effort is to be made to obtain accurate information on the rolling and yawing tendencies of the airplane with various methods of control while in stalled flight.

A series of pressure distribution tests recently completed in the variable-density wind tunnel on an R. A. F. 30 airfoil with flaps should also be of considerable assistance in studying the effectiveness of ailerons, and particularly how it varies with scale. The results of these tests are being prepared for publication.

Maneuverability.—The work on the comparative maneuverability of airplanes has been continued. A series of maneuverability tests has now been carried out on two pursuit airplanes. The results have been analyzed and a report prepared covering the tests on one airplane. The results obtained on the second airplane are being studied. The degree of maneuverability is determined basically by the flight path obtainable by an airplane, and considerable attention has been given to improving the methods of determining the flight path in flight. A program of work for a similar research on an airplane of the observation type has been outlined, and preliminary plans for measuring the maneuverability of commercial monoplanes are under consideration. This work has required greater sensitivity on the part of recording instruments, particularly angular-velocity recorders, than has been required for any other flight research activity and has made necessary, among other things, a careful study of damping oils for use in such instruments. It has been sought to obtain an oil which would permit uniform accuracy of the instrument under various conditions of temperature and rate of motion of the airplane.

Ice formation.—The formation of ice on aircraft has been regarded for some time as an element of danger. It appears that ice will form under a variety of atmospheric conditions,

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resulting not only in an increase in the weight of the airplane but also in the deformation of the aerodynamic shapes on which the lift and drag depend.

Flight tests have been conducted in order to study the formation of ice under a variety of weather conditions, such as fog, rain, and sleet. Photographs were made of the ice deposits on wings, wires, and struts. In several instances, ice formation was obtained on the propellers. While no means of preventing this hazard was discovered, the formation could often be partially or wholly eliminated by flying at different altitudes, or at temperatures at which the minimum deposit was found. It appears thus far that the only safe procedure in service is for the pilot to land before the deposit assumes such proportions as to interfere with control. It was noted, however, that the ice forms in dangerous amounts only within a small range of temperature below 32° F. A report has been published covering this phase of the work.

A small refrigerated wind tunnel for studying the problems of ice formation has been in operation during the year, considerable time having been devoted to means for controlling the amount of water sprayed into the air stream, the size of the water particles, and the temperatures of the air and the water.

The first phase of the problem undertaken, that of studying the possibility of using a protective coating on the aircraft surfaces to prevent the forming of ice, has yielded mainly negative results. It has been found, however, that glucose, corn sirup, and some similar substances in solid or semisolid form, and certain liquids, as a mixture of glycerin and alcohol, do have some effect in preventing the formation of ice. A report is in preparation covering this phase of the work.

Structural safety.—The determination of the air loads experienced by airplanes under all conditions of flight has constituted a large part of the work of the flight research section. The distribution of load over the wings, tail surfaces, and the fuselage of a pursuit airplane has been measured under all conditions of flight. The results have been studied from the standpoint of the structural designer, and a report covering this entire research is practically completed. The results bring out several points of great importance, one being the torsional deflection of the wing under load and the resulting change of load distribution, and another being the effect of inertia loads on the airplane structure. Under certain conditions of flight the latter loads combine with the aerodynamic loads in such a manner as to give new maxima.

The above investigation has furnished additional data as to the loads on the tail surfaces of a pursuit airplane, supplementing those obtained in an investigation made last year for that specific purpose. As a result, there has been made available knowledge of the tail-surface loading experienced on pursuit airplanes having control surfaces of both thick and thin section. Both investigations show the necessity of increasing the design requirements for the tail surfaces of airplanes which are to be required to execute maneuvers at high speed. The information has already resulted in an arbitrary increase by the military services in the loads for which the tail structure must be designed. The subject has been studied and discussed in conference with representatives of the services to determine a satisfactory basis for the establishment of a permanent set of specifications covering loads on tail surfaces.

The determination of load distribution is being continued in flight, and two airplanes are now being arranged for pressure-distribution tests. One of these, an observation airplane, is being prepared for a complete pressure-distribution investigation over the wings and tail surfaces; the second airplane is being arranged for an investigation of the loads on wing tips of various plan form. This latter investigation is for the express purpose of determining the exactness of the existing arbitrary specifications of wing-tip loading and to determine the possibility of developing a wing tip with a constant location of the center of pressure and a desirable load distribution, in order to reduce the possibility of excessive load on the tip portion of the wing.

The research on the distribution of water pressure over the bottoms of various types of seaplane floats and hulls has been continued throughout the year. An investigation conducted on a twin-float seaplane has been completed and the results published. A similar investigation has been completed on a flying-boat hull, the results of which are now being prepared for publication. As in the former tests, the latter investigation has covered the conditions of landing, take-off, and taxiing. With the flying boat, it was possible to maneuver on much rougher water, and the pressures were measured under conditions which were as bad as the seaplane could withstand without breaking up. The maximum pressures recorded were about 15 pounds per square inch, as compared with a maximum of approximately 10 pounds per square inch on the floats previously investigated. As a result of the tests on the three seaplanes, there have been derived static load distributions to be recommended as safe practice in design. Apparatus is now being assembled for static tests on one of the seaplane floats.

The work on airships during the past year has consisted chiefly in preparation for publication of reports of researches previously conducted on the U. S. S. *Los Angeles*. One report covering the pressure distribution on the hull and tail surfaces has been prepared for publication. A preliminary study of the velocity of air in gusts has been completed and a report prepared.

Landing and take-off.—Other things being equal, an airplane which can land and take off in a smaller space than another airplane is obviously safer. A series of tests was carried out on a Douglas mail airplane carrying various loads to find the length of landing and take-off runs with and without brakes on the wheels. The brakes were found to be advantageous both from the standpoint of landing and taxiing. The results of this investigation have been published.

Blind flying.—In order to afford some information on the physical reactions of a pilot while flying through fog, or other conditions under which he would have to rely entirely upon his sense of balance or upon his instruments to assume and hold the position of normal flight, experiments were made by a number of service pilots of various ages and experience. The pilots were blindfolded during the tests and the movements of the airplanes were closely followed and recorded by an observer pilot. These tests showed that there is an unmistakable tendency on the part of the pilot to direct the airplane along a spiral path and that normal controlled flight is not possible over any extended period unless the pilot has either some object outside the airplane which he can use to orient himself, or a good set of instruments, including a bank indicator and a turnmeter, in which he has complete confidence.

The pilots varied somewhat in the manner in which they handled the airplane, but as a whole the younger pilots seemed to respond much more quickly to the "feel" of the controls and the various eccentric positions the airplane assumed during their flight. The usual flight lasted about three minutes before the airplane assumed a dangerous high-speed condition beyond the pilot's control.

Aerodynamic Efficiency.—A large part of the work of the laboratory may be classified under the general heading of the study of aerodynamic efficiency. Under this heading are included the study of means of reducing the drag of the airplane and the mutual interference of its parts, investigations with reference to propeller efficiency, and tests of airfoils.

The reduction of engine drag by the use of cowling.—The investigation of the effect of cowling on the drag and cooling of a Wright Whirlwind J–5 engine as fitted to the fuselage of a cabin monoplane and of an open-cockpit biplane was continued with interesting results. In the tests carried out in the propeller research tunnel 67 thermocouples were installed over the engine for recording the temperatures, and various degrees of cowling were employed ranging from that in which the engine was completely exposed to that in which the engine was entirely covered. The latter cowling resulted in a large reduction in the drag of the engine-fuselage combination. When subsequently applied to an AT–5 airplane in flight, it resulted in an increase of speed of about 20 miles per hour. The wind-tunnel tests indicated the possibility of still greater savings in the drag of nacelles. The results of the tests in the propeller research tunnel have been published, and that part of the investigation is regarded as finished, but further work on the development of the N. A. C. A. cowling has been carried on through flight tests.

In order to determine the effect of the new cowling on the drag of the nacelles of wing engines, flight tests were carried out on a trimotor Fokker transport airplane. It was thought that this airplane, having three J–5 engines, offered an excellent opportunity for demonstrating the value of the new cowling. All three engines were cowled, the two wing engines being fitted with larger nacelles to suit the larger diameter of the cowling, and the center or nose engine having the cowling somewhat modified to properly fair in with the large fuselage to the rear.

Flight tests with the original installation showed very little increase in speed. A study of the air flow about the nacelles by means of threads attached to their surfaces indicated a bad interference condition between the nacelles and the wing, and it was found that some improvement could be effected by fairing the nacelles into the wing. This question of the interference between the wing and nacelles was then taken up in the variable-density wind tunnel.

Flight tests are still in progress in connection with the development of the N. A. C. A. cowling, on a Navy XF7C–1 pursuit type airplane powered with a Pratt and Whitney Wasp engine. The air flow is being studied, particularly in the vicinity of the slot where the flow leaves the cowling and at the nose of the cowling. The engine is equipped with thermocouples, in order that the temperatures may be carefully watched. The shape of the after portion of the cowling has been changed in various ways, and the shape of that portion which influences the flow from the slot has been found to be rather critical. Tests are being made with a simple ring surrounding the engine, similar to the Townend ring, and with modifications of the same. The tests show favorable results for both the complete N. A. C. A. cowling and the ring type from the standpoint both of performance and cooling.

Interference.—The experiments in cowling the engines of the Fokker trimotor led to a series of tests in the variable-density tunnel to ascertain how the interference between the engine nacelles and the wing might best be reduced. Tests were made of a wing-nacelle combination in which the nacelle was located in various positions with reference to the wing and faired into the wing in various ways. The results, which, however, do not include the effect of the slip stream, indicate the importance of interference effects and the necessity of still further investigation along these lines. They show that a marked improvement in the performance of airplanes with outboard nacelles would result if the nacelles were equipped with the N. A. C. A. cowling and so located that they would be partially inclosed in the wing. A report has been published covering this investigation.

Models and equipment have been constructed for the investigation of the interference between a flat plate and a streamline body. Further interference effects will be studied in the variable-density tunnel in connection with tests of a cabin airplane model now being designed. Valuable information on this question will also be obtained, it is believed, in connection with the wing-nacelle tests soon to be taken up in the propeller research tunnel.

Investigations of propeller efficiency.—The propeller research tunnel has been in successful operation throughout the year, and it has been possible to investigate a number of questions relating to the efficiency of propellers under various conditions of operation, which had not been possible previously. A preliminary investigation of the effect of high tip speeds had indicated no loss in propulsive efficiency as the tip speeds were increased up to 900 feet per second. The airplane engine used in the tests at that time did not have sufficient power to permit tests at higher tip speeds. This investigation has been continued on a Curtiss D–12 engine installed on an open-cockpit fuselage. The larger engine has made it possible to run the same propellers up to speeds of 1,350 feet per second, and in addition to test a series of special propellers of similar plan form, but differing in section and camber. These tests indicate a reduction in efficiency beginning at tip speeds of 950 to 1,000 feet per second and continuing at the rate of about 10 per cent loss in efficiency per 100 feet per second increase in tip speed. In these tests readings were also made of the deflection of the blades and of the velocity and twist of the slip stream back of the propeller. This information will be used in computing the characteristics of a series of airfoils for use in propeller design. A report is now in preparation giving the results of the tests at high tip speeds.

As a contribution to the data available on the interference of a body behind a propeller, tests were made on a series of geometrically similar propellers but of different diameters, operating in front of the same fuselage. The propeller diameters varied from 9 feet to 10.5 feet, and it was found that the propulsive efficiency was about 2½ per cent higher for the largest propeller than for the smallest. A Technical Report has been prepared on the results of this investigation.

In order to ascertain whether any great improvement in propeller efficiency might be expected from changes in plan form, a series of tests was made on propellers varying in this respect.

Only a small difference in efficiency was noted for the series tested, but the form with the thinnest airfoil section had the highest efficiency, and it was shown to be advantageous as regards propulsive efficiency for a propeller operating in front of a body such as a radial engine, to have its pitch reduced toward the hub. The results of this work also have been prepared for publication as a Technical Report.

To gain some preliminary information on the efficiency of geared propellers as compared to directly driven propellers, a series of tests was made using a J–5 geared and ungeared engine on a large and a small fuselage. The results of these tests have also been prepared for publication. The investigation was made in such a manner that the propeller-body interference factors were isolated, and it was found that, considering this interference only, the geared propellers had an appreciable advantage in propulsive efficiency, partially due to the larger diameter of the propellers with respect to the bodies, and partially because the geared propellers were located farther ahead of the engines and bodies.

The question has often been raised as to how the efficiency of a propeller may be affected when the blades are cut down to adjust a given propeller to a particular engine. In order to obtain some information on this question, a 10-foot propeller was cut down in diameter in five successive steps to 8 feet 6 inches. At each diameter the propeller was tested at several pitch settings. It was found that the loss in propulsive efficiency for the greatest decrease in diameter amounted to 5 per cent. This loss is partly chargeable, of course, to the increase in body interference and partly to the less favorable shape of the propeller tips. This information is being prepared for publication as a Technical Report.

Another investigation which should yield results which will be helpful to propeller designers is that of the effect of the wing behind the propeller on the propulsive efficiency. A preliminary test has been made in connection with this problem, and the information prepared for publication. A much more complete investigation of this question is now being made, however. This will include a study of the effect of the wing on the propeller efficiency, the effect of the propeller slip stream on the wing characteristics, and the interference between a wing nacelle and the wing. The investigation is being carried out in the propeller research tunnel by use of a model wing of 16-foot span and an aspect ratio of 5. A nacelle containing an electric motor which drives a 4-foot propeller is to be located in various positions relative to the wing, and measurements made of the lift, drag, and pitching moment of the wing and of the propulsive efficiency of the propeller with all the various combinations.

In order to put all the information obtained on the effect of these various factors on propeller efficiency into a form readily usable by propeller designers, a series of design charts is being prepared for publication.

Airfoil studies.—Studies of airfoil characteristics and particularly of scale effect, are being carried out from time to time in the various wind tunnels by force and pressure-distribution tests. A series of seven airfoils was tested during the year in the propeller research tunnel. They included the Clark Y, the Göttingen 398, the N. A. C. A. M–6, and the N. A. C. A. 84. These airfoils were of 2-foot chord and 12-foot span. The Reynolds Number was about 2,000,000, which is about half the maximum obtainable in the variable-density tunnel. The above series included two airfoils with corrugated surfaces, as well as some other variations in surface conditions. The results were in good agreement with results obtained in the variable-density tunnel at a corresponding Reynolds Number, suitable correction having been made, of course, for the tunnel-wall effect in the variable-density tunnel and the effect of the air-stream boundary in the open-throat propeller research tunnel. The corrugated airfoils gave a slightly greater drag than the smooth, but a marked flattening of the lift curve in the vicinity of maximum lift was found, which is regarded as advantageous from the standpoint of safety.

The question of the effect of scale on investigations of pressure distribution in the wind tunnel as compared with those made in flight has never been satisfactorily answered. In order to throw some light on this matter, a series of pressure-distribution tests was made in the variable-density wind tunnel at 1 and 20 atmospheres pressure. A liquid manometer was used for the 1-atmosphere tests but for the 20-atmosphere tests a manometer of the optically recording diaphragm type was used. The airfoils tested included the M-6, a symmetrical (R. A. F. 30) airfoil equipped with trailing-edge flaps, an R. A. F. 31 airfoil equipped with a Handley Page leading-edge slot, Clark Y, and others. The results on the Handley Page slotted airfoil have been published. The others are in preparation for publication. It may be stated that, in general, the scale effect shown by these tests is slight.

It has not been possible in the past to secure very satisfactory agreement between the air flow about airfoils as determined by pressure-distribution measurements in the wind tunnel and as computed from theoretical considerations. In order to ascertain whether a better agreement may be obtained between results of tests at high Reynolds Number, as in the variable-density tunnel, and the computed results, there were included in the above program one Joukowsky section and two modified Joukowsky sections. The agreement with theory was found to be fair, although the scale effect, as stated above, was, in general, not striking. The results of this investigation are in preparation for publication.

Another investigation of interest consisted in testing the variable-density wind tunnel of a group of eight airfoils approximately 20 per cent of the chord in thickness. The purpose was to study, in particular, the effect of scale on discontinuities in the characteristic curves near the region of maximum lift. Six of the eight airfoils exhibited discontinuities at a Reynolds Number of 150,000, and these discontinuities became less pronounced as the Reynolds Number was increased. None of the airfoils showed a discontinuity when the Reynolds Number was increased to 720,000.

In view of the fact that the results of airfoil tests in the variable-density tunnel have, in general, not been corrected for the effect of the tunnel walls, and furthermore, in order to put the data on these airfoils in a form more convenient for ready reference, the data on all airfoils tested in the variable-density tunnel have been recomputed and replotted.

What is believed to be one of the most valuable investigations carried on thus far in the variable-density wind tunnel consists in an investigation of the effect of thickness and of the shape of the mean camber line on airfoil characteristics. It is planned to make tests on a family of about 80 airfoils having the same relative variation in thickness along the chord, but having six values of the maximum thickness, 6, 9, 12, 15, 18, and 21 per cent of the chord. The airfoils are based on five differently shaped mean camber lines, each having 4° of camber.

Aerodynamic efficiency may be increased by applying the principle of boundary-layer control to the wings and possibly also to other parts of an airplane. Certain advantages in this direction have already been obtained by means of the Handley Page type of slotted wing. Still greater improvement seems to be possible by the use of a properly located narrow slot opening into the wing and so arranged that air may be discharged from the wing or sucked into it by suitable means. An investigation of the possibilities of this type of slotted wing has been carried out in the atmospheric wind tunnel during the past year. A model equipped with a slot adjustable both in position and width was used. Arrangements were made for applying either suction or pressure and the power required to produce the flow was measured. Large increases in lift were obtained with moderate pressures, and the minimum drag was reduced.

Airship investigations.—The aerodynamic efficiency of an airship is evidently dependent on careful design, not only of the hull and control car, but also of the control surfaces. Some further work has been done during the year in connection with flight tests previously made on the U. S. S. *Los Angeles*. Data obtained in speed and deceleration tests have been prepared for publication. A report covering the pressure distribution on the hull and tail surfaces, and a report covering the investigations to determine the drag of the airship with and without water-recovery apparatus, have been published. Speed and deceleration tests for the purpose of determining the drag of a small commercial type airship have been carried out in conjunction with the Goodyear-Zeppelin Corporation, and apparatus is now being assembled for similar tests on a TC airship and on a small service type airship.

The variable-density wind tunnel and the propeller research tunnel both offer facilities for making model tests on airships at higher Reynolds Number than can be conducted in other tunnels. This fact has led to a series of tests now in progress in the variable-density wind tunnel on a model of the *ZRS-4* airship and preparation for tests on a large model in the propeller research tunnel. The tests in the variable-density tunnel have consisted of lift, drag, and pitching-moment measurements of the *ZRS-4* model in comparison with a model of lower fineness ratio. The tests are being made with and without a control car. It is planned in the propeller research tunnel to measure the pressure distribution over the hull of the airship model, its lift and drag at various angles of pitch, and at the same time to measure the forces and moments exerted on the elevator hinge.

Miscellaneous investigations of particular interest in connection with airship work have included some preliminary studies on gusts and also on the use of a Friez type cup anemometer for measuring the velocity of a gusty wind.

Developments in Equipment.—It is constantly necessary to make improvements in the equipment of the laboratory and to add new pieces of equipment, if the work is to keep up with the advancement of the art. In connection with the work of the atmospheric wind tunnel, there has been developed an integrating manometer for use in pressure-distribution measurements. By means of a number of tubes of different cross-sectional area connecting with a common reservoir, the chord load at any particular wing section is integrated automatically and is thus measured by means of a single liquid column. This manometer has saved considerable labor in the working up of the results of pressure-distribution tests.

The balance of the variable-density wind tunnel as rebuilt is similar in principle to the old balance, but differs in some minor details. It consists of a cradle of structural steel which surrounds the lower half of the air stream and which is suspended by rods from balance beams which are visible through peepholes in the outer shell. The model is rigidly fastened to the cradle by vertical struts which are protected from the air stream as far as possible by fairings. The sliding weights on the beams, as well as coarse weights which are carried on bridges, are operated by electric motors with control switches on the outside.

It has been found possible during the past year to improve the operation of the tunnel in a number of ways. An objectionable vibration, which at times resulted in damage to the knife edges, has been greatly reduced by mounting the structure supporting the balance on rubber shock absorbers similar to those used in mounting certain aircraft engines.

A slight twist, which was found to exist in the air stream, was eliminated by installing longitudinal deflectors in the return passage, and the velocity distribution at the test section was improved by introducing resistance at certain parts of the cross section by the attachment of wire mesh to the honeycomb.

The reduction in turbulence in the new tunnel as compared to the old was effectively demonstrated by means of a series of sphere tests, a report of which has been published. There tests also served to substantiate the principle upon which the variable-density tunnel is based, since it was found possible to obtain the same drag at a given Reynolds Number whether obtained by varying the density, velocity, or sphere size.

The only alteration made in the propeller research tunnel has been the installation of a dial type scale for the drag balance in place of the ordinary beam type previously used. This eliminates the delay formerly experienced in getting this scale in balance before each reading.

A small water channel has been found useful for studying the flow along surfaces of various contour and through model entrance and exit cones. The channel is 8 inches wide and the character of flow about a body is made visible by scattering aluminum dust on the surface of the water.

A small water tunnel having a 2½-inch throat diameter in which a speed of 45 feet per second may be obtained has been found useful for studying cavitation on airfoils of various shape. A 5-stage turbine type pump was developed for circulating the water. This has the advantage that the water can be circulated at high speed without the milky appearance which resulted from cavitation when a single driving propeller was used.

Development work on the high-speed tunnel has progressed somewhat slowly as tests are made only when the pressure in the variable-density tunnel is being reduced to 1 atmosphere. Experiments have been made with different designs of open and closed throat and with vanes for preventing twisting of the air stream. It has been possible to obtain an air speed of 1,290 feet per second in a throat 12 inches in diameter, and it has also been possible, by the use of optically recording diaphragm type manometers similar in principle to those used in flight tests, to record the pressure distribution on an airfoil section and at the same time the dynamic pressure. A balance has been designed for this tunnel, and this is now under construction. It will be possible with this balance to measure the lift, drag, and pitching moment of an airfoil which will be mounted in the stream passing directly through from one side to the other. The balance consists of a forked member which holds the two ends of the airfoil and provides means for changing the angle of attack. The aerodynamic forces are made to deflect steel beams and the deflection is recorded optically on a photographic film. Timing lines will be provided by a timer, which is standard equipment in connection with the instruments used at this laboratory. Another curve on the same film will indicate the dynamic pressure in the air stream.

In connection with the design of the full-scale wind tunnel, mentioned earlier in this report, considerable study has been given to the effect of varying the shape of the entrance and exit cones of open-throat tunnels in order to determine whether it is practical to use an elongated jet, and thus make possible the testing of an airplane of large span without too great a cross-sectional area at the throat. A series of tests was carried out on a number of different shapes of entrance and exit cones in the atmospheric wind tunnel. In each pair of cones three airfoils were tested having dimensions of 3 inches by 15 inches, 4 inches by 20 inches, and 5 inches by 25 inches. Force tests were made in order to determine the effect of the change of shape of the air stream. The series consisted first of a circular cone; second, a rectangular one having a ratio of height to width of 1 to the square root of 2; third, one of the same proportions having semicircular ends; and fourth, one similar to the above having the ratio of height to width of 1 to 2. The Prandtl correction was found to apply to the circular cone, and it was found possible to derive corrections for the other cones to give the same results. A report covering this work is in preparation.

It has been decided to adopt the fourth shape of throat mentioned above, for the full-scale tunnel—that is, one having a ratio of height to width of 1 to 2 and having semicircular ends. The height of the jet will be 30 feet and the width 60 feet. A scale model of the proposed tunnel has been built and tests are in progress to study such questions as energy ratio and air-flow conditions.

The development of flight research methods and the consequent necessity for increased accuracy of measurements have called for greater refinement in the recording instruments used in flight research. Laboratory tests are being conducted almost continuously on the instruments to reduce errors caused by mechanical friction and time lag in the parts, changes in the viscosity of the damping oil, lack of balance of moving parts, etc. This work is particularly necessary for instruments used in accelerated flight, and a considerable portion of this work has been concerned with the angular-velocity recorders and recording accelerometers. For investigations where measurements must be made in a very short period of time, such as when impact loads are measured, it has been necessary to greatly increase the film speed. A new electric motor has been constructed for driving the film in order to obtain more driving torque without increasing the size or weight of the motor, and this, together with a new low-friction dynamically balanced film drum, has given speeds approximately ten times those obtainable with the standard motor and drum. A control force recorder suitable for recording stick forces in accelerated and level flight has been designed and constructed during the year and is now being tested.

