TWENTY-THIRD ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1937

INCLUDING TECHNICAL REPORTS
Nos. 577 to 611

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1938

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - - - Price, $2.50 (Buckram)

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-third Annual Report of the Committee covering the fiscal year ended June 30, 1937.

FRANKLIN D. ROOSEVELT.

The WHITE HOUSE,
January 7, 1938.

LETTER OF SUBMITTAL

National Advisory Committee for Aeronautics,
Washington, D. C., November 29, 1937.

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-third Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1937.

During the past year the United States has maintained its position in the forefront of progressive nations in the technical development of aircraft for both military and commercial purposes. This has been due chiefly to sound organization and liberal support of scientific laboratory research in aeronautics in this country.

The War, Navy, and Commerce Departments, having equal representation on the Committee, cooperate in every way in its work, and each receives the results of the scientific investigations conducted. Thus the research needs of all branches of aviation are met without overlapping or duplication of effort. The Committee's activities, however, are limited to research. They do not include experimental engineering in the application of research results to the development of military, naval, or commercial aircraft.

The greatly increased interest of the major powers in fostering aeronautical research and their determined efforts to excel in this rapidly advancing engineering science constitute a scientific challenge to America's present leadership. It is the responsibility of the National Advisory Committee for Aeronautics to see to it that the United States will not become dependent upon any foreign nation for fundamental scientific data on which to base the design of American aircraft. To do this effectively it will be necessary that this Committee continue to have the liberal and far-sighted support of the President and of the Congress.

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.

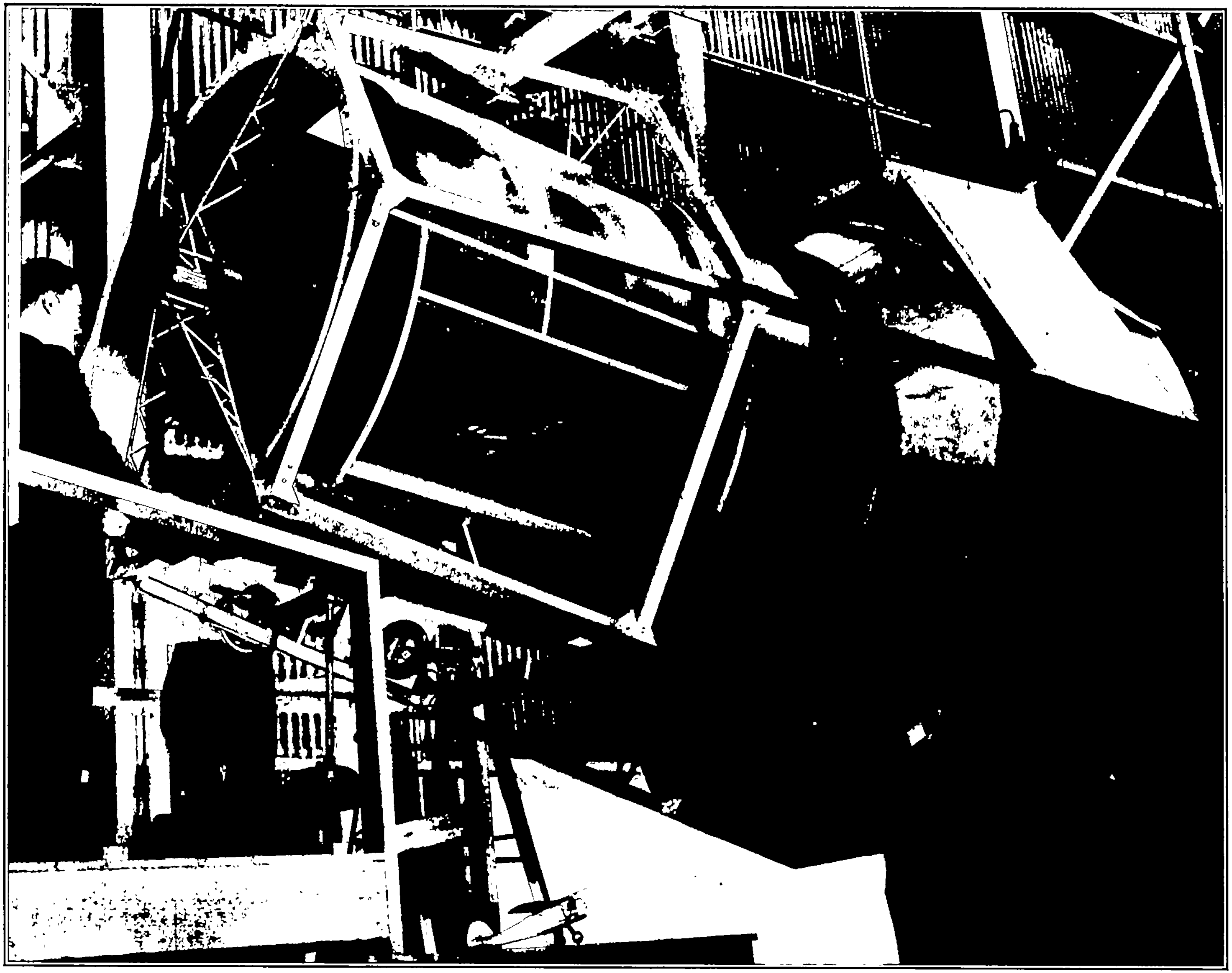
Unified conduct, for all agencies, of scientific research on the fundamental problems of flight.

OFFICE OF AERONAUTICAL INTELLIGENCE

WASHINGTON, D. C.

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

38548—38——2



THE NEW N. A. C. A. FREE FLIGHT WIND TUNNEL IN WHICH INVESTIGATIONS OF AIRPLANE STABILITY AND CONTROL CHARACTERISTICS CAN BE MADE ON AN AIRPLANE MODEL IN FREE FLIGHT.

TWENTY-THIRD ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 10, 1937.*

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, this Committee submits herewith its twenty-third annual report, covering the fiscal year 1937.

Responsibilities of this organization.—The prescribed functions of this organization 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 the discharge of its functions under the law the primary responsibilities of the National Advisory Committee for Aeronautics are: (1) To recognize in advance the trend of aeronautical development, civil and military; (2) to anticipate the research problems that will arise; and (3) to design and provide research equipment to meet the needs of this rapidly advancing engineering science, and then to conduct the necessary scientific investigations.

Created by law in 1915 as an independent Government establishment, the Committee, with the consistent and liberal support of the President and of the Congress, has gradually developed a large and well-equipped aeronautical research laboratory at Langley Field, Virginia. In this laboratory it has conducted fundamental scientific research in aeronautics with the sincere and indispensable cooperation and assistance of the War, Navy, and Commerce Departments. As a result, the scientific basis for aircraft design in the United States for both military and civil uses is not excelled in any other country. Long adherence to sound policy has won for the United States general recognition as a leader among the progressive nations in improving the performance, efficiency, and safety of aircraft.

The continued improvement in the performance of both military and commercial aircraft has confronted this Committee with a variety of problems that are pressing for immediate solution. Among examples of such problems may be mentioned the need for devising a method for studying the stalling characteristics of highly tapered wings; the determination of the necessary load factors and their variation with size and speed; the problem of reducing or eliminating if possible the formation of ice on wings, propellers, and control surfaces, and of providing effectively for the automatic removal of ice when it does form; problems involved in the design of wings, control surfaces, and flaps, as well as other devices to secure better control at low speeds incident to taking off and landing; problems of suppressing vibration and flutter, improving engine and propeller efficiency, capacity, and dependability, extending the range, enlarging the capacity, and at the same time constantly increasing the speed and safety of aircraft.

In addition to meeting urgent needs of the present, the Committee tries to look into the future and to anticipate some of the problems that may arise. For example, what are the maximum requirements for military and commercial aircraft going to be? Will speeds in excess of 400 miles per hour be required? How much will the size of commercial aircraft exceed 50 tons within the next few years? What are the problems that will require scientific analysis before such craft can be successfully designed and constructed? Will airships be further developed for naval use or for transoceanic transportation and, if so, what are fundamental problems this Committee should investigate?

The organization of research.—To analyze the present and probable research needs of aviation, civil and military, the N. A. C. A. has set up standing technical subcommittees on aerodynamics, power plants for aircraft, aircraft materials, and aircraft structures. The subcommittees are organized along lines similar to the main Committee and include specially qualified representatives of all the governmental agencies concerned with aeronautical development, as well as experts from private life. The members of the subcommittees, like the members of the main Committee, serve as such without compensation. The subcommittees prepare and recommend research programs. The more fundamental problems are usually assigned for investigation at the Committee's laboratory at Langley Field, Virginia, primarily because of its special equipment for aeronautical research. Problems are also assigned to the National Bureau of Standards, so as to make the best use of available Government facilities and at the same time to avoid duplication in the field of aeronautical research. In the same manner problems are assigned and funds transferred to universities and technical schools. In this way aeronautical research is stimulated and coordinated.

Advances in the science of aeronautics have given rise to various trends, as the possibilities of aircraft increase. At the present time the trend of design of aircraft in all nations is definitely toward higher speeds and larger structures, with greater range and carrying capacity. This is true in both the military and commercial fields. Scientific and technical problems do not diminish but on the contrary increase in number and in difficulty with each advance in speed or size. It is the duty of this Committee to supply the fundamental data on which the design of new aircraft is based. If the Committee does not meet this responsibility adequately, the United States will quickly fall behind, because of the great emphasis now being placed on aeronautical research and development by other progressive nations.

Research facilities.—Up to 1932 the Committee had constructed at its laboratories at Langley Field, Virginia, known as the Langley Memorial Aeronautical Laboratory, special equipment such as the variable-density tunnel, the propeller-research tunnel, the full-scale tunnel, and the hydrodynamic laboratory—a seaplane towing basin. They were at the time of construction the only such pieces of equipment in the world. The possession of such equipment was one of the chief factors in enabling the United States to become the recognized leader in the technical development of aircraft. Since 1932 this research equipment has been reproduced by foreign countries and in some cases special research equipment for the study of problems in aeronautics has been developed and constructed abroad which is more modern than and superior to the equipment existing at Langley Field.

Since 1932 the importance of scientific research in aeronautics has been more generally appreciated by European nations and several of the larger powers have greatly augmented their research facilities and activities. The competition in the development of research equipment and facilities between the progressive nations is just as intense as the competition in the production of aircraft of superior performance. This condition has impressed the Committee with the advisability of providing additional facilities promptly as needed for the study of problems that are necessary to be solved, in order that American aircraft development, both military and commercial, will not fall behind.

In answering this scientific challenge the Committee has under construction at its laboratories at Langley Field a new wind tunnel having a diameter of 19 feet that can be operated under a pressure of three or more atmospheres at an air speed of more than 200 miles per hour. This tunnel will permit the investigation of the characteristics of large models of aircraft at much higher values of Reynolds Number than can be obtained in any of the Committee's existing wind tunnels. The Committee also has under construction a refrigerated wind tunnel for the investigation of the problems of ice formation on aircraft. This tunnel has throat dimensions of 7½ by 3 feet and will embody features and principles which, it is believed, will make it an effective instrument for the purpose intended.

