TWENTY-FOURTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1938

INCLUDING TECHNICAL REPORTS

NOS. 612 TO 644

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TECHNICAL REPORTS

LETTER OF TRANSMITTAL

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 transmit herewith the Twenty-fourth Annual Report of the Committee covering the fiscal year ended June 30, 1938.

Franklin D. Roosevelt.

The White House,
January 9, 1939.

LETTER OF SUBMITTAL

NATIONAL ADVISORY COMMITTEE, FOR AERONAUTICS,
Washington, D. C., December 17, 1938.

MR. PRESIDENT:

In compliance with the provisions of the act of Congress approved March 3, 1915 (U. S. C., title 50, sec. 153), I have the honor to submit herewith the Twenty-fourth Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1938.

The past year has been one of continued progress in the technical development of both military and commercial aircraft. In the light of world events, it has become increasingly important that American aircraft, both military and commercial, have the highest possible efficiency. In the development of air strength for national defense, and in the extension of commercial trade routes in the air, a definite advantage will lie with that nation that has the most efficient aircraft.

Up to the present, the United States has led in the technical development of aircraft. The major reason for that leadership has been the farsighted support of organized scientific research in the Committee's laboratories at Langley Field, Va. American leadership is now threatened by the great expansion of research facilities in other nations. The Committee is making an earnest study of the problem presented by this condition, and is determined to make every effort to provide the scientific data necessary to keep America first in the technical development of aircraft. This will undoubtedly require material expansion in research facilities to keep pace with the accelerated research progress abroad. Upon the completion of studies now in progress, a special report on this subject will be submitted.

Respectfully submitted.

JOSEPH S. AMES, *Chairman.*

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

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

HEADQUARTERS, NAVY BUILDING, WASHINGTON, D. C.

LABORATORIES, LANGLEY FIELD, VA.

Created by act of Congress approved March 3, 1915, for the supervision and direction of the scientific study of the problems of flight (U. S. Code, Title 50, Sec. 151). Its membership was increased to 15 by act approved March 2, 1929. The members are appointed by the President, and serve as such without compensation.

TECHNICAL COMMITTEES

AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
AIRCRAFT MATERIALS
AIRCRAFT STRUCTURES
AIRCRAFT ACCIDENTS
INVENTIONS AND DESIGNS

Coordination of Research Needs of Military and Civil Aviation

Preparation of Research Programs

Allocation of Problems

Prevention of Duplication

Consideration of Inventions

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

LANGLEY FIELD, VA.

Unified conduct, for all agencies, of scientific research on the fundamental problems of flight.

OFFICE OF AERONAUTICAL INTELLIGENCE

WASHINGTON, D. C.

Collection, classification, compilation, and dissemination of scientific and technical information on aeronautics.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

MEETING, OCTOBER 20, 1938.

Left to right: Hon. C. M. Hester; Capt. S. M. Kraus, U. S. N.; Brig. Gen. A. W. Robins, U. S. A.; Dr. L. J. Briggs; Dr. E. P. Warner; Dr. Orville Wright; Dr. Joseph S. Ames, Chairman; Dr. C. G. Abbot; J. F. Victory, Secretary; Rear Adm. A. B. Cook, U. S. N.; Hon. E. J. Noble; Dr. Vannevar Bush; Dr. J. C. Hunsaker; Dr. G. W. Lewis, Director of Aeronautical Research. (Absent: Col. C. A. Lindbergh and Maj. Gen. H. H. Arnold, U. S. A. One vacancy: U. S. Weather Bureau.)

TWENTY-FOURTH ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 15, 1938.*

TO THE CONGRESS OF THE UNITED STATES:

In accordance with the act of Congress approved March 3, 1915 (U. S. C., title 50, section 151), which established the National Advisory Committee for Aeronautics, the Committee submits herewith its Twenty-fourth Annual Report for the fiscal year 1938.

Overshadowing influence of air power.—The crisis in Europe in the fall of 1938 brought forcibly to world-wide attention the overshadowing influence of air power in international affairs. The realization that aircraft had been built in great numbers and developed to a point where they are capable of operating at high speeds over long distances with large bombing loads thrust upon the world a new concept of national defense. The imminent prospect of noncombatants being subject to indiscriminate attack by aircraft stirred the imaginations and fears of all peoples. The sudden and rather general appreciation of the potentialities of modern air power is the most significant event that has occurred in modern times in connection with strengthening the desires of peoples to avoid war.

The Committee in its annual report for 1924 discussed the increasing importance of aircraft in warfare in the light of the failure of the Limitations of Armaments Conference, held in Washington in 1921–22, to place any limitations upon the use of aircraft in warfare. The Committee at that time pointed out some of the appalling possibilities in the indiscriminate use of aircraft. These included not merely air attacks on recognized military objectives, but also attacks on civilian populations. Subsequent attempts by international conference to minimize the consequences to noncombatants have been without avail.

The Committee, therefore, in the interests of peace and security, recommends the development by the Army and Navy of adequate and effective air arms, and the early adoption of a sound program for expanding the productive capacity of the aircraft industry and for training the necessary active and reserve personnel.

Relation of aeronautical research to national defense.—The history of 1938 bears witness as to how a nation in the space of a few years, by concentrating much of its scientific research and industrial resources, on the development of air power, could gain, for the time being, a dominating position. The continued effectiveness of an air arm, however large, is dependent on constant progress in the new engineering science of aeronautics. The efficiency of an air force is in approximately direct proportion to the emphasis that is placed on scientific research in aeronautics, combined of course with engineering development, production, and training.

What has happened during the past few years that has so greatly increased the relative importance of air power in the national defense programs of nations? Of first importance are the contributions of research laboratories which have so greatly extended the speed, range, and carrying capacity of aircraft. Methods of construction also have been improved. These have included a trend toward designs of aircraft that would permit of duplicating many of the parts by the use of machinery, and thus has an approach to mass production been made. Although the designs of military aircraft of the different categories and the manufacturing methods employed in the United States have not differed widely from those in Europe, nevertheless in Europe the larger quantities manufactured have accelerated progress toward mass production methods.

Once a nation has embarked upon a program intended to develop its air strength to maximum effectiveness, the provision of adequate laboratory research facilities and the training of skilled research personnel become of fundamental importance. The major European powers at the present time are engaged on relatively large aircraft building programs which are being prosecuted under feverish pressure. Mere numbers of aircraft, however, are not in themselves sufficient for an adequate modern air force. It is of even greater importance that the aircraft be of the most effective design. The advances in aeronautical science are so rapid that assiduous attention to the subject cannot with safety be suspended for even a brief period. Where a few years ago we were pleased with speeds of around 200 miles per hour, we now seek to attain with fully loaded service airplanes speeds of 300 and 400 miles per hour. It is not only good policy from a financial consideration, but also vital from the standpoint of national defense, that American aircraft have a performance equal or superior to that of a potential enemy. This principle necessitates serious consideration of American aeronautical research and experimental facilities.

The President and the Congress of the United States have wisely supported what has heretofore been considered a liberal program of scientic research in aeronautics. This program for years was in advance of that of other nations, and the result was that American aircraft, civil and military, have for years had superior performance, efficiency, and safety. In the commercial field, where direct evidence is available, this is proved by the large number of American-built commercial airplanes used by foreign air lines.

During the past 4 years, however, there has been increasing emphasis on aeronautical research on the part of European powers. They have greatly developed and extended their research facilities. In the rapidly advancing science of aeronautics, research problems increase in number and in difficulty with every material advance in speed, and the importance of prompt solution becomes relatively greater. The Committee's laboratories at Langley Field, Va., are working under high pressure. The requirements of the Army, the Navy, and the Civil Aeronautics Authority for the immediate solution of pressing problems are being met. But they are met at the expense of interfering with or neglecting the more fundamental scientific long-range investigations that in the end mean much to the advancement of American aeronautics. The Committee, therefore, in October 1938, created a Special Committee on Future Research Facilities. It is expected that its recommendations will be made the subject of a special report to the Congress. In the meantime, the addition to the Committee's research facilities at Langley Field of a structures research laboratory is urgently needed, as hereinafter set forth.

Relation of aeronautical research to commercial air transportation and to private flying.—Remarkable advances continue to be made in the field of commercial air transportation, and in this field the United States has for years held a recognized leadership. Although in private flying the progress has not been so rapid, the United States nevertheless has definitely excelled other nations in this field also. These gratifying conditions have been due to a combination of causes. The Civil Aeronautics Authority has provided indispensable assistance in the encouragement and regulation of civil and commercial aviation. The American aircraft industry, with its highly trained technical personnel and excellent manufacturing facilities, has been keenly alert to improve the design and quality of aircraft. The air transport lines have shown commendable initiative and efficiency in operation and have done their utmost to eliminate accidents and the causes of accidents. The high efficiency and safety of American civil and commercial aircraft are in no small measure due to the fact that the results of the scientific investigations of the Committee are generally applicable to the design of civil and commercial aircraft as well as to military aircraft.

Although popular attention during the past year has been largely focused on the significance of military aircraft developments, farsighted and determined efforts are also being made by European nations to extend their commercial and political influence by establishing and extending world trade routes of the air. Service by air lines operating under the American flag to South America and across the Pacific will soon be augmented by regular trans-Atlantic service, and it is expected that there will be inaugurated during the coming year trans-Atlantic service to the Mediterranean area. The British have established a through service by air from England to the Straits Settlements, India, and Australia, with connection to Hong Kong. One significant development in Great Britain is the policy of carrying all first-class mail by airplane throughout the Empire wherever there is air service. This practice is gradually becoming general in European nations. The British, French, and Germans have made test flights preparatory to inaugurating North Atlantic air transport services. In addition, the French are preparing to establish a service across the South Atlantic. The Dutch air transport lines now extend from Holland to Australia. Japan is rapidly expanding its air lines in eastern Asia.

In the highly competitive field of international air transportation a definite advantage will lie with that nation that has the most efficient aircraft. Continued active support of scientific laboratory research will not only pay large dividends in this field, but is absolutely essential to success.

The use of private aircraft on a much larger scale in the United States would, of course, be desirable in that it would enlarge the productive capacity of the aircraft industry, create a reservoir of pilots constituting a distinct national asset in the event of war, and provide in effect a new industry in the United States with large opportunities for employment. The technical improvement of the instruments of air transportation will be reflected in lower operating costs and in increasing availability for public service. The Committee believes that civil aeronautics will in time prove as revolutionary in the lives of the people as the automobile. To achieve such a contribution to the progress of civilization will require not merely sound economic promotional impetus, such as the good-roads movement gave to the development of the automobile, but it will definitely require the earnest and serious support of scientific research and encouragement of experimental engineering development that will put into useful form the results of laboratory research.

The Civil Aeronautics Act of 1938.—The Civil Aeronautics Act of 1938 superseded and largely repealed the Air Commerce Act of 1926. Briefly, it established a Civil Aeronautics Authority of five members and an Administrator, for the encouragement and regulation of civil and commercial aviation, and transferred to that organization the Bureau of Air Commerce of the Department of Commerce and the Bureau of Air Mail of the Interstate Commerce Commission. The act also established an Air Safety Board for the impartial and constructive investigation of aircraft accidents. The Civil Aeronautics Authority was by that act given representation on the National Advisory Committee for Aeronautics equal to that accorded by law to the Army and the Navy. In addition, therefore, to having two members on the main Committee, the Authority also has representation on the various technical subcommittees of the National Advisory Committee for Aeronautics on the same basis as the Army and the Navy.

In connection with the broad powers given the Authority by the act to encourage the development of civil and commercial aviation, the Authority, the Administrator, and the Air Safety Board are authorized to "avail themselves of the assistance of the National Advisory Committee for Aeronautics and any research or technical agency" of the Government. Those agencies are "authorized to conduct such scientific and technical researches, investigations, and tests as may be necessary to aid the Authority, the Administrator, and the Air Safety Board in the exercise and performance of their powers and duties." To assure continuance of the proven policy of coordination of the research needs of military and civil aviation and to prevent overlapping or duplication in this field, the Civil Aeronautics Act of 1938 further provided that "Nothing contained in this act shall be construed to authorize the duplication of the laboratory research activities of any existing governmental agency."

Responsibilities of the Committee.—The functions of the Committee as prescribed by its organic act are "to supervise and direct the scientific study of the problems of flight, with a view to their practical solution" and "to direct and conduct research and experiment in aeronautics."

To determine the present and future research needs of aviation, civil and military, the Committee has established standing technical subcommittees on aerodynamics, power plants for aircraft, aircraft materials, and aircraft structures. The subcommittees are composed primarily of specially qualified representatives of the governmental agencies concerned. The members of the subcommittees, like the members of the main Committee, serve as such without compensation.

The subcommittees recommend research programs. Most of the problems recommended for investigation are assigned to the Committee's laboratory at Langley Field, Va. Some problems are assigned to the National Bureau of Standards, when it is to the advantage of the Government to do so in order effectively to utilize existing facilities and to avoid duplication. Problems are also assigned to universities and technical schools. This policy, the Committee believes, stimulates and coordinates aeronautical research, and also has the advantage of training research personnel.

The Committee regards it as its duty to recognize in advance the trend of aeronautical development, civil and military; to anticipate the research problems that will arise; to design and provide research equipment as needed to solve the problems; to conduct the more fundamental scientific investigations in its own laboratories; and then to transmit the results directly to the governmental agencies and to those units of the aircraft industry that are most concerned.

Research facilities.—With the consistent support of the President and of the Congress, the Committee has developed at Langley Field, Va., a large and well-equipped aeronautical research laboratory, known as the Langley Memorial Aeronautical Laboratory. The rapid advance in the relatively new engineering science of aeronautics has been made possible chiefly by the design and construction of novel research equipment as needed.

At the present time the laboratories of this Committee comprise the following units: The 8-foot 500-mile-per-hour wind tunnel; the full-scale wind tunnel with a throat 60 by 30 feet; the 20-foot propeller-research-tunnel; the 5-foot variable-density wind tunnel; a 7- by 10-foot wind tunnel; a 4- by 6-foot vertical wind tunnel: a 15-foot free-spinning wind tunnel; two high-velocity jet-type wind tunnels of 11- and 24-inch throat diameters, respectively; the 2,900-foot N. A. C. A. tank; an engine-research laboratory; a flight-research laboratory; and an instrument laboratory.

In a serious effort to be prepared to solve the fundamental problems as they arise, the Committee has recently constructed three new pieces of research equipment: A 19-foot pressure wind tunnel that will permit the investigation of the characteristics of large models under conditions much more nearly paralleling those of free flight than can be obtained in any existing wind tunnel; a refrigerated wind tunnel with a throat 7½ by 3 feet, for the investigation of problems of ice formation on aircraft; and a free-flight wind tunnel 12 feet in diameter, for studying stability and control characteristics of airplanes. The Committee has also constructed an additional shop building in which to prepare models for test in the full-scale wind tunnel and in the 19-foot pressure tunnel.

The Committee has under construction a two-dimensional flow wind tunnel, the purpose of which is to conduct investigations at higher values of Reynolds Number. The Committee has submitted estimates to modernize its 20-foot propeller-research tunnel constructed in 1927. At that time it was the largest wind tunnel in the world. It has been an exceedingly valuable piece of equipment, but the science has progressed to a point where much greater accuracy in research equipment is required. Hence the necessity for modernization. The Committee has also just completed modernizing its 7- by 10-foot wind tunnel and its 5-foot vertical wind tunnel.

Need for research on aircraft structures.—The Committee on Aircraft Structures urgently recommends that the main Committee provide at the earliest possible date a laboratory for research on aircraft structures. With the advance in size and speed of aircraft and the increasing complexity and efficiency of metal construction, the problems involved require the conduct of laboratory research on structures on an increasing scale. The main Committee, in approving the subcommittee's recommendation, came to the conclusion that this is the greatest single need for additional research equipment and that, in the interests of safety and of further progress in aeronautics, it should be provided at the earliest possible date.

Airships.—It is noted with satisfaction that approval has been given to the building of a rigid airship for naval uses as authorized by the Congress in June 1938. Although the dimensions of this airship are to be small in comparison with the largest airships heretofore built, its construction will serve to keep alive the older of the two branches of aeronautical science. From a technical standpoint it is inadvisable that airships, which have contributed so much in the past and which those familiar with the status of their development believe can contribute much more of value in the future to aeronautics, should be allowed to stand idle while other branches of aeronautics are intensively developed.

There is reason to believe that the application of recent aerodynamic knowledge, improved materials, and modern engines can be combined to produce more efficient airships. It would be a mistake to regard the airship as a craft which has reached the zenith of its development.

Building even a small airship at this time is a favorable augury that the airship branch of aeronautics, neglected in this country during the past few years, may soon resume its appropriate place in the progress of aeronautical science.

Status of Committee in time of war.—The late Maj. Gen. Oscar Westover, Chief of the Army Air Corps, shortly before his death on September 21, 1938, had, as Chairman of a Special Committee on the Relation of the National Advisory Committee for Aeronautics to National Defense in Time of War, submitted a report on this subject. The report covered the need for maintaining the efficient functioning of the Committee's organization in time of war and recommended a plan, to go into effect upon the declaration of an emergency, whereby the Committee's organization will be stabilized and may be increased as necessary to meet the needs of the Army and the Navy. The recommendations in the Westover report were approved by the main Committee. Upon their approval by the Secretaries of War and of the Navy, the plan will become effective under the provisions of the National Defense Act of 1920 as amended.

PART I

REPORTS OF TECHNICAL COMMITTEES

In order to carry out effectively its principal function of the supervision, conduct, and coordination of the scientific study of the problems of aeronautics, the National Advisory Committee for Aeronautics has established a group of technical committees and subcommittees. These technical committees prepare and recommend to the main Committee programs of research to be conducted in their respective fields, and as a result of the nature of their organization, which includes representation of the various agencies concerned with aeronautics, they act as coordinating agencies, providing effectively for the interchange of information and ideas and the prevention of duplication.

In addition to its standing committees and subcommittees, it is the policy of the National Advisory Committee for Aeronautics to establish from time to time special technical subcommittees for the study of particular problems as they arise.

The Committee has four principal technical committees—the Committee on Aerodynamics, the Committee on Power Plants for Aircraft, the Committee on Aircraft Materials, and the Committee on Aircraft Structures. Under these committees there are six standing subcommittees. The membership of these technical committees and subcommittees is listed in Part II.

The Committees on Aerodynamics and Power Plants for Aircraft have direct control of the aerodynamic and aircraft-engine research, respectively, conducted at the Committee's laboratory at Langley Field, and of special investigations conducted at the National Bureau of Standards. Most of the research under the supervision of the Committee on Aircraft Materials is conducted by the National Bureau of Standards. A large part of the research under the cognizance of the Committee on Aircraft Structures is carried on by the National Bureau of Standards. In addition, a number of structural investigations, including in particular investigations of a theoretical nature, are conducted at the Committee's laboratory at Langley Field and at educational institutions.

The four technical committees recommend to the main Committee the investigations in their respective fields to be undertaken by educational institutions under contract with the National Advisory Committee for Aeronautics, and keep in touch with the progress of the work and the results obtained. The experimental investigations in aerodynamics, aircraft power plants, aircraft materials, and aircraft structures undertaken by the Army Air Corps, the Bureau of Aeronautics of the Navy, the National Bureau of Standards, and other Government agencies are reported to these four committees.

REPORT OF COMMITTEE ON AERODYNAMICS

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

LANDING SPEED AND SPEED RANGE

Wing flaps are now universally used on high-performance airplanes. Although previous research conducted by the Committee has established the relative merits of the usual types of flap employed, it has become apparent that more specific design data for flap application are essential. This is particularly true of flaps that are used over only part of the span. In addition, it has seemed advisable to carry further the development of the flaps that show greatest promise of improvement in airplane performance, in particular the slotted-flap and the multiple-flap arrangements. The work of the Committee on high-lift devices during the past year has been directed towards these objectives.

In the 7- by 10-foot wind tunnel, an investigation for the further development of the slotted flap mentioned in the last annual report has been carried out. By careful attention to the shape of the slot and the flap position, it has been possible to develop a maximum lift coefficient of 2.8. With reasonably high lift coefficients, it was possible to obtain drag coefficients lower than those obtained with any other type of flap tested to date. The latter flap characteristics should result in improved take-off and climb characteristics. With the flap in the retracted position, the drag of the wing at high speed is not increased by the flap installation when a small auxiliary flap is used to close the gap formed by the slot on the lower surface. The results are being prepared for publication.

An investigation has been made in the 7- by 10-foot wind tunnel of a multiple-flap arrangement in which a slotted flap was combined with a smaller plain flap, a split flap, and a second slotted flap. The results indicate that the double slotted flap is the most promising. Further work is planned with flaps of larger chord and with airfoil sections other than the

N. A. C. A. 23012, which is the only airfoil thus far used in the investigation.

Tests have also been made in the 7- by 10-foot wind tunnel of a Clark Y wing having split flaps with a gap between the flap and the lower surface of the wing. The results, given in Technical Note No. 650, show that any gap between the flap and the wing reduced the lift, the drag, and the pitching moments, but that the center-of-pressure movement and the ratio of lift to drag were little affected.

The effects of partial-span plain flaps have been investigated on both rectangular and tapered wings. The Clark Y airfoils tested were equipped with center-section and with tip-section flaps. The results (Technical Note No. 663) showed that the aerodynamic characteristics of partial-span plain flaps were, in general, similar to those of split flaps of the same span but that the lift and the drag were less for the wing with plain flaps than for the wing with split flaps of comparable size.

The "venetian-blind" type of flap has recently been receiving some attention in Europe, and tests of several different arrangements of this device have been completed in the 7- by 10-foot tunnel. The results thus far obtained indicate that the venetian-blind flap functioned similarly to a split flap when its axis was located forward of the trailing edge of the wing a distance equal to the flap chord. When the flap axis was moved back to the wing trailing edge and the flap was deflected, it acted like a multiple slotted flap and high lifts were obtained, together with low drag. The maximum lift, for the same size of flap, exceeded that of the Fowler flap, which has given the highest lifts up to the present time. Further investigation of this type of flap is contemplated.

The investigation of airfoils with flaps in the variable-density tunnel has been continued for the purpose of providing more reliable design data on the airfoil section characteristics of wing-flap combinations at the usual full-scale values of the Reynolds Number. The results of tests of ordinary and split flaps are being prepared for publication. The characteristics of the high-lift low-drag slotted flap arrangement developed in the 7- by 10-foot wind tunnel are being determined at high Reynolds Number. Preliminary results indicate a large maximum lift increment that is substantially constant over the entire scale range.

In order to provide further design data for flap application, and in particular to furnish information for structural design of the wing and the flap, pressure-distribution tests have been made in the 7- by 10-foot wind tunnel of several different wing-flap combinations. The results of such an investigation of an N. A. C. A. 23012 airfoil with an N. A. C. A. 23012 external-airfoil flap are presented in Technical Report No. 614, and a similar investigation of Clark Y and N. A. C. A. 23012 airfoils equipped with Fowler flaps is described in Technical Report No. 620. The results of pressure-distribution measurements made with a slotted flap and with a plain flap on N. A. C. A. 23012 airfoils have been published in Technical Report No. 633. Similar results from a split flap on a Clark Y-H airfoil were published in Technical Note No. 627.

The results of the investigation mentioned in the last annual report on the variation in the maximum lift coefficient obtainable with a given airplane in flight, depending upon differences in wing loading, altitude, wing-surface roughness, and the rate of change of angle of attack have been published as Technical Note No. 622. Data were obtained on the same airplane in the full-scale tunnel, and a comparison between lift coefficients measured in flight and in the full-scale tunnel is presented in Technical Report No. 618. These results show a rather close agreement between flight and tunnel measurements provided the influence of the propeller, the tail load for trim, and the effect of rate of change of angle of attack with time are taken into account.

CONTROL AND CONTROLLABILITY

As was stated in the last annual report, a critical analysis of the Committee's research on lateral-control devices which has been carried out in the past several years indicated that, for normal-flight conditions, ordinary ailerons with the gap between the aileron and the wing sealed are the most generally satisfactory. The flight investigation to verify this conclusion has since been completed and the results published in Technical Note No. 632. Additional data obtained on the same subject in conjunction with other tests on a pursuit-type airplane further substantiate the conclusion that any gap, even a very small one, is detrimental. In the case of the pursuit airplane, the maximum rate of roll obtainable was increased about 20 percent by sealing the gap of the ailerons, although the gap was only slightly more than one-eighth inch.

A method of reducing aileron operating forces suggested and analyzed in Technical Note No. 586 has been investigated in flight and the results presented in Technical Note No. 653. The method involves the use of a differential movement of the ailerons in conjunction with up-floating angle of the ailerons to obtain some degree of balance. The use of narrow-chord full-span tabs deflected downward on both ailerons was found effective in adjusting the up-floating angle to a desired value, and this in conjunction with the proper differential linkage is very effective in reducing aileron operating forces.

