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AERONAUTICS

EIGHTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1922

ADMINISTRATIVE REPORT WITHOUT TECHNICAL REPORTS

December 5, 1922.—Read; referred to the Committee on Naval Affairs and ordered to be printed

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

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 eighth annual report of the committee for the fiscal year ended June 30, 1922.

The attention of the Congress is invited to the presentation by the National Advisory Committee for Aeronautics of a national aeronautical policy at the conclusion of its report. The constructive recommendations therein contained for the advancement of aeronautics deserve the thoughtful consideration of all members of the Congress.

Warren G. Harding.

The White House

December 5, 1922.

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Warren G. Harding.

The White House,
December 5, 1922.

LETTER OF TRANSMITTAL.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., November 23, 1922.

MR. PRESIDENT: In compliance with the provisions of the act of Congress approved March 3, 1915 (Public, No. 273, 63d Cong.), I have the honor to transmit herewith the eighth annual report of the National Advisory Committee for Aeronautics, including a statement of expenditures for the fiscal year ended June 30, 1922.

The contributions of the committee to the science of aerodynamics have, during the past year, placed America in the forefront of progressive nations in this respect. In the art of aviation there has been substantial progress in the design and performance of military and naval types of airplanes, but commercial aviation has made very little headway. This has been due not so much to the inherent problems and difficulties of air navigation, nor to lack of technical knowledge, but to lack of airways, landing fields, and Federal regulation and licensing of aircraft and operators.

The measures deemed timely and appropriate for the advancement of aeronautics are embodied in a national aeronautical policy presented by the National Advisory Committee for Aeronautics at the conclusion of its eighth annual report. The history of America and of all other civilized nations shows that governments have found it necessary and advantageous to aid in the development of means of transportation, as in Federal land grants to American railroads, and in the good roads movement. The latter has not only developed the automobile industry, but has been the direct means of awakening the people to the possibilities and advantages of motor traffic.

Aircraft will prove even more revolutionary than the railroad or the automobile. In the judgment of the National Advisory Committee for Aeronautics it is necessary and proper that the Federal Government should aid in the development of air navigation by providing Federal regulations and establishing airways and landing fields.

Respectfully submitted.

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

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

SUMMARY OF NATIONAL AERONAUTICAL POLICY.

The national aeronautical policy proposed by the National Advisory Committee for Aeronautics is set forth at the end of this report. The recommendations therein presented for the consideration of the President and of the Congress deal with the following subjects:

AERONAUTICS AND THE PROGRESS OF CIVILIZATION.
THE NEED FOR FEDERAL AND STATE LFGISLATION.
THE IMPORTANCE OF SCIENTIFIC RESEARCH.
AVIATION FOR NATIONAL DEFENSE.
HELIUM FOR AIRSHIPS.
THE AIR MAIL SERVICE.
AEROLOGICAL SERVICE ALONG AIRWAYS.
FEDERAL AID NECESSARY.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

2722 NAVY BUILDING, WASHINGTON, D. C.

CHARLES D. WALCOTT, Sc. D., *Chairman*,
Secretary, Smithsonian Institution, Washington, D. C.
S. W. STRATTON, Sc. D., *Secretary*,
Director, Bureau of Standards, Washington, D. C.
JOSEPH S. AMES, Ph. D., *Chairman Executive Committee*,
Director, Physical Laboratory, Johns Hopkins University, Baltimore, Md.
THURMAN H. BANE, Major, United States Army,
Chief, Engineering Division, Air Service, Dayton, Ohio.
WILLIAM F. DURAND, Ph. D.,
Professor of Mechanical Engineering, Stanford University, California.
JOHN F. HAYFORD, C. E.,
Director, College of Engineering, Northwestern University, Evanston, Ill.
JEROME C. HUNSAKER, Commander, United States Navy,
Bureau of Aeronautics, Navy Department, Washington, D. C.
CHARLES F. MARVIN, M. E.,
Chief, United States Weather Bureau, Washington, D. C.
WILLIAM A. MOFFETT, Rear Admiral, United States Navy,
Chief, Bureau of Aeronautics, Navy Department, Washington, D. C.
MASON M. PATRICK, Major General, United States Army,
Chief of Air Service, War Department, Washington, D. C.
D. W. TAYLOR, D. Eng.,
Washington, D. C.
ORVILLE WRIGHT, B. S.,
Dayton, Ohio.

EXECUTIVE COMMITTEE.

JOSEPH S AMES, *Chairman*.
S. W. STRATTON, *Secretary*.

THURMAN H. BANE,
JOHN F. HAYFORD,
JEROME C. HUNSAKER,
CHARLES F. MARVIN,
WILLIAM A. MOFFETT,
MASON M. PATRICK,
D. W. TAYLOR,
CHARLES D. WALCOTT,
ORVILLE WRIGHT,

GEORGE W. LEWIS, *Executive Officer*.
JOHN F. VICTORY, *Assistant Secretary*.

EIGHTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Washington, D. C., November 23, 1922.

To the Congress:

In accordance with the provision of the act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics, the committee submits herewith its eighth annual report. In this report the committee has described its activities during the past year, the technical progress in the study of scientific problems relating to aeronautics, the assistance rendered by the committee in the formulation of policies for the general development of aviation, the regulation of air navigation, the coordination of research work in general, the examination of aeronautical inventions, and the collection, analysis, and distribution of scientific and technical data. This report also contains a statement of expenditures estimates for the fiscal year 1924, and recommendations for advancing the science and art of aeronautics.

FUNCTIONS OF THE COMMITTEE.

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

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

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

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

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

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

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

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

ORGANIZATION OF THE COMMITTEE.

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

During the past year Commander Jerome C. Hunsaker, United States Navy, was appointed by the President a naval member of the committee to succeed Rear Admiral David W. Taylor, United States Navy, who retired from active duty in the Navy. Dr. Michael I. Pupin, of Columbia University, New York City, resigned, and the vacancy thus caused was filled by the President by the reappointment of Admiral Taylor in a civilian capacity, because of his broad experience with aeronautical problems and his thorough knowledge of the science of aerodynamics.

The full 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 6, 1921, and that held on October 19, 1922.

The present organization of the committee is as follows:

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

MEETINGS OF THE ENTIRE COMMITTEE.

At the semiannual meeting of the entire committee, held in April, 1922, Doctor Ames, chairman of the executive committee, made a complete report of the research work in progress under the committee's direction at the Langley Memorial Aeronautical Laboratory, at Langley Field, Va., in the course of which he exhibited lantern slides showing novel methods used and results obtained. This detailed presentation of the committee's activities at Langley Field so aroused the interest of the members that it was decided to hold the next meeting of the entire committee at Langley Field.

The annual meeting was accordingly held at Langley Field on October 19, 1922. Doctor Ames conducted a tour of inspection of the general research laboratory, the aerodynamical laboratory, the new compressed-air wind tunnel, the engine dynamometer laboratory, the hangars, and the airplanes equipped with specially designed instruments and apparatus developed in connection with the prosecution of the committee's research program. The compressed-air wind tunnel was operated for the first time in the presence of all the members. Doctor Ames presented to the committee the members of the engineering staff in charge of the various divisions of work. Each of these men reported in full on the problems on which he was engaged, what he was trying to accomplish, his successes and his difficulties.

The annual meeting was held in the main laboratory building in the afternoon. The committee reviewed the status of the current research program and discussed the problems requiring solution. All the members agreed that the funds available were insufficient to permit the full program for the coming year to be undertaken. The officers of the committee were requested to urge the appropriation by Congress of funds sufficient to carry on the entire research program.

The officers of the committee were reelected for another year as follows: Dr. Charles D. Walcott, chairman; Dr. S. W. Stratton, secretary; Dr. Joseph S. Ames, chairman executive committee.

By courtesy of the President and of the Secretary of the Navy, the trip to Langley Field and return was made on the President's yacht, the *Mayflower*, which added greatly to the comfort of the trip and afforded an excellent opportunity for the more thorough discussion of aeronautical problems.

THE EXECUTIVE COMMITTEE.

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

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

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

The executive committee has organized the necessary clerical and technical staffs for handling the work of the committee proper. General responsibility for the execution of the programs and policies approved by the executive committee is vested in the executive officer, Mr. George W. Lewis. In the subdivision of general duties he has immediate charge of the scientific and technical work of the committee, being directly responsible to the chairman of the executive committee, Dr. Joseph S. Ames. The assistant secretary, Mr. John F. Victory, has charge of administration and personnel matters, property, and disbursements, under the direct control of the secretary of the committee, Dr. S. W. Stratton.

SUBCOMMITTEES.

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

ADMINISTRATIVE.	TECHNICAL.
Governmental relations.	Aerodynamics.
Publications and intelligence.	Power plants for aircraft.
Personnel, buildings, and equipment.	Materials for aircraft.

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

COMMITTEE ON GOVERNMENTAL RELATIONS.

FUNCTIONS.

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

ORGANIZATION.

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

COMMITTEE ON PUBLICATIONS AND INTELLIGENCE.

FUNCTIONS.

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

ORGANIZATION.

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

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT.

FUNCTIONS.

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

ORGANIZATION.

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

QUARTERS FOR COMMITTEE.

The headquarters of the National Advisory Committee for Aeronautics are located in the Navy Building, Seventeenth and B Streets NW., Washington, D. C., in close proximity to the Army and Navy Air Services. The administrative office is also the headquarters of the various subcommittees. The scientific investigations authorized by the committee are not all conducted at the Langley Memorial Aeronautical Laboratory, but the facilities of other governmental laboratories and shops are utilized, as well as the laboratories connected with institutions of learning whose cooperation in the scientific study of specific problems in aeronautics has been secured.

THE LANGLEY MEMORIAL AERONAUTICAL LABORATORY.

The Langley Memorial Aeronautical Laboratory is located on Langley Field, Va., on a plot set aside for the committee's use when the field was originally laid out by the War Department. It is at this laboratory, and the flying field used in connection therewith, that the committee prosecutes under its own direction scientific research on the more fundamental problems of flight. The laboratory as a whole now comprises six units, namely, a research laboratory building, including administrative and drafting office, machine and woodworking shops, and photographic and instrument laboratories; two aerodynamical laboratories, one containing an open-type wind tunnel and the other a compressed-air wind tunnel; two engine dynamometer laboratories, one of a permanent type, now under construction, and the other merely a converted airplane hangar; and on the flying field an airplane hangar 120 feet by 132 feet. The permanent engine dynamometer laboratory referred to is now in process of erection under specific authority of Congress.

OFFICE OF AERONAUTICAL INTELLIGENCE.

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral branch of the committee's activities. Its functions are the collection, classification, and diffusion of technical knowledge on the subject of aeronautics to the Military and Naval Air Services and civil agencies interested, including especially the results of research and experimental work conducted in all parts of the world. It is the officially designated Government depository for scientific and technical reports and data on aeronautics.

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

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

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

Committee and subcommittee members	1,660
Langley Memorial Aeronautical Laboratory	1,660
Paris office of committee	4,205
Army Air Service	2,294
Naval Air Service, including Marine Corps	2,463
Manufacturers	4,205
Educational institutions	4,210
Bureau of Standards	1,087
Miscellaneous	10,382
Total distribution	32,166

The above figures include the distribution of 14,868 technical reports and 9,238 technical notes of the National Advisory Committee for Aeronautics. Three thousand one hundred and five written requests for reports were received during the year in addition to innumerable telephone and personal requests and 13,910 reports were forwarded upon request.

AERONAUTICAL INVENTIONS.

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

ASSISTANCE FROM ARMY AND NAVY.

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

USE OF NONGOVERNMENTAL AGENCIES.

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

WORK IN PROGRESS FOR THE ARMY AND THE NAVY.

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

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

For the Naval Bureau of Aeronautics.—The following researches were undertaken by the committee at the request of the Navy:

Comparative study of the stability, controllability, and maneuverability of airplanes, in continuation of studies already made, including the following models: *VE-7*, *SE-5*, *Fokker D-VII*, and *MB-3*. This work involved the design of an accelerometer and a photographically recording air-speed meter.

Study of effective dihedral and later controllability.

Study of pressure distribution over the envelope and controls of a "C" class airship, involving the design and construction of a multiple manometer for the measurement of the distribution of pressure, and a recording gyro rate-of-turn indicator.

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

A study of biplane and triplane combinations.

The committee's technical assistant in Europe made purchases abroad of special aircraft radiators desired by the Navy.

For the engineering division of the Army Air Service.—The following instruments were designed by the committee in connection with its own investigations and the investigations enumerated above, undertaken for the Navy, and one of each of the instruments was furnished the engineering division of the Army Air Service:

Kymograph, including constant-speed electric drive, for the measurement of airplane oscillations.

Accelerometer.

Multiple manometer for the measurement of the distribution of pressure.

Photographically recording air-speed meter.

Recording gyro rate-of-turn indicator.

Angle-of-incidence recorder and indicator.

Recording manometer for wind tunnel.

Tilting manometer.

Micromanometer.

An investigation of the development of a fog landing device of the pressure type was conducted for the Army, and report transmitted to their engineering division.

REVISION OF NOMENCLATURE FOR AERONAUTICS.

That aeronautics is a progressive science is demonstrated by the need for periodical revision of the official nomenclature for aeronautics. The committee has previously issued four reports on this subject, the first in 1917, the second in 1918, the third in 1919, and the fourth, known as Report No. 91, in 1920. This latter report, at the time of its issuance, was officially promulgated by the Secretary of the Navy for use throughout the Navy, and by the Chief of the Army Air Service for use in his service.

During the year 1922, a special conference on aeronautical nomenclature was authorized by resolution of the executive committee. The committee officially invited the Chief of the Army Air Service, the Chief of the Bureau of Aeronautics of the Navy Department, the Director of the Bureau of Standards, the Second Assistant Postmaster General, the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the Aeronautical Chamber of Commerce to designate representatives to serve on this special conference on aeronautical nomenclature. This representative group was engaged in a revision of the nomenclature during the spring and summer of 1922. Their work was officially approved by the executive committee on August 31, 1922, and the new nomenclature for aeronautics was authorized to be published as Report No. 157. This report supersedes all previous publications of the committee on this subject.

BIBLIOGRAPHY OF AERONAUTICS.

The bibliography of aeronautics for the years 1910 to 1916 was issued by the committee in 1921. The next presentation of a bibliography of aeronautics will cover the years 1917, 1918, and 1919 in one volume, and will be issued by the committee in 1923. The bibliography for 1920 and 1921 is nearing completion, and will be issued in one volume. Beginning with 1922, it is the policy of the committee to issue the bibliography annually.

Citations of the publications of all nations are included in the languages in which the publications originally appeared. The arrangement is 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.

SAFETY OF PASSENGER-CARRYING AIRPLANES.

Pending the enactment of legislation for the regulation of air navigation, the National Advisory Committee for Aeronautics, in May, 1922, called upon the operators of aircraft to voluntary equip their aircraft to promote the safety and comfort of passengers. The committee stated that the suffering and loss of life attending forced landings of aircraft on land and water could be lessened by making use of existing knowledge and facilities. To that end, the committee urged that large seaplanes should be provided with radio and other signaling equipment, be seaworthy as well as airworthy, and carry at all times fire extinguishers, life preservers, a first-aid kit, and a supply of food and fresh water; and that airplane operating over the land should carry radio or other signaling apparatus, fire extinguishers, and a first-aid kit.

AMERICAN AERONAUTICAL SAFETY CODE.

The project for establishing a safety code for aeronautics has during the past year taken concrete form and the work of formulating such a code is in active progress. The work is being pursued according to the scheme of procedure of the American Engineering Standards Committee, which in 1920 recognized the United States Bureau of Standards and the Society of Automotive Engineers as joint sponsers for this project.

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

Airplane structure, including design, construction, and test.
Power plants for aircrafts, including design, construction, and tests.
Equipment and maintenance of airplanes.
Lighter-than-air craft, including balloons, airships, and parachutes.
Airdromes and traffic rules, including landing fields, airports, signals, and qualifications for pilots.

The sectional committee consists of 32 members and the five subcommittees include 32 members who are not also members of the sectional committee. The following organizations have representation on the sectional committee:

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

The work was started with a synopsis of a safety code and a preparatory draft made up from existing rules already in existence as compiled by various organizations for their own use. During the year the subcommittees have been studying and amplifying this preliminary draft, modifying it to fit experience in practical aviation work and supplementing it with material on subjects not already completely covered. Two of the subcommittees have issued revised drafts for general comment and criticism before taking final action upon them. The work of the other three subcommittees is approaching a similar stage and a meeting of the sectional committee and the five subcommittees is to be held in November, 1922, which will undoubtedly show material accomplishments in this important work.

National uniformity in procedure and practice will undoubtedly be facilitated by this work and such uniformity can better be secured in the early stages of the art before diverse and conflicting local practices and laws become established.

The safety code may be used as a source of well-considered information by agencies undertaking the establishment of airdromes and airways or commercial air services and will also be of assistance to the manufacturers of aircraft.

CANADA'S CONTINUED COURTESY TO AMERICAN AIR PILOTS.

In June, 1920, the committee received from the State Department information to the effect that the Canadian Air Board had promulgated regulations permitting United States qualified aircraft and pilots to fly in Canada until November 1, 1920, on the same basis as if the United States had established air regulations as contemplated under the Convention for the Regulation of International Air Navigation. The Canadian Air Board has repeatedly extended this for successive periods of six months, and it remains a matter of courtesy pending the enactment of a separate treaty with Canada on the subject, because our Government has not ratified the Convention for the Regulation of International Air Navigation. In May, 1921, the Secretary of State requested the advice of the committee on the subject of further extensions of these courtesies by the Canadian Air Board. The committee, by resolution adopted at its meeting held on May 12, 1921, recommended that the State Department accept, on behalf of the Government of the United States, a further extension by six months of the period during which American pilots and aircraft will be permitted to fly in Canada under existing conditions; and that the State Department express to the Government of Canada the deep appreciation of the Government of the United States for the repeated courtesies of the Government of Canada in this matter, and at the same time express the hope that Federal legislation may be enacted at an early date which may lead to a more permanent and definite solution of the matter.

The committee is of the opinion that the existing situation is highly undesirable, and serves to emphasize the need for the early enactment of Federal legislation for the regulation of air navigation, which is one of the recommendations contained in the national aeronautical policy.

REPORT OF THE COMMITTEE ON AERODYNAMICS.

ORGANIZATION.

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

Dr. John F. Hayford, Northwestern University, chairman.
Dr. Joseph S. Ames, Johns Hopkins University, vice chairman.
Maj. T. H. Bane, United States Army.
Dr. L. J. Briggs, Bureau of Standards.
Commander J. C. Hunsaker, United States Navy.
Dr. Franklin L. Hunt, Bureau of Standards.
Maj. H. S. Martin, engineering division, McCook Field.
Prof. Charles F. Marvin, Chief Weather Bureau.
C. I. Stanton, Air Mail Service.
Prof. Edward P. Warner, Massachusetts Institute of Technology, secretary.
Dr. A. F. Zahm, United States Navy.

FUNCTIONS.

The functions of the committee on aerodynamics are as follows:

1. To determine what problems in theoretical and experimental aerodynamics are the most important for investigation by governmental and private agencies.

2. To coordinate by counsel and suggestion the research work involved in the investigation of such problems.

3. To act as a medium for the interchange of information regarding aerodynamic investigations and developments in progress or proposed.