The Committee during the past year developed an entirely new type of wind tunnel. The experience of the Committee in the operation of the free-spinning wind tunnel indicated the advantage of being able to reproduce and observe aircraft motion under controlled conditions in a wind tunnel. Methods of studying stability, control, and motion of an aircraft in previous types of wind tunnels, where the model is fixed on a balance, are long and laborious, and leave much to be desired in accuracy. Realizing the need for studying stability, control, and motion of a model of an aircraft when flying unrestrained, the Committee developed in the past year a new form of wind tunnel known as a "free-flight wind tunnel."

The first tunnel of this type constructed was 5 feet in diameter, and was so arranged that by tilting the tunnel its longitudinal axis could be set parallel to the glide path of the model under test. To do this the tunnel was suspended from above at a single point so that the axis of the wind tunnel could be varied through a wide range of angles, making this tunnel what might be called a "tilting wind tunnel."

The results obtained with this small tunnel were so encouraging that the Committee proceeded with the construction of a free-flight wind tunnel having a diameter of 20 feet.

With the establishment of commercial service across the Pacific Ocean by seaplane transports and the early prospect of such service across the Atlantic, operators and designers are focusing their attention on aircraft of larger sizes having improved efficiency and carrying more passengers and a heavier mail and express load. The design of the seaplane hull is a most important factor affecting the efficiency of transoceanic transports. Anticipating the need for extensive investigation of seaplane hull models in connection with the development of larger seaplanes, the Committee during the past year modernized its hydrodynamic laboratory. The towing basin was lengthened from 2,000 feet to 2,900 feet. The towing carriage was enlarged and the operating speed increased so that investigations can now be made at speeds corresponding to the higher take-off and landing speeds of seaplanes.

The Committee's laboratories are on a portion of Langley Field assigned to this organization by the Secretary of War and are under the direct control of the Committee. The Committee believes that its laboratories, despite the recent great expenditures on research organizations abroad, are as yet unexcelled by those of any other single nation. In addition to the new research equipment under construction as noted above, the Committee's laboratories include: An 8-foot 500-mile-per-hour wind tunnel; a 60- by 30-foot full-scale wind tunnel; a 20-foot propeller-research tunnel; a 5-foot variable-density wind tunnel; a 7- by 10-foot wind tunnel; a 5-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; a hydrodynamic laboratory; an engine research laboratory; a flight research laboratory; and an instrument research laboratory.

Relation of Committee's work to national defense.—The relationship of the work of this organization to national defense has long been recognized and appreciated by the War and Navy Departments. The Army and Navy air organizations rely upon the N. A. C. A. to anticipate and to meet their research needs and thus to enable them to achieve and maintain leadership in the highly competitive field of military aircraft development. The safety and security of our country in time of war may depend upon a decision in the air. The course of a war will certainly be influenced in favor of that side which can gain supremacy in the air. Sound tactical organization, large numbers of aircraft, sufficient trained personnel, and ample productive capacity in the industry are not in themselves sufficient. The aircraft that engage the enemy in action must, if possible, be superior in performance. The hope of retaining our present superiority in technical development, in the face of the increasing emphasis being placed upon aeronautical research and development abroad, will depend largely upon the ability of this organization to solve promptly and effectively the fundamental problems attendant upon rapid progress in this branch of engineering science.

In this connection, the economic value of the work of this organization is worthy of reference. The procurement programs of the Army and Navy call for the expenditure of large sums to carry into effect the national defense policy approved by the Congress. Unless the aircraft procured are at least equal in performance to those possessed by other nations, their net value to the Army and Navy in time of war would be almost at the vanishing point. A national investment in inferior military aircraft would not only invite the risk of loss of the aircraft in time of war, but also the trained flying personnel. It would be as disappointing and disastrous as it usually is to try to win on the second-best hand in a poker game. Without up-to-date, reliable results of scientific laboratory research, our Army and Navy would not be able, even with the most sincere cooperation of the industry, to design and procure aircraft with any assurance that they would not be "second best" in time of war.

Commercial aviation.—The continued search for trends of development, and the effort to meet these trends by the provision of adequate research facilities and investigation of the right problems, also have a very important bearing upon the development of commercial aviation. Researches initiated primarily to meet military needs are in many cases broadened in scope to meet the needs of commercial aviation. Research problems peculiar to commercial aviation alone are also investigated. The Committee is materially assisted in this respect by suggestions from the Bureau of Air Commerce and from the air transport lines. Aircraft manufacturers also offer research suggestions and are alert to incorporate changes which the Committee's researches indicate will improve the safety or efficiency of aircraft. That the United States leads the world in the development and operation of commercial aircraft is due not alone to this healthy condition, but also in large measure to the national policy of air mail payment and to the indispensable assistance of the Bureau of Air Commerce in providing unexcelled air navigation facilities and otherwise helping in every practicable way to promote the safety and efficiency of air navigation. We cannot in this connection underestimate the importance of the meteorological service of the Weather Bureau in aid of safety, nor the numerous and valuable contributions to commercial aviation that have resulted from the experiments and developments on aircraft, engines, instruments, and accessories by the Army and Navy.

Our growing air transport business finds a healthy reflection in an aircraft production industry better equipped to respond to the needs of national defense in time of emergency. A healthy nucleus of an aircraft industry capable of rapid expansion in time of need is essential to our national defense. If it were not for the stimulation and support given the manufacturers by the growth of commercial air transportation in the United States, the aircraft industry would be so much weaker that, in view of disturbed world conditions at this time, there would be need for some form of artificial stimulation and development of productive capacity. That we are not confronted with such a problem at this time is due partly to the fact that the results of the Committee's researches have made possible the development of commercial air transports in the United States superior to those of any other country. This has not only facilitated a rapid growth of commercial air transportation in this country, but has given to the American aircraft industry an advantage in world markets, evidenced by orders received from foreign countries for commercial airplanes of American manufacture.

The improved efficiency and safety of American air transports have permitted economies in operation, which in turn have resulted in material lessening of the cost of carrying air mail and of passenger fares.

Economic value of research.—No money estimate can be placed upon the economic value of greater national security through development of the means of producing superior military aircraft. Nor can a money estimate be placed upon the economic value of lives and property saved through improvements in the safety of aircraft. Nor can the educational advantages offered by air travel, the time saved, and the pleasure afforded to passengers be evaluated, nor the value to the nation of extending its national influence through world trade routes of the air. The researches of this Committee, however, do have a tremendous economic value that can be measured in dollars and cents. Improvements in aircraft that have resulted from the Committee's investigations and that have a definite economic value are numerous. Careful computations have been made of the economic value of a few of the more important contributions of this organization. These indicate that the annual savings in money made possible by the Committee's researches exceed the total appropriations for this organization since its establishment in 1915.

Summary.—With the rapid expansion of aviation in national defense, it is more than ever necessary that facilities be available for the prompt and adequate study of those fundamental problems in aeronautics that influence the speed, range, capacity, and control of aircraft.

The Committee believes that the future development of American aeronautics is largely dependent upon the support and effort given to the orderly and sustained prosecution of fundamental scientific research. It is the confident hope of the Committee that the United States will never be in a position where fundamental information necessary for the design of aircraft of maximum performance, efficiency, and safety will have to be imported from any foreign nation.

In commercial aviation the major problem is one of improving safety without penalizing those factors that are necessary to increase the speed, efficiency, operating range, and comfort of aircraft. When this Committee was established over twenty-two years ago there was but little appreciation of the value of aeronautics to national defense and practically no appreciation of the possibilities of aircraft in commerce.

Aviation has now become such an important factor in national defense, in the promotion of transportation in the United States, and in the extension of international commerce and good will that the organization and conduct of aeronautical research have attained the greatest significance and importance.

Foreign nations are making determined efforts to design and produce superior research facilities and to develop superior aircraft, both civil and military. The Committee in order fully to meet its responsibilities is endeavoring to modernize, improve, and augment its research facilities so as to maintain the present advantage of the United States.

To assure effective functioning on the urgent problems of the Army and Navy in time of war means for stabilizing the personnel of this organization must be found. From a study of the problem thus far it appears that enactment of legislation for this purpose may be necessary.

The Committee believes that the results achieved in the past and the problems to be faced justify a continuation of the liberal support of its work, and it further believes that in order to secure the best results there should be no change in its functions or in its status as an independent Government establishment.

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 Committees for Aeronautics to establish from time to time special technical subcommittees for the study of particular problems as they arise.

During the past year there has been a major change in the organization of the Committee's standing technical committees. The Committee on Aircraft Structures and Materials, which was one of the three principal technical committees, its Subcommittee on Structural Loads and Methods of Structural Analysis and the latter's Subcommittee on Research Program on Monocoque Design have been replaced by two coordinate committees, both reporting direct to the main Committee, namely, the Committee on Aircraft Materials and the Committee on Aircraft Structures. This change was made in recognition of the greatly increased importance of the problems of structural design in the field of aeronautics, and of the need for greater concentration of effort on these problems.

With this change in organization, 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. The greater part of the research under the cognizance of the Committee on Aircraft Structures is carried on by the National Bureau of Standards, but a number of structural investigations, especially those of a theoretical nature, are conducted at educational institutions and at the Committee's laboratory at Langley Field. 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

Flaps.—The use of wing flaps on high-performance airplanes is now almost universal. The research that has been conducted by the Committee during the past several years on the most promising forms of flaps has resulted in establishing their relative merits and has made possible the selection of the most satisfactory type for a given design. During the past year, attention has been directed mainly toward obtaining more specific design data for flap application.

In the variable-density wind tunnel, tests of ordinary and split flaps of 20-percent wing chord on the N. A. C. A. 23012 airfoil have been made with a large range of flap settings at a value of the effective Reynolds Number of about 8,000,000, for the purpose of providing designers with more reliable data as to the airfoil section characteristics for these combinations at large values of the Reynolds Number. While the results have not been completely analyzed, they corroborate, in general, the conclusions drawn from previous tests at lower values of the Reynolds Number.

The split flap is somewhat more favorable to speed range and landing speed than is the ordinary flap.

In the 7- by 10-foot wind tunnel a study of slotted flaps is under way in which tests of flaps of various shapes with slots of various forms are being conducted on an N. A. C. A. 23012 wing of 3-foot chord. With this installation, airfoil characteristics corresponding to a Reynolds Number of about 2,500,000 are being determined. The results to date indicate that with a properly designed slotted flap, unusually high maximum lift coefficients may be obtained. In addition, very low profile drag coefficients at high lift coefficients may be obtained with the flap deflected, which should result in improved take-off and climb characteristics. For controlling the glide-path angle, the slotted flap may be deflected beyond the angle for maximum lift without appreciably changing the lift coefficients. With this type of operation, the flap is similar to the glide-control flap previously described in Technical Note No. 552.

The results of the investigation in flight and in the full-scale wind tunnel, of a Zap flap mounted on a Fairchild 22 airplane, previously mentioned, have been published in Technical Note No. 596. Results of a similar investigation on the external-airfoil flap are presented in Technical Note No. 604.

Tests have also been made in the 7- by 10-foot wind tunnel for private companies and for the Bureau of Aeronautics of the Navy Department of the aerodynamic characteristics of several models equipped with flaps.

Maxwell slot.—The results of tests of another device for the improvement of speed range, the Maxwell leading-edge slot, mentioned in last year's report, have been published in Technical Note No. 598.