The results of the flight investigation of conventional and floating wing-tip ailerons on a tapered wing have been published in Technical Report No. 630.

The angular accelerations of an airplane in roll due to the application of ailerons is one of the factors representative of the control effectiveness. In order to determine what relation exists between airplane size and the angular accelerations in roll, a study is being made of data obtained over a period of several years on airplanes of various sizes. An analysis based on consideration of the time required to deflect the ailerons with a given effort by the pilot shows that the inertia of the control system is a factor of major importance as regards the accelerations obtainable.

The results of an experimental study of the forces that a pilot can exert on the control wheel of an airplane have been published in Technical Note No. 623. These data are supplementary to those previously published on the forces that can be exerted on the control stick and rudder pedal.

Lateral controls for use with full-span flaps.—Since it appears desirable to maintain as high lift coefficients as possible both for landing and taking off, the use of full-span flaps is indicated as being desirable. In this connection, the problem of satisfactory lateral control is of primary importance, and several devices for obtaining lateral control with full-span flaps have been investigated in the 7- by 10-foot wind tunnel during the past year.

A wing with a full-span slotted flap was tested with ailerons of three different types: retractable ailerons, slot-lip ailerons with the lip of the slot acting as aileron, and plain ailerons on the trailing edge of the slotted flap. The results are published in Technical Note No. 659 and indicate that, from considerations of rolling and yawing moments produced and of stick forces desired, the retractable aileron is the most satisfactory means of lateral control for use with a full-span slotted flap.

Another investigation was made to determine the control characteristics of a rectangular and a tapered N. A. C. A. 23012 wing with plain trailing-edge ailerons and full-span split flaps, the flaps retracting ahead of the ailerons. The results, published in Technical Note No. 661, show that satisfactory control could be obtained with the plain ailerons and the full-span split flap arranged to extend and retract with a hinge axis fixed ahead of the ailerons, or with the flap axis moved back to the aileron axis when the flap was deflected.

Flight with unsymmetrical power.—The failure or the intentional stopping of one engine on a multi-engine airplane results in peculiarities of control and has important effects on the performance of the airplane. In order to determine the magnitude of these effects, a large model simulating a modern twin-engine transport airplane, was investigated in the 20-foot wind tunnel. Various changes in the angle of the engines to the wing (toe-out) were tried, as well as several tail-surface arrangements. The results indicated that toeing-out of the engines or toeing-in of the rudders appear impracticable as methods of reducing the yawing moment after engine stoppage. From considerations of performance the yawed mode of flight on one engine increased the drag somewhat more than the banked mode of flight. With the particular model tested, the yaw angle required for balanced flight averaged about 5° and the bank angle required was about 2°. The results of the tests have been published in Technical Note No. 646.

MANEUVERABILITY

The investigation of the maneuverability of several Navy airplanes for the purpose of determining principally the maximum acceleration in roll and pitch to which the airplanes may be subjected has been continued. The results obtained on two airplanes have been reported to the Navy. A third airplane is now undergoing test.

An investigation has also been made of the maneuverability of a low-wing monoplane with a wing loading of 20 pounds per square foot. Previous tests of this nature, the results of which have been published, have been on airplanes with much lighter wing loadings. In general, the radii of the paths followed in recent maneuvers were considerably greater than for the machines previously tested. A report on this investigation is in preparation.

STABILITY

The extensive program of systematic research on stability problems that was formulated after a review of all the available data on the subject has continued to serve as the basis for the investigations of stability being conducted with the various facilities available to the Committee.

Research to determine the most desirable degree of stability for airplanes has been continued. One phase of the work, a mathematical study of the lateral motion induced by different types of asymmetric gusts, has been completed and the results have been published in Technical Report No. 638. The report deals with the effect of various amounts of dihedral and fin area on the motion resulting from encounters with unsymmetrical gusts of various types. The importance of proper coordination between fin area and dihedral, and in particular an unfavorable effect of relatively excessive dihedral with small fin area, is indicated.

As stability research progresses, it becomes increasingly evident that the effect of the various factors on the control and maneuverability of an airplane is of more importance than their effect on the stability itself. The requirements for stability and control generally conflict—that is, conditions that lead to greater stability also lead to greater control stiffness and less maneuverability—and compromises must be made in design. With the increase in airplane size, the nicety of adjustment needed to produce both good stability and good control characteristics is considerably increased. Several analyses are in progress with a view to obtaining detailed information on the effect of varying the stability on the control characteristics.

The study of the relationship between the longitudinal-stability characteristics and the elevator control effectiveness is well advanced. Although no definite conclusions can be drawn as yet, it appears that the effect on the elevator control force of varying the degree of longitudinal stability through a wide range may be considerably smaller than generally supposed. A similar investigation with regard to lateral stability has revealed the fact that very little information exists on the normal flying requirements for rudder control. Most design parameters are based on the amount of control needed to prevent ground looping and to recover from spins and do not apply satisfactorily to airplanes with wheel brakes or stable landing gears, nor to the spinning categories. The investigation has therefore been extended to include a study of the functions of the rudder control.

Allied to these investigations, which primarily deal with improvement of the airplane for operation by the human pilot, is a study being made of the stability of the airplane when operated by an automatic pilot. The operation of an ideal pilot, one in which the response to a disturbance is instantaneous, has been investigated and the results prepared for publication. The effect of practical factors, such as the amount the airplane may deviate from the desired conditions before the pilot starts to respond and the time taken for the pilot to deflect the control surface, are now being considered.

With the continued study of stability problems, a better understanding of the subject is being obtained and more application of the findings is being made in actual design. As a result, there is a need for more information on the influence of the different variables in design on the stability derivatives upon which stability depends. During the past year, study was made of all available data on the derivative N_V, the change of yawing moment with change of sideslip, and the need for a systematic series of experiments on different fuselage shapes and fin arrangements is clearly indicated. A compilation of the data reviewed has been published in Technical Note No. 636.

Technical Report No. 635 has been published giving the results of an analytical investigation of the effect of the wing on the stability derivatives. The effects of taper, twist, dihedral, and aspect ratio are treated, and the data given in the report make possible the ready computation of the stability derivatives of a wing with any combination of these variables.

The stability problem is further complicated by the effect on the tail of the downwash from the wings and the wake of the wings. In the full-scale wind tunnel, downwash angles and wake characteristics have been measured in the tailplane region behind wings of various taper and aspect ratios and for flaps of various spans. From an analysis of these data, it was possible to derive a satisfactory theoretical basis for predicting downwash and wake phenomena. A report is being prepared presenting the results obtained. Also under preparation is a report containing a large number of charts covering plain and flapped wings of various types, by means of which the designer may readily compute downwash angles, wake velocities, and wake thickness in the region of the tailplane. The work is being extended to include the effects of slipstream and fuselage interference.

The investigation of wing-fuselage interference in the variable-density wind tunnel, which was extended to include the effect of adding tail surfaces to typical combinations, has been completed. A report dealing, among other things, with the wake effect and downwash angles at the tail is being prepared.

Stalling.—During the past year the considerable attention that has been given to the study of the stall has been necessitated by the undesirable stalling characteristics that exist in some airplanes of modern design.

In Technical Note No. 645 the stalling problem as related to modern low-wing monoplanes is discussed, and it is noted that basically the solution of the stalling problem consists of the elimination of rolling instability of wings. In view of the merit of low-wing monoplanes in other respects there is great need for research on this subject. For the present it seems desirable to provide means to forewarn the pilot of the approaching loss of stability when the angle of attack is being increased. The various aerodynamic effects that give warning of the stall are considered in detail.

The special wing of 5:1 taper equipped with stall-control flaps mentioned in the last annual report has been tested in flight and in the full-scale wind tunnel. The stall-control flaps are of large chord, being hinged at the 40 percent point of the wing chord. They have the effect of shifting the lift curve to the left and therefore of causing the stall to occur at a lower angle of attack. By means of these flaps it was possible to vary the span loading in any desired manner and to cause the stall to start either at the wing root or at the tip. The shape of the peak of the lift curve could be varied without materially altering the value of the maximum lift coefficient. With what appeared to be about the optimum flap setting as regards maximum lift and development of the stall, the lift curve for the complete wing was shifted about 6° to the left. The effect of this shift of the lift curve on the proper attitude of the airplane during an approach glide and landing was somewhat confusing to the pilot accustomed to the characteristics of the plain wing. Confusion would be eliminated, of course, if all landings were made with the flaps in the same position. The results of this investigation are now being prepared for publication.

The stalling characteristics of a number of airplanes ranging in size from small single-engine machines to the largest four-engine types have been studied in flight during the past year. These studies have been made by visual and photographic observations of silk tufts attached to the upper surface of the wing. Such tufts appear to be a reliable means of indicating the manner in which the stall spreads along the span, after some experience is acquired in the proper interpretation of their behavior. It has been found that the loss of lift corresponding to the stall is indicated when the tufts reverse direction or become entirely limp, whereas a fluttering or unsteadiness of the tufts is simply an indication that the stall is impending.

From observations made in these tests it appears that the type of stall which starts at the center and progresses towards the tip is the only one that produces sufficient change in the behavior of the airplane as the stall is approached to serve as a pronounced warning before rolling instability actually develops. A violent rolling motion, however, is not necessarily associated with a stall that starts at the tip. In fact, on one machine the stall started at the tip and progressed inboard so gradually and symmetrically that a gentle stall was obtained. When the stall spreads suddenly over a large portion of the wing, large rolling moments and a violent action are likely to occur, for in such cases the spread of the stall on the two wings is not likely to be symmetrical. An early stall at the wing root provides a warning of the impending loss of control but in certain cases the tail buffeting accompanying root stalling has been regarded as objectionable.

The conflicting requirements therefore leave many questions yet to be answered regarding the attainment of desirable stalling characteristics. One point not to be overlooked is that strong static longitudinal stability at high angles of attack makes it difficult to stall a machine completely; in such a case the likelihood of an inadvertent stall is much reduced.

An investigation in the variable-density wind tunnel is now in progress to determine the relative efficiency of various methods, such as twist, change of section, and change of camber, for the prevention of tip stalling. In the same wind tunnel, another investigation is in progress on wings with sweepback and sweepforward and different amounts of taper to investigate the effect of these factors on the spanwise location of the stall.

One promising method of maintaining lateral control and quasi-stability until the stall is well developed over the inner portions of the wing is the use of leading-edge slots over the outer part of the wings in front of the ailerons. In order to establish data on the best type of fixed slot for use with the N. A. C. A. 23012 airfoil, fixed slots of several forms and at several chord locations with and without slotted flaps have been investigated in the 7- by 10-foot wind tunnel. The results are being prepared for publication.

A mechanical device has been developed to provide a warning of the impending stall on airplanes in cases where the warning is not an inherent feature caused by the nature of the airflow around the wing and the tail. This N. A. C. A. stall-warning indicator operates when the angle of attack reaches the maximum safe value regardless of the air speed, so that it gives a warning independent of the wing loading. The warning indicator thus functions in proper relation to the critical airflow conditions over the wing regardless of variations in the weight carried by the machine or of variation in acceleration as in turns. Experimental installations of this device have thus far given very promising results.

SPINNING

During the past year the 15-foot free-spinning wind tunnel has been chiefly occupied in determining the spinning characteristics of scale models of ten specific airplanes. Tests for the purpose of making a direct comparison between model and full-scale spin behavior on a low-wing monoplane have been made and the results analyzed. Progress has also been made in the systematic investigation mentioned in the last annual report to determine the effects of changes in wing arrangement, in tail arrangement, and in mass distribution.

Observations made in the course of routine tests of specific designs have been definitely useful in extending the general knowledge of spinning. It has been pointed out in a published report that the effect of aileron setting on spin characteristics may be appreciable. This conclusion is substantiated by more recent results both with models and in flight. For models of modern low-wing monoplanes it has been found that recovery is frequently expedited by leaving the ailerons deflected with the spin (right aileron up in a right spin), and a study is being made of the possibility of utilizing aileron deflections to improve recovery.

General conclusions previously presented with regard to satisfactory tail design have been verified during the past year by observations made in the course of routine tests. It is of interest to note that three models having dual fin and rudder construction have been tested and all have shown very satisfactory recovery characteristics.

Experience gained in the testing of four models in the trainer and the observation-scout categories indicates that spin characteristics for the landplane type will be less satisfactory than for the single-float seaplane.

In order to increase the available information as to the degree of reliability of the free-spinning tunnel in the prediction of full-scale characteristics for specific designs, a comparison has been made of the spinning and recovery characteristics of a low-wing monoplane tested in this tunnel and in flight. This comparison, together with the additional information obtained as a result of flight service trials, indicates that model tests give a useful, but not infallible, indication of full-scale spin behavior.

Discrepancies that have appeared between model and full-scale results indicate the need for further research on scale effect, effect of power, and effect of manner of control operation.

The investigation of the relative importance of wing arrangement, tail arrangement, and mass distribution that was mentioned in the last annual report is now about half completed. Results published thus far (Technical Notes Nos. 608, 630, and 664) have indicated that the choice of wing design may be affected by the mass distribution. Unpublished results of additional tests indicate that a forward location of the center of gravity is preferable to a rearward location regardless of wing or tail arrangement. An analysis has been started with the object of evolving a suitable airplane-spin criterion to aid designers in securing satisfactory recovery.

The results of the investigation with the spinning balance in the 5-foot vertical tunnel of the effect of stagger of rectangular biplane cellules, mentioned last year, have been published as Technical Note No. 625. An investigation of the effects of airfoil section on the spinning characteristics of rectangular monoplane wings with rounded tips has been described in Technical Note No. 633. The airfoil sections investigated were the N. A. C. A. 0009, 23018, and 6718, and the data for the Clark Y wing presented in Technical Note No. 612 were included for comparison. These data can be used in studying the steady-spinning characteristics of particular airplanes, and the results of the analysis given in these papers can be used to predict whether changing the wing loading or the weight distribution of an airplane will be beneficial or detrimental to its steady-spinning characteristics. For comparable cases, these results and the results obtained on models in the free-spinning wind tunnel have shown the same general tendencies.

In connection with the determination of spinning characteristics of various models in the spin tunnel, there has been a continued demand for the Committee to determine experimentally the moments of inertia of full-size airplanes. These measurements are carried out by means of the swinging gear, which has been in use for several years.

TAKE-OFF

The investigation discussed in the last annual report of the transition period in take-off between the end of the ground run and the beginning of the climb has since been described in Technical Report No. 626. Additional data concerning the ground run and the transition to climbing flight in take-off have been obtained in conjunction with an investigation of the effect of two types of full-span flap on take-off, one being a high-drag type represented by the Zap flap and the other being a low-drag type represented by the external-airfoil flap. These tests are an extension of an earlier investigation made with a machine of such low power that the results were not representative of conditions ordinarily encountered in transport or military operation. The data obtained in these tests are now being analyzed.

As has been pointed out, the characteristics of the propeller have a pronounced influence on the take-off. An extensive investigation of full-scale propellers has been conducted in the 20-foot wind tunnel to provide information on modern propellers. This constitutes a considerable extension of the Committee's early investigations to provide propeller design data and covers principally the changes in design necessitated by higher engine power and airplane speed. These trends call for propellers of higher pitch, more blades, and changes in blade form. The investigation has now been completed, and is discussed more completely in a later part of this report. Of six reports published during the year on the results of the investigation, three (Technical Reports Nos. 639, 640, and 643) contain data directly applicable to the take-off problem.

LANDING

In connection with the general study of landing characteristics of airplanes, an investigation of ground effect has been carried out with a glider of aspect ratio 7.5 towed by an automobile at various heights above the ground up to about 50 feet. The data obtained in this investigation, which was made both with a plain wing and with a wing fitted with a split flap, are now being analyzed. For the plain wing the slope of the lift curve was increased about 30 percent with the glider 5 feet above the ground, as compared with the slope when it is 50 feet above the ground. The drag at a lift coefficient of 1.0 was about 15 percent less when the glider was close to the ground. The maximum lift coefficient of the plain wing was much higher (about 25 percent) in actual landings than in simulated landings made at considerable altitude.

Landing loads.—As stated in the last annual report, the Committee is undertaking the accumulation of statistical information on the loads experienced by the landing gear. This investigation has been continued during the past year and tests have been made with seven additional airplanes covering the complete range of sizes of airplanes now in operation. A tricycle type of landing gear as well as conventional types was included. The attitude and the vertical velocities of the airplanes immediately prior to contact, in addition to the linear and angular accelerations, were determined.

Tricycle-type landing gear.—There has been a very definite growth of interest among American manufacturers in the use of tricycle-type landing gears during the past year, and the indications are that many new models of transport and private-owner machines, in particular, will be equipped with this type of gear. During the past year the Committee has continued the investigation of the shimmy of castering wheels and also its study of the landing loads experienced with the tricycle-type landing gear.

The analytical study of the shimmy of castering wheels that was mentioned in the last annual report has been completed and the results are being prepared for publication. The report will give methods for estimating the spindle damping that is necessary to avoid shimmy.

An airplane fitted with a nose wheel was used in tests of the effect of caster length on the tendency of the wheel to shimmy for comparison with tests made on a small-size model. A conclusion based on model tests that the provision of lateral freedom of the wheel would eliminate shimmy was not confirmed by the tests of the full-size machine.

Apparatus has been constructed for conducting tests with various types of airplane wheels in order to determine the friction required to prevent shimmy. By means of this apparatus the weight, the caster length, and the spindle angle can be varied as desired in order to cover a wide range of conditions. Tires ranging in characteristics from those of the extra-low-pressure type to those of a solid tire are being investigated.

As noted previously, landing-load tests have been made with one airplane having a tricycle type of landing-gear arrangement. Plans are also under way for tests of another machine having this type of landing gear. In both of these cases, particular attention is being paid to the determination of the loads on the nose wheel.

It has been found advantageous to employ actual airplanes or relatively large models of large airplanes in the Committee's full-scale tunnel in order to study various changes that may be made to improve service airplanes. Difficulties may sometimes be located and changes studied by means of wake surveys. From the test results, it was found that, for the high-speed condition, the drag of retracted landing gears accounted for from 2 to 9 percent of the drag of the airplanes. It was shown that this drag could be greatly reduced by improving the fairing of the landing gear in the retracted condition. In one case it was found possible to reduce the drag of an airplane by 14 percent by modifying the engine cowling. Other reductions in drag were found to be possible by redesigning exhaust stacks. The profile drag of service wings was measured by momentum surveys in the wakes of the respective wings, and by a comparison of this information with data obtained on smooth wings of the same sections it was found that the surface roughness, consisting of protruding rivet heads, lap joints, etc., accounted for from 10 to 35 percent of the wing profile drag. These investigations indicated the possibility of increasing the speeds of several airplanes by varying amounts of from 15 to 23 miles per hour and they demonstrate the advantage of being able to put the actual airplane in the tunnel as compared with the use of models.

AIRFOILS

Section characteristics.—Comparisons of airfoil data from the variable-density wind tunnel with results of other large-scale tests, including data now becoming available from the N. A. C. A. full-scale wind tunnel, other large wind tunnels, and the British compressed-air tunnel, have been of decided assistance to the program of airfoil investigation. These comparative data have aided in formulating turbulance corrections for wind-tunnel test data, such as those employing the concept of an "effective Reynolds Number," but such corrections cannot be considered ultimately satisfactory. The basic program of airfoil investigation has therefore been primarily concerned during the year with the development of better methods of conducting tests, and of methods for the derivation of new airfoil forms in the light of modern boundary-layer theory.

Investigations of airfoil section in the variable-density wind tunnel of the type that led to the development of the commonly used sections of the N. A. C. A. 230 series have been continued. Profile-drag coefficients determined from tests in the variable-density wind tunnel have, however, tended to appear high as compared with results from the N. A. C. A. full-scale tunnel and from foreign sources. The results from the variable-density wind tunnel have also indicated larger rates of increase of drag with airfoil thickness than have those from other sources. These discrepancies have been considered and corrections for turbulence and tip effects have been applied which tended to reduce them.

Further investigations of this subject have been made, including tests of three symmetrical airfoils in the full-scale wind tunnel (Technical Report No. 637). The results of these tests confirmed the existence of discrepancies in addition to those arising from differences in turbulence between airfoil data from the full-scale and variable-density wind tunnels. The results from the full-scale tunnel indicated the presence of support-strut-interference effects in the variable-density tunnel causing the measured drag to be too large, the drag increments due to support interference being greater for thick airfoils than for thin ones.

A subsequent investigation in the variable-density wind tunnel confirmed the presence of marked drag increments due to support-strut interference, the increment increasing with airfoil thickness. The application of corrections for this factor to the data obtained from the variable-density wind tunnel substantially removes the above-mentioned discrepancies. The most important result is that the smaller increase of drag with thickness affects the choice of optimum airfoil sections for airplane wings. Reports are being prepared presenting the results of these investigations.

A preliminary investigation has been made in the variable-density wind tunnel to study the stalling processes for four typical airfoil sections over the critical range of Reynolds Number. The flow was studied by means of tufts and a mixture of lampblack and oil spread on the surface and the observations were correlated with force measurements. The results tend to substantiate the analysis of stalling in Technical Report No. 586.

Transition on airfoils.—Because the aerodynamic characteristics of airfoils in relation both to maximum lift and minimum drag depend markedly on the transition from laminar to turbulent flow in the boundary layer, knowledge of the region in which transition occurs is a matter of considerable practical importance. The maximum possible extent of the laminar boundary layer is therefore of particular interest. In one respect, this extent is limited by the position of the laminer separation point. Of the various methods available for calculating this position, the method presented in Technical Report No. 504 seems to be the most reliable. This method, however, has the disadvantage that the computations are usually cumbersome and lengthy.

A method of rapidly estimating the position of the laminar separation point from the given pressure distribution along a body has been found; the method is applicable to a fairly wide variety of cases. The laminar separation point was found by the method of Technical Report No. 504 for a particular series of velocity distributions along a flat plate. They consisted of a region of uniform velocity followed by a region of uniformly decreasing velocity. It was found that such a velocity distribution can frequently be assumed equivalent to the actual velocity distribution along a body in so far as the effects on laminar separation are concerned. The agreement between the position of the separation point calculated according to the present method and that found from more elaborate calculations is very good. This rapid method of estimating the position of the laminar separation point is soon to be presented in a Technical Note and should find frequent use in connection with estimates of possible position of the transition point and the attendant effects in various practical cases.

As another part of the Committee's general program for studying transition, measurements have been made on the N. A. C. A. 0009, 0012, and 0018 airfoils in the full-scale wind tunnel. The smoothly polished airfoils were of 6-foot chord and were tested over a range of Reynolds Number from approximately 1,500,000 to 5,000,000. Measurements were made both by means of total-head tubes in the boundary layer, so as to obtain the boundary-layer profiles, and by means of a hot wire at the airfoil surface. The results of this investigation, which show a variation of the transition point as a function of airfoil thickness, Reynolds Number, and lift coefficient, are published in Technical Report No. 637.

Another investigation of boundary-layer conditions, especially dealing with the location of the transition from laminar to turbulent flow, is in progress in the 8-foot high-speed tunnel. Here, by the use of two airfoils of different size and with the possible speed range and the low-turbulence air stream of this tunnel, the combined effects of scale and compressibility in relation to transition may be investigated.

A determination of the profile drag and the transition point in the boundary layer on a very smooth wing section in flight has been carried out at a Reynolds Number of about 4,500,000 with one airplane. These data are of value for comparison with data from the full-scale tunnel to evaluate any residual effects of the relatively small turbulence of the full-scale wind tunnel on the characteristics of aerodynamically smooth bodies.

In order to extend the range of profile-drag measurements at low turbulence to high Reynolds Numbers, flight tests were also made on an airplane of such size and speed that a Reynolds Number of 15,000,000, based on the chord length, was obtained. A portion of the wing of this airplane was made very smooth by the application of a combination of rubber and metal coatings. A paper on the results of these measurements is in preparation.

Roughness.—A continuation of the investigation of wing-surface conditions is being carried out in the 8-foot high-speed tunnel. The effect on wing drag of various construction conditions occurring in practice, such as butt joints with gaps, butt joints that are not flush, faired lap joints, spot welds, rib stitching, etc., have been determined. The investigation concludes with a systematic study of irregularities in wing profile.

Compressibility effects.—The analysis of a large amount of data obtained from investigations of the nature of the compressibility burble has been completed and prepared for publication as a Technical Report. An investigation of the variation of the drag coefficients of cylinders of simple shape for a wide range of Reynolds Number and speed that has been conducted as time permitted has been completed and the results published in Technical Report No. 619.