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

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

The committee on aerodynamics by reason of the representation of the various organizations interested in aeronautics is in close contact with all aerodynamical work being carried out in the United States. In this way the current work of each organization is made known to all, thus preventing duplication of effort. Also all research work is stimulated by the prompt distribution of new ideas and new results which add greatly to the efficient conduction of aerodynamic research. The committee keeps the research workers in this country supplied with information on all European progress in aerodynamics by means of a foreign representative who is in close touch with all aeronautical activities in Europe. This direct information is supplemented by the translation and circulation of copies of the more important foreign reports and articles.

The aerodynamic committee has direct control of the aerodynamical research conducted at Langley Field, the propeller research conducted at Leland Stanford University under the supervision of Dr. W. F. Durand, and some special investigations conducted at the Bureau of Standards and at a number of the universities. The investigations undertaken at the Washington Navy Yard aerodynamical laboratory, the Bureau of Standards, and the Massachusetts Institute of Technology are reported to the committee on aerodynamics.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY.

Wind tunnels.—The committee's No. 1 wind tunnel at Langley Field is now operating steadily on aerodynamic research, which consists mainly of airfoil and pressure distribution tests. A third honeycomb, consisting of very small cells, has been added to the tunnel this year at the entrance of the experimental section, greatly improving the quality of the air flow in the tunnel. The automatic speed regulators operate satisfactorily and obviate the necessity for hand regulation during a test. A speed of 30 m./sec. has been adopted as the regular testing speed.

A new compressed-air wind tunnel which the committee is constructing is now practically completed, and in fact preliminary runs have been made with it. This wind tunnel will operate normally at a speed of 25 m./sec. and at a pressure of 20 atmospheres, thus giving conditions equivalent to full scale. The mechanical difficulties of operating the balance inside of the compressed-air tank are considerable, but have been overcome by the use of full electrical control of all adjustments and the balance may be so arranged as to be automatically balancing.

The high-speed wind tunnel at McCook Field has been completed except for the balance and gives velocities of over 200 miles per hour. The large open-air wind tunnel of the Bureau of Standards is now under operation and in light winds gives an air flow of satisfactory steadiness.

The small wind tunnel at the Massachusetts Institute of Technology has been operating for some time with a much higher efficiency than before reconstruction and the large wind tunnel has just been completed. The Washington Navy Yard wind tunnels, under the direction of Doctor Zahm, have carried out in connection with the routine tests a number of very important investigations, a more detailed report of which is given in this report.

Flight section.—During the year the committee has constructed two steel hangars, each 66 feet by 120 feet, for the housing of its experimental airplanes. Facilities are also included for airplane construction and repair which greatly facilitates the carrying out of flight research. There are in commission at the present time three JN4h airplanes, one VE–7, one S. E. 5, one DH–4, and one Thomas Morse MB–3 airplane. In addition to these airplanes, the following airplanes are now being refitted and will be ready for flight within a few months: A Spad 7, a Nieuport 23, a Fokker D–7, and a DH–9, the latter airplane to be fitted up for passenger carrying. During the past year the flying time of the airplanes has been 110 hours, representing 449 flights. Forty-six per cent of the flying time has been confined to actually making measurement in the air. During the year no accidents of any kind have occurred and no forced landings were experienced even though several cross-country flights were made.

Instruments.—The principal pieces of apparatus constructed for the wind tunnel consisted of the automatic balance for use in the compressed-air tunnel, a high-pressure manometer designed to stand a pressure of 20 atmospheres, and a wire balance for the No. 1 wind tunnel for making biplane and triplane tests. The compressed-air wind tunnel balance consisted essentially of a built-up aluminum ring completely surrounding the experimental chamber of the tunnel. The model is supported from this ring and the forces on the ring are measured by balance beams with motor-driven weights. This balance is capable of weighing forces up to approximately 500 kilograms and yet is sensitive to about 5 grams.

During the year there has been designed and constructed an accelerometer which will record accelerations along three mutually perpendicular axes. Another instrument which has been constructed this year is a three component turn meter for recording the angular velocities about three perpendicular axes. This instrument consists of three motor-driven gyroscopes mounted on pivots and restrained from precessing by springs. Any angular velocity therefore causes a precessional force, slightly deflecting the springs and thereby moving a light beam which traces a curve on a moving film. Means are provided for recording all three quantities upon a single film.

A new motor has been developed for driving the film drum of the recording instruments This motor is very small and light, runs at a low speed, and gives perfect synchronization between the instruments. It was originally developed to drive a kymograph where the usual direct-current instrument motor would be too heavy and bulky. The operation of the motor was so satisfactory, however, that it is now being adopted for all of our recording instruments.

A recording angle of attack meter has been developed during the year which consists of a pivoted vane out at the wing tip with electrical means for transmitting motion to a mirror in the recording instrument. The first instrument had some inherent errors, but a second one is now being built which will eliminate them.

A trailing streamline case with a pitot tube in the nose and stabilizing tail at the rear has been developed for recording the angle of flight path and the air speed on instruments inside of the case. The case is lowered on two wires below the airplane which allows us to record these quantities in a place which is entirely free from the influence of the airplane. There has also been constructed a trailing pitot tube of the same type, but with rubber tubes connecting it with the cockpit of the machine so that the installation error of the air speed head on the wing may be determined directly.

A recording statoscope has been constructed for use in some of our researches which has proved quite satisfactory. It consists of a recording air speed meter connected on one side to a large thermos bottle.

Airfoil tests.—A number of airfoil tests have been carried out at high speeds in the N. A. C. A. No. 1 wind tunnel for McCook Field in order to obtain high values of VL. A number of other tests have been made on various airfoils to determine the effect of turbulence and spindle interference on their lift and drag.

An extensive investigation has been carried out this year in order to determine the distribution of pressure accurately over the wing tips of an airfoil. Four wing-tip shapes were tried—rectangular, elliptical, a positive rake, and a negative rake. The tests show that the loading in some cases was very severe but that the wing with the negative rake gave the most satisfactory distribution of load.

There is now being carried out for the Navy Department an extensive investigation on the separate forces on the airfoils of a biplane and triplane. This investigation is to be carried out on five different wing sections and with all combinations of gap and stagger.

Work has been started on measuring the lift and drag of various wing sections on one airplane by gliding flights with the propeller stopped. The methods used eliminate the effect of vertical currents which in the past has made it difficult to obtain consistent results. The sections which are being tried first are the R. A. F. 15, the Eiffel 36, and the U. S. A. TS No. 5.

Stability.—During the year a number of investigations have been carried out in flight on stability. By means of several recording instruments the oscillation of an airplane was studied completely, by the simultaneous determination of the air speed, the altitude, the angle of the machine, the angle of the path, and the angle of attack. The resulting curves of these various quantities were very close to sine curves but with different phase relations.

The effect on the dynamic stability of a change in the longitudinal moment of inertia was carefully studied on one airplane. While the increase in moment of inertia increased the period of oscillation slightly it did not, however, decrease the damping to a measurable extent.

An investigation has been carried out for the engineering division, McCook Field, to determine the magnitude and quality of the small oscillations occurring in flight for several types of airplanes and under all air conditions. A large number of records were taken with the N. A. C. A. kymograph about longitudinal, lateral, and vertical axes in smooth and bumpy air.

The value of the damping in roll has been determined for the JN4h in flight by suddenly applying to the airplane a known moment and measuring the resultant angular velocity. This moment was applied by sending the airplane up with 150 pounds of sand in a box on each wing tip. When a record was ready to be made, the sand in one of these boxes was suddenly released, thereby giving a large unbalanced moment. The resulting angular velocity was then recorded by a recording turn meter.

Controllability.—An investigation has been carried out during the year in the No. 1 wind tunnel on the effectiveness of ailerons when applied to wing sections of varying thickness and plan form. It was found that whereas the thickness of the section had very little effect upon the aileron efficiency that tapering the section in plan form increased the control at high angles of attack.

Some work has been done in flight on finding the cause for a sluggish control on certain airplanes. It was found that this was due to the use of a very thick section for the control surface which left the movable parts in a turbulent wake so that it did not become effective until it had been rotated several degrees from its neutral position. This condition was greatly improved by the use of a much thicker movable portion so that the air followed each side more closely.

Maneuverability.—An extensive investigation of maneuverability has been made during the year in order to find a satisfactory definition of this term and to find definite means of measuring it. The work was all done on a JN4h by measuring the angular velocity produced by definite movements of its controls. It is hoped, however, that the work may be repeated on several other airplanes in order to determine what factors of design influence maneuverability.

The angular velocity was measured on a JN4h while it was undergoing various stunts such as loops, rolls, and spins with a recording turn meter, as there seemed to be no data available on the maximum angular velocity and accelerations experienced in stunting.

Landing and taking off.—Accelerometer control position and air-speed records were taken on a JN4h when taking off and landing in order to see just how the pilot operated the controls under these conditions as well as to see at what speed the airplane usually left and struck the ground. A large number of landings were made in different ways and with different pilots and the resulting data should be of value both to the pilot and to the designer.

An investigation was undertaken for engineering division, McCook Field, in order to investigate the practicability of a pressure device for measuring the proximity of the ground. The device consisted in mounting below the upper and lower wing a static head in such a way that the pressure difference between them was constant for all flight speeds. On approaching the ground, however, a slight pressure difference was shown but it was not found possible to detect the presence of the ground from a height greater than 15 feet.

Stresses in flight.—There is now being carried out an extensive investigation on the distribution of pressure over the wings of a high-speed airplane both in uniform flight and while stunting. The airplane selected for this purpose was a Thomas Morse MB-3 especially strengthened, which was capable of flying as high as 150 miles an hour. Pressures on holes distributed over the surfaces of the wing were recorded on two of the N. A. C. A. multiple manometers. Along with the pressures were also recorded the acceleration, the positions of all controls, and the air speed.

The accelerations along all three axes of an SE-5 while stunting have been determined with the new N. A. C. A. three component accelerometer. This is probably the first time the three accelerations have been simultaneously recorded.

Spheres.—The resistance of a 15 and 20 centimeter sphere was measured in the No. 1 wind tunnel over a large speed range, reaching higher values of VL than have been recorded before. The effect of turbulence on the resistance was also studied.

The resistance of spheres up to 40-centimeter diameter was measured in flight by trailing them on a fine wire below the airplane. While the results showed agreement with the wind tunnel tests beyond the critical point, a separate curve of resistance coefficient for each sized sphere was obtained at low VL's. Some preliminary work was carried out to determine sphere resistance by dropping large rubber balls from a considerable altitude onto a surface of water. If the sphere were light, a uniform velocity was attained quickly; but if heavy, acceleration occurred during most of the fall.

Airships.—The committee is measuring the dsitribution of pressure over the whole envelope and control surfaces of a nonrigid airship for the Navy. Pressure pads are cemented to the surfaces and tubes lead down to multiple manometers in the car. Pressures are measured at different flight speeds and under all conditions of maneuvering in order to get the greatest loads that can occur.

A number of model tests on airships have been made in the wind tunnels at the Bureau of Standards and at the navy yard.

Airplane performance.—The performance was measured of a JN4h with three combinations of wings, and a VE-7 having the same weight, engine, and propeller as the other airplanes It was found that variations in the wing section and area had only a small effect on the performance, while the streamlining and radiator mounting had a large effect.

AERODYNAMIC THEORY.

During the past year the study of the theory of air forces has received particular attention from the National Advisory Committee for Aeronautics. This work is still in progress, since it is considered to be of great importance. The chief aim of technical research work must always be to condense the large number of single and isolated tests into simple methods of computation generally applicable.

Dr. Max Munk, technical assistant of the committee, has succeeded in developing and working out for practice simple methods of calculations covering almost all of the important parts of aerodynamics. These computations will give results comparable in exactness to the actual tests, and included in the solutions are many important problems where formerly little was known for lack of tests. A specific example is the solution of the problem of the forces on an airship in a turn.

The chief result of the past year's work are:

1. The simple elementary calculation of the lift and stability of any wing section as dependent on its shape.

2. The simple elementary calculation of the transverse air forces and their distribution on an airship hull when flying under various conditions involving pitch and yaw or the effects of gusts.

3. Calculation of the lift and stability of biplane wings formed from any wing section. These calculations are based on the characteristics of the basic section. The method is also applicable to triplanes and multiplanes.

4. New and simple rules for the design of efficient air propellers, taking into consideration the air friction on the blades.

5. Rules for the determination of the most economical speed of airships.

The foregoing can immediately be employed with advantage on the corresponding technical problems, and several of them have actually been used. Nos. 1 and 2 will be the chief means of obtaining information under their respective heads.

In addition to papers on these subjects, Doctor Munk has prepared several treatises which are not yet ready for practical application. They form an intermediate stage, to be further improved and simplified, for the critical reduction of experimental data, and thus become useful. These papers are:

6. New method for the calculation of the longitudinal stability of airplanes.

7. Method for the calculation of air propellers.

8. Solution of the problem of the twisted wing with an elliptical plan form. This includes the calculation of the rolling moment produced by ailerons and the damping moment of a wing in roll.

The calculation of the air forces on wing sections.—The wings are the most important part of an airplane, and a thorough knowledge of their properties is a fundamental condition for successful design and systematic improvement. During the past year a practical method has been developed for the computation of the aerodynamic properties of wing sections. Older methods were not practical and not generally applicable. They made use of certain intricate mathematical transformations which can be understood and performed only by specialists in the particular branch of mathematics involved. Furthermore, the older methods could be applied only to certain mathematically shaped wing sections. The various papers in existence on this subject differed chiefly in the shape of the wing sections to which they referred.

It has been shown that the relation between the air forces and the shape of the wing section is by no means as complicated as was formerly thought. On the contrary, lift and moment can be deduced from the shape of the section by elementary methods in a way similar to, and no more difficult than, for instance, the computation of the section modulus from the shape of the section. The lift always consists of two parts. One part is the lift of a plane under the same conditions and having a constant center of pressure at 25 per cent of the chord. This is always known. Only the remaining second part of the lift is to be calculated, and at given velocity of flight and density of air it is constant for all angles of attack. This is exceedingly simple, because the different portions of the wing act independently of each other. It was not realized that the lift at the angle of attack 0° is the sum of the elements of the lift created by the single portions of the wing section, and that these portions of the lift are proportional to the mean height of the section through the chord at each point, and to a simple function of the distance from the leading edge. This is nevertheless the case, and hence a single summation involving some multiplication and addition is all that is necessary to calculate the second part of the lift, which is then added to the first part. The center of pressure of the second part is found in a similar manner, and is usually nearly 50 per cent of the chord. If the angle of attack is increasing, the first part of the lift increases and the second remains constant. This explains in the most elementary and simple manner the phenomenon of the travel of the center of pressure. Two forces act at different points and their ratio changes. Every engineer understands from this why the center of pressure travels and to what degree. For a symmetrical section with equal upper and lower camber the second part of the lift is zero on account of the symmetry, and therefore the calculation gives a constant center of pressure at approximately 25 per cent of the chord, which is in agreement with experience.

This method may be applied to the calculation of the effect of turning an elevator. A comparison has been made between the lift of a given elevator when alone and when behind a stabilizer. It was found that the effect was increased by the stabilizer being placed in front but never more than double the effect even with an infinite stabilizer.

The computation of the transverse air forces on airships.—In connection with the accident to the *R-38* and the design construction of the *ZR-1* in this country, the lack of reliable and general knowledge of the transverse forces on airships became apparent. There were available only a relatively small number of model tests, of doubtful value on account of the large scale ratio, and these did not refer to the case of an airship in a turn.

An investigation of this problem led to the determination of the fact that these forces bear a very simple relation to the shape of the airship. New methods were employed, fundamentally different from those previously employed in aerodynamics, differing from them in their simplicity and in their practical application. The intricate equations for the magnitude of the flow at each point were repalced by a consideration either of the entire energy of the surrounding flow or of its momentum. This new method of attack clears up problems in almost every branch of aerodynamics and corrects a number of erroneous opinions. For instance, for an airship in pitch it results that the unstable couple of the air force is proportional to the volume of the airship. This leads to new and accurate views in regard to the size of fin surface required for stability. The transverse forces on each portion of the airship are simply proportional to the slope of the curve of the cross section when plotted against the length. For an airship in a turn a similar and quite as simple result is obtained. Other results refer to an airship with an elliptical cross section and to the air forces in gusts. In other words, the problems concerning the air forces on airship hulls and the structural stresses produced are now as clear and simple as any other technical problem, and the required data may now be obtained in a short time from simple calculations.

The computation of air forces on biplane wings.—Practically all wing sections are investigated in the monoplane form. This is true for all theoretical investigations of the properties of wing sections and for practically all wind-tunnel tests. Theoretical relations between the air forces on the same wing section when used in the biplane or triplane arrangement were not known. Model tests on this problem gave results which apparently were contradictory. The National Advisory Committee for Aeronautics, therefore, considered it to be of sufficient importance to justify investigation.

A simple relation has been worked out between the forces on a monoplane wing and the forces on the same wing when in the biplane arrangement. The method employed involves the use of an air flow around a pair of airplane wings equivalent to the flow around a biplane section. It is now possible to compute quickly the air forces on biplane wings from the characteristics of the section as a monoplane wing.

The interference of the two biplane wings always diminishes the lift, but not in a fixed ratio. It was found that the lift created by the shape of the section is diminished only half as much as the lift created by the inclination of the wing, or the angle of attack.

The paper on the computation of the air forces on biplane wings also includes the calculation of the travel of the center of pressure. It is found that the two parts of the lift previously mentioned have fixed centers of pressure as for the case of the monoplane, and that the travel of a given center of pressure is the consequence of the change of ratio of the magnitude of the two parts of the lift. The position of the two centers of pressure depends only on the dimensions of the biplane, and not on the wing section itself.

This paper also includes the problem of the distribution of the lift over the upper and lower wings. This knowledge is necessary in the calculation of structural stresses. The effects of stagger and decalage for different wing sections are considered. The influence of the span, "aerodynamical induction," is also taken into account. The paper contains much information which the designer requires in making calculations involving lift, drag, and moment. These calculations are simplified by the use of tables.

Propeller theory.—The present methods of propeller design do not give entirely satisfactory results. The rules derived from experience and those from theoretical investigations do not agree even in the method for obtaining the best efficiency. Much lies in the diameter required and in the distribution of thrust over the blade. At present it is quite difficult to design a propeller to fit exactly a given set of conditions. This indicates that the theory is either incomplete or wrong. Several studies of the propeller problem show that the present theory is incomplete in two respects, and therefore must yield incorrect results. Others have generalized Munk's wing theory to the propeller without noting that the conditions are so different that the theory no longer holds good. The friction of air does not alter the design of a wing, but it is the dominant influence in the design of a propeller, and hence must not be neglected. An exact design for given conditions requires an exact consideration of the inflow, so far only the axial inflow was considered. The propeller theory has been modified so as to also take care of the tangential inflow.

In another paper the important value of the drag coefficient of propeller blades has been derived from a series of free flight tests.

The reduction of this new propeller theory to practice by simplifying it and bringing the necessary coefficients into agreement with the results of experience is now under way. It is probable that the work will lead to the desired goal of enabling the designer to find on the first trial the required diameter for a propeller.

Longitudinal stability of airplanes.—The great amount of work done in connection with the stability of airplanes indicates that information is still lacking.