BUREAU OF STANDARDS

Wind-tunnel investigations.—Substantial progress has been made in the investigation of wind-tunnel turbulence and its bearing on the problem of standardization of wind tunnels. Technical Report No. 320 of the National Advisory Committee for Aeronautics describes the apparatus used for the measurement of one quantity which is of interest in turbulent motion, namely, the mean amplitude of the fluctuations of the air speed. The primary element is a hot-wire anemometer, the wire being about 0.017 millimeter in diameter. The report contains the theory of the lag of the anemometer, a theory, description, and experimental test of a method of compensating for the lag, and some typical experimental results.

Measurements in the three wind tunnels at the Bureau of Standards at a number of possible working sections showed a large range of values of the turbulence as measured with the hot-wire anemometer. It was possible, therefore, to determine experimentally in a quantitative manner the effect of turbulence in wind-tunnel measurements on spheres and airship models. Direct correlation was established between the forces and the turbulence. For spheres, the relation between the critical Reynolds Number (Reynolds Number at which the drag coefficient is 0.3) and the turbulence was determined in the form of a "calibration" curve by means of which spheres may be used for quantitative measurements of turbulence. Experimental proof was obtained that the discrepancies in the results on the N. P. L. standard airship models are due mainly to differences in the turbulence of the wind tunnels in which the tests were made.

It was found possible to account for the observed effects of turbulence in terms of the boundary-layer theory, by assuming that the flow in the boundary layer may be either laminar or turbulent as determined by the Reynolds Number formed from the speed at the outer edge of the boundary layer and the thickness of the boundary layer. The value of the Reynolds Number at which the change occurs is assumed to depend on the magnitude of the initial turbulence (that of the wind-tunnel air stream), decreasing as the initial turbulence increases. It is found necessary to assume that the body itself sets up turbulence shortly behind the maximum cross section. As a result, airship models in which the maximum cross section is far forward are much less sensitive to the wind-tunnel turbulence than those in which the maximum cross section is well aft.

Apparatus has been designed and is under construction for a study in some detail of the transition from laminar to turbulent flow on a flat plate.

The report on the characteristics of 24 airfoil sections at speeds from 0.5 to 1.08 times the speed of sound has been published as Technical Report No. 319 of the National Advisory Committee. A series of sections with plane lower surfaces and cylindrical upper surfaces has been constructed for test, since one section of this type included in the first series showed better lift-drag ratios than other sections of different shape but of the same thickness.

The measurements of the rolling and yawing moments produced by ailerons of various chords and spans on 10 by 60 inch models of Clark Y and U. S. A. 27 sections have been extended to large angles of attack, in cooperation with the Aeronautics Branch of the Department of Commerce and the National Advisory Committee for Aeronautics. Measurements of hinge moments are in progress.

Aeronautic instrument investigations.—The work on aeronautic instruments has continued to be conducted in cooperation with the Bureau of Aeronautics of the Navy Department and the National Advisory Committee for Aeronautics.

A report has been prepared on the present status of air navigation instruments which is to be submitted by the subcommittee on instruments, after approval and contribution by its members, to the committee on problems of air navigation.

The bureau cooperated with the Bureau of Aeronautics in the preliminary technical work incident to the annual conference of the Army Air Corps and the Bureau of Aeronautics with instrument manufacturers on current purchase specifications. Two important changes, one relating to the size of instrument cases and the other to the standard test temperatures, were adopted in the conference. A uniform size of instrument case, based on a dial 2¾ inches in diameter, was adopted as a standard for altimeters, air-speed indicators, and tachometers, and a uniform size, based on a dial 1⅞ inches in diameter, for engine thermometers and pressure gauges. These new sizes are in considerable favor with aircraft operators and are likely to be adopted as a general standard. The lowest temperature at which the performance of instruments is determined has been changed from $-20°$ to $-35°$ C. The standard temperatures at which instruments are now tested are $-35°$, $+20°$, and $+45°$ C.

The development program covered new and improved apparatus for testing aircraft instruments, improvements in service instruments, and the development of aircraft instruments for special purposes. An accelerometer-testing apparatus was constructed in which the accelerations are secured by means of a rotating table and the indications of the instrument under test photographed. A nonmagnetic vibration rack for use in testing magnetic compasses is now under construction which is similar to previously constructed racks except that it is to be of nonmagnetic materials as far as possible. Two accelerometers, one with a maximum pointer, have been constructed for use in measuring the acceleration of airplanes in the direction perpendicular to the floor of the airplane. An oil-pressure gauge has been modified so as to test the feasibility of using a nonfreezing liquid in the tubing between the engine and the indicator instead of the oil, in order to improve the performance of oil-pressure gauges in aircraft which operate at low temperatures. Work has continued on the further development of the electric resistance thermometer for measuring free air temperatures and, in cooperation with instrument manufacturers, on the development of a satisfactory type electric tachometer for multiengined aircraft.

A report has been prepared on the fundamentals of instrument mechanism design, considering factors such as inertia effects and damping in its relation to the effect of vibration of the aircraft. A report is in preparation on the results thus far obtained on the variation of the torsion modulus of nonferrous and ferrous materials with temperature, and further experimental work is being planned. Revision of the report covering the elastic afterworking of diaphragm metals is in progress based on the study of the data in Technical Note No. 261. An experimental program has been drawn up covering work on the friction of step and shoulder bearing pivots in which particular attention is given to the effect of the finish of the pivots.

The investigation of damping liquids for aircraft instruments has centered during the past year on extending the low-temperature limit of the viscosity data published in Technical Report No. 299 to $-50°$ C. and in finding a suitable liquid for the ball-type inclinometer. In extending the results to lower temperatures an apparatus was constructed in which the liquid bath could be cooled by carbon dioxide "ice." The damping liquid for the inclinometer must be such that its viscosity is not too great at $-35°$ C., and great enough at $+30°$ C. to damp out the rotation of the ball of the inclinometer when the latter is under vibration. This rotation coupled with linear oscillations causes the ball to climb the tube. As a criterion of the usefulness of a liquid at low temperatures the temperature at which its kinematic viscosity is five times that at $+30°$ C. has been proposed. The greatest temperature change required to produce the fivefold increase in viscosity of the liquids so far investigated is about 50° C. for liquids having a viscosity of 0.05 poise (25° C.) and about 70° C. for liquids of 0.025 poise. Liquids with these characteristics do not fully meet the requirements of the ball inclinometer.

WASHINGTON NAVY YARD

The wind-tunnel equipment at the Washington Navy Yard consists of an 8 by 8 foot closed-circuit type and a 4 by 4 foot N. P. L. type. The large tunnel is employed continuously in making tests on current airplane design models and on problems connected with current design. The small tunnel is used for miscellaneous investigations, but practically all of the tests are made to answer questions arising in the course of design studies. A limited number of extended investigations are undertaken from time to time, although most of the general problems are now submitted for study to the National Advisory Committee for Aeronautics.

Airplane models.—During the past year 22 model airplanes representing 18 designs were given complete tests in pitch and yaw. Many of these designs were given additional tests covering such items as effect of wing location, effect of nacelle location, effect of changes in control surfaces, etc. In several models serious interference effects were eliminated by patient testing of slight successive modifications. Work of this nature requires considerable time in the wind tunnel but it supplies information of the greatest value.

Airfoils.—No extended series of wing sections has been investigated during the past year, but a group of nine new airfoils is to be tested at the first opportunity. Routine tests have been made on three airfoil sections in connection with the tests on airplane models in which they were used.

A short investigation was made on the effect of the curvature of concave under cambers with particular reference to the burbling that occurs on the bottom surface at low angles of attack. During this study a few tests were made to investigate the possibility of simple methods of flow control, but the results were not very encouraging.

Floats and fuselages.—Four seaplane floats have been tested for drag at various speeds in continuation of the series previously tested. Additional tests are to be made as the models become available.

Nine fuselage models have been tested, also in continuation of a previous series. This completes the fuselage tests laid out two years ago, but a new series is to be started during the coming year. These models are based on current designs and are selected to cover the various types used in design.

Windshields.—Several tests have been made on windshields of various forms designed to give better protection to the crew or to reduce drag. Part of this work has been done on complete model airplanes, and part on special fuselage models. It is felt that this type of testing is in general rather unsatisfactory. There appears to be a great need, however, for some windshield design data along the lines of protection of the gunner in a rear cockpit. This general problem is now under investigation by the National Advisory Committee for Aeronautics.

Nacelle interference.—Nacelle interference with wings has been determined for a series of models, in order to obtain certain design data. The tests indicate that the best fairing varies with angle of attack and that it must be worked out for each design. Further work along this line at the Washington Navy Yard appears to be unnecessary in view of the proposed research by the National Advisory Committee for Aeronautics.

Struts.—Three extensive series of struts have been tested during the past year. The first series consisted of 11 modifications of the Navy No. 1 strut, the program being so laid out as to include the study of the effects of fineness ratio and trailing-edge radius. A report covering these tests is now being prepared. The second series consisted of five theoretical shapes supplemented by three standard struts. The tests included pressure distributions and drag measurements, which were compared with the calculated values. A report by Dr. R. H. Smith on this work has been published by the National Advisory Committee for Aeronautics as Technical Report No. 335. The third series was less systematic than the other two and consisted chiefly in measurement of the effect on drag of slight modifications in the contour, surface, and size of standard struts.

Slots and flaps.—Four wing models incorporating the Handley Page automatic slot have been given thorough tests for slot operation with reference to the angles of opening and closing for various linkage systems. These tests also included force measurements on the leading airfoil, and velocity explorations in the slot. All the models were tested in connection with the adaptation of the slot to service-type airplanes, rather than as a detached investigation.

Lighter-than-air.—Some calibration tests have been made on the new oscillator which was completed during the past year. The results appear very satisfactory, and further oscillation tests are to be made when the time is available.

A series of power cars for use on rigid airships is being given tests for drag at various speeds. This series includes a group having the N. A. C. A. Venturi cowling in several forms. The general problem of the interference and drag of power cars on airships is being continued by the National Advisory Committee for Aeronautics both in the variable-density wind tunnel and in the propeller research tunnel.

MATÉRIEL DIVISION, ARMY AIR CORPS

WIND TUNNELS.—The reinstallation of the McCook Field 5-foot and 14-inch wind tunnels at Wright Field was completed in February, 1929. The new installations are practically the same as at McCook Field, with only minor improvements, and the air flow, etc., are essentially the same.

Routine tests.—In addition to the calibration check, only one routine wind-tunnel model test, that of a 1/10-scale model of the XO–14 airplane, has been run. The primary purpose of this test was to compare the lift and drag characteristics obtained in the wind tunnel with the characteristics of the complete airplane obtained from glides without thrust.

Wing flutter.—A preliminary wind-tunnel investigation of wing flutter has been made. This investigation covered different types of flutter in several common wing sections at angles near the burble point and near the angle of zero lift. The distribution of the mass, the shape of the tips, and the elastic axis were all variable, and the frequency was further varied by added weight and by adjustment of the support.

Engine cowling.—A series of cowlings for air-cooled engines mounted in wing nacelles was tested for drag and cooling properties, and the data obtained were made available to designers.

Tail surfaces.—An investigation of the characteristics of the horizontal tail surfaces of a ⅙-scale model of the AT-4 fuselage with two tail surface arrangements, begun at McCook Field, was completed during the past year.

Pressure distribution.—Pressure distribution on the Clark Y and Göttingen 398 wings has been determined at very close intervals over the leading edge to facilitate the design of automatic slots.

FULL-SCALE EXPERIMENTS—*Glide testing.*—A "zero thrust" indicator has been devised which makes glide testing practicable for determining the lift and drag characteristics of airplanes in flight. Polar curves have been obtained for the XO-2, the XO-6, and the XO-14 airplanes. The profile drag of the XO-6 was found to be greater with a corrugated wing surface than with a smooth surface. A torque meter adaptable to geared engines has been designed, which, used in combination with data obtained from glide tests, will determine power and propeller efficiency in flight.

Performance reduction.—The performance data obtained both in summer and in winter on four airplanes have been reduced to standard air performances by different methods which were proposed to improve present methods of reduction; no improvement, however, was found, and therefore no changes have been made in the methods.

Slots and flaps.—Controlled leading-edge slots with trailing-edge flaps were tested on the Driggs Dart airplane and found to be of some benefit in taking off and landing, but the reduction of high speed and climb was not measured. Automatic slots were tried on the PT-3 airplane and found to reduce high speed and climb with no improvement in landing or take-off qualities.

OLEO JIG.—A jig for the drop testing of oleo and other shock absorbers has been completed, making it possible to closely approximate actual landings and accurately record accelerations and stresses.

EDUCATIONAL INSTITUTIONS

Massachusetts Institute of Technology.—A new Venturi-type 5-foot wind tunnel has been added to the equipment at the Massachusetts Institute of Technology. This wind tunnel is of the closed-throat and open-return type, and has an air speed of about 100 miles per hour with a 75-horsepower motor. Thesis investigations have been made on the effect of yaw on the autorotation of a monoplane airfoil; the heat transfer from the lower surface of an airfoil at various angles of attack; and the air flow around, and the resistance of, a horizontal opposed engine in a wing, with comparative V and radial engine tests. In a special high-speed tunnel a study of heat transfer from finned surfaces has been made, and wind-tunnel work has also been in progress on the mutual interference effects of airplane propellers and other parts of the airplane.

Stanford University.—An investigation has been completed on the effect of fuselage fineness upon propeller performance, and tests of six 3-bladed adjustable pitch propeller models have been conducted for the Army Air Corps. In the investigation of the profile drag of certain airfoils, a single special-form airfoil of Clark Y section has been given a preliminary test, and the indications are that this airfoil has no induced drag, so that it will be possible to measure the profile drag directly with a balance.

New York University.—At the Daniel Guggenheim School of Aeronautics a number of tests were made, in cooperation with the Goodyear-Zeppelin Corporation, on an airship model suspended in the wind tunnel at various angles to the wind, close to the ground and to the hangar. Three-component measurements of forces were made, and information relating to the forces present in the ground handling of airships was obtained. A cabin fuselage of typical form was tested with various types of forward windshield arrangements, and the results indicated the possibility of developing a type of windshield combining desirable aerodynamic properties with satisfactory vision. In these tests it was found that a slight modification in the shape of the forward part of the cabin fuselage might increase the resistance of the fuselage to a detrimental extent. A study was made of the fairing between wings and fuselage, in which it was found that a fairing lying in a horizontal plane gave no aerodynamic advantage, but that fairing in a vertical plane would reduce the combined resistance of the fuselage and wings appreciably. By means of a rigid I beam whose deflection, recorded optically on a drum, gave a measure of the loads without the complication of any shock absorption in the apparatus itself, drop tests of oleo struts were made under conditions simulating actual use, and in addition the displacement of the struts was measured by optical methods. Complete load-time and displacement-time curves were thus obtained for a number of oleo struts.

California Institute of Technology.—At the Guggenheim Laboratory of the California Institute of Technology, a new 10-foot wind tunnel has recently been completed and its flow characteristics calibrated. A set of automatic balances was especially designed for the new tunnel and has been calibrated. Theoretical investigations have been under way on the motion of compressible inviscid fluids and of incompressible viscous fluids, and on the forces and moments acting on the individual wings of a biplane cellule. Wind-tunnel tests have been conducted on the drag of a sphere and of replicas of the N. P. L. streamline models tested several years ago in various wind tunnels in this country. Study has been made of the bending strength of tubes with small thickness-diameter ratio, and of the strength of corrugated duralumin sheet under compressive loads parallel to the corrugations.

University of Michigan.—Investigations have been under way at the University of Michigan on boundary-layer removal by suction, and on the lift, drag, and stability, including rolling and yawing moments, of a low-wing monoplane and of an amphibian with outboard engines. Several problems relating to the air resistance of automobiles and of engineering structures have also been investigated.

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, Stevens Institute of Technology.
Dr. H. C. Dickinson, Bureau of Standards.
Carlton Kemper, National Advisory Committee for Aeronautics.
Lieut. E. R. Page, United States Army, Matériel Division, Air Corps, Wright Field.
Lieut. Commander James M. Shoemaker, United States Navy.
Prof. C. Fayette Taylor, Massachusetts Institute of Technology.

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

COMPRESSION-IGNITION ENGINES.—The research work in connection with the development of the high-speed, compression-ignition engine for aircraft use has been continued. Particular attention has been given to the problem of improving the processes of combustion by obtaining a more even distribution of the fuel in the combustion chamber. The results have been lower specific fuel consumptions and higher percentages of computed full-load torque with a clear exhaust.

Analysis of theoretical cycle efficiencies.—The theoretical investigation of a number of design factors controlling the actual cycle efficiencies of compression-ignition engines has been continued. A method of calculating cycle efficiencies and mean effective pressures for the dual cycle has been developed in order to determine the effect of compression ratio, maximum cylinder pressure, and excess air on the theoretical cycle efficiency. The calculations show that increasing the compression ratio from 8 to 18 for a constant maximum cylinder pressure of 800 pounds per square inch increases the indicated mean effective pressure 10 per cent. The same percentage increase would also be obtained by raising the maximum cylinder pressure from 700 to 1,200 pounds per square inch for a compression ratio of 14. A report on the investigation to determine the effect of compression ratio and maximum cylinder pressure on the cycle efficiency of compression-ignition engines operating on the dual combustion cycle is being prepared for publication.

In order to determine the error that is made in the cycle calculations by considering the specific heats of the gases of combustion to be constant, two series of calculations have been made; one using constant specific heat values, the other using specific heat values that vary with the temperature. In each series of calculations the working fluid was considered to be actual cylinder gases, the mixture to vary at different points of the dual cycle, and the combustion of the fuel to be complete. The investigation covered a range of compression ratios from 10 to 16 and maximum cylinder pressures from 700 to 1,200 pounds per square inch, full-load fuel, and no excess air. It was found that the cycle efficiency and indicated mean effective pressure were 13 per cent greater when the specific heats of the gases were considered to be constant than when the specific heats were considered to vary with the temperature. Calculations have also been made for excess air quantities at full load from 0 to 72 per cent for the above range of compression ratios and maximum cylinder pressures. Increasing the full load percentage of excess air increases the cycle efficiency and percentage of fuel burned at constant volume, and decreases the indicated mean effective pressure, with increase of the compression ratio and maximum cylinder pressure. The results also show that the quantity of fuel required to raise the pressure of a given volume of mixture from one pressure to another is independent of the quantity of excess air present. The average variation was not over 1 per cent for 26 out of 31 sets of calculations and one-half of these did not vary more than 0.5 per cent.

Of the total amount of energy liberated by the combustion of fuel in an internal-combustion engine, 25 to 37 per cent is obtained for useful work. The remainder is lost in the exhaust gases and in radiation, conduction and convection to the cylinder walls and piston. As these three methods of heat transmission rarely occur singly, an investigation is being made of the available literature to determine the possibility of segregating and reducing these losses by a knowledge of their magnitude and part of the cycle in which they have the greatest effect.

Combustion-chamber investigation—Integral type.—Work has been continued with the cylinder head having a vertical disk-type combustion chamber formed between horizontally arranged inlet and exhaust valves. This combustion chamber has only a slight degree of air turbulence, because of a large rectangular orifice between the cylinder and the combustion chamber. The fuel-injection system used with this engine consists of a cam-operated fuel-injection pump and a spring-loaded automatic injection valve having various combinations of seven small round orifices arranged at different angles, but in the same plane. The injection valve was placed in the top of the combustion chamber and the sprays were directed toward the rectangular orifice. Several nozzles having two additional orifices delivering fuel to the air in the upper portion of the combustion chamber have also been tested. These 9-orifice nozzles give a slight increase in engine performance and a clearer exhaust than the 7-hole nozzles, which indicates that the improvement in combustion efficiency is due to the better fuel spray distribution obtained with the two additional orifices.

At 1,500 r. p. m. with a fuel quantity giving approximately three-fourths full-load torque, which corresponds to engine operation at cruising speeds, and maximum cylinder pressures less than 500 pounds per square inch, the 5-inch bore by 7-inch stroke test engine developed an indicated mean effective pressure of 104 pounds per square inch. The corresponding fuel consumption was 0.36 pound per indicated horsepower per hour. Based on a mechanical efficiency of 85 per cent for multicylinder engine operation, this performance gives a brake mean effective pressure of 82 pounds per square inch and a fuel consumption of 0.45 pound per brake horsepower per hour. A clear exhaust is maintained up to 82 per cent of full-load torque.

A series of tests has been made to determine the friction losses of the component parts of a single-cylinder Universal test engine when operated with a compression ratio of 13.5 and a speed of 1,500 r. p. m. The two major items of friction were the pumping and piston-ring losses, which amounted to 29.4 and 22.3 per cent, respectively, of the total friction. These test results indicate the need for an assembly of compression and oil rings which will maintain the high-compression pressures required for operation of the compression-ignition engine and at the same time will give low piston-ring friction.

Combustion-chamber investigation—Precombustion chamber type.—The investigation to determine the effect of high combustion-air turbulence as influenced by the design of the cylinder head, and of the type of fuel spray, on the performance characteristics of a high-speed compression-ignition engine has been continued with the cylinder head having a pear-shaped precombustion chamber. In determining the performance characteristics of this combustion chamber a centrifugal fuel spray had been previously used which gave good distribution within the precombustion chamber. Operation with this type of fuel spray gave low indicated mean effective pressures and high maximum cylinder pressures. The fuel spray has been changed to a noncentrifugal spray injected from an orifice of 0.050 inch diameter placed flush with the precombustion chamber. The injection duration for full-load fuel quantity with this fuel valve and nozzle and a cam-operated fuel injection pump is 34 crank degrees. At 1,500 r. p. m., full load fuel, i. e., the fuel quantity giving 15 per cent excess air in the cylinder, the single-cylinder test engine developed an indicated mean effective pressure of 133 pounds per square inch. The corresponding fuel consumption was 0.040 pound per indicated horsepower per hour. The maximum cylinder pressure as indicated by the disk-type maximum cylinder pressure indicator was 760 pounds per square inch. The exhaust was colorless and smokeless up to 85 per cent of full load. This full-load indicated mean effective pressure represents an increase in indicated mean effective pressure of 13.7 per cent obtained without an increase in the maximum cylinder pressure.

Fuel-injection systems.—The mathematical analysis of automatic injection valves has been continued. The effects of operating forces and valve design have been investigated for a diaphragm-loaded valve and for a valve in which the loading is given by the extension or compression of a member of the valve. Experimental records of the motion of a helical spring-loaded valve are being obtained to determine the agreement between the mathematical analysis and the actual conditions. The motion of the injection-valve stem is recorded on a film drum moving at a speed of 1,000 inches per second. It has been found that the valve stem opens fully in approximately 0.003 second and the fuel-spray formation and cut-off follow the opening and closing of the valve within a few hundred-thousandths of a second. Furthermore, it has been learned that unless the valve is fitted with a mechanical stop the stem oscillates, giving in extreme cases a pulsating effect to the fuel spray. The experiments conducted so far indicate that the secondary discharges which have been previously discussed in Technical Report No. 258 of the committee are caused by a bouncing of the moving member of the injection valve. This secondary discharge has been partially eliminated by enlarging the area of the by-pass valve of the injection system under investigation.

The time lag at which the fuel is injected into the cylinder of a compression-ignition engine is an important factor in the combustion efficiency of the engine. To determine the time lag it is necessary to know the time interval required for any given pressure at the fuel pump or the fuel-distributing mechanism to reach the injection valve. The time lag of the fuel-injection system is a function of the valve design, the valve opening pressure, the pressure in the injection system and the length of tube between the fuel pump or distributor and the injection valve. An investigation of the factors affecting injection time lag is being conducted at this laboratory. Photographic records of the motion of the timing valve and the injection-valve stems are obtained by using small mirrors which are rotated by the movement of the stems and reflect two light beams on a revolving film drum. The time lag of the injection system is the time interval which elapses between the start of lift of the timing valve and the start of lift of the injection valve. For an injection pressure of 4,000 pounds per square inch and an injection tube length of 70 inches the time lag is approximately 0.0025 second. At an engine speed of 1,500 r. p. m. this corresponds to approximately 25 crank degrees.

The ratio of the length to the diameter of the orifice of an injection valve for a compression-ignition engine has an effect on the distribution and penetration of the fuel spray delivered from the valve. In order to provide information for the designers of compression-ignition engines, the sprays from single orifices varying in diameter from 0.005 to 0.040 inch are being photographed by means of the N. A. C. A. spray photography equipment. From the photographs both the penetration and distribution of the fuel spray are obtained. The length-diameter ratio of the orifices is being varied from 4.00 to 0.75. The photographs are being taken for injection pressures from 2,000 to 8,000 pounds per square inch, valve-opening pressures from 2,000 to 4,000 pounds per square inch, and for spray-chamber air densities from 4 to 17 atmospheres. The photographs are being taken for both a straight stem and a helical grooved stem in the injection valve.