Work now in progress in the 24-inch high-speed wind tunnel consists of an extension of the earlier wing development carried out in the 11-inch high-speed wind tunnel. The energy loss involved in the compressibility burble tends to act as a limiting condition for the speeds of airplanes of current and typical design either through propeller restrictions or ultimately through restrictions on other parts of the airplanes. Although knowledge of the phenomenon has increased markedly through experimental work over the last four years, the phenomenon is still one of the most important flow problems in current aerodynamics. Further study of the mechanics of this flow phenomenon is being made.

Wing characteristics.—The calculation of the characteristics of 22 tapered wings of varying aspect ratios and taper ratios has been completed and shows reasonably good agreement with experimentally determined values of pitching moment, aerodynamic-center position, lift-curve slope, and drag variation. The results have been published as Technical Report No. 627.

The same aerodynamic characteristics have also been calculated for a few wings with partial-span flaps. Fair agreement with test results was obtained in most cases. The results are to be published, together with information on the theoretical factors involved in the determination of characteristics of tapered wings with partial-span flaps.

As a part of a recent study of the stalling of wings, a series of tests is in progress in which photographs are obtained of the action of tufts on wings with sweepback and sweepforward and different amounts of taper, to investigate the effect of sweep on the spanwise location of stalling. Another investigation using wings of different taper is being made to find the relative efficiency of various methods of preventing tip stalling.

AERODYNAMIC INTERFERENCE

The investigations conducted in the variable-density wind tunnel of the effects of split flaps and special junctures on the aerodynamic interference between wing and fuselage have been published as Technical Notes Nos. 640, 641, and 642. The investigation of the effects of adding tail surfaces has been completed and a report presenting the results is being prepared. Of interest are the small size of the increments to the drag caused by the tail surfaces, as well as the agreement between theoretical considerations and experimental determination of the wake effects and the downwash angle at the tail. The induced interference of the fuselage on the downwash angle, moreover, was negligible at low angles of attack and small at high angles. Asymmetrical combinations, however, showed initial deviations in the flow direction at the tail at low lift coefficients.

An experimental investigation of the mutual effects of interference and compressibility phenomena is in progress in the 8-foot high-speed wind tunnel. Results have been obtained for several arrangements of radial-engine nacelles on a wing to determine the effect of present-day nacelle arrangements at high speeds, but conclusions cannot as yet be drawn.

DRAG AND COOLING

Engine location.—One of the most obvious possibilities for substantial improvement in aerodynamic efficiency lies in the reduction of the drag of the engine installation and the cooling system. Tests were conducted in the full-scale wind tunnel on a representative 4-engine model to evaluate the drag of a typical liquid-cooled power plant. These tests showed that the engine nacelles increased the drag of the airplane about 8 percent and the cooling system (prestone and oil radiators) accounted for over 15 percent more. Further tests were made simulating the arrangement of engines placed within the wing with extension shafts to either tractor or pusher propellers. The extension-shaft drive practically eliminated the nacelle drag.

For the development of an efficient cooling system for engines or radiators located in the wing, investigations have been conducted in the 7- by 10-foot atmospheric wind tunnel and in the full-scale wind tunnel. The general principle of the arrangements investigated is that of low-velocity cooling with the cooling element placed at the largest section of a duct. Arrangements already tested have shown large reductions in drag under all flight conditions.

In the 7- by 10-foot wind tunnel the tests were made to simulate a radiator or engines enclosed entirely within the wing and cooled by air led through ducts from the wing surface. The results obtained on a wing model with full-span ducts and radiators have been reported in preliminary form. For certain locations of the duct inlet and outlet the total power required to cool such an installation is only the power required to force the air through the radiator. Thus the cooling power may be of the order of 2 or 3 percent of the engine power as compared with the 10 to 15 percent now required on radiator installations. The results of these tests will be published as a Technical Report.

Radiator study.—A comprehensive study of aircraft-radiator design and installation has been made. The choice of radiator dimensions is made on the basis of cooling efficiency, which is the ratio of heat dissipated to power required for cooling. The power required for cooling is made up of three factors: (1) power to force the cooling air through the radiator; (2) power to carry the weight of the radiator; (3) power to overcome form drag. The importance of these three power expenditures varies with installation, airplane performance, pressure drop, coolant, and altitude. The heat dissipation varies with mass flow of air through the radiator, the length-diameter ratio of the radiator tubes, and the temperature difference between air and coolant.

This study on radiators comprises one phase of the heat-transfer problem. The problem of intercooler design and installation is also under investigation at the present time. The radiator problem is concerned with the case where nearly all the thermal resistance is at one surface, while the intercooler problem is concerned with a case of two surfaces having relatively the same thermal resistance.

Cowling research.—The information from tests on the propeller-cowling-nacelle combinations presented in Reports Nos. 592, 593, and 596 and Technical Note No. 620 has been summarized for design purposes in a report entitled "Design of N. A. C. A. Cowlings for Radial Air-Cooled Engines." The main emphasis of this report is placed on the method of obtaining the dimensions of the cowling. A practical method of designing cowlings and some examples are presented.

A study of the factors affecting the pressure available for ground cooling in front of air-cooled engine cowlings has been made. Most of the work was conducted on a model of about one-third full scale. A number of isolated tests on four full-scale airplanes were made as a basis of comparison of model and full-scale results. The available pressure in front of the cowling increases rapidly with the diameter of the opening of the cowling up to 30 or 40 percent of the propeller radius. The cowling should be located as close to the propeller as practicable. Disks located in the front of the nose of the cowling greatly increased the average pressure in front of the engine. It is important that the plane of the disk be even with the nose of the cowling. The size of the disk should be such that the area of the front opening is optimum for the total conductivity used. A report is being prepared on this investigation.

Investigation of the nose-slot cowling has been continued on a full-size airplane. The ground cooling of the engine was improved by proper cowling design and a $\Delta P/q$ of 1.6 was obtained in full-throttle climb. In order to expedite the study of the problem, it was decided to continue the work in the 20-foot wind tunnel. These tests are now in progress and should supply sufficient information to determine the best design of nose-slot cowling for any given design condition. In connection with the wind-tunnel investigation the cost in drag of the bluntness of the radial-engine cowling is being investigated and means to reduce this drag are being studied.

Scoops and vents.—An investigation of air-inlet and outlet openings suitable for cooling and ventilating systems, carburetor intake, and engine exhaust has been undertaken. A momentum theory of the generalized induced-flow system was derived to serve as a basis for the explanation and the correlation of experimental results, particularly the results of wind-tunnel tests of separate openings. This theory provides a simple method of determining roughly the effects of the internal induced-flow system. It suggests the optimum locations for inlet openings, the optimum angle and velocity of the jet for outlet openings, and the cost of departures from those optimums; and it illustrates the close relationship of the several types of induced-flow system. An extensive experimental investigation was made in the N. A. C. A. 5-foot vertical wind tunnel of a large number of openings in a flat plate and of a few in an airfoil, all tests covering the complete range of self-induced flow and the practically useful range of blower-induced flow. The experimental results verified the trends indicated by the theory wherever comparisons were practicable, and the quantitative agreement between theory and experiment is considered satisfactory for the most efficient opening shapes and locations. The test conditions and the models were systematically varied so that the results indicate the effects of wind velocity; size, shape, and location of openings; length and angle of ducts; and some of the interference between an opening and a body, and between inlet and outlet openings in the same body.

The location of the carburetor intake has been separately investigated in the propeller-research wind tunnel. A ramming effect due to the dynamic pressure of the air stream may be desirable. Tests of several intakes were made with the radial engine cowling used in the propeller investigation. The best results were obtained with a well-rounded entrance located near the leading edge of the cowling on the outside. The propeller also contributed to the ramming effect when the scoop was so located. The results of the tests are published in Technical Note No. 631.

PROPELLERS

An extensive investigation of full-scale propellers started last year has been completed. A number of propellers with various airfoil sections, different numbers of blades, and several plan forms and pitch distributions were tested in conjunction with two bodies representing radial-engine and liquid-cooled-engine nacelles. A range of positive blade-angle settings up to 45° at the 75-percent radius was covered, as well as some negative settings.

Many of the conclusions were presented in the last annual report and these have not been altered by the tests made this year. Because of the large amount of data, it was found advisable to prepare a series of reports each devoted to a particular phase of the study. Eight reports have been prepared, six of which have been published as Technical Reports Nos. 639 to 644.

With regard to compressibility, Technical Report No. 639 indicates that at normal pitch settings losses in efficiency become evident at tip speeds of from 0.5 to 0.7, the velocity of sound for the take-off and climbing conditions of flight. The loss increases rapidly with speed and amounts to more than 20 percent of the thrust power in some instances for tip speeds of 0.8 the velocity of sound.

The loss for the take-off condition increased with blade-angle setting up to about 20°, diminishing at higher values. For the climbing condition the loss increased up to a 25° setting. The loss in efficiency for controllable propellers is partly regained by the lower blade angles necessitated by the higher power coefficients developed at the higher tip speeds. On the other hand, the loss for fixed-pitch propellers is increased by the loss in speed and power caused by the higher power coefficient. The complex effects of compressibility were subject to detailed study and an appendix to the report develops methods for making corrections in practical problems.

Technical Report No. 640 discusses the effect of the number of blades, indicating that, for the same solidity (total blade width), the efficiency is increased by increasing the number of blades. Even when the solidity was doubled by changing a 2-blade to a 4-blade propeller, the loss in efficiency was only 2 percent. At the same time the take-off efficiency was improved.

The negative thrust condition occurs in diving at high speeds and idling at low speeds. Technical Report No. 641 gives data and examples for calculating the magnitude of the thrust developed under these conditions of operation.

When a spinner is added to the propeller of a radial air-cooled engine, the principal effect is an improvement in the flow through the engine cowl. With some installations of liquid-cooled engines, however, the spinner covers up the propeller hub and the round blade shanks. The propulsive efficiency was increased 6 percent in one case. Blade shanks of good airfoil shape were found superior to the round shanks with both types of nacelles. (See Technical Report No. 642.)

Technical Report No. 643, relating to plan forms, indicates that some improvement may be expected by having the blade width in the inner half of the blade greater than is the usual practice. The take-off efficiency, however, is reduced.

A more accurate method of measuring propeller deflections was developed and is described in Technical Report No. 644. Measurements gave much smaller deflections than the methods formerly used. Torsional deflections of only $\frac{1}{10}$° at the 0.70 radius were noted. The bending deflection was also small.

The results of the study of airfoil sections indicate that no section thus far tried is the best for all conditions of operation. Highest maximum efficiencies were obtained with airfoils of low camber such as the N. A. C. A. 2400–34 and the Clark Y. For both controllable and fixed-pitch propellers of the same diameter, the R. A. F. 6 was best in the take-off range. Blade sections for controllable propellers, not limited in diameter, should be selected mainly on a basis of drag.

There has been a feeling that propellers designed with low basic pitches and then set to high angles suffered because of the large change in pitch with radius. Tests in which a propeller was twisted to give a uniform pitch when set at 35° gave a lower maximum efficiency than a normal propeller set to this angle. A gain in take-off efficiency at low angle settings was noted.

Tests in wind tunnels do not yield data on the static thrust of propellers because the propeller creates an appreciable velocity through the tunnel. The static thrust is useful in certain aspects of performance computation and, in order to obtain this information for direct comparison with values obtained in the tunnel, the wind-tunnel set-up has been installed on an outdoor rig. A series of tests on propellers previously tested in the tunnel has been completed and the data are now being analyzed.

THEORETICAL AERODYNAMICS

Normal force and pressure distribution over airfoils.— For the calculation of air loads along the wing chord in airplane design it has been customary for the designer to employ an arbitrary normal-force distribution that agrees only very roughly in form to the distribution which would result from experimental observations. This method, while admittedly crude, is rapidly and easily employed. Consequently, it is frequently used in preference to the theoretical method of Technical Report No. 411. Moreover, the theoretical method itself predicts a distribution which is in none too good agreement with experiment. A modification of this theoretical method (Technical Report No. 563) that yields results in good agreement with experiment has been advanced but this modified theory is even more laborious to employ.

A method for the prediction of the chordwise normal-force distribution in which attempt is made to retain the simplicity of the arbitrary method and the exactness of the modified theoretical method has recently been developed by the Committee. This method is applicable to ordinary airfoils (Technical Report No. 631) and to airfoils with plain, split, and serially hinged trailing-edge flaps (Technical Report No. 634) but does not give separately the pressure acting on the upper and lower surfaces of the airfoils. At present the Committee is continuing work on a method of determining these pressures. This method as evolved is easily and rapidly applied and to date appears to be accurate enough for design purposes.

Theory of unsteady flow.—A theoretical study has been made of transient, or nonstationary flows, about airfoils and the results presented in Technical Report No. 629. It has been shown that the two-dimensional problem can be made to depend on two significant functions: one introduced by Wagner and the other introduced by Theodorsen. These functions are Laplacian transforms of each other. The growth of lift on an airfoil in two dimensions becomes analogous to the growth of electric current in a circuit. The function of Wagner then corresponds to the indicial current admittance and the function of Theodorsen to the alternating current complex admittance. As in electric-circuit theory the current due to any applied voltage can be built up by superposition, so in the case of the airfoil the lift due to any "applied vertical velocity" can be obtained by superposition. Thus, many practical general problems concerning the transient behavior of lift under changing flow conditions can be handled.

In the analysis of some of the results recently obtained in the wind tunnels, more particularly in the gust tunnel, application has been made of the fundamental theory of unsteady flow. The existing theory, however, considers only the case of a wing of infinite span and consequently does not entirely fit the conditions of the tunnel tests. A study has therefore been started to extend the theory to cover the three-dimensional case of the wing with finite span. Although a rigorous treatment has not yet been evolved, a practical extension to the two-dimensional theory has been worked out. A Technical Note presenting the present development is in preparation. A second note presenting an operational mathematical method of applying the unsteady-lift theory to specific dynamical problems is also being prepared.

Compressible flow.—A theoretical investigation of the effects of compressibility on the flow past an obstacle was made and the results applied to the cases of symmetrical Joukowsky profiles and elliptical profiles. The results were obtained in a closed form and are exact in so far as the second approximation to the compressible flow is concerned, the first approximation being the result for the corresponding incompressible potential flow. For the case of the symmetrical Joukowsky profile (Technical Report. No. 621) the angle of attack was taken to be arbitrary and the circulation chosen according to the Kutta condition. Formulas were developed for the velocity increments at the surface of the airfoil due to compressibility. In addition, formulas for the lift and the moment were given for thin profiles at small angles of attack. For the case of the elliptical profile, since the angle of attack was taken to be zero, expressions for the velocity distribution at the surface only were obtained (Technical Report No. 624). At the present time an investigation is in progress concerning the moment on an elliptic cylinder immersed in a two-dimensional subsonic compressible flow.

WIND-TUNNEL CORRECTIONS

Reasonably satisfactory theoretical methods have been available for years for correcting the results from open and closed wind tunnels of different commonly used sections, such as circular and square, in which the span of the airfoil or airplane model does not exceed about 75 percent of the tunnel width or diameter. It is still necessary to determine experimentally the corrections to allow for individual shapes of throat, as in the case of the oval throat of the full-scale wind tunnel, or for the cases in which the airfoil spans the jet completely, as in the cases of the Committee's high-speed wind tunnels.

The full-scale wind tunnel.—Comparisons between test data obtained in flight and in the full-scale wind tunnel have shown that the results obtained in the tunnel closely approximate free-flight conditions. The results of a comparison of the maximum lift coefficients obtained with a Fairchild 22 airplane in flight and in the tunnel, mentioned in the last annual report, have now been published as Technical Report No. 618.

As a part of a general research program which has as its objective the improvement of the correlation of data obtained in the various wind tunnels of the Committee, the aerodynamic characteristics of three 6- by 36-foot airfoils of symmetrical section have been determined in the full-scale wind tunnel. The thickness ratios of these airfoils ranged from 9 to 18 percent to cover a normal range of wing thickness. A comparison of these data with results obtained with the same airfoil sections in other wind tunnels will result in improving the precision with which wind-tunnel data may be applied to flight conditions. The results of this investigation are presented in Technical Report No. 647.

The 7- by 10-foot and the 4- by 6-foot wind tunnels.—An investigation has been started in the 7- by 10-foot wind tunnel, in which the airfoils span the rectangular throat, to determine the correction necessary to reduce airfoil data obtained in that tunnel to true airfoil section characteristics. Thus far, the investigation has yielded a satisfactory correction to the lift that is in good agreement with the theory. The corrections for the drag and the pitching moment are not yet considered entirely satisfactory, and further tests are contemplated.

Until recently the 5-foot diameter vertical tunnel has been used principally for investigations relating to the spinning problem. This tunnel has now been changed to have a rectangular 4- by 6-foot closed throat and is to be used chiefly for studies involving two-dimensional flow. The modification of this tunnel now makes available a piece of equipment that should be fairly well adapted to this type of work and also well adapted to general aerodynamic research at moderate values of the Reynolds Number.

The 11-inch, the 24-inch, and the 8-foot high-speed wind tunnels.—Preparatory to an investigation of special airfoils suitable for high-speed applications, an extensive investigation of tunnel-wall effects has been made for the 11-inch, the 24-inch, and the 8-foot high-speed wind tunnels. Inasmuch as these tunnels are all of circular throat and the airfoils are mounted similarly in all, it was possible by a comparison of the results from airfoils of corresponding chord from the three tunnels to determine the correction for each. Preliminary work was conducted in the 11-inch and the 24-inch wind tunnels. Later, tests identical in nature were made in the 24-inch and the 8-foot wind tunnels to check the the preliminary work and finally to evaluate the wall effect and the end-leakage corrections for the drag and the lift-curve slope.

EFFECTS OF ICE FORMATION AND ITS PREVENTION

The icing of aircraft is still one of the most serious problems confronting airplane operators. An investigation was made during the past year in the full-scale wind tunnel to determine what effect ice formation has on the aerodynamic characteristics of a wing. A formation simulating one depicted in photographs forwarded by one of the air-line companies was built up on an N. A. C. A. 23012 airfoil and tested. It was found that the maximum lift coefficient was reduced from 1.32 to 0.80 by the formation and the profile-drag coefficient was increased by 90 percent. It can be seen that the increased stalling speed resulting from such a formation could be very dangerous, particularly if the pilot had to rely upon his air-speed indicator to warn him of the approaching stall.

In order to obtain a clear statement of the various aspects of the icing problem, a questionnaire was submitted to air-line operators during the past year requesting them to outline the difficulties experienced in flight and to suggest a line of research. The replies obtained from this questionnaire have served as the basis for the preparation of a comprehensive program of research. The carrying out of this program will be facilitated by the new refrigerated tunnel, which has been recently added to the Committee's equipment. This tunnel makes possible the testing of models having a chord up to 6 feet.

Preliminary tests have been carried out in this tunnel to study the use of exhaust heat as a means of preventing ice formation on the leading edge of a wing. The possibility of using steam generated by the exhaust heat to prevent ice formation is being investigated on an airplane in flight. In these tests, the exhaust from one cylinder of a 9-cylinder engine is used to generate steam that is conducted to a condenser covering a portion of the leading edge of the wing. From the results of the tests both in the wind tunnel and in flight, it appears that, although there is plenty of heat available in the exhaust, merely heating the leading edge of the wing is insufficient. It is now planned to extend the study to investigate means of distributing heat over the entire wing chord.

Additional flight tests have been made to test the usefulness of preparations that decrease the adhesion of ice to the wing. Preparations containing soluble materials have thus far been found to be practically worthless. Other tests conducted with a mercury-amalgamated surface showed that, even though the adhesion of ice to the wing was reduced to a very small amount, the ice would continue to form in practically the same manner as on the untreated surface.

ROTATING-WING AIRCRAFT

In the hope of developing an improved method of direct control for rotating-wing aircraft, research during the past year has been restricted to a theoretical study of rotor control systems. The effect of periodically feathering the blades of an articulated rotor has been analyzed in detail and the aerodynamic identity of the Hafner and Cierva control systems has been mathematically demonstrated. As yet the study has not been extended to cover feathering control of rigid rotors but it is hoped that this can be done in the near future.

A study of the torque equilibrium in the autogiro rotor has been completed and the results published in Technical Report No. 623. This study simplifies and improves the previous method of calculating the inflow velocity required to maintain autorotation in a given rotor. Correct estimation of the inflow is particularly important because all rotor characteristics depend directly on inflow velocity.

MISCELLANEOUS TESTS OF MODELS AND AIRPLANES

In accordance with requests of the Army and Navy and in keeping with the policy of the Committee, a large number of complete airplane models have been investigated in the full-scale, the 20-foot, and the 7- by 10-foot wind tunnels. Most of the models have been tested for the military services but some have been tested for manufacturers at their expense.

In order to determine means for eliminating errors due to variations of wind velocity with height, a series of flight performance tests has been made with airplanes under conditions such that the effect of the gradients could be determined. The results of these tests, which are now being analyzed, indicate that such gradients as are experienced in ordinary weather may influence the rate of climb by as much as 10 percent.

NATIONAL BUREAU OF STANDARDS

WIND-TUNNEL INVESTIGATIONS

The aerodynamic activities of the National Bureau of Standards have been conducted in cooperation with the National Advisory Committee for Aeronautics.

Wind-tunnel turbulence.—The most useful method of describing the statistical properties of wind-tunnel turbulence appears to be that in terms of intensity and scale, corresponding to the description of the molecular motion of a gas by average molecular velocity and mean free path. Extensive measurements of scale and intensity and of their aerodynamic effects on the drag of spheres were published last year in Technical Report No. 581.

It is also possible to give a somewhat more detailed picture by considering the fact that eddies of different size are present and investigating the distribution of intensity with size. The procedure is analogous to the classical treatment of light waves. By inserting electrical filters in the amplifier circuit of the usual hot-wire equipment, it is possible to determine the "spectrum" of turbulence. The spectral distribution curve gives the fraction of the total energy of the turbulence arising from frequencies in a narrow region as a function of the mean frequency of the region.

Some studies of this type have been made during the past year. In the interim G. I. Taylor has shown that the spectrum curve is the Fourier transform of the correlation curve used in determining the longitudinal scale of the turbulence, and one may readily be computed from the other. Our measurements confirm this result, and the forms of the curves suggest that wind-tunnel turbulence is a generalized chance phenomena.

The study of the change in the spectrum as the turbulence decays shows that the energy in various frequency bands does not decay independently or according to any simple law but that there is a continual transfer from low frequencies to high frequencies.

The results of these studies were presented at the Fifth International Congress for Applied Mechanics and will be published in the proceedings of the Congress.

Effect of turbulence on boundary layers.—In the annual report last year a rather extensive account was given of the work then in progress on the study of the speed distribution in the boundary layer of an elliptic cylinder at tunnel speeds high enough to produce transition from laminar to eddying flow and for intensities of turbulence of 0.85 and 4.0 percent. A description was given of a simple device consisting of a hot wire on a sliding band, for quickly locating the transition. With this device a survey was made of the effect of intensity and scale of turbulence on the location of the transition zone. It was found that the distance of the transition zone from the nose was a function of the product of the intensity of the turbulence by the fifth root of the ratio of a characteristic dimension of the cylinder to the scale of the turbulence, corresponding to the theoretical relation suggested by G. I. Taylor. A report on the work is in process of publication as a Technical Report.

Investigation of boundary layer by diffusion of heat.—Studies of turbulence within a thick boundary layer in which the flow is eddying have been continued. The layer is formed on the surface of a flat plate 10 feet wide and 24 feet long installed in the 10-foot wind tunnel. At a distance of 18 feet from the leading edge, the boundary layer is about 3 inches thick. The distribution of the fluctuations of the component in the direction of mean flow has been measured by the usual hot-wire equipment. The component of the fluctuations normal to the plate has been measured by the method of thermal diffusion and some work has been done by the same method on the component parallel to the plate but normal to the direction of mean flow.

Dr. H. K. Skramstad has devised a relatively simple method of measuring the eddy shearing stress, or more specifically, the mean value of the product of the component of the velocity fluctuation in the direction of the mean flow and the component at right angles to the plate. The exploring head is a hot wire at 45° to the direction of the mean flow and measurements are made with the wire in various planes with respect to the direction of the velocity gradient, the wire holder being rotated about an axis parallel to the direction of mean flow. The head is used with the usual compensated amplifier and thermal milliammeter. It can be shown that the eddy shearing stress is proportional to the difference between the maximum and minimum readings which are found at opposite inclinations of the wire in the plane of the velocity gradient. Measurements are in progress with this apparatus.

Modernization of wind tunnel.—It has been obvious for some time that further progress could be expedited with a wind tunnel of low turbulence. The 4½-foot wind tunnel has been rebuilt as a return-circuit wind tunnel, the same 75-horsepower motor being used and the 4½-foot octagonal working section being retained. A contraction ratio of 7.1 was found feasible in the present building. A series of wire screens of no. 18 mesh is used in place of a honeycomb, although provision is made for a honeycomb if its installation proves desirable. There is every indication that the turbulence in this modernized tunnel is less than one-tenth percent of the mean speed.