In a treatise on longitudinal stability of airplanes the problem has been treated from the viewpoint of the engineer rather than that of a mathematician. The paper gives the required information directly from a formula instead of showing a general way only for each single case in which a solution may be obtained. The new method also answers the question as to whether or not the airplane is too stable and it is as undesirable that it be too stable as that it be not stable enough. The old methods of treating the problem were concerned only with the lack of sufficient stability. The new method gives results agreeing better with experience in some points than did the older methods. It is more finished than the older methods, and easier to modify as experimental data are obtained.

The choice of the speed of an airship.—An airship pilot can increase considerably the range of his airship and its economy by always choosing the right speed suitable to the incidental speed and direction of the wind. The problem is then to give general rules for this suitable speed. The most important special case is that of a strong head wind. It was believed by experienced airship pilots that in this case a speed of twice the wind speed is the best speed, thus giving the airship a speed equal to the wind speed relative to the earth. It was found, however, that this is too high a speed, and that rather a speed 50 per cent greater than the wind speed is the most economical, thus giving the airship half the speed of the wind relative to the earth, and lowering the structural stresses, which are particularly dangerous in a storm.

The problem of the twisted elliptical wing.—The technical methods of computing any air force, for example the air force produced by a wind, are founded on an ever-growing system of physical and mathematical truths, more exact, logical, and capable of development than technical aerodynamics. It is essential to develop this scientific aerodynamics, although it will necessarily be confined to a small number of specialists, in order to be able to provide the necessary methods to be used in their application.

The solution of the problem of the twisted wing as presented during the past year is a forward step in the advancement of aerodynamics. The problem was to compute the lift and its distribution on a wing of elliptical plan form and variable angle of attack along the span. This includes indirectly the problem of the wing in roll and the important problem of the wing with displaced ailerons, which can be treated by the consideration of an equivalent distribution of the angle of attack. The particular solution refers primarily to wings with an elliptical plan form, but the results give sufficient information for any other plan form. The calculations are comparatively simple, and consist chiefly in a harmonic analysis. The calculations for several interesting cases are now under way, and the results, when presented in tabular form, will be of direct practical use.

STANFORD UNIVERSITY.

An extensive propeller investigation has been carried on during the past year for the National Advisory Committee for Aeronautics at the Stanford University wind tunnel. The investigation is under the direction of Dr. William F. Durand. A general outline of the scope of the past year's investigations is as follows.

The purpose of (3) is to determine the extent and character of the modifications to be expected due to the existence of obstructions of various forms, as in the case of actual propellers, operating commonly in front of a fuselage or nacelle.

The purpose of (4) is to develop, so far as may be found practicable, the relations between model and full-size forms and the extent to which the accepted laws of comparison require a corrective factor.

Of this general field of study, division No. (1) has been fairly covered in the work of the past three years as represented in N. A. C. A. Reports Nos. 14, 30, and 64, and as reviewed analyzed, and unified in N. A. C. A. Report No. 141.

WASHINGTON NAVY YARD.

Wind tunnels.—Both the 4 by 4 foot and the 8 by 8 foot wind tunnels at the Washington Navy Yard under the direction of Dr. A. F. Zahm of the Bureau of Aeronautics, have been employed continuously on testing of a diversified nature. While a majority of the tests made have had direct reference to naval designs, a considerable amount of research has been carried out. In many cases routine tests have been extended beyond the limits set by immediate requirements so that a large amount of valuable data is being accumulated. Parts of these data are compiled from time to time and issued as Technical Notes. The important test results are usually published by the National Advisory Committee for Aeronautics as Technical Reports.

Air-propeller research.—(1) The examination by means of wind-tunnel test, of a set of propeller models selected with reference to a systematic scheme of distribution over the field of normal forms and proportions.

(2) The examination of the same models as in (1) by means of the airfoil theory of the propeller, with aerodynamic characteristics of the various sections employed, derived by special wind-tunnel tests.

(3) The examination of the same models as in (1), (or a sufficient number to insure adequate representation of the field) when set up and operating in the vicinity of other bodies representative of the nose of a fuselage, the nose and body, airplane wings, etc.

(4) The selection of a few type forms, representative of the field of design covered in (1) and their test full size in the air.

The purpose of (1) is obvious.

The purpose of (2) is to develop a series of coefficients or relative factors between the known aerodynamic characteristics of a series of standard forms of blade cross section, as made up into propeller blades, and the results to be anticipated from direct model test of the forms. With such a set of coefficients, the probable performance characteristics for many intermediate types and combinations of form and proportion could presumably be determined by a relatively simple computation.

Airfoils.—Certain airfoil sections possess considerable aerodynamic merit for a particular use but are either too thin or too thick for efficient wing beams. The *Sloane*, *Albatross*, and *USA-27* are examples. The *Sloane* and the *Albatross* are quite thin, particularly at the rear beam. Modifications have been drawn up in an attempt to thicken these airfoils while retaining their distinguishing aerodynamic characteristics. On test several of these models have shown improvement over the original section. In the same manner the *USA-27* was reduced in thickness, and the resulting airfoil appears to represent an improvement for general use.

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Tests on a series of tapered airfoils supply some interesting data on the effect of taper; in particular, a verification of the assumption the center of pressure movement is substantially uniform at normal angles for all increments of the span.

An investigation on the Handley-Page slotted wing included a determination of the effects of changing the airfoil section, the size, form, location, and number of slots. The investigation also included a study of the use of wing flaps in conjunction with the slots. A maximum lift coefficient of CL = 2.62 was obtained with two slots and a flap setting of about 65°. This value could not be realized in practice.

A study of variable camber airfoils was carried out simultaneously with a study of the modification in camber which would be necessary in practice. That is, starting from a chosen high-speed section the camber was increased in accordance with predetermined mechanical means which left certain irregularities in the airfoil curvature. In a similar manner a high-lift airfoil was used as a basic section and the effect of reducing the camber studied. The data so obtained is sufficient to enable a preliminary design to be made at any time.

Tests were also made on an interesting variable area biplane model supplied by Elias & Bros. This model was in the biplane form with a fixed lower wing. The front portion of the upper wing was also fixed, but the rear portion was attached so as to rotate about a lateral axis passing through the points of attachment of the front struts to the lower wing. Rotating this rear portion therefore changes the camber, angle of attack, and area of the upper wing.

An extensive investigation on lateral control with *USA-27* and *RAF-15* airfoils gave some very remarkable results which will soon be available for use.

Routine tests have been made or are now under way for all naval aircraft. Particular attention has been given to the use of wind-tunnel data in design and performance estimation. Improved methods of test and of model construction yield results which are quite dependable.

This type of testing is the chief function of the Washington Navy Yard and has been developed to suit the needs of design. It is customary to add to each routine test some variation of modification which may be regarded as research and which will prove of value in future design. As an example of this, the fairing used on the trailing edge of the upper wing of a biplane where a section is cut out just above the pilot's cockpit might be made in alternate forms and so tested.

A considerable amount of testing has been carried out on a model of the *ZR-1* rigid airship. This model was made according to the original design which called for a length of about 645 feet. Later, the design was modified by the addition of a 10-meter section at the center of buoyancy. The model was then modified by the addition of a corresponding section and given additional tests. It was found that the forces and moments on either model could be calculated from the corresponding values on the other model and that such calculated values were in remarkable agreement with test values.

The test data included the forces and moments in pitch and yaw for the models bare and fitted with six types of control surfaces, and damping coefficients for the long model with the type of controls finally selected.

Only one model kite balloon was tested during the year. This was designated as the *NU* and is noteworthy for the unusual arrangement of the four fins at 45° to horizontal and vertical.

Tests have been made on a series of C class airship models in which the fineness ratio was varied from 2.0 to 10. That is, the cross sectional area at each station was kept constant while the spacing of the stations was varied. This series supplements the former series in which various amounts of parallel middle body were inserted in the C class model at its center of buoyancy.

Tests have also been made at the request of the National Advisory Committee for Aeronautics on two streamline models supplied by the national physical laboratory. These tests are in connection with the comparison and standardization of all large wind tunnels. The models are to be tested at all wind tunnels having facilities for this work.

A series of radiators, including the Lamblin, have been tested for cooling and resistance at various speeds up to 130 m. p. h. The results are in accordance with former data.

A research on balanced controls has been partially completed. A series of four double-cambered surfaces with aspect ratio of 3 were constructed to represent approximately the elevator and stabilizer of the average airplane. One had a plain elevator and three were fitted with the Handley Page type of balance in varying amounts. Tests have been made for lift, drag, and center of pressure under various conditions. Hinge moments are to be taken later. It was clearly brought out that the effectiveness of this type of control depends on the location of the axis of rotation of the movable part and that there is a sudden decrease in efficiency when the control has moved through an angle large enough to cause a gap between its leading edge and the trailing edge of the fixed surface.

Tests were also made to determine the nature of the air flow over the deck of an airplane carrier. Jets of steam were found suitable for this purpose and were used in preference to the silken threads formerly employed. The steam photographs satisfactorily against a black background.

Tests on target sleeves with varying cone angles indicated that the angle did not, within the limits tested, determine the steadiness of the cone, since all were equally steady. There was, however, some difference in resistance which might be worth consideration when such sleeves are to be towed from aircraft.

One of the most valuable items so far added to the equipment of the Washington Navy Yard wind tunnel is a special vector protractor for drawing vector diagrams directly from test data. The time saved by this device is not only considerable but very important, since it allows the engineer in charge of the tests to follow the results very closely and plan the work accordingly. Much unnecessary testing is saved.

Improvements to the plane table recently installed allow rapid and accurate checks to be made on all models. This feature is very important and is perhaps the deciding factor in making check runs on a model. It was formerly found difficult to check on test readings when considerable time elapsed between runs. If the model be carefully aligned before each run, however, no trouble is found.

A satisfactory air turbine has been designed and constructed for use in tests which involve a study of slip stream effects. No opportunity to run tests of this nature has so far been had, but it is expected to make a research of this type on at least one model airplane in the future.

The operation of the three dimensional balance has been improved considerably by the elimination of certain defects originally present. One of these defects was the shifting of the lift tare due to a temperature effect on the vertical rods. It is a remarkable fact that the new balance pays for itself every year in time saved, when compared with the old Eiffel balance. The actual testing of an airfoil, for example, on the new balance requires about two hours as compared with two days on the Eiffel balance, and the data are in form for immediate use, without further calculation.

A résumé of the developments at the Washington Navy Yard wind tunnels would not be complete without mention of the clip which was designed for holding airfoils under test on the new balance. This clip is in the form of an inverted U with streamline shanks about one-sixteenth of an inch thick. The depths of the shanks and the distance between them are great enough to hold the airfoil rigidly, yet they are of such low resistance that the total correction is of the order of 10 per cent at the minimum drag reading. Furthermore the streamline form does not disturb the flow over the model as shown by repeated tests. The only correction necessary is that for the resistance of the clip.

BUREAU OF STANDARDS.

Wind tunnel investigations.—The Bureau of Standards is now equipped with three wind tunnels, as follows:

No. 1. A tunnel of the N. P. L. type of octagonal cross section, 54 inches between opposite faces, with a speed range from 17 to 90 miles per hour. This tunnel is provided with a modified N. P. L. balance and a second balance designed for very heavy models, which is used chiefly for drag measurements. It is also equipped with a torsional oscillator.

No. 2. A high-speed tunnel of the Venturi type, 36 inches in diameter at the working portion, and of circular cross section. This tunnel has a speed range of from 11 to 180 miles per hour, the maximum speed being attained with an expenditure of 110 horsepower. The tunnel is steady and relatively free from turbulence. It is equipped with a modified N. P. L. balance, but wire-suspension methods have been extensively employed.

No. 3. The third tunnel is 10 feet in diameter in the working portion and is not housed. It has a faired entrance followed by a honeycomb, and the exit is expanded through a cone to a diameter 14.2 feet at the propeller end. A maximum speed of 75 miles per hour is obtained with an expenditure of 250 horsepower. Wind conditions at Washington are so favorable that this tunnel can be used during a large portion of the time. Wire-balance methods have been used exclusively in this tunnel.

In addition to routine testing, the work in these tunnels during the year has included an extended investigation for the Ordnance Department of the aerodynamical characteristics of aircraft bomb models equipped with various fin forms and tail braces. An investigation has also been made for the Air Service regarding the aerodynamical characteristics of var ous airship hulls with and without controlling surfaces. A part of this work has been carried out in the large tunnel with models 1 foot in diameter and has included extended measurements of pressure distribution over an airship model at various angles of attack. In the course of the work it has been found necessary to consider corrections not ordinarily applied, such as the effect of spindle interference on the torque of an airship model. Another investigation for the Air Service has dealt with the protective action of screens on an airship at the entrance of a hangar. This work has been conducted in the tunnels and with larger models in the open, both natural and artificial winds being used. In cooperation with the National Advisory Committee for Aeronautics, determinations have been made of the wind speed in the tunnels independently of Pitot tube measurements. Small hydrogen balloons, having the same average density as the air, were carried through the tunnel by the wing stream in such a manner as to eclipse successively three beams of light which traversed the tunnel at right angles to its axis.

The instant of eclipse was recorded photographically on a rapidly moving film on which time intervals of one one-thousandth of a second were recorded. Speed measurements obtained in this way agreed with those obtained by the standard Pitot tube within one-half of 1 per cent. This work is still in progress.

In cooperation with the Ordnance Department measurements have been made of the head resistance and cross-wind forces on models of projectiles and aircraft bombs at wind speeds up to 1,200 feet per second. The wind stream was supplied by a large centrifugal compressor, the compressed air being allowed to escape continuously through an orifice 12 inches in diameter. The models were supported in this air stream by suitably designed balances of various types. These measurements have been made possible through the courtesy of the General Electric Co.

Aeronautic instruments section.—The aeronautic instruments section of the Bureau of Standards has continued the program of cooperative research and development work on aircraft instruments with the National Advisory Committee for Aeronautics, the Army, the Navy, and other Government departments and private concerns. In addition, a considerable amount of routine testing on instruments has also been carried out.

A second report on the effect on altitude on air-speed indicator readings has been submitted to the National Advisory Committee for Aeronautics. This report gives the results of the tests on Venturi and Pitot-Venturi air nozzles in the low-pressure wind tunnel referred to in last year's report.

The investigation of materials for instrument diaphragms has been continued and a report has been submitted to the National Advisory Committee for Aeronautics for publication. Further information has been obtained concerning the laws of deflection of metallic diaphragms and also in regard to the effect of temperature and humidity on a number of leathers, rubberized and treated fabrics, and rubber dams, materials suitable for nonmetallic diaphragms. In connection with this investigation measurements of the drift and recovery characteristics of metallic ribbons under tension have been continued and extended. An interferometer method is used. A report has been prepared in which is formulated the mathematical treatment of the deflection Bourdon tubes as presented in various published papers. An apparatus for measuring the deflection and hysteresis of such tubes has been developed. Technical Note No. 90 of the National Advisory Committee for Aeronautics on "Sylphon" diaphragms has also been published.

Extensive laboratory tests have been made on over 40 types of airplane compasses including British, French, German, Italian, and American service and experimental instruments. These experiments have been carried out in cooperation with the Bureau of Navigation and the Bureau of Aeronautics, United States Navy. The data are important in connection with the development of improved types of aircraft compasses.

Practically all of the instruments referred to in last year's report as under development for the Army and the Navy have been completed during the past year. Further developments include an electrically driven gyroscopic turn indicator, a temperature compensated barograph which gives a record of the altitude corrected for air temperature, a temperature compensated thermobarograph similar to the above instrument but which gives in addition a record of the air temperature, a combined altimeter and barograph which simultaneously indicates the altitude and makes a record of the same, a new type of statoscope with electrically operated valve, all made in cooperation with the Air Service, United States Army; also an angle of incidence recorder, an electric resistance thermometer for determining the gas and air temperature in lighter-than-air craft, a kymograph for recording airplane oscillations optically, a water speed indicator to show the taking off and landing speeds of airplanes, all made in cooperation with the Bureau of Aeronautics, United States Navy.

Further additions have been made to the already extensive collection of aeronautic instruments maintained by the Bureau of Standards for the convenience of Government officials and others interested in aeronautic-instrument development and many conferences have been held at the Bureau of Standards and elsewhere with Government officials and others interested in aeronautic-instrument development.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

Wind tunnels.—The small wind tunnel has been operating since November, 1921, and has made it possible to run tests at 60 miles per hour with the same power formerly required to reach 40 miles per hour. The large wind tunnel is completed except in minor details and should be in operation about December 15, 1922.

Instruments.—Experiments have been made on wire balances of various forms but none of great originality or complexity. The most notable instrumental addition to the wind-tunnel equipment has been a very satisfactory automatic control for the speed. This operates on the principle of the Tyrrell regulator in conjunction with a static pressure balance similar to Prandtl's. It is very much simpler and cheaper than any automatic regulator previously constructed.

Airfoils.—About 35 airfoils have been tested during the year, most of them for the Army but some for airplane companies. A number of those tested have been tapered in plan and thickness and several have been fitted with flap gears or other variable camber devices. Several Joukowski arifoils were investigated in connection with a study of wing theory. The airfoil work has been very much expedited and will be carried on with increased ease in the future as a result of the production by Mr. W. H. Nichols of an automatic machine for cutting the models. Mr. Nichols' machine produces models with greater accuracy and a higher finish than it has been the usual practice to obtain by handwork and at a saving of cost and time of from 50 to 90 per cent. Models can be cut in any material which will work in a milling machine.

Stability.—Tests on a large number of models have been made under the direction of Prof. Edward P. Warner for the engineering division, McCook Field, and the routine test to which models of all the airplanes are subjected includes an estimate of the statical longitudinal stability. Wind-tunnel results have been found to check well in almost all cases with the reports of pilots

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and have been a guide to modification of design for improved stability and balance. As a phase of stability investigation, in order to determine the reasons for the peculiarities shown by certain airplanes, the downwash has been determined in numerous instances and very peculiar results have been found for the downwash behind the wings of certain monoplanes and biplanes with holes in the upper wing or other irregularity in form. A new apparatus for measuring damping of roll was also constructed and tests made to determine the validity of calculations of damping factor by the ordinary method.

Controllability.—The work along this line has been extended to the measurement of pitching and yawning moments resulting from various elevator and rudder setting on models of a dozen modern military airplanes. All of this work has been carried out for the engineering division, McCook Field. The controllability tests have given data also for the calculations of loads on tail surfaces under given conditions and with particular assumptions as to the manner in which the controls are operated, and the variation between the tail load coefficients for different airplanes has been found remarkably small. An investigation has recently been made also to determine the effect on control of varying the form of the tail surfaces and the length of the fuselage, and the wind-tunnel results in these particulars have been partially checked in similar experiments in free flight. Further checking is hoped for in the near future.

Maneuverability.—The constant attempt in this connection has been to establish a relation between wind-tunnel testing and the behavior of the airplane in flight. A theory has been built up for the determination of the maximum angular velocity of airplanes when turning with vertical bank, taking account of the power of the controls as determined in the wind tunnel. The maximum angular velocity for numerous military airplanes has been predicted in accordance with this theory and it is hoped that it will soon be possible to make measurements in flight for the purpose of checking the calculations from the model test.

REPORT OF THE 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, chairman.
Henry M. Crane, Society of Automotive Engineers.
Harvey N. Davis, Harvard University.
Dr. H. C. Dickinson, Society of Automotive Engineers, acting secretary.
Leigh M. Griffith, Langley Memorial Aeronautical Laboratory.
Capt. G. E. A. Hallett, United States Army.
Lieut. Commander S. M. Kraus, United States Navy.
George W. Lewis, National Advisory Committee for Aeronautics.
C. I. Stanton, Air Mail Service.