Considerable work has already been done at the laboratory on the determination of the coefficient of discharge of liquids through small round orifices. This investigation is to be extended to cover the effect of the length-diameter ratio of the orifice and also the effect of the injection valve as a whole. The tests which have been started are being conducted in conjunction with the research on the effects of the length-diameter ratio of the orifice on the spray characteristics. The same range of injection pressures, valve-opening pressures, and chamber densities will be investigated and the same spray nozzles will be employed.

A dual-rate fuel-injection valve has been designed to give a varying rate of injection in accordance with the combustion requirements of the dual-combustion cycle. The first part of the fuel charge is injected through orifices of small diameter and the remainder of the fuel charge through an annular orifice. The primary injection is controlled by a poppet valve loaded by a helical spring and the main injection by the lips of the orifice, loaded through a combination of spring disks. In designing this valve to fulfill theoretical combustion requirements, it was necessary to devise methods by which calculations could be made to determine the desired rate of fuel injection at any point in the injection cycle. A method was also developed for the calculation of instantaneous injection pressures and from these pressures the instantaneous rates of fuel discharge. The effective mass centers of the spray and the combustion air were calculated for the various crank degrees during injection, and the fuel sprays were so directed as to make the two coincide as nearly as possible. Preliminary tests have been made of the fuel valves and the quantity and rate of fuel injected were found to check the design calculations.

An investigation of the problems of fuel distribution and injection encountered in the operation of fuel-injection systems for multicylinder compression-ignition engines of aircraft type has been undertaken. A 6-plunger cam-operated fuel-injection pump has been constructed and subjected to preliminary development tests. The fuel quantities delivered by each individual plunger through the dual-rate fuel-injection valve were measured and the timing of start and duration of spray from each valve determined by means of an oscilloscope. Preliminary engine tests have also been made with this fuel pump.

Indicators for internal-combustion engines.—A large amount of valuable information on the combustion characteristics of various fuel sprays can be obtained from accurate indicator cards of high-speed compression-ignition engines. The great difficulty has been to obtain an indicator which would accurately follow the variation of pressure within the cylinder of the compression-ignition engine. Work has been continued on the design of an optical-type engine indicator which will give the variation of pressure for a single engine cycle. While the necessary design and development work is being done, a commercial balanced-pressure, electric-recording indicator which gives a composite card, has been altered so as to give results of a higher degree of accuracy. These alterations include an 80 per cent reduction in the weight of the moving disk, a decrease in the seat width from 0.031 to 0.004, and the use of a light-weight paper which requires only half the primary voltage.

In order to compare performance data of compression-ignition engines, it is necessary that the maximum cylinder pressures be accurately indicated. The work of improving the various types of maximum cylinder-pressure indicators has been continued. At the present time the maximum cylinder pressures are indicated by means of a modified Bureau of Standards balanced-pressure diaphragm-type indicator. The balance condition of the diaphragm is indicated by the flash of a neon lamp.

Two-Stroke Cycle, Gasoline-Injection Engine Investigation.—The design of a single-cylinder, 2-stroke cycle, gasoline-injection, electric-ignition, air-cooled test engine has been continued. This work has for its object the determination of the fundamental factors affecting the operation of such a power plant in order that the inherent advantages of greater power output per unit weight of an engine of this type may be made available for pursuit-type aircraft. A standard Liberty air-cooled engine cylinder has been altered and adapted to the crankcase of an N. A. C. A. Universal test engine. The design of the combustion and scavenging-air system and the propeller-type blower for cooling the cylinder has been completed and construction of the blower unit started. The fuel-injection system will consist of a cam-operated fuel-injection pump and two automatic injection valves. Tests have been made of several injection valves designed to give a well-distributed sheet of fuel spray. A fuel-injection pump is being designed with plunger port, fuel admission, and cut-off which will permit of consistent operation at the higher pump speeds necessary with the 2-stroke cycle engine.

Supercharger Investigation—*Roots type supercharger.*—The analysis of data on geared centrifugal, turbocentrifugal, and Roots type superchargers has been continued. The adiabatic efficiency of these superchargers has been computed from the test data available. The computations and curves on the power required by a geared centrifugal supercharger to compress 1 pound of air per second at various pressure differences are being checked. Computations are also being made on the test data now available and on the data from tests now in progress to determine the effect of various types of superchargers on the net engine power obtained at various altitudes.

A report has been prepared for publication presenting the results of tests to determine the effect of supercharger capacity on engine and airplane performance. The performance in level flight and in climb of a DH–4 M–2 airplane powered with a Liberty engine was determined for four supercharger capacities obtained by varying the drive-gear ratio of the supercharger. The engine power was measured with a calibrated propeller. The results of these tests show that there was very little sacrifice in sea-level performance obtained with the larger gear ratio as compared with that obtained with the smallest.

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The steel impellers reported last year as being under construction for the Roots type supercharger have been tested. The dimensions of these impellers and the clearances obtained with the impellers assembled in a supercharger case were satisfactory. Tests have been conducted on these impellers to determine the change in impeller diameter with change in speed. It was found that rotating the steel impellers at 9,000 r. p. m. increased the diameter 0.018 inch as compared with an increase of 0.009 inch for the aluminum and magnesium alloy impellers at the same speed. On account of the method of construction the steel impellers were not satisfactory for laboratory testing in the Roots type supercharger.

The turbo-centrifugal supercharger.—Tests to determine the performance in climb and level flight of a modified DH-4 M-2 airplane equipped with a turbocentrifugal supercharger are in progress. Test data have been obtained which will give the rate of climb, speed, power delivered to the propeller, and the fuel consumption. A worm-gear reduction drive for a tachometer has been constructed and used to obtain the rotational speed of the supercharger impeller at altitude. The flight work for both supercharged and unsupercharged conditions has been completed and the test data obtained on the flights are now being reduced to the conditions of a standard atmosphere. The results obtained have been compared with similar results previously obtained on the same airplane with a Roots type supercharger. This comparison shows the same ceiling and practically the same rate of climb for the two types of superchargers, but the level-flight performance at higher altitudes showed a decided improvement when the turbocentrifugal supercharger was used. A report is being prepared for publication which will present the comparative performance as obtained with the turbocentrifugal supercharger and the Roots type supercharger.

Effect of valve timing on supercharged-engine performance.—For unsupercharged engines a valve timing is usually selected which gives maximum charging efficiency at a given engine speed. This same valve timing is used when the engine is equipped with a supercharger and operated at altitude. With increase in altitude of the supercharged engine, however, the differential pressure available for inducting the charge into the cylinder increases. In order to determine the effect of valve timing on the performance of a supercharged engine, tests are being made with an N. A. C. A. Universal test engine operating under conditions of exhaust and inlet pressures simulating those of a supercharged engine for altitudes up to 20,000 feet. Since the timing of the exhaust and inlet valves can be altered over a wide range while the engine is in operation, the equipment is particularly adaptable to this investigation. The engine tests have been started and the performance determined with normal valve timing for both supercharged and unsupercharged test conditions.

Hub dynamometer.—The determination of the flight performance of airplanes would be greatly simplified if the power delivered to the propeller could be accurately measured at all times. The designing of a hub dynamometer for this purpose and the testing of its component parts have been continued. The dynamometer is of the hydraulic type. Three torque cells filled with liquid are interposed between the propeller and the engine. As the engine power is transmitted through the cells the liquid within the cell is subjected to pressure which is transmitted through small tubes to an optical recording system. The optical recording system produces a continuous photographic record of cell pressures. A torque cell of the type to be used in the dynamometer has successfully passed a fatigue test of 5,000,000 stress reversals. Several methods of driving the film drum have been tested and a compound-wound electric motor was found to give the most satisfactory operation. This motor showed satisfactory speed and torque characteristics when revolved on a dynamometer at speeds at 3,000 r. p. m. An optical system for the dynamometer has been constructed and is now being tested.

Cowling of Air-Cooled Engines.—Information obtained in tests to determine the effect of different amounts and kinds of cowling on the cylinder temperatures and the performance of a Wright J-5 engine has been prepared for publication. The cowlings investigated varied from the extreme of no cowling on the engine to the other extreme of the engine completely cowled and the cooling air flowing inside the cowling through an opening in the nose and out through an annular opening in the rear of the engine. Air speeds from 60 to 100 miles were investigated.

These tests show that increasing the amount of cowling reduces the drag, but has the disadvantage of increasing the cylinder temperatures. Satisfactory cooling was obtained with the cowling that covered 35 per cent of the cylinder cooling area, but the cowling which covered 73 per cent of the cooling area gave excessive temperatures. The cowling which completely inclosed the engine gave a reduction of 40 per cent in drag at 100 miles per hour as compared with the uncowled engine and did not give excessive cylinder temperatures.

BUREAU OF STANDARDS

Supercharging of aircraft engines.—The altitude laboratory is again in service after extensive alterations and will be used to test a Curtiss D–12 engine equipped with a Roots type supercharger. As the excess air delivered by the supercharger below its critical altitude will be recirculated, steps are being taken to increase further the capacity of the refrigerating system.

Not only have tests of the Curtiss D–12 engine been made under ideal supercharging conditions—that is, with air supplied to the carburetor at sea-level pressure for altitudes from 0 to 27,000 feet—but similar tests have been made with the carburetor air maintained at other constant pressures. The results are being prepared for publication and should be of value in analyzing the performance of exhaust-driven as well as gear-driven superchargers. For example, the normal sea-level power of this engine is 400 horsepower at the test speed (2,000 r. p. m.), the normal power at 15,000 feet is 200, and ideal supercharging at this altitude gives 430 horsepower. Hence, to restore full sea-level power at 15,000 feet requires a supercharger consuming only 30 horsepower or producing not more than 6 pounds exhaust back pressure.

Phenomena of combustion.—The major work with the constant-pressure bomb has been an intensive study of the gaseous explosive reaction with oxygen, of butane and of composite fuels made up of butane and carbon monoxide. Results obtained with these fuels confirm the conclusions stated in Technical Report No. 305 for composite fuels made up of carbon monoxide and methane or hydrogen. The facts that (*a*) the equivalent reaction order of a composite fuel may be determined from the reaction orders of its components and (*b*) the velocity constant of the fuel may be determined from the velocity constants of the components, support the assumption that high-order reaction processes consist of many simultaneous simpler ones, each running its course within the reaction zone according to its own order and mechanism, independently of any other reactions occurring at the same time. A report of this work soon to be published by the National Advisory Committee for Aeronautics is entitled "The Gaseous Explosive Reaction at Constant Pressure—The Reaction Order and Reaction Rate."

Data already available on the effect of total pressure are being supplemented by a large number of photographic records obtained at total pressures less than 1 atmosphere.

Combustion in an engine cylinder.—Preliminary runs to determine the "explosion time" (i. e. the interval for the flame to travel from the spark plug to the most distant window) and the "duration of flame" (the interval between the occurrence of the spark and the disappearance of the flame in the cylinder) were made under various operating conditions on a single-cylinder engine equipped with 31 quartz windows in the cylinder head. From these trials, the visual method of estimating flame travel appeared to be sufficiently promising to warrant considerable refinement in the test equipment. Accordingly, the stroboscope drive and phase-changing device were redesigned to reduce backlash to a minimum, and the engine was provided with a heavier flywheel to increase smoothness of operation. When measurements are resumed in the near future the cylinder pressure corresponding to each observation of flame position will be determined with the balanced diaphragm indicator.

Temperatures and pressures in an aircraft engine.—The review of the literature has been continued with particular attention to gas temperatures and pressures and to published information regarding the characteristics and use of available high-speed engine pressure indicators. Methods of analyzing indicator diagrams to show temperatures and heat generation and flow have also been studied. Such methods are of considerable interest in that they constitute the most promising means of estimating the cyclic fluctuation of charge temperature in high-speed engines and also afford a means of comparing in detail the deviations of the actual cycle from the ideal. The program for experimental work includes (1) the making of indicator diagrams on a single-cylinder variable-compression Liberty engine provided with a balanced diaphragm indicator of the type described in Technical Report No. 107 and equipped to burn gaseous or liquid fuels under a wide range of test conditions, and (2) the development of a method of interpreting these diagrams to show temperature variations, combustion progress, and heat interchange between the working gas and its surroundings. A number of preliminary runs have been made on propane in an effort to eliminate possible sources of error in the test equipment and procedure.

Effect of spark character on ignition ability.—The study of spark ignition was resumed this year at the request of the National Advisory Committee for Aeronautics and the Navy Department. A special laboratory has been fitted up and provided with a single-cylinder test engine equipped for comparing the effectiveness of different sparks under controlled operating conditions. Optical methods have been developed for (*a*) studying the physical condition of the fuel charge at the time of ignition, (*b*) estimating the apparent flame temperatures during combustion, and (*c*) determining the volume of charge affected by sparks of different characteristics. By passing a series of sparks through an explosive mixture of oxygen and hydrogen at low pressure in a discharge tube cooled with liquid air, the region where ignition takes place can be determined from the location of the ice formed and the number of molecules reacting can be determined from the change in pressure. The latter may afford a direct means of comparing the overall effectiveness of different sparks.

Preliminary work has been done on the effect of adding high resistance in the secondary of the ignition system and on the effect of capacitance in shielded ignition systems. Preparations are being made to undertake the routine testing of "shielded harnesses."

Automatic carburetor altitude control.—The 2-cylinder multiplied-pressure pump designed and built to control automatically an altitude adjustment on the carburetor of the Wasp engine has shown excessive variation in delivered pressure at constant speed and altitude. It is expected that the development of a more reliable check valve will overcome this erratic behavior, after which the device will be installed in a Navy pursuit airplane for flight test.

Gaseous fuels for aircraft engines.—The relative engine performance to be expected with a number of pure fuels used either singly or in mixtures has been determined from a theoretical analysis based on an ideal Otto cycle and also from actual engine tests. Considering the great differences between the ideal and actual cycles the results of the two methods agree suprisingly well. The power and efficiency obtainable under similar conditions are found to be nearly the same with the exception of methane, which gives about 10 per cent less power. The antiknock characteristics of the gases are much better than those of the liquid fuels and thus higher compression ratios with their attendant advantages are possible with the gaseous fuels. A limited number of trials with gaseous fuels at compression ratios as high as 9:1 in a variable-compression single-cylinder Liberty engine indicate that the useful compression ratios for such fuels may be limited by their tendency to preignite rather than by their tendency to detonate. Hydrogen and carbon monoxide are not very satisfactory as regards engine performance. This work was done at the request of the Navy and funds for its extension to other gaseous fuels will be made available by an industrial concern through the National Research Council.

Effect of air humidity on engine performance.—It has been shown (N. A. C. A. Technical Note No. 309) that failure to allow for the effect of differences in atmospheric humidity may introduce errors as great as would be occasioned by failure to allow for changes in barometric pressure. Under extreme conditions either correction may amount to nearly 10 per cent of the indicated power. Nomograms for the convenient determination of humidity values from psychromatic data, based on the Ferrel formula, will be found in the above reference. The work on humidity is to be continued at the request of the Navy.

Vapor lock in airplane fuel systems.—Funds were made available through the Society of Automotive Engineers for a study of aviation gasolines in order to develop, if possible, suitable means of distinguishing between fuels which are suitable for use in airplane engines and those which are unsuitable on account of possible difficulty from vapor lock. Measurements on representative aviation gasolines freed from water and dissolved gases show, as in the case of motor gasolines, that the vapor pressure data can be computed with sufficient accuracy (within 5 mm. Hg) from the 10 per cent American Society for Testing Materials distillation temperatures. The solubility of water, air, and other gases in aviation gasolines and the contribution of these constituents to the total vapor pressure have been studied. Bubble formation and growth with commercial aviation gasolines under typical flow conditions are being studied at present in the laboratory. Data on the temperatures occurring under flight conditions at various points in an airplane fuel system were obtained recently at Langley Field and have been made available to the bureau. Arrangements are being made to secure similar data on other types of airplanes in cooperation with the Army and the Navy. It is expected that the laboratory experiments will indicate the temperature-pressure conditions likely to result in vapor lock with any gasoline and the flight data will show whether the present Federal specifications for aviation gasoline can safely be changed to admit more volatile fuels.

Type testing of commercial engines.—After further conference with representatives of the Army and the Navy, the basis on which commercial aircraft engines are rated was modified slightly in November, 1928. Instead of requiring the engine manufacturer to specify both rated speed and rated power, he is asked to designate only the maximum speed at which the engine should be operated at full throttle. This is taken as the rated speed and the rated power is determined by the average brake horsepower developed in a 5-hour nonstop run at full throttle and rated speed. The remaining nine 5-hour periods of the endurance test are run with the engine throttled sufficiently to reduce the speed about 3 per cent.

The number of engines submitted for test has exceeded all estimates and the torque stand unit at College Park, in service since May, 1928, was recently supplemented by two such units at Arlington Farms, Va. Future work will be concentrated at the Arlington testing laboratory, where an office, shop, and four torque stands will eventually be available. During the year, tests have been undertaken on 26 engines, and of this number 12 failed, 5 were withdrawn, 7 have been approved, and 2 are still under test. Ten of the failures occurred prior to January 1, 1929. Seven more engines have qualified as ready for immediate test. At the end of June, 25 engines had received approved type certificates from the Department of Commerce. Many of these were engines approved on the basis of Army or Navy tests.

NEW ENGINE TYPES

The major effort in the development of aircraft engines during the past year has been centered on the problem of reducing head resistance. The matériel division of the Army Air Corps has concentrated its efforts on the study of high-temperature liquid cooling, especially as applied to the Curtiss D–12 and V–1570 series of engines. The high-temperature liquid cooling investigation with Prestone as a cooling liquid has been successfully carried to the flight stage by the application of this system of cooling in three pursuit type airplanes equipped with reduced tubular core, wing skin, and Heinrich type of radiators. With the different installations a study was made of the reduction in weight, frontal area, fuel consumption, and improvement in performance and maneuverability of the airplane. As a result of this investigation, all Curtiss D–12 and V–1570 engines now on production contract are equipped for either Prestone or water cooling. Parallelling the investigation the matériel division has studied different types of fuels with a view to permitting the use of high compression ratios when operating at the higher temperatures.

The application of the low-drag cowling to air-cooled radial type engines has been investigated by the committee at its laboratories at Langley Field and further investigated by the matériel division, with special reference to the application of this type of cowling to military types of airplanes. Both the Army and the Navy, in the application of the low-drag cowling to radial air-cooled engines, have found that the performance of aircraft has been improved. However, the cowling has not been definitely adopted for any particular type, as the visibility characteristics have not been satisfactory.

During the past year 26 aircraft engines have been submitted to the Department of Commerce for test. The air regulations of the Department of Commerce require that engines used in interstate air commerce shall be of types which have been approved after suitable tests. Of the 26 engines submitted, only 7 have been approved and 2 are still undergoing tests. At the end of October, 1929, 32 aircraft engines had received their approved type certificates from the Department of Commerce.

It is of interest to note that all of the engines submitted to the Department of Commerce for test are of the air-cooled type, having either radial or in-line type cylinder arrangement. The majority of the engines submitted are of the fixed radial air-cooled type, having either 5, 7, or 9 cylinders.

The Bureau of Aeronautics of the Navy Department and the matériel division of the Army Air Corps have continued the development of the accepted standard types of engines used by the services.

Development work has been continued on the Curtiss V–1570 and D–12 engines, with a view to obtaining satisfactory operation and performance, using higher compression ratios and Prestone cooling.

The Curtiss V–1570 is a 12-cylinder V-type water-cooled engine, which was built for both geared and direct drive. Both types are rated by the Department of Commerce at 600 horsepower at 2,400 r. p. m.

The only other water-cooled aircraft engines which are used in military types of aircraft are the Packard A–1500 and the Packard A–2500. The 3A–1500 is rated at 600 horsepower at 2,500 r. p. m., and the 3A–2500 is rated at 770 horsepower at 2,000 r. p. m.

The Pratt & Whitney Co. has further developed and refined the Wasp 9-cylinder radial engine. This engine is rated at 450 horsepower at 2,100 r. p. m. and is standard equipment for a number of types of service airplanes in the Army and is also extensively used in commercial service.

The Hornet engine, manufactured by the same company, is rated at 525 horsepower at 1,900 r. p. m. and is still one of the most used of the larger-powered air-cooled radial engines both in military and commercial service.

The Curtiss Aeroplane & Motor Co. has continued the development of the Chieftain (H–1640). This is a 12-cylinder 2-row radial engine rated at 600 horsepower at 2,200 r. p. m. The arrangement of providing two rows of cylinders and having a 2-throw crank shaft makes possible the reduction of the over-all diameter and the elimination of providing the counterweight that is required on all single-throw crank shafts for fixed radial engines.

The Curtiss Challenger (R–600) engine, which develops 170 horsepower, is the same design as the Chieftain, having two rows of six cylinders. The engine is largely used in commercial type aircraft. Further development has been continued on both these engines

Air-cooled engines.—The latest development in the air-cooled engine field is the Wright V–1460 12-cylinder inverted V-type engine. The cylinder dimensions are 4⅞-inch bore and 6½-inch stroke, with a piston displacement of 1,456 cubic inches. This engine has been undergoing tests at Wright Field.

In the new series of radial air-cooled engines developed by the Wright Aeronautical Corporation, known as the J–6 series, there are three engines, a 5-cylinder engine rated at 160 horsepower, a 7-cylinder engine rated at 220 horsepower, and a 9-cylinder engine rated at 300 horsepower, all at 2,000 r. p. m. In the development of the J–6 series the Wright Aeronautical Corporation had in mind the advantages of interchangeability of parts, and in each engine the cylinders and many other parts are the same and are interchangeable.

The Wright Cyclone engine, known as the R–1750, is a 9-cylinder radial engine rated at 525 horsepower at 1,900 r. p. m. Further development has been continued on this particular engine and it is being used by the Navy Department as standard equipment for some of the larger type service airplanes and seaplanes.

Compression-ignition engines.—The Packard Motor Car Co. demonstrated its 9-cylinder air-cooled radial-type compression-ignition engine by a flight from Detroit to the committee's laboratories at Langley Field. The flight was made to the annual aircraft manufacturers' conference and the engine was demonstrated to those attending. The following companies are now developing compression-ignition oil engines for aircraft purposes: The Allison Engineering Co., the Emsco Aero Engine Co., the Westinghouse Electric & Manufacturing Co., and the Packard Motor Car Co.

On October 30, 1929, 32 different types of aircraft engines had approved-type certificates issued by the Department of Commerce. Following is a list of engines that have received their approved-type certificates:

Aircraft Comet, 7-cylinder, radial, air-cooled, 130 horsepower at 1,825 r. p. m.

Aircraft Engine Corporation, L–A1, 7-cylinder, radial, air-cooled, 140 horsepower at 1,800 r. p. m.

American Cirrus, 4-cylinder, in-line, air-cooled, 90 horsepower at 2,100 r. p. m.

Alliance, Hess Warrior, 7-cylinder, radial, air-cooled, 115 horsepower at 1,925 r. p. m.

Arnold Harris, 8-cylinder, "Vee," water-cooled, 90 horsepower at 1,400 r. p. m.

Axelson Machine Co., 7-cylinder, radial, air-cooled, 115 horsepower at 1,800 r. p. m.

Continental, A–70, 7-cylinder, radial, air-cooled, 165 horsepower at 2,000 r. p. m.

Curtiss Challenger, R–600, 6-cylinder, radial, air-cooled, 170 horsepower at 1,800 r. p. m.

Curtiss Conqueror V–1550, 12-cylinder, "Vee," water-cooled, 600 horsepower at 2,400 r. p. m.

Curtiss Conqueror GV–1570, geared, 12-cylinder, "Vee," water-cooled, 600 horsepower at 2,400 r. p. m.

Curtiss Chieftain H–1640, 12-cylinder, radial, air-cooled, 600 horsepower at 2,200 r. p. m.

Curtiss D–12, 12-cylinder, "Vee," water-cooled, 435 horsepower at 2,300 r. p. m.

Dayton Bear, 4-cylinder, in-line, air-cooled, 100 horsepower at 1,500 r. p. m.

Fairchild Caminez 447–C, 4-cylinder, radial, air-cooled, 120 horsepower at 960 r. p. m.

Kinner K–5, 5-cylinder radial, air-cooled, 90 horsepower at 1,810 r. p. m.