AERONAUTIC-INSTRUMENT INVESTIGATIONS

The work on aeronautic instruments has been conducted in cooperation with the National Advisory Committee for Aeronautics and the Bureau of Aeronautics of the Navy Department.

Investigations.—A report on the results on experiments to determine the performance characteristics of venturi tubes used in aircraft for operating air-driven gyroscopic instruments has been issued as Technical Note No. 624.

The gyroscopic instruments now used in navigating aircraft have been described, and data on their performance given, in a report which is to be submitted for publication as a Technical Note. The report includes a discussion of the new gyromagnetic compass.

A report on the theory and performance of rate-of-climb indicators as now designed is in preparation. The latest instruments indicate rate of climb in the standard atmosphere and are compensated for temperature.

An investigation of corrugated diaphragms has been started during the fiscal year. A satisfactory procedure of manufacturing the diaphragms hydraulically has been evolved. Performance data are being obtained on single, geometrically similar diaphragms of various diameters and thicknesses of beryllium copper and phosphor bronze. The manufacturers of aircraft instruments have cooperated, particularly by furnishing information on methods of manufacture and in suggesting problems for investigation.

Considerable progress has been made in the development of a synthetic lubricant for use in instruments. The lubricant does not spread on brass, steel, or jewels, has a low vapor pressure, and may be usable at temperatures down to about $-30°$ C. Life tests are in progress.

Tests and test methods.—A turntable used to test accelerometers has been modified so that single-component instruments may be subjected to a continuous sinusoidal acceleration and to a part cycle of such an acceleration. The frequency and the amplitude of the acceleration are controllable to an adequate degree. The modification consists of the addition of a fixed pulley concentric with the turntable, and a pulley free to turn at the rim of turntable. When the pulleys are connected by a belt and the turntable rotates, the rim pulley rotates with respect to the turntable. A single-component accelerometer properly mounted on the rim pulley is thus subjected to a sinusoidal acceleration. Varying the diameter of the rim pulley gives an independent control of the frequency of the sinusoidal acceleration. Part cycles are obtained by the use of a friction clutch and stops to control the rim pulley.

An apparatus for subjecting aircraft instruments to a drop test has been designed and constructed.

Extensive tests were made on experimental resistance thermometers for use in measuring oil and intake-air temperatures. As a result, manufacturers greatly improved the reliability of the instruments under adverse service conditions.

A test apparatus for measuring oxygen delivered by oxygen regulators at various altitudes was designed, orifices being utilized for making the flow measurement.

New instruments.—Development is being continued on an air speed-acceleration recorder and a fuel flowmeter of the orifice type. A stick-force indicator was constructed. A number of pressure gauges were modified to indicate either suction or pressure when applied to the inside of the diaphragm capsule.

SUBCOMMITTEE ON AIRSHIPS

The Subcommittee on Airships formulates and recommends programs of airship research to be undertaken at the Langley Memorial Aeronautical Laboratory, and maintains contact with the work in progress.

The present program provides for an investigation in the Committee's 20-foot wind tunnel of boundary-layer control on airship forms. The investigation is to be conducted on a model approximately 20 feet in length, having a fineness ratio of 6. An arrangement with blower in the nose and an arrangement with stern propeller, with control of the boundary layer by both suction and discharge jets, will be included.

The information being obtained by the Committee's laboratory on the subject of gust intensities and gradients, in connection with the problem of structural loads on airplanes in flight, is of interest also in connection with airship design and operation. This work is described briefly in the report of the Committee on Aircraft Structures.

The subcommittee has kept informed of the latest developments in connection with airship design, construction, and operation, particularly the activities in Germany, where interest in the airship remains active, in spite of the unfortunate disaster to the *Hindenburg*. A technical Note (No. 637) has been issued by the Committee giving the results of an investigation by the Goodyear-Zeppelin Corporation of the fatigue strength of aluminum-alloy airship girders of several different types. A number of translations of German papers dealing with airship problems have been issued by the Committee as Technical Memorandums.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The Subcommittee on Meteorological Problems keeps in contact with the progress of investigations being conducted by the various agencies on problems relating to atmospheric conditions which are of particular importance in connection with aircraft design and operation.

Atmospheric disturbances and their effect on airplane accelerations.—The study by the Langley Memorial Aeronautical Laboratory of gust intensities and gradients and their effect on the accelerations on airplanes in flight has been continued. Additional data have been obtained in flight investigations with light airplanes. Measurements have also been made on two very large airplanes, and the more recent results indicate that there is no correlation between gust intensity and gradient. One particularly interesting acceleration record obtained on a very large airplane indicated a true gust velocity of approximately 57 feet per second, and the gust was found to reach maximum intensity in a distance of about 150 feet. This gust was downward in direction, and was experienced within a cumulo-nimbus cloud associated with a warm front.

Through the cooperation of a number of air-transport operators, the accumulation of data on accelerations on transport airplanes due to atmospheric disturbances has been continued. The total flying time represented by the records obtained is 57,000 hours. Records have been obtained in air-line operation over practically every part of the United States, on the routes from the East Coast to Bermuda, and to the northern part of South America, over the Andes Mountains, and across the Pacific.

A number of acceleration-altitude recorders recently completed are now being adjusted and calibrated for distribution to various Weather Bureau stations to obtain information as to the relation between gust intensity and altitude. A special instrument has been developed to indicate to the pilot when an acceleration of 2 g is reached, in order that he may observe particularly the atmospheric conditions involved.

Lightning hazards to aircraft.—The possible hazards to aircraft in flight due to lightning has been given special attention by the Subcommittee on Meteorological Problems during the past year. A special meeting of the subcommittee, to which representatives of the air-line operators were invited, was held on November 30, 1937, for the discussion of this problem. A number of experiences of pilots in connection with electrical phenomena were described. It was noted that, while there had been a number of instances of airplanes being struck, the resulting damage to the aircraft was of a very minor nature, and in most cases passengers, and occasionally even the pilots, were not aware of the incident. As a result of the discussion, it was agreed that, although the lightning hazards to aircraft did not appear serious at the present time, it was desirable that the problem be given further study. A Special Subcommittee on Lightning Hazards to Aircraft was therefore appointed, particularly to prepare two programs of investigation—one a short-range program, for the study of problems of immediate importance; and the other a long-range program, to provide for the extension of the present rather meager scientific knowledge of the nature of these electrical disturbances and the ways in which they may affect aircraft in flight.

Under the cognizance of this special subcommittee, investigations are being conducted in electrical research laboratories, of the effect of electric discharges simulating lightning strokes on sheet metal of the type used in aircraft construction. As the first step in the long-range program, information is being collected by means of questionnaires distributed among air-line pilots, as to incidents of electrical phenomena and the accompanying atmospheric conditions.

Ice formation on aircraft.—The study by the Langley Memorial Aeronautical Laboratory of the problem of ice formation on aircraft has been continued. The Committee has recently completed the N. A. C. A. ice tunnel for model tests in connection with this program, and a program of investigation of the aerodynamic effects of ice formation on airplanes and means of prevention or elimination is being initiated. In addition, the feasibility of ice prevention on airplanes by the utilization of heat from the exhaust is being investigated on an airplane in flight.

SUBCOMMITTEE ON SEAPLANES

The world-wide interest in seaplanes of large size has been intensified by the serious discussion of the possibility of replacing the very large and very fast luxury liners by fleets of large flying boats as proposed in the report of the United States Maritime Commission on "Aircraft and the Merchant Marine." The full effects of this proposal, together with those of the announced intention to build machines of practically double the size of existing machines for this country's own transoceanic services, have not yet appeared, but that they will have an important bearing on both domestic and foreign developments cannot be doubted.

In the case of such large craft, with the high wing loadings proposed, the aerodynamic drag of the hull becomes an important part of the total drag, even though the size of the hull may be reduced somewhat by putting accommodations in the wings. The air speed and the fuel required for a given voyage may be quite seriously affected if the requirements for taking off from the water are considered without reference to the more important requirement of low drag in flight. Work on the improvement of the forms of hulls suitable for flying boats of large size is being conducted with these facts in mind.

A large part of the hydrodynamic research in the past year has been devoted to investigations of a specific nature at the N. A. C. A. tank in connection with the development of projected seaplanes. These investigations were chiefly concerned with the effect of changes in hull form on water resistance and spray and required the use of larger models than may be towed in other tanks in the United States. The N. A. C. A. tank therefore has an important relation to the present development of large military and commercial flying boats.

In the specific investigations as well as the general research program, the projects of immediate interest to the military services have been given first priority. Tests of models of fifteen flying-boat hulls have been completed in the past year. Tank tests of a special nature, not applying to aeronautics but requiring high towing speeds, have also been conducted for the Bureau of Construction and Repair, the Bureau of Ordnance, and the Bureau of Engineering of the Navy Department. The magnitude of the work on these projects caused a reduction in the time devoted to fundamental hydrodynamic problems but gave an opportunity for a more detailed study of some accumulated data and the preparation of the data for publication.

Plant and equipment.—The enlargement and improvement of the N. A. C. A. tank, begun last year, have been completed and a very definite improvement in the operation of the tank has been observed. The basin now has a length of 2880 feet and the towing carriage is powered to travel at speeds up to 80 miles per hour. As anticipated, these features have increased the speed and efficiency of routine testing. In addition, a reserve capacity has been created for hydrodynamic research at speeds greater than are obtainable elsewhere.

The enlargement of the tank has required parallel improvement of the associated equipment. The great length of the basin has necessitated the development of new methods of aligning and leveling the rails, and the suppression of waves and surges. Various refinements and additions have been made to the carriage and the towing gear for the purpose of improving the ease and accuracy of recording the results of tests. A number of auxiliary devices have been constructed for use in the special tests that have been made and the range of adaptability of the equipment has been greatly increased.

Tests of models of representative flying-boat hulls.—In the investigation of the effect of form of hull on hydrodynamic resistance, tests have been made of large models of the hulls representing a variety of methods used to obtain satisfactory take-off performance.

N. A. C. A. model 36 was originally designed to be used in tests of stub-wing stabilizers and, in order to facilitate fitting different types of stubs, was given a rather long parallel middle-body. This form has proved to be of considerable interest to seaplane designers, not only because the parallel body gives a form of hull that makes it possible to use a convenient arrangement of the interior, but also because the aerodynamic drag as measured in the Committee's twenty-foot wind tunnel over a wide range of angle of attack is quite low. The general tank tests indicate that the hydrodynamic characteristics are favorable and that the water resistance at the hump speed is exceptionally low. The results of these tests are presented in Technical Note No. 638.

Effect of rivet heads on frictional resistance.—The increasing use of flush riveting in the construction of all-metal aircraft has led to a need for information as to the effect of rivet heads on hydrodynamic resistance during take-off. The increase in frictional resistance caused by typical rivet heads was determined at the N. A. C. A. tank by tests of planing surfaces fitted with full-size rivets. The surfaces were towed at the high water speeds encountered by seaplanes during take-off and the relative resistance of the various shapes of head were measured. An analysis of the data, published in Technical Note No. 648, shows that for the rivet heads investigated the increase in frictional resistance is directly proportional to the height of the head. The order of merit of commonly used heads for seaplane hulls is therefore flush countersunk, oval countersunk, brazier, and round. The magnitude of the increase in hydrodynamic resistance depends, of course, on the number of rivets required in the structure.

Uses of tank data.—Investigations of resistance in the N. A. C. A. tank are made general in application by the fact that the models are tested over a wide range of speed, load, and trim. The results are intended to be used as a basis for design calculations to determine take-off resistance and to compare the advantages and disadvantages of various forms of hull. A discussion of possible uses of the "general" test data is presented in Technical Report No. 625. Among the subjects treated in this report are selection of best beam, importance of maximum trim, location of the center of gravity, and comparison of hull lines. It is concluded that the ranges of load and speed employed in the general tests are ample to cover future increases in the size of seaplanes.

In Technical Note No. 643 it is shown that in the solution of some design problems the normal resistance curve for a flying boat may be approximated by two straight lines. By the use of this approximation, charts are developed to aid in the rapid solution of certain problems involving the effect of the shape of the resistance curve on take-off time and distance or the determination of the accelerating forces required to meet specified take-off performance.

The N. A. C. A. trim indicator.—Further experience with the N. A. C. A. trim indicator has emphasized the importance of holding a seaplane at the trims that give least resistance during take-off.

The Committee has constructed and made available for loan to operators and manufacturers a form of trim indicator based on the principle described in Technical Note No. 486. The instruments have proved to be of great assistance in the test flying of large flying boats of new design, particularly those designed for commercial transoceanic service. It is in these types of service and on long-range military seaplanes, which, heavily loaded, must take off with comparatively little reserve power, that a "precision" take-off is essential. A relatively small increase in the total load with which a seaplane may safely take off represents a large increase in payload. Accordingly, it appears that a trim indicator of some form is essential to economical operation of seaplanes in transoceanic service.

In seaplanes that have a large excess power that may be used for take-off, the use of a trim indicator is of much less importance for routine service.

For test flying and in the training of pilots to fly a particular design the optical type of instrument is very useful and is simple and easily adapted to almost any arrangement of instrument board and windshield. An interesting application of the N. A. C. A. trim indicator in this manner was its installation and use for 100 hours of testing in an experimental flying model of a large flying boat.

SPECIAL SUBCOMMITTEE ON VIBRATION AND FLUTTER

As a result of the trend toward larger and relatively more elastic structures in airplane design, the problem of flutter has become increasingly important. The study of this problem at the Langley Memorial Aeronautical Laboratory and by other organizations has been continued during the past year.

The Special Subcommittee on Vibration and Flutter has held two meetings during the past year particularly for the consideration of the subject of flutter. Because of the activities of a special subcommittee recently appointed by the Committee on Aircraft Structures in the study of stresses due to resonant vibration and of the proof testing of aircraft structures in flight, the discussion at these meetings was chiefly limited to the subject of flutter. Reports of progress in the investigation of the subject were presented by the representatives of the various Government organizations. At the second meeting the report recently completed by the Committee's laboratory for issuance in advance confidential form to American manufacturers was presented and discussed.

The flutter problem.—The theoretical investigation of flutter started more than four years ago by the Langley Memorial Aeronautical Laboratory has been extended and generalized. In particular, the scheme of calculation of the critical flutter speed has been simplified to a routine method of calculation that includes the effect of structural damping. A large number of charts have been prepared to facilitate judgment of the effects of the various wing parameters affecting the flutter speed. The effects of the essential parameters in the cases of flexure-torsion, flexure-aileron, torsion-aileron, and flexure-torsion-aileron flutter have been listed and discussed. A series of nearly one hundred experiments in the high-speed tunnel recently completed has shown that the flutter speed can be calculated on the basis of the theory with good accuracy if the parameters are correctly specified or measured. Experiments made on cantilever wings indicate that, by slight modifications, the two-dimensional flutter theory can be used to predict the flutter speed, even for wings of fairly small aspect ratio. A study has been made of the actual mode of vibration involved in flutter and of the respects in which this mode differs from the vibration modes at zero air speed. A number of interesting conclusions have been reached; in particular, that the bending frequency involved in a flutter problem is greater than the frequency involved in a vibration mode at zero air speed, the difference depending mainly on the structural damping. The three-dimensional flutter problem is essentially understood as a problem of minimum boundary value, which fortunately can be handled by slight semi-empirical modifications of the two-dimensional flutter theory.

The problems of identifying the parameters and possible types of flutter on an airplane have been discussed. In the case of the airplane tail assemblage this may be particularly difficult and ground or flight tests may be necessary or desirable. The effects on the flutter speed of large bodies, such as nacelles or floats, on the wing or attached to it have also been investigated, as well as the effect of wing bracing and restraining wires. A report has been prepared presenting the results of this work. This report will include also a theoretical study of forced vibrations and air damping of the wing system, supplying a clearer perspective of the nature of flutter.

Vibration of tapered beams.—An exact solution has been developed for the equation of torsional vibration of a large class of tapered beams. Experimental measurements on five model beams give frequencies in agreement with the theory.

Air damping of vibration.—Fundamental data have been obtained on air damping by vibrating a flat plate in a chamber in which the pressure and the nature of the gas could be changed. The results have been expressed in terms of two new nondimensional coefficients which play a role in vibration similar to that of drag coefficient and Reynolds Number in steady flow.

Damping of propeller vibration.—A technique and method of analysis of the separate components of damping of the vibration of a freely suspended propeller have been developed. Air damping of the blades and friction in the hub were found to be predominant, in comparison with internal damping in the material of the blade.

Airplane vibration.—A systematic method of measurement and analysis of airplane vibration is being planned in order to be able to predict flutter velocities in actual airplanes. Measurements have been made on the tail assembly of one airplane to determine the frequencies and modes of vibration that determine the flutter characteristics.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

INCREASE IN ENGINE POWER

The power output of air-cooled engines has been limited by the quantity of waste heat that could be dissipated efficiently by the fins to the cooling air. The dimensions of the fins used on the cast-aluminum cylinder heads of present engines are dictated by the casting technique of the foundry. As the final step in the Committee's research on the effect of fin dimensions on heat transfer a method has been developed for attaching preformed metal fins to air-cooled cylinders so that advantage can be taken of the improvement in cooling resulting from large increases in the fin surface. This method removes all restriction in regard to dimensions of the cooling fins that can be used and opens the way to more efficient cooling and to a further large increase in the power of air-cooled engines.

High octane number fuels.—The continued increase in the power output of aircraft engines is principally obtained by the use of premium fuels having high antiknock values. The investigation to determine the maximum permissible engine performance with these fuels has been continued at the Committee's laboratory. The work is being carried out on fuels having octane numbers of 87 to 100 to which various amounts of tetraethyl lead have been added. This investigation is under the cognizance of the Subcommittee on Aircraft Fuels and Lubricants and is described in the report of that subcommittee.

Flow through poppet valves.—The intermittent air flow through poppet valves in engines is calculated by the use of coefficients determined under conditions of steady air flow. The Committee is determining the coefficients of flow for large-diameter poppet valves when operated in the same manner as in the engine. Measurements of the flow coefficients have been made at camshaft speeds from 130 to 1,200 revolutions per minute, at pressure differences up to 7.5 pounds per square inch and at valve lifts from 0.1 to 0.6 inch. The flow coefficients measured with steady flow can be applied to intermittent conditions without correction for valve opening speed or camshaft speed. The results of this investigation are being prepared for publication.

Piston temperatures.—With increase in the power of aircraft engines the aluminum-alloy piston and the cast-iron piston rings are required to transmit proportionally larger quantities of heat to the cylinder wall. An investigation is in progress to determine the important factors controlling piston cooling and to study the effect of engine and cooling conditions on piston temperatures. A method has been developed for attaching thermocouples to the piston and measuring piston temperatures under engine operating conditions. The thermocouple and potentiometer circuit is completed at bottom center for 20° of crank angle through contacts mounted on pneumatically operated plungers. Piston temperatures are being surveyed on a high-output single-cylinder Diesel engine and a modern air-cooled engine.

The 2-stroke-cycle engine.—The use of the 2-stroke instead of the 4-stroke cycle is an attractive method for increasing engine power per unit of displacement. The 2-stroke-cycle engine requires a pump to force the combustion and scavenging air into the engine cylinder. The Committee's research on the liquid-cooled spark-ignition fuel-injection engine has included a study of the effect on performance of variable exhaust-valve and inlet-port timing, scavenging pressure, and engine speed.

The sleeve-valve engine.—The two outstanding advantages of the single sleeve-valve engine over the poppet-valve engine are increased breathing capacity and higher allowable rotative speeds. These characteristics are fundamental requirements of future aircraft engines. The Committee's analysis indicates a decided superiority of the sleeve-valve over the two-poppet-valve type and a somewhat lesser superiority of the sleeve-valve over the four-poppet-valve type, equal flow coefficients being assumed for the sleeve and poppet valves. Since the flow coefficients may differ enough in the two cases to modify these conclusions appreciably, an investigation is in progress to determine the relative coefficients of flow through inlet and exhaust valves and sleeve ports under conditions of steady and intermittent flow.

COMBUSTION RESEARCH

The study of combustion in spark-ignition engines has been continued. New knowledge has been obtained of the combustion under knocking conditions with fuels of high octane number. Particular attention has been

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given to the determination of the effect of air flow within the cylinder on the distribution of fuel sprays, the rate of combustion, and the reproducibility of successive engine cycles. Several methods have been investigated for the recovery of waste heat from the engine exhaust gases.

Ignition lag in compression-ignition engines.—The variations in ignition lag and combustion associated with changes in air temperature and density have been studied for a Diesel fuel in a constant-volume bomb. The highest temperature of the bomb approximated that attained in a compression-ignition engine in the usual range of injection advance angles. The ignition lag was found to be essentially independent of the quantity of injected fuel. In order to obtain the best combustion and thermal efficiency, it was desirable to use the largest ignition lag consistent with a permissible rate of pressure rise. Technical Report No. 617 has been published giving the results of this investigation.

Knock in aircraft engines, if continued, may cause preignition, with consequent loss in engine power. The N. A. C. A. combustion apparatus is being used for a series of tests in which conditions causing knock are compared to conditions causing preignition. The preignition is caused by an electrically heated hot spot that can be maintained at a maximum temperature of 1,900° F. It is possible to adjust the hot-spot temperature so that flame proceeding from the spark plug at the opposite side of the combustion chamber causes auto-ignition of the charge at the hot spot. The results of this investigation are being prepared for publication.

Detonation research.—A photographic study of the combustion in a spark-ignition engine has been made, including both schlieren and flame photographs taken at high rates of speed. The results of this investigation have been published in Technical Report No. 622.

Exhaust-gas analysis.—In order to determine the lower heating value of a fuel from its calorimetric heat of combustion it is necessary to know the hydrogen-carbon ratio of the fuel. The methods described in the literature have not given satisfactory results with gasoline. An investigation is being made to develop a satisfactory method of analysis for these volatile hydrocarbons.

An investigation has been made to determine the interrelationship of the constituents of the exhaust gases of internal-combustion engines and the effect of engine performance on these relations. The work has included a study of single-cylinder and multi-cylinder spark-ignition engines and single-cylinder compression-ignition engines. Definite relations independent of engine design and operating conditions were found between the constituents of exhaust gases, air-fuel ratio, water of combustion, and combustion efficiency. Technical Report No. 616 gives the results of this investigation.

Air flow in cylinders.—With fuel injection into the engine cylinder, increased air turbulence assists in atomizing and distributing the fuel spray. The air flow within the cylinder of an engine has been investigated by the use of an engine with a glass cylinder. The data are recorded by motion pictures taken at rates of 2,500 frames per second of the motion of goose down inducted with the inlet air. The shrouded inlet valves considerably increased the distribution of the fuel within the cylinder. The air flow reduced the penetration of fuel sprayed from an annular orifice more than from round-hole orifices. The tangential swirl set up during the inlet stroke was found to continue throughout the compression and expansion strokes. A report is in preparation describing the investigation.

An investigation of the effect of air flow within the combustion chamber of a spark-ignition engine has been conducted on the N. A. C. A. combustion apparatus. By means of spark-schlieren photography and time-pressure records, a study has been made of the effects of air swirl on the combustion propagation. The air flow was produced by shrouds on the inlet valves, and was comparable with that obtained in the glass-cylinder engine. Directing the air in an orderly swirl resulted in great improvement in the reproducibility of successive engine cycles. When the velocity of the intake air was changed by blocking one of the inlet valves without changing the engine speed, there was a considerable increase in the rate of combustion. This same increase was obtained when two inlet valves were used by doubling the engine speed. The results of this investigation are being prepared for publication as a Technical Report.

FUEL CONSUMPTION

For modern long-range aircraft, the fuel load is approximately one-half the useful load, and means must be found for reducing the fuel consumption of the engines under cruising conditions. Research has been conducted on the design and development of an N. A. C. A. indicating fuel flowmeter and a mixture-ratio indicator for use in flight. The effect of operation at various percentages of full-load torque and of rated speed on the minimum specific fuel consumption of an air-cooled engine has been determined.

Fuel distribution.—The use of a fuel-injection system instead of the conventional carburetor should result in more uniform fuel distribution, more rapid engine acceleration, and satisfactory engine operation irrespective of the attitude of the aircraft. An investigation has been completed to obtain a comparison of the performance of an engine with a carburetor, with fuel injection into the inlet manifold, and with fuel injection into the cylinder. The results of this investigation, which are being prepared for publication as a Technical Note, show that slightly more power was obtained when the fuel was injected into the cylinder because of the increased volumetric efficiency due to the cooling action of the fuel spray. Fuel injection into the cylinder also permitted the use of manifolding that offered less restriction to the air flow. The minimum specific fuel consumption and the cylinder-head temperatures were the same regardless of the method used for distributing the fuel to the air.