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

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

LANGLEY MEMORIAL AERONAUTICAL LABORATORY.

Extension of laboratory facilities.—A new power plant laboratory building is being constructed immediately adjacent to the original building, a specific appropriation of $10,000 having become available for this purpose on July 1. The new building being too small to serve all of the power plant laboratory requirements, it is intended to at this time remove to it only one of the dynamometers from the old building. A new Diehl 75 horsepower electric dynamometer will be installed in the new building. The equipment of the main laboratory machine and instrument shops has been materially increased during the year by the addition of machine tools received from the surplus equipment of the Air Service, so that the shops are now well equipped to take care of the requirements of the entire laboratory. The physical and electrical laboratory equipment has also been considerably augmented.

Fuel-injection engine.—The work on this research has continued from the status reported last year, both in the physical laboratory study of fuel spray characteristics and in the study of pump and injection-valve characteristics in actual engine operation upon the test stand. The development is being carried on at the request and with the support of the Bureau of Aeronautics, Navy Department.

The photographic study of the characteristics of fuel-injection sprays was actively prosecuted only during the first portion of the year, because it early became evident that the original apparatus was inadequate to give the results desired. The first apparatus is completely described in the report for last year, and reference should be made to that report for information regarding the equipment and methods used. Even though the exposure was made by the light of an electric spark produced by the discharge of a Leyden jar or a condenser, and therefore occupied a very brief interval of time, it was found that its duration was too great for the purposes of the study of spray-drop velocity. If it be assumed that the average size of the fuel drop in the spray is of the order of 0.003 inch, and that these drops have an initial velocity approximately equal to that of sound, it is apparent that the drop will travel approximately 0.012 inch during an exposure lasting only one one-millionth of a second, or some four times its own diameter. The drop thus leaves an elongated image on the photographic negative and so produces a general blurring of the whole spray photograph. This elongation of the image also prevents any serious study of the size or shape of the droplets. For these reasons, the length of the exposure should evidently be reduced to the very minimum, certainly to an amount not exceeding one three-millionth of a second. That the drop initially moves at the assumed high velocity is evident from the application of ordinary hydraulic flow formula in the case of high pressure fuel sprays, the jet efflux velocity with a fuel pressure of 6,000 pounds per square inch being about 1,000 feet per second. During the actual tests fuel pressures up to 15,000 pounds per square inch have been used, and it is expected that fuel pressures as high as 10,000 pounds per square inch may be required in the actual operation of fuel-injection engines at the required high speeds. The initial velocity of the drop will of course be rapidly reduced by the air resistance, but may still be one-half of the maximum value at a point 2 inches or so from the nozzle and in the portions of the spray nearest the axis.

With the original apparatus, the exposures were not frequent enough to show the development of the spray characteristics or the velocity of the drops. The highest exposure speed obtained was approximately 1,350 per second, and it was found that the complete development of the high-pressure sprays occupied only three or four exposures. This was not sufficient to clearly define the spray action from the moment of initial appearance of the fuel at the orifice to the time of complete spray formation. Furthermore, the exposure frequency was much too slow to make it possible to follow the progress of individual drops of even small groups of drops, for the purpose of determining their actual velocity. At 1,350 exposures per second, the spray front with a velocity even as low as 100 feet per second will have traveled some nine-tenths inch between exposures, or much too far to permit identification of particular drops or groups of drops. This made it impossible to determine the velocity distribution throughout the spray, so that the study of this feature requires a photographic frequency of certainly not less than 5,000 per second. Furthermore, the illumination secured with the original apparatus was quite insufficient to produce a satisfactory degree of definition, except when the attempt at series photography was abandoned and the various condensers so connected that their combined discharge was dissipated in a single spark. This however prevented the taking of more than one photograph of each fuel spray.

Tests with the original apparatus having developed the above limitations, work with the same was discontinued and the design and development of an entirely new equipment was begun. Owing to the special nature of the requirements, it became necessary to use much more elaborate and powerful apparatus for the intermittent illumination, as well as to entirely revise the method of distributing the images upon the photographic film, so that the production of this new apparatus has proved to be a matter of some magnitude. This new equipment consists essentially of a 100,000 volt 2-kilowatt special transformer which charges a large plate-storage condenser through four kenetrons. This storage condenser is of 0.194 mf. capacity and discharges through a water resistance of about 10,000 ohms to a smaller 0.008 mf. condenser of the same type, which in turn discharges across the magnesium-pointed spark gap of the quenched type which provides the illumination. The system constitutes a kind of electrical intermitent relief valve, the discharge frequency of which is determined by the relation dimensions of the elements. The photographic exposure frequency can by this means be carried far higher than with any mechanical device, so that the desired frequency of 5,000 per second is well within reach.

The energy dissipated in the spark is about 7 joules per spark, as compared to some 1.5 joules with the first apparatus, so that the illumination will be quite ample to secure good photographic exposures with the lens somewhat stopped down. It is of interest in this connection to note that the ordinary magneto or battery system ignition spark used on aircraft and automobile engines dissipates only from 0.03 to 0.10 joule per spark. It is believed that the duration of the spark can be reduced to less than one and one-millionth of a second, although the desired value of one and three-millionth seconds may be obtainable for the quantity of energy dissipated.

The exposures are distributed along a stationary film by means of a revolving mirror, the films being held in a curved holder arranged for daylight loading. The original method of holding the film upon the surface of a high-speed drum had apparently nearly reached its limitations in the first apparatus and was a somewhat difficult manipulation to carry out. The new moving-image method has the advantage of a visual observation on a ground glass. Further the original method required a darkened room, a feature which would be somewhat dangerous in connection with the high voltages required with the new method. Owing to the very special nature of the apparatus it has been impossible to secure delivery of many of the items, so that it will be some time before actual research work with this new equipment can be started. Sufficient has been done, however, to show that no fundamental difficulties are to be expected.

With reference to the other main division of the fuel-injection engine research, viz, the study of fuel pumps and injection valves in an actual operating engine, it may be said that this work has been continuously prosecuted during the year, mainly upon the single-cylinder Liberty test engine mentioned in the report of last year. Although this unit was recognized as being unsuitable for fuel-injection operation, largely because of the flaring combustion chamber form of the Liberty cylinder, no other more suitable engine was available for the purpose. An improvised injection apparatus was installed on this engine consisting of a primary pump which delivered fuel at a constant and controllable pressure of from 50 to 500 pounds per square inch to the suction of a cam-and-spring-operated injection pump mounted on the camshaft and which delivered the charges at pressures up to 6,000 pounds per square inch to a spring-loaded injection valve screwed into one of the regular spark-plug bosses. The conical or fan-shape fuel spray was thrown nearly straight across the cylinder, the top of the special piston being shaped to accommodate the spray to the best advantage. Owing to the unfavorable form of the combustion chamber caused by the necessity of extending the piston head nearly to the cylinder head in order to secure sufficient pressure and temperature for compression ignition (280 to 340 pounds per square inch), which virtually cut off the ring of air between the upper piston wall and the flaring combustion-chamber wall, it was impossible to reach more than about 50 per cent of the air when injection was timed to occur just before top dead center. This necessitated the undesirably early timing of the fuel injection and led to some preignition and detonation. Delaying the injection until after top dead center resulted in excessive after-burning or combustion on the expansion stroke, with consequent drop in power and efficiency.

Notwithstanding these handicaps, the work on this engine has been well worth while and has yielded much valuable experience and data on the general problem. The maximum power secured with Diesel engine fuel oil has been around 27 B. H. P. at 1,800 revolutions per minute, combustion being incomplete and exhaust quite dark. An output of 23 B. H. P. at 1,750 revolutions per minute was obtained with a fuel consumption rate of 0.55 pound per B. H. P. per hour. The combustion was clean and the action regular, but the required early injection led to maximum pressures that were undesirably high. The best economy was obtained at a power output of around 16 B. H. P. at 1,720 revolutions per minute, at which a fuel-consumption rate as low as 0.47 pound per B. H. P. per hour was secured. The mechanical efficiency during this run was 65 per cent, so that the fuel consumption per indicated horsepower is around 0.31 pound per hour. Considering the high mechanical friction of this engine and the other inherent handicaps, this performance is considered satisfactory for the purpose of demonstrating that there is no fundamental reason why fuel-injection engines can not be operated at the high speeds required for aircraft propulsion.

The fuel oil is of the type sold generally in this country as Diesel fuel oil and is distinguished primarily by the combination of low price, high flash point, and low viscosity. The samples used in this work had a flash point of from 175° F. to 220° F., specific gravity of around 0.86, and a Saybolt universal viscosity of from 40 to 50 seconds at 60° F. This type of fuel is therefore quite safe as compared to aviation gasoline or even commercial automobile gasoline.

A new type of fuel pump and several new forms of injection valves are now either completed or nearly so, a new cylinder of improved combustion-chamber form is being designed for the single-cylinder Liberty crankcase, and many minor tests have been made to determine the best forms of the injection-valve elements. A 300 horsepower Maybach engine has been put through calibration tests in its original form and is now being made ready for the installation of fuel-injection equipment to demonstrate the operation of multicylinder engines by this means.

The single-cylinder universal-test engine mentioned in previous reports has been completed but is not yet completely set up on the dynamometer test stand. The necessarily somewhat complicated structure required to give the intended universality of function and control has presented some problems of construction and operation which have delayed the placing of this unit in service. These difficulties are now mainly solved, and it is expected that active work with this most interesting test engine will begin in the immediate future.

Supercharging compressor.—The application of the Roots type blower to the supercharging of aeronautic engines has been further studied during the year. Following the test of the special supercharger blower on the dynamometer, both alone and as connected to a Liberty-12 aircraft engine, the combined supercharger and Liberty unit was mounted in a DH–4 airplane and further tested in flight.

Much difficulty has been experienced in securing a suitable propeller and the incidental delays have prevented the progress in development that was expected. Besides the standard DH–4 propeller, three special propellers have been tried. None of the propellers used have proved satisfactory. The best solution probably lies in the use of an adjustable-pitch propeller, and a propeller of this type is now on order. It is hoped that the development of this device will proceed at such a rate that a reasonably satisfactory adjustable-pitch propeller will shortly be available for installation on the supercharged Liberty engine. Until this is done, the only alternative is the successive trial of ordinary fixed-pitch propellers of such large diameter and pitch that they have to be specially built for the purpose. At the best, this latter procedure is objectionable, since the supercharged engine calls for propeller characteristics which vary with the flying altitude.

This original model of the Roots type supercharger has run a total time of 125 hours, of which some 7 hours were on test flights made since the combined unit was installed in the DH-4 during August. The only important failure in the supercharger was occasioned by the seizing and consequent partial destruction of that end of both rotors next the driving-gear compartment. The cause of this is not definitely known, but the failure is charged to the entrance of some foreign body. New rotors were installed, and advantage was taken of the opportunity to replace the driving gears and some minor parts which had shown signs of wear.

Aside from the difficulty with the propeller equipment, the principal faults devolved in the supercharger-engine unit were: An entirely unexpected amount of air leakage in the ducts between supercharger and engine, difficulty in securing accurate adjustment of the control valve, overheating of the engine due to the insufficient capacity of the standard radiator, and increased rotor contact evidently due to the more elastic mounting as compared to the test stand. The several faults enumerated are being corrected by proper changes in the equipment. Although the supercharger is directly connected to the engine crank shaft, only a slightly elastic fabric coupling intervening, no difficulty has been experienced from acceleration, although the maximum load has been repeatedly applied by suddenly opening the engine throttle at various speeds. Furthermore, the present rotors are made from an aluminum alloy having a specific gravity of 3.2 and it is expected to replace these with rotors made from a magnesium alloy with a specific gravity of 1.8, so that a further margin of reserve is provided against the stresses produced by acceleration.

In the few flight tests which have so far been made, the lack of a suitable propeller, the air leakage from the ducts, and the increased slip due to the increased rotor clearances have combined to prevent the securing of results as favorable as were prophesied upon the basis of the laboratory test stand results. The operation has been satisfactory, however, and it is believed that the application of a suitable adjustable-pitch propeller and additional radiator capacity, plus a tightening and refinement of the mechanical installation will make it possible to secure flight test results fully as favorable as estimated in the report of last year.

The possibility of considerably reducing the weight and increasing the efficiency of the positive displacement blower as applied to the supercharging of aeronautic engines has been given some study and will be energetically attacked during the coming year. It is felt that the weight of the present device can be very materially lowered by reducing the size of the unit and running it at much higher speed. It would then also appear possible to make the rotors of materials better suited to resist the abrading or partial seizure caused by contact with each other or with the surrounding case. Inasmuch as there is ordinarily no sliding contact in this type of compressor, the direct mechanical friction losses are very low when the shafts are mounted upon ball bearings, so that the efficiency of the device is determined largely by the way in which the air is compressed and the amount of slippage by the rotors. Furthermore, it may be that other forms of positive displacement blowers may be inherently better suited for development for this particular purpose. The application of valves or sliding vanes of some form to the ordinary Roots type of blower in order to produce some degree of adiabatic compression and therefore increase the adiabatic compression efficiency, will be carefully investigated.

The high-speed fan-type supercharger mentioned in the report of last year as having been partly developed by the American Expeditionary Forces in Paris during the closing period of the war, has been studied from the standpoint of the development of a rotor blade form which would give a satisfactory life and compression efficiency, and at the same time retain to a maximum degree the advantage of low rotary inertia which alone makes the high-speed direct-driven fan-type compressor of possible interest for this work. Tests made of this device have shown an efficiency somewhat lower than yielded by the positive displacement supercharger, but it is believed that this disadvantage may be eliminated by the installation of suitable guide vanes in the inlet passage and also in the diffusion chamber surrounding the rotor. This machine possesses the inherent advantage of light weight and continuously uniform discharge, so that its development is of great interest.

BUREAU OF STANDARDS.

The aeronautic power plant work carried on at the Bureau of Standards during 1921 and 1922 has been done in cooperation with the National Advisory Committee for Aeronautics, the engineering division of the Air Service, and the Bureau of Aeronautics of the Navy Department.

Altitude tests of aircraft engines.—Altitude tests have been made of two engines, a 300-horsepower aircraft engine, the Packard 1237, and an airship engine of equal horsepower, the Packard 1551. The former engine was tested for the engineering division of the Army Air Service and the latter for the Bureau of Aeronautics of the Navy Department. The test for the Army was made in accordance with the standard altitude laboratory tests of engines outlined by the engineering division and previously followed in tests of the German Maybach and B. M. W., and the American Liberty and Hispano-Suiza engines. The program of tests followed in the case of the Navy engine was quite comprehensive and that department has requested similar tests on a number of engines during the coming year.

An aneroid type of automatic air-fuel ratio control has been developed and calibrated in close cooperation with the engineering division of the Air Service. This work was done in the altitude laboratory using a 300-horsepower Wright aircraft engine.

A series of indicator cards has been taken on an engine when operating under a wide variety of conditions typical of those met with in flight up to altitudes of about 25,000 feet. It is believed that this series of cards is the most complete ever obtained on an aviation engine. This work was carried out under the auspices of the engineering division of the Army Air Service.

The investigation of the effect of changes in compression ratio on aircraft engine performance, started several years ago at the request of the National Advisory Committee for Aeronautics, has been continued and a report will be prepared during the ensuing year.

Ignition.—An investigation has been made of the liability of spark plugs to discharge over the outer surface of the insulator when used under conditions paralleling those in a supercharged engine at extremely high altitudes. This investigation was carried out under the auspices of the engineering division of the Air Service. A compilation has been made of data now available on the voltage required to produce a spark under the various conditions of pressure, temperature, etc., met with in the cylinders of internal-combustion engines. This has been supplemented and the more important conclusions checked by a considerable number of measurements.

During some engine tests the engineering division of the Air Service found that the widening of a spark-plug gap apparently decreased the tendency of the plug to preignite. The bureau was asked to investigate the causes for this behavior. The results of a series of tests indicated that an increase in the gap width of some spark plugs would cause the spark to occur at a different place in the plug and would thus reduce the effective spark advance resulting in an apparent reduction in the tendency to preignite.

As one of the phases of the investigation of combustion, a series of measurements has been made at the rate of combustion of mixtures of permanent gases ignited by sparks of different electrical quality. The results obtained so far give no evidence of any effect on the rate of combustion by even extreme variations in the energy in the igniting spark.

Carburetion.—Several methods for the inherent control of the fuel-air ratio supplied by aircraft carburetors have been tentatively tried out at the request of the engineering division of the Air Service. It is hoped that the possibilities and limitations of these methods can be more completely determined during the coming year.

A short investigation has been made of the effect of changes in the viscosity and density of fuels on the metering of carburetors.

An investigation has been started of the differences in the fuel-air ratios supplied by carburetors when steady and pulsating air streams pass through them. A report giving the preliminary results obtained in this investigation is in preparation for submission to the engineering division of the Air Service under whose auspices this work is being done.

An investigation of the disintegration of liquid jets into drops and the transportation of the drops by a moving air stream is in progress.

Fuels.—At the request of the Bureau of Aeronautics of the Navy Department an investigation has been made to determine the most satisfactory benzol-gasoline blend for use as a fuel in a conventional type of aircraft engine having a compression ration of 6. This involved an estimation of the supply of benzol available, its corrosive properties, the freezing point of benzol-gasoline blends, as well as the metering characteristics of carburetors and the performance of an engine when using these blends as a fuel The Bureau of Mines cooperated in this investigation by preparing an estimate of the benzol available and assisted in the determination of the corrosive properties of a number of samples.

The tendency of a fuel to detonate is of great importance in the determination of its suitability for use in high-compression engines. An analysis based on the work of many experiments has been incorporated in a technical note entitled "The Background of Detonation," and published by the National Advisory Committee for Aeronautics.

From a considerable amount of miscellaneous information obtained incidental to the investigations in the altitude laboratory, it has become apparent that fuel conforming to the present United States Government specifications for aviation gasoline may be so volatile as to form vapor locks in the gasoline, thus making it impracticable for use in a gravity-feed fuel system. This question is being further investigated and the results will be placed before the interdepartmental committee on petroleum specifications.

A short investigation of the effect of slight changes in the method of gasoline distillation (the presence or absence of cotton on the thermometer bulb), as described in specifications, has been made and reported to the interdepartmental committee on petroleum specifications.

Internal combustion engine lubrication.—The greater proportion of the lubrication work of the section has been carried out under the auspices of the engineering division of the Air Service. These investigations, which are in progress, are outlined in the following paragraphs:

(1) The development of apparatus and the methods of manipulation for the more ready use and standardization of the Waters oxidation test. This test promises to be one of the most important means of specifying satisfactory oils for internal-combustion engines.

(2) The investigation of the relations between the values obtained from the present "cold test" and more direct measurements of plasticity at low temperatures for application in predicting the rate at which oils will flow into the suction of engine oil pumps under severe winter conditions.

(3) The investigation of the friction losses in standard types of engine bearings with oils of varying characteristics under the severe condition of heavy loads and low speeds.

(4) The investigation of the action of lubricants under very high unit pressures, such as are encountered in ball bearings and gear teeth.

(5) The development of a method for the examination of finished lubricating oils by means of vacuum distillation and the examination of the properties of the several oil fractions so obtained.

As none of these investigations have been completed, no reports have been prepared, but a report covering all the engine tests on lubricants so far conducted at the bureau has been forwarded to the engineering division of the Air Service.