LeBlond 60, 5-cylinder, radial air-cooled, 65 horsepower at 1,950 r. p. m.

LeBlond 90, 7-cylinder, radial, air-cooled, 90 horsepower at 1,975 r. p. m.

Lycoming R–645, 9-cylinder, radial, air-cooled, 185 horsepower at 2,000 r. p. m.

Michigan Aero Engine Corporation Rover, 4-cylinder, in-line, air-cooled, inverted, 55 horsepower at 1,900 r. p. m.

Packard 3A–1500 direct, 12-cylinder, "Vee," water-cooled, 525 horsepower at 2,100 r. p. m.

Packard 3A–2500 direct, 12-cylinder, "Vee," water-cooled, 800 horsepower at 2,000 r. p. m.

Pratt & Whitney Hornet, 9-cylinder, radial, air-cooled, 500 horsepower at 1,900 r. p. m.

Pratt & Whitney Hornet, 9-cylinder, radial, air-cooled, 525 horsepower at 1,900 r. p. m.

Pratt & Whitney Hornet, 9-cylinder, radial, air-cooled, 575 horsepower at 1,950 r. p. m.

Pratt & Whitney Wasp, 9-cylinder, radial, air-cooled, 450 horsepower at 2,100 r. p. m

Velie, 5-cylinder, radial, air-cooled, 55 horsepower at 1,815 r. p. m.

Warner Scarab, 7-cylinder, radial, air-cooled, 110 horsepower at 1,850 r. p. m.

Wright J–5 Whirlwind, 9-cylinder, radial, air-cooled, 220 horsepower at 2,000 r. p. m.

Wright J–6, R–540, 5-cylinder, radial, air-cooled, 165 horsepower at 2,000 r. p. m.

Wright J–6, R–760, 7-cylinder, radial, air-cooled, 225 horsepower at 2,000 r. p. m.

Wright J–6, R–975, 9-cylinder, radial, air-cooled, 300 horsepower at 2,000 r. p. m.

Wright Cyclone R–1750–A, 9-cylinder, radial, air-cooled, 525 horsepower at 1,900 r. p. m.

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.
Lieut. R. S. Barnby (C. C.), United States Navy.
S. K. Colby, United States Aluminum Co.
Warren E. Emley, Bureau of Standards.
Commander Garland Fulton (C. C.), United States Navy.
Henry A. Gardner, Institute of Paint and Varnish Research.
Dr. H. W. Gillett, Battelle Memorial Institute.
Prof. George B. Haven, Massachusetts Institute of Technology.
C. H. Helms, National Advisory Committee for Aeronautics.
Zay Jeffries, Aluminum Co. of America.
J. B. Johnson, matériel division, Army Air Corps, Wright Field.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Lieut. Alfred J. Lyon, United States Army, matériel division, Air Corps, Wright Field.
Lieut. Commander H. R. Oster (C. C.), United States Navy.
H. S. Rawdon, Bureau of Standards.
E. C. Smith, Central Alloy Steel Corporation.
G. W. Trayer, Forest Products Laboratory, Forest Service.
Starr Truscott, National Advisory Committee for Aeronautics.
Hon. Edward P. Warner, Editor, Aviation.

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 investigation 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 and steel industries are represented on the committee. In order to cover effectively the large and varied field of research on materials for aircraft, four subcommittees have been formed, as follows:

Subcommittee on metals:

H. S. Rawdon, Bureau of Standards, chairman.
Dr. H. W. Gillett, Battelle Memorial Institute.
Zay Jeffries, Aluminum Co. of America.
J. B. Johnson, matériel division, Army Air Corps, Wright Field.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
E. C. Smith, Central Alloy Steel Corporation.
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:
- C. H. Helms, National Advisory Committee for Aeronautics, chairman.
- Dr. W. Blum, Bureau of Standards.
- Warren E. Emley, Bureau of Standards.
- Henry A. Gardner, Institute of Paint and Varnish Research.
- 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.

Subcommittee on aircraft structures:
- Starr Truscott, National Advisory Committee for Aeronautics, chairman.
- Lieut. C. E. Archer, United States Army.
- Lieut. H. Z. Bogert, United States Army, matériel division, Air Corps, Wright Field.
- C. P. Burgess, Bureau of Aeronautics, Navy Department.
- Charles Ward Hall, Hall-Aluminum Aircraft Corporation.
- Lieut. Lloyd Harrison, United States Navy.
- Kenneth M. Lane, Aeronautics Branch, Department of Commerce.
- George W. Lewis (ex officio member).
- Charles J. McCarthy, Chance Vought Corporation.
- Dr. L. B. Tuckerman, Bureau of Standards.

Much 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

Meetings of the committee were held several times during the year to consider reports on the work being conducted by the subcommittees. Particular attention was given the continuation of work on the development of methods for protecting light alloys, particularly duralumin, from corrosion. This work was begun some years ago and has always formed a major subject for investigation.

SUBCOMMITTEE ON METALS

The study of the properties of metals as related to their application to aircraft construction has been carried out at the Bureau of Standards, in cooperation with the Bureau of Aeronautics of the Navy Department, the matériel division of the Army Air Corps, and the National Advisory Committee for Aeronautics. Special attention has been given to the subject of the permanence under service conditions of the light alloys which in wrought form are used for structural purposes. The study of the corrosion resistance of the duralumin type of alloy has been continued and marked progress has been made in the development of suitable protective measures to be observed in its use. The study of its endurance under fatigue stresses has also been continued and tentative values for its fatigue resistance have been obtained.

Intercrystalline embrittlement of sheet duralumin.—The National Advisory Committee for Aeronautics issued two Technical Notes during the year dealing with two different phases of this investigation, thus bringing the total number of Technical Notes on this subject to six. These new notes (Nos. 304 and 305) deal with the results of weather-exposure tests of duralumin and the effect of corrosion when accompanied by stress.

Intercrystalline embrittlement of sheet duralumin.—Weather-exposure tests.—The exposure tests have been in progress for two years at the Bureau of Standards and the naval air station at Hampton Roads, Va., and 18 months at the naval air station, Coco Solo, Canal Zone. Quite definite conclusions are believed to be warranted on the basis of the results to date, which on the whole are very consistent with the tentative views previously expressed on the basis of the laboratory test results. The test racks at Hampton Roads were damaged in some unknown way during the year and some of the racks knocked into the water. These have been recovered and it is interesting to find that, although the rate of corrosion was altered as a result of the two months' immersion in the sea water, the relative order of corrosion resistance of the various materials, heat-treated and coated in various ways, was practically unchanged by the more severely corrosive conditions.

The tests in general have shown, beyond question, that the lack of permanence observed in sheet duralumin under some conditions is a corrosion phenomenon and not a "spontaneous" phase change within the alloy. A corrosive attack of an intercrystalline nature is very largely responsible for the embrittlement produced. In the exposure tests, like the laboratory tests, the rate of embrittlement was greatly accelerated by a marine atmosphere and by a tropical climate. The tests were carried out upon full-size tension bars, the change in the tensile properties being used as a measure of the effect of corrosion. This method is by far the best in cases like the present, in which the tensile properties of the material undergo material change without corresponding change in surface appearance. In numerous cases of coated specimens, the surface, after exposure, appears still in good condition. The underlying metal, however, may show marked evidence of attack by its changed tensile properties. Variations in composition of duralumin which do not result in wide departure from the ordinary duralumin composition are apparently of almost negligible importance so far as corrosion behavior is concerned. Of the high-strength aluminum alloys which differ materially in composition from duralumin, the alloy containing copper as the principal alloying element was most susceptible to intercrystalline attack.

Variations in the heat-treatment procedure used for duralumin appear to be major factors which determine the susceptibility of heat-treated duralumin sheet to embrittlement during exposure to the weather. The quenching rate, as determined by the use of cold or hot water or oil as quenching media, and the aging treatment (room-temperature aging versus accelerated aging) are most important in this respect. The use of hot water or oil as a quenching medium for sheet duralumin, or the use of an accelerated aging treatment, should be very carefully guarded against for duralumin which must withstand severe climatic conditions, such as marine and tropical service.

Cold working of properly heat-treated sheet duralumin by stretching or cold rolling does not affect very greatly the susceptibility of the material to embrittlement by intercrystalline attack when exposed to the weather. With improperly heat-treated duralumin this factor is of much more importance.

The exposure tests have clearly shown that corrosion of the more familiar or pitting type may occur with any duralumin. The effect upon the tensile properties, although similar in character, is, in most cases, decidedly less than that of the intercrystalline type. So far it has not been possible to correlate definitely the tendency of the alloy toward this form of corrosive attack with any condition of the material resulting from any particular heat treatment or other condition.

The determination of the permanence of coatings on duralumin when exposed to the weather has been successfully made by applying the coating to tension bars of duralumin which had been improperly heat-treated and were hence quite susceptible to attack. The relatively rapid attack of the underlying or basic metal following the breakdown of the coating was shown in the tension tests of such specimens after exposure. In this way it has been very clearly shown that aluminum coatings are by far the most dependable. The useful life of clear varnishes is very short, but the addition of aluminum pigment increases the permanence of the varnish very greatly. On the other hand, the addition of aluminum pigment to rubberlike coatings, while decidedly successful in the laboratory, has not given satisfactory results under exposure conditions. Surface oxidation by the anodic process and similar coatings have no lasting protective value unless well greased, and even when greased they have not proved to be resistant against *severe* exposure conditions (Coco Solo), although with milder exposure conditions (Washington) quite satisfactory results have been obtained. Simple grease coatings reinforced with aluminum powder have given satisfactory service under mild exposure conditions but not entirely so for severe (marine) conditions. In general, it is quite evident from all data available that for inland use (mild exposure), the coating need not be scrutinized very closely. For marine service, however, the choice of a suitable coating appears to be very limited.

The above statements apply particularly to fairly thick sheet, such as 14 gage. Exposure tests of thin (0.008 inch) sheet, even under rather mild conditions (Washington), have shown a marked difference in tensile properties after six months, a drop in elongation from 17 to 4 per cent being observed. Under the more severe conditions at Coco Solo a similar change occurred in a much shorter time. Unlike the thicker material, the corrosion resistance of thin sheet apparently can not be greatly improved by modifying the method of heat treatment. Thin sheet duralumin (0.010 inch), aluminum coated, as in the Alclad process was found to be much more resistant, although even here the corrosion resistance was not so high as that shown by the same material in thicker sheets.

Intercrystalline embrittlement of sheet duralumin—Stress-corrosion tests.—In the laboratory, accelerated corrosion tests have been continued throughout the year in order to determine whether the corrosion resistance of duralumin may be influenced by stress acting simultaneously with the corrosive attack. The material, in the form of tension bars, was corroded while stressed (*a*) in static tension in some cases nearly to and in other cases considerably below the yield point, and (*b*) while repeatedly stressed in flexure. The tests were carried out as in the previous work; that is, after exposure to the corrosive conditions for a predetermined period the tensile properties of the corroded material were determined. The tests have served particularly well to demonstrate the marked superiority of aluminum-coated duralumin when subject to severely corrosive conditions. This material was in good condition after 60 days' exposure to accelerated corrosion (sodium chloride solution containing hydrogen peroxide) while subjected to 20,000 pounds per square inch tension, which is about one-half its "yield stress" (0.006 in/in extension under load). With a stress of 31,000 pounds per square inch accompanied by corrosion, 40 days' attack did not very materially affect it, nor did rather severe scratching of the surface produce any marked effect during stress corrosion at 20,000 pounds per square inch.

With plain duralumin properly heat-treated, however, 13 days' attack in stress corrosion at 25,500 pounds per square inch tension reduced the ductility from 22 to 4 per cent, although unstressed material likewise was severely attacked, the ductility being reduced to 8 per cent. With material improperly heat-treated the effect on the plain duralumin was still more strongly marked. On the whole, static tensile stress does not appear to increase the corrosive attack very decidedly.

Corrosion accompanied by repeated flexural stress constitutes a severe test. Plain duralumin, properly heat-treated, repeatedly flexed to 10,000 pounds per square inch maximum fiber stress, showed such low tensile properties after 7 days as to render it practically worthless, although some bars remained intact for 30 days. The attack on improperly heat-treated duralumin was much more severe, a life of only 5 days, instead of 30 being attained in this case. Aluminum-coated duralumin exposed to the same conditions showed no deterioration whatsoever after prolonged attack (24 days). Indeed, some specimens after 65 days' attack showed as high tensile properties as in their initial state. It is quite evident that any material showing high resistance to corrosion under stress conditions of this character can be regarded as a dependable one for extremely severe service conditions.

Weather-exposure tests of magnesium and magnesium alloys.—The program of exposure tests was extended this year to include magnesium and magnesium alloys. The same testing procedure is being followed as in the case of duralumin; that is, full-size tension bars are used for the exposure specimens, the tensile properties of which are to be determined after different exposure periods. The materials used are of commercial quality and represent both the rolled sheet and the cast alloy. They were furnished by the two leading manufacturers of this type of material.

The sheet materials consist of cold-rolled magnesium, an alloy composed of 96 per cent of magnesium and 4 per cent of aluminum, which previous investigators have reported to have a low corrosion resistance, and an alloy containing 95.6 per cent magnesium, 4 per cent aluminum, and 0.4 per cent manganese, which has been reported to have a relatively high corrosion resistance. Likewise, in the case of the cast alloys, two compositions differing markedly in their corrosion resistance were used. The castings were in the form of flat tension bars.

The bars have been exposed to the weather at the Bureau of Standards and at the naval air station, Coco Solo, Canal Zone. A third set to be used as "control" bars, has been stored within sealed glass jars containing a desiccating substance for maintaining a truly dry atmosphere.

The problem of protecting this type of material against corrosion appears to be mainly that of finding a suitable coating together with the proper treatment of the surface prior to the application of the coating. For each of the three exposures and for each of the five materials, the specimens are exposed in the bare state as well as in the coated condition. The coatings used are those which appear most promising according to either the results already obtained with duralumin or by other investigators. As is well known, the adherence of coatings on magnesium is determined in large measure by the surface characteristics, and in order to obtain good adherence, one-half of the number of specimens comprising each set were treated with a phosphate solution whereby a fine matte surface was produced. The remainder were used in the untreated condition, i. e., as rolled or as cast.

The coatings applied included a variety of types: spar varnish with aluminum pigment, rubber base with graphite pigment, lacquers of the nitrocellulose type applied over various undercoats, linseed oil with lampblack as a pigment. One transparent coating, vinyl acetate resin, has been included.

Results are expected from these exposure tests within a shorter period of time than in the case of duralumin.

High-frequency fatigue.—Six high-frequency flexural fatigue machines are now in operation at the Bureau of Standards 14 hours a day. A series of tests on 14 different materials in the aluminum and magnesium light alloy group is in progress. The materials under consideration are:

1. Pure magnesium, as rolled.
2. Pure magnesium, annealed.
3. Magnesium alloy (4 per cent aluminum, 0.4 per cent manganese, remainder magnesium), as rolled.
4. Eleven different aluminum alloys of various compositions and heat treatments.

Tests on the magnesium alloy (4 per cent aluminum, 0.4 per cent manganese, remainder magnesium) have been completed and runs are now in progress on two of the aluminum alloys.

Results of the tests on the magnesium alloy indicate an endurance limit of 5,000 to 6,000 pounds per square inch for the longitudinal specimens, with a maximum of 7,000 pounds per square inch for the transverse specimens tested. The material was found to be so variable that the determination of a more definite endurance limit could only be made by a statistical study of a much larger number of tests than have been made. The results of such an extended series of tests on this material would not repay the extra labor and time. It is believed that the transverse specimens indicated a higher value for the endurance limit only because it happened that those transverse specimens tested were a little better than the longitudinal specimens selected for test.

Generally the specimens were not run much more than 200,000,000 cycles. If failure had not occurred when this stage was reached, "coaxing" was resorted to, i. e., the stress was increased and the test continued at the higher stress. As is generally known, numerous investigators have found that a specimen which is tested at a stress below its endurance limit is actually strengthened by this process and if retested at a higher stress will last longer than a specimen tested initially at that stress. This fact has been made use of in the determination of the endurance limit. If, from tests already made, a "coaxing" test shows that a specimen lasts longer at the higher of the two stresses of that test than it would have if tested initially at that stress, then the lower or initial stress is considered as being lower than the endurance limit of that material.

Tests on one of the aluminum alloys have progressed far enough to allow the making of the statement that the endurance value is close to 12,000 pounds per square inch. For the other the preliminary results indicate a value in the neighborhood of 10,000 pounds per square inch.

Fatigue of Alclad duralumin.—This investigation has been carried on in cooperation with the Aluminum Co. of America.

Over 118 specimens obtained from corroded and uncorroded Alclad and comparable duralumin sheets have been tested. Some of these specimens have been subjected to over 100,000,000 cycles of stress.

The results from specimens of corroded material indicate that the corroded Alclad specimens have approximately the same life as the uncorroded specimens, while for the corroded duralumin specimens the results lie below the results obtained for those uncorroded. This is added evidence for the greater durability of aluminum-covered duralumin.

SUBCOMMITTEE ON WOODS AND GLUES

With the great reduction in the use of wood in military aircraft, the Bureau of Aeronautics of the Navy Department and the matériel division of the Army Air Corps have practically ceased to initiate activities regarding woods and glues. Wood is still largely used in commercial-airplane structures, but it is quite evident that its use is gradually decreasing. With the development of production methods by large aircraft manufacturers it appears that the use of metal ribs is more economical than the older types of built-up wooden ribs. However, in commercial types of airplanes where large numbers are not in production, the spruce spar, usually routed from the solid, is still more economical than the built-up metal spar and satisfies the requirements.

With the decreased use of wood in aircraft structures there has been also a decrease in interest in the initiation of new investigations as to woods and glues for aircraft structures. The work of this subcommittee has correspondingly decreased and attention is now being directed toward the making available in the most convenient form of the information which has been accumulated. The investigations on the strength of airplane woods, plywood webs for box beams, wing rib design, lateral buckling and twisting of beams, twisting of members under compression, influence of blocks and fillets on wooden beams, and the study of continuous beams, will be reported in publications now in preparation. It is believed that these reports will summarize the information available so completely that very little additional information will be required by manufacturers who desire to use wood in their aircraft structures. The work of preparing these reports is now in progress and they should appear during the coming year.

SUBCOMMITTEE ON COVERINGS, DOPES, AND PROTECTIVE COATINGS

Much of the work on the development of coverings, dopes, and protective coatings is carried out at the Bureau of Standards, and in many cases it involves cooperation with the work of the subcommittee on metals. Investigations are also carried out by the exposure of test panels at the United States naval air stations at Hampton Roads, Va., and Coco Solo, Canal Zone. Exposure tests were also made on the roof of the laboratory of Mr. H. A. Gardner.

Some of the more important investigations in progress during the last year are outlined below.

Gas cell fabrics.—The gas cell made of the substitute for goldbeaters' skin fabric which was constructed last year and installed in the *Los Angeles* has not given as good results as was anticipated. This is another instance of the failure of production materials and processes to show as good performance as was obtained from laboratory materials and processes. It is believed probable that the production material did not completely reproduce the material developed in the laboratory, and in order to determine whether it is possible by ordinary commercial methods to reproduce the laboratory material, three orders, each for 1,000 yards of fabric of this type, have been placed by the Bureau of Aeronautics of the Navy Department with three different manufacturers. Each of these is to follow his own methods and it is hoped that the laboratory quality may be obtained from at least one of the manufacturers. If this is done, it will be possible to determine how the processes followed differ and to learn how to reproduce the material more perfectly.

The disappointing results obtained from the one type of substitute for goldbeaters' skin fabric have led to continued study of other types, and one manufacturer is attempting to produce a substitute along independent lines.

Protective coatings for duralumin and magnesium.—Exposure tests of coatings for aluminum and magnesium alloys have been continued in cooperation with the subcommittee on metals. The test specimens have been exposed at Coco Solo, Canal Zone, at the naval air station at Hampton Roads, Va., and at the Bureau of Standards. Tension tests are made of the specimens after exposure to determine the change in tensile properties due to corrosive attack.

In the tests on duralumin, coatings of aluminum have been found to be most dependable. The protective value of clear varnishes is of very short duration, but their permanence is greatly increased by the addition of aluminum pigment. Surface oxidation by the anodic process, and other coatings of similar nature, when well greased, and also grease coatings reinforced with aluminum powder, have given satisfactory service under mild exposure conditions, but have not proved resistant under severe conditions. From all the data available it appears that for mild exposure conditions there are a number of satisfactory coatings, but for marine service the choice of a suitable coating is very limited.

A number of types of protective coatings, including some of the same as were used on duralumin specimens, are being tested on magnesium alloys. The most important of these are spar varnish with aluminum pigment, rubber-base coatings with graphite pigment, lacquers of the nitrocellulose type applied over various undercoatings, linseed oil with lampblack as a pigment, and vinyl acetate resin. The results from the exposure tests on magnesium specimens are not yet available.

Substitute for silk parachute cloth.—The feasibility of processing cotton textiles for parachutes on a large scale so that the resulting material would have properties approximating those of silk cloth was discussed with members of several finishing plants. The methods were tested on a large scale and were modified to conform to commercial practice in nonessential details and where necessary. These modified procedures gave satisfactory results with yarn processing. However, large-scale operations on cloth did not give as good results as were to be expected from the smaller scale work.

The prospect of obtaining cotton yarn which is suitable for the making of parachute fabric which may be used as a substitute for silk has improved somewhat as domestic cotton spinning mills have begun to spin cotton yarns which meet the requirements for this use.

The spinning of the cotton yarns at the Bureau of Standards was completed. Some of these yarns were woven into fabrics, which were processed, and the remainder were processed and then woven into experimental fabrics. This work has resulted in considerable valuable data on the effect of the various treatments on the properties of the yarns and fabrics and has pointed the way to the most satisfactory constructions and processes.

Ordinary H H balloon cloth sufficient for three parachutes was processed in three ways. Two commercially available fabrics which may be suitable for parachute construction were processed to improve their strength. All this material has been forwarded to the Naval Aircraft Factory at Philadelphia, Pa., to be manufactured into parachutes for testing purposes.

It has been found possible to increase the tear resistance of the cotton fabric materially by a change in the weave. Preliminary experiments have been completed and fabric for two additional parachutes will be woven from commercial yarn using the modified weave.

SUBCOMMITTEE ON AIRCRAFT STRUCTURES

Practically all the investigations under the cognizance of this subcommittee are conducted at the Bureau of Standards. 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 in progress or completed during the past year are outlined below.

Welded joints in tubing.—This investigation was originally requested by the Aeronautics Branch of the Department of Commerce. It was desired that the various types of joints used in welded fuselage construction should be studied to determine their strengths and to develop improved joints.

The first group of joints tested numbered 165 in all. These joints were designed from data supplied by aircraft manufacturers. They were welded under procedure control, and were tested in special fixtures.

Although no quantitative data are available as yet, several conclusions based on observation may be made. The most serious problem encountered in designing reinforcement in a welded joint is the formation of cracks in gusset plates after cooling. It is evident that the problem is one of design as well as of welding technique. Best results seem to be obtained by making the thickness of gusset plates somewhat greater than the tube thickness and keeping the plan area of the gusset as small as possible. Whenever possible the design should allow for movement of the members as the joint cools.

The results of this first series of tests are being prepared as a progress report for publication as a Technical Note of the National Advisory Committee for Aeronautics.

From data based on the results of these tests more improved joints will be made and finally the best type for each purpose will be determined.

Form factors for tubing of duralumin and steel under combined column and beam loads.—The experimental work on this nvestigation has been continued. A very careful and time-consuming study of the experimentaliresults which have been obtained led to a satisfactory analysis.

The experimental results were combined on a semitheoretical basis which permitted a direct comparison of columns made of materials of markedly different physical properties.

By using this method it was possible not only to combine in a single chart the tubes of widely different properties and of different dimensions but to obtain also a considerable increase of maximum allowable stresses over the old method of treatment of the experimental results. In the case of certain tubes in the range of high l/r ratios the increase amounted to over 100 per cent.

Although the experimental results were obtained on tubes within a limited range of dimensions, the consistency with which the experimental points fall close to the average curves makes it seem probable that this method will prove to be more generally applicable to tubes of other diameters and of other wall thicknesses.

A report on this work has been published by the National Advisory Committee for Aeronautics as Technical Note No. 307, Strength of Tubing under Combined Axial and Transverse Loading.