The N. A. C. A. fuel flowmeter.—The use of a fuel flowmeter, which indicates instantaneous rates of fuel flow, makes it possible to operate aircraft engines at mixture ratios which will result in low specific fuel consumptions. In multiengine aircraft the fuel flowmeter makes it possible for all engines to be operated at the required rates of fuel flow. The N. A. C. A. flowmeter, which indicates mass rate of fuel flow, has been modified as a result of flight tests of the Army Air Corps and is now considered a satisfactory instrument for use in flight.

Mixture-ratio indicator.—The need in aircraft for a mixture-ratio indicator capable of indicating mixtures both leaner and richer than the theoretically correct mixture has led to the development by the Committee of an instrument capable of indicating any practical fuel-air ratio. A laboratory design has been used successfully and a design suitable for flight testing has been built. A report on the flight performance of this instrument is being prepared for publication.

ENGINE COOLING

The power output and the specific fuel consumption at which air-cooled engines can be operated are dependent upon satisfactory engine cooling. The use of radial air-cooled engines having two and three banks of cylinders for the obtaining of increased power requires a large increase in the effectiveness of the cooling fins placed on the cylinder head and barrel. Particular attention must be given to the cooling of the cylinder barrel to insure satisfactory operation of the piston and piston rings with engines of higher power.

Fin dimensions.—The quantity of heat dissipated from a finned surface is a function of the dimensions of the fins. The analysis being made to determine the best proportions for metal fins for given rates of heat flow has been continued. Thin, closely spaced aluminum fins of optimum proportions were found to give approximately 25 percent more cooling for the same fin weight and pressure drop (4 inches of water) than thicker, correctly proportioned fins having a spacing of 0.14 inch. As the heat dissipation from the cylinder walls of air-cooled engines is proportional to the 0.65 power of the indicated horsepower developed, it follows that a 25-percent improvement in cooling should permit a 42-percent increase in the engine power.

The power required to cool the widely spaced finned cylinders was slightly more than for the closely spaced finned cylinders at a pressure drop of 4 inches of water. For a pressure drop of 12 inches of water, however, the power required to cool the widely spaced fins was found to be approximately 25 percent more than for the fins of optimum design. Although thin, closely spaced fins are difficult to construct by present methods they have been found to be desirable, especially when constructed of metals of high thermal conductivity.

Heat-transfer coefficients.—The investigation to determine the surface heat-transfer coefficients of finned cylinders has been continued. Heat-transfer tests have been conducted on fin surfaces spaced 0.010 inch and on widely spaced, thick-finned surfaces. The object of these tests was to determine the trend of curves correlating the surface heat-transfer coefficients. A report is being prepared presenting the results of this investigation.

Flow around finned cylinders.—In order to obtain a better understanding of the phenomena attending the cooling of air-cooled engines, photographs were taken, by the use of titanium tetrachloride, of the air flow between the fins of a large-scale cylinder model. The double spiral, which has been shown to occur in the flow through bent pipes, was observed. The flow has an outward radial component, away from the cylinder axis, in the region near the center of the fin space, and an inward radial component along the fin surfaces. The radial components of the velocity tend to disappear as the fin spacing is reduced. At a fin space corresponding to 5/32 inch for a cylinder diameter of 4.66 inches, the radial components were very clearly evident, whereas, at a fin spacing corresponding to 1/8 inch, no indication of a radial velocity component could be detected. The radial components also disappeared at low velocity.

The problem was studied further by tests on model finned cylinders both in ducts and in the front of an engine cowling. Two Technical Notes, Nos. 649 and 655, show the effect of streamlining the cylinder and the effect of baffle length on optimum fin spacing. Also, it is shown by analysis and from experimental results that cooling on a finned cylinder obeys the same physical laws known to apply to heat transfer for pipes. The solution of a practical case is made comparatively easy by the use of these laws and knowledge of the cooling performance of actual engines.

An investigation has been undertaken to determine the characteristics of the cooling in the front of a cowled engine. The irregular flow existing in this region results in a cooling dependent on air speed in a little-understood manner. The tests show the effect on the cooling of variations of position, fin orientation, fin spacing, and fin width, with the propeller operated to simulate the cruising condition and the ground condition, and with a spinner to increase cooling pressure in take-off. The results from these tests will show both the nature of the phenomenon and how to make the best use of it for cooling.

Cylinder temperature correction factors.—Technical Report No. 645 has been prepared presenting the results of the investigation made to determine the correction factor for correcting cylinder temperatures of air-cooled engines to a standard atmospheric temperature. The correction factors include flight-test conditions such as level flight, climb, and take-off, the condition with the airplane stationary on the ground, and the conditions of a constant mass flow of cooling air, and of a constant velocity of the cooling air.

Heat-transfer process.—A study has been made of the transfer of heat from the gases of combustion to the cylinder wall, and from the cylinder wall to the cooling fins on air-cooled cylinders. Necessary empirical constants in the heat-transfer equations have been determined from engine tests of a Wright Cyclone cylinder. The effects on cylinder temperature of the following engine conditions were determined: Exhaust back pressure, air fuel ratio, spark timing, carburetor air temperature, engine speed, brake mean effective pressure, cooling-air temperature, and pressure drop across baffled cylinder. Equations were obtained for the cylinder head and barrel temperatures as functions of the engine and cooling conditions. A simple method of comparing the cooling of different air-cooled engines has been developed. A report on this investigation is being prepared.

Blower cooling of engines.—Preliminary studies have been made to determine the relative merits of cooling air-cooled engines by induced flow and by a blower. The necessity for blower cooling at high altitudes with present engines and at sea level with future engines requiring higher pressure drop has been reviewed. Blowers and blower arrangements of several types have been examined with the object of determining their suitability for various conditions with special reference to large airplanes and to flying at high altitudes.

The N. A. C. A. air-cooled cylinder.—The cylinders of air-cooled engines are formed of a cast aluminum head screwed and shrunk onto a steel liner. The dimensions of the fins that can be cast on the head are limited by the casting technique of the foundry. The dimensions of the fins on the barrel are limited by difficulties in machining. The Committee has discovered a method of attaching preformed fins to the cylinder head so that all restrictions as to fin dimensions that can be used are removed and advantage can be taken of the improvement in cooling resulting from large increases in the fin surface. The internal drag horsepower required to cool the N. A. C. A. cylinder is a negligible amount of the engine power developed. This method of construction should make possible large increases in the power output of air-cooled engines without sacrifice of satisfactory engine cooling.

SUPERCHARGER RESEARCH

The altitude selected for flight with transport aircraft is dependent to a large extent upon weather conditions. The requirement of flight at high altitudes has greatly increased the interest in highly supercharged engines.

Performance of superchargers.—Computations have been made to determine the power required and the heat that must be dissipated to maintain discharge-air temperatures of from 60° to 240° F. when an airplane is operating at altitudes from sea level to 80,000 feet with superchargers having a range of compression exponents from 1.0 to 2.0. The boost pressures covered a range from zero to 100 pounds per square inch. The results of this analysis will be applied to an engine to determine the net power and the fuel consumption under these supercharged conditions with gear-driven and turbine-driven superchargers.

Air intercoolers.—The reduction in the antiknock quality of a fuel with increase in inlet-air temperature necessitates the use of an efficient intercooler to reduce the air temperature on supercharged and boosted engines. The present core-type intercoolers have been found to crack and leak at boost pressures of the order of 15 pounds per square inch. A new type of finned intercooler has been tested to determine its heat transfer.

Supercharging of aircraft cabins.—An analysis has been made of the requirements of superchargers for maintaining cabin pressures at high altitude. The results indicate that the Roots-type blower should be very satisfactory for this service because the volume of air required can be controlled by the quantity of by-passed air. The power expended on the by-passed air is small.

COMPRESSION-IGNITION ENGINES

The use of compression-ignition engines in aircraft offers advantages because of the inherent low fuel consumption and the reduction in fire hazard. These two characteristics are of particular importance for trans-oceanic aircraft. The Committee's research on the compression-ignition engine for aircraft includes a study of the factors influencing the injection and combustion of fuel sprays suitable for this type of engine and the development of a combustion-chamber form that gives good mixing of the fuel and the air. The problems involved in the application of this combustion chamber to the radial air-cooled engine are being investigated.

Combustion research.—The ignition lag and the rate of combustion of the fuel oil in compression-ignition engines can be varied by the addition of small quantities of certain chemicals to the fuel oil. The Committee has investigated a range of fuel oils, mixtures of fuel oil and alcohol, and fuel-oil dopes to determine their effect on power output and fuel consumption. The engine power has been shown to be practically unaffected by fuel quality; fuels with long ignition lag may be expected to result in rough running. Combustion inhibitors in the form of small percentages of isoamyl nitrate, ethyl nitrate, and tetranitromethane have been shown to lower the rate of pressure rise and to have a negligible effect in increasing power outputs. Alcohol mixed with fuel oil may give a maximum power increase of 4 percent at, however, a prohibitive increase in fuel consumption. In general, it has been found that special fuels are unnecessary in obtaining best performance with a compression-ignition engine; that no gain in power or economy results from their use. A Technical Report presenting the results of this investigation is being prepared.

A study of combustion rates as influenced by the type of fuel, the rate of injection, and the injection advance angle has been started to cover a range of engine speeds from 1,500 to 2,500 r. p. m. The combustion rates are being determined from an analysis of indicator diagrams.

The investigation of ignition lag with the constant-volume bomb has been extended to include several Diesel fuels of different cetane number and different concentrations of Diesel fuel dopes. The results indicate that, at the lower air temperatures in the bomb, the variation in fuel rating order for a series of fuels is somewhat greater than it is in the C. F. R. engine or the N. A. C. A. test engines. The variation in ignition lag over a range in cetane number decreases markedly with increase in air temperature and density. A summary of these results is being prepared for publication.

The 4-stroke-cycle engine.—The problems connected with the adaptation of the N. A. C. A. displacer type of combustion chamber to an air-cooled cylinder having a 5-inch bore and a stroke of 5½ inches are being investigated. Indicated mean effective pressures of 250 pounds per square inch have been obtained at 2,200 r. p. m. with a boost pressure of 10 pounds per square inch. The dimensions and arrangement of the finning on the aluminum cylinder head and the steel cylinder barrel are being studied to insure adequate cooling.

A report describing tests under simulated altitude conditions has been prepared and published as Technical Note No. 619.

A liquid-cooled cylinder has been designed for a single-cylinder engine having a bore of 6⅛ inches and a stroke of 7 inches to investigate problems peculiar to obtaining a high output from a cylinder of a size comparable with the largest air-cooled engine cylinder now in use. The N. A. C. A. displacer-piston combustion chamber will be used with a conventional air-cooled engine and a pushrod-operated valve gear.

As a means of obtaining better utilization of the combustion air, a cylinder head has been constructed embodying a modification of the vertical-disk displacer combustion chamber to allow the use of two inlet and two exhaust valves, and two advantageously located injection valves. With this arrangement all the combustion air will be forced to flow past the fuel-injection valves. Preliminary performance tests of the cylinder head have been made with a single fuel-injection valve mounted in the top of the cylinder for comparison with the performance obtained with the two fuel-injection valves.

The 2-stroke-cycle engine.—An investigation of the effect of variation of the exhaust function has been completed over a wide range of exhaust timings and exhaust-valve cam dwells for several engine speeds and scavenging pressures. Tests have been made to compare the engine performance with the 62 inlet ports in the cylinder liner arranged to direct the air into the cylinder at a common angle or in several bands at different angles to the radial. The best performance was obtained with the single-entry angle of 56° common to all ports. Design alterations to the connecting rod, exhaust valve cams, and inlet ports have been made to make it possible to increase the maximum engine speed from 1,900 to 2,400 r. p. m.

NATIONAL BUREAU OF STANDARDS

Phenomena of combustion.—A spherical bomb with central ignition and auxiliary equipment which yields simultaneous photographic records of the travel of flame and the development of pressure during gaseous explosions has been in use throughout the year. In such a bomb the samples of fuel required are very small, initial conditions may be accurately controlled, and combustion progresses under idealized circumstances, since the spreading flame is undisturbed by turbulence, by contact with restraining walls, or by heat losses other than the unavoidable loss due to radiation. It is therefore possible to study the rate of energy liberation and the speed of flame relative to the remaining unburned charge throughout the succeeding stages of the burning. Although these factors are of fundamental importance in the engine cylinder, they cannot be accurately measured there because of the complicated geometrical configuration of the combustion chamber.

Early experiments with the spherical bomb indicated clearly that high accuracy in the measurement of pressure and flame radius was essential to satisfactory results. The difficulties of attaining such high accuracy in following the extremely rapid course of an explosion necessitated careful development of both the experimental apparatus and the technique of securing and analyzing the observations.

During this development period, mixtures of carbon monoxide and oxygen were used. The results of these test experiments show not only that the apparatus is capable of serving the purpose for which it was designed, but also indicate some interesting characteristics of this particular explosion process.

In general, the inflammation of a unit mass of this mixture produces an increase in pressure which does not vary greatly with the temperature and pressure prevailing in the unburned charge. However, the energy liberation per unit mass of charge is, without exception, less than would be expected if the burning were completed in the front surface of the flame.

Very early in the explosion, while the rise in pressure is too small to measure, the flame records all show that the spatial velocity increases for a short time. These low initial velocities cannot be accounted for solely by low speeds of advance of the flame into the unburned mixture, but indicate that the amount of expansion or energy liberation per unit mass of charge is much lower in the very early part of the explosion than later on.

The observed behavior of the flame can be explained by assuming that the burning is not complete in the flame front, but continues throughout a zone of considerable thickness behind the front. Other possible ways to study this hypothesis in the light of more direct evidence are being considered.

Records have been made of explosions of the hydrocarbon fuels benzene, N-heptane and iso-octane with air, but these results are not yet sufficiently complete for presentation.

Explosions in tubes.—At the request of the Bureau of Air Commerce, now the Civil Aeronautics Authority, the possible hazards of explosions of maximum-power mixtures of gasoline vapor and air in tubes simulating gasoline-dump ducts were studied. The results indicated that destructive peak pressures are not to be expected in any open-end tubes of dimensions appropriate for dump ducts on aircraft. The ducts should be free from constrictions and from weak, flat areas which might be caused to vibrate violently during an explosion.

Ignition cable.—The energy which must be furnished by the spark coil to cause the spark plug to fire is proportional to the capacitance of the secondary circuit. In many ignition systems the greatest portion of the capacitance is due to the high-tension ignition cable. By decreasing the capacitance of the ignition cable with respect to the engine, less energy is required from the spark coil and consequently less energy from the battery. The capacitance of the cable is decreased by decreasing the size of the conductor.

Measurements have shown current discharges of 30 to 80 amperes across the spark electrodes. These discharges last about one millionth part of a second and consist of 10 to 14 oscillations. After the initial discharge it is desirable to damp out all other oscillations as quickly as possible so as to reduce electrode wear. This is done by the use of a high-resistance conductor.

Decrease in heat transfer from the spark plug to the rubber insulation may be accomplished by using a conductor in the cable which is a poor conductor of heat.

With the decreased cross-sectional area the conductor must be sufficiently strong to make it possible to draw the cable through conduit.

A material which has been found to satisfy these requirements is stainless steel.

Spark plugs.—The present methods of testing spark plugs have failed to supply the necessary information for selecting a suitable plug for a particular engine operating under service conditions. New methods of testing are now under investigation.

Electrical equipment.—Studies have been made of low-tension cable, and tests of auxiliary electrical equipment. Facilities have been provided for testing electric motors which operate at speeds in excess of 24,000 r. p. m.

Temperature surveys.—Temperature surveys have been made on all new types of Navy airplanes, both on the ground and in flight. The measurements have been extended to include oil temperature and intake-mixture temperature.

Flow characteristics of fuel lines.—In connection with the aviation vapor-lock project of the Cooperative Fuels Research Committee, the Bureau is investigating the resistance to fuel flow in component parts of aircraft fuel systems as a function of rate of flow and relative amounts of liquid and vapor flowing. The object of this work is to provide the designers of fuel-feed systems with reliable data on gasoline flow under vaporizing conditions.

Engine testing.—For the information of the military services, two small experimental engines were subjected to approximate altitude tests. These engines were submitted in connection with the development of auxiliary power plants for use in large aircraft. At the request of the Matériel Division of the Army Air Corps, a series of 50-hour endurance tests were conducted on the torque stand on a 9-cylinder radial aircraft engine, for the purpose of comparing different oils and two types of oil tank.

Measurement of surface wear.—A new method of evaluating surface wear, by successive measurement of minute indentations made in the surface with a diamond point, has been developed. This method seems particularly promising for the measurement of piston and cylinder wear in engines, where measured clearances, including as they do the effects of piston growth and cylinder distortion, frequently give highly misleading indications as to wear.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Engine performance with iso-octane fuels.—As mentioned above in the report of the Langley Memorial Aeronautical Laboratory, the Committee has continued the investigation to determine the maximum permissible engine performance with fuels having octane numbers of 87 to 100 to which tetraethyl lead has been added. Data have been obtained on a pent-roof combustion chamber and on a flat-disk combustion chamber. The results have indicated that the knocking characteristics of any one fuel in a given engine can be expressed as a curve showing the critical relationship between the inlet-air temperature and the density of the combustion gases at top center. From this curve it can be determined whether or not various combinations of inlet-air pressure, inlet-air temperature, and compression ratio will result in knock. This method (described in Technical Note No. 647) of expressing the knocking characteristics of a fuel has been suggested as a means of rating fuels.

The effect of irregular spark timing on the knocking properties of fuels has been discussed in Technical Note No. 651. It was found that on the Committee's high-speed engine a change of one crankshaft degree in spark timing was equivalent to a change of 0.4 pound per square inch in allowable inlet pressure.

The investigation of the correlation of the effects of the engine variables on the knocking limits of the fuel is being conducted on a high-speed C. F. R. engine. Tests are being made to determine the effect of mixture density and temperature on knock at various engine speeds. Tests are also being conducted on four fuels each having an octane number of 100 by the C. F. R. method. The fuels differ, however, in the amount of tetraethyl lead added to the base fuel to bring the octane number to 100.

Stability of aviation oils.—The original program has been completed on the investigation of the stability of aircraft engine lubricating oil, conducted by the National Bureau of Standards in cooperation with the Bureau of Aeronautics of the Navy. From extensive laboratory data obtained on a large number of aviation oils by the use of several variations of each of three general methods, a laboratory method has been found which gives a satisfactory correlation with data on the same oils obtained in a Pratt and Whitney Hornet engine. This correlation has been verified by service tests, and makes possible the prediction of the service stability of an aviation oil from the results of comparatively simple laboratory tests.

Additional information has been obtained on the evaporation losses which occur at temperatures approximately those on the cylinder wall near the combustion chamber and around the upper piston ring. These data throw considerable light on the effect of refining processes on oil consumption.

Work on the stability of compounded oils has been continued and information on this characteristic has been obtained for many of the compounding materials found effective commercially for reducing engine wear.

Ring-sticking with aviation oils.—Preliminary work at the National Bureau of Standards with a single-cylinder engine has indicated the possibility of evaluating the ring-sticking characteristics of aviation oils by tests of this type, and of investigating the effect of compounding agents in reducing the tendency to cause ring-sticking.

Extensive information has been obtained on the thickening of oils at the high temperatures encountered around the upper rings and a considerable amount of useful data obtained relating the extent of thickening to the processes used in manufacturing the oil.

Wear, oiliness, and corrosion characteristics of aviation oils.—In cooperation with the Bureau of Aeronautics and the Air Corps, work has been continued at the National Bureau of Standards on the investigations of the relations between oil characteristics and bearing corrosion, with special reference to master rod bearings, and wear reduction of cylinder-wall and piston-ring materials. Most of the necessary equipment has been constructed and assembled, and some preliminary information has been obtained, but the work has not progressed sufficiently far to permit any conclusions to be drawn as yet. Emphasis is being placed on the effects of compounding agents in reducing bearing corrosion, wear of cylinder walls and piston rings, and frictional losses in master-rod bearings.

The first run of an R-1535 engine to study the problem of wear with various oils was terminated after 35 hours by a mechanical failure. Further running under different conditions and with a smaller engine is being considered. In spite of the fact that no other data which are exactly comparable will thus be obtained, very valuable information has been collected regarding the relative merits of wear determination by the indentation method as well as by conventional gauge measurements. The former is a new method and consists of making almost microscopic indentations in the wearing surfaces, and the surface wear is then accurately indicated by optically measuring the changes in the lengths of these marks. By this method excellent data are obtained on the actual thickness of the material worn off the surface, and the results so far indicate that on engine cylinders and pistons even the most accurate conventional gauge measurements may be deceptive in the region of small total wear, or where the differences in wear are small. Since in the case of the R-1535 engine test both methods were used, some very interesting data on distortion as well as on wear are being obtained. The report on the tests with this engine is in preparation.

REPORT OF COMMITTEE ON AIRCRAFT MATERIALS

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

Effect of weathering on light-metal alloys.—A report on this investigation has been prepared for publication summarizing the effect of continuous exposure to the weather on aluminum and magnesium alloys in sheet form as used in aircraft. The tests included the various alloys and protective surface treatments commercially available when the investigation was started. The results of the five-year program have definitely established the relative merits of most of the commonly used alloys and protective treatments with respect to atmospheric corrosion resistance, as follows:

(a) **Aluminum alloys.**—Aluminum alloys containing magnesium as the essentially alloying constituent are very resistant to attack even under the very severe exposure conditions prevailing in many of the tests. They head the list of all the alloys tested. Next in order are the alloys containing magnesium and silicon. The third group of alloys, those containing copper, are susceptible to intercrystalline corrosive attack and, when in thin-sheet form, often lose much of their initial tensile strength and ductility as a result of a corrosive attack of this character.

(b) **Surface treatment.**—For prolonged exposure of aluminum alloys, a surface layer of pure aluminum is overwhelmingly superior to any other protective method available. Of the other protective measures, the most satisfactory ones depend upon surface oxidation. This forms an excellent basis for the adherence of coatings applied thereon. The surface film produced by anodic oxidation is by far superior to any other of this type of treatment, although it too should be followed by another coating for most satisfactory service. All oxide surface films can be greatly improved by "sealing." The use of the chromic acid solution in one type of anodizing treatment is excellent for this purpose, according to the test results.

(c) **Applied organic coatings.**—All the various kinds of vehicle of the varnish type used in the applied coatings yielded excellent results when pigmented with aluminum. Other pigments were decidedly less satisfactory.

(d) **Magnesium alloys.**—Magnesium-alloy sheet properly protected by (1) suitable surface treatment to obtain adherence of the coating, (2) a primer, and (3) surface coating of the kind mentioned above, withstood very satisfactorily five years' continuous exposure to the weather in a tropical marine location (Coco Solo, Canal Zone).

New series of exposure tests of aircraft metals.—During the year a comprehensive series of exposure panels was installed, with the cooperation of the Bureau of Aeronautics of the Navy Department, at the Naval Air Station at Hampton Roads, Virginia. The materials used are representative of commercial aluminum and magnesium alloy and of stainless-steel sheet of various kinds. The light-metal alloy sheets are exposed (a) in the bare condition, (b) after being coated in accordance with the principles established in the previous work, (c) joined together in couples, the components of which are of different compositions, by spot welding and by rivets of various compositions. This last phase of the test is considered to be of major importance in this series of exposure tests. The stainless-steel panels are exposed in the same manner, except that no coatings have been applied. To provide information on conditions such as those involved in the use of sea aircraft, two types of exposures have been used. In one series, the panels are exposed continuously to the marine atmosphere; in the second, the racks are located at mean tide level so as to provide total immersion at high tide followed by free exposure to the air at periods of low tide. Samples are removed at intervals for testing in the laboratory to determine the changes in surface conditions resulting from corrosion and the attendant changes in mechanical properties. Yearly reports summarizing the results are planned.

Structural changes in aircraft metals occurring as a result of service stressing.—A report has been prepared for publication by the Committee entitled "Effect of Working Stress on the Impact Resistance, X-ray Diffraction Patterns and Microstructure of 25S Aluminum Alloy." The aluminum alloy 25S, because of its importance as a propeller material, was the material tested. In general, the results were negative in their nature. No evidence was obtained to indicate a decrease in impact resistance, either at normal or subzero temperature, as a result of continued fatigue stressing below the endurance limit; nor was any indication obtained by X-ray diffraction examination of impending fatigue failure of material severely fatigue-stressed but without actual crack formation. Certain suspected microstructural features first observed to occur in used propeller blades, but later noted in unused blades, were found not to be indicative of inferior mechanical properties. Work on this subject on the possible deleterious effect of continued fatigue-stressing has been extended to chromium-molybdenum steel (SAE X4130) of the type used extensively in aircraft construction.