Measurement of minimum speed.—Opportunity was afforded during the year, in connection with the investigation of the maximum lift coefficient of a 2R₁12 wing on a Fairchild 22 airplane, to obtain a comparison between the flow conditions in flight and in the full-scale wind tunnel and thus study the effect of various test procedures and conditions on the measured minimum speed of an airplane. The main flight program covered the effect of wing loading and altitude on minimum speed. By extension of the program the effects of propeller position, throttle setting, wing-surface roughness, and the rate at which the angle of attack was increased were investigated. It was found that for a constant weight the minimum speed might vary by 5 percent, depending on the factors. The maximum lift coefficient obtained with one loading cannot be directly applied to the computation of the minimum speed with another loading, because of the variation of the lift coefficient with speed.

CONTROL AND CONTROLLABILITY

For a number of years the Committee has been engaged in a systematic wind-tunnel investigation of lateral control with special reference to the improvement of control at low air speeds and at high angles of attack. Many different ailerons and other lateral-control devices have been subjected to the same systematic investigation in the 7- by 10-foot wind tunnel and the devices that seemed most promising have been tested in flight. As has been stated in previous reports, the wind-tunnel and flight results were not always in agreement and indicated that, in determining actual control effectiveness from wind-tunnel results, it was necessary to include what had been previously considered secondary factors. A mathematical method of analysis was consequently developed to include those secondary factors and this method of analysis has been in use for about two years.

The experience gained has resulted in a revised basis of comparison of lateral-control devices and on this revised basis a critical résumé and analysis of the Committee's research to date on lateral control has been made and has been published in Technical Report No. 605. The analysis indicates that for normal-flight conditions, ordinary ailerons with the gap between the aileron and the wing sealed are the most generally satisfactory. An added advantage of these ailerons is that they appear to be practically free from icing hazards.

Slot-lip ailerons.—The complete results of the wind-tunnel and flight investigation of slot-slip ailerons have been published in Technical Report No. 602. It was stated in the last annual report that slot-lip ailerons installed on a Fairchild 22 airplane produced unsatisfactorily sluggish control, although such sluggishness was not detected by the pilots when these ailerons were installed on the W1–A airplane. An analysis made during the year has shown that the difference between the response of the two airplanes is explainable by the difference in their lateral-stability characteristics. Although some reduction in the drag of the slot-lip ailerons over that previously reported was obtained with a modified slot shape, the drag of this type of aileron is still considered excessive for modern high-performance airplanes.

The wind-tunnel investigation mentioned last year of the special form of slot-lip aileron, consisting of a plain aileron forming the trailing edge of an airfoil equipped with an external-airfoil flap, has been completed. The characteristics of these ailerons on an N. A. C. A. 23012 wing equipped with 20 and 30 percent chord full-span external-airfoil flaps of the same section were measured and are reported in Technical Report No. 603. These ailerons were found to be capable of developing large rolling moments but the hinge moments had certain undesirable characteristics and should receive further study.

Ailerons on tapered wings.—At the request of the Army Air Corps an investigation of the effectiveness of conventional ailerons on a tapered wing was made for direct comparison with a straight wing having ailerons of the same size. A 2:1 tapered wing with conventional flap-type aileron was mounted on a Fairchild 22 airplane and investigated in flight and in the full-scale wind tunnel. Conventional ailerons on this wing were found to be slightly more effective than ailerons of the same dimensions on a straight wing. The improvement was of the order of only 5 percent at low speed, and was so slight that it was not apparent to the pilots in the handling of the airplane. The results are being prepared for publication.

An investigation of ordinary sealed ailerons on two wings having medium and high taper ratios and partial-span split flaps has been described in Technical Report No. 611. The report presents aerodynamic information necessary for aileron design, including rolling, yawing, and hinge moments, as well as the aerodynamic characteristics of the wings.

Floating wing-tip ailerons.—Comparative tests were made in the full-scale wind tunnel and in flight to determine the relative effectiveness of floating-tip ailerons and conventional trailing-edge ailerons. The tests were made on a Fairchild 22 airplane equipped with a 2:1 tapered wing the wing tips of which could be removed and replaced by floating-tip ailerons. The floating-tip ailerons were made as large as seemed reasonable from considerations of structural weight. These ailerons were found to be approximately one-half as effective in producing rolling moment as conventional ailerons on the same wing. The floating-tip ailerons produced small favorable yawing moments while the trailing-edge ailerons produced appreciable unfavorable yawing moments.

Combinations of spoilers.—At the request of the Bureau of Aeronautics of the Navy Department, the lateral-control possibilities of combinations of spoilers arranged in tandem were investigated in the 7- by 10-foot wind tunnel. Since the time of response with such an arrangement was questionable, the investigation consisted primarily of measuring the response characteristics by means of a motion-picture study of the motion of a wing model restrained by springs but free to move when the control device was operated. The rolling moments produced by the control devices were measured with the same installation. It was found that while a combination of front and rear spoilers without lag was possible, no improvement in control was obtained over that with the rear spoiler or retractable aileron alone when the wing was equipped with a full-span flap.

Reduction of aileron control forces.—With the increase in size and speed of airplanes, increased interest has been shown in means of reducing the forces required to operate ailerons. On a large percentage of airplanes aerodynamic balances of the Frise or slotted types are used, with an accompanying loss in control effectiveness. In addition, such balances, with their projecting surfaces, are subject to icing difficulties.

The use of trailing-edge tabs in the conventional manner to balance the control forces of ailerons is accompanied by a sacrifice of some control effectiveness. A less conventional but apparently more successful method of applying tabs to ailerons is to use a very narrow-chord full-span tab to increase the up-floating angle of the ailerons by deflecting the tabs downward on both ailerons in conjunction with a proper differential movement of the ailerons. A study of aileron hinge moments as affected by differential linkages has been made and the results published in Technical Note No. 586. The value of a tab and differential linkage system has been investigated with a large wing in the 7- by 10-foot wind tunnel and on a Fairchild 22 airplane in flight. The ability of the arrangement to reduce the control forces to any desirable value was verified in both installations.

The flight investigation, in addition to verifying, in general, the principles involved in the theoretcal analysis, has indicated certain practical details requiring further study. The effect of the tabs on the aileron floating angle appears to be critically dependent on the tab shape. Tabs consisting of flat plates extending back of the aileron trailing edge were found to have very little effect on the aileron floating angle and consequently little effect on the control forces, whereas tabs inset within the aileron contour are satisfactory.

Wind-tunnel tests have shown that the effectiveness of a given aileron may be increased considerably by sealing the gap between the aileron leading edge and the wing to prevent leakage of air at this point. The effectiveness of the seal is greatest for narrow-chord ailerons, the increase being of the order of 50 percent when the aileron chord is about 10 percent of the chord. The increase in effectiveness may be utilized to improve the controllability or, if the controllability is satisfactory, to reduce the control forces by the substitution of a smaller sealed aileron for one having a gap at the hinge.

The actual application of this system of improving lateral control or reducing aileron stick forces depends on how much leakage occurs at the hinge in a normal aileron installation. In order to study this problem, measurements were made of the lateral control of the Fairchild 22 airplane, which has ailerons having a chord of 18 percent of the wing chord, with the original aileron installation and with a fabric seal over the gap at the hinge. A 30-percent improvement in the control effectiveness was obtained. On the basis of these findings, sealed ailerons of half the chord of the original ailerons, or 9 percent of the wing chord, were installed on the airplane. These ailerons are about as effective as the original unsealed ailerons but require less than half the operating effort.

Two-control operation of an airplane.—Control of an airplane by means of two controls instead of the three normally used has appeared to offer promise of simplifying the operation of an airplane. Flights have been made with airplanes in which both aileron-elevator and elevator-rudder combinations were utilized for two-control operation, but considerable uncertainty remains as to which of these modes of operation is likely to prove the better and also whether either of them is capable of affording the controllability required for safety in flight.

In order to obtain additional information on the subject, an analytical study was made of two-control operation of a conventional airplane by the method of the theory of disturbed motion and is presented in Technical Report No. 579. Control maneuvers were computed for various combinations of rolling and yawing moments with an airplane for which the lateral-stability derivatives were varied. It was concluded that, while the most desirable control characteristics would depend somewhat on the lateral-stability characteristics and on the rate of application of the control device, the two-control operation of an airplane would be most generally satisfactory with controls which gave primarily a rolling moment with a slight amount of favorable yawing moment.

Flying qualities of large airplanes.—As was mentioned in the last annual report, a research is in progress to determine how much is known quantitatively regarding the actual stability, controllability, and maneuverability of large airplanes, and also what the procedure should be in any investigation to determine these characteristics in quantitatve form. During the past year a program of investigation in flight covering the measurement of all the quantities believed to be of importance with respect to flying qualities, has been formulated, the instrumentation developed, and the program successfully tried with a single-engine five-place high-wing cabin monoplane. Some modifications in the original program regarding the measurement of the general stability and the effectiveness of the rudder control were indicated to be desirable. The modified program and certain items referring to asymmetric power conditions that could not be investigated with a single-engine airplane are being studied with a twin-engine bombardment monoplane, and the measurements have been initiated on modern transport airplanes.

Flight with unsymmetrical power.—The problem of flight with only the propellers on one side operating was investigated as part of the investigation of the power-on characteristics of large multi-engine models in the full-scale tunnel.

Flight with zero yaw, accomplished by banking the airplane slightly to balance the side forces due to the propellers and rudder, was found preferable to balancing the side forces by yawing without banking, both as regards the maximum ceiling and the rudder deflection required. For unsymmetrical power conditions, the losses in performance, aside from the reduction of the thrust, are due to the drag of the inoperative propellers and the deflected rudder. The propeller drag is the major item unless the propeller is feathered or allowed to free-wheel.

MANEUVERABILITY

At the request of the Bureau of Aeronautics, Navy Department, the Committee is undertaking an investigation of the maneuverability of several Navy airplanes primarily for the purpose of determining the maximum angular accelerations in pitch and roll to which the machines may be subjected. The tests have been completed on two airplanes. The investigation includes measurements of the angular accelerations in rolling produced by abrupt use of the ailerons alone and also by combined use of the ailerons and other controls. Pitching accelerations are investigated in abrupt pull-ups from level flight and in recoveries from vertical dives. In all cases the angular accelerations are correlated with the linear accelerations of the center of gravity. In addition to the measurements of angular acceleration, information is being obtained on the pressure inside the wings during vertical dives and data are obtained to compare the loss of altitude in recoveries from dives with that predicted by means of charts developed as a result of previous investigations.

In connection with the study of the vertical-dive maneuver, the velocity-altitude relations for airplanes have been studied. Charts have been prepared (Technical Note No. 599) that present in a readily usable form the solution of the relation between time, velocity, and altitude for airplanes having various terminal velocities. The variation of density with altitude is taken into account on these charts.

STABILITY

A review of all available previous and contemporary work on stability, which was mentioned in the last annual report, has been completed and an extensive program outlined for systematic research in the various facilities available to the Committee. Work is now in progress upon several of the projects deemed to be the most urgent.

The investigation of new equipment for the study of stability is being continued. An experimental 5-foot free-flight wind tunnel has been developed to a point of satisfactory operation. This tunnel can be used to study the free-flight behavior of models up to 22 inches in span. With a tunnel of this type it is possible to investigate inherent and controlled stability, motion in gusty air, stalling characteristics, the power of controls, and many other factors directly related to the actual free-flight behavior of the airplane. Even at the very low scale of tests possible in the present 5-foot tunnel, observation of model behavior has led to very interesting conclusions regarding the effects of such factors as the adverse yawing moments of ailerons, the effect of the position of the wing wake on the damping of longitudinal oscillations, the behavior of an aircraft when the tail is in the violent wake behind deflected split flaps, etc. The free-flight tunnel, of which the present 5-foot experimental version is the first and only one of the type, gives promise of greatly facilitating the entire study of aircraft motion.