A study of the results showed that the strength of tubing depends greatly upon the yield point of the material. Although the test results showed that the ultimate strength of the tubing was probably as high as could be obtained on commercial tubing, the yield point of the tubing used in this investigation was considerably higher than the specified minimum. If the requirements as to yield point were raised, higher stresses could safely be used in design. It seems probable that it will be found possible to alter these specifications so as to take advantage of this increase in reducing the weight of tubular aircraft construction. This investigation is being continued to cover a wider range of dimensions of tubing, and to determine if possible the causes underlying the characteristic differences in the relationship between tensile properties and modulus of rupture of duralumin and chrome-molybdenum tubing.

Airship girders and airship structural members.—During the past year tests on experimental plate girders of the Arnstein type have been continued. Two short girders fabricated by the Naval Aircraft Factory were tested in compression.

In connection with tests of girders of the Arnstein type a new procedure has been worked out for the determination of their minimum cross-section area. Preliminary tests indicate that by means of this procedure it is possible to determine the minimum cross-section area of a girder, fabricated from flanged-sheet material containing lightning holes, within less than 1 per cent of the actual value.

Several girders made by the Goodyear-Zeppelin Corporation for the new 6,500,000 cubic-foot airships of the Navy were tested in compression and under combined bending and axial loading, respectively.

Electrically welded steel tubing.—Tests on low-carbon steel tubing formed from flat strip and welded by the electrical resistance process, which have been carried on in cooperation with the manufacturers, Steel and Tubes (Inc.), have been completed and will be reported shortly in the Bureau of Standards Journal of Research. The tubes tested varied from 0.625 inch to 3 inches outside diameter and from 0.028 to 0.120 inch in wall thickness.

As was to be expected from the method of manufacture this tubing, as produced commercially, shows much less variation in wall thickness than seamless steel tubing.

The tests included tension, compression, torsion, hydrostatic, and flanging tests of the tubes as a whole, tension tests of the weld alone, indentation (hardness) tests on both weld and base metal, and micrographic examination of the weld and adjacent material.

All the tests showed that, except in the case of the swaged-annealed tubing, the properties of the base metal (the metal not affected by the welding operation) can be used in determining the working stresses for different structural uses of tubing made by the process used in the manufacture of this electrically welded tubing. No allowance is necessary for the altered structure in and adjacent to the weld.

So far this tubing has been produced commercially only in carbon steel. Crome-molybdenum tubing has, however, been produced experimentally. If welded alloy tubing showing equivalent results under test can be produced commercially by this process it should add materially to the progress of aircraft construction.

End fixation of struts.—Some degree of end fixation is usually present in compression members, as used in aircraft, but rarely is it sufficient to justify designing on the basis of fixed ends. A quantitative evaluation is needed of the added strength afforded by the degree of fixation actually used. At the request of the Bureau of Aeronautics, the Bureau of Standards has undertaken a study of this problem with the purpose of securing data for the design of aircraft.

As was expected, the problem has not proved simple. It has been studied from the theoretical standpoint and a search has been made in the files of technical and scientific journals for clues to previous work. Only the vaguest suggestions for methods of attacking the problem were found in publications.

The study, however, seemed to indicate fairly definitely the most promising line of attack. This consists in applying elastic restraints to the ends of the members under compression proportional to the transverse stiffness of the members. The study further indicated that useful results were to be expected mainly in the transition range of l/r below the Euler range.

The theoretical studies have further brought out the very useful result that in these end fixation tests it is possible to eliminate the end correction found necessary by Karman in his "round-end" tests. The relationship shows that results obtained with apparatus for a particular fixation factor will be applicable to columns of the same slenderness ratio but with a smaller fixation factor to be calculated directly from the dimensions and the end load found. This relationship is true whether the columns are deflecting elastically or whether the stresses are carried beyond the elastic limit. This relationship simplifies very materially the testing procedure.

Apparatus has been designed and constructed for making the tests, and preliminary testing is now in progress.

The results have been more encouraging than was expected in an investigation in an admittedly difficult field and one about which so little is known.

Technique of testing flat plates under normal pressure.—Work has been completed on a small experimental frame. From the facts brought out by the use of various packing and holding systems it has been possible to design a larger fixture and measuring device. This larger machine will accommodate plates of square section from 25 square inches area up to 900 square inches and rectangular plates of a 3 to 1 side ratio of areas of 75 square inches up to 2,700 square inches.

Considerable difficulty was encountered in securing the base plate and clamping bars. Efforts along this line were finally successful and the assembling of the apparatus is now nearly completed, so that the actual tests of specimens can be started soon.

REPORT OF COMMITTEE ON PROBLEMS OF AIR NAVIGATION

ORGANIZATION

In response to the need for the coordination of scientific research being conducted by a number of different agencies, both within and without the Government, on the problems of air navigation, particularly in the fields of navigation instruments, aerial communications, and meteorological problems, the National Advisory Committee for Aeronautics in 1928 established a new standing committee on problems of air navigation, with members representing the principal agencies concerned with the development of aids to air navigation.

The committee on problems of air navigation is at present composed of the following members:

Hon. William P. MacCracken, jr., chairman.
Dr. L. J. Briggs, Bureau of Standards.
Lloyd Espenschied, American Telephone & Telegraph Co.
Brig. Gen. B. D. Foulois, United States Army, chief of matériel division, Air Corps, Wright Field.
Paul Henderson, National Air Transport (Inc.).
Capt. S. C. Hooper, Director of Naval Communications, Navy Department.
Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation.
Capt. E. S. Land, United States Navy, The Daniel Guggenheim Fund for the Promotion of Aeronautics.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Col. Charles A. Lindbergh.
Prof. Charles F. Marvin, Weather Bureau.
C. M. Young, Assistant Secretary of Commerce for Aeronautics.

FUNCTIONS

The functions of the committee on problems of air navigation are as follows:

1. To determine the problems in the field of air navigation that are most important for investigation by governmental and private agencies.
2. To coordinate by counsel and suggestion the research work involved in the investigation of approved problems.
3. To act as a medium for the interchange of information regarding investigations and developments in air navigation, in progress or proposed.
4. To meet from time to time on call of the chairman and report its actions and recommendations to the executive committee.

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

SUBCOMMITTEE ON PROBLEMS OF COMMUNICATION

The membership of the subcommittee on problems of communication is as follows:

Lloyd Espenschied, American Telephone & Telegraph Co., chairman.
Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation, vice chairman.
C. H. Helms, National Advisory Committee for Aeronautics, secretary.
Maj. William R. Blair, United States Army, Signal Corps, War Department.
Dr. J. H. Dellinger, Bureau of Standards.

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George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
W. G. Logue, Radiomarine Corporation of America.
J. L. McQuarrie, International Telephone & Telegraph Co.
Eugene Sibley, Aeronautics Branch, Department of Commerce.
Lieut. E. E. Stone, United States Navy, Office of the Director of Naval Communications, Navy Department.

The subcommittee on problems of communication when originally organized had as its chairman Dr. Edward B. Craft, of the Bell Telephone Laboratories, and Doctor Craft's recent death has deprived the subcommittee of the leadership of one particularly well qualified for the work. During his illness and until the appointment of Mr. Espenschied, Doctor Hunsaker, the vice chairman, has served as acting chairman. Appreciation is also due to Commander W. J. Ruble, United States Navy, the first secretary of the subcommittee, for his services in connection with the organization of the subcommittee.

The subcommittee has outlined in a general way some of the important problems in the field of aircraft communications, and each of these phases of the subject has been assigned to an individual member of the subcommittee for the preparation of a statement as to the present status of its development and needs for the future. Among the problems being studied in accordance with this plan are radio goniometry as applied to a network of airways, radio transmission between ground and aircraft, and the standardization of aircraft radio power supply.

Ignition shielding.—The problem of the interference of the engine ignition with radio reception has also been considered. The suppression of ignition interference to radio reception appears to depend upon the complete shielding of the electrical equipment. At a conference of interested manufacturers held at the Bureau of Standards on June 11, 1929, steps were taken to standardize the shields for magnetos, wiring, and spark plugs. Tests made at the Langley Memorial Aeronautical Laboratory to determine the shielding effect of the N. A. C. A. cowling indicated that the cowling would be useful to the extent of eliminating the need for a shield for the spark plug. Since the spark plug offers the most difficult problem with respect to shielding, the cowling may serve an additional useful purpose.

Distribution of weather information.—As a result of cooperation between the Weather Bureau and the Aeronautics Branch of the Department of Commerce reports of weather conditions are now being broadcast every 30 minutes from 24 radio stations located along more than 75,000 miles of airways, to airplanes flying on definite schedules. This information covers a band 100 miles wide on each side of the airways. In conjunction with the weather service, radiobeacons are also established. Fifteen additional radio stations are under construction at this time. A simple radio receiving set aboard the airplane enables the pilot to be constantly advised of changing weather conditions.

SUBCOMMITTEE ON INSTRUMENTS

The subcommittee on instruments is at present organized as follows:

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

A large number of the investigations in connection with the development of instruments for air navigation are conducted by the Bureau of Standards in cooperation with the Bureau of Aeronautics of the Navy, the Army Air Corps, and the National Advisory Committee for Aeronautics. These investigations have been carried out under the cognizance of the committee on aerodynamics and are outlined in the report of that committee. Among the investigations now under way are a study of the fundamentals of instrument mechanism design, an investigation of damping liquids for aircraft instruments, and a study of the present status of air navigation instruments. In some instances manufacturers of aircraft instruments and engineering societies are cooperating in the invesgatition of particular problems.

Vibration of aircraft instrument panels in flight.—A survey has been made of the problem of the vibration of instrument panels in an airplane in flight. This problem includes a study of the effect of vibration on the performance of various aircraft instruments; the measurement of the vibration of typical instrument boards in aircraft; and the effecting of a general agreement as to the standard amount of vibration which an instrument should be able to withstand. Laboratory work has been done by the Bureau of Standards on the effect of vibration on instruments, various instruments submitted by the Bureau of Aeronautics for type test having been given vibration tests on a specially designed vibration rack. The Bureau of Standards has also designed an apparatus for investigating the second phase of the problem, namely, the measurement of the vibration of instrument panels in aircraft. The general problem of instrument-board vibration is still under consideration by the subcommittee.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The membership of the subcommittee on meteorological problems is as follows:

Prof. Charles F. Marvin, Weather Bureau, chairman.
Thomas H. Chapman, Aeronautics Branch, Department of Commerce.
Dr. W. R. Gregg, Weather Bureau.
Dr. W. J. Humphreys, Weather Bureau.
Dr. J. C. Hunsaker, Goodyear-Zeppelin Corporation.
George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Lieut. F. W. Reichelderfer, United States Navy, naval air station, Lakehurst.
Dr. C. G. Rossby, Daniel Guggenheim Fund for the Promotion of Aeronautics.
Capt. Bertram J. Sherry, United States Army, Signal Corps, War Department.

One of the principal agencies engaged in the study of meteorological problems as related to air navigation is, of course, the Weather Bureau, but practically every organization concerned with the operation of aircraft is interested in problems of this nature. The chief problems which have received consideration by the subcommittee on meteorological problems during the past year are ice formation on aircraft in flight, fog and fog dispersal, and the structure of the atmosphere.

Ice formation on aircraft.—The subcommittee has kept in touch with the work being conducted at the Langley Memorial Aeronautical Laboratory on the study of ice formation on airplanes. This problem is being investigated both in flight and in a special low-temperature wind tunnel. The results of these tests indicate that ice forms on aircraft in dangerous amounts only within a small range of temperature below 32° F., and the best method so far discovered to prevent ice formation is for the pilot to observe the temperature of the air through which he is passing by means of an accurate strut thermometer and avoid flying through atmosphere at the dangerous temperatures. At the Bureau of Standards a study has been made of possible coatings on aircraft to prevent ice formation, and the coatings suggested as a result of this study are being tested in the low-temperature tunnel at Langley Field.

Fog and fog dispersal.—The problem of fog as a danger to safe flying has been given considerable attention by a number of agencies. One of the most important investigations in connection with this problem has been the work carried on by the Daniel Guggenheim Fund for the Promotion of Aeronautics, in cooperation with other organizations, on the development of instruments for safe flying through fog. The Weather Bureau, with the cooperation of the Guggenheim Fund, has made a study of fog and haze, and an interesting report on the subject, prepared by H. C. Willett, was published in the Monthly Weather Review for November, 1928. Experiments have been conducted at Wright Field, Hadley Field, and the Lakehurst Naval Air Station on the possibility of fog and cloud dispersal by means of sand particles carried aloft, given a very high electrical charge, and scattered through the air. A summary of experimental work on the problem of fog dispersal is in preparation.

Structure of the atmosphere.—The principal problem considered by the subcommittee on meteorological problems during the past year was the study of the structure of the atmosphere. A digest of the status of this problem was prepared at the Weather Bureau by Mr. Welby R. Stevens, and a request of the airship subcommittee that the problem be given attention with a view to the initiation of research to increase the knowledge of the subject was given careful consideration.

One of the important phases of the study of this subject is the type of instrument to be used, and considerable thought has been given to the requirements of such an instrument. It is belived that it is desirable to study the variation in velocity and direction of air currents in a space approximately the size of a large airship and that the instrument for this purpose should have a minimum moment of inertia and should give an automatic record.

On suggestion of the subcommittee, a 3-cup type anemometer was tested in the variable-density wind tunnel at Langley Field, and as a result of these tests it was found that this particular instrument did not follow closely enough the fluctuations of velocity to be suitable for indicating the rapid changes in the velocity of air as in gusts.

The study of the sensitiveness of anemometers has been given considerable attention at the Weather Bureau during the last few months, and interesting results have been obtained from this investigation.

The possibilities of studying the turbulence of the upper air by motion-picture photographic records of the movements of smoke are also being considered by the subcommittee.

At the Langley Memorial Aeronautical Laboratory a preliminary investigation was made to obtain information on the velocity and acceleration of air in gusts. Recording air-speed apparatus was mounted on a building at an altitude of about 70 feet, and continuous records of the velocity of the air were obtained for periods when the air was particularly gusty or bumpy. In these tests the most violent acceleration measured was one in which the air velocity changed 20.6 miles per hour in 0.25 second (an acceleration of 121.6 feet per second per second). With the exception of one other case the acceleration never exceeded 80 feet per second per second. In these experiments it was found that the velocity of the mean wind had no definite relation to the accelerations measured. A further and more complete investigation is contemplated.

PART IV

TECHNICAL PUBLICATIONS OF THE COMMITTEE

The National Advisory Committee for Aeronautics has issued technical publications during the past year covering a wide range of subjects. There are four series of publications, namely, Technical Reports, Technical Notes, Technical Memorandums, and Aircraft Circulars.

The Technical Reports present the results of fundamental research in aeronautics carried on in 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. In all cases the reports were recommended for publication by the technical subcommittees having cognizance of the investigations. During the past year 28 Technical Reports were submitted for publication.

Technical Notes 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 issued during the past year, in mimeographed form, 21 Technical Notes.

Technical Memorandums contain translations and reproductions of important foreign aeronautical articles of a miscellaneous character. A total of 51 Technical Memorandums was issued during the past year.

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

Summaries of the 28 Technical Reports and lists of the Technical Notes, Technical Memorandums, and Aircraft Circulars follow:

SUMMARIES OF TECHNICAL REPORTS

The first annual report of the National Advisory Committee for Aeronautics for the fiscal year 1915 contained Technical Reports Nos. 1 to 7; the second annual report, Nos. 8 to 12; the third annual report, Nos. 13 to 23; the fourth annual report, Nos. 24 to 50; the fifth annual report, Nos. 51 to 82; the sixth annual report, Nos. 83 to 110; the seventh annual report, Nos. 111 to 132; the eighth annual report, Nos. 133 to 158; the ninth annual report, Nos. 159 to 185; the tenth annual report, Nos. 186 to 209; the eleventh annual report, Nos. 210 to 232; the twelfth annual report, Nos. 233 to 256; the thirteenth annual report, Nos. 257 to 282; the fourteenth annual report, Nos. 283 to 308; and since the preparation of the fourteenth annual report for the year 1928 the committee has authorized the publication of the following Technical Reports, Nos. 309 to 336:

Report No. 309, entitled "Joint Report on Standardization Tests on N. P. L. R. A. F. 15 Airfoil Model," by Walter S. Diehl, Bureau of Aeronautics, Navy Department.

This report contains the wind-tunnel test data obtained in the United States on a 36 by 6 inch R. A. F. 15 airfoil model prepared by the British Aeronautical Research Committee for international trials. Tests were made in cooperation with the National Advisory Committee for Aeronautics at the Bureau of Standards, Langley Memorial Aeronautical Laboratory, Massachusetts Institute of Technology, and McCook Field.

In addition to brief descriptions of the various wind tunnels and methods of testing, the report contains an analysis of the test data. It is shown that while in general the agreement is quite satisfactory there are two cases in which it is unsatisfactory. Since the lack of agreement in the latter is probably explained by errors known to be inherent in the methods of determining and applying corrections in these particular tests, it is concluded that the agreement obtained is more a matter of technique than a wind-tunnel characteristic.

Report No. 310, entitled "Pressure Element of Constant Logarithmic Stiffness for Temperature Compensated Altimeter," by W. G. Brombacher and F. Cordero, Bureau of Standards.

The usual type of altimeter contains a pressure element, the deflections of which are approximately proportional to pressure changes. An evenly divided altitude scale is secured by using a mechanism between the pressure element and pointer which gives the required motion of the pointer. A temperature-compensated altimeter was constructed at the Bureau of Standards for the Bureau of Aeronautics of the Navy Department which contained a manually operated device for controlling the multiplication of the mechanism to the extent necessary for temperature compensation. The introduction of this device made it difficult to adjust the multiplying mechanism to fit an evenly divided altitude scale. To meet this difficulty a pressure element was designed and constructed which gave deflections which were proportional to altitude; that is, to the logarithm of the pressure. Mathematically, the logarithmic stiffness S' of the element equals

$$S' = \frac{d \log_e P}{dy}$$

from which is derived the deflection y for the change in pressure from P_o to P

$$y = \frac{\log_e P - \log_e P_o}{S'}$$

The element consisted of a metal bellows of the sylphon type coupled to an internal helical spring which was designed so as to have a variable number of active coils. This report presents a description of and laboratory data relating to the special pressure element for the altimeter. In addition, equations which apply generally to springs and pressure elements of constant logarithmic stiffness are developed, including the deflection and the spacing between the coils in terms of the constants of the helical spring and pressure element.

Report No. 311, entitled "Aerodynamic Theory and Test of Strut Forms," Part I, by R. H. Smith, aerodynamical laboratory, Bureau of Construction and Repair, Navy Department.

The whole study under this title is in two parts, only the first of which is reported here. In this part the symmetrical inviscid flow about an empirical strut of high service merit is found by both the Rankine and the Joukowski methods. The results can be made to agree as closely as wished. Theoretical stream surfaces as well as surfaces of constant speed and pressure in the fluid about the strut are found. The surface pressure computed from the two theories agrees well with the measured pressure on the fore part of the model but not so well on the after part. From the theoretical flow speed the surface friction is computed by an empirical formula. The drag integrated from the friction and measured pressure closely equals the whole measured drag. As the pressure drag and the whole drag are accurately determined, the friction formula also appears trustworthy for such fair shapes.

Report No. 312, entitled "The Prediction of Airfoil Characteristics," by George J. Higgins, National Advisory Committee for Aeronautics.

This paper describes and develops methods by which the aerodynamic characteristics of an airfoil may be calculated with sufficient accuracy for use in airplane design. These methods for prediction are based on the present aerodynamic theory and on empirical formulas derived from data obtained in the N. A. C. A. variable-density wind tunnel at a Reynolds Number corresponding approximately to full scale.

Report No. 313, entitled "Drag and Cooling with Various Forms of Cowling for a Whirlwind Radial Air-Cooled Engine–I," by Fred E. Weick, National Advisory Committee for Aeronautics.

The National Advisory Committee for Aeronautics has undertaken an investigation in the 20-foot propeller research tunnel at Langley Field on the cowling of radial air-cooled engines. A portion of the investigation has been completed in which several forms and degrees of cowling were tested on a Wright Whirlwind J–5 engine mounted in the nose of a cabin fuselage. The cowlings varied from the one extreme of an entirely exposed engine to the other in which the engine was entirely inclosed. Cooling tests were made and each cowling modified, if necessary, until the engine cooled approximately as satisfactorily as when it was entirely exposed. Drag tests were then made with each form of cowling, and the effect of the cowling on the propulsive efficiency determined with a metal propeller.

The propulsive efficiency was found to be practically the same with all forms of cowling. The drag of the cabin fuselage with uncowled engine was found to be more than three times as great as the drag of the fuselage with the engine removed and nose rounded. The conventional forms of cowling, in which at least the tops of the cylinder heads and valve gear are exposed, reduce the drag somewhat, but the cowling entirely covering the engine reduces it 2.6 times as much as the best conventional one. The decrease in drag due to the use of spinners proved to be almost negligible.

The use of the cowling completely covering the engine seems entirely practical as regards both cooling and maintenance under service conditions. It must be carefully designed, however, to cool properly. With cabin fuselages its use should result in a substantial increase in high speed over that obtained with present forms of cowling on engines similar in contour to the J–5.

Report No. 314, entitled "Drag and Cooling with Various Forms of Cowling for a Whirlwind Radial Air-Cooled Engine–II," by Fred E. Weick, National Advisory Committee for Aeronautics.

This report gives the results of the second portion of an investigation in the 20-foot propeller research tunnel of the National Advisory Committee for Aeronautics, on the cowling and cooling of a Whirlwind J–5 radial air-cooled engine. The first portion, which is reported in N. A. C. A. Technical Report No. 313, pertains to tests with a cabin fuselage. This report covers tests with several forms of cowling, including conventional types, individual fairings behind the cylinders, individual hoods over the cylinders, and the new N. A. C. A. complete cowling, all on an open cockpit fuselage. Drag tests were also made with a conventional engine nacelle, and with a nacelle having the new complete cowling.

In the second part of the investigation the results found in the first part were substantiated. It was also found that the reduction in drag with the complete cowling over that with conventional cowling is greater with the smaller bodies than with the cabin fuselage; in fact, the gain in the case of the completely cowled nacelle is over twice that with the cabin fuselage. The individual fairings and hoods did not prove effective in reducing the drag. The results of flight tests on an AT–5A airplane (reported in the appendix to N. A. C. A. Technical Report No. 313) have been analyzed and found to agree very well with the results of the wind-tunnel tests.

Report No. 315, entitled "Aerodynamic Characteristics of Airfoils–VI," by the National Advisory Committee for Aeronautics.

This collection of data on airfoils has been made from the published reports of a number of the leading aerodynamic laboratories of this country and Europe. The information which was originally expressed according to the different customs of the several laboratories is here presented in a uniform series of charts and tables suitable for the use of designing engineers and for purposes of general reference.

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

The absolute system of coefficients has been used, since it is though 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 length, the latter also serving as the datum line. The shape of the section is also shown with reasonable accuracy in order to enable one to more clearly visualize the section under consideration, the outside of the heavy line representing the profile.

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

Report No. 316, entitled "Tables for Pressure of Air on Coming to Rest from Various Speeds," by A. F. Zahm and F. A. Louden, construction department, Washington Navy Yard.

In Technical Report No. 247 of the National Advisory Committee for Aeronautics theoretical formulas are given from which was computed a table for the pressure of air on coming to rest from various speeds, such as those of aircraft and propeller blades. In that report, the table gave incompressible and adiabatic stop pressures of air for even-speed intervals in miles per hour and for some even-speed intervals in knots per hour. Table II of the present report extends the above-mentioned table by including the stop pressures of air for even-speed intervals in miles per hour, feet per second, knots per hour, kilometers per hour, and meters per second. The pressure values in Table II are also more exact than the values given in the previous table.

To furnish the aeronautical engineer with ready numerical formulas for finding the pressure of air on coming to rest, Table I has been derived for the standard values specified below it. This table first presents the theoretical pressure-speed formulas and their working forms in C. G. S. units as given in N. A. C. A. Technical Report No. 247, then furnishes additional working formulas for several special units of speed.

Report No. 317, entitled "Wind Tunnel Tests on a Series of Wing Models through a Large Angle of Attack Range. Part I. Force Tests," by Montgomery Knight and Carl J. Wenzinger, National Advisory Committee for Aeronautics.

This investigation covers force tests through a large range of angle of attack on a series of monoplane and biplane wing models. The tests were conducted in the atmospheric wind tunnel of the National Advisory Committee for Aeronautics. The models were arranged in such a manner as to make possible a determination of the effects of variations in tip shape, aspect ratio, flap setting, stagger, gap, decalage, sweep back, and airfoil profile. The arrangements represented most of the types of wing systems in use on modern airplanes.