Cooling problems.—Under the auspices of the engineering division of the Air Service an investigation was initiated to determine the ratio of power dissipated as heat by cooled engine cylinders to the power losses chargeable to their cooling fins. Only preliminary results had been obtained when the request for the investigation was withdrawn by the engineering division.

The cooling characteristics of several types of aircraft radiators have been measured as a continuation of work in previous years. A summary of the investigations at the bureau relative to aircraft radiators, which was compiled during the fiscal year 1921, was sent to press during the current year.

A mathematical analysis of thermal conduction in the fins of air-cooled engine cylinders was completed and submitted to the engineering division of the Air Service. Although this report is a detailed mathematical treatment of the subject, a series of graphic charts are included, which are so arranged as to avoid all necessity for reference to laborious mathematics and can serve as a guide for the designing engineer. This report is being published by the National Advisory Committee for Aeronautics.

An investigation has been started having as its object the determination of methods for the measurement of the distribution of air flow in the several tubes of a honeycomb radiator and around the fins of air-cooled engine cylinders. This work, which is being carried on under the auspices of the National Advisory Committee for Aeronautics, has not yet been completed.

Phenomena of combustion.—This work, which was initiated several years ago, has been continued with the support of the National Advisory Committee for Aeronautics.

Apparatus has been developed for the measurement of flame velocities by two independent methods, one using an adaptation of the Bunsen-Gouy method and the other a transparent constant pressure bomb. The second method has been developed entirely at the Bureau of Standards and promises to yield results of great value.

A large number of measurements of the flame velocity of carbon monoxide and oxygen mixtures have been made at a number of temperatures and with varying amounts of inert gases present as dilutents. The results of the several thousand observations taken have indicated that very reliable generalizations on the reaction rates at high temperatures may be possible. It is hoped to continue the work with fuels of more complex chemical structure and obtain information of a fundamental nature on the phenomena of combustion of internal-combustion engine fuels.

Miscellaneous.—In some of the engine tests made at the bureau the fracture of thin meta diaphragms has been found very convenient as a means of comparing maximum cylinder pressures. The method of mounting the diaphragms and using them to compare maximum pressures has been described in a technical note published by the National Advisory Committee for Aeronautics under the title "Comparing Maximum Pressures in Internal Combustion Engines."

A technical note entitled "The Use of Multiplied Pressures for Automatic Altitude Adjustments" has been submitted to the National Advisory Committee for Aeronautics for publication. This note suggests a method of obtaining automatic adjustments of aircraft-engine carburetor, variable-pitch propeller, etc., which, so far as is known, has never been tried but which appears to have many very desirable characteristics.

NEW ENGINE TYPES.

Several new types of aircraft engines have been designed, and some completed, during the past year, by the Bureau of Aeronautics of the Navy Department and the engineering division of the Army Air Service.

One of the most important advances in increasing the reliability of aircraft engines was the adoption by the Bureau of Aeronautics of the Navy Department of specifications covering a 300-hour endurance test to which all types of engines will be subjected prior to acceptance for service. Previously it has been considered that if an engine could complete a 50-hour endurance test it was quite satisfactory. The Bureau of Aeronautics, realizing that the failure of aircraft engines is directly attributed to the failure of minor parts, initiated a 300-hour endurance test, and as a result engines which were previously considered suitable for only 50 hours of service have been developed to successfully complete tests in accordance with the 300-hour specifications. The first engine to undergo this test was the Aeromarine U–8–D, which was followed a few weeks later by the Packard 1551 airship engine. In June, 1922, the Wright E–2 engine was operated continuously for 250 hours at wide-open throttle, and showed special durability during this run. As a result of the 300-hour continuous-operation tests, it has been possible to develop intake and exhaust valves which will stand 300 hours of continuous operation.

The engineering division of the Army Air Service has been concerned chiefly with the final development of the model W 700-horsepower engine. This engine has so far passed a successful 50-hour endurance test, and has been installed and tested in a model GA–2 airplane. The development of the 1,000-horsepower model W 18-cylinder engine is still being continued, and tests are being made of the component parts, such as cylinder head, pistons, etc.

The Army Air Service has continued the development of the Almen barrel-type engine, and has recently tested the latest model of this engine, which developed 350 horsepower.

Supercharger development has continued along the lines of adapting the exhaust driven type to different engines and the redesigning of the compressor element so as to be geared-driven from the engine. New designs provide for the placing of the supercharger at the side of the engine, and further provide for automatic waste-gate control. Installation and tests have been started of the Sturtevant geared supercharged in the DH–4B airplane, with Liberty engine.

The engineering division has further continued its study of air-cooled cylinders, carburetors, and ignition systems. Tests have been conducted in flight on different types of cooling systems, in cooperation with the Bureau of Standards, with a view to working out a practical method for the design of radiators of given types for known conditions. Fifty-hour service tests have been conducted on the 1921 Liberty engine, the Curtiss CD–12, the Wright model 2 with light pistons, and the Packard 2025 engine.

The Bureau of Aeronautics of the Navy Department has successfully developed an air-cooled engine, with the cooperation of the Lawrance Aero Engine Corporation. The Bureau of Aeronautics developed a set of specifications in June, 1921, and in November of the same year the first experimental engine was delivered to the aeronautical engine testing laboratory at the Washington Navy Yard. A complete and exhaustive study was made to determine the weak points of the engine. Subsequent engines have incorporated in their designs new features which were developed as a result of these tests. The engine is now in production and is known as the Lawrance D–1, developing 220 horsepower at 1,800 revolutions per minute, the total weight being 425 pounds.

The Wright E–2, 180-horsepower engine was subjected to a service test at the Washington Navy Yard, and it was found that there were a few details in the construction which limited its service performance to not more than 50 hours without overhauling. After exhaustive tests the Wright Aeronautical Corporation modified the original E–2 in accordance with Navy specifications and developed the E–3. The changes involved consist of open cylinder sleeves, silchrome valves, aluminum-bronze valve seats, and Kelly metal for the main and connecting-rod bearings. With the new modifications the engine successfully passed a 250 hours' endurance run, developing more than its rated horsepower during the complete test.

The Curtiss CD–12 pursuit engine was modified according to specifications with the cooperation of the Curtiss Aeroplane & Motor Corporation. The redesigned engine was renamed the D–12 and is essentially the same as the original CD–12 engine, having, however, heavier crankshaft, silchrome valves, and a number of other features which make it one of the most reliable engines in the country.

The Aeromarine Plane & Motor Co., with the assistance of the Bureau of Aeronautics, has developed a six-cylinder vertical-in-line engine for lighter-than-air craft. The notable features of this engine, which is known as the U–6–D, are monolithic cylinder construction, removable cylinder sleeves, removable cylinder heads, and a new type valve gear arrangement.

As a result of the excellent performance of the Aeromarine U–6D airplane engine, the Bureau of Aeronautics prepared specifications covering the development of a similar engine of the eight-cylinder type. The eight-cylinder engine has its cylinders set at 60°, develops 220 horsepower at 1,800 revolutions per minute, and was the first engine to complete successfully the standard 300-hour endurance test required by the Bureau of Aeronautics.

The Bureau of Aeronautics contracted with the Packard Motor Car Co. for the design and development of an airship engine to incorporate as its main features reliability and durability. The first engine has been delivered, and passed the standard 50-hour acceptance test. The characteristics of the engine are individual cylinder construction, permitting the removal of any one cylinder without removing the engine from the power car, better ignition system, and low fuel consumption with great durability. The engine has recently successfully completed a standard 300-hour endurance test, developing approximately 340 horsepower at 1,400 revolutions per minute.

The Wright Aeronautical Corporation has developed for the Bureau of Aeronautics a 12-cylinder 60° V engine of 525 horsepower at 1,800 revolutions per minute. This engine was designed principally for installation in torpedo-carrying airplanes. The first engine of this type has completed the standard 50-hour acceptance test, the principal characteristics of the construction being open cylinder sleeves, removable cylinder heads, and aluminum-bronze valve seats.

REPORT OF COMMITTEE ON MATERIALS FOR AIRCRAFT.

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

ORGANIZATION.

Prof. Charles F. Marvin, chairman.
Dr. G. K. Burgess, Bureau of Standards, vice chairman.
Mr. Henry A. Gardner, Institute of Industrial Research.
Prof. George B. Haven, Massachusetts Institute of Technology.
Commander J. C. Hunsaker, United States Navy.
Mr. A. M. Hunt, American Magnesium Corporation.
Dr. Zay Jeffries, Aluminum Co. of America.
Mr. J. B. Johnson, engineering division, Air Service.
Prof. E. P. Warner, Massachusetts Institute of Technology.
Dr. Carlisle P. Winslow, Forest Service.
Prof. H. L. Whittemore, Bureau of Standards, acting secretary.

FUNCTIONS.

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

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

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

Subcommittee on metals (Dr. G. K. Burgess, chairman).
Subcommittee on woods and glues (Prof. H. L. Whittemore, chairman).

Subcommittee on coverings, dopes, and protective coatings (Mr. Henry A. Gardner, chairman).

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

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

SUBCOMMITTEE ON METALS.

General.—The research work of the metallurgical division of the Bureau of Standards during the past year has not been as directly associated with aircraft problems as in the preceding years, although many of the investigations carried out are indirectly related to aircraft problems.

The work of developing steel springs for aeronautic instruments with particular reference to the development of precision altimeters has been continued. A report cooperative with the aeronautic instrument section of the bureau on "Precision Altimeter Design" has been issued (Report No. 126), "Altitude Instruments," National Advisory Committee for Aeronautics).

The study of the physical properties of the A. S. T. M. tentative standard white-metal bearing alloys is of particular value in engine design. This work was reported at the June meeting of the A. S. T. M.

A considerable number of failed or defective parts of aircraft material have been examined to determine the causes and reports submitted. This is illustrated by studies which were made of duralumin shapes from an all-metal seaplane which showed surface markings. A comparative study was also made of two grades of duralumin sheet, one of which welded satisfactorily and the other showing cracks adjacent to the weld.

An investigation is at present in progress to study the resistance to corrosion of various sheet metals, suitable for fuel tanks, by various blended airplane-engine fuels.

The general study of corrosion of steels which is in progress is indirectly associated with aircraft design.

Other work in the division indirectly related to aircraft design which may be stated is:

Wear of steels and other metals.

Revision of Circular 76 on "aluminum and its Light Alloys."

Revision of Circular 80 on "Protective Metallic Coatings for Rust-proofing of Iron and Steel."

Light alloys.—The committee has been particularly interested in the tests on sheet duralumin, including both tensile impact and flexural fatigue tests. One meeting of the committee was held at the Bureau of Standards to witness the methods of conducting the tests and also to witness the test on a full-sized duralumin girder of the Navy airship *ZR-1*.

A comprehensive series of tests on sheet duralumin is being carried out by the Bureau of Standards for the Bureau of Aeronautics, Navy. These include tensile tests, tensile-impact tests, tensile-impact fatigue, and flexural-fatigue tests. Of this series of tests probably the flexural-fatigue tests are the most important since there is comparatively little published information concerning the fatigue characteristics of duralumin. Flexural-fatigue tests of sheet duralumin were chosen in preference to rotating beam or pure tensile-fatigue tests because it was desired to test the material as nearly as possible in the condition in which it is most used. After a number of tentative machines had been built and tried out four machines were constructed which have given satisfactory results. Because of the lightness of the sheet material to be tested the design of these machines has required care in the details of the design involving a study of the free periods of vibration of all the moving parts in order to make it possible to run the machines at reasonable speeds without the appearance of distributing resonant vibrations. In their final form the machines are running at speeds of 350 alternations of stress per minute for the thinnest material (0.02″) up to about 1,200 alternations per minute for the thickest material.

The results so far obtained are very consistent and show no appreciable difference in the fatigue resistance of the various thicknesses of material tested up to 50,000,000 alternations at about 18,000 pounds per square inch maximum fiber stress. There is no indication of the existence of an endurance limit such as was indicated by Professor Moore's test on steel. This result is consistent with information informally received of tests in progress at McCook Field with the rotating beam machines. It is planned to carry this series of tests consistently for all thicknesses of material to 100,000,000 alternations of stress. Because of the limited number of machines available and the necessity of running the thinner materials at relatively low speeds these tests will necessarily take considerable time for completion. Further investigation is desirable to see whether it is possible to develop methods of fatigue testing which can be run at much higher speeds. It would also be highly desirable to see whether the Strohmeyer rise of temperature method and the Smith deflection method can in any way be correlated with the fatigue resistance of duralumin, since a short method of estimating the fatigue resistance of materials is urgently needed.

Tests on duralumin girders.—Tests on 200 duralumin girders, duplicates of those being used in the construction of the new airship *ZR-1*, and including a number of especially designed girders, have been tested at the Bureau of Standards for the Bureau of Aeronautics, Navy Department. These girders have been tested as pin-ended columns under axial loads, axial loads combined with uniformly distributed lateral loads, and as beams under lateral loads alone. The strength of the girders, as shown by these tests, has in no case been lower and in many cases higher than the strength of similar girders constructed abroad for which test results are available. The material from which they are manufactured is of higher strength and more uniform in quality than samples of German girders which have been available for test. The design of the girders is such that the failure in all cases has been due to flexure within elastic limit and consequently the strength of the girders is determined wholly by the modulus of elasticity of the material and the geometrical dimensions. The geometrical dimensions of the girders have been accurately controlled in manufacture so that check results on duplicate girders have been very consistent.

SUBCOMMITTEE ON COVERING, DOPES, AND PROTECTIVE COATINGS.

Extensive investigations have been carried on in connection with the development of fabrics, dopes, and protective coatings at the Bureau of Standards and at the Institute of Industrial Research, the latter under the direction of Mr. H. A. Gardner. The investigations have largely been instituted and financed by the Bureau of Aeronautics, Navy Department.

Gas cell fabric and dopes.—The investigation in connection with a possible substitute for goldbeater's skin has been continued. A great number of different fabrics have been devised for this purpose and extensive tests have been carried out to determine their weathering properties, gas-holding properties, strength, etc. The results to date indicate that the materials proposed for this purpose may also be used on the outer cover cloth of rigid airships and on the envelopes of nonrigid airships. It is believed that the weight of the fabrics now used on nonrigid air ships can be reduced about 50 per cent. The most promising type of substitute for goldbeater's skin is that devised by H. A. Gardner and is now under further investigation, the Bureau of Standards cooperating in this latter investigation.

Certain combinations of rubber and tung-oil varnishes have been found to have low permeability and, to date, have shown satisfactory durability. The varnish may or may not contain pigments or metallic fillers. The minimum allowable weights of each material used are being determined at present, as well as the effect of each in reducing permeability to oxygen and helium.

Experimental work is being continued in order to determine the proportions of rubber and tung-oil varnish necessary to insure flexibility and low permeability at low temperatures. A study of adhesives suitable for attaching goldbeater's skin to fabrics is being made.

A large number of tests have been made in the development of acetate and nitrate dopes, balloon fabric dopes, etc.

The new solvents of cellulose acetate have an elevated boiling point, and may be used as "high boilers" in acetate dopes for all types of aircraft.

At the last meeting of the materials committee a report on acetate dope was presented and a substitute for Navy Department aeronautical specification No. 1–A was recommended to the executive committee for adoption. The new specification has been so revised as to prevent disputes over various patented plasticizing agents which have previously been used.

Investigations have been continued upon paints, aluminum, and other protective coats for fabrics, duralumin, and other metal parts of seaplanes.

SUBCOMMITTEE ON WOODS AND GLUES.

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

The effect of isolated factors on seasoning.—The Forest Products Laboratory has completed during the past year four special drying chambers for this project and a number of drying runs on birch were made. A number of previous dry-kiln runs on ash were reanalyzed and a report prepared. A preliminary analysis of the results secured indicates a very high drying rate at low temperatures and low humidities coupled with great uniformity of drying and the absence of the warping and twisting which would ordinarily be expected.

Causes of brashness of wood.—The preliminary work carried out has shown in the case of spruce, at least, that the thickness of the cell walls is no criterion as to brashness. So far none of the physical characteristics seem to have a definite bearing upon the solution of the problem. However, in the material examined there was very definite evidence that the brashness (beyond that expected of normal material) was caused by the presence of decay. This tentative conclusion is of tremendous importance, and it should be followed up consistently with various other species, especially with microchemical stains, and otherwise to determine the extent to which it is applicable. If the preliminary conclusions are substantiated, it would also be desirable to develop shop methods for the detection of decay.

Development of waterproof glues.—The work of the past year has been mainly upon blood albumen glue and upon a number of new materials not previously studied, such as pyroxylin cements, rubber compounds, and natural gums and resins. The latter work has not been of an intensive character, but was more in the nature of prospecting work to see if these materials had possibilities. Little work was done on casein glue.

The investigation in connection with glues includes a further study of the sizing of glued joints to test the efficiency of the specimen and a study of the variation of pressure and temperature on glued joints, and a study of the properties of commercial waterproof glues.

Use of plywood in wing beams.—The investigation of the use of plywood in this connection has been continued, as it is recognized that plywood has a number of advantages over ordinary wood for use as wing ribs or cheek pieces in wing beams. The data on sheer strength and plywood indicate the desirability of using this material for wing beams with the face grain at an angle of about 45° to the length of the beam. Tests on one type of box beam have been made and the work is now under way to a second type of uniform section.

Development of metal tips to propeller blades.—The work has covered studies on the attachment of brass and monel metal to four species of wood with various sizes of screws. Tests were made on the holding power of individual screws countersunk to various depths and soldered flush with the surface as in recommended tipping practices. These data have furnished an indication of the proper depth of countersinking to afford maximum holding power of the screw. The analysis of the data and preparation of a report on work thus far accomplished was completed June 30, 1922.

Influence of stains, molds, and decay on properties of wood.—It is very evident and generally recognized that decay in advanced stages may reduce the mechanical properties of wood to such an extent as to make it unfit for all strength purposes. However, the extent to which incipient decay can be tolerated, if at all, has not been studied in detail. Such a study presents an exceedingly important, and at the same time very difficult and complicated problem, involving as it does, a thorough study of the fungi, the conditions leading to infection, the effect of kiln drying on the life of the fungi, the chemical changes brought about by fungous action, supplemented by studies of the influence of fungous infection on the mechanical properties. Preliminary tests indicate that ordinary kiln processes destroy some borers and inhibit the growth of various fungi, but these tests are not broad enough nor exclusive enough to be considered final.

Determination of fundamental design factors in lattice, truss, and plywood forms, with special reference to wing-rib design.—It is intended that this study should afford general data establishing, without the need of further test, the most effective type of construction for wing ribs of any given airfoil and chord length.

Tests on many types of wing ribs, with the modifications and improvements that have followed, have given some information of value in the design of wing ribs in general. But before it will be possible to select the proper type of rib for use in a given case and to design highly efficient members without test, it will be necessary to make a fundamental study on standard forms.

PRELIMINARY REPORT OF SPECIAL COMMITTEE ON DESIGN OF AIRSHIP ZR-1.

At the request of the Bureau of Aeronautics of the Navy Department, the National Advisory Committee for Aeronautics appointed a special subcommittee to examine and report on the design and construction of Navy fleet airship No. 1, known as the *ZR-1*. The committee was organized as follows:

Dr. Henry Goldmark, New York City, chairman.
Prof. William Hovgaard, Boston.
Dr. L. B. Tuckerman, Bureau of Standards.
Dr. Max M. Munk, National Advisory Committee for Aeronautics.
Mr. W. Watters Pagon, Baltimore, secretary.