Lateral stability.—Most existing work on stability deals with the inherent stability of the craft itself with the controls either fixed or free. Actually, the most usual condition of flight is that in which the aircraft is held to a definite course by either a human pilot or a compass-controlled automatic pilot. The pilot endeavors to bring the craft back to the course after a disturbance and in so doing alters the stability characteristics. A study of the stability of controlled motion along a definite course is now in progress and should show the effects of various ways of using the controls. It may also lead to a modification of present ideas regarding the importance and proper values of certain factors which affect the motion, since the present ideas are based on requirements for inherent stability.

In any study of stability with reference to a certain course, it is of great practical importance to know how the factors that govern the stability influence the magnitude and violence of the motion when an atmospheric disturbance is encountered. A mathematical study of motion in gusty air is being carried out and is approaching completion for the case of lateral motion.

A report on lateral stability in power-off flight has been published as Technical Report No. 589. This report parallels Technical Report No. 521, which deals with longitudinal stability. It includes discussions of the problem and of the individual factors involved. A number of charts are presented from which the lateral stability of a new design can be quickly and easily estimated.

One of the factors that most critically affects the lateral-stability characteristics is the rate of change of yawing moment with change in sideslip. There has been considerable uncertainty as to what allowance to make for the effect of the fuselage when this factor is estimated. During the past year, the Committee has undertaken a study of all readily available data on this factor with a view to developing suitable empirical relationships for its estimation. A technical note is being prepared giving the results of this investigation.

The investigation of the effect of tip shape and dihedral of rectangular monoplane wings on the lateral-stability characteristics, reported last year, has yielded basic information on the subject. For practical application to complete airplanes, however, the wing-fuselage interference would seem to be an important factor in determining the stability characteristics. Quantitative information on this effect will be obtained from an investigation that has been started in the 7- by 10-foot wind tunnel with fuselages of various cross sections and with tapered, swept-back, swept-forward, and rectangular wings.

Longitudinal stability.—Work is now in progress on a general study of longitudinal stability with power on. An attempt is being made to prepare charts similar to those in Technical Reports 521 and 589 to enable the designer to estimate quickly the effect of power on the stability.

The investigation of wing-fuselage interference in progress in the variable-density wind tunnel has been extended to include the study of the effects of adding tail surfaces to typical combinations. Conventional tail surfaces and horizontal tail surfaces with end plates are both being investigated with a view toward exploring the parameters of combination as affecting the aerodynamic interference, particularly as regards longitudinal stability. The effect on the moment of the tail surfaces entering the wing wake is noticeable but small, particularly when compared with the effect of the wing stall.

The analysis, reported last year, of the horizontal tail surface required for airplanes equipped with wing flaps, has been completed. A rational system for computing the horizontal tail area was evolved and has been presented in Technical Note No. 597.

A comprehensive investigation has been undertaken in the Committee's full-scale wind tunnel to determine the effect of propeller operation on the important characteristics of airplanes, such as the lift, stability, control, balance, etc. Full-scale data have been obtained for five airplanes having different geometrical arrangements, and a report presenting an analysis of these results is in preparation. These tests include measurements of the air-stream velocities and downwash angles in the region of the tail plane, and a study is being made to determine the variation of these quantities with the propeller thrust.

Stalling.—The problem of avoiding excessive danger from the stall has been a recurrent one. Most airplane manufacturers dealt with the problem rather satisfactorily several years ago, either empirically or through a reasonably sound understanding of the phenomenon, gained as the result of research work both here and abroad.

In general, the solutions embodied the use of increased static longitudinal stability, thus providing a definite warning of the approaching stall through the backward movement, position, and forces on the control column, together with a gradually developing stall secured either by allowing the upper or lower wing of a biplane to stall first or by the use of monoplanes with little or no taper and with "poor" wing-fuselage junctures, which further tended to bring about a gradually developing stall, beginning at mid-span. These measures assured that the stalled condition would develop progressively after a reasonably definite warning; furthermore, lateral control was often maintained up to or beyond the stall (wing maximum lift), owing to the fact that the essentially effective parts of the wing system remained unstalled even after the angle of attack had exceeded that of maximum lift. Inasmuch as the pilot has little incentive to go beyond this point, such a solution was and still is considered satisfactory.

With such satisfactory solutions in common use, attention has for the past few years been diverted from the problem of minimizing stalling dangers. Recently however, modern design trends are bringing the problem back again in an acute form. These trends are toward higher wing loadings and landing speeds; the substitution of efficient high-speed sections having more sudden and hence less desirable stalling characteristics; the almost exclusive use of tapered-wing monoplanes; the use of increased taper; the low-wing position which contributes to reduced longitudinal stability with increasing lift; the use of "good" wing-fuselage junctures; and, finally, high-lift devices. The high-lift devices may further add to the dangers of tip stalling, add to balance and stability difficulties, and usually cause a vicious section stall corresponding to a sudden, large, and usually unsymmetrical loss of lift.

These trends have already gone so far that it now appears that many airplanes in common use cannot be considered reasonably safe, even for experienced pilots. The worst offenders may give no indication of an approaching stall which, when it occurs, is manifested by a vicious uncontrolled rolling dive, that results from a sudden loss of lift on the right or left wing and a simultaneous loss of lateral control.

During the year practical methods of avoiding these conditions in modern types of airplanes have been sought. The investigations have proceeded mainly on the theory that the vicious stall may best be avoided in monoplanes by causing the wing to stall progressively from the center toward the tips. Not only are the sudden loss of lift and violent roll thus avoided, but lateral control is maintained through the first stages of the stall and the tendency toward an upwash on the tail surfaces associated with the loss of lift near the center of the wing may be used to bring about a marked increase in longitudinal stability as the stall is approached.

In the first investigation conducted in flight, sharp leading-edge strips extending out along the wing from either side of the fuselage were employed to bring about the desired symmetrical center-stalling characteristic. Wind-tunnel experiments with airfoils having sharp leading-edge sections over a small portion near their midspan had indicated how the flight investigation should proceed. The flight investigations for the power-off condition showed that an airplane having vicious stalling characteristics could be improved as expected by thus bringing about a gradually and symmetrically developing center stall. The extreme maximum lift coefficient was, of course, slightly reduced, but the practical gliding or approach speed was not increased; in fact, it was actually reduced. This phase of the flight investigation is, however, only preliminary in that the airplane tested had no flaps or other high-lift devices, whereas the problem is of most practical interest and is probably more difficult when high-lift devices are employed. The investigations are being extended.

The method employed to start center stalling may be objectionable on the grounds that the sharp leading edges will always tend to reduce the maximum lift. An investigation in the variable-density tunnel of methods of accomplishing the same result without loss of maximum lift led to the development of a new device known as the "stall-control flap." The flap tends to produce a well-rounded lift curve similar to that produced by the sharp leading edge but, together with a split flap or other conventional high-lift device, high maximum lift coefficients may be obtained. A special wing incorporating a stall-control flap has been constructed and installed on an F-22 airplane converted to a low-wing type. Flight tests are now being started on this airplane and from preliminary results it appears that, besides bringing about the desired center stall, several attendant advantages, such as favorable induced yawing moments from the ailerons, may be realized through its use.

SPINNING

The 15-foot free-spinning wind tunnel has been kept busy with routine testing of scale models of specific airplanes. The Matériel Division of the Army Air Corps, and the Bureau of Aeronautics of the Navy Department, are requiring spinning tests of models of new designs that are expected to be spun extensively in service. Four such models have been tested during the past year and three more are being prepared for testing in the immediate future. The work carried on in this connection includes not only tests of the particular design, but also investigation of changes necessary to improve the spinning characteristics where such changes appear to be necessary.

The free-spinning tunnel is available for the testing of models for commercial concerns, and two such models have been tested during the year.

A certain amount of general information is being gleaned from the test results with specific designs. Conclusions stated in the last annual report regarding the importance of the tail unit in spinning have been confirmed and amplified during the past year. As a result of tests of a number of models of modern low-wing monoplanes, it now appears possible to draw certain conclusions about the effect of changes in mass distribution on such designs. In most cases the spinning characteristics of low-wing types have been improved, and in no case have they been impaired, by moving weight from the fuselage to the wings. This fact is of special significance in view of the present trend toward multi-engine airplanes with the engines in the wings.

During the past year a method has been developed for measuring, on free-spinning models, the hinge moment required to reverse completely the rudder during the spin. Such measurements have been made on three models. Indications are that the requirements of rapid recovery from the spin and reasonably low rudder moments are in certain cases very difficult to meet with a rudder that is also satisfactory in normal flight.

In addition to the spinning of models of specific airplanes, a systematic investigation is being carried out in the free-spinning tunnel to determine the effects of changes in wing arrangement, in tail arrangement and mass distribution. This investigation is about 20 percent completed. It is designed to reveal the relative importance of the various factors which affect spinning and to show which of these factors is most deserving of more detailed study. The results to date tend to confirm the conclusion that the tail arrangement is the most important single item. The effects of wing plan form and tip shape are, however, of considerably greater importance than has hitherto been thought to be the case. The effect of wing section appears to be relatively slight.

Tests of a model of the Fleet airplane on the spinning balance, reported last year, have been published as Technical Report No. 607. An investigation on the spinning balance of effect of wing plan form on the spinning characteristics has also been completed and the results published in Technical Note No. 612. The tests included a rectangular wing with square tips and with rounded tips and a tapered wing with rounded tips. An investigation in progress will show the effect of airfoil section on the spinning characteristics of monoplanes with rounded tips.

An investigation on the spinning balance of the effect of stagger of rectangular biplane cellules has been completed and will be the subject of a report. The range of stagger investigated was from negative 25 percent stagger to positive 25 percent stagger. While no general conclusions can be drawn regarding the effect of stagger, the results can be used in studying the steady spinning characteristics of particular airplanes.

Tests for the purpose of making a direct comparison between the actual spinning behavior of a low-wing monoplane and the behavior of a model of the same airplane in the spinning tunnel have been started. Some difficulty and delay have been encountered in obtaining a suitable airplane for the tests. Two have been tried in flight. With one, the oscillating nature of the spin made measurements impossible. With the second airplane, the rudder forces built up to such a magnitude on the entry into the spin as to make it extremely uncertain that the pilot could supply the force necessary to assure that the airplane would recover from the prolonged spins required for the measurements. The mechanical advantage available to the pilot in operating the rudder of this airplane was increased and the forces that the pilot had to apply were reduced to the extent that it was possible to continue the tests.

TAKE-OFF

The results of the investigation of the rolling friction of airplane wheels, mentioned in last year's report, have been published in Technical Report No. 583.

In the calculated prediction of the take-off performance of airplanes, common practice has been either to neglect the transition period between the end of the ground run and the beginning of the steady climb or to take it into account by assuming a simple motion, since the actual motion is too complex for simple mathematical treatment. This lack of knowledge regarding the motion of the airplane in the transition introduces, of course, a degree of uncertainty into the results. As mentioned last year, an investigation of this phase of the take-off was undertaken in an effort to eliminate this uncertainty. The study is now completed and the results are being prepared for publication. It was found that the calculated value of the air-borne distance required in taking off over a 50-foot obstacle might be subject to an error of about 10 percent if the transition is neglected.