The effect of each variable is illustrated by means of groups of curves. In addition, there are included approximate autorotational characteristics in the form of calculated ranges of "rotary instability."

A correction for blocking in this tunnel which applies to monoplanes at large angles of attack has been developed, and is given in an appendix.

Report No. 318, entitled "Speed and Deceleration Trials of U. S. S. *Los Angeles*," by S. J. De France, National Advisory Committee for Aeronautics, and C. P. Burgess, Bureau of Aeronautics, Navy Department.

The trials reported herein were instigated by the Bureau of Aeronautics of the Navy Department for the purpose of determining accurately the speed and resistance of the U. S. S. *Los Angeles* with and without water recovery apparatus, and to clear up the apparent discrepancies between the speeds attained in service and in the original trials in Germany.

The trials proved very conclusively that the water-recovery apparatus increases the resistance about 20 per cent, which is serious, and shows the importance of developing a type of recovery having less resistance.

Between the American and German speed trials without water recovery there remains an unexplained discrepancy of nearly 6 per cent in speed at a given rate of engine revolutions.

Warping of the propeller blades and small cumulative errors of observation seem the most probable causes of the discrepancy.

It was found that the customary resistance coefficients C are 0.0242 and 0.0293 without and with the water-recovery apparatus, respectively. The corresponding values of the propulsive coefficient K are 56.7 and 44.6. If there is any error in these figures, it is probably in a slight overestimate of C and an underestimate of K. The maximum errors are almost certainly less than 5 per cent.

No scale effect was detected indicating variation of C with respect to velocity.

Report No. 319, entitled "Aerodynamic Characteristics of Twenty-Four Airfoils at High Speeds," by L. J. Briggs and H. L. Dryden, Bureau of Standards.

The aerodynamic characteristics of 24 airfoils are given for speeds of 0.5, 0.65, 0.8, 0.95, and 1.08 times the speed of sound, as measured in an open-jet air stream 2 inches in diameter, using models of 1-inch chord. The 24 airfoils belong to four general groups. The first is the standard R. A. F. family in general use by the Army and Navy for propeller design, the members of the family differing only in thickness. This family is represented by nine members ranging in thickness from 0.04 to 0.20 inch. The second group consists of five members of the Clark Y family, the members of the family again differing only in thickness. The third group, comprising six members, is a second R. A. F. family in which the position of the maximum ordinate is varied. Combined with two members of the first R. A. F. family, this group represents a variation of maximum ordinate position from 30 to 60 per cent of the chord in two camber ratios, 0.08 and 0.16. The fourth group consists of three geometrical forms, a flat plate, a wedge, and a segment of a right circular cylinder. In addition one section used in the Reed metal propeller was included. These measurements form a part of a general program outlined at a conference on propeller research organized by the National Advisory Committee for Aeronautics and the work was carried out with the financial assistance of the committee.

Report No. 320, entitled "The Measurement of Fluctuations of Air Speed by the Hot-Wire Anemometer," by H. L. Dryden and A. M. Kuethe, Bureau of Standards.

The hot-wire anemometer suggests itself as a promising method for measuring the fluctuating air velocities found in turbulent air flow. The only obstacle is the presence of a lag due to the limited energy input which makes even a fairly small wire incapable of following rapid fluctuations with accuracy. This paper gives the theory of the lag and describes an experimental arrangement for compensating for the lag for frequencies up to 100 or more per second when the amplitude of the fluctuation is not too great. An experimental test of the accuracy of compensation and some results obtained with the apparatus in a wind-tunnel air stream are described. While the apparatus is very bulky in its present form, it is believed possible to develop a more portable arrangement.

Report No. 321, entitled "Fuel Vapor Pressures and the Relation of Vapor Pressure to the Preparation of Fuel for Combustion in Fuel Injection Engines," by William F. Joachim and A. M. Rothrock, National Advisory Committee for Aeronautics.

This investigation on the vapor pressures of fuels was conducted at the Langley Memorial Aeronautical Laboratory at Langley Field, Va., in connection with the general research on combustion in fuel injection engines. The purpose of the investigation was to study the effects of high temperatures such as exist during the first stages of injection on the vapor pressures of several fuels and certain fuel mixtures, and the relation of these vapor pressures to the preparation of the fuel for combustion in high-speed fuel injection engines.

Report No. 322, entitled "Investigation of Air Flow in Open-Throat Wind Tunnels," by Eastman N. Jacobs, National Advisory Committee for Aeronautics.

Tests were conducted on the 6-inch wind tunnel of the National Advisory Committee for Aeronautics during May and June, 1928, to form a part of a research on open-throat wind tunnels. The primary object of this part of the research was to study a type of air pulsation which has been encountered in open-throat tunnels, and to find the most satisfactory means of eliminating such pulsations.

In order to do this it was necessary to study the effects of different variables on all of the important characteristics of the tunnel. This paper gives not only the results of the study of air pulsations and methods of eliminating them, but also the effects of changing the exit-cone diameter and flare, and the effects of air leakage from the return passage.

It was found that the air pulsations in the 6-inch wind tunnel could be practically eliminated by using a moderately large flare on the exit cone in conjunction with leakage introduced by cutting holes in the exit cone somewhat aft of its minimum diameter.

Report No. 323, entitled "Flow and Force Equations for a Body Revolving in a Fluid," by A. F. Zahm, construction department, Washington Navy Yard.

This report, submitted to the National Advisory Committee for Aeronautics for publication, is a slightly revised form of United States Navy Aerodynamical Laboratory Report No. 380, completed for the Bureau of Aeronautics in November, 1928. The diagrams and tables were prepared by Mr. F. A. Louden; the measurements given in Tables IX to XI were made for this paper by Mr. R. H. Smith, both members of the aeronautics staff.

Part I gives a general method for finding the steady-flow velocity relative to a body in plane curvilinear motion, whence the pressure is found by Bernoulli's energy principle. Integration of the pressure supplies basic formulas for the zonal forces and moments on the revolving body.

Part II, applying this steady-flow method, finds the velocity and pressure at all points of the flow inside and outside an ellipsoid and some of its limiting forms, and graphs those quantities for the latter forms. In some useful cases experimental pressures are plotted for comparison with theoretical.

Part III finds the pressure, and thence the zonal force and moment, on hulls in plane curvilinear flight.

Part IV derives general equations for the resultant fluid forces and moments on trisymmetrical bodies moving through a perfect fluid, and in some cases compares the moment values with those found for bodies moving in air.

Part V furnishes ready formulas for potential coefficients and inertia coefficients for ah ellipsoid and its limiting forms. Thence are derived tables giving numerical values of those coefficients for a comprehensive range of shapes.

Report No. 324, entitled "Flight Tests on U. S. S. *Los Angeles*. Part I. Full Scale Pressure Distribution Investigation," by S. J. De France, National Advisory Committee for Aeronautics.

The investigation reported herein was conducted by the National Advisory Committee for Aeronautics at the request of and in conjunction with the Bureau of Aeronautics, Navy Department. The purpose was primarily to obtain simultaneous data on the loads and stresses experienced in flight by the U. S. S. *Los Angeles*, which could be used in rigid airship structure design. A secondary object of the investigation was to determine the turning and drag characteristics of the airship. The stress investigation was conducted by the Navy Department.

The aerodynamic loading was obtained by measuring the pressure at 95 locations on the tail surfaces, 54 on the hull, and 5 on the passenger car. These measurements were made during a series of maneuvers consisting of turns and reversals in smooth air and during a cruise in rough air which was just short of squall proportions.

The results of the pressure measurements on the hull indicate that the forces on the forebody of an airship are relatively small. The tail surface measurements show conclusively that the forces caused by gusts are much greater than those caused by horizontal maneuvers. In this investigation the tail surface loadings caused by gusts closely approached the designed loads of the tail structure.

The turning and drag characteristics will be reported in separate papers.

Report No. 325, entitled "Flight Tests on U. S. S. *Los Angeles*. Part II. Stress and Strength Determination," by C. P. Burgess, Bureau of Aeronautics, Navy Department.

The tests described in this report furnished data on the actual aerodynamic forces, and the resulting stresses and bending moments in the hull of the U. S. S. *Los Angeles* during as severe still-air maneuvers as the airship would normally be subjected to, and in straight flight during as rough air as is likely to occur in service, short of squall or storm conditions. The maximum stresses were found to be within the limits provided for in accepted practice in airship design. Normal flight in rough air was shown to produce forces and stresses about twice as great as the most severe still-air maneuvers. No light was thrown upon the forces which might occur in extreme or exceptional conditions, such as the storm which destroyed the *Shenandoah*.

The transverse aerodynamic forces on the hull proper were found to be small and irregular. Owing to the necessity of conserving helium, it was impossible to fly the airship in a condition of large excess of buoyancy or weight in order to determine the air pressure distribution at a fixed angle of pitch. However, there is every reason to believe that in that condition the forces on the actual airship are as close to the wind-tunnel results as can be determihed by present type of pressure-measuring apparatus.

It is considered that the most important data obtained are the coefficients of tail-surface forces and hull-bending moments. These are tabulated in this report.

Report No. 326, entitled "Tests of Five Metal Model Propellers with Various Pitch Distributions in a Free Wind Stream and in Combination with a Model VE–7 Fuselage," by E. P. Lesley and Elliott G. Reid, Stanford University.

This report describes the tests of five adjustable blade metal model propellers both in a free wind stream and in combination with a model fuselage with stub wings, which were conducted at Stanford University under research authorization of the National Advisory Committee for Aeronautics. The propellers are of the same form and cross section but have variations in radial distributions of pitch. By making a survey of the radial distribution of air velocity through the propeller plane of the model fuselage it is found that this velocity varies from zero at the hub center to approximately free stream velocity at the blade tip.

The tests show that the efficiency of a propeller when operating in the presence of the airplane is, over the working range, generally less than when operating in a free wind stream, but that a propeller with a radial distribution of pitch of the same nature as the radial distribution of air velocity through the propeller plane suffers the smallest loss in efficiency.

Report No. 327, entitled "The Effect of Supercharger Capacity on Engine and Airplane Performance," by O. W. Schey and W. D. Gove, National Advisory Committee for Aeronautics.

Supercharging has already demonstrated its value as a means of improving the performance of an airplane at moderate and high altitudes. In order to obtain a maximum increase in the performance of an airplane designed to meet definite service requirements, it is necessary that a supercharger of the proper capacity be selected.

The effect of different supercharger capacities on the performance of an airplane and its engine was investigated by the staff of the National Advisory Committee for Aeronautics at Langley Field, Va. The tests were conducted on a DH–4 M–2 airplane powered with a Liberty 12 engine. In this investigation four supercharger capacities, obtained by driving a Roots type supercharger at 1.615, 1.957, 2.4, and 3 times engine speed, were used to maintain sea-level pressure at the carburetor to altitudes of 7,000, 11,500, 17,000, and 22,000 feet, respectively.

The performance of the airplane in climb and in level flight was determined for each of the four supercharger drive ratios and for the unsupercharged condition. The engine power was measured during these tests by means of a calibrated propeller.

Although the results of this investigation are not conducive to general conclusions as to the proper capacity or type of supercharger for use with all types of airplanes, the information collected on the variation with altitude and supercharger capacity of such factors as carburetor air temperatures, power required to drive the supercharger, and the net engine power is of value as a guide in the selection of the most suitable supercharger capacity for airplanes having different performance characteristics than those of the one tested.

Several interesting conclusions pertaining to the effect of the capacity of a Roots type supercharger on the performance of this particular airplane have been drawn from the results of these tests.

It was found that very little sacrifice in sea-level performance was experienced with the larger supercharger drive ratios as compared with performance obtained when using the smaller drive ratios.

The results indicate that further increase in supercharger capacity over that obtained when using the 3:1 drive ratio would give a slight increase in ceiling and in high-altitude performance, but would considerably impair the performance for an appreciable distance below the critical altitude.

As the supercharger capacity was increased, the height at which sea-level high speeds could be equaled or improved became a larger percentage of the maximum height of operation of the airplane.

Report No. 323, entitled "Water Pressure Distribution on a Twin-Float Seaplane," by F. L. Thompson, National Advisory Committee for Aeronautics.

The investigation reported herein was conducted by the National Advisory Committee for Aeronautics at the request of the Bureau of Aeronautics, Navy Department. This is the second of a series of investigations to determine water-pressure distribution on various types of seaplane floats and hulls, and was conducted on a twin-float seaplane. It consisted of measuring water pressures and accelerations on a TS–1 seaplane during numerous landing and taxiing maneuvers at various speeds and angles.

The results of this investigation show that water pressures as great as 10 pounds per square inch may occur at the step in various maneuvers and that pressures of approximately the same magnitude occur at the stern and near the bow in hard pancake landings with the stern well down. At other parts of the float the pressures are less and are usually zero or slightly negative for some distance abaft the step. A maximum negative pressure of 0.87 pound per square inch was measured immediately abaft the step. The maximum positive pressures have a duration of approximately one-twentieth to one one-hundredth second at any given location and are distributed over a very limited area at any particular instant. The greatest accelerations measured normal to the thrust line at the C. G. occurred in pancake landings, and a maximum of 4.3 g was recorded. Approximate load-distribution curves for the worst landing conditions are derived from the data obtained to serve as a guide in static tests.

Report No. 329, entitled "The Torsional Strength of Wings," by C. P. Burgess, Bureau of Aeronautics, Navy Department.

This report is submitted to the National Advisory Committee for Aeronautics by the Bureau of Aeronautics, Navy Department. It describes a simple method for calculating the position of the elastic axis of a wing structure having any number of spars. It is shown that strong drag bracing near the top and bottom of a wing greatly increases the torsional strength. An analytical procedure for finding the contribution of the drag bracing to the torsional strength and stiffness is described, based upon the principle of least work, and involving only one unknown quantity.

The validity of the new method of analysis is tested by applying it to a two-fifths scale model of the large steel tubular 3-spar wing of the Huff-Daland XHB monoplane. The calculated stresses are checked by comparison with the strains observed by means of electric telemeter strain gages secured to the spars during sand load tests in the static testing laboratory of the Army Air Service engineering division at Dayton, Ohio.

The torsional strength of a wing determines very largely the distribution of air forces upon it, and the tendency to flutter. Insufficient torsional strength produces washin or an increasing angle of attack toward the wing tips in the high incidence condition, further increasing the load on the front spar in the condition which is already the most severe. Conversely, torsional yielding in the low incidence and nose-dive conditions produce washout of the wing shape and may exaggerate the critical condition for the rear spar.

The mathematical theory of the forces producing flutter is not yet sufficiently far advanced to determine by direct calculation the critical air speed at which flutter will commence. Comparison with successful practice must still be the principal criterion upon which to judge the adequacy of the torsional strength of a new design of wing. Obviously this comparison will be greatly facilitated by use of a coefficient of torsional rigidity including the principal factors in torsional strengths. A coefficient for comparing the torsional rigidity of different wings is derived in this report.

Report No. 330, entitled "Experimental and Analytical Determination of the Motion of Hydraulically Operated Valve Stems in Oil Engine Injection Systems," by A. G. Gelalles and A. M. Rothrock, National Advisory Committee for Aeronautics.

This research on the pressure variations in the injection system of the N. A. C. A. spray photography equipment and on the effects of these variations on the motion of the timing valve stem was undertaken in connection with the study of fuel injection systems for high-speed oil engines. The spray photography equipment employed for these tests consists of a fuel injection system for producing an oil spray, an electrical spark system for illuminating the spray, and a photographic camera for recording its development. The fuel injection system contains a high-pressure hand pump for producing the injection pressures, an oil reservoir for maintaining the pressures of the fuel during the injection, a timing valve for timing the start of the oil spray, an injection valve for atomizing the oil, and a by-pass valve for controlling the cut-off of the spray. Additions were made to the apparatus in order to record the motion of the timing valve stem photographically.

The timing valve stem was held against its seat by a helical spring so adjusted that the total hydraulic force on the stem actuated it immediately after it had been mechanically lifted from its seat. The lift of the stem was recorded photographically to determine the effects of injection tubes 7 inches and 43 inches long. The pressure variations at the seat and in the injection valve tubes were analyzed and the lifts of the stem for both tubes computed from the analysis and compared with the experimental records.

The calculations indicate that the hydraulic pressure at the timing valve seat was rising at a rate of 350,000,000 pounds per square inch per second when the timing valve stem had been lifted 0.004 inch, and that the hydraulic pressure throughout the tube did not approximate that of the oil in the reservoir until 0.0028 second after the timing valve started to open with the 43-inch tube and 0.003 second with the 7-inch tube. The calculations and experiments indicate that after the by-pass valve started to open the hydraulic pressure in the tube dropped to the closing pressure of the timing valve in 0.0015 second with the 43-inch tube and in 0.0004 second with the 7-inch tube. The photographic records of the stem motion show that the stem reached the maximum lift approximately 0.001 second later with the 43-inch tube than with the 7-inch tube, and that the valve stem seated 0.0005 second later with the 43-inch tube than with the 7-inch tube.

The general equation for the motion of the stem of a spring-loaded valve when the motion is controlled by hydraulic pressure is

$$f=\lambda s+m\frac{d^2s}{dt^2}$$

where

f = hydraulic force on the stem at any time t seconds after the start of motion plus or minus the friction of the stem in its guide,

λ = scale of spring,

s = compression of the spring at any time t seconds after the start of motion,

m = mass of moving parts.

The methods of analysis of the pressure variations and the general equation for the motion of the spring-loaded stem for the timing valve are applicable to a spring-loaded automatic injection valve, and in general to all hydraulically operated valves. A sample calculation for a spring-loaded automatic injection valve is included.

Report No. 331, entitled "Collection of Wind-Tunnel Data on Commonly Used Wing Sections," by F. A. Louden, Bureau of Aeronautics, Navy Department.

This report was prepared at the request of the National Advisory Committee for Aeronautics in the Bureau of Aeronautics of the Navy Department in order to group in a uniform manner the aerodynamic properties of commonly used wing sections as determined from tests in various wind tunnels.

The data have been collected from reports of a number of laboratories. Where necessary, transformation has been made to the absolute system of coefficients and tunnel wall interference corrections have been applied. Tables and graphs present the data in the various forms useful to the engineer in the selection of a wing section.

Report No. 332, entitled "The Effect of Cowling on Cylinder Temperatures and Performance of a Wright J-5 Engine," by Oscar W. Schey and Arnold E. Biermann, National Advisory Committee for Aeronautics.

This report presents the results of tests conducted by the staff of the National Advisory Committee for Aeronautics to determine the effect of different amounts and kinds of cowling on the performance and cylinder temperatures of a standard Wright J-5 engine. These tests were conducted in conjunction with drag and propeller tests in which the same cowlings were used.

The engine was mounted in the nose of a cabin fuselage and placed in the air stream of the committee's 20-foot propeller research tunnel, which is located at the Langley Memorial Aeronautical Laboratory. The power was measured by means of a torque dynamometer placed within the fuselage. Sixty-nine iron-constantan thermocouples and three recording pyrometers were used for obtaining the cylinder temperature measurements.

Four different cowlings were investigated, in tests herein reported, varying from the one extreme of no cowling on the engine to the other extreme of the engine completely cowled and the cooling air flowing inside the cowling through an opening in the nose and out through an annular opening at the rear of the engine. Each cowling was tested at air speeds of approximately 60, 80, and 100 miles per hour.

For the conventional type of engine cowling the results of these tests indicate that increasing the amount of cowling has the advantage of reducing the drag, but the disadvantage of increasing the cylinder barrel temperatures. Satisfactory cooling was obtained with the conventional cowling that covered 35 per cent of the cylinder cooling area. With the conventional cowling that covered 73 per cent of the cooling area the cylinder temperatures were excessive even though a large portion of the cooling air was permitted to flow inside the cowling through slots in the front of the cowling.

For the cabin fuselage with the N. A. C. A. cowling, which completely inclosed the engine and took in all of the cooling air through a 28-inch diameter opening in the nose, the drag was reduced 40 per cent at 100 miles per hour, as compared with the same unit with no cowling on the engine. The mean temperatures of the spark-plug boss and the cylinder head were slightly reduced for the same test conditions, but the barrel temperatures were increased.

The spark-plug boss temperatures, as used by many manufacturers, are a valuable indication of engine performance, but they alone should not be used as a criterion to determine the amount an engine can be cowled, since the barrel temperatures do not vary in parallel with them.

Report No. 333, entitled "Full-Scale Turning Characteristics of the U. S. S. *Los Angeles*," by F. L. Thompson, National Advisory Committee for Aeronautics.

This paper presents a description of the method employed and results obtained in full-scale turning trials on the rigid airship U. S. S. *Los Angeles*. This investigation was requested by the Bureau of Aeronautics, Navy Department, and was carried out in conjunction with pressure distribution and stress investigation. The pressure and turning investigations were conducted by representatives of the National Advisory Committee for Aeronautics and the stress investigation by the Bureau of Aeronautics.

The results of this investigation are not sufficiently comprehensive to permit definite conclusions as to the variation of turning characteristics with changes in speed and rudder angle. They indicate, however, that the turning radius compares favorably with that for other large airships, that the radius is independent of the speed, that the position of the point of zero yaw is nearly independent of the rudder angle and air speed, and that a theoretical criterion for stability in a turn gives a close approximation to actuality. The method of determining turning characteristics by recording instruments aboard the airship appear to be satisfactory, with the exception that a better method of determining the small angular velocities of airships should be devised.

Report No. 334, entitled "The Torsion of Members Having Sections Common in Aircraft Construction," by George W. Trayer and H. W. March, Forest Products Laboratory.

Structural members designed for pure torsion are usually made with circular, elliptical, rectangular, or other regular cross sections that have already yielded to direct mathematical treatment as regards torsion. However, members designed primarily for thrust or bending and consequently as a usual thing of irregular section are subjected to torsion also, and under certain conditions they may fail by buckling and twisting through lack of sufficient torsional rigidity. In order to design against the possibility of such failure in thin deep beams or in compression members with thin, outstanding parts, we must be able to calculate their torsional rigidity. Such sections as I, T, L, and U have not been brought within the range of mathematical analysis, and up to a few years ago the engineer had practically nothing on which to base an estimate of the torsional strength and rigidity of rods of irregular section. This publication presents the results of investigations of the torsion of structural members undertaken by the Forest Products Laboratory and financed by the Bureau of Aeronautics, Navy Department, under the national defense act.

Within recent years a great variety of approximate torsion formulas and drafting-room processes have been advocated. In some of these, especially where mathematical considerations are involved, the results are extremely complex and are not generally inteligible to engineers. The principal object of the investigation was to determine by experiment and theoretical investigation how accurate the more common of these formulas are and on what assumptions they are founded and, if none of the proposed methods proved to be reasonably accurate in practice, to produce simple, practical formulas from reasonably correct assumptions, backed by experiment. A second object was to collect in readily accessible form the most useful of known results for the more common sections.

This report reviews informally the fundamental theory of torsion and shows how the more common formulas are developed from it. Formulas for all the important solid sections that have yielded to mathematical treatment are listed. Then follows a discussion of the torsion of tubular rods with formulas both rigorous and approximate.

It is shown by a series of tests of prisms of simple section that wood is a suitable material for the experimental investigation of the torsion problem. Accordingly wood was used for the experiments on full-sized members because of the ease with which it can be worked into different shapes and because of its low torsional stiffness. The possible effect of different moduli of rigidity in radial and tangential planes was investigated mathematically, and the effects of rate of loading and of moisture content were determined experimentally. Furthermore, soap films were used in order to take advantage of a mathematical similarity that exists between the torsion problem and the problem of finding the deflection of a thin membrane under pressure. The analogy is discussed in detail in the report.

Our experimental work with beams of irregular sections that have not yielded to mathematical treatment is described. From these experiments and certain mathematical considerations empirical formulas are set up for irregular sections whose component parts are rectangles.

Report No. 335, entitled "Aerodynamic Theory and Test of Strut Forms—Part II," by R. H. Smith, aerodynamical laboratory, Bureau of Construction and Repair, Navy Department.

This report, submitted to the National Advisory Committee for Aeronautics for publication, presents the second of two studies under the same title. In this part five theoretical struts are developed from distributed sources and sinks and constructed for pressure and resistance tests in a wind tunnel. The surface pressures for symmetrical inviscid flow are computed for each strut from theory and compared with those found by experiment. The theoretical and experimental pressures are found to agree quantitatively near the bow, only qualitatively over the suction range, the experimental suctions being uniformly a little low and not at all near the stern.

This study is the strut sequel to Fuhrmann's research on airship forms, the one being a study in two dimensions, the other in three. A comparison of results indicates that the agreement between theory and experiment is somewhat better for bodies of revolution than for cylinders when both are shaped for slight resistance. The consistent deficiency of the experimental suctions which is found in the case of struts was not found in the case of airships, for which the experimental suctions were sometimes above, sometimes below their theoretical values.