Effect of sub-zero temperatures on aircraft metals.—Study has been continued to determine the factors responsible for the decrease in impact resistance of ferritic steels with decreasing temperature and to endeavor to improve this condition. The results of tests of welded steels at low temperature, $-80°$ C., indicate that this question is one of real importance in welded structures.

Elastic properties of high-strength aircraft metals.—An extensive report has been prepared for publication summarizing the work done in this investigation. It is entitled "Elastic Properties of 18-8 Chromium-Nickel Steel as Affected by Plastic Deformation." A new approach is offered for the determination of the elastic properties, yielding results of a more practical and useful nature than those by more conventional testing procedure. Despite the fact that the austenitic steels, of which this is a representative, possess only pseudo-elastic properties, their other characteristics make them very desirable for many structural applications.

Durability of magnesium.—The durability of magnesium alloys, especially in sheet form, is largely determined by the surface protective measures used in connection with such materials. This is most marked in a marine atmosphere but, as mentioned above, properly protected magnesium alloy in sheet form has withstood continuous exposure under tropical marine conditions for five years without serious impairment of its properties. Study has been continued with the hope of simplifying and improving current methods of surface treatment of magnesium. It has not yet been deemed advisable, however, to substitute a new process for the widely used anodic treatment in the dichromate-phosphate solution, despite the encouraging results obtained.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

The problems investigated by this subcommittee at the National Bureau of Standards during the past year included the development of a flexible substitute for glass, of a substitute for silk for parachute shroud lines, and of a plastic material for aircraft structures.

Two items mentioned in the 1937 report are omitted from this. The problem of finding a substitute for linen webbing is considered completed. Materials for acoustical and thermal insulation are now in general use and are considered satisfactory when first installed. The subcommittee is watching their performance to see whether or not they deteriorate with age under service conditions.

Development of flexible substitute for glass.—During the current year efforts in connection with the development of a flexible substitute for glass for windshields have been largely concentrated on the development of improved compositions of the cellulose acetate and methyl methacrylate types, particularly with regard to shrinkage and weathering characteristics. This work has been carried on with the active cooperation of the manufacturers' laboratories and it is believed that the marked improvement which has been noted in the commercial sheets in recent months can be attributed at least in part to the stimulus which this investigation has provided to the development of better formulations and methods of processing.

It has been found that the tendency of the early methyl methacrylate resin to craze in service was due either to the presence of a small amount of monomer or solvent in the sheet or to strains left in the finished sheet or produced during forming operations. Seasoning the sheet at a high temperature and careful control of the temperature during shaping have eliminated the crazing, at least for the two-year period during which such sheets have been exposed. Accordingly, heat seasoning of the methacrylate sheets has been adopted by the manufacturers, with the result that today these products have improved surface hardness and freedom from crazing and undergo practically no shrinkage when exposed to the weather.

For the cellulose acetate sheets, the primary problem has been one of increasing the resistance to sunlight or weathering in general. In order to study the effect of various plasticizers on this property, approximately 60 experimental sheets were made by cooperating manufacturers during the course of the year. These are now being examined for weathering stability by means of both accelerated and roof exposure tests, and some of these have been found to be remarkably resistant to deterioration by ultraviolet light. The tests have also indicated that by suitable heat seasoning of the cellulose acetate sheet during manufacture shrinkage as observed in laboratory heating tests can be reduced to a small percentage of that now obtained with the commercial products. Specimens of the original and of the heated materials have been placed on the roof to observe their further shrinkage upon aging.

A reliable accelerated aging test for transparent plastics would be very helpful in evaluating proposed new windshield materials and in experimental work on improvement in formulation of existing types. Accordingly, considerable emphasis has been placed recently on the determination of the effect of ultraviolet light from various sources on the deterioration of plastics. Mercury arc, carbon arc, and so-called sunshine bulbs have been used as the light source, and both temperature and humidity conditions have been varied. Specimens of the transparent plastics used in these tests are at present being exposed at Coco Solo, Miami, and Washington. It is expected that as a result of this experimental work a laboratory test can be developed which will enable the suitability of new products for use as windshields on aircraft to be speedily determined.

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Substitute for silk shroud lines for parachutes.—Cotton shroud lines have been made which, though of lower strength-weight ratio than is obtainable from silk, appear to have equal or greater ability to absorb shock. These cords are to be given a practical service test.

New types of synthetic fibers which are being produced on a semicommercial scale have great promise for shroud lines. Arrangements have been made for the production of some experimental lines from these fibers.

Development of plastic material for aircraft structures.—An investigation was initiated to develop a reinforced plastic which will be satisfactory for airplane construction with respect to strength, stiffness, bending endurance, resistance to flow under load, and related properties. The major problem of devising a molding process adaptable to the fabrication of large sections is being given special consideration. The preparation of specimens with various types of resins and reinforcing agents and the determination of the stress-strain curves of these experimental materials both in tension and in compression is in progress.

REPORT OF COMMITTEE ON AIRCRAFT STRUCTURES

During the past year there was organized under the Committee on Aircraft Structures a Special Subcommittee to Make Survey of Technique and Equipment for Elastic Examination of Large Aircraft Structures in Lieu of Destruction Tests. This subcommittee was appointed for the purpose of maintaining active contact with developments in strain gauges and other equipment necessary to determine strains and other elastic phenomena in complete airplane structures. In addition, the subcommittee recommends financial support, when considered desirable, for those developments that show promise of producing useful instruments for work of this nature. As a result of recommendation of the subcommittee, research at the Massachusetts Institute of Technology to develop electrically strain-sensitive materials and technique for their application has been sponsored.

There has also been organized under the Committee on Aircraft Structures a Special Subcommittee to Direct Research in Applied Structures, for the purpose of making recommendations as to special facilities which should be made available for aircraft structural research, and as to the program of investigations to be conducted. This subcommittee is maintaining close contact with investigations of aircraft structural problems, and in particular with the research programs of the Langley Memorial Aeronautical Laboratory and the National Bureau of Standards.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

STRESSED-SKIN DESIGN

When the National Advisory Committee for Aeronautics was established in 1915, relatively little was known regarding aerodynamics and aircraft engines as compared with the knowledge of structures. As a consequence the Committee directed its first researches mainly in the less well known fields. With the introduction of the stressed-skin, or monocoque, type of structure in recent years, there has developed a need for research in airplane structures. Accordingly, the Committee has for some time been conducting theoretical research in structures at Langley Field. In order to supplement this theoretical research, facilities are now being provided where a limited amount of structural testing can be done to check the theories developed.

Stress analysis of monocoque structures.—It has been known for some time that the stress distribution in box beams is affected materially by the shear deformation of the flanges, a phenomenon sometimes referred to as "shear lag." The subject has been investigated theoretically and experimentally.

The investigation of simple structures, which was mentioned last year, has been extended to cover more complicated structures. Technical Report No. 636 presents a method of stress analysis applicable to structures, such as wings or fuselages, and describes strain-gauge tests made to verify the theory.

General stability of monocoque structures.—One of the important problems that confronts the designer of monocoque structures is that of the stiffness required of the transverse members to hold the stiffened shell in shape. As these members are not required to carry loads of any appreciable magnitude, the problem is mainly one of elastic instability. The problem has been studied theoretically with the result that solutions have been obtained for certain cases. Tests are now being planned to check the design formulas derived.

Fixity coefficients for panel columns.—In the design of the compression panels in stressed-skin wings and monocoque fuselages, one of the problems is to determine the end fixity of these parts. As a preparation for this study, the end fixity of compression members in continuous beams and rigid-joint trusses have been studied. In this connection two papers have been published: Technical Note No. 617, which is concerned with the basic theory, and Technical Note No. 652, which contains a set of tables that are necessary for the solution of practical problems.

Extensions have recently been made to the theory presented in Technical Note No. 617 to render it more useful in the solution of practical problems. For example, when the equation for neutral stability is tested for three assumed loads, each of which is less than the true critical load, it is possible to estimate the true critical load. A paper on this method of estimating the critical load is now in preparation.

The essential principles of the foregoing theory are now being applied to determine the critical buckling strength of parallel columns in stressed-skin structures, with the result that practical formulas have been derived for some cases.

Skin-stiffener panels.—Theoretical studies of the compressive strength of skin stiffener panels have been continued. Most of the work on this problem, however, has been experimental. Preparations are being made to check the theory for the strength of skin-stiffener panels in compression presented in Technical Report No. 582. When these tests are completed, it will be possible to plan more satisfactorily the program for future studies of this problem.

Analysis of experimental observations in problems of elastic stability.—In 1932 Southwell presented a method for the analysis of experimental observations in problems of elastic stability. Briefly, the method is concerned with the interpretation of simultaneous readings of load and deflection. As therein presented, the method requires that the initial deflection reading be taken at zero load. In the vicinity of zero load, deflection readings are usually somewhat questionable. The deflection readings are reliable only after enough load has been applied thoroughly to seat the specimen and the loading fixtures. Furthermore, it is not always convenient to take the initial deflection reading at zero load. Also, something may happen to render the first few readings valueless and it may not be practicable to repeat them. For use under such circumstances, a more general method has been devised wherein the initial readings may be taken at any load less than the critical load. This general method has been presented in Technical Note No. 658.

Buckling above the elastic limit.—In nearly all practical structures the designer tries to proportion the parts so that the material is efficiently used. This objective requires that the cross-sectional area of each part be as small as possible. The result is that much of the material is subjected to stresses above the elastic range. The problem of buckling above the elastic range is therefore a very important one.

A number of theoretical studies have been undertaken in the investigation of this problem. One part of the theoretical study has been to determine what parts of the problem should be experimentally studied.

Local failure of compression members.—Several extensive studies have been made of local failure in compression members of thin metal. The greater importance attached to other problems has delayed completion of these investigations. It is hoped, however, that during the coming year at least one paper on this subject will be published.

STRUCTURAL LOADS ON AIRPLANES IN FLIGHT

Applied loads on airplane structures—gust loads.—Coordinated measurements of acceleration and air speed on transport airplanes have been continued, and the total flying time represented on the records has been extended to 57,000 hours. In several cases high accelerations were recorded on the largest airplanes coming within the scope of the program, the most outstanding being an acceleration of -2.2 g, measured from the $+1$ g level-flight datum, on a four-engine airplane of 52,000 pounds gross weight. The effective gust velocity of -38 feet per second in this case occurred within a cumulo-nimbus cloud associated with a warm front.

Gust research.—Measurements of gust intensities and gradients on light airplanes have been continued and the data extended. Meanwhile tests in the gust tunnel on models of these airplanes have indicated minimum and maximum limits of gust gradient beyond which the airplane is incapable of indicating accurately the true gust characteristics. The tests have therefore been extended to include measurements on two very large airplanes in order to obtain data beyond the limitations of the smaller airplanes. The more recent results of this research indicate that there is no correlation between gust intensity and gradient, so that the problem is reduced to the question of finding the steepest gradient likely to occur coincident with the stronger gusts. In one outstanding case measured on a very large airplane, a true gust velocity of approximately 57 feet per second was found to reach maximum intensity in a distance of about 150 feet.

Gust tunnel.—During the past year the gust tunnel has been provided with means for controlling the velocity distribution so that gusts ranging from those having substantially a sharp edge (viz, gusts reaching maximum velocity in a distance from one-quarter to one-half the chord length of the models) to those having mild linear gradients, can be represented. The equipment has been developed so as to function very satisfactorily and a number of tests have been made.

In sharp-edge gusts, Küssner's original theoretical results have been verified and his assumptions applicable to finite rectangular wings have been found to apply for aspect ratios as low as 2.0. The experimental accelerations in general are very slightly below the theoretical ones. It has also been found that the theoretical results are valid for tapered wings when the mean geometrical chord is used as the basis of the calculations.

In gusts with moderate gradients, the effect of pitching has been determined on a number of models, and relations between gust gradient, airplane size, and acceleration have been evolved, with pitching taken into account. In a few cases anomalous results indicate the existence of influences the nature of which is not yet understood; it has been concluded, for this reason, that, in general, calculations based on the usual assumptions or data on stability are likely to be in error, and that close approximations to the true motion must be determined by experiment.

Tests of a model equipped with a dynamically overbalanced flap indicated that such a gust-alleviating device is ineffective in sharp-edge gusts but causes appreciable reduction in acceleration in gusts with moderate gradient. In the particular case investigated, the acceleration was reduced about 40 percent in a gust reaching maximum intensity in 14 chord lengths with a flap having a chord 10 percent of that of the wing.

Load distribution.—A study of the variation of the net wing loads under combined angular and normal accelerations has been undertaken. The study includes consideration of the loading conditions produced by unsymmetrical landings, aileron deflection, and unsymmetrical gusts, as well as conditions produced by angular accelerations in yaw. The results are to be applied to the analysis of several types of airplane for the purpose of determining those conditions, in addition to the usual symmetrical loading conditions, that should be included in a complete rational analysis of the structural strength for each respective type.

Tail loads.—The problem of tail loads in maneuvers has been reviewed in the light of present available information on the controlling physical factors. Flight tests have been planned for the purpose of verifying computed results.

The problem of tail loads in gusts is receiving attention experimentally. A bomber-type airplane has been equipped with a special vertical tail unit permitting the measurement of gust loads during normal flight in rough air. A number of records have been obtained.

Hull pressures and stresses.—In addition to several routine tests to determine hull pressures and accelerations during rough-water landings of new seaplanes and flying boats, an extensive installation of recording instruments has been made on a large flying boat. These instruments include bottom-pressure gauges, strain gauges, and several instruments for measuring the motion of the airplane in landing and take-off. A large number of tests have been made but the data have not yet been fully analyzed.

Dynamic overstress.—Measurements of acceleration and wing stress have been made on an M-130 flying boat (*Hawaii Clipper*) of Pan American Airways during a round-trip flight between Alameda, California, and Hong Kong. As this airplane is large, with a wing frequency in bending of only 4.33 cycles per second, the results supply significant practical evidence of the existence or absence of overstress in gusts resulting from rapid application of load. Although several strong, abrupt gusts were encountered at air speeds as high as 200 miles per hour, no evidence of overstress was observed, the measured stresses showing excellent agreement with the datum stresses at unit load factor multiplied by the measured gust load factors determined by an accelerometer.

Stress history.—A fairly complete stress history obtained during the flight on the M-130 flying boat provided data applicable to the problem of fatigue of airplane structures. Although the fatigue resistance of the structure under flight conditions is not definitely known, it can be stated on the basis of existing data on this subject that fatigue failure resulting solely from stress variations in rough air (viz, in the absence of serious vibration) does not appear to be a possibility within the probable life of any airplane.

NATIONAL BUREAU OF STANDARDS

Aircraft tubing.—Two reports on tubing used in aircraft have been published within the last year, one on column strength, as Technical Report No. 615 of the National Advisory Committee for Aeronautics, and the other on crinkling strength and bending strength, as Technical Report No. 632. The report on column strength covers round and streamline tubing of four different materials, namely, chromium-molybdenum steel, 17ST aluminum alloy, stainless steel, and heat-treated chromium-molybdenum steel. The report on crinkling strength and bending strength is the result of tests completed during the year on round chromium-molybdenum steel and 17ST aluminum-alloy tubing.

Both reports give an account of the tests, including the laboratory work and the subsequent analysis of the laboratory data; they consider the theoretical aspects of the problem; and finally, empirical formulas are given for the column strength, in the first report, and for the crinkling strength and the bending strength in the second report, in terms of the dimensions of the tubes and the yield strengths of the materials. These formulas have also been written for materials just complying with applicable Navy Department Specifications.

Considerable attention has been given to the testing of round aircraft tubing under combined axial, compressive, transverse, and torsional loading. Apparatus has been designed and constructed for such tests.

Round heat-treated chromium-molybdenum steel tubing has been donated by the Summerhill Tubing Company for the purpose of making crinkling tests, bending tests, torsional tests, and tests under combined loading.

Flat plates under normal pressure.—Seven circular plates of 17ST aluminum alloy 5 inches in diameter and ranging in thickness from 0.021 to 0.072 inch have been tested under normal pressure with their edges clamped, and the measured deformations have been compared with those predicted from Way's theory of such plates. Way's curves were extended to ratios of center deflection to plate thickness equal to 1.5. Satisfactory agreement was obtained up to center deflections of this order between the observed and calculated center deflections. Comparison of the measured and the calculated distribution of radial stresses for one of the plates also showed close agreement for all portions of the plate except those near the edge, where the measurements are most difficult to make and where errors due to deviations from the ideal clamping conditions have a maximum effect.

A plot of the "Navy yield pressure" (an arbitrary measure of appreciable yielding obtained from the pressure-set curve) for these plates, led to a simple empirical relation which described this quantity as a function of the tensile strength of the plate material and the dimensions of the plate within ± 20 percent.

With the existence of such a relation for circular plates it appears probable that a similar relation could be derived from tests of rectangular plates in the presence of nearly ideal clamping conditions. The tests of square plates made to date gave values for yield pressure scattering within ±70 percent about the same curve as that derived from the tests of circular plates.

Beams and stressed-skin research.—A report of the study of strain distribution and buckle shape, and stringer deformation in the two sheet stringer panels has been submitted to the National Advisory Committee for Aeronautics for publication as a Technical Note. The report includes a comparison of the measured buckle shape and measured strain distribution in these panels with those given by theories of S. Timoshenko, J. M. Frankland, and K. Marguerre. The measured effective width was compared with that given by nine different formulas for effective width that have been presented in the literature. Southwell's method of plotting was applied to the measurements of stringer deformation and stringer strain. In many cases the points on the plots of twisting and bending rotation of the stringers and of bending strain were scattered about a straight line throughout their entire range, and in all these cases the slope of the straight line was in agreement with the observed measured buckling load of the panel. It should be mentioned in this connection that the failure of these particular panels occurred at stresses considerably below the yield strength of the material.

An experimental study of the effect of rivet spacing and of spot spacing on the strength of sheet-stringer panels has been started with tests to failure of four 24ST aluminum alloy panels. The rivet spacing in these particular panels was unusually large, ranging from 2 to 6 inches, and consequently the first pronounced deformation of the sheet was a buckling between rivets. This occurred in every case at a stress close to that predicted from Howland's assumption that the sheet between rivets should buckle like an Euler column with clamped ends.

Fourteen more panels remain to be tested. The whole series includes rivet spacings from 0.5 to 6 inches, spot spacings from 0.75 to 4 inches, sheet thicknesses from 0.024 to 0.107 inch, and stringer spacings from 1.5 to 4 inches.

Generalization of Southwell's method.—Analysis of the observed deformations of the stringers in the sheet-stringer panels tested at this Bureau had indicated that the elastic buckling loads of many structures may be predicted from deflection or strain readings below the buckling load by making use of a method of plotting which was developed by Southwell for the particular case of the instability of an initially bent column. An explanation for the wide applicability of this method of plotting has been derived by L. B. Tuckerman from Westergaard's general theory of the buckling of elastic structures. This generalization of Southwell's method also indicates more clearly the limitations of the method. It shows, also, how the method may theoretically be used to derive not only the lowest buckling load but buckling loads of higher order as well. This was checked experimentally by obtaining the first, second, and third Euler loads from strain readings on bent columns and the first and second Euler loads from strain readings on an eccentrically loaded column. It seems doubtful, however, whether the experimental accuracy on complicated structures will be sufficient to make this possibility practical. A paper describing this work has been prepared for publication in the Journal of Research of the National Bureau of Standards.

Monocoque boxes.—Experimental work on this project during the past year has been limited to column tests of extruded 24ST aluminum-alloy H-sections with freely supported ends and with elastically restrained ends. Similar sections are used as stiffeners in monocoque constructions. The tests were desired in connection with Lundquist's analysis of sheet-stringer panels under compression.

The results of the tests were embodied in a detailed report which has been submitted for publication as a Technical Report of the National Advisory Committee for Aeronautics. The report gives an account of the tests and the subsequent analysis of the laboratory data, and also an empirical nondimensional column formula (straight-line) for the plastic range and the resulting formula for E/E. These formulas are also presented in the conventional form to apply to material just complying with Navy Department Specification 46A9a.

The experimental work on the monocoque boxes themselves has been delayed by the difficulty of obtaining suitable specimens. Because of the cost of the specimens, it was found that for the present only one box could be procured, and it was decided to make this of more or less typical construction, 10 by 24 by 95 inches, of 24ST material, with approximately five bays spaced by bulkheads of typical stiffness.

The tests which are to be made with this specimen during the coming year are to include strain explorations under axial load, under pure bending about the lift axis, under bending about the lift axis combined with bending about the drag axis, and under bending about the lift axis combined with shear. The load is to be kept below the ultimate in each test so that the specimen will still be intact after each loading. After the completion of all the tests within the elastic range the specimen is to be tested to failure in end compression.

Strength of riveted joints in aluminum alloy.—In view of the interest of airplane manufacturers in riveted joints of the flush type the work done on this investigation during the past year has been limited chiefly to determining the mechanical properties of flush riveted joints and preparing a report of the results.

Shearing and tensile tests have been completed on joints fabricated by eight manufacturers in accordance with their own practice. Among the types represented are two types of 78-degree rivets, two types of 100-degree rivets and the "flush brazier" rivet, all used with various combinations of counterpressed and countersunk sheets. Joints employing brazier-head and special-oval-countersunk-head rivets were fabricated at the National Bureau of Standards and were included for comparison.

The shearing strength of joints having counterpressed sheets was considerably greater at some values of the ratio of rivet diameter to sheet thickness than the strength of joints made with brazier-head rivets. There was a marked decrease in the shearing strength with increase of this ratio. In several joints the sheet was found to contain injurious cracks which originated during the counterpressing operations.

A report showing the mechanical properties in graphical form, together with photomacrographs and drawings, is being prepared.

Airplane vibration.—Close cooperation was maintained throughout the year with the Bureau of Aeronautics in its program for the development of suitable equipment for picking up and recording vibration amplitudes and strains on airplanes in flight. A number of schemes for accomplishing this were discussed at conferences between the Bureau of Aeronautics, representatives of various commercial organizations, and representatives of the National Bureau of Standards.

As part of this program calibration tests were carried out on strain gauges of the electromagnetic type and of the variable-inductance type, both constructed by the Sperry Gyroscope Company, as well as tests of the carbon-resistance strain gauges known as "Ess strips" which have been developed by Professor de Forest.

In connection with the calibration tests a device was constructed for subjecting dynamic strain gauges to uniform sinusoidal strains up to 0.001 over a range of frequencies from 0.05 to 200 cycles per second. The device has been subjected to preliminary trials and a number of changes in design have been made to give a more nearly uniform axial strain on the strip of sheet metal to which the gauges are attached.

Investigation of fatigue resistance of fabricated structural elements of aircraft.—The method and test equipment developed for testing the fatigue strength of aluminum-alloy wing beams were described in detail in Technical Note No. 660. This paper also gives the results of tests on two wing beams that had been removed from an airplane. Further tests are in progress.

The magnitude of the alternating axial load applied to the two beams tested was computed from the amplitude of strain as indicated by 2-inch Tuckerman optical strain gauges, and also, on the assumption that the motion was sinusoidal, from the mass, amplitude, and frequency of one of the terminal weights. The results of the two methods of computation differed by 8 percent and 10 percent in the two cases. The results of the second method were the smaller in both cases. The over-all strain could not be used because of uncertainties in the effective length due to reinforced portions along the beams and to unknown deformations at the terminals. A fourth method, contemplated in future tests, consists in determining the mass and acceleration of one of the weights directly. This would require an accelerometer of very short relaxation time. A tentative design for such an instrument has been made.

The test program is somewhat complicated by the fact that some of the specimens contain asymmetric reinforcements near the center. As a consequence, the centroidal axes of these beams are not straight, and centering the load requires a large displacement of the centers of gravity of the terminal weights from the line connecting the centroids of the end sections. It is desirable to include these asymmetric reinforcements in the test length of the specimens in order to investigate the possibly serious stress concentrations due to their presence in the airplane structure. Terminal attachments have been designed to permit ample adjustment of the transverse displacement of the terminal weights.

Tensile and compressive properties of duralumin, magnesium and alloy steels.—A paper entitled "The 'Pack' Method for Compressive Tests of Thin Specimens of Materials Used in Thin-walled Structures" is in process of publication as a Technical Report of the National Advisory Committee for Aeronautics. This paper includes a detailed description of the procedure for making "pack" compressive tests. It also includes the results of tests to give a comparison of the stress-strain graphs of packs and compact solid specimens taken from the same bar of metal, and to determine the reproducibility of the test where two or more packs were taken longitudinally or transversely from sheets of 17ST aluminum alloy, No. 1025 carbon steel, and annealed chronium-molybdenum steel. An abstract of a résumé of this paper, which was presented at the Fifth International Congress for Applied Mechanics, was published in the Journal of Applied Mechanics of the American Society for Mechanical Engineers, for September 1938.