The investigation served also to emphasize the difficulties which are encountered in attempting to obtain representative comparisons directly from take-off tests and which arise from the fact that it is practically impossible for a pilot to conform exactly to a prescribed procedure throughout a series of complete take-offs, particularly if the air conditions are not absolutely steady. At present an attempt is being made to develop a method whereby the true take-off capabilities of an airplane may be evaluated without consideration of the personal element or the air conditions. One solution that appears promising is to determine from individual tests the relation between ground run, distance, and speed, and the relation between angle of climb and speed, the latter to be measured at some altitude where smooth-air conditions prevail. These quantities should not be appreciably affected by piloting and when properly combined, together with a suitable allowance for the transition, should provide an accurate measure of the take-off performance of an airplane. An investigation has been made to determine the feasibility of this system and the results are being analyzed.

The characteristics of the propeller producing the thrust are an important influence on the take-off. Available propeller data have to a great extent been rendered inadequate because of the changes in design necessitated by higher engine power and airplane speeds, requiring larger propellers of higher pitch and with three or more blades. For the purpose of establishing the design factor for propellers in this category, an extensive investigation on full-scale propellers has recently been made in the propeller-research wind tunnel. The investigation is more completely covered in a later section of this report.

The above-mentioned investigation that was made in the variable-density wind tunnel of ordinary and split flaps of 20 percent of the wing chord on N. A. C. A. 23012 airfoils indicates that neither of these flaps can be considered a satisfactory high-lift device for use in take-off because of the high profile drag caused by these flaps at high values of the lift coefficient. In this respect the ordinary flap is inferior to the split flap. At any value of the lift coefficient where the flaps are useful, a lower value of the profile drag coefficient can be obtained with the split flap than with the ordinary flap.

The stall-control flap previously mentioned, especially when combined with a low-drag trailing-edge high-lift device, appears to offer improvements in the take-off characteristics of flying boats and airplanes equipped with three-wheel landing gears, because this flap permits high lift coefficients to be obtained with the airplane in a level attitude.

LANDING

Landing loads.—At the request of the Bureau of Air Commerce and the Army Air Corps, the Committee is undertaking the accumulation of statistical information on the loads sustained by the landing gear in landings. Investigations have been made with four airplanes and one autogiro. Measurements of the attitude and vertical velocities immediately prior to contact and simultaneous measurements of the linear accelerations of the center of gravity and the angular accelerations in pitch are made in order to correlate the magnitude and direction of the resultant ground reaction and the approximate distribution of force between the main and tail wheels with the motion and attitude of the airplane at contact. The investigation will be continued as more aircraft become available. A preliminary analysis is being made of the data obtained thus far.

Stable landing gears.—The tricycle landing gear has recently been receiving considerable attention because of its possibilities for greatly improving the stability and handling characteristics of the airplane on the ground and for increasing the ease with which landings may be made. A study of the various factors affecting the geometrical arrangement of the landing gear has been made.

With the use of tricycle landing gears, the shimmy of the castering nose wheel has presented a problem. The Committee has made an analytical investigation of the stability of castering wheels as a result of which information was obtained as to the cause of wheel shimmy and several means of overcoming it were suggested. The allowance of a certain amount of lateral freedom of the wheel on its axle was indicated as a remedy. Model tests, and full-scale tests with the W1–A airplane, verified the indications of the analytical investigation and have shown that the shimmy of the castering wheel may be overcome by allowing a relatively small amount of lateral freedom of the wheel. To center the wheel, damping of the sidewise motion should be provided, which in the investigation described was done by curving the axle slightly.

The accelerations in landing of an airplane with a tricycle landing gear have been studied to ascertain whether the passengers might experience relatively severe accelerations in an emergency landing. The study revealed that the predominant acceleration was due to braking forces applied to the main wheels and that the vertical acceleration due to nosing over on the nose wheel should not be serious from the standpoint of passenger comfort.

AIRFOILS

The work on airfoils carried on by the Committee during the past year has been confined mainly to the consolidation of the large amount of data obtained in recent years and to the extension of its usefulness by providing more diversified and accurate methods of its application to practical problems.

Section characteristics.—Airfoil data obtained in the variable-density wind tunnel since 1930 have been corrected by the empirical method mentioned last year, to give more accurate section characteristics than it has been possible to obtain previously from tests of rectangular airfoils in the variable-density wind tunnel. These corrected data are to be presented in two reports. The first of these (Technical Report 610) presents the complete results obtained from the investigation of related forward-camber airfoils, of which the N. A. C. A. 23012 airfoil is representative. The second report, now in preparation, will contain the complete results for a large number of miscellaneous airfoils investigated since 1930 and will also include a table giving the improved section characteristics for the airfoils on which data are presented in Technical Report No. 460. These results are reasonably complete at one value of the Reynolds Number. Since airfoil data must be employed in practice at widely different values of the Reynolds Number, scale effect must also be taken into account.

The results of an investigation of airfoil scale effect which have been available only in condensed form as a confidential report have been published in full in Technical Report No. 586. These data give the most reliable basis available for the prediction of airfoil-section data at values of the Reynolds Number other than that at which the section data published in the reports mentioned in the preceding paragraph were obtained. However, uncertainties in the present knowledge must be admitted, and it appears that entirely satisfactory results must await future research at full scale in a nonturbulent air stream. The difficulty is the lack of knowledge about the transition from laminar to turbulent flow in the boundary layer of the airfoil.

Many of the effects of scale, turbulence, and surface condition are intimately connected with the transition from laminar to turbulent flow in the boundary layer. The importance of these effects may be realized from an analysis of the effects of transition on the drag of airfoil sections. If it is assumed that the boundary layer over the surface of an airfoil is entirely laminar, remarkably low drag coefficients are found for the higher values of Reynolds Number. The drag coefficient for a flat plate with laminar boundary layer is 0.0008 at a Reynolds Number of 10,000,000. If the boundary layer is assumed to be turbulent from the leading edge onward, the drag coefficient is more than seven times as large as the laminar value at the same value of Reynolds Number, actually amounting to 0.0057.

It is known, however, that it is not possible to have a laminar boundary layer over the entire airfoil surface. Calculations made by the method given in Technical Report No. 504 show that at zero lift on the N. A. C. A. 0012 airfoil section separation would be expected if the boundary layer were laminar at about 55 percent of the chord back of the leading edge, because of the adverse pressure gradient existing over the rearward portion of the airfoil. If transition occurs at this point, the drag will be intermediate between the values given for the completely laminar and the completely turbulent flows, but will still be markedly less than that for the completely turbulent layer.

Some experimental results, including data from recent tests in the 8-foot high-speed wind tunnel and some theoretical considerations as well, indicate that with very smooth wings in an air stream having zero turbulence the transition may tend to remain near the laminar separation point. If such is the case, savings of approximately 40 percent of the wing profile drag at a Reynolds Number of 10,000,000 are indicated, as compared with that predicted from a normal extrapolation of data from the variable-density wind tunnel.

In this connection some direct evidence on the nature of transition has been obtained from an investigation carried out in the nonturbulent N. A. C. A. smoke tunnel. Boundary-layer surveys were made throughout the transition region on a smooth flat plate having an adverse pressure gradient. The investigation showed that while the extent of the transition region decreased considerably with an increase in Reynolds Number, the point at which marked changes in the laminar boundary-layer flow first occurred was independent of the Reynolds Number throughout the range included in the investigation. The transition region was close to the position at which separation of the laminar boundary layer was to be expected unless premature transition was brought about by slight roughness near the leading edge of the plate. The tests were carried to a Reynolds Number of 150,000 based on the distance from the leading edge to the calculated point of separation. Visual observation of the flow over the plate indicates that similar conditions may exist over the range of Reynolds Number up to 500,000. A technical note is being prepared presenting the results of this investigation.

Wing characteristics.—The calculation of the characteristics of tapered wings from airfoil section data has been continued with several wings of varying aspect ratio and taper ratio. The basic section data and the data on scale effect, if applied by the method described in Technical Report No. 572, will enable the user to reduce the wind-tunnel data and to estimate the best wing for a given airplane. The calculated characteristics of 20 tapered wings will be compared with the experimental results for the same wings.

Measurement of profile drag in flight.—It has been feasible to investigate the profile drag of an airfoil section in flight by means of the pitot traverse method. This method has been used in an investigation of the comparison of air-flow conditions in flight and in the full-scale wind tunnel, the data obtained being evaluated to determine the profile drag from the momentum loss in the wake of an airfoil. The airfoil was an N–22 section and was first investigated with a smooth surface that was later modified by the addition of a thread having a diameter of 0.01 inch and located on the upper surface about 5 percent of the chord back of the leading edge. The results indicated that the addition of the small thread increased the profile drag of the smooth airfoil by about 18 percent. The addition of another small thread to the under surface of the airfoil at the same chordwise location further increased the profile drag, the total increase due to the two threads being about 32 percent.

EFFECT OF RIVETS AND OTHER SURFACE IRREGULARITIES ON WING DRAG

Past investigations in the full-scale and variable-density wind tunnels have shown that rivet heads and other surface irregularities increase the drag of wings appreciably. As aircraft have been made otherwise more efficient, the importance of the increases in drag due to small surface irregularities has become more apparent and a need has arisen for more complete information on the magnitude of such drag increases.

An investigation has been made in the 8-foot high-speed wind tunnel to provide data on the effect on wing drag, over a comprehensive range, of rivet size, type, and arrangement, lap type and arrangement, and surface roughness. This investigation was made with a model of an N. A. C. A. 23012 airfoil of 5-foot chord at air speeds from 80 to 500 miles per hour at values of the Reynolds Number up to 18,500,000.

Rivets.—During the investigation tests were made of $\frac{3}{32}$- and $\frac{1}{16}$-inch brazier-head rivets, $\frac{3}{32}$-inch thin brazier-head rivets, and $\frac{3}{32}$-inch countersunk rivets in various chordwise and spanwise arrangements. The $\frac{3}{32}$-inch brazier-head rivets in a typical arrangement increased the drag of the smooth airfoil 27 percent at 225 miles per hour. The drag increases due to the other protruding rivet heads were approximately proportional to the height of the heads, indicating that rivets with the thinnest practical heads should be used. The countersunk rivets increased the drag 6 percent under the same conditions. Increasing the spanwise pitch of the rivets had little effect unless it was made more than 2.5 percent of the wing chord. The investigation showed that more than 70 percent of the rivet drag was due to the rivets on the forward 30 percent of the wing. About 66 percent of the rivet drag was due to the rivets on the upper surface of the airfoil.

Lapped joints.—A typical arrangement of conventional plain laps facing aft increased the drag over that for the smooth airfoil by 8 percent. Joggled laps increased the drag only half as much. Plain laps facing forward were found to be slightly inferior to plain laps facing aft, but if they were faired by rounding the edges of the sheets, the increase in drag was less than that with conventional laps facing aft. Rivets and laps employed together increased the drag only slightly more than rivets alone.