Along with these five theoretical struts were made three empirical struts of high repute, the British strut given in Reports and Memoranda No. 183, the German strut No. 53, and the United States Navy No. 2, and all eight tested for total resistance. Of the five theoretical struts, No. I excels as a fairing, No. V as a strut. No. V and the United States Navy No. 2 have about equal merit as struts, with the German No. 53 a close second and the British a poor third, the relative merits being 100, 103, and 112, respectively, of Reynolds Number 12×10^4.

Report No. 336, entitled "Tests of Large Airfoils in the Propeller Research Tunnel, Including Two with Corrugated Surfaces," by Donald H. Wood, National Advisory Committee for Aeronautics.

This report gives the results of the tests of seven 2 by 12 foot airfoils (Clark Y, smooth and corrugated, Göttingen 398, N. A. C. A. M-6, and N. A. C. A. 84). The tests were made in the propeller research tunnel of the National Advisory Committee for Aeronautics at Reynolds Numbers up to 2,000,000. The Clark Y airfoil was tested with 3° of surface smoothness.

The effect of small variations of smoothness of an airfoil is shown to be negligible. Corrugating the surface causes a flattening of the lift curve at the burble point and an increase in drag at small flying angles.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

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299. The Effect of Fillets Between Wings and Fuselage on the Drag and Propulsive Efficiency of an Airplane. By Melvin N. Gough.
300. The Variation in Pressures in the Cockpit of an Airplane in Flight. By Thomas Carroll and William H. McAvoy.
301. Drag and Cooling with Various Forms of Cowling for a Whirlwind Engine in a Cabin Fuselage. By Fred E. Weick.
302. A New Method for the Prediction of Airplane Performance. By E. P. Lesley and E. G. Reid.
303. Condensed Data on the Aircraft Engines of the World. Compiled by C. S. Fliedner.
304. Corrosion Embrittlement of Duralumin. V. Results of Weather-Exposure Tests. By Henry S. Rawdon.
305. Corrosion Embrittlement of Duralumin. VI. The Effect of Corrosion, Accompanied by Stress on the Tensile Properties of Sheet Duralumin. By Henry S. Rawdon.
306. Curves Showing Column Strength of Steel and Duralumin Tubing. By Orrin E. Ross.
307. Strength of Tubing Under Combined Axial and Transverse Loading. By L. B. Tuckerman, S. N. Petrenko, and C. D. Johnson.
308. Pressure Distribution on a Slotted R. A. F. 31 Airfoil in the Variable Density Wind Tunnel. By Eastman N. Jacobs.
309. Correcting Engine Tests for Humidity. By Donald B. Brooks.

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310. Wind Tunnel Pressure Distribution Tests on a Series of Biplane Wing Models. Part I: Effects of Changes in Stagger and Gap. By Montgomery Knight and Richard W. Noyes.
311. The Use of Wheel Brakes on Airplanes. By Thomas Carroll and Smith J. De France.
312. Sphere Drag Tests in the Variable Density Wind Tunnel. By Eastman N. Jacobs.
313. The Formation of Ice upon Airplanes in Flight. By Thomas Carroll and William H. McAvoy.
314. Spiral Tendency in Blind Flying. By Thomas Carroll and William H. McAvoy.
315. Viscosity of Diesel Engine Fuel Oil Under Pressure. By Mayo D. Hersey.
316. Wind Tunnel Tests on a Model of a Monoplane Wing with Floating Ailerons. By Montgomery Knight and Millard J. Bamber.
317. Tests of Four Racing Type Airfoils in the Twenty-Foot Propeller-Research Tunnel. By Fred E. Weick.
318. Full Scale Investigation of the Drag of a Wing Radiator. By Fred E. Weick.
319. Some Experiments on Autorotation of an Airfoil. By Shatswell Ober.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

482. Ignition and Combustion Phenomena in Diesel Engines. By F. Sass. Translation from Zeitschrift des Vereines deutscher Ingenieure, September 10, 1927.
483. Ignition Points and Combustion Reactions in Diesel Engines. Part I. By J. Tausz and F. Schulte. Communication from the Petroleum Research Laboratory of the Institute of Applied Chemistry, Technical High School, Karlsruhe.
484. Ignition Points and Combustion Reactions in Diesel Engines. Part II. By J. Tausz and F. Schulte. Communication from the Petroleum Research Laboratory of the Institute of Applied Chemistry, Technical High School, Karlsruhe.
485. Research on the Control of Airplanes. By Melvill Jones. From Nature, May 12, 1928. Lecture delivered at the Royal Institution, February 10, 1928.
486. Tank Tests of Twin Seaplane Floats. By H. Herrmann, G. Kempf, and H. Kloess. Translation from Luftfahrtforschung, January 3, 1928.
487. The Constructional Design of Metal Flying-Boat Hulls, Part I. Workshop Notes on the Building of Metal Hulls, Part II. By M. Langley. From The Aeroplane, March 28, and July 25, 1928.
488. Determination of the Air Forces and Moments Produced by the Ailerons of an Airplane. By C. Wieselsberger and T. Asano. Translation from Zeitschrift für Flugtechnik und Motorluftschiffahrt, July 14, 1928.
489. On the Take-Off of Heavily Loaded Airplanes. By Louis Breguet. Translation from La Revue Scientifique, No. 12, 1927.
490. Structures of Thin Sheet Metal, Their Design and Construction. By Herbert Wagner. Translation of preprint of a paper read at seventeenth meeting of the Wissenschaftliche Gesellschaft fur Luftfahrt, at Danzig, Germany, June 2–5, 1928.
491. Propeller Problems. By A. Betz. Translation of reprint from Zeitschrift für angewandte Mathematik und Mechanik, November, 1927.
492. Influence of Fuselage on Propeller Design. By Theodor Troller. Translation from Zeitschrift für Flugtechnik und Motorluftschiffahrt, July 28, 1928.
493. Aerodynamic Characteristics of Thin Empirical Profiles and Their Application to the Tail Surfaces and Ailerons of Airplanes. By A. Toussaint and E. Carafoli. Translation from L'Aerophile, June, 1928.
494. "Safety" Fuels for Aircraft Engines. By A. Grebel. Translation from Memoires et compte rendu des Travaux de la Societe des Ingenieure Civils de France, July-August, 1927.
495. Device for the Automatic Control of Airplanes. By Alfred Gradenwitz. (Drexler control.) Translation from Der Motorwagen, March 31, 1928.
496. Photogrammetric Take-Off and Landing Measurements. By Bruno Spieweck. Translation from Yearbook of the Wissenschaftlichen Gesellschaft für Luftfahrt, December, 1926.

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497. Effect of Oxygen on the Ignition of Liquid Fuels. By H. Pahl. Translation from Zeitschrift des Vereines deutscher Ingenieure, June 16, 1928.
498. Fluttering of the Tail Surfaces of an Airplane and the Means for Its Prevention. By F. N. Scheubel. Translation from Yearbook of the Wissenschaftlichen Gesellschaft für Luftfahrt, December, 1926.
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502. Analysis of Flight and Wind-Tunnel Tests on Udet Airplanes with Reference to Spinning Characteristics. By H. Herrmann. Translation from Zeitschrift für Flugtechnik und Motorluftschiffahrt, January 14, 1929.
503. Effect of Stressed Covering on Strength of Internal Girders of a Wing. By H. Tellers. Translation from Yearbook of the Wissenschaftlichen Gesellschaft für Luftfahrt, 1927.
504. Mechanical Control of Airplanes. By H. Boykow. Translation from Yearbook of the Wissenschaftlichen Gesellschaft für Luftfahrt, 1928.
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507. Landing and Braking of Airplanes. By Louis Breguet. Translation from La Chronique des Avions Breguet, supplements to Nos. 8 and 9, 1928.
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510. Theoretical Investigation of the Effect of the Ailerons on the Wing of an Airplane. By C. Wieselsberger. Translation from report of the Aeronautical Research Institute, Tokyo Imperial University, No. 30, Volume II, 16, December, 1927.
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During the past year the committee issued bibliographies of aeronautics for the years 1926 and 1927. It has previously issued bibliographies for the years 1909 to 1916, 1917 to 1919, 1920 to 1921, 1922, 1923, 1924, and 1925. A bibliography for the year 1928 is now in the hands of the printer, and should be ready for distribution during the coming year. A bibliography is now being published annually by the committee. All issues of the Bibliography of Aeronautics to date were prepared by Paul Brockett.

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

SUMMARY OF PROGRESS IN AIRCRAFT DEVELOPMENT

AERODYNAMICS

With an appreciation that the main theoretical foundations of this new science have been aid and that its further advances will be along the lines of extensions of or additions to existing theory, the aeronautical research laboratories in the United States have been largely engaged during the past year with problems relating to aerodynamic safety and efficiency.

In any general survey of the problems studied by the National Advisory Committee for Aeronautics in the past, or the problems to be undertaken in the future, it is highly important that the influence of the immediate technical requirements of air commerce and the military and naval services be recognized. To meet these requirements a large part of the research program of the committee is concerned with problems of immediate technical interest to the services and the industry.

The major problems contemplated or now under investigation are concerned with some phase of the general subject of safety in flight. The most important of these are the studies of spinning, low-speed control, stability, and load distribution under various conditions of flight.

A second group of almost equal importance is concerned with problems of aerodynamic improvement by the reduction of drag. A third group is concerned with problems relating to general design and operation, such as landing and taking off, local loading on wings, propeller characteristics, and the prevention of ice formation.

The problem of spinning is at present considered the most important of all the investigations now being undertaken by the committee. There are two phases of this problem, the prevention of spins from unintentional stalls at low altitude, and the uncontrolled spin generally known as the flat spin. Considerable progress has already been made in the study of this problem and the present research programs call for the intensive study that the importance of this subject justifies.

There follows below a brief summary of the work that has been accomplished during the past year and a reference to future research programs.

Wind tunnels.—The investigation of turbulence undertaken by the Bureau of Standards has yielded information of great value in the interpretation of wind-tunnel data. Many discrepancies formerly observed in tests on the same model in various wind tunnels may now be fully explained. This condition applies particularly to models having a critical Reynolds Number, such as spheres and streamline bodies. Tests have been made in the variable-density wind tunnel in which a given Reynolds Number was obtained from various combinations of model size, wind speed, and air density. These tests show conclusively that within reasonable bounds the Reynolds Number effect is absolutely independent of the values of the component terms. Furthermore, tests on large airfoils made in the propeller research tunnel are found to check very closely with tests at the same Reynolds Number in the variable-density tunnel. It may now be stated with assurance that the validity of the wind tunnel as a method of test is completely proven.

The present wind-tunnel testing program necessarily includes a large amount of work on low-speed control, spinning, interference, and propeller characteristics. Much of this work is now under way in some form or other. However, the main part of the spinning program will be undertaken upon completion of the special vertical wind tunnel, and most of the interference and low-speed control program must await the completion of the full-scale wind tunnel.

Spinning.—The program of wind-tunnel investigations on the problem of spinning included force, pressure distribution, and autorotation torque tests up to 90° angle of attack on models of a wide variety of wing sections. The pressure distribution and force tests have been completed and the results published. During the past year an autorotation dynamometer has been completed and the first of a series of tests is now being made with this equipment. The program provides for the measurement of the pitching and yawing moments as well as the rolling moments.

At the Massachusetts Institute of Technology an investigation was made on the effect of yaw on the autorotation of a monoplane airfoil.

The mass distribution of an airplane is an important factor in its recovery from a spin. The flight research section of the laboratory has completed an apparatus for the accurate measurement of the mass distribution of an airplane, and the moments and ellipsoids of inertia of several military and commercial airplanes have been determined. A study of these inertia data, together with the information as to the type of spin executed by each of these airplanes, indicates that a definite relation exists between the mass distribution and the type of spin. The chief difficulty in definitely determining this relation is the lack of accurate knowledge of the magnitude of the variables that enter into the dynamics of the spin, such as the radius and the rate of rotation. A method for the measurement of these variables in flight has been perfected, and complete data have been obtained on one airplane. From these data the dynamic forces producing and maintaining the spin have been determined. The future program will include the study of a number of types of airplanes, and in particular one airplane which has normal spinning characteristics, and in which the mass distribution will be changed until a flat spin is produced.

Stability.—The stability characteristics of most airplanes are satisfactory below angles of attack of maximum lift, but very few have satisfactory characteristics in stalled flight. In the investigation in the atmospheric wind tunnel of stability in stalled flight, a series of tests has been conducted to determine the effect on stability of twisting a wing and at the same time determine the effect of changing the profile along the span. The investigation showed that both methods gave improved stability characteristics.

Controllability.—A study has been made in the atmospheric wind tunnel of the effectiveness of various types of ailerons, particularly from the standpoint of stalled flight and the spin. It is planned to conduct in the near future a series of flight tests on a special monoplane arranged for the convenient changing of the wings, ailerons, and tail surfaces. In this investigation it is expected that accurate information on the rolling and yawing tendencies of the airplane with various methods of control will be obtained while in stalled flight.

The Bureau of Standards has completed an investigation on the measurement of the rolling and yawing moments produced by ailerons of various chords and spans on 10 by 60 inch models of the Clark Y and U. S. A. 27 airfoil sections. This investigation covers angles of attack up to the stalled position.

In the variable-density wind tunnel a series of pressure-distribution tests on the R.A.F. 30 airfoil with flaps has been completed, and the information obtained in these tests will be of considerable assistance in the study of the effectiveness of ailerons, and also of scale effect.

Maneuverability.—The committee has continued the study of maneuverability, and has carried out a series of tests on two types of pursuit airplanes. The maneuverability of the airplane is determined basically by the flight path obtainable, and during the past year considerable attention has been given to improving the methods for determining the flight path. A report covering the study of the maneuverability of one pursuit airplane has been completed, and a report on the second airplane is in progress.

The future program provides for a study of the maneuverability characteristics of an observation type of airplane and also of a commercial monoplane.

Structural safety.—The major activity of the flight research section of the laboratory has been in connection with the determination of the air loads experienced by airplanes under the various conditions of flight. The results obtained in the measurement of the load distribution on the wings, tail surfaces, and fuselage of an airplane in all conditions of flight have been studied from the standpoint of the structural designer. This investigation brought out several points of great importance, one of which was the torsional deflection of the wing under load, which results in a change in the load distribution, and another the effect of the inertia loads on the airplane structure. In this investigation accelerometers were placed at the center of gravity, at the wing tips, and in the tail unit. In the measurement of the inertia loads it was found that under certain conditions of flight they combine with the aerodynamic loads to give new maxima.

From this investigation additional information was obtained on the pressure distribution on the tail surfaces of pursuit type airplanes, and on the difference in the loads experienced with control surfaces of thick and thin section. The results obtained on both types of airplanes indicated the necessity for an increase in the design requirements as to tail loads for airplanes which are expected to execute maneuvers at high speeds, and from a study of the results and from conference with the subcommittee on aircraft structures a satisfactory basis has been established for the preparation of design specifications for tail surface loads.

In order to obtain information as to the possible need of modifications in the existing specifications for loading on wing tips, and to develop a wing tip with constant location of the center of pressure, the program for the study of the distribution of air loads on the observation type airplane has been planned so as to include the investigation of the loads on wing tips of various plan forms.

Water-pressure distribution.—The study of the distribution of water pressure on various types of seaplane floats and hulls has been continued. This investigation was first carried out on a single-float and a twin-float seaplane, and has recently been completed on an H-16 flying boat. With the flying boat it was possible to maneuver on rough water, so that the maximum pressures recorded were considerably higher than those obtained on the smaller seaplanes. On the H-16 the maximum pressures were 15 pounds per square inch, as compared with a maximum of approximately 10 pounds per square inch on the floats of lighter seaplanes.

This investigation will be continued during the coming year, and will include the measurement of the deflection of a seaplane float in static test with the loading exactly the same as that obtained in the flight tests.

Aerodynamic efficiency.—A large number of the investigations on the research program of the committee may be classified as problems of aerodynamic efficiency. These include the study of the reduction of the drag of the airplane and engine, the study of the mutual interference of the airplane and its parts, the investigation of propeller efficiency, and the study of airfoil characteristics.

Reduction of drag.—One of the most important investigations undertaken by the committee has been the study of the effect of cowling and cooling a radial air-cooled engine. The importance of this study can readily be appreciated when it is realized that the majority of engines in both military and commercial service are of this type. Only one manufacturer in the United States is now in production on water-cooled engines for military and commercial purposes.

The propeller research tunnel made possible the study of this problem at full scale. The cowling and cooling of a Wright Whirlwind engine were investigated with both a cabin monoplane and an open-cockpit biplane. Various degrees of cowling were included in the investigation, from the uncowled engine to a cowling that entirely inclosed the engine. The latter type, designated as the N. A. C. A. cowling, showed a large reduction in drag, and this cowling, subsequently applied to the AT-5, the Lockheed Vega, and other airplanes, showed a very substantial increase in high speed. The results of the investigation in the propeller research tunnel have been published as Technical Reports Nos. 313 and 314, Drag and Cooling with Various Forms of Cowling for a Whirlwind Radial Air-Cooled Engine, Parts I and II.

The investigation of the drag of engine nacelles with various forms of cowling indicated the possibility of still greater savings in drag than when the engine is mounted in the fuselage of an airplane. To determine the effect on the drag of mounting an engine nacelle in or near the wing of an airplane flight tests were carried out on a 3-engined transport airplane. This airplane was equipped with three J-5 engines, and the two wing engines and the engine in the fuselage were cowled with the N. A. C. A. cowling. The results obtained were very disappointing, as the flight tests showed only a very slight increase in high speed. An investigation of the problem indicated a large increase in drag due to serious interference between the wings and the engine nacelle.

In order to study this interference effect, tests were conducted in the variable-density wind tunnel at 10 atmospheres on a one-tenth scale model of the Fokker wing. The investigation included the study of the nacelle and interference drag with the engine nacelle mounted in various positions above and below the wing. In the installation of the cowling on the full-sized Fokker airplane, it was believed that the interference drag would be considerably reduced by fairing the cowling into the wing. The tests in the variable-density tunnel with the nacelle faired into the wing showed an appreciable decrease in drag. The mounting of the engine nacelle in or near the leading edge of the wing showed the least interference drag.

The Matériel Division of the Army Air Corps has conducted an investigation in the wind tunnel on models of various forms of complete cowling. Particular attention was given in these tests to the measurement of the air flow through the cowling.

The investigation of the cowling is being continued at the Langley Memorial Aeronautical Laboratory on a pursuit type airplane powered with a Pratt & Whitney Wasp engine. A study is being made of the air flow in the vicinity of the slot where the air leaves the cowling and the air flow entering the slot. The engine cylinders are equipped with thermocouples and a careful study is being made of the variation of cylinder temperatures with change of air flow. Various forms of cowling are being studied in this investigation, including the British Townend ring. The results so far obtained on both the N. A. C. A. cowling and the ring type are favorable as regards both performance and cooling.

Interference.—The successful application of cowling to radial type engines installed in multi-engined airplanes is dependent upon the control or decrease of the interference drag. The results of the investigation of engine nacelles and wings in the variable-density wind tunnel indicated a marked improvement in the performance of an airplane with outboard nacelles. These tests were made without propeller, however, and therefore did not include the effect of the propeller slipstream. To investigate this problem further, there has been constructed a large model of an engine nacelle on which a propeller will be operated by a 20-horsepower electric motor. This nacelle will be tested in combination with the wing in the propeller research tunnel. The program includes the placing of the nacelle in all possible positions with reference to the wing, and the results should yield information which will enable the designer so to place the engine and nacelle with reference to the wing or wing cellule as to obtain the least drag, both of the nacelle itself and from interference effects.

In connection with the further improvement of the aerodynamic efficiency of the airplane, the committee plans an investigation during the coming year to determine the interference drag between different combinations of wing and fuselage forms. The investigation will also include a study of the drag characteristics of various forms of landing gears and windshields.

Propeller efficiency.—An investigation has been conducted in the propeller research tunnel of the effect on propeller efficiency of high tip speeds. Tests with propellers operating at tip speeds above the velocity of sound up to speeds of 1,350 feet per second have been included in the investigation. The results indicate a reduction in propulsive efficiency beginning at tip speeds of 950 to 1,000 feet per second, and a loss of efficiency of about 10 per cent for each 100 feet per second increase in tip speed above 1,000 feet per second. In these tests measurements were made of the deflection of the blades and of the velocity and twist of the slip stream back of the propeller.

In an investigation of the effect on propulsive efficiency of the interference of the body behind the propeller, a series of geometrically similar propellers varying in diameter from 9 to 10½ feet was tested. The results indicated that the propulsive efficiency is about 2½ per cent higher for the largest propeller than for the smallest.

To determine the effect of changes in plan form on propeller efficiency, a series of tests was made on propellers varying in this respect. The results indicated only a slight difference in efficiency, but the form with the thinnest airfoil section showed the highest efficiency, and for propellers operating in front of a body such as the radial engine it was found that the propulsive efficiency is increased if the propeller pitch is reduced toward the hub.

At Stanford University an investigation has been carried out on the effect of fuselage fineness on propeller performance.

A comparative study of the efficiency of geared and direct-drive propellers on the J–5 engine has been made in the propeller research tunnel, with a large and a small fuselage. The investigation was made in such a manner that the propeller-body interference factors were isolated, and it was found that, considering this interference only, the geared propeller had an appreciable advantage in propulsive efficiency. This advantage is partially due to the larger diameter of the geared propellers with respect to the bodies, and partially to the fact that the geared propellers were located farther ahead of the engines and bodies.

The investigation of the general problem of propeller efficiency as affected by various factors is being continued, and will include the effect of the wing on propeller efficiency, the effect of the propeller slip stream on wing characteristics, and interference effects between a wing nacelle and the wing. It is planned to prepare a series of design charts covering all the information obtained on the effect of various factors on propeller efficiency.

Airfoils.—The investigation of airfoil sections at high speeds has been continued at the Bureau of Standards during the year, and a report has been issued on the characteristics of 24 sections at 0.5 to 1.08 times the speed of sound. In this group of airfoils one section having a plane lower surface and a cylindrical upper surface showed better lift-drag ratios than any other section of different shape but of the same thickness, and a series of airfoils of this type will be tested during the coming year.

In order to compare airfoil characteristics as determined in the propeller research tunnel with the results of tests in the variable-density wind tunnel at a corresponding Reynolds Number, a series of seven airfoils was tested, including the Clark Y, the Göttingen 398, the N. A. C. A. M–6, and the N. A. C. A. 84. The models tested had a chord of 2 feet and a span of 12 feet, and the Reynolds Number obtained in the propeller research tunnel was about 2,000,000. The results of the tests were in good agreement with the results obtained in the variable-density tunnel at a corresponding Reynolds Number. Two of the large models tested were made with corrugated surfaces, and showed a slightly greater drag than the airfoils with smooth surfaces. The lift curves of the models with corrugated surfaces showed a marked flattening in the vicinity of maximum lift.

For the purpose of studying the scale effect in investigations of pressure distribution, a series of pressure-distribution tests on wing models was made in the variable-density wind tunnel at 1 to 20 atmospheres. The airfoils tested included the M–6, the R. A. F. 30, the Clark Y, and the R. A. F. 31 equipped with the Handley Page leading-edge slot. The results of this investigation are being prepared for publication.

In order to study the effect of scale on discontinuities in the lift curve near the region of maximum lift, a group of eight airfoils approximately 20 per cent of the chord in thickness were tested in the variable-density wind tunnel. Six of the eight airfoils exhibited discontinuities at a Reynolds Number of 150,000. The discontinuities became less pronounced as the Reynolds Number was increased and disappeared entirely when the Reynolds Number reached 720,000.

An investigation is to be made in the variable-density wind tunnel on a family of about 80 airfoils to determine the effect of thickness and shape of the mean camber line on airfoils characteristics. The airfoils included in the program will have the same relative variation in thickness along the chord, and will have six values of maximum thickness varying from 6 to 21 per cent of the chord. The airfoils are based on five differently shaped mean camber lines, each having 4° of camber.

The investigation in the atmospheric wind tunnel at Langley Field of the problem of boundary-layer control has been continued. The model used in this investigation is provided with a narrow slot which opens into the wing and is so arranged that air may be discharged from or sucked into the wing. The slot is adjustable, both as to position on the surface of the wing and as to width. The results of these tests show considerable increase in lift with moderate pressures and a reduction in the minimum drag.