The "pack" compressive test has been found useful during the past year in determining the compressive stress-strain graphs of materials taken from thin-walled structural sections, as well as from sheet. Tests made on packs assembled from specimens taken from channels of high-strength aluminum alloy showed no evidence that the packs failed by primary instability, despite deviations from flatness in the formed material which led to the presence of small voids between the specimens of the pack.

PART II

ORGANIZATION AND GENERAL ACTIVITIES

ORGANIZATION

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915 (U. S. Code, title 50, sec. 151). The Committee is composed of fifteen members appointed by the President and serving as such without compensation. The duties of the Committee are to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution," and to "direct and conduct research and experiment in aeronautics" in such laboratories as may be placed under its direction.

Prior to the enactment of the Civil Aeronautics Act of 1938, the membership of the Committee as provided by law included two representatives each from the War and Navy Departments; one each from the Smithsonian Institution, the United States Weather Bureau, and the National Bureau of Standards; and eight other persons "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." In recent years one of these eight positions has been filled by a representative of the Bureau of Air Commerce. The Civil Aeronautics Act of 1938 provided that the Civil Aeronautics Authority therein created for the encouragement and regulation of civil and commercial aviation should have two representatives on the Committee, the same as the Army and the Navy. As the total membership remains at fifteen, the result is that the governmental members now number nine and the nongovernmental members six.

The Civil Aeronautics Act of 1938 also provided that, upon the effective date of the act (August 22, 1938) the terms of office of the nongovernmental members of the Committee should expire, and that the President should appoint successors to six, two each for periods of one, three, and five years, respectively, and thereafter for terms of five years. The provision of law referred to is Section 1107 (e) of the Civil Aeronautics Act of 1938, which reads as follows:

"The ninth paragraph of the Act approved March 3, 1915 (38 Stat. 930), as amended by the Act of March 2, 1929 (45 Stat. 1451; U. S. C., 1934 ed., title 50, sec. 151), is further amended by inserting after the words 'naval aeronautics'; in that paragraph the following: 'two members from the Civil Aeronautics Authority;', by striking out the word 'eight' in that paragraph and inserting in lieu thereof the word 'six', and by striking out the colon after the words 'allied sciences' and inserting in lieu thereof a period and the following: 'The members of the National Advisory Committee for Aeronautics, not representing governmental agencies, in office on the date of enactment of the Civil Aeronautics Act of 1938, shall continue to serve as members of the Committee until the effective date of section 1107 of the Civil Aeronautics Act of 1938. Upon the expiration of their terms of office the President is authorized to appoint successors to six of such members for terms of office to expire, as designated by the President at the time of appointment, two at the end of one year, two at the end of three years, and two at the end of five years from December 1, 1938. Successors to those first appointed shall be appointed by the President for terms of five years from the date of the expiration of the terms of the members whom they succeed, except that any such successor, appointed to fill a vacancy occurring prior to the expiration of a term, shall be appointed only for the unexpired term of the member whom he succeeds:'."

In accordance with the above provision of law, the President, under date of August 23, 1938, made the following appointments as members of the Committee:

To represent the Civil Aeronautics Authority (without definite tenure):

Honorable Edward J. Noble, Chairman, Civil Aeronautics Authority.

Honorable Clinton M. Hester, Administrator, Civil Aeronautics Authority.

For the terms expiring December 1, 1943:

Dr. Joseph S. Ames.

Dr. Orville Wright.

For the terms expiring December 1, 1941:

Dr. Edward P. Warner.

Dr. Vannevar Bush.

For the terms expiring December 1, 1939:

Colonel Charles A. Lindbergh.

Dr. Jerome C. Hunsaker.

Of the eight appointments thus made by the President, four were reappointments and four were new appointments. The four members reappointed are:

Dr. Joseph S. Ames (Chairman), President Emeritus of Johns Hopkins University, the last of the original members of the Committee appointed by the President in 1915, who served as Chairman of the Executive Committee from 1919 to 1937, and as Chairman of the main Committee from 1927 to the present time.

Dr. Orville Wright, of Dayton, Ohio, the world's first aviator, who has served continuously since his appointment by the President in 1920.

Dr. Edward P. Warner, of Greenwich, Connecticut, former Assistant Secretary of the Navy for Aeronautics, who has served continuously since his appointment by the President in 1929, and has also served as Chairman of the Committee on Aerodynamics since 1935.

Colonel Charles A. Lindbergh, who has served continuously as a member since his appointment by the President in 1931.

The four new appointments are:

Honorable Edward J. Noble, Chairman, Civil Aeronautics Authority.

Honorable Clinton M. Hester, Administrator, Civil Aeronautics Authority.

Dr. Vannevar Bush, President, Carnegie Institution of Washington, D. C.

Dr. Jerome C. Hunsaker, Professor in Charge, The Daniel Guggenheim Aeronautical Laboratory, Massachusetts Institute of Technology.

The four members whose terms expired August 22, 1938, and who were not reappointed, are:

Honorable Harry F. Guggenheim.

Dr. William P. MacCracken.

Dr. Denis Mulligan.

Dr. David W. Taylor.

Dr. Taylor was first appointed a naval member of the Committee February 16, 1917, while serving as Chief Constructor, United States Navy, with the rank of Rear Admiral. When he retired from the Navy, he was immediately reappointed on October 16, 1922, as a member of the Committee from private life, in recognition of his outstanding ability. He was a great source of strength to the organization. His twenty-one years as a member included four years as Secretary of the Committee, eleven years as Vice Chairman of the Committee, and eight years as Chairman of the Committee on Aerodynamics.

Dr. MacCracken was Assistant Secretary of Commerce for Aeronautics when he was appointed a member of the Committee April 5, 1929, and throughout the entire period of his service he was an active and interested member. He rendered faithful and valuable service on various committees, and for six years was Chairman of the Committee on Power Plants for Aircraft. He had also served as Vice Chairman of the Executive Committee since October 21, 1937.

Mr. Guggenheim was President of the Daniel Guggenheim Fund for the Promotion of Aeronautics, Incorporated, when he was appointed a member of the Committee April 5, 1929. He brought to the Committee a well-informed and independent viewpoint on the problems of flight, which made him especially valuable as a constructive critic.

Dr. Mulligan had succeeded Dr. Fred D. Fagg, Jr., who had resigned, as Director of the Bureau of Air Commerce, and Dr. Mulligan accordingly succeeded Dr. Fagg as a member of the Committee April 16, 1938. Both Dr. Fagg and Dr. Mulligan, as successive heads of the Bureau of Air Commerce, had been thoroughly cooperative with the Committee in seeking to advance the science of aeronautics through unified control and conduct by the Committee of scientific laboratory research.

During the past year the Committee lost through death two other members, namely, Dr. Willis Ray Gregg, Chief of the United States Weather Bureau, on September 14, 1938, and Major General Oscar Westover, Chief of the Army Air Corps, on September 21, 1938.

Dr. Gregg had served as the Weather Bureau representative on the Committee since October 10, 1934, and had served as Chairman of the Executive Committee since April 22, 1937. He had given unsparingly of his time and talents to promote the effective organization and prosecution of the Committee's work.

General Westover had served as a War Department representative on the Committee since January 25, 1936. Prior to that he had become very familiar with the organization and work of the Committee, having had three previous tours of duty in the office of the Chief of the Army Air Corps since 1919 and one as Commanding Officer of Langley Field, where the Committee's laboratories are located. During this entire period he was deeply interested in the Committee's work and did much to assist this organization by promoting cooperation between the Army Air Corps and the Committee.

Major General Henry H. Arnold, who had succeeded General Westover as Chief of the Army Air Corps, was appointed a member of the Committee on October 10, 1938.

The present membership of the Committee is shown on page vi of this report. There is one vacancy on the Committee, the filling of which will await the appointment of a new Chief of the United States Weather Bureau.

Under the rules and regulations governing the work of the Committee as approved by the President, the Chairman and Vice Chairman of the Committee are elected annually. At the meeting held on October 20, 1938, Dr. Joseph S. Ames was reelected Chairman for the ensuing year, and Dr. Vannevar Bush was elected Vice Chairman to succeed Dr. David W. Taylor. At the meeting held on December 16, 1938, Dr. Vannevar Bush was elected Chairman of the Executive Committee and Dr. Charles G. Abbot Vice Chairman of the Executive Committee for the ensuing year.

The Committee's headquarters, including its offices of aeronautical intelligence and aeronautical inventions, are located in the Navy Building, Washington, D. C., in close proximity to the air organizations of the Army and Navy.

The office of aeronautical intelligence was established in the early part of 1918 as an integral branch of the Committee's activities. Scientific and technical data on aeronautics secured from all parts of the world are classified, catalogued, and disseminated by this office.

To assist in the collection of current scientific and technical information and data, the Committee maintains a technical assistant in Europe (Mr. John J. Ide), with headquarters at the American Embassy in Paris.

CONSIDERATION OF AERONAUTICAL INVENTIONS

By act of Congress approved July 2, 1926, an Aeronautical Patents and Design Board was established consisting of Assistant Secretaries of the Departments of War, Navy, and Commerce. In accordance with that act as amended by the act approved March 3, 1927, the National Advisory Committee for Aeronautics passes upon the merits of aeronautical inventions and designs submitted to any aeronautical division of the Government, and submits reports thereon to the Aeronautical Patents and Design Board. That board is authorized, upon the favorable recommendation of the Committee, to "determine whether the use of the design by the Government is desirable or necessary and evaluate the design and fix its worth to the United States in an amount not to exceed $75,000."

During the past year the inventions section received for consideration 1,100 new submissions. It conducted the necessary correspondence and granted interviews as requested by the inventors. Approximately three percent of the new submissions were received through the Aeronautical Patents and Design Board. In those cases reports on the merits of the submissions were made to that board, and in all other cases replies were submitted directly to the inventors.

AERONAUTICAL RESEARCH IN EDUCATIONAL INSTITUTIONS

The Committee has continued to follow the policy initiated as a result of recommendation of the Federal Aviation Commission, of making available a special allotment of $25,000 from each year's funds for aeronautical research in educational institutions. Under this allotment during the fiscal year 1938, contracts were made with five universities and technical schools for ten special investigations and reports, on the basis of the probable usefulness and value of the information to aeronautics.

Several of the papers prepared under contracts have been published by the Committee, and in other cases the results obtained in the investigations have supplied a basis for further research. During the past year two contract reports have been issued as Technical Notes, and four others are now being revised and edited for publication by the Committee.

COOPERATION WITH THE AVIATION INDUSTRY

In the formulation of its research programs, the Committee includes provision for the problems of aeronautical research which are of particular importance to the aviation industry, in connection with both the design and operation of aircraft. The representatives of the industry refer their problems of this nature to the Committee as they arise, either by correspondence or through personal contact. The Committee avails itself of every opportunity to obtain suggestions and recommendations from representatives of the aircraft manufacturers and operators as to investigations which are of special importance to them.

Although it was found necessary this year to postpone for one year the Aircraft Engineering Research Conference usually held each May at the Committee's laboratory at Langley Field, the Committee has continued to maintain close contact with the research needs of the industry. The conference was postponed because of the extensive program of construction of new research facilities being carried out at the laboratory, which had been undertaken by the Committee to meet the challenge offered by the great emphasis being placed by the principal foreign nations on scientific research in aeronautics, and their greatly increased research activities. As has been the long-standing policy of the Committee, when the need arises in connection with any particular problem of the industry a special conference is called, or, as previously stated, a special subcommittee is established, including in either case representation from the industry.

One of the important problems of the industry at the present time is the problem of flutter, and the Special Subcommittee on Vibration and Flutter, established under the Committee on Aerodynamics, is giving this subject special attention. It is believed that the recent results obtained by the Committee's laboratory on this subject, which are being made available in advance confidential form to American manufacturers, will be of great importance in connection with this problem. The investigation is described briefly in the report of the special subcommittee in part I.

Another problem of great importance in connection with airplane design is the aerodynamic loads imposed on the structure in flight as a result of atmospheric disturbances. As previously stated, the Committee has accumulated, with the cooperation of air-transport operators over a period of a number of years, a large amount of statistical data on these loads. These data have been obtained by means of the N. A. C. A. V-G recorder, which gives a record of accelerations and air speeds. At the present time about 25 of these instruments are in use on American air lines, and the records obtained to date represent a total of approximately 57,000 flying hours. Further information regarding this study is presented in the report of the Committee on Aircraft Structures.

The problem of lightning hazards to aircraft has been brought to the Committee's attention by the air-transport operators, and to assist in the study of this problem a Special Subcommittee on Lightning Hazards to Aircraft has been established under the Subcommittee on Meteorological Problems, as was mentioned in the report of that subcommittee. Under the cognizance of this special subcommittee investigation is being made of the effect of electrical discharges simulating lightning strokes on sheet metal of the type used in aircraft construction. In addition, in order to obtain information as to the meteorological aspects of the problem, the air lines are supplying data from their pilots as to incidents of lightning strokes and the atmospheric conditions observed in connection with these incidents.

Realizing that frequently the value of information is greatly enhanced by its prompt availability, every effort is made to place in the hands of the industry at the earliest possible date the results of researches that are of particular interest to commercial aviation. It sometimes appears, in the course of an extensive investigation being conducted by the Committee, that the results so far obtained will be of special interest and value to the aircraft industry if made available immediately. In such cases the Committee issues the information in advance confidential form to American manufacturers and the Government services.

SUBCOMMITTEES

The Advisory Committee has organized four main standing technical committees, with subcommittees, for the purpose of supervising its work in their respective fields. The four main technical Committees on Aerodynamics, Power Plants for Aircraft, Aircraft Materials, and Aircraft Structures and their subcommittees supervise and direct the aeronautical research conducted by the Advisory Committee and coordinate the investigations conducted by other agencies.

As previously stated, it is the policy of the Committee to establish from time to time special technical subcommittees for the study of particular problems as they arise. In accordance with this policy a Special Subcommittee on Vibration and Flutter has been organized under the Committee on Aerodynamics. During the past year three such special subcommittees have been formed: a Special Subcommittee on Lightning Hazards to Aircraft, under the Subcommittee on Meterological Problems; and, under the Committee on Aircraft Structures, a Special Subcommittee to Make Survey of Technique and Equipment for Elastic Examination of Large Aircraft Structures in Lieu of Destruction Tests, and a Special Subcommittee to Direct Research in Applied Structures.

The work of the standing technical committees and subcommittees has been described in part I.

The organization of the committees and of the subcommittees is as follows:

COMMITTEE ON AERODYNAMICS

Dr. Edward P. Warner, Chairman.
Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.
Dr. L. J. Briggs, National Bureau of Standards.
Comdr. W. S. Diehl, United States Navy.
Dr. H. L. Dryden, National Bureau of Standards.
John Easton, Civil Aeronautics Authority.
Lt. Comdr. L. M. Grant, United States Navy.
J. T. Gray, Civil Aeronautics Authority.
Maj. Carl F. Greene, Air Corps, United States Army, Matériel Division, Wright Field.
Delbert M. Little, United States Weather Bureau.
Maj. Alfred J. Lyon, Air Corps, United States Army, Matériel Division, Wright Field.
Elton W. Miller, National Advisory Committee for Aeronautics.
Comdr. F. W. Pennoyer, Jr., United States Navy.
H. J. E. Reid, National Advisory Committee for Aeronautics.
Maj. John P. Richter, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. A. F. Zahm, Division of Aeronautics, Library of Congress.

SUBCOMMITTEE ON AIRSHIPS

Dr. J. C. Hunsaker, Chairman.
Starr Truscott, National Advisory Committee for Aeronautics, Vice Chairman.
John Easton, Civil Aeronautics Authority.
Commander Garland Fulton, United States Navy.
Maj. C. F. Greene, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Francis W. Reichelderfer, United States Weather Bureau, Chairman.
Col. E. S. Gorrell, Air Transport Association of America.
Dr. W. J. Humphreys, United States Weather Bureau.
Dr. J. C. Hunsaker, Massachusetts Institute of Technology.
R. W. Knight, Civil Aeronautics Authority.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Delbert M. Little, United States Weather Bureau.
Comdr. Wilber M. Lockhart, United States Navy.
Dr. Charles F. Marvin.
Dr. C. G. Rossby, Massachusetts Institute of Technology.
Maj. B. J. Sherry, United States Army, Signal Corps, War Department.

SPECIAL SUBCOMMITTEE ON LIGHTNING HAZARDS TO AIRCRAFT

Delbert M. Little, United States Weather Bureau, Chairman.
J. C. Franklin, Transcontinental & Western Air, Inc.
Lt. Comdr. L. M. Grant, United States Navy.
Charles H. Helms, National Advisory Committee for Aeronautics.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
K. B. McEachron, General Electric Company.
Irving R. Metcalf, Civil Aeronautics Authority.
Lt. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. F. B. Silsbee, National Bureau of Standards.
Dr. John B. Whitehead, Johns Hopkins University.

SUBCOMMITTEE ON SEAPLANES

Dr. J. C. Hunsaker, Chairman.
Theophile dePort, Matériel Division, Army Air Corps, Wright Field.
Comdr. W. S. Diehl, United States Navy.
J. T. Gray, Civil Aeronautics Authority.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Lt. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
A. L. Morse, Civil Aeronautics Authority.
Capt. H. C. Richardson, United States Navy.
Lt. Comdr. A. O. Rule, United States Navy.
Starr Truscott, National Advisory Committee for Aeronautics.

SPECIAL SUBCOMMITTEE ON VIBRATION AND FLUTTER

H. J. E. Reid, National Advisory Committee for Aeronautics, Chairman.
Lt. Frederick R. Dent, Jr., Air Corps, United States Army, Matériel Division, Wright Field.
Comdr. W. S. Diehl, United States Navy.
Charles H. Helms, National Advisory Committee for Aeronautics.
Dr. George W. Lewis, National Advisory Committtee for Aeronautics (ex officio member).
Comdr. R. D. MacCart, United States Navy.
Irving R. Metcalf, Civil Aeronautics Authority.
Ford L. Prescott, Matériel Division, Army Air Corps, Wright Field.
Dr. Walter Ramberg, National Bureau of Standards.
Edward I. Ryder, Civil Aeronautics Authority.
Dr. Theodore Theodorsen, National Advisory Committee for Aeronautics.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Dr. Vannevar Bush, Chairman.
Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.
Comdr. Rico Botta, United States Navy.
Dr. H. C. Dickinson, National Bureau of Standards.
John H. Geisse, Civil Aeronautics Authority.
Carlton Kemper, National Advisory Committtee for Aeronautics.
Gaylord W. Newton, Civil Aeronautics Authority.
Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Dr. H. C. Dickinson, National Bureau of Standards, Chairman.
Comdr. Rico Botta, United States Navy.
Lt. J. W. C. Brand, United States Navy.
Dr. O. C. Bridgeman, National Bureau of Standards.
H. K. Cummings, National Bureau of Standards.
L. S. Hobbs, The Pratt and Whitney Aircraft Company.
Robert V. Kerley, Matériel Division, Army Air Corps, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Gaylord W. Newton, Civil Aeronautics Authority.
Arthur Nutt, Wright Aeronautical Corporation.
Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.
Addison M. Rothrock, National Advisory Committee for Aeronautics.

COMMITTEE ON AIRCRAFT MATERIALS

Dr. L. J. Briggs, National Bureau of Standards, Chairman.
Prof. H. L. Whittemore, National Bureau of Standards, Vice Chairman.
S. K. Colby, Aluminum Co. of America.
Lt. Comdr. C. F. Cotton, United States Navy.
Edgar H. Dix, Jr., American Magnesium Corporation.
John Easton, Civil Aeronautics Authority.
Warren E. Emley, National Bureau of Standards.
Comdr. Garland Fulton, United States Navy.
J. T. Gray, Civil Aeronautics Authority.
C. H. Helms, National Advisory Committee for Aeronautics.
J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
H. S. Rawdon, National Bureau of Standards.
E. C. Smith, Republic Steel Corporation.
Paul F. Voigt, Jr., Carnegie-Illinois Steel Corporation.
Dr. Edward P. Warner.

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

H. S. Rawdon, National Bureau of Standards, Chairman.
A. W. Dallas, Civil Aeronautics Authority.
E. H. Dix, Jr., American Magnesium Corporation.
Comdr. Garland Fulton, United States Navy.
J. B. Johnson, Matériel Division, Army Air Corps, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
E. C. Smith, Republic Steel Corporation.
Prof. H. L. Whittemore, National Bureau of Standards.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

Warren E. Emley, National Bureau of Standards, Chairman.
C. J. Cleary, Matériel Division, Army Air Corps, Wright Field.
A. W. Dallas, Civil Aeronautics Authority.
C. H. Helms, National Advisory Committee for Aeronautics.
E. F. Hickson, National Bureau of Standards.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
J. E. Sullivan, Bureau of Aeronautics, Navy Department.
G. W. Trayer, Forest Service, Department of Agriculture.

COMMITTEE ON AIRCRAFT STRUCTURES

Dr. L. J. Briggs, National Bureau of Standards, Chairman.
John Easton, Civil Aeronautics Authority.
Lt. Comdr. L. M. Grant, United States Navy.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.

Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Eugene E. Lundquist, National Advisory Committee for Aeronautics.
Comdr. R. D. MacCart, United States Navy.
Lt. C. K. Moore, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. Walter Ramberg, National Bureau of Standards.
Richard V. Rhode, National Advisory Committee for Aeronautics.
Edward I. Ryder, Civil Aeronautics Authority.
Dr. L. B. Tuckerman, National Bureau of Standards.
Dr. Edward P. Warner.

SPECIAL SUBCOMMITTEE TO MAKE SURVEY OF TECHNIQUE AND EQUIPMENT FOR ELASTIC EXAMINATION OF LARGE AIRCRAFT STRUCTURES IN LIEU OF DESTRUCTION TESTS

Richard V. Rhode, National Advisory Committee for Aeronautics, Chairman.
Lt. Comdr. L. M. Grant, United States Navy.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Comdr. R. D. MacCart, United States Navy.
Irving R. Metcalf, Civil Aeronautics Authority.
R. L. Templin, Aluminum Company of America.
Dr. L. B. Tuckerman, National Bureau of Standards.

SPECIAL SUBCOMMITTEE TO DIRECT RESEARCH IN APPLIED STRUCTURES

Lt. Comdr. L. M. Grant, United States Navy, Chairman.
Capt. Paul H. Kemmer, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Eugene E. Lundquist, National Advisory Committee for Aeronautics.
Edward I. Ryder, Civil Aeronautics Authority.
Dr. L. B. Tuckerman, National Bureau of Standards.

COMMITTEE ON AIRCRAFT ACCIDENTS

Dr. Edward P. Warner, Chairman.
Lt. W. A. Evans, United States Navy.
Maj. E. V. Harbeck, Jr., Air Corps, United States Army.
J. W. Lankford, Civil Aeronautics Authority.
Dr. George W. Lewis, National Advisory Committee for Aeronautics.
Lt. Comdr. A. O. Rule, United States Navy.
Maj. Lowell H. Smith, Air Corps, United States Army.
Grove Webster, Civil Aeronautics Authority.

COMMITTEE ON AERONAUTICAL INVENTIONS AND DESIGNS

Dr. L. J. Briggs, National Bureau of Standards, Chairman.
Hon. Clinton M. Hester, Civil Aeronautics Authority.
Dr. J. C. Hunsaker.
Capt. S. M. Kraus, United States Navy.
Brig. Gen. A. W. Robins, Air Corps, United States Army, Matériel Division, Wright Field.
John F. Victory, Secretary.

COMMITTEE ON PUBLICATIONS AND INTELLIGENCE

Dr. Joseph S. Ames, Chairman.
Dr. Charles G. Abbot.
Miss M. M. Muller, Secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

Dr. Joseph S. Ames, Chairman.
Dr. Vannevar Bush.
John F. Victory, Secretary.

TECHNICAL PUBLICATIONS OF THE COMMITTEE

The Committee has four series of publications, namely, technical reports, technical notes, technical memorandums, and aircraft circulars.

The technical reports present the results of fundamental research in aeronautics. The technical notes are mimeographed and present the results of short research investigations and the results of studies of specific detail problems which form parts of long investigations. The technical memorandums are mimeographed and contain translations and reproductions of important foreign aeronautical articles. The aircraft circulars are mimeographed and contain descriptions of new types of foreign aircraft.

The following are lists of the publications issued:

LIST OF TECHNICAL REPORTS ISSUED DURING THE PAST YEAR

No.