Surface roughness.—The effect of five different degrees of surface roughness on airfoil drag was investigated. At 225 miles per hour the drag of the smooth airfoil was increased 44 percent by covering the surface with 0.0013-inch carborundum grains. Even the roughness due to spray painting increased the drag 14 percent at this speed. Sandpapering the painted surface with No. 400 sandpaper made the drag as low as that of the highly polished airfoil. The investigation showed that there is considerable scale effect on the drag due to roughness.

Effect on drag of wing due to manufacturing discrepancies.—In order to determine the effect on the drag of a wing due to manufacturing discrepancies, such as waves in the metal covering sheets and inaccuracies in the profile, tests were made on a model wing constructed to represent average present-day tolerances and workmanship. The drag of this "service wing" was 11 percent greater than that of the truer wind-tunnel model when both had the same arrangement of rivets and laps, and was 42 percent greater than the drag of the smooth-surface wind-tunnel model without rivets or laps. This excess in drag of 42 percent is equivalent to 273 extra horsepower on airplanes of the size and speed of those used on present air lines.

AERODYNAMIC INTERFERENCE

Wing-fuselage interference.—A report is now being prepared on the interference investigation recently completed in the full-scale wind tunnel with an Air Corps YO–31A observation monoplane. The airplane was first tested with the original gull wing and then with parasol wing arrangements in which the wing was placed at various heights above the fuselage. When the parasol tests were made the gull-wing roots were replaced by a straight center section. For the purpose of determining the interference effects the principal component parts of the airplane were tested separately. in addition to the tests of the complete machine for each wing arrangement.

An investigation of the effects of triangular and elliptical cross-sectional fuselage shapes on the aerodynamic interference between wing and fuselage has been completed in the variable-density wind tunnel, together with tests of a special shape of juncture. During the course of the tests it was shown that ordinary critical combinations could be sometimes benefited, as regards the occurrence of the interference burble, by very smoothly finished surfaces at the wing junctures. In this respect one special shape of juncture showed a very powerful effect, its use resulting in the suppression of the premature interference burble entirely, with no increase in the minimum drag.

An investigation has also been made to obtain a comparison between a combination including the airfoil-type fuselage, and an efficient conventional wing-fuselage combination. Tail surfaces have been added to typical combinations in an investigation comprising an extension of the program of wing-fuselage interference. An interesting development of this phase thus far is the surprisingly low drag found possible for such a complete model combination.

FORCED VIBRATIONS AND AIR DAMPING OF A WING SYSTEM

A theoretical study has been made of the vibration response and air damping of a wing-aileron system in a uniform air stream to impressed alternating forces and moments. The mathematical treatment is a direct continuation of that presented in Technical Report No. 496 to analyze the flutter problem. The response characteristics of the vibrating wing-aileron system in a complete range of velocities and frequencies up to the critical flutter conditions can be determined in any specific case without extensive calculations. Thus not only are the critical flutter velocity and frequency readily determined, but also the vibration response and the air damping at intermediate conditions. The study thus presents a more complete picture of the phenomenon of flutter than has previously been available in aerodynamic literature. In particular, it is shown that in the case of forced vibrations large responses may often be expected when flutter conditions are approached, even when actual flutter cannot occur. The results of this work are being prepared for publication.

PROPELLERS

Investigation of full-scale propellers.—The results of the investigation of six full-scale propellers in conjunction with a standard nacelle unit equipped with six different N. A. C. A. cowlings have been published in Technical Report No. 594. The investigation covered the complete range of flight conditions, including ground operation, take-off, climbing, and high-speed flight. The range of the advance-diameter ratio was extended far beyond that of earlier full-scale experiments, blade angles of 45° at 75 percent radius being included, which are equivalent to air speeds of more than 300 miles per hour for propellers of normal size and diameter.

An extensive investigation of full-scale propellers, which was planned last year and which will provide considerable data in addition to those just mentioned, has been proceeding for several months in the 20-foot propeller-research tunnel. A large number of tests of propellers of 10-foot diameter driven by a 600-horsepower engine have been made in conjunction with a cowled nacelle such as would house a radial air-cooled engine. A number of tests have been made also in conjunction with a nacelle for liquid-cooled engines.

The propellers on which this investigation is being made are of modern type, with the blade gradually fairing into the hub section, in contrast to the older type with airfoil sections carried in very close to the hub. Comparative tests indicate a small aerodynamic advantage for the latter type, but their use is precluded by the characteristics of existing engines.

In this investigation blade-angle settings up to 45° at 75-percent radius were also used and in several cases blade-angle settings up to 60°. A maximum efficiency was obtained under the conditions of this investigation at a setting of about 30° and there was little falling off even at 60°. This investigation gives further evidence that the old practice of designing propellers with a low basic pitch and then setting the blades at much higher angles should be modified for high-pitch propellers. It appears that high-pitch propellers should be designed to have a constant pitch when the blades are set at 20° to 30° at the 75-percent radius. This method will result in a smaller washout of pitch toward the hub at the higher blade-angle settings, which is of some advantage in obtaining the best thrust distribution for minimum energy loss.

During this investigation particular attention has been paid to the effect of tip speed on the efficiency in the take-off and climbing range of propeller operation. A small progressive loss in efficiency begins to appear when the tip speed reaches approximately 700 feet per second. There seems to be some variation with the airfoil section of the propeller, the Clark Y section holding its efficiency under these conditions to higher tip speeds than does the R. A. F. 6 section. Calculations from the data obtained show, however, that when applied to the controllable propeller the change in power coefficient is such that the propeller must be set at a lower blade angle than would be required if no tip-speed effect were present, with the result that the tip-speed effect is practically eliminated.

Analysis of the data obtained with propellers differing in airfoil sections, but otherwise similar, shows that the differences in characteristics are very small, as was expected. The analysis is not yet complete and other deductions may be possible after further examination.

A definite improvement is noted with a spinner on the propeller of a liquid-cooled engine, in contrast to radial-engine installations, where it was found that the use of a spinner over the hub had a negligible effect. An improvement of about 4 percent in the net efficiency of the liquid-cooled installation was caused by the spinner. In this connection a spinner just covering the hub and having the nacelle lines faired into it was found to be as good as a larger spinner.

A number of tests have been made in the negative torque (windmilling) region covering the conditions from zero thrust to propeller locked at blade-angle settings from 0° to 90°. The data from these tests will provide information on the drag of idling and stopped propellers and on the braking effect of the propeller in the diving of military types of aircraft. It appears that the stopped propeller feathered to a blade-angle setting of 90° causes the least drag, but an idling propeller set at 50° and operating against normal engine friction has nearly as low a drag.

A series of five reports, each covering a section of this propeller investigation, is now being prepared. The many factors involved in a study of this scope require a division of the subject for the sake of clarity of presentation, as well as facility in use. Other reports may be required to present analyses of minor phases and data yet to be obtained.

Investigation of oppositely rotating tandem propellers.—The continual increase in the power ratings of airplane engines and the large propellers required, as well as the effect of torque reaction when large geared engines are used in small high-performance airplanes, have turned attention to the possibilities of oppositely rotating tandem propellers. The Army Air Corps requested an investigation of the problem, and Stanford University, which is a pioneer in propeller testing in the United States, agreed to make the investigation under contract with the Committee as a part of the Committee's program of cooperation with universities.

The investigation was made with model propellers of 3-foot diameter, and the results indicate that a 4-blade propeller is slightly inferior in performance to two 2-blade propellers of the same diameter and blade dimensions rotating in opposite directions. Both are, of course, inferior to normal 2-blade propellers. The spacing of the tandem propellers was varied from 8 to 30 percent of the propeller diameter, and practically no effect of spacing was noted except that the closer spacings produced more noise. At the lower blade-angle settings the rear propeller had to be set at a smaller angle than the front one in order to absorb the same power, but, as the blade-angle settings of the propeller were increased to give higher pitches, the rear propeller gradually required a setting higher than the front propeller. Increasing the propeller spacing of the tandem propellers when the blade-angle settings were in the low range also required an increase in the setting of the rear propeller. It is proposed to extend this investigation to compare a 6-blade propeller with two oppositely rotating 3-blade propellers.

Investigation of model propellers in yaw.—The characteristics of propellers whose axes are at an angle to the air stream are of considerable importance in the study of airplane stability with power on, and to some extent in the calculation of airplane performance. A series of tests of model propellers of 3-foot diameter in yaw has been made at Stanford University under contract with the Committee to provide data of this nature, and the results have been published in Technical Report No. 597.

Prediction of propeller performance from airfoil section data.—The analysis of airfoil section data as applied to the selection of sections for propeller blades has been continued during the past year. In addition methods for predicting the performance of propellers from the section data are being devised and further analysis made of the distribution of energy losses for conventional propellers. The characteristics of three propellers having different blade sections have been analytically determined from the section data obtained in the variable-density wind tunnel and the smaller high-speed wind tunnels, and three full-scale propellers of the same design will be tested in the 20-foot wind tunnel. The experimental data obtained should provide an excellent check on the method of predicting the performance analytically.

Propeller vibration.—The model method of determination of the dangerous vibration frequencies of propellers mentioned in the twenty-first anual report of the Committee has been verified and superseded by a method applicable directly to any propeller in question. The method consists in the use of a carbon-resistance strain gage attached to the propeller and a means for producing artificially forced vibrations of any mode, the propeller being electrically driven at full speed in a partial vacuum.

Propeller noise.—Experimental work on the sound emission from propellers has been continued, particularly with a view to obtaining greater absolute accuracy in the measurements. The intensity of the sound emitted from the propeller in various directions has been measured for the five lowest harmonics for the purpose of obtaining data for use as a basis for theoretical work. The measurements have been completed for the range of propeller tip speeds below the speed of sound in air and will be continued into the supersonic speed range.

A paper has been published (Technical Note No. 605) indicating the effect of blade thickness on propeller noise. The theoretical relations given in the paper permit calculation of sound intensity of long wave lengths from a propeller with symmetrical sections at zero blade angle. With the aid of experimental data, an empirical factor was introduced into the theoretical relations to make possible the calculations of higher harmonics of the rotation noise.

THEORETICAL AERODYNAMICS

Compressible flow.—The study of compressible flow about symmetrical Joukowsky profiles has been continued, and expressions have been developed for determination of the velocity and therefore the pressure distribution over the airfoils. In particular, lift and pitching-moment formulas have been obtained for thin profiles at large angles of attack. It has been found that the expression for lift is analogous to that for incompressible flow, but that the expression for pitching moment, in addition to being analogous to that for incompressible flow, contains a term which amounts to a shift in the center of pressure toward the leading edge. In addition to developing the expressions for lift and pitching moment, the limiting value of the ratio of the air-stream velocity to the velocity of sound in an undisturbed stream has been calculated for several Joukowsky profiles, and the effect of angle of attack and thickness upon this ratio has been determined.

Pressure distribution on flapped airfoils.—A method has been devised for calculating the chordwise pressure distribution over airfoils with ordinary flaps. The distribution has been determined by altering the theoretical distribution and may be applied to airfoil sections having more than one flap. Technical Reports Nos. 360 and 563 show a disagreement between experimental and theoretical forces and pressure distribution. In the more recent analysis the empirical correction to the theory was determined through knowledge of the lift, pitching moment, and flap deflection. Work is continuing on this method of analysis to develop an expression for airfoils with split flaps.