Struts.—At the Washington Navy Yard three extensive series of tests on struts have been made in the past year. The first series included 11 modifications of the Navy No. 1 strut, the program being so arranged as to cover the study of the effects of fineness ratio and trailing edge radius. The second series, conducted on five theoretical shapes supplemented by three standard struts, included pressure distribution and drag measurements, and the results of the tests were compared with calculated values. In the third series the effect on drag of slight modifications in standard struts was measured. The results obtained in these investigations have been published as Technical Reports of the National Advisory Committee for Aeronautics.

Ice formation.—The study of ice formation on airplanes in flight has been continued during the year, both in the special low-temperature wind tunnel and in flight. Flight tests have been made under a variety of weather conditions such as fog, rain, and sleet. Photographs have been made for study of the ice deposits on wings, wires, and struts. In several instances ice formed on the propellers. It was found that ice will form under a number of different atmospheric conditions, but forms in dangerous amounts only within a small range of temperature below 32° F. In the low-temperature wind tunnel a study has been made of the possibility of preventing the formation of ice on airplane parts by the use of a protective coating. The results up to the present time have not been of a positive nature, but it has been found that glucose, corn sirup, and a mixture of glycerin and alcohol do have some effect in the prevention of ice formation. A report on this investigation is in preparation for publication.

Airships.—Flight tests on airships during the past year have been confined to speed and deceleration tests, conducted in conjunction with the Goodyear-Zeppelin Corporation, to determine the drag of a small commercial-type airship. Similar investigations will be carried out on a TC-type airship for the Army Air Corps, and on the metal-clad airship *ZMC-2* at Lakehurst for the Bureau of Aeronautics of the Navy.

The results obtained in the investigation previously conducted by the committee for the Bureau of Aeronautics on the U. S. S. *Los Angeles* have been carefully studied, and a report has been prepared on the pressure distribution on the hull and tail surfaces and on the drag of the airship with and without the water-recovery apparatus.

In the variable-density wind tunnel a series of tests is now in progress on a model of the *ZRS-4* airship and a model of lower fineness ratio. The investigation includes the determination of the lift, drag, and pitching moments on both models, with and without control car.

An investigation will be carried on in the propeller research tunnel on a larger model of the *ZRS-4* airship, and will include the measurement of the pressure distribution over the hull and the determination of the lift and drag of the airship at various angles of pitch, and measurements at the same time of the forces and moments exerted on the elevator hinge.

In the wind tunnel at New York University tests are being carried on for the Goodyear-Zeppelin Corporation to obtain information as to the forces involved in the ground handling of airships. The forces are being measured on a model of an airship suspended at various angles to the wind, close to the ground and to a model of a hangar.

Fields for future research.—Previous summaries have pointed out the desirability of progress in aerodynamics along the lines of increase in safety and refinement in design. In the further improvement of the design of aircraft more knowledge is essential regarding maximum air loads and air-load distribution on the airplane structure, more information on methods of reducing drag, and in particular on the proper location of power plants for minimum interference and the greatest improvement in propulsive efficiency. The solution of the problem of increase in safety will come from an intensive study of spinning, low-speed control, and stability characteristics of aircraft. The major problems on the research program of the committee are concerned with some phase of the general subjects of safety in flight and improvement in aerodynamic efficiency.

AIRPLANE STRUCTURES

TREND OF DESIGN—*Standardization of types.*—The tendency toward standardization of types has continued. An increasing appreciation by designers of the importance of large aspect ratio and low parasite drag is reflected in the increase in the number of airplanes of the monoplane type, which now seems firmly established as a preferred type of design for large airplanes for use in regular scheduled commercial service. The monoplane has not been universally accepted, however, since two large biplanes have been constructed during the past year for this type of service. In the smaller classes of airplanes, of the three or four passenger type there has been a large increase in new types of monoplanes. This increase exceeds 300 per cent, yet the biplane still exceeds the monoplane in actual number of types and still holds a dominant position from the standpoint of production. This is particularly true for military service, where maximum maneuverability must be obtained and the span kept as low as practicable.

The demand on the part of the passenger and pilot for comfort is reflected in the great increase in the number of closed-body types, the increase in this type during the past year being nearly 300 per cent. For 2-place and 3-place airplanes, the open-cockpit type appears to be preferred. This is probably not so much a matter of comfort as a question of lower cost.

The military services are taking advantage of the existence of well-proven types of large commercial airplanes to acquire examples for transport service. Development of these types into strictly military types would be very costly and the independent development of parallel military types even more costly. Hence the number of types of very large purely military airplanes must remain very few as a matter of economy.

Number and location of engines.—Operating conditions in the United States, especially over the mountainous parts of the transcontinental air routes, require that the multiengined commercial airplane shall be able to fly at an altitude of 10,000 feet with one engine not running. It is further necessary that an airplane operating over this route shall be able to take off with its full load at altitudes from 5,000 to 7,000 feet. These rather severe requirements have made it necessary to increase the power of the engines of all large passenger airplanes operating over the transcontinental route.

At present nearly all of the large transport airplanes are of the 3-engined type, one engine being placed in the nose of the fuselage.

In the design of the newer types of transport airplanes the tendency is to place all the engines in wing nacelles or in the wing itself. In the designs of this type so far constructed four engines have been used instead of two. This arrangement of engines shows an appreciation of the value of comfort for the passengers and the desire to avoid the disagreeable vibration and noise, which has been very difficult to control when the engine is mounted in the fuselage.

The use of multiengined airplanes has been extended to the light or sport type. The latest designs have provided for two engines of relatively small horsepower, mounted in the wings.

In foreign types of airplanes there is a marked tendency to mount the engines above the wing. This arrangement has been followed in only one or two designs built in this country.

In all multiengined airplanes care is being exercised to provide that the propellers do not overlap and that the propeller wash does not seriously interfere with the structural parts of the airplane, as such interference creates a vibration which is very disagreeable to the passengers. The effect of the propeller slip stream on adjacent structures in the design of any aircraft to carry passengers is most important.

In designing passenger airplanes the designer is being forced to consider the comfort of the passenger as a primary feature in the design. The chief factors involved are noise and vibrations due to the engine and to aerodynamic forces on the structure. These latter may be the result either of the wash from the propeller or from the variations in pressure and velocity of the air over the fuselage, due to the peculiarities in design.

Amphibian airplanes.—The obvious advantages of the amphibian type are being more generally appreciated and the construction of airplanes of this character is being extended to additional commercial and military types, and especially to the smaller types intended for commercial purposes.

Landing gear.—Landing gears of the orthodox type have been more or less standardized by the manufacturers of this type of equipment. Most commercial and military types are now fitted with oleo gears. There is, however, an increased appreciation of the gain in performance which may be obtained by either simplifying the landing gear or retracting the landing gear while in flight. A number of the designs of retractable landing gear which have appeared during the year show promise, and efforts are being made to reduce the drag of the stationary type landing gear.

Shock absorbers.—The hydraulic type of shock absorber is now almost universally used, even on relatively light airplanes. However, the development of a new type of tire having a very large cross-sectional area and operating under low air pressure may make it unnecessary to provide shock absorbing mechanisms other than the tire itself in the lighter types of airplanes.

Wheel tail skids.—The use of a wheel either with a hard or a pneumatic tire to replace the tail skid has been extended, especially to the larger types of airplanes. The use of such wheels, especially in connection with wheel brakes on the main landing wheels, has proved successful in the operation of a number of standard types.

Brakes.—Brakes are now almost universally used on commercial type airplanes. Practically all manufacturers make some provision for the fitting of brakes, either as regular equipment or at the option of the purchaser.

Difference between military and commercial types.—The steady demand for increased performance in military airplanes, and in particular the demand for the ability to perform violent maneuvers at high speeds, has made it necessary to raise the structural strength requirements of many types of military airplanes to a higher standard than ever before. These requirements are now so severe that it may be doubted whether they will ever be applied generally to commercial airplanes. In meeting these requirements by improved design features and by improving methods of construction and materials used, the results will undoubtedly influence commercial airplane design.

In spite of the continued increase in the quality of design, materials, and construction of commercial airplanes, which is resulting from the requirements of the Department of Commerce, the unsuitability of commercial airplanes for military use is increasingly apparent. This does not prevent the use of certain types of transport airplanes for similar purposes by the military services, for here the demands on the airplane are practically the same in both civil and military use.

STRUCTURAL MATERIALS—*Metal construction.*—Although the number of parts in which wood is used continues to decrease, there are still many arguments advanced in favor of it. It is notable, however, that as the demands on the structure are increased there is a tendency to reduce the use of wood, especially in small sections. Many airplanes are now produced in which practically the only wooden members are the wing spars, everything else, except possibly a few fairing strips, being of metal. Metal wing spars of various original designs have been proposed but apprarently their general use has been delayed by their relatively greater cost.

Welding is entering more and more largely into the construction of airplanes generally. The reliability of the welded structures appears to be regarded as entirely satisfactory. However, certain designers continue to voice objections to welding, and insist on the use of bolted or riveted joints.

The problem of internal corrosion has always been before the designer who used closed sections, and this has led to the development and use of corrosion-resisting structural materials. When such materials are generally available, designers will be able to do many things at present not approved in this country. Among other things it may be expected that the use of thin steel in sections which derive their strength from the complex character of their curvature will appear. Proposals are already being made for the use of this material in combination with a special system of spot welding.

Steel tubing.—Steel tubing of the corrosion-resisting type is still not available generally, but methods of protecting the steels ordinarily used in aircraft have been developed to a point where they may be said to be standardized.

AIRSHIPS

The placing of a contract for the building of two 6,500,000 cubic foot airships for the Navy Department in October, 1928, was a definite step in the resumption of airship building in the United States and a step toward the creation of an airship industry in the United States. Progress on design has proceeded at a normal rate. Fabrication of parts has begun. The keel ring of the first of these airships was laid on November 7, 1929. The first of these airships is due for completion in 1931, the second in 1932.

The Goodyear-Zeppelin Corporation, of Akron, Ohio, the contractor for the airships *ZRS-4* and *ZRS-5*, has practically completed the airship shed in which the airships are to be erected. The shed is 1,175 feet long, 325 feet wide, and 180 feet high. In the design of the shed the operating experience of the past four years has been carefully considered and the type of design is thought to be much superior to any types that have as yet been built.

Experimental investigation and research on the development of improved materials for airships have been continued.

Experimental flight operations have been continued with the *Los Angeles*. Improvements in water-recovery apparatus have been accomplished. Carrying, launching, and recovering service type airplanes have been accomplished in a more comprehensive manner than heretofore This work is preliminary to the design of apparatus for use with the Navy Department's new airships.

Development of improved methods of mechanical aid to the handling of rigid airships has been continued. The mobile mooring mast is a reasonably satisfactory piece of equipment and is helpful in the handling of airships. Further improvements in this mast are in contemplation and should increase its utility. No difficulties have been encountered in the use of the stub mooring mast as a riding point for an airship. As yet the problem of making a flying moor to the stub type of mast has not been satisfactorily solved.

The metal-clad airship.—The Aircraft Development Corporation has completed and delivered the metal-clad airship, *ZMC-2*. The airship has successfully completed its flight trials. The Navy Department has placed the airship in service at the naval air station at Lakehurst, where further tests will be made to obtain more comprehensive data as to the performance and general utility of this type of airship construction.

Helium.—The new Government plant near Amarillo, Tex., has been placed in operation, making available increased quantities of helium, and with the increase in production lower costs for the helium are being quoted.

A commercial company which has been producing helium for airships announces the discovery of a new field containing a natural gas with over 6 per cent helium, a very much larger percentage than that in any gas hitherto available in production quantities. This concern has moved the major portion of its plant to this new source of helium-bearing gas.

The Navy Department purchased a new type of helium tank car which carries the helium in 28 seamless drawn pipes instead of three forged cylinders. The cost of this type of car is materially less than the cost of a car carrying forged cylinders.

Progress in Germany.—The around-the-world flight of the *Graf Zeppelin* was an outstanding achievement in airship operation.

Progress in Great Britain.—After many delays the British airship *R-101* has made several flights. The second British airship, *R-100*, is practically complete and ready for flight trials.

AIRCRAFT ENGINES

An important factor influencing aircraft engine development during the past year has been the large number of new designs which have appeared on the market. The influx of a large number of new engines has influenced development along three separate lines: First, designers have attempted to increase the tractive horsepower available by reducing the head resistance; second, their interest has been increased in the possibilities of the compression-ignition engine; and third, they have attempted to reduce the initial and maintenance costs of the engine.

The introduction of the low-drag cowling which reduced the head resistance of the direct air-cooled radial type engine to a point where it approached or was less than the head resistance of the water-cooled engine and its radiator, was the result of investigations conducted at the committee's laboratories at Langley Field.

A study of high-temperature liquid cooling at Wright Field indicated the possibility of further reducing the drag of the liquid-cooled type engine by the use of small radiators.

To meet the reduced drag obtained in liquid-cooled engines by using liquids of high boiling point, designers of radial air-cooled engines are now concerned with reducing the overall diameter of the radial engine.

The compression-ignition engine offers many possibilities for obtaining high fuel economy, and a number of manufacturers are now designing and constructing aircraft engines of this type.

To reduce the initial cost of the engine, many of the smaller manufacturers are concentrating on one model, while one of the large manufacturers has a series of 5, 7, and 9 cylinder engines, which are built with the same bore and stroke, resulting in marked manufacturing and maintenance economies.

The application of the low-drag cowling to the radial engine was investigated in the 20-foot propeller research tunnel at Langley Field under full-scale conditions. The Army, Navy, and commercial services have found that the application of the cowling to different types of airplanes has definitely improved the performance. At the annual air races held in Cleveland this year and in the transcontinental nonstop flights, all previous records were lowered by airplanes equipped with radial engines and using the low-drag cowling.

To improve the visibility and reduce the drag, the side-valve radial engine and the 2-cycle engine are being developed in an attempt to reduce the overall diameter by doing away with the overhead valve gear.

The matériel division of the Army Air Corps has concentrated on the study of high-temperature liquid cooling of aircraft engines. Ethylene glycol has been used for several years experimentally with some success by the Army and the Navy, but it was not until last year that liquid-cooled engines were put in service.

As a result of the high operating temperatures obtained with ethylene glycol, a much more uniform cylinder temperature is maintained, with the absence of hot spots. The experience of both services indicates that higher compression ratios may be used in engines with this type of cooling.

The committee, at the request of the Navy Department, undertook the investigation of the compression-ignition engine using Diesel oil as a fuel. The results of the investigation carried on under the direction of the committee have been widely disseminated. The first experimental aircraft compression-ignition engine, known as the Attendu engine, was constructed and tested at the Naval Aircraft Factory in Philadelphia.

During the past year, interest and activity in the development of this type of engine have increased and have been stimulated by the flights of the Packard 9-cylinder radial compression-ignition engine and the Junkers 6-cylinder in-line water-cooled engine.

The Packard Motor Car Co. has been experimenting for the past two and a half years with the radial air-cooled compression-ignition engine and has made successful flight tests with very good fuel economy. At present, experimental engines are being developed by the Allison Engineering Co., the Emsco Aero Engine Co., and the Packard Motor Car Co.

During the year a large number of aircraft engine manufacturers completed their designs and facilities for manufacturing. The Warner and the Kinner companies have concentrated on one model and are building new facilities for its manufacture. The Curtiss Aeroplane & Motor Co. erected a new factory to produce the Challenger engine, and the Wright Aeronautical Corporation has built a special factory in St. Louis to manufacture the new Gypsy engine.

The concentration on one model of an engine in a single factory will no doubt have an influence on reducing the cost per horsepower of aircraft engines. Nearly all the new engine development has followed the conventional design of the fixed radial air-cooled type, being either 5, 7, or 9 cylinder engines.

In all commercial aircraft operations there has been a demand for higher-powered engines. Air transport service airplanes are now equipped with engines of the highest power obtainable, either of the Wasp, Hornet, or Cyclone type. The Wright Aeronautical Corporation has replaced the well-known J–5 engine with a new series known as the J–6, of 160, 220, and 300 horsepower.

There has been a definite tendency during the year to increase the revolutions per minute of radial type engines by refined design, resulting in the purchaser being benefited by the lower cost per horsepower.

No new types of water-cooled engines were brought out during the past year and only one manufacturer in the United States is in current production on water-cooled engines.

High-powered air-cooled engines for both military and commercial service are being developed with reduction gears. The use of reduction gears promises to become general in large multiengined airplanes, especially in flying boats.

It is interesting to note that all the recent engines submitted for type tests to the Department of Commerce are air-cooled. About one-third of all the engines submitted for test are finally approved. At present there are available for both military and commercial aviation 32 approved type engines manufactured in the United States.

FACTORS THAT HAVE CONTRIBUTED TO THE PRESENT STATE OF AERONAUTIC PROGRESS

Among the major factors that have contributed to the present state of aeronautical development in America are the great expanse of the United States and the distances that can conveniently be covered by aircraft with a material saving of time and without the usual handicaps attendant upon crossing international boundaries. This is one great natural advantage that will continue to promote the use of aircraft in America. The most important active influence upon aeronautics has been the far-sighted constructive policy of the Federal Government, liberally supported by the President and the Congress, in providing for the continuous prosecution of organized scientific research and of fundamental engineering development through the various governmental agencies concerned. Next in importance has been the progress made by the aircraft industry during the past four years or since the adoption of the Army and Navy 5-year aircraft programs. The military services have cooperated effectively with each other, with the industry, and with public-spirited organizations. These factors have had to do with the development of the airplane itself. Foremost among the factors that have promoted the use of aircraft was the development and extension of the air mail service under Government operation until its fundamental purpose had been demonstrated, namely, that it was practicable to carry mails by aircraft on regular schedule and at reasonable costs. This activity when taken over by private contractors led directly to the establishment of air transport lines which are growing steadily.

A major step in the national aviation policy was the enactment in 1926 of the air commerce act, under which national airways and aids to air navigation were established by the Department of Commerce with the cooperation of the Weather Bureau in giving special weather report service, and under which provision was made for the regulation, licensing, and inspection of aircraft and airmen under uniform rules and regulations.

American business men have been both farsighted and patriotic in their willingness to enter into the development of aeronautics on a sound economic basis and without the direct cash subsidies that have been deemed indispensable in other countries. This means that American aeronautics will be developed to meet the needs of the people unhampered and unaffected in nature or extent by a policy of limited cash subsidy.

The most recent major factor promoting the use of aircraft in America has been the development of reliable air transport, largely assisted by air mail contracts which have been the main support of most long-distance air transport companies. The air mail service under private operation of carriers continues to give the best demonstration of the practicability of the use of aircraft for civil purposes. At the annual meeting of the entire committee, held on October 24, 1929, a resolution was adopted reiterating the opinion expressed in 1921 in a special report to the Congress, submitted through the President and published as Senate Document No. 358, Sixty-sixth Congress, third session. The committee is still of the opinion, as then expressed, that, "The air mail service is in effect an experimental laboratory for the development of the civil uses of aircraft," and viewing it from this angle alone, believes it is worth what it costs over and above the difference between the revenue derived from the excess postage and the cost of carrying, if any.

The Daniel Guggenheim Fund for the Promotion of Aeronautics, which is terminating its activities at the end of the year 1929, has been a helpful factor in many ways. Its major work in establishing schools of aeronautical engineering in various universities will continue indefinitely to exercise a good influence on aeronautics.

The great economic question confronting aeronautics at this time is, Are the people willing in increasing numbers to pay the present costs of air travel? We think not. Costs must be reduced to a competitive basis where after making allowance for time saved and for the inherent attractiveness of air travel the costs will be fairly comparable with other means of transportation. We believe this can be done, but not by governmental regulation of rates and services. The problem of reducing costs, however, is too involved to be accomplished in this manner. It is easy to see that reduction in unit costs can be accomplished by increase in volume, but volume can not be satisfactorily increased with costs as they are. The answer is to improve the airplane; make it lighter and stronger; make it faster and more controllable; make it carry more pay load and consume less fuel and oil; construct it more simply and cheaply and make it easier to maintain and overhaul; make it more reliable by improving methods and facilities of air navigation; improve the landing and take-off characteristics of the airplane so as to enable it to land and take off in small areas—in short, improve its aerodynamic efficiency and make it more controllable, especially at low speeds. All of these problems are included in the current research programs of the committee, and the efforts of all existing agencies, governmental and private, are coordinated in an organized plan to solve them.

OUTLOOK FOR THE FUTURE

Among the factors that make the future of aeronautics particularly bright may be mentioned the following:

Improved radio communication and direction-finding facilities have become a practical reality and will be developed and extended on national airways.

To supplement the national airways certain States, notably New York and Virginia, are taking an interest in the development of State airports and airways, and in the opinion of the committee, it is but proper that the States generally should do this.

Airports are being established in the progressive cities and towns of America.

Larger airplanes are being built with more consideration for the safety, stability, and comfort of passengers.

Business executives and others who value time are using the airplane with increasing confidence.

The youth of the land is interested in aeronautics and is eager to fly. The attendance at flying schools manifests this and the standard of instruction in such schools is improving to meet increasing Federal requirements for approved certificates.

Metal construction is coming gradually into general use. This will make airplanes stronger and safer, and by lengthening their lives and decreasing structural maintenance will operate to decrease flying costs.

The fuel-injection aircraft engine using Diesel oil instead of gasoline gives promise of decreasing the fire hazard, of decreasing costs of operation, and of increasing the fuel economy and range of operation.

Aerodynamic improvements are being constantly made that decrease the drag and improve the controllability, the general efficiency, and the safety of airplanes.

The governmental agencies concerned with aeronautics are organized on a sound and logical basis and function in cooperation. The Army and Navy air organizations are constantly improving the airplane to meet the needs of national defense and these improvements invariably find an application in commercial aircraft. The education of aeronautical engineers has received an impetus from the grants to several universities by the Daniel Guggenheim Fund for the Promotion of Aeronautics. Details of the technical progress made in other nations are promptly made available in America through the committee's Office of Aeronautical Intelligence. The results of scientific research on the fundamental problems of flight are made available by the committee and utilized by the industry. The committee's facilities for such research are being materially extended under appropriations from Congress for the construction of a wind tunnel suitable for testing full-sized airplanes, and for the construction of a seaplane channel necessary for the investigation and improvement of the landing and take-off characteristics of seaplanes. The air mail service will no doubt be extended to serve the needs of the country as rapidly as conditions warrant.

The great fundamental problem of how most effectively to increase the use of aircraft by the people can be met in part by increased activity on the part of those private organizations which concern themselves with the civic, national, and scientific development of the country, in promoting the establishment of airports and in educating the people generally as to the service that aircraft can render on a sound economic basis. But withal there remains the necessity of improving the safety and efficiency of the airplane, and in the last analysis the answer is to be found in the continuous prosecution of organized scientific research.

CONCLUSION

The United States leads other nations in the use of aircraft for commercial purposes; in the private ownership and operation of aircraft; in the extent and lighting of airways; in the provision of weather-report service; in the number of airports and intermediate landing fields; in the development of radio communication and directional finding facilities; in the transportation of mail by air; in crop dusting and forest patrol by air; in aerial photographic surveying and mapping; in the development of cowling for air-cooled engines, and of engine starters; in the development of catapult launching and deck arresting devices; and in the development of parachutes. In addition the United States has taken the lead in the analysis and study of causes of aircraft accidents. America is abreast of other nations in the development of military types of airplanes, in its airship development program, in the development and use of metal construction for aircraft, and in the development of air-cooled and fuel-injection engines. America is definitely behind other nations in the development of seaplane floats and in the development and use of seaplanes, water-cooled engines, and large air transports, and also in the development of air passenger traffic. America holds the world's seaplane altitude record but is far behind in maximum speed.

The authorization by the Congress of a seaplane channel for the committee will enable America to improve her position in the matter of seaplane floats, which will permit the building of better seaplanes. The committee has recently recommended a program for the development of liquid-cooled engines, which are deemed essential for the attainment of maximum speeds. It is only a question of time, in the committee's judgment, when America will lead the world in air passenger traffic, for it is producing the requisite technical knowledge so to improve the safety and efficiency of aircraft as to bring this about without direct cash subsidies, and because its great area will make an important factor of the time to be saved by air travel.

We are, however, confronted as are other nations with the serious fundamental problems of increasing the safety and decreasing the costs of aviation. The committee feels that the answer is to be found through scientific research. The committee is grateful to the President and to the Congress for the support that has been given to scientific research in aeronautics. The committee believes that the continuous and systematic study and investigation of the basic problems of flight is the most fundamental activity of the Government in connection with the development of aeronautics, and in the discharge of its responsibility under the law recommends the continued support of its work in the fields of pure and applied research in aeronautics.

Respectfully submitted.

National Advisory Committee for Aeronautics,
Joseph S. Ames, *Chairman.*

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