612. Heat-Transfer Processes in Air-Cooled Engine Cylinders. By Benjamin Pinkel, N. A. C. A.
613. The Variation with Reynolds Number of Pressure Distribution over an Airfoil Section. By Robert M. Pinkerton, N. A. C. A.
614. Pressure Distribution over an N. A. C. A. 23012 Airfoil with an N. A. C. A. 23012 External-Airfoil Flap. By Carl J. Wenzinger, N. A. C. A.
615. Column Strength of Tubes Elastically Restrained against Rotation at the Ends. By William R. Osgood, National Bureau of Standards.
616. Interrelation of Exhaust-Gas Constituents. By Harold C. Gerrish and Fred Voss, N. A. C. A.
617. Auto-Ignition and Combustion of Diesel Fuel in a Constant-Volume Bomb. By Robert F. Selden, N. A. C. A.
618. Comparative Flight and Full-Scale Wind-Tunnel Measurements of the Maximum Lift of an Airplane. By Abe Silverstein, S. Katzoff, and James A. Hootman, N. A. C. A.
619. Drag of Cylinders of Simple Shapes. By W. F. Lindsey, N. A. C. A.
620. Pressure Distribution over Airfoils with Fowler Flaps. By Carl J. Wenzinger and Walter B. Anderson, N. A. C. A.
621. Compressible Flow about Symmetrical Joukowski Profiles. By Carl Kaplan, N. A. C. A.
622. A Photographic Study of Combustion and Knock in a Spark-Ignition Engine. By A. M. Rothrock and R. C. Spencer, N. A. C. A.
623. A Study of the Torque Equilibrium of an Autogiro Rotor. By F. J. Bailey, Jr., N. A. C. A.
624. Two-Dimensional Subsonic Compressible Flow past Elliptic Cylinders. By Carl Kaplan, N. A. C. A.
625. A Discussion of Certain Problems Connected with the Design of Hulls of Flying Boats and the Use of General Test Data. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.
626. The Transition Phase in the Take-Off of an Airplane. By J. W. Wetmore, N. A. C. A.
627. The Experimental and Calculated Characteristics of 22 Tapered Wings. By Raymond F. Anderson, N. A. C. A.
628. Aerodynamic Characteristics of a Large Number of Airfoils Tested in the Variable-Density Wind Tunnel. By Robert M. Pinkerton and Harry Greenberg, N. A. C. A.

629. On Some Reciprocal Relations in the Theory of Nonstationary Flows. By I. E. Garrick, N. A. C. A.
630. A Flight Comparison of Conventional Ailerons on a Rectangular Wing and of Conventional and Floating Wing-Tip Ailerons on a Tapered Wing. By H. A. Soulé and W. Gracey, N. A. C. A.
631. Airfoil Section Characteristics as Applied to the Prediction of Air Forces and Their Distribution on Wings. By Eastman N. Jacobs and R. V. Rhode, N. A. C. A.
632. The Crinkling Strength and the Bending Strength of Round Aircraft Tubing. By William R. Osgood, National Bureau of Standards.
633. Pressure Distribution over an N. A. C. A. 23012 Airfoil with a Slotted and a Plain Flap. By Carl J. Wenzinger and James B. Delano, N. A. C. A.
634. Calculation of the Chordwise Load Distribution over Airfoil Sections with Plain, Split, or Serially Hinged Trailing-Edge Flaps. By H. Julian Allen, N. A. C. A.
635. Theoretical Stability and Control Characteristics of Wings with Various Amounts of Taper and Twist. By Henry A. Pearson and Robert T. Jones, N. A. C. A.
636. Approximate Stress Analysis of Multistringer Beams with Shear Deformation of the Flanges. By Paul Kuhn, N. A. C. A.
637. Determination of Boundary-Layer Transition on Three Symmetrical Airfoils in the N. A. C. A. Full-Scale Wind Tunnel. By Abe Silverstein and John V. Becker, N. A. C. A.
638. The Influence of Lateral Stability on Disturbed Motions of an Airplane with Special Reference to the Motions Produced by Gusts. By Robert T. Jones, N. A. C. A.
639. The Effect of Compressibility on Eight Full-Scale Propellers Operating in the Take-Off and Climbing Range. By David Biermann and Edwin P. Hartman, N. A. C. A.
640. The Aerodynamic Characteristics of Full-Scale Propellers Having 2, 3, and 4 Blades of Clark Y and R. A. F. 6 Airfoil Sections. By Edwin P. Hartman and David Biermann, N. A. C. A.
641. The Negative Thrust and Torque of Several Full-Scale Propellers and Their Application to Various Flight Problems. By Edwin P. Hartman and David Biermann, N. A. C. A.
642. Tests of Five Full-Scale Propellers in the Presence of a Radial and a Liquid-Cooled Engine Nacelle, Including Tests of Two Spinners. By David Biermann and Edwin P. Hartman.
643. The Aerodynamic Characteristics of Four Full-Scale Propellers Having Different Plan Forms. By Edwin P. Hartman and David Biermann, N. A. C. A.
644. The Torsional and Bending Deflection of Full-Scale Aluminum-Alloy Propeller Blades under Normal Operating Conditions. By Edwin P. Hartman and David Biermann.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

No.
616. The Measurement of Air Speed of Airplanes. By F. L. Thompson, N. A. C. A.
617. Stability of Structural Members under Axial Load. By Eugene E. Lundquist, N. A. C. A.
618. Increasing the Strength of Aluminum-Alloy Columns by Prestressing. By M. Holt and E. C. Hartmann, Aluminum Research Laboratories.
619. Compression-Ignition Engine Performance at Altitudes and at Various Air Pressures and Temperatures. By Charles S. Moore and John H. Collins, N. A. C. A.
620. Energy Loss, Velocity Distribution, and Temperature Distribution for a Baffled Cylinder Model. By Maurice J. Brevoort, N. A. C. A.
621. Pressure Drop across Finned Cylinders Enclosed in a Jacket. By Vern G. Rollin and Herman H. Ellerbrock, Jr., N. A. C. A.
622. Flight Tests of an Airplane Showing Dependence of the Maximum Lift Coefficient on the Test Conditions. By H. A. Soulé and James A. Hootman, N. A. C. A.
623. Maximum Forces Applied by Pilots to Wheel-Type Controls. By William H. McAvoy, N. A. C. A.
624. Performance Characteristics of Venturi Tubes Used in Aircraft for Operating Air-Driven Gyroscopic Instruments. By Harcourt Sontag and Daniel P. Johnson, National Bureau of Standards.
625. Spinning Characteristics of Wings. IV—Changes in Stagger of Rectangular Clark Y Biplane Cellules. By M. J. Bamber and R. O. House, N. A. C. A.
626. Static Thrust Analysis of the Lifting Airscrew. By Montgomery Knight and Ralph A. Hefner, Georgia School of Technology.
627. Pressure Distribution over a Clark Y-H Airfoil Section with a Split Flap. By Carl J. Wenzinger, N. A. C. A.
628. Plastics as Structural Materials for Aircraft. By G. M. Kline, National Bureau of Standards.
629. A Sound Pressure-Level Meter without Amplification. By E. Z. Stowell, N. A. C. A.
630. Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. II—Mass Distributed along the Fuselage. By Oscar Seidman and A. I. Neihouse, N. A. C. A.
631. Wind-Tunnel Tests of Carburetor-Intake Rams. By Frank H. Highley, N. A. C. A.
632. Improvement of Aileron Effectiveness by the Prevention of Air Leakage through the Hinge Gap as Determined in Flight. By H. A. Soulé and W. Gracey, N. A. C. A.
633. Spinning Characteristics of Wings. V—N. A. C. A. 0009, 23018, and 6718 Monoplane Wings. By M. J. Bamber and R. O. House, N. A. C. A.
634. The N. A. C. A. Optical Engine Indicator. By Robert E. Tozier, N. A. C. A.
635. Tank Tests of a Model of One Hull of the Savoia S-55-X Flying Boat—N. A. C. A. Model 46. By John M. Allison, N. A. C. A.
636. The Estimation of the Rate of Change of Yawing Moment with Sideslip. By Frederick H. Imlay, N. A. C. A.
637. Preliminary Fatigue Studies on Aluminum Alloy Aircraft Girders. By Goodyear-Zeppelin Corporation.
638. Tank Tests of Model 36 Flying-Boat Hull. By John M. Allison, N. A. C. A.
639. A Preliminary Investigation of Boundary-Layer Transition along a Flat Plate with Adverse Pressure Gradient. By Albert E. von Doenhoff, N. A. C. A.
640. Interference of Wing and Fuselage from Tests of 18 Combinations in the N. A. C. A. Variable-Density Tunnel—Combinations with Split Flaps. By Albert Sherman, N. A. C. A.
641. Interference of Wing and Fuselage from Tests of 17 Combinations in the N. A. C. A. Variable-Density Tunnel—Combinations with Special Junctures. By Albert Sherman, N. A. C. A.
642. Interference of Wing and Fuselage from Tests of Eight Combinations in the N. A. C. A. Variable-Density Tunnel—Combinations with Tapered Fillets and Straight-Side Junctures. By Albert Sherman, N. A. C. A.
643. A Study of Flying-Boat Take-Off. By Walter S. Diehl, Bureau of Aeronautics, Navy Department.

644. Flight and Wind-Tunnel Tests of an XBM-1 Dive Bomber. By Philip Donely and Henry A. Pearson, N. A. C. A.
645. Some Aspects of the Stalling of Modern Low-Wing Monoplanes. By Hartley A. Soulé and Melvin N. Gough, N. A. C. A.
646. Wind-Tunnel Tests of a 2-Engine Airplane Model as a Preliminary Study of Flight Conditions Arising on the Failure of One Engine. By Edwin P. Hartman, N. A. C. A.
647. Engine Performance and Knock Rating of Fuels for High-Output Aircraft Engines. By A. M. Rothrock and Arnold E. Biermann, N. A. C. A.
648. The Increase in Frictional Resistance Caused by Various Types of Rivet Heads as Determined by Tests of Planing Surfaces. By Starr Truscott and J. B. Parkinson, N. A. C. A.
649. The Effect of Air-Passage Length on the Optimum Fin Spacing for Maximum Cooling. By Maurice J. Brevoort, N. A. C. A.
650. Wind-Tunnel Tests of a Clark Y Wing Having Split Flaps with Gaps. By Carl J. Wenzinger, N. A. C. A.
651. Effect of Spark-Timing Regularity on the Knock Limitations of Engine Performance. By Arnold E. Biermann, N. A. C. A.
652. Tables of Stiffness and Carry-Over Factor for Structural Members under Axial Load. By Eugene E. Lindquist and W. D. Kroll, N. A. C. A.
653. A Flight Investigation of the Reduction of Aileron Operating Force by Means of Fixed Tabs and Differential Linkage, with Notes on Linkage Design. By H. A. Soulé and James A. Hootman, N. A. C. A.
654. Fuel Consumption of a Carburetor Engine at Various Speeds and Torques. By Oscar W. Schey and J. Denny Clark, N. A. C. A.
655. Principles Involved in the Cooling of a Finned and Baffled Cylinder. By M. J. Brevoort, N. A. C. A.
656. Hydrodynamic and Aerodynamic Tests of Models of Floats for Single-Float Seaplanes—N. A. C. A. Models 41-D, 41-E, 61-A, 73, and 73-A. By J. B. Parkinson and R. O. House, N. A. C. A.
657. Tank Tests to Show the Effect of Rivet Heads on the Water Performance of a Seaplane Float. By J. B. Parkinson, N. A. C. A.
658. Generalized Analysis of Experimental Observations in Problems of Elastic Stability. By Eugene E. Lundquist, N. A. C. A.
659. Wind-Tunnel Tests of Three Lateral-Control Devices in Combination with a Full-Span Slotted Flap on an N. A. C. A. 23012 Airfoil. By Carl J. Wenzinger and Millard J. Bamber, N. A. C. A.
660. Fatigue Testing of Wing Beams by the Resonance Method. By William M. Bleakney, National Bureau of Standards.
661. Wind-Tunnel Investigation of Rectangular and Tapered N. A. C. A. 23012 Wings with Plain Ailerons and Full-Span Split Flaps. By Carl J. Wenzinger and Milton B. Ames, Jr., N. A. C. A.
662. Gyroscopic Instruments for Instrument Flying. By W. G. Brombacher and W. C. Trent, National Bureau of Standards.
663. The Effects of Partial-Span Plain Flaps on the Aerodynamic Characteristics of a Rectangular and a Tapered Clark Y Wing. By R. O. House, N. A. C. A.
664. Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. III—Mass Distributed along the Wings. By Oscar Seidman and A. I. Neihouse, N. A. C. A.
665. Tests of N-85, N-86, and N-87 Airfoil Sections in the 11-Inch High-Speed Wind Tunnel. By John Stack and W. F. Lindsey, N. A. C. A.
666. Longitudinal Stability in Relation to the Use of an Automatic Pilot. By Alexander Klemin, Perry A. Pepper, and Howard A. Wittner, New York University.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

No.

839. The Design of Airplane Engine Superchargers. By Werner von der Nüll. From Luftfahrtforschung, April 20, 1937.
840. Research and Design Problems Introduced by Increased Power Output. By Oskar Kurtz. From Luftwissen, April 1937.
841. Synthetic Resins in Aircraft Construction—Their Composition, Properties, Present State of Development and Application to Light Structures. By K. Riechers. From Luftwissen, August 1937.
842. Universal Logarithmic Law of Velocity Distribution as Applied to the Investigation of Boundary Layer and Drag of Streamline Bodies at Large Reynolds Number. By G. Gurjienko. From Report No. 257 of the Central Aero-Hydrodynamical Institute, Moscow, 1936.
843. Detonation and Autoignition. Some Considerations on Methods of Determination. By G. D. Boerlage. From Journees Techniques Internationales de L'Aeronautique, November 23-27, 1936.
844. Flow in Smooth Straight Pipes at Velocities above and below Sound Velocity. By W. Frössel. From Forschung auf dem Gebiete des Ingenieurwesens, March-April 1936.
845. On the Theory of Hydrofoils and Planing Surfaces. By F. Weinig. From Luftfahrtforschung, June 20, 1937.
846. The Buckling of Curved Tension-Field Girders. By G. Limpert. From Luftfahrtforschung, July 20, 1937.
847. Stresses in Reinforcing Rings Due to Axial Forces in Cylindrical and Conical Stressed Skins. By K. Drescher and H. Gropler. From Luftfahrtforschung, February 20, 1937.
848. Planing-Surface Tests at Large Froude Numbers—Airfoil Comparison. By A. Sambraus. From Luftfahrtforschung, August 20, 1936.
849. Rate-of-Climb Recorder. By Helmut Danielzig. From Luftwissen, May 1937.
850. Engines and Propellers for Powered Gliders and Light Airplanes. By H. Gropp. From Flugsport, November 24, 1937.
851. Twisting Failure of Centrally Loaded Open-Section Columns in the Elastic Range. By Robert Kappus. From Luftfahrtforschung, September 20, 1937.
852. Systematic Airfoil Tests in the Large Wind Tunnel of the DVL. By H. Doetsch and M. Kramer. From Luftfahrtforschung, October 12, 1937.
853. Effect of Air-Fuel Ratio on Detonation in Gasoline Engines. By L. A. Peletier. From Second World Petroleum Congress, Paris, June 1937.
854. Twisting of Thin-Walled Columns Perfectly Restrained at One End. By Lucio Lazzarino. From L'Aerotecnica, October 1937.
855. Model Experiments on the Forces and Moments on an End Plate Fitted to a Wing. By O. Schrenk. From Luftfahrtforschung, November 20, 1937.
856. The Lift Distribution of Wings with End Plates. By W. Mangler. From Luftfahrtforschung, November 20, 1937.

857. Investigation of Ignition and Combustion Processes of Diesel Engines Operating with Turbulence and Air-Storage Chambers. By Hans Petersen. From Forschung auf dem Gebiete des Ingenieurwesens, November–December 1937.
858. The Focke Helicopter. By H. Focke. From Luftwissen, February 1938.
859. A New Spinning-Test Method. By M. Kramer and K. B. Krüger. From Luftfahrtforschung, October 12, 1937.
860. The Design of Floats. By W. Sottorf. From Luftfahrtforschung, April 20, 1937.
861. Compression Struts with Nonprogressively Variable Moment of Inertia. By B. Radomski. From Luftfahrtforschung, September 20, 1937.
862. The Influence of Notches under Static Stress. By K. Matthaes. From Luftfahrtforschung, January 20, 1938.
863. On the Determination of the Take-Off Characteristics of a Seaplane. By A. Perelmuter. From Report No. 255, Central Aero-Hydrodynamical Institute, Moscow, 1936.
864. Load Tests on a Stiffened Circular Cylindrical Shell. By E. Schapitz and G. Krümling. From Luftfahrtforschung, December 20, 1937.
865. Behavior of Static Pressure Heads at High Speeds. By Helmut Danielzig. From Luftfahrtforschung, June 20, 1937.
866. Calculation of Load Distribution in Stiffened Cylindrical Shells. By H. Ebner and H. Köller. From Luftfahrtforschung, December 20, 1937.
867. Theoretical Study of Various Airplane Motions after Initial Disturbance. By Fr. Haus. From Bulletin du Service Technique de L'Aeronautique, No. 17, June 1937.
868. The Dornier Wind Tunnel. By H. Schlichting. From Luftfahrtforschung, March 20, 1938.
869. The Conversion of Energy in a Radiator. By A. Weise. From Gesammelte Vorträge der Hauptversammlung 1937 der Lilienthal-Gesellschaft für Luftfahrtforschung vorgetragen in München vom 12–14, October 1937.
870. Behavior of a Plate Strip under Shear and Compressive Stresses beyond the Buckling Limit. By A. Kromm and K. Marguerre. From Luftfahrtforschung, December 20, 1937.
871. Performance of Rotating-Wing Aircraft. By K. Hohenemser. From Ingenieur-Archiv, December 1937.
872. The Present Status of Airship Construction, Especially of Airship-Framing Construction. By Hans Ebner. From Zeitschrift für Flugtechnik und Motorluftschiffahrt, June 6 and June 28, 1938.
873. Experimental Study of Ignition by Hot Spot in Internal Combustion Engines. By Max Serruys. From Publications Scientifiques et Techniques du Ministere de L'Air, No. 115, 1937.
874. Effect of Propeller Slipstream on Wing and Tail. By J. Stüper. From Luftfahrtforschung, April 6, 1938.
875. Heat-Stressed Structural Components in Combustion-Engine Design. By Otto Kraemer. From Zeitschrift des Vereines deutscher Ingenieure, March 12, 1938.
876. Investigations on the Downwash behind a Tapered Wing with Fuselage and Propeller. By H. Muttray. From Luftfahrtforschung, March 20, 1938.
877. Wind-Tunnel Investigations on Flexural-Torsional Wing Flutter. By H. Voigt. From Luftfahrtforschung, September 20, 1937.

AIRCRAFT CIRCULAR ISSUED DURING THE PAST YEAR

No.

209. Fairey "Battle" Medium Bomber Airplane (British). An All-Metal Low-Wing Cantilever Monoplane. From The Aeroplane, June 16 and August 18, 1937.

FINANCIAL REPORT

The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1938, as contained in the Independent Offices Appropriation Act approved June 28, 1937, was $1,259,850. A supplemental appropriation of $453,000 was made available in the Second Deficiency Appropriation Act, fiscal year 1937, approved May 28, 1937, for the same purposes specified in the Committee's regular appropriation act for 1937, to continue available until June 30, 1938, and providing that $353,000 should be available only for the construction and equipment of facilities and for the purchase of an airplane of the light metal private type; and providing further, that the unexpended balance of the supplemental appropriation of $1,367,000 for 1937 be continued available until June 30, 1938. That unexpended balance was $206,071. The total amount available for expenditure during the fiscal year 1938, therefore, was $1,918,921. The amount expended and obligated was $1,918,868, itemized as follows:

Personal services	$987,571
Supplies and materials	118,162
Communication service	3,037
Travel expenses	13,454
Transportation of things	3,509
Furnishing of electricity	39,828
Repairs and alterations	28,625
Special investigations and reports	92,671
Equipment	255,049
Structures	376,962
Expended and obligated	1,918,868
Unobligated balance	53
Total, general appropriation	1,918,921

The appropriation for printing and binding for 1938 was $21,000, of which $20,987 was expended.

The sum of $7,786 was received during the fiscal year 1938 as special deposits to cover the estimated cost of scientific services to be furnished private parties. The total cost of investigations completed for private parties during the fiscal year, amounting to $4,940, was deposited in the Treasury to the credit of Miscellaneous Receipts. The sum of $7,184 remained in special deposits on account of tests started during the fiscal year 1937 and unfinished as at June 30, 1937. The cost of these investigations, which were completed during fiscal year 1938, amounting to $6,178, was also deposited in the Treasury to the credit of Miscellaneous Receipts, making a total of $11,118 so deposited during the fiscal year 1938.

An allotment of $250 was received from the State Department for payments during the fiscal year 1938 to employees stationed abroad, on account of exchange losses due to appreciation of foreign currencies. Of this amount $144 was paid during the fiscal year 1938 to employees of the Committee stationed in the Paris

Office, leaving a balance of $106 which was turned back into the Treasury.

Of the allotment of $2,000 for participation in the Greater Texas and Pan American Exposition at Dallas, which closed October 31, 1937, the amount of $1,995 was expended and the unobligated balance of $5 was returned to the original appropriation.

CONCLUDING STATEMENT

Air power at the present time is a dominant factor in the strength of a nation and in enabling it to maintain its independent existence and territorial integrity. Accepted theories of warfare give a steadily increasing place to air power.

Air power is primarily dependent not only upon numbers of airplanes, but the airplanes themselves must have performance at least equal to that of an enemy. The fact that modern military aircraft require frequent replacement by improved types brings forcibly to our attention the necessity of basing their design upon the best and most reliable data from research laboratories. New information is being obtained in the aeronautical laboratories of many nations, and unless our own laboratories keep pace, the United States cannot hope to compete with foreign nations in the development of either military or commercial aircraft.

The relation of laboratory research to the development of efficient aircraft is being increasingly appreciated by the world powers. The United States for a number of years has held undisputed leadership in the field of aeronautical research. At the present time that leadership is being challenged. Unless, therefore, we fully recognize the challenge and make provision for extending the Committee's research facilities and for increasing the number of its trained research personnel, the United States will definitely fall behind.

The struggle of nations to extend their influence to other countries, is resulting in determined efforts to establish air trade routes. A few years ago, great distances were an insuperable barrier to transoceanic air transportation, but the rapid improvement of aircraft has shrunk the map of the world.

Looking to the future, the progressive nations are making sacrifices and expending their national energies and resources for the purpose of advancing their air commerce. The United States, in extending and developing its domestic and international air commerce, is confronted with serious competition in the operation of air lines over the Atlantic and Pacific Oceans and to South America. In this connection the importance of scientific research cannot be overemphasized, as the long distances of flight over water demand a maximum of efficiency in aircraft. The United States leads at the present time in domestic and international air commerce. It should cherish this position and bend every effort to extend further its commercial air transportation.

The establishment of the Civil Aeronautics Authority has improved governmental aeronautical organization. The governmental agencies concerned with aeronautics are now organized on a sound and logical basis and function in cooperation. The aircraft manufacturing and operating industries have shown a commendable spirit of cooperation with the Government and with each other, and are alert to apply the results of the Committee's researches in a constant effort to improve the performance, efficiency, and safety of both military and civil aircraft. The Committee believes that the continuous and systematic conduct of scientific laboratory research on the basic problems of flight is the most fundamental activity of the Government in connection with the development of aeronautics. The Army, Navy, and Civil Aeronautics Authority are equally represented on the Committee. With their hearty cooperation the Committee coordinates the research needs of military, naval, and commercial aviation, and conducts the more fundamental scientific investigations in one central Government laboratory at Langley Field, Va. In this way a maximum of progress is obtained at minimum expense without overlapping or duplication.

In the rapidly advancing science of aeronautics the technical development of aircraft is directly dependent upon scientific laboratory research. The recent great expansion of research facilities by other nations will bring to an end the period of American leadership in the technical development of aircraft unless the United States also constructs additional research facilities. This subject is being studied by a special committee which includes in its membership the heads of the Army Air Corps, the Navy Bureau of Aeronautics, and the Civil Aeronautics Authority. The recommendations of that special committee will probably become the subject of a special report to the President and the Congress.

The Committee is grateful to the President and the Congress for the support accorded its work in the fields of basic and applied research in aeronautics. The Committee is determined to make every effort to meet its responsibilities by providing the scientific foundation for keeping America first in the technical development of both military and commercial aircraft.

Respectfully submitted.

National Advisory Committee for Aeronautics,

Joseph S. Ames, *Chairman.*