WIND-TUNNEL CORRECTIONS

The interference of the wind-tunnel boundaries on the downwash behind an airfoil has been experimentally investigated, and the results have been compared with the available theoretical results for open-throat wind tunnels. This investigation has yielded results that are particularly valuable in correcting the downwash angle in the region of the tail plane. The experimental results show that the theoretical assumption of an infinite free jet at the test section of the wind tunnel may lead to erroneous conclusions if applied to the downwash in the region behind an airfoil where the tail surfaces would normally be located. The results of a theory based on the more accurate concept of an open-jet wind tunnel as a finite length of free jet provided with a closed exit passage gave good qualitative agreement with the experimental results. The results of this investigation have been presented in Technical Report No. 609.

The investigation to determine the scale effect on the maximum lift of an airfoil has been extended by additional tests in flight and in the full-scale wind tunnel. The investigation was made with a $2R_112$ airfoil mounted on a Fairchild 22 airplane, and the variations of Reynolds Number in flight were obtained chiefly by varying the wing loading of the airplane and by varying the altitude at which the tests were made. The maximum lift as obtained in flight and in the full-scale wind tunnel agreed within 2 percent, the results thus further substantiating the agreement obtained with sphere tests, which indicated a low percentage of turbulence in the full-scale wind tunnel.

The investigation of the factors leading to discrepancies between the power-on performance of an airplane as predicted from wind-tunnel data and as measured in flight is being continued. In order to avoid the difficulties usually experienced in obtaining precise measurements of climbing performance, the excess horsepower available for climb is being determined in level flight.

This determination is accomplished by the towing of parachutes of various sizes to absorb the excess horsepower at various speeds. The horsepower is computed from the tension in the towing line and the velocity of the airplane. This method avoids, in particular, the errors usually experienced in climb owing to variations in the wind velocity with altitude. A second airplane is being equipped to study quantitatively the effect on climbing performance of variations in the wind velocity with height by correlating the excess horsepower measured in level flight with the rates of climb actually experienced in several climb tests. The results will be checked by tests of the same airplanes in the full-scale wind tunnel under power-on conditions.

COMPRESSIBILITY EFFECTS DUE TO HIGH SPEED

Aerodynamic phenomena encountered at high speeds have heretofore been considered of importance mainly in relation to the adverse effects on propellers operating at high tip speeds. It has now been established that marked adverse effects due to compressibility may occur on other parts of airplanes when the forward speed of the airplane is approximately one-half the speed of sound. Investigations conducted in both the 24-inch and the 8-foot high-speed tunnels have shown that the compressibility burble results in a large energy loss. A large increase in drag may therefore occur when the flow about any part of the airplane produces a local velocity equal to the speed of sound. A bluff body and one having a high curvature produce high induced velocities, and therefore the critical speed of such bodies is low.

The results from an investigation in the 11-inch high-speed tunnel on the drag of circular and elliptical cylinders and prisms of triangular and square cross sections show that the critical velocities or, in other words, the forward speed at which compressibility effects become noticeable, may be as low as 0.4 the velocity of sound.

Similar results have been obtained in the 8-foot high-speed tunnel on a wing-nacelle combination. One-fifth-scale models of a family of radial-engine cowlings were tested on a nacelle with a wing of 2-foot chord.

Five of the cowling shapes had previously been tested in the propeller-research tunnel, and at the lower speed possible in the propeller-research tunnel these cowlings were considered satisfactory. One cowling shape was found to have a critical speed between 280 and 350 miles per hour, depending upon the attitude of the cowling and nacelle. When the compressibility burble, or shock wave, occurred at the critical speed the drag of the combination was increased from 50 to 200 percent, with only a slight increase in the tunnel speed.

During the investigation it had been found that if the pressure distribution over the cowling was known, the critical speed could be accurately predicted. Therefore, two cowlings were designed with the nose curvatures proportioned to reduce the peak negative pressure and obtain a uniform negative pressure distribution over the nose. By so changing the nose shape the critical speed of the cowling was increased to more than 500 miles per hour and approached the critical speed of the N. A. C. A. 23012 wing, which was used for the investigation. It was found that when the critical speed of the cowlings was increased other advantages were obtained. The cowling with the highest critical speed also had the lowest drag throughout the entire speed range, and the drag remained substantially constant over a larger range of angle of attack.

In order to determine at a large scale the possible variation in pitching moment with speed, four wings of 2-foot chord were tested in the 8-foot high-speed wind tunnel through a range of speeds up to that at which the compressibility burble was experienced. The four wings tested had the following N. A. C. A. sections: 0012, 23012, 23012–64, and 4412. The N. A. C. A. 23012 and 23012–64 airfoils were chosen as sections of low pitching moment and the N. A. C. A. 4412 as a section of high pitching moment. All the sections tested showed an increase in pitching-moment coefficient with increased speed, the increase amounting to as much as 45 percent at 500 miles per hour. This change in pitching moment has little practical significance in the case of an airplane on which a wing section having low pitching moments is used, because the resulting absolute change in pitching moment at high speeds would be of little importance in the design of the wing or tail surfaces. In the case of an airplane with a wing section of high pitching moment the change may be very important in high-speed dives.

BOUNDARY-LAYER CONTROL

The investigation of boundary-layer control has been continued in the propeller-research tunnel, and tests have been completed on a tapered wing of N. A. C. A. 8318 section with upper-surface suction slots to control the boundary layer. Tapering the slot was found to be very effective in producing an even distribution of control over the span, and the suction power required was intermediate between the low power required for a thick wing and the high power required for a thin wing. Measurements of boundary-layer thickness were made both with and without the control in operation.

ICE PREVENTION

In view of the fact that several accidents during the last year may be directly attributed to ice formation on the airplanes, a survey has been made of the ice-prevention investigations that have been conducted by the various Government and commercial organizations. A compilation of these data is being made so as to make available to all concerned information that may be valuable in preventing accidents due to ice formation.

In order to determine the effect of rubber de-icers on the aerodynamic characteristics of a wing, a model of a 5-tube de-icer was tested on an N. A. C. A. 23012 wing of 5-foot chord in the 8-foot high-speed tunnel. The results show that for both the inflated and deflated conditions the de-icers did not appreciably affect the lift or pitching moment for high-speed or cruising conditions, but with either two or three tubes of the de-icer inflated the drag of the wing was increased in the order of 80 percent. The conventional de-icer equipment deflated increased the drag of the wing 16 percent at 200 miles per hour. At air speeds greater than 200 miles per hour the de-icer lifted from the wing and in some cases breaks in the rubber were produced. In order to reduce the drag of the de-icer in the deflated condition a flush installation was made by the use of a metal attachment strip, which on the full-scale airplane would be 1/32-inch thick. With this installation the drag increment was reduced from 16 to 9 percent, but the same difficulty was experienced in the lifting of the de-icer from the wing at speeds greater than 200 miles per hour.

ROTATING-WING AIRCRAFT

The development of the direct-control type of autogiro has been delayed to some extent by the introduction of certain secondary difficulties connected with the provision of a satisfactory variation of control forces with air speed and with the elimination of vibration. A study of the effect on certain rotor characteristics of a periodic variation in blade-pitch angle has been made, and the results have been published in Technical Report No. 591. The predicted value of the flapping motion of the rotor blade was radically altered when the periodic pitch variation was inserted in the rotor analysis, and an appreciable influence of the periodic pitch on the rotor thrust coefficient was indicated. An analysis has been made of the factors involved and a method developed of predicting the periodic variation of the pitch angle. The results have been published in Technical Report No. 600.

An investigation has recently been conducted both in flight and in the full-scale wind tunnel on a direct-control autogiro to determine the lift, drag, control forces, flapping motion of the rotor blade, and periodic variation in pitch angle. The tests in the full-scale wind tunnel were made on the complete autogiro, on the rotor alone, and on the machine without the rotor to determine the interference effects between various parts. The data obtained from these tests are being analyzed for use in the study of any desired variation of the location of the center of pressure on the rotor.

An investigation has been started in the propeller-research tunnel on a series of model autogiro rotors having airfoil sections of different thickness and different mean camber lines, and will include two rotors that differ only in plan form of the rotor blades. This work is an extension of an investigation previously made in which the effect of airfoil section and plan form on the lift-drag ratio of an autogiro rotor was studied.

The analysis of the results obtained during the autogiro jump take-off tests has been completed and published in Technical Note No. 582. The report covers a theoretical study of the jump take-off without forward speed and includes an experimental verification.

An analytical study of the rotor-blade oscillations in the plane of the rotor disk has been made, and the results have been published in Technical Note No. 581.

A study of the autogiro rotor-torque equation has been made, and a report is in preparation which will include a solution of the problem in chart form.

MISCELLANEOUS TESTS OF COMPLETE MODELS OF AIRPLANES

The improved aerodynamic efficiency of the modern airplane has made it increasingly important to make tests on a complete model of a projected airplane before it is constructed. Consequently a large number of complete models have been tested in the 7- by 10-foot, the 20-foot, and the full-scale wind tunnels. Most of these tests have been conducted at the request of the Army and Navy, but several models have been tested for manufacturers at their expense.

The models tested in the full-scale tunnel have been ½ and ¼ scale, and the tests have included considerable development work that could be conveniently carried out on these large-scale models at considerably less cost than would be involved in doing the same work on the actual airplane after it has been constructed. Although this development work has restricted to some extent the research programs in the tunnels, it is felt that the tests have resulted in a large saving of money to the Government. It might also be pointed out that the development work in the wind tunnel will save much of the time required to take an airplane through the experimental stages and place it in production.

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.—Within the last few years the equipment used in the study of wind-tunnel turbulence has been redesigned for use with an alternating-current power supply instead of storage batteries. A description of the new equipment and of its performance has been published in Technical Report No. 598.

As mentioned in last year's report, the investigation of turbulence has been extended to include the measurement of the scale or eddy size of the turbulence as well as the intensity. The most satisfactory method of introducing turbulence into the wind-tunnel stream was found to be by means of screens placed across the stream, the scale being controlled by the size of the screen and the intensity by the distance downstream from the screen. The measurements of scale and intensity have been made and the aerodynamic effect of these two factors has been determined. The results of this work have been published as Technical Report No. 581. The screens described in this report are now regarded as standard equipment in the Bureau's 4½-foot wind tunnel and are used to introduce turbulence of the desired scale and intensity within the limits obtainable.

Preparations are being made to continue the study of turbulence by measuring the distribution of energy in turbulent motion with the wave length of the turbulence. According to recent theories the spectral distribution of energy is a characteristic property of turbulence related to the intensity and scale.

Boundary layer near an elliptic cylinder.—During the past year boundary-layer investigations have been in progress with an elliptic cylinder of 12-inch major axis and 4-inch minor axis, placed with the major axis parallel to the wind. The laminar boundary layer formed about the cylinder was previously studied and the results were published as Technical Report No. 527.

The recent work has consisted of the measurement of velocity distributions in the boundary layer with the air speed in the tunnel high enough to produce transition from laminar to turbulent flow in the layer before separation occurred. Two cases were investigated: the first with the low turbulence normally prevailing in the wind tunnel and the second with the stream turbulence raised to about 4 percent by means of the 1-inch screen placed 18 inches ahead of the cylinder.