The first meeting was held in Washington, June 19, 1922, and was called to order by Rear Admiral D. W. Taylor, United States Navy, then acting chairman of the executive committee. The committee has held a total of 15 meetings up to November 4, 1922. On that date the chairman of the special committee submitted the following preliminary summary of the committee's findings:

The final report will show that the committee has formed a favorable opinion of the design of the *ZR-1*. It is agreed that in its design all available information on the subject has been applied and that the engineers in charge have used good judgment throughout. The committee approves the policy of basing the fundamental design largely upon that of a successful airship, using the detailed computations as a check upon its strength. The airship selected as a prototype is the German dirigible *L-49*, which embodies the experience obtained in the construction and operation, through a period of over 10 years, of fully 100 successful airships. The calculations which were made are fuller and more detailed than any the committee has found on record elsewhere.

In reaching its conclusions, the committee has considered all elements of design and construction. It has inquired into the quality of the structural materials used and into the methods of construction and finds them satisfactory. Full-sized tests of over 200 typical girders demonstrated that the girders meet the design requirements as to strength. The committee has studied all the methods in use for computing the stresses in rigid airships, and is satisfied that the methods used in the design of the *ZR-1* are sufficiently accurate. The aerodynamic forces, *i. e.*, those exerted by the surrounding air during flight, as to which but little definite information has hitherto been available, were made the subject of special study. The valuable results obtained were used in the investigation of the design.

The committee has further studied the records of rigid airships built in the past. The only known case of a disastrous accident due to structural failure in flight is that of the British airship *R-38* (*ZR-2*). The reasons for this failure have not, in the opinion of the committee, been definitely established. The committee has compared the design of the *ZR-1* with that of the *R-38* from every point of view. Comparative stress calculations indicate that the *ZR-1* is measurably stronger. Certain possible causes other than lack of structural strength for the failure of rigid airships, have been considered, and the committee feels satisfied that in design of the *ZR-1* careful provision has been made to guard against them.

The committee has also examined the prescribed program of tests and trials which are to be carried out before the airship is put into service, and feels that the full execution of this series of scientific tests will furnish a great additional assurance of successful service.

INTERNATIONAL STANDARDIZATION OF WIND-TUNNEL RESULTS.

During the past year, the committee has entered into an agreement with the Aeronautical Research Committee of Great Britain, through the National Physical Laboratory, to arrange for the conduct of certain definite tests in the wind tunnels of the world. The tests are to be made on standard airfoil and airship models which have been designed and constructed by the National Physical Laboratory. The National Advisory Committee for Aeronautics undertook to arrange for the tests in the wind tunnels of the United States. In September, 1922, the committee received from the National Physical Laboratory two airship models for comparative tests. The models have been tested under the direction of Dr. A. F. Zahm, at the aeronautical laboratory of the Washington Navy Yard.

The National Advisory Committee has further authorized the testing of standard models in the United States, the models consisting of three cylinders, having length-diameter ratios of 5 to 1, and four models of U. S. A. 16 wing section, each having an aspect ratio of 6 and the length varying from 18 to 36 inches. The tests on both cylinder models and wing models are to be made over as wide a range of V/L as possible, and to include determinations of lift, drag, and pitching moments every 4° from $-4°$ to $+20°$. The streamline airship models to be tested will have the proportions of the Navy "C" class airship described in a recent report of the Washington Navy Yard wind tunnel. Four streamline airship models, of 4, 6, 9, and 12 inches diameter, respectively, are to be tested, and are to be supported by spindles of lenticular form, the least diameter of spindle being one-twentieth the diameter of the model, and the fineness ratio of the spindle being 3. After completion of the tests in the wind tunnels of the United States, the models will be sent to laboratories in European countries and in Canada for test.

TECHNICAL PUBLICATIONS OF THE COMMITTEE.

The committee on publications and intelligence has recommended the publication of 26 technical reports to be included in the eighth annual report. A summary of the technical reports published in the eighth annual report follows. The reports cover a wide range of subjects on which research has been conducted under the cognizance of the various subcommittees, each report having been approved by the subcommittee concerned and recommended to the executive committee for publication. The technical reports presented represent fundamental research in aeronautics carried on at different aeronautical laboratories in this country, including the Langley Memorial Aeronautical Laboratory, the aeronautical laboratory at the Washington Navy Yard, the Bureau of Standards, the United States Weather Bureau, the Forest Products Laboratory, the Stanford University, and the Massachusetts Institute of Technology.

Considerable technical information is obtained by the committee that is of immediate interest to those interested in experimental and research problems in connection with aeronautics. To make this information immediately available, the National Advisory Committee for Aeronautics has authorized the committee on publications and intelligence to issue a series of "Technical Notes." In accordance with this authorization, the committee has issued 58 technical notes on subjects that were of immediate interest not only to research laboratories but also to airplane manufacturers. A list of the technical notes issued during the year follows the general summary of the technical reports.

The first annual report of the National Advisory Committee for Aeronautics contained Technical Reports Nos. 1 to 7; the second annual report, Nos. 8 to 12; the third annual report, Nos. 13 to 23; the fourth annual report, Nos. 24 to 50; the fifth annual report, Nos. 51 to 82; the sixth annual report, Nos. 83 to 110; the seventh annual report, Nos. 111 to 132, and since the the preparation of the seventh annual report the committee has issued the following technical reports, Nos. 133 to 158.

Report No. 133, entitled "The Tail Plane," by Max M. Munk, National Advisory Committee for Aeronautics.—This report deals with the calculation of the equilibrium, statistical stability, and damping of the tail plane. The author has simplified the present theory of longitudinal stability for the particular purpose of obtaining one definite coefficient characteristic of the effect of the tail plane.

This coefficient is obtained by substituting certain aerodynamic characteristics and some dimensions of the airplane in a comparatively simple mathematical expression. Care has been taken to confine all aerodynamical information necessary for the calculation of the coefficient to the well-known curves representing the qualities of the wing section. This is done by making use of the present results of modern aerodynamics. All formulas and relations necessary for the calculation are contained in the paper. They give in some cases only an approximation of the real values. An example of calculation is added in order to illustrate the application of the method.

The coefficient indicates not only whether the effect of the tail plane is great enough, but also whether it is not too great. It appears that the designer has to avoid a certain critical length of the fuselage, which inevitably gives rise to periodical oscillations of the airplane. The discussion also shows the way and in what direction to carry out experimental work.

Report No. 134, entitled "Performance of Maybach 300-Horsepower Airplane Engine," by S. W. Sparrow, Bureau of Standards.—This report contains the results of a test made upon a Maybach engine in the altitude chamber of the Bureau of Standards, where controlled conditions of temperature and pressure can be made the same as those of the desired altitude.

The results of this test lead to the following conclusions: From the standpoint of thermal efficiency the full-load performance of the engine is excellent at densities corresponding to altitudes up to and including 15,000 feet. The brake mean effective pressure is rather low even at wide-open throttle. This tends to give a high weight per horsepower, inasmuch as the weight of many engine parts is governed by the size rather than the power of the engine. At part load the thermal efficiency of the engine is low. Judged on a basis of performance the engine's chief claim to interest would appear to lie in the carburetor design, which is largely responsible for the excellent full-load efficiency and for its poor part-load efficiency.

Report No. 135, entitled "Performance of B. M. W. 185-Horsepower Airplane Engine," by S. W. Sparrow, Bureau of Standards.—This report deals with the results of a test made upon a B. M. W. engine in the altitude chamber of the Bureau of Standards, where controlled conditions of temperature and pressure can be made to simulate those of the desired altitude.

A remarkably low value of fuel consumption—0.41 pound per b. h. p. hour—is obtained at 1,200 revolutions per minute at an air density of 0.064 pound per cubic foot and a brake thermal efficiency of 33 per cent and an indicated efficiency of 37 per cent at the above speed and density. In spite of the fact that the carburetor adjustment does not permit the air-fuel ratio of maximum economy to be obtained at air densities lower than 0.064, the economy is superior to most engines tested thus far, even at a density (0.03) corresponding to an altitude of 25,000 feet.

The brake mean effective pressure even at full throttle is rather low. Since the weight of much of the engine is governed more by its piston displacement than by the power developed, a decreased mean effective pressure usually necessitates increased weight per horsepower. The altitude performance of the engine is, in general, excellent, and its low fuel consumption is the outstanding feature of merit.

Report No. 136, entitled "Damping Coefficients Due to Tail Surfaces in Aircraft," by Lynn Chu, Massachusetts Institute of Technology, condensed and modified by Edward P. Warner.—The object of the investigation described in this report was to compare the damping coefficients of an airfoil as calculated from a knowledge of the static characteristics of the section with those obtained experimentally with an oscillation. The damping coefficients so obtained, according to the conventional notation, can be considered either as due to pitching or as due to yawing, the oscillation in these experiments being so arranged that the surfaces oscillate about a vertical axis. This is in reality the case when the influence is yawing about the standard Z-axis, but it can also be considered as a pitching motion when the model is so rigged that its standard Y-axis becomes vertical. This horizontal oscillation has the advantage of eliminating the gravity action and avoiding the use of counterweights, whose presence in the wind tunnel is undesirable because of their interference with the air flow. The real point of the investigation was to separate the damping due to rotation from that due to translation. By varying the distance between the center of pressure and the center of rotation on the oscillator, the variation of damping moment can be observed and the rotational and translational effects can be separated.

The report is presented in three parts:

Part I. "Theoretical Damping Coefficients."

Part II. "Experimental Damping Coefficients."

Part III. "Comparison of Calculated and Experimental Damping Coefficients."

Report No. 137, entitled "Point Drag and Total Drag of Navy Struts No. 1 Modified," by A. F. Zahm, R. H. Smith, and G. C. Hill, Bureau of Construction and Repair, United States Navy.—This report deals with the results of tests on struts conducted at the Washington Navy Yard. Two models of the modified Navy strut, No. 1, were tested in the 8 by 8 foot wind tunnel. The tests were made to determine the total resistance end effect and the pressure distribution at various wind-tunnel speeds with the length of the strut transverse to the current. Only the measurements made at zero pitch and yaw are given in this report.

Report No. 138, entitled "The Drag of C Class Airship Hull with Varying Length of Cylindric Midships," by A. F. Zahm, R. H. Smith, and G. C. Hill, Bureau of Construction and Repair, United States Navy.—A model of the C class airship hull, when severed at its major section and provided with a cylindric mid-body of variable length, had its air resistance increased about in proportion to the length of the mid-body up to 3 diameters, and in about the manner to be expected from the increase of skin friction on this variable length. For greater length the drag increased less and less rapidly.

As usual for such models, the drag for any fixed length, at 20 to 60 miles an hour, is accurately of the parabolic form $R \alpha V^n$, and hence the drag coefficient is of the hyperbolic form $C \alpha V^{n-2}$, where n is slightly less than 2.

The variation of C with length is stated in the conclusion.

Report No. 139, entitled "Influence of Model Surface and Air Flow Texture on Resistance of Aerodynamic Bodies," by A. F. Zahm, Bureau of Construction and Repair, United States Navy.—This report is an analysis of the resistance equation

$$D = \rho L^2 V^2 f\left(\frac{VL}{\nu}\right).$$

It is shown that the expression $f\left(\frac{VL}{\nu}\right)$ applies only to a special case of uniform air flow and model surface texture. In order to obtain comparable results under various conditions it is necessary to use a more general form of the resistance equation, such as

$$D = \rho L^2 V^2 f\left(\frac{VL}{\nu}, \frac{l}{L}, \frac{\nu}{V}, \frac{V}{a}, \frac{V^2}{Lg}\right)$$

in which $\frac{l}{L}$ is a measure of the model surface texture, and $\frac{\nu}{V}$ a measure of the air flow texture. These two functions have particular application in the comparison of tests from different aerodynamical laboratories.

Report No. 140, entitled "Lift and Drag Effects of Wing-Tip Rake," by A. F. Zahm, R. M. Bear, and G. C. Hill, Bureau of Construction and Repair, United States Navy.—This report deals with a description and report of tests carried out at the Washington Navy Yard on models of the *RAF-6, Albatross* and *Sloane* airfoils to determine the effectiveness of the conventional wing-tip rake in improving airfoil characteristics. Two degrees of rake were tested on each model; the trailing edge being always longer than the leading edge. The results are compared with the values computed by standard formulae in use at the time the tests were conducted.

Report No. 141, entitled "Experimental Research on Air Propellers, V," by W. F. Durand and E. P. Lesley, Stanford University.—In the previous reports on experimental research on air propellers, by W. F. Durand and E. P. Lesley, as contained in the National Advisory Committee for Aeronautics Reports Nos. 14, 30, and 64, the investigations were made progressively and each without reference to results given in preceding reports and covering only information relating to forms perhaps adjacent in geometrical form and proportion. The report on "Experimental Research on Air Propellers, V," is a review of the entire series of results of the preceding reports with a view of examining through graphical and other appropriate means the nature of the history of the characteristics of operation as related to the systematic variation in characteristics of forms, etc., through the entire series of such characteristics. In reviewing the results a check was made of doubtful points by repetition of tests, to remove inconsistencies where found, and generally to develop for the series of models represented by these tests a consistent set of results as judged by the relation of those for any one model to those for all models adjacent in geometrical form and proportion. The report presents the results of this general analysis and review of the previous series of experimental observations. There is also added a series of nomographic diagrams for the rapid graphical solution of the problems such as are considered in the report. The diagrams have been prepared for both metric and English units.

Report No. 142, entitled "General Theory of Thin Wing Sections," by Max M. Munk, National Advisory Committee for Aeronautics.—In this report Doctor Munk has developed a simple method of calculating the air forces to which thin wings are subjected at small angles of attack, if their curvature is not too great. Two simple integrals are the result. They contain only the coordinates of the wing section. The first integral gives the angle of attack at which the lift of the wing is zero, the second integral gives the moment experienced by the wing when its angle is zero. The two constants thus obtained are sufficient to determine the lift and moment for any other angle of attack. This refers primarily to a two-dimensional flow in a nonviscous fluid. However, in combination with the theory of the aerodynamical induction, and with our empirical knowledge of the drag due to friction, the results are valuable for actual wings also. A particular result obtained is the calculation of the elevator effect. The following is an outline of the subject as treated in this report:

I. Introduction.
II. Calculation of the elevator effect.
III. General formula for any section.
IV. Examples of the zero angle.
V. Thin sections with upper and lower boundaries.
VI. The moment coefficient.
VII. Examples of the moment coefficient.
VIII. Table of the sections investigated.

Report No. 143, entitled "Analysis of Stresses in German Airplanes," by Wilhelm Hoff, Deutsche Versuchsanstalt für Luftfahrt.—This report contains an account of the origin of the views and fundamental principles underlying the construction of German airplanes during the war. The report contains a detailed discussion of the aerodynamic principles and their use in determining the strength of airplanes, the analysis of the strength qualities of materials and in the construction, the calculated strength of air flows and a description of tests made in determining the strength of airplanes.

Report No. 144, entitled "The Decay of a Simple Eddy," by H. Bateman, California Institute of Technology.—The principal result obtained in this report is a generalization of Taylor's formula for a simple eddy. The discussion of the properties of the eddy indicates that there is a slight analogy between the theory of eddies in a viscous fluid and the quantum theory of radiation. Another exact solution of the equations of motion of a viscous fluid yields a result which reminds one of the well-known condition for instability in the case of a horizontally stratified atmosphere.

Report No. 145, entitled "Internal Stresses in Laminated Construction," by A. L. Heim, A. C. Knauss, and Louis Seutter, Forest Products Laboratory.—This report reviews the procedure employed in an investigation of the sources and influence of internal stresses in laminated construction, and discusses the influence of shrinkage and swelling stresses caused by atmospheric conditions upon the tensile strength across grain in laminated construction with special reference to airplane propellers.

The investigation covered three sources of internal stress, namely, the combination of plain-sawed and quarter-sawed material in the same construction, the gluing together of laminations of different moisture contents, and the gluing together of laminations of different densities.

Glued specimens and free specimens, made up under various manufacturing conditions, were subjected to various climatic changes inducing internal stresses and then were tested. The strength of free unstressed pieces served as a standard of comparison for glued pieces and indicated what internal stresses were developed in the glued construction.

The following recommendations as to propeller specifications are made for the species studied:

1. That all propellers be covered with aluminum leaf coating or other approved finish which will prevent, so far as possible, any gain or loss in moisture content of the propeller.
2. That for the most extreme conditions of service propellers be made entirely of quarter-sawed material.
3. That for moderate conditions of service propellers made entirely from plain-sawed stock be permitted, provided they are well protected against moisture change.
4. That for species in which the ratio of radial to tangential shrinkage exceeds 0.75 the mixing of plain-sawed and quarter-sawed stock be permitted in propellers for moderate service, provided that they are well protected against moisture change.
5. That all propeller stock be allowed to come to equilibrium under fixed conditions of temperature and relative humidity before gluing.
6. That density specifications be such as to eliminate all brash material, but not to require matching for density.
7. That moisture content of wood, gluing conditions, and protective coating be such that the moisture content of the propellers will not exceed 15 per cent at any time. Beyond this point animal glue is not likely to give satisfactory results.

Report No. 146, entitled "The Six-Component Wind Balance," by A. F. Zahm, Bureau of Construction and Repair, United States Navy.—Dr. Zahm's report is a description of the six-component wind-tunnel balance in use at the aerodynamic laboratory, Washington Navy Yard.

The description of the balance gives the mechanical details and the method of operation, and is accompanied by line drawings showing the construction of the balance. The balance is of particular interest, as it allows the model to be set up quickly and accurately in roll, pitch, and yaw, without stopping the wind. It is possible to measure automatically, directly, and independently the drag, cross-wind force, and lift; also the rolling, pitching, and yawing moments. It is also possible to make the balance self-recording.

Report No. 147, entitled "Standard Atmosphere," by Willis Ray Gregg, United States Weather Bureau.—This report was prepared at the request of the National Advisory Committee for Aeronautics and discusses the need of a standard set of values of pressure, temperature and density at various altitudes and points out the desirability of adopting such values as are most in accord with actual average conditions, in order that corrections in individual cases may be as small as possible. To meet this need, so far as the United States is concerned, all free-air observations obtained by means of kites and balloons at several stations in this country near latitude 40° N., have been used, and average values of pressure, temperature, and density, based upon those observations, have been determined for summer, winter, and the year, and for all altitudes up to 20,000 meters (65,000 feet). These values are presented in tables and graphs in both metric and English units; and in the tables of densities there are also included values of density for other parts of the world, more particularly for Europe. A comparison with these values shows that, except in the lowest levels, the agreement is very satisfactory. A further comparison with values of density determined from Toussaint's law of temperature decrease, $t = 15 - .0065z$, in which t is the temperature in °C, and z the altitude in meters, indicates very good agreement with those values up to 10 kilometers. It is therefore recommended that the United States adopt Toussaint's formula for values of density up to 10 kilometers and the values presented in the tables for all higher altitudes.

Report No. 148, entitled "The Pressure Distribution over the Horizontal Tail Surfaces of an Airplane, III," by F. H. Norton and W. G. Brown, Langley Memorial Aeronautical Laboratory.—This report contains the results of an investigation of the distribution of pressure over the tail surfaces of a full-sized airplane during accelerated flight for the purpose of determining the magnitude of the tail and fuselage stresses in maneuvering.