Marked differences were found between the types of transition occurring in the two cases. Transition with the low stream turbulence was the result of a laminar separation, and occurred within a very short length of the surface, about an inch ahead of the point of separation of the turbulent layer. Work with the higher stream turbulence gave no evidence of a laminar separation, but showed a gradual transition extending over about a third of the distance from the leading to the trailing edge of the cylinder (i. e., over about 4 inches). This latter type of transition was very difficult to detect by any single means and was found only by careful study of the velocity distributions in the layer. In order to throw more light on the transition phenomena at the higher stream turbulence measurements were made of the fluctuations in velocity throughout the layer at various points about the surface. These measurements also showed the gradual nature of the transition.

Studies of transition.—The two different types of transition found on the elliptic cylinder suggested an extension of the work to cover the general effects of turbulence and Reynolds Number on transition, the purpose of the extension being to learn under what conditions each type of transition exists and how the region of transition shifts with changes in Reynolds Number and changes in scale and intensity of the stream turbulence.

As was pointed out previously, the location of the transition region could be determined with the available equipment only by extensive measurements of the distribution of mean velocity or fluctuation of velocity across the boundary layer. In order to facilitate the investigation, a new device for quickly and easily detecting transition was sought. Previous work has shown that transition occurs in the neighborhood of the point where the intensity of skin friction is a minimum. This immediately suggested the use of some device, such as the Stanton surface tube developed in England, by which the surface friction may be measured. However, the adaptation of the surface tube was not considered feasible on the elliptic cylinder. Instead a sliding steel band 6 inches wide and 0.002 inch in thickness was fitted about the cylinder so that the heated element of a hot-wire anemometer, fixed at the center of the band, could be moved around the contour of the ellipse at a small fixed distance from the surface.

While an actual measurement of the velocity by this means is not readily possible, the wire can be used to detect where the speed is a minimum as the band is slipped around the surface. In the tests already made a platinum wire 0.016 millimeter in diameter and 13 millimeters long was mounted 0.21 millimeter from the surface of the band. The device has proved quite satisfactory and shows sufficient promise to justify further development. It may be possible to use a device of this sort for locating transition on an airplane wing in flight.

Investigation of boundary layer by diffusion of heat.—The method of thermal diffusion described in Technical Report No. 524 has been applied to the study of velocity fluctuations in a thick turbulent boundary layer formed on the surface of a flat plate 10 feet wide and 24 feet long. The procedure consists of measuring with a thermocouple the spread of the heated wake downstream from a fine but long heated wire placed transverse to the flow in the boundary layer. The spread of the wake is caused by the components of turbulent motion normal to the mean direction of flow, and the purpose of the work is to compute the magnitude of the components from the measured spread. By this means the magnitude of the velocity fluctuations normal to the surface has been determined. In a similar manner it is planned to determine the magnitude of the component parallel to the surface. By the usual hot-wire equipment the component in the direction of the mean flow will be measured so that finally a comparison between all three components of the fluctuations will be possible.

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.

Reports on aircraft instruments.—A report on the pressure drop in tubing used to connect aircraft instruments to vacuum pumps and pitot-static tubes has been published as Technical Note No. 593, and a report on electrical thermometers is being published as Technical Report No. 606.

An experimental investigation of the performance characteristics of venturi tubes used in aircraft for operating air-driven gyroscopic instruments has been completed and a report prepared.

Progress has been made on reports on the effect of vibration on service aircraft instruments and on gyroscopic instruments for aircraft.

Tests and test methods.—It was originally planned to measure humidity in the aerograph test apparatus by the dew-point method. A simpler method has been developed in which advantage is taken of the fact that completely saturated salt solutions have a characteristic vapor pressure so that a particular salt solution produces a practically constant relative humidity when placed in a closed chamber. Corrections can be applied for the relatively small variation of the relative humidity with temperature.

Altitude mercurial barometers for field use should withstand shipment without breakage and should be designed so that the accumulation of gas above the mercury column is easily removable. Principally for these reasons it is advisable to fill the barometer tube in the field. Experiments with the Barnes type, which meets these requirements, indicate that the procedure to be followed is too complicated. In cooperation with an instrument manufacturer, the common-type altitude barometer has been modified to make it possible for the tube to be filled in the field by following a relatively simple procedure. The barometer must be designed so that the end of the tube is always well covered with mercury while the barometer is tipped from the normal to the upside-down position. The usual capillary restriction in the end of the tube must be of such size that the passage of gas is not impeded by mercury sticking in the capillary.

Laboratory test methods have been developed, and data on the performance obtained, on fuel-air-ratio indicators of the thermal conductivity type. In these tests known mixtures of nitrogen and hydrogen and of nitrogen and carbon dioxide were passed through the instrument subject to various conditions, such as temperature, pressure, and voltage.

New instruments.—Instruments designed and constructed for the Bureau of Aeronautics include: a helium purity meter utilizing a porous plug of a type recently developed commercially; a superheat meter of the electrical-resistance type for a K airship; an experimental pitot-static tube for installation on the wing tip of monoplanes. Development of a fuel flowmeter of the orifice type is in progress.

SUBCOMMITTEE ON AIRSHIPS

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

The Committee recently published as Technical Report No. 604 the results of the investigation conducted by the laboratory at the request of the Bureau of Aeronautics of the Navy to determine the pressure distribution at large angles of pitch on fins of different span-chord ratios on a large model of the airship *Akron*. This investigation was requested by the Bureau to provide information particularly desired by the Special Committee on Airships of the Science Advisory Board, of which Dr. W. F. Durand, of Stanford University, is chairman. Mention is made here of the publication of the technical reports of this committee, which cover certain phases of airship technical problems.

Models and apparatus are being prepared for the investigation in the Committee's 20-foot wind tunnel of boundary-layer control on airship forms. This investigation will include a form with blower in the nose, and also a form with propeller in the rear with control of the boundary layer by both suction and discharge jets.

At a meeting of the Subcommittee on Airships held in January 1937, plans were discussed for the extension of the investigation of the forces acting on an airship during ground handling, as published in Technical Report No. 566, to include a study of the effect of wind gradient and also of the effect of fin angle. Consideration was also given to the desirability of conducting an investigation at the Committee's laboratory on the loads on the tail surfaces of an airship in flight, and also an investigation of the forces on a large airship model with tail surfaces of the form used on the *Hindenburg*.

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 the atmospheric conditions which are of particular importance in connection with aircraft design and operation.

Atmospheric disturbances in relation to airplane accelerations.—Extensive measurements of gusts have been made by the Langley Memorial Aeronautical Laboratory by means of flights to altitudes of 19,000 feet with a large military-type airplane and flights with a small light airplane. From partial analysis of the data obtained, it appears that it may be possible to correlate the gust strength and gradient with the energy available for turbulence in the atmosphere. The new results do not invalidate the conclusions previously reached tentatively that, in stable atmospheric conditions, with large wind gradients, vertical gust velocities of the order of 30 feet per second are reached in a horizontal distance of about 100 feet, and that the gust gradient increases with decreasing gust intensity.

Surveys of clouds of cumulus type indicate, in general, stronger downward-acting than upward-acting gusts. On one occasion a downward gust of 53 feet per second, which reached maximum intensity in a distance of 53 feet, was experienced.

The development of a special acceleration-altitude recorder for installation at various Weather Bureau stations throughout the country is nearing completion. When available, these instruments will be used in conjunction with air-speed recorders to obtain data on the relation between gust intensity and altitude.

The accumulation and analysis of records of accelerations on transport airplanes in regular operation is being continued with the cooperation of a number of the air transport operators. The records obtained represent conditions encountered in operation over practically every part of the United States, in transpacific operation, and in operation over the Andes Mountains in South America. Records from flying boats in the transpacific service indicate effective gust velocities as great as 33 feet per second, which is substantially equal to the maximum recorded on flying boats in service between Florida and the West Indies and South America and on land transports.

Investigation of wind gustiness.—The study of wind gustiness, including both atmospheric turbulence under ordinary conditions and the fluctuations of wind velocity during the passage of cold fronts, conducted by the Daniel Guggenheim Airship Institute at Akron, Ohio, in cooperation with the Weather Bureau and the Bureau of Aeronautics of the Navy, has been continued. Additional measurements are being made by means of instruments installed on the radio tower at Akron and on movable towers placed at various positions in relation to the radio tower and to each other, with supplementary records obtained by the use of balloons and theodolites.

Ice formation.—The problem of ice formation is receiving considerable attention at the Langley Memorial Aeronautical Laboratory, and a report has recently been issued to American manufacturers giving the results of a study of the prevention of ice formation on propellers. In this report information is given as to the conditions under which ice forms on propellers, and an investigation conducted by the Committee on the propeller de-icer developed under the sponsorship of the Bureau of Air Commerce in cooperation with the B. F. Goodrich Company and Transcontinental and Western Air, Incorporated, is described.

The problem of ice formation on wings and ailerons is also being studied, and a report is being prepared presenting all the information at present available. In addition, a program is being formulated for the study of the effect on the aerodynamic characteristics of a wing, of ice particles that adhere after the de-icer has acted. Data on the shape and location of such particles for use in the preparation of this program have been supplied through the cöoperation of the Air Transport Association of America.

Electrical phenomena.—The question of the possible effect of electrical phenomena on airplanes has been brought to the Committee's attention and will be discussed at a meeting of the Subcommittee on Meteorological Problems to be held in the near future. Observations of pilots on the subject have been obtained from a number of sources, and the question will be thoroughly studied by the subcommittee.

SUBCOMMITTEE ON SEAPLANES

World-wide interest in seaplanes has grown at an accelerated rate and almost every month has brought word of the launching of new craft of greater size and speed. Designers are discussing with confidence the construction of flying boats of magnitudes that would have been considered impracticable a few years ago and are looking forward to the construction of even larger and faster flying boats within a relatively short time.

With the increases in size and range have come increased get-away speeds and heavier loads on the hulls. The power required for the take-off of such large flying boats is sometimes 100 percent greater than that ordinarily used in flight, and in such cases the designer is confronted with the necessity of choosing between the use of larger engines involving a serious increase in weight and the possibility of shortened engine life as a result of running at excessive power during take-off.

The cost of these large flying boats makes it essential that the form of hull selected shall be the best possible compromise between the requirements of low drag in flight and good performance on the water. Research in the N. A. C. A. tank has therefore been directed toward the improvement of the over-all performance of flying boats and seaplanes by the reduction of the resistance on the water and the general improvement of the form of the hull. In contrast to previous work, the aerodynamic improvement is being given consideration at the same time.

Improvements to N. A. C. A. tank.—In anticipation of the demand for tests of models of larger hulls at higher take-off speeds, the Committee is enlarging the N. A. C. A. tank and increasing the speed of the towing carriage. When the work now under way is completed the tank will have 2,880 feet of water at a depth of 12 feet, which is an increase of 900 feet. The extension has been specially constructed to permit the generation and propagation of waves for use in testing models in waves and the simulation of operation in rough water.

The increase in length has been matched by an increase in the speed of the towing carriage. It is expected that when the alterations are completed the carriage will have a maximum speed of about 80 miles per hour. The carriage will also be able to tow much larger models.

At lower speeds, with models of the same size, it will be possible to increase the amount of testing per day because the ratio of the distance that can be used in testing and obtaining readings to the distance required for stopping and starting the carriage will be considerably increased.

A two-story office building has been built at the southern end of the tank and the shop spaces have been extended 100 feet.

Effect of variation in dimensions and form of hull on take-off.—The result of incorporating longitudinal steps on the forebody of a V-bottom hull was determined by an