As the pressures to be measured in accelerated flight change in value with great rapidity, it was found that the liquid manometer used in the first part of this investigation would not be at all suitable under these conditions; so it was necessary to design and construct a new manometer containing a large number of recording diaphragm gauges for these measurements. Sixty openings on the tail surfaces were connected to this manometer and continuous records of pressures for each pair of holes were taken during various maneuvers. There were also recorded, simultaneously with the pressures, the normal acceleration at the center of gravity and the angular position of all the controls.

The present investigation consisted in measuring on a standard rigged JN4H airplane the distribution of pressure over the whole of the horizontal tail surfaces while the airplane was being put through maneuvers as violently as it was thought safe, including spinning and pulling out of dives.

Report No. 149, entitled "Pressure Distribution over the Rudder and Fin of an Airplane in Flight," by F. H. Norton and W. G. Brown, Langley Memorial Aeronautical Laboratory.—This investigation was carried out by the National Advisory Committee for Aeronautics at the Langley Memorial Aeronautical Laboratory for the purpose of determining the loads which occur on the vertical tail surfaces in flight. The method consisted in measuring the pressures simultaneously at 28 points on the rudder and fin by means of a recording multiple manometer. The results show that the maximun load encountered was 7 pounds per square foot on the rudder and fin, and it is probable that this might rise to 10 pound per square foot in a violent barrel roll; but in steady flight the average loads do not exceed 0.6 pound per square foot. The maximum load on the rudder and fin may occur at the same instant as the maximum load on the horizontal tail surfaces and the maximum normal acceleration. The torsional moment about the axis of the fuselage due to the rudder and fin may rise as high as 250 foot-pounds. The results obtained from this investigation have a direct application to the design of the rudder, fin, and fuselage.

Report No. 150, entitled "Pressure Distribution Over Thick Aerofoils—Model Tests," by F. H. Norton and D. L. Bacon, Langley Memorial Aeronautical Laboratory.—This investigation was undertaken by the National Advisory Committee for Aeronautics in order to study the distribution of loading over thick wings of various types. The unloading on the wing was determined by taking the pressure at a number of holes on both the upper and lower surfaces of a model wing in the wind tunnel. The results from these tests show, first, that the distribution of pressure over a thick wing of uniform section is very little different from that over a thin wing; second, that wings tapering either in chord or thickness have the lateral center of pressure, as would be expected, slightly nearer the center of the wings; and, third, that wings tapering in plan form and with a section everywhere proportional to the center section may be considered to have a loading at any point which is proportional to the chord when compared to a wing with a similar constant section. These tests confirm the belief that wings tapering both in thickness and plan form are of considerable structural value because the lateral center of pressure is thereby moved toward the center of the span.

Report No. 151, entitled "General Biplane Theory," by Max M. Munk, National Advisory Committee for Aeronautics.—This report deals with the air forces on a biplane cellule. The first part of the report deals with the two-dimensional problem neglecting viscosity. For the first time a method is employed which takes the properties of the wing section into consideration. The variation of the section, chord, gap, stagger, and decalage are investigated, a great number of examples are calculated, and all numerical results are given in tables. For the biplane without stagger it is found that the loss of lift in consequence of the mutual influence of the two wing sections is only half as much if the lift is produced by the curvature of the section as it is when the lift is produced by the inclination of the chord to the direction of motion.

The second part deals with the influence of the lateral dimensions. This has been treated in former papers of the author, but the investigation of the staggered biplane is new. It is found that the loss of lift due to induction is almost unchanged, whether the biplane is staggered or not.

The third part is intended for practical use and can be read without knowledge of the first and second parts. The conclusion from the previous investigations are drawn, viscosity and experimental experience are brought in, and the method is simplified for practical application. Simple formulas give the drag, lift, and moment. In order to make the use of the simple formulas still more convenient, tables for the dynamical pressure, induced drag, and angle of attack are added so that practically no computation is needed for the application of the results.

Report No. 152, entitled "The Aerodynamic Properties of Thick Airfoils," by F. H. Norton and D. L. Bacon, Langley Memorial Aeronautical Laboratory.—This investigation was undertaken by the National Advisory Committee for Aeronautics as an extension of N. A. C. A. Report No. 75, for the purpose of studying the effect of various modifications in a given wing section, including changes in thickness, height of lower camber, taper in thickness, and taper in plan form with special reference to the development of thick, efficient airfoils. The method consisted in testing the wings in the N. A. C. A. 5-foot wind tunnel at speeds up to 50 meters (164 feet) per second while they were being supported on a new type of wire balance. Some of the airfoils developed showed results of great promise. For example, one wing (No. 81) with a thickness in the center of 4.5 times that of the U. S. A. 16 showed both a uniformly higher efficiency and a higher maximum lift than this excellent section. These thick sections will be especially useful on airplanes with cantilever construction.

Report No. 153, entitled "Controllability and Maneuverability of Airplanes," by F. H. Norton and W. G. Brown, Langley Memorial Aeronautical Laboratory.—This investigation was carried out by the National Advisory Committee for Aeronautics at Langley Field for the purpose of studying the behavior of the *JN4h* airplane in free flight under the action of its controls, and from this to arrive at satisfactory definitions and coefficients for controllability and maneuverability. The method consisted in recording the angular velocity about the three axes, together with the air speed, control positions, and acceleration. An analysis of the records leads to the following results:

1. Both the maximum angular velocity and maximum angular acceleration are proportional to the displacement of the controls.

2. Both the maximum angular velocity and maximum angular acceleration for a given control movement increase with the air speed, rapidly immediately above the stalling speed, then nearly proportional to the speed.

3. The time required to reach each maximum angular velocity is constant for all air speeds and control displacements for a given airplane.

4. The minimum time required to reverse the direction of an airplane by a steeply banked turn is a rough indication of its general maneuverability.

5. Doubling the lateral moment of inertia of an airplane increases the time required to bank to 90°, with a maximum control angle by only 10 per cent.

6. Controllability has been defined as applying to the moment produced about the center of gravity by the action of the controls, and maneuverability as the resultant motion.

7. A simple method is described for measuring the controllability coefficients, $\frac{dL}{di_z}$, $\frac{dM}{di_y}$, and $\frac{dN}{di_x}$, and the maneuverability coefficients $t\Phi$, $t\theta$, $t\psi$, and $\frac{(V\,min)^2}{g}$.

These results are of practical value, as they give a quantitative means of measuring airplane maneuverability and controllability, which will allow designers to accurately compare the merits of different airplanes.

Report No. 154, entitled "A Study of Taking Off and Landing an Airplane," by T. Carroll, Langley Memorial Aeronautical Laboratory.—This report covers the results of an investigation carried on at the Langley Memorial Aeronautical Laboratory of the National Advisory Committee for Aeronautics for the purpose of discussing the various methods of effecting the take-off and the landing of an airplane, and to make a direct analysis of the control movements, the accelerations, and the air speeds during these maneuvers. The recording instruments developed at the laboratory were used in this test and the records obtained by them were made the basis for a comparative study of the two extreme methods of taking off (the tail-high and the tail-low methods) and of various types of landings. It is believed that this is the first time that an accurate record has been obtained of the movements of the controls durng these important maneuvers, and the records are of further interest from the fact that they were taken synchronously with records of the air speed and accelerations.

The records themselves should be of considerable value to a student pilot in enabling him to visualize the movements of the controls and the consequent effect upon the air speed and acceleration. This opens a very important field for research in the study of the technique of piloting, either of student pilots or for the "refresher" courses or other checking up on pilots in general. With these instruments it will be possible to obtain records of the maneuvering of any pilot in practically any type of airplane, and from the records so obtained any fault or roughness can be immediately noted. This can be done not only in the maneuvers of taking off or landing but in any sort of straight flight or "stunting."

Report No. 155, entitled "A Study of Airplane Maneuvers with Special Reference to Angular Velocities," by H. J. E. Reid, Langley Memorial Aeronautical Laboratory.—This investigation was undertaken by the National Advisory Committee for Aeronautics for the purpose of increasing our knowledge of the behavior of the airplane during various maneuvers and to obtain values of the maximum angular velocities and accelerations in flight. The method consisted in flying a JN4h airplane through various maneuvers while records were being taken of the control position, the air speed, the angular velocity, and the acceleration along the Z-axis. The results showed that the maximum angular velocity about the X-axis occurred in a spin and amounted to 2.43 radians per second, while about the Y-axis the maximum was 0.96 radians per second in a barrel roll. The maximum angular acceleration about the X-axis of −2.10 radians per (second)^2 occurred in a spin, while the maximum about the Y-axis was 1.40 radians per (second)^2 when pulling suddenly out of a dive. These results have direct application to the design of airplane parts, such as propeller shaft and instruments.

Report No. 156, entitled "The Altitude Effect on Air Speed Indicators—II," by H. N. Eaton and W. A. MacNair, Bureau of Standards.—In an investigation described in Report No. 110 of the National Advisory Committee for Aeronautics, "The Altitude Effect on Air Speed Indicators," it was shown that under certain conditions, particularly for the relatively low-speed flight of airships, the viscosity effect was important; but the data obtained were not sufficiently accurate to allow a determination of the general law to be made.

This report describes a more recent investigation, in which the data obtained were sufficiently accurate and complete to enable the viscosity correction to be deduced quantitatively for a number of the air-speed pressure nozzles in common use.

The report opens with a discussion of the theory of the performance of air-speed nozzles and of the calibration of the indicators, from which the theory of the altitude correction is developed. Then follows the determination of the performance characteristics of the nozzles and the calibration constants used for the indicators. In the latter half of the report the viscosity correction is computed for the Zahm Pitot-Venturi nozzles, Army and Navy types, which are the most commonly used air-speed nozzles in the United States. It will be found that the viscosity correction is far from negligible, since under certain conditions it may amount to 20 per cent or more of the indicated air speed. Tables and plots are given to enable the readings of Pitot type and Zahm Pitot-Venturi type indicators to be corrected for any atmospheric conditions which may be experienced by either heavier-than-air or lighter-than-air craft and for air speeds up to approximately 200 miles per hour. Evidence is also adduced tending to show that the effect of the compressibility of the atmosphere on the performance of Venturi air-speed nozzles is not numerically greater than the corresponding effect on Pitot tubes, and can be neglected over the range of flying speeds commonly attained today.

Report No. 157, entitled "Nomenclature for Aeronautics," by the National Advisory Committee for Aeronautics.—This "Nomenclature for Aeronautics" was prepared by a special conference on aeronautical nomenclature of which Dr. Joseph S. Ames was chairman. The conference was authorized by resolution of the executive committee of the National Advisory Committee for Aeronautics on January 26, 1922, and the committee officially invited the Chief of the Army Air Service, the Chief of the Bureau of Aeronautics of the Navy Department, the Director of the Bureau of Standards, the Second Assistant Postmaster General, the Society of Automotive Engineers, the American Society of Mechanical Engineers, and the Aeronautical Chamber of Commerce to designate representatives to serve on the conference on aeronautical nomenclature. This report supersedes all previous publications of the committee on this subject. It is published with the intention of securing greater uniformity and accuracy in official documents of the Government and in so far as possible in technical and commercial publications.

Report No. 158, entitled "Mathematical Equation for Heat Conduction in the Fins of Air-Cooled Engines," by D. R. Harper 3d and W. B. Brown, Bureau of Standards.—The problem considered in this report is that of reducing actual geometrical area of fin-cooling surface, which is, of course, not uniform in temperature, to equivalent "cooling" area at one definite temperature, namely, that prevailing on the cylinder wall at the point of attachment of the fin. This makes it possible to treat all the cooling surface as if it were part of the cylinder wall and 100 per cent effective.

The quantities involved in the equations are the geometrical dimensions of the fin, thermal conductivity of the material composing it, and the coefficient of surface heat dissipation between the fin and the air stream. Several assumptions of a physical nature are thus necessarily involved in making the problem possible of solution. These are set forth in detail, and the limitations which result from them in applying the equations to numerical calculation are carefully pointed out.

An expression for approximate fin effectiveness is developed, based upon simple mathematics and very convenient in form for engineering use. The essence of the paper is an examination into the magnitude of the errors involved in using this expression without correction and a determination of the corrections needed for accurate work. The mathematical expressions involved are quite complicated, including Fourier's series, super-Fourier's series, Bessel functions of zero order of two kinds with imaginary arguments, etc. The results of the work are collected in graphical form in a series of charts, so that the design engineer can use the simple formula first developed and apply to it corrections readily read from the charts, thus avoiding entirely all higher mathematics.

LIST OF TECHNICAL NOTES ISSUED BY THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS DURING THE PAST YEAR.

No. 57. The Caproni Seaplane. By Max Munk, N. A. C. A.

58. Absolute Coefficients and the Graphical Representation of Aerofoil Characteristics. By Max Munk, N. A. C. A.

59. The Dynamometer Hub for Testing Propellers and Engines During Flight. By O. Enoch. Translated from Zeitschrift für Flugtechnik und Motorluftschiffahrt, Vol. X, No. 19, by Paris Office, N. A. C. A.

60. On a New Type of Wind Tunnel. By Max Munk, N. A. C. A.

61. Performance of a Vane-Driven Gear Pump. By R. H. Heald, Bureau of Standards.

62. The Problem of Fuel for Aviation Engines. Lecture given by Prof. Kutzbach, of Dresden, Scientific Collaborator of the Adlershof Aeronautical Laboratory. Translated by Paris Office, N. A. C. A. Edited by W. S. James, Bureau of Standards.

63. The Employment of Airships for the Transport of Passengers. By Umberto Nobile. Translated from Giornale dei Genio Civile, Anno LIX, 1921. By Paris Office, N. A. C. A.

64. N. A. C. A. Recording Air Speed Meters. By F. H. Norton, N. A. C. A.

65. Langley Field Wind Tunnel Apparatus. By D. L. Bacon, N. A. C. A.

66. Göttingen Wind Tunnel for Testing Aircraft Models. By L. Prandtl. Translated from Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft für Luftfahrt, September, 1920. By N. A. C. A.

67. Ground Influence on Aerofoils. By A. E. Raymond, Massachusetts Institute of Technology.

68. The Hydrodynamics of Eddies. By A. Betz. Translated from Zeitschrift für Flugtechnik und Motorluftschiffahrt, July 15, 1921. By N. A. C. A.

69. An Investigation on the Effect of Raked Wing Tips. By F. H. Norton, N. A. C. A.

70. The Effect of Staggering a Biplane. By F. H. Norton, N. A. C. A.

71. Experiments with Slotted Wings. Three articles translated from Zeitschrift für Flugtechnik und Motorluftschiffahrt, July 30, 1921. By N. A. C. A.

72. Aneroid Investigations in Germany. Abstract from the German. By M. D. Hersey, Massachusetts Institute of Technology.

73. The Choice of Wing Sections for Airplanes. By Edward P. Warner, secretary, committee on aerodynamics, N. A. C. A.

74. Mutual Influence of Aerofoil and Propeller. By L. Prandtl. Translated from Ergebmisse der Aerodynamischen Versuchsanstalt zu Göttingen, N. A. C. A.

75. Effects of Verying Relative Vertical Position of Wing and Fuselage. By L. Prandtl. Translated from Ergebmisse der Aerodynamischen Versuchsanstalt zu Göttingen, by N. A. C. A.

76. A Mechanical Device for Illustrating Airplane Stability. By F. H. Norton.

77. A Preliminary Investigation of a New Method for Testing Aerofoils in Free Flight. By F. H. Norton.

78. Impact Tests for Woods. By Bureau of Standards.

79. Effect of Aerofoil Aspect Ratio on the Slope of the Lift Curve. By Walter S. Diehl. Bureau of Aeronautics, Navy Department.

80. The Dead Weight of the Airship and the Number of Passengers that Can be Carried. By Colonel Crocco. Translated from Rendiconti dell 'Istituto Sperimentale Aeronautico, September, 1920. By Paris Office, N. A. C. A.

81. Langley Field Wind Tunnel Apparatus. Part I, Regulators for Speed of Wind Tunnel Drive Motor. Part II, A Vernier manometer with Adjustable Sensitivity. By D. L. Bacon.

82. Notes on the Construction and Testing of Model Airplanes. By Walyer S. Diehl, Bureau of Aeronautics, Navy Department.

83. Theory of the Propeller. By A. Betz. Translated from the German by the N. A. C. A.

84. New Data on the Laws of Fluid Resistance. By C. Wieselsberger. Translated from the German by N. A. C. A.
85. Air-Force and Three Moments for F-5-L Flying Boat. By Aeronautics Staff, Construction Department, Navy Yard, Washington, D. C.
86. Surface Area Coefficients for Airship Envelopes. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.
87. Hydrostatic Test of an Airship Model. By Aeronautics Staff, Construction Department, Navy Yard, Washington, D. C.
88. Report of Test of Oil Scraper Piston Ring and Piston Fitted with Oil Drain Holes. By Aeronatutical Engineering Laboratory, Navy Yard, Washington, D. C.
89. The Choice of the Speed of an Airship. By Max M. Munk, N. A. C. Z.
90. Sylphon Diagrams. Method for Predicting their Performance and Purposes of Instrument Design. By H. N. Eaton and G. H. Keulegan, Bureau of Standards.
91. Notes on Propeller Design—I: The Energy Losses of the Propeller. By Max M. Munk, N. A. C. A.
92. Full-scale Determination of the Lift and Drag of a Seaplane. By Max M. Munk, N. A. C. A.
93. The Background of Detonation. By S. W. Sparrow, Bureau of Standards.
94. Notes on Propeller Design—II: The Best Distribution of Thrust over a Propeller Blade. By Max M. Munk, N. A. C. A.
95. Notes on Propeller Design—III: The Aerodynamical Equations of the Propeller Blade Elements. By Max M. Munk, N. A. C. A.
96. Notes on Propeller Design—IV: General Proceedings in Design. By Max M. Munk, N. A. C. A.
97. N. A. C. A. Control Position Recorder. By F. H. Norton, N. A. C. A.
98. Notes on the Design of Latticed Columns Subject to Lateral Loads. By Charles J. McCarthy, Bureau of Aeronautics, Navy Department.
99. Notes on the Standard Atmosphere. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.
100. Theory of the Slotted Wing. Lecture by A. Betz. Translated from "Berichte und Abhandlungen der Wissenschaftlichen Gesellschaft fur Luftfahrt," No. 6, 1922. By N. A. C. A.
101. Comparison Maximum Pressure in Internal Combustion Engines. By S. W. Sparrow and Stephen M. Lee, Bureau of Standards.
102. Skin Frictional Resistance of Plane Surfaces in Air. Abstract of recent German tests, with notes. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.
103. Simple Formula for Estimating Airplane Ceilings. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.
104. Notes on Aerodynamic Forces—I. Rectilinear Motion. By Max M. Munk, N. A. C. A.
105. Notes on Aerodynamic Forces—II. Curvilinear Motion. By Max M. Munk, N. A. C. A.
106. Notes on Aerodynamic Forces—III. The Aerodynamic Forces on Airships. By Max M. Munk, N. A. C. A.
107. Structural Safety during Curved Flight. By A. Rohrbach. Translated from the German by N. A. C. A.
108. The Use of Multiplied Pressures for Automatic Altitude Adjustments. By Stanwood S. Sparrow, Bureau of Standards.
109. The Twisted Wing with Elliptic Plan Form. By Max M. Munk, N. A. C. A.
110. The Effect on Rudder Control of Slip Stream, Body, and Ground Interference. By H. I. Hoot and D. L. Bacon, N. A. C. A.
111. Stresses Produced on an Airship Flying through Gusty Air. By Max M. Munk, N. A. C. A.
112. The N. A. C. A. Three Component Accelerometer. By H. J. E. Reid, N. A. C. A.
113. Report on General Design of Commercial Aircraft. By Edward P. Warner.
114. Supplementary Report on Oil-Scraper Piston Rings. By H. S. McDewell.

FINANCIAL REPORT.

The appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1922, as carried in the sundry civil appropriation act approved March 4, 1921, was $200,000, under which the Committee reports expenditures and obligations during the year amounting to $193,859.26, itemized as follows:

Salaries (including engineering staff)	$79, 054. 88
Wages	22, 641. 86
Equipment	12, 336. 00
Supplies	31, 336. 62
Transportation and communication	4, 167. 89
Travel	5, 604. 56
Special investigations and reports	35, 825. 00
Construction of buildings	2, 892. 45
Total	193, 859. 26

RESEARCH PROGRAM AND ESTIMATES.

The estimates for the fiscal year 1924, as revised and reduced by the Committee in accordance with request of the Bureau of the Budget, total $353,700. This is the minimum sum which will permit of the prosecution of the Committee's approved research programs. The net appropriation for the current fiscal year is $225,600, including $25,000 for increase of compensation to employees and for the erection of a building. The increase requested in the appropriation for next year is required for the following projects:

Operation of new compressed-air wind tunnel $31, 300

The Committee's compressed-air wind tunnel is the only one in existence and was erected at a cost of approximately $70,000. It offers an opportunity of obtaining fundamental information not otherwise obtainable that will make possible the design and construction of more stable and more efficient aircraft.

Development of commercial type instruments for determiningthe controllability, stability, and maneuverability of airplanes 26, 300

At the present time new-type airplanes are accepted or rejected by the Army and Navy entirely upon reports of personal observation of test pilots. This method is wasteful, as new types in the past have been accepted and built in quantities and later proved unsatisfactory. The carrying out of this investigation will provide an accurate means of graphically recording the true characteristics of airplanes, which will serve to prevent the expenditure of public funds for the quantity production of aircraft that may later prove unsatisfactory in service.

Thorough investigation of the problem of aerodynamic forces on rigid airships 46, 600

It is impossible at the present time, on account of lack of knowledge, to accurately measure the loads or stresses on a rigid airship in flight. The values now used for the aerodynamic forces are mere assumptions, as no investigation has ever been conducted to determine the magnitude of these forces. The military services are now engaged in the construction of two large airships. A thorough investigation of the aerodynamic forces on these airships is essential, not only to increase their safety in flight, but to obtain fundamental knowledge in a way never before attempted, which knowledge is absolutely necessary for the successful development of airships.

Development of a more efficient aircraft engine 44, 500

The greatest single need in aeronautics is the development of a more reliable, more economical aircraft engine. The Committee has conducted a preliminary confidential investigation, from which it is convinced that it is possible to develop such an engine using heavy fuel instead of gasoline, and eliminating the ignition system, valves, and valve-operating mechanism, thereby greatly increasing the safety, reliability, and economy of aircraft engines.

Determination of propeller characteristics in free flight 5, 000

It is not possible, at the present time, with the knowledge available, to design a propeller which will give the most efficient operation for any given set of conditions. The selection of an appropriate type of propeller for a new type of airplane is largely a matter of cut-and-try. This wasteful method can be eliminated by obtaining with a propeller torque dynamometer the actual characteristics of the propeller in flight. This information, when tied in with the fundamental information obtained from wind-tunnel tests, will make possible a method of designing airplane propellers to obtain maximum efficiency for any given condition.

Total additional funds necessary 153, 700

Aeronautics is still in its infancy. No restrictions were placed on its development for military purposes by the arms conference, which fact alone is sufficient to assure its greater relative importance in future warfare, whether over land or sea. The development of aeronautics for civil and commercial purposes as an advance in our civilization is alone sufficient to justify the liberal, intelligent support of the Government. The cardinal principle in the national aviation policy is the development of civil and commercial aeronautical activities in all parts of the country, as the best means of assuring the existence of a healthy, progressive aircraft industry, and a reserve of flyers, which are both necessary for national defense in time of need.

To keep pace with military developments abroad, and to hasten the day of practical commercial aviation in this country, more knowledge is necessary on the fundamental problems of flight. To curtail or postpone the research programs recommended by the Advisory Committee is to deny to the American people necessary knowledge that we are now better organized than ever before to obtain, and will definitely mean the retarding of the development of aviation, civil and military, even though liberal appropriations be made, as they should be, for the Army, Navy, and Postal Air Services.

By formal resolution the National Advisory Committee for Aeronautics has reaffirmed the principle that liberal support of well-directed research is true economy. The Bureau of the Budget, after careful consideration of the committee's estimates, approved four of the five items requiring additional funds for the next fiscal year. But the additional amount allowed by the Bureau of the Budget for the study of these additional problems is wholly inadequate. The committee therefore adheres to its estimate of $353,700 and urges upon the Congress that in a well-balanced budget of national expenditures the importance of the development of aeronautics for all purposes should be recognized, and that liberal support should be given scientific research as the backbone of real progress.

IMPORTANCE OF SCIENTIFIC INVESTIGATION IN A GENERAL AERONAUTICAL PROGRAM.

On the occasion of the organization of the National Aeronautic Association in Detroit October 11–14, 1922, there was held the first National Air Institute, at which Dr. Joseph S. Ames presented a paper on the "Importance of Scientific Investigation in a General Aeronautical Program," which is here reproduced by the committee:

"Before anything can be said on this subject it is essential that we should agree as to what is meant by scientific investigation or scientific research.

"First of all, I do not mean the study of costs of manufacture or production by a skilled man, however scientific his training is for the purpose. I do not mean the work done by an efficiency expert or by an economic expert. I do not mean the processes by which an engineer improves the operation of an engine or applies a new material to an old purpose. I prefer to limit the use of the words to their original meaning as established in university laboratories for physics, chemistry, zoology, etc.

"By a scientific research is meant the investigation by trained scientific men in a properly equipped laboratory of the fundamental phenomena of nature. The study of why an airplane wing has lift, of how the lifting force is distributed over the wing, of how this distribution is affected by changing the shape of the wing, are all scientific researches. They could not be effected except by trained scientists working under the same conditions as in a physical laboratory.

"Modern airplane construction to-day rests upon the classical experiments of Langley, Maxim, the Wright brothers, and Eiffel. The marvelous achievements during the late war would have been impossible without the experimental work done at the National Physical Laboratory of Great Britain and at the Gottingen Aerodynamic Laboratory. The underlying reason why so little progress has been made in design since the war is that there has been so little added to our knowledge of aerodynamics in recent years, owing to the lack of financial support given work of this kind, not simply in this country but in all the countries of Europe.

"In considering any program for the development of aviation the first point to emphasize is the need of stirring the imagination of the people as a whole to make them realize the importance of aviation to them as individuals; the second point is to make the men already interested in aviation appreciate that all progress depends upon the acquirement of knowledge, of new knowledge. This last can be obtained only by long-continued investigations directed by men who know the problems and the methods to be used for their solution.

"The experimental work in this country in aerodynamics is placed by Congress in charge of the National Advisory Committee for Aeronautics, a committee of 12, consisting of officers of the Army and Navy, men at the head of various Government scientific agencies, and professional men from civil life. They have organized various technical subcommittees on aerodynamics, power plants, and materials. Each of these consists of the leading engineers and constructors in the country. Programs of work are arranged and work in progress is discussed by these subcommittees at their monthly meetings. The main committee has at Langley Field, Va., two laboratories, one for aerodynamics and one for power plants; here also is its flying station, where experiments upon actual airplanes in flight are performed. For the support of this all-important work less than $100,000 is available from the appropriation made by Congress. If $500,000 were available each year, it would not be too much. As it is, the amount of knowledge gained in the course of a year is not great. Everyone who is able to picture the future needs of airplanes must see that this underlying study of fundamental principles must be hastened.

"As General Patrick has said, in a letter to the Bureau of the Budget:

'Aeronautics is progressing rapidly and greater technical knowledge is necessary if we are to keep pace with developments abroad. Engineering experimentation conducted by the Army and Navy, and based upon existing knowledge, will contribute measurably to the general development of aviation, but, in my judgment, well directed scientific research, as conducted by the National Advisory Committee for Aeronautics, is essential to substantial progress. The Army Air Service depends upon the Advisory Committee for the study and solution of the more difficult problems.'

"And Admiral Moffett, in writing to the same body, says:

'Scientific research in aeronautics is essential to the continued development of aircraft for naval purposes. The Naval Bureau of Aeronautics relies upon the National Advisory Committee for Aeronautics to conduct the necessary investigations on fundamental problems and to furnish original information and data not otherwise obtainable.

'The increased importance of aircraft in naval warfare is recognized by the General Board of the Navy, and plans for the greater development of naval aviation have been approved. Unless the National Advisory Committee for Aeronautics has the requisite funds and facilities for providing fundamental information, it will not be possible to keep abreast of the development of naval aviation in other countries.'

"It is not too much to say that all the manufacturers of airplanes in America wait from month to month for the information which only the reports from the National Advisory Committee's laboratories can give.

"I shall take three illustrations only of recent researches at Langley Field, so as to make clear the bearing of such work upon the practical side of the matter:

"Every designer and constructor of airplanes must know not simply the total force which the wings and each part of the airplane structure may be subjected to in steady flight and in maneuvers, but also how this force is distributed—where is the greatest load, how does it vary in amount and position in a loop or in a dive, etc. In the same connection, it must be known how this distribution of force is affected by changing the shapes of the various parts—should, for a particular purpose, the wings be square cornered or elliptical, or should they have a rake off, etc. All these questions and practically all others that can be asked about similar matters can now be answered as the result of the committee's investigations. Furthermore, the committee is now prepared to make a complete study of similar problems concerning airships. Until this knowledge is available, the construction of airships must be guided by purely empirical considerations.

"Again, when an airplane is completed and ready for its acceptance tests, the method in use to-day in this country and also in Europe, is to have the machine flown by one or more test pilots. They make a report concerning their impressions; does it respond easily to controls; does it feel stable, etc. These are simply reports of men's reactions, and may or may not have relation to facts. Furthermore, any pilot's impression is in reality a mental comparison between the machine he is operating and one he is accustomed to and may like. Such a comparison is not designed to be favorable to new models or to new devices. The committee has constructed an instrument which records photographically the motion of each of the controls of an airplane and also simultaneously the effect of such motion. The linear and angular velocities and accelerations are obtained from these records, and every question concerning the controllability, maneuverability, and stability of the airplane may now be answered definitely. We have advanced from psychological impressions and guesses to records and facts.

"Lastly, when a new design of airplane or of an airplane part is made, it is customary to construct a model of it, one-twentieth the size or less, and to experiment upon this. The method now in universal use is to suspend the model from suitable balances in a stream of air drawn through a large tube at a velocity of 60 miles an hour or more. The balances register the forces and moments acting on the model. From the results of such measurements one decides whether the original design is good or not. But is one justified in making such a decision? Why should the same laws apply to a little model inside the wind tunnel, as it is called, and to the actual airplane flying freely through the air? Evidently there is ground for grave uncertainty. The committee has perfected a method for obviating this. It has been known from aerodynamic theory for some time that the change in scale, from airplane to its model, could be compensated by compressing the air from ordinary pressure to 20 or 25 atmospheres; as the structure moving through the air is reduced in size from 50 feet to 2 feet, the molecules of the air are brought, by comparison, closer and closer together until their distance apart is one twenty-fifth of what it was originally. The effect of change in scale is thus fully compensated and experiments upon a model in this compressed air have a real meaning. The committee has constructed a large steel tank, 34 feet long and 15 feet in diameter, inside which is placed a wind tunnel with its balances, etc., and in which the air may be kept in a state of high compression. The information to be obtained from the apparatus will be the most important ever given airplane designers.

"These three illustrations should serve to prove that without such experimentation progress in aviation is impossible, and that, therefore, the liberal support of aerodynamic laboratories should be urged most strongly in any aviation program."

A NATIONAL AERONAUTICAL POLICY.

The committee here presents for the consideration of the President and of the Congress a summary of its views and its more important recommendations, which if acted upon as a whole would constitute an effective national aeronautical policy.

AERONAUTICS AND THE PROGRESS OF CIVILIZATION.

Aeronautics, though its development has barely begun, has already exerted a great influence on civilization. Its necessity for military purposes has been definitely established; its adaptation to commercial purposes has just commenced.

No one can safely visualize the future of aeronautics. Its importance in warfare and usefulness in commerce will increase with each passing year. No restrictions were placed on its development for military purposes by the arms conference. This fact alone is sufficient to assure its greater relative importance in future warfare, over both land and sea.

The development of aeronautics in the few years since its first practical introduction has been one of the marvels of our age. The record made by the Air Mail Service during the past year, of nearly 2,000,000 miles without a single fatal accident, is the corner stone of progress for commercial aeronautics. History records that each improvement in the means of transportation and communication between peoples has lightened the burden of man's labors, increased his prosperity, and broadened his knowledge of his fellow man.

The tremendous possibilities that the new science of aeronautics holds for the advancement of the human race can not be realized in a day. Science has only begun to grasp intelligently the fundamental problems involved in its development. With the help of well-directed scientific research, with the imagination of the people fully aroused, and with comprehensive, helpful legislation enacted, aeronautics will begin to yield, in peaceful pursuits, its real contribution to the progress of civilization.

THE NEED FOR FEDERAL AND STATE LEGISLATION.

The National Advisory Committee for Aeronautics reiterates its former recommendations that Federal legislation be enacted to provide for the regulation and licensing of aircraft aviators, the establishment of airways and landing fields, and the general development of civil and commercial aviation. For this purpose the committee again strongly recommends the creation by law of a bureau of civil aeronautics in the Department of Commerce.

From many considerations it is necessary that the Federal Government rather than the States should regulate aviation. Uniformity of rules of the air and of all regulations will facilitate the growth of aeronautical activities in all parts of the country.

The committee on a uniform aviation act of the National Conference of Commissioners on Uniform State Laws, after a thorough study of the problem, has recognized the desirability of Federal control and has reached the conclusion that "the Supreme Court of the United States will almost certainly sustain an all-inclusive Federal act for the regulation of aviation." The same committee recommends the enactment of uniform State laws confined to the "elementary principles concerning the lawfulness of flight, the responsibility for damages, and similar matters." The National Advisory Committee for Aeronautics indorses these views and believes that the enactment of comprehensive Federal legislation supplemented by uniform State laws along the lines indicated is not only desirable but essential if America, the birthplace of aviation, is to become foremost in its development.

THE IMPORTANCE OF SCIENTIFIC RESEARCH.

Substantial progress in the science and art of aeronautics depends primarily upon the continuous acquisition of knowledge. The necessary knowledge can be obtained only by long-continued and well-directed scientific research. The investigation and study of the fundamental phenomena of flight is the definite prescribed function of the National Advisory Committee for Aeronautics. The limited funds and facilities available for research under the committee's direction will slowly yield answers to only the most pressing problems awaiting solution.

Even if civil aeronautical activities were flourishing in all parts of the country and liberal appropriations were made, as they should be, for military and naval aviation, there would be but little, if any, substantial progress in aeronautics unless at the same time the continuous prosecution of scientific research were liberally provided for. This is the most important subject in the whole field of aeronautics. The Army and Navy air services depend upon the Advisory Committee for the scientific study and solution of the more difficult problems. In order that the committee may more effectually aid the advancement of aeronautics and measure up more fully to its own responsibilities, the committee strongly recommends that ample funds and facilities be provided for the complete execution of the research programs that have been approved.

AVIATION FOR NATIONAL DEFENSE.

Aviation has been proven indispensable to both the Army and the Navy. Neither can operate effectively without an adequate air service. What was considered adequate in the World War will not do in the future. There must be a greater proportion of aircraft of all types, and they must all be of the most modern design. For this latter purpose, the committee emphasizes the need for continuous development. As the types and uses of aircraft for military and naval purposes differ in important particulars, the War and Navy Departments must continue to have charge of aircraft development for their respective services. Appropriations for aviation in the Army and Navy should in the interests of national defense be ample, now and at all times, to provide for continuous development. While it is possible that other and older branches of the two military services may have reached the periods of their greatest development, this is certainly not so with aeronautics.

While public sentiment is demanding reduction of the Army and Navy to a prewar basis, it is the judgment of the National Advisory Committee for Aeronautics that it does not demand that the air services of the Army and Navy be so reduced, nor even that they be reduced proportionately with other branches of the Army and Navy. The novelty of warfare in the air, the lack of civil aeronautical activities upon which to draw in time of need, the rapid developments in aeronautics that are taking place in other countries, the absolute necessity of aviation for national defense, and other factors all combined, have led the people to the support of a policy of progress and development in the aeronautical branches of the Army and Navy, however much they may insist upon the curtailment of other military and naval expenditures.

HELIUM FOR AIRSHIPS.

The exclusive possession of helium-bearing gases by the United States is a national asset. The possession of this asset imposes two distinct responsibilities upon the Nation: First, that the method of extraction of helium be improved and the cost thereof lessened, with a view to its use in all future American airships; second, that the limited known supply, now escaping at the rate of 500,000,000 cubic feet per year, or an amount sufficient to fill 250 large airships, be conserved for future use by the American people.

Reliable assurances have been given that with existing knowledge the present cost of production can be greatly reduced if the extraction of helium were to be undertaken on a production instead of an experimental basis. But, whether or not we now undertake to realize the advantages which the use of helium affords, the committee unqualifiedly recommends that Congress provide for the conservation of existing natural resources, through the acquisition and sealing by the Government of the largest and best helium fields.

THE AIR MAIL SERVICE.

The Air Mail Service is the pioneer agency in the world for the successful practical application of aviation to useful pursuits of peace. Originally inaugurated as an experimental laboratory to encourage the development of civil aviation, it has not only been successful in that respect, but is now on the threshold of a wonderful achievement. There is little doubt but that the air mail will soon link our Atlantic and Pacific coasts in 28 or 30 hours' service as a regular performance. Its recent record of more than 12 months' operation in all kinds of weather and over all kinds of country, flying nearly 2,000,000 miles without a single fatality, serves to demonstrate in a forceful manner the safety and utility of airplanes under competent organization and control. In the judgment of the National Advisory Committee for Aeronautics the Air Mail Service is now just beginning to yield the substantial results for which it was established, and there should no be now question as to the advisability of its continuance.

AEROLOGICAL SERVICE ALONG AIRWAYS.

When transcontinental airways are established it will be necessary for the Weather Bureau to provide aerological service along such airways as they are established. The committee recommends, therefore, that in the consideration of any future legislation for the encouragement of civil aviation adequate provision of law and appropriation be made for the extension of the aerological work of the Weather Bureau, without which there can be no safety in the air nor success in commercial aviation.

FEDERAL AID NECESSARY.

The increasing relative importance of aircraft in warfare is alone sufficient to justify the expenditure of public funds to aid the development of air navigation on a commercial bais. It has been the history of civilized nations that governments have found it necessary to aid in the development of means of transportation. The wonderful growth of transcontinental railroads in America was greatly aided by land grants from our Government. Progressive European nations are spending large sums, through direct and indirect subsidies, for the promotion of civil and commercial aviation. The practical development of aviation in America will not be realized until the Government gives intelligent support and effective aid, principally by regulating and licensing and by cooperation with the States in the establishment of airways and landing fields.

Respectfully submitted.

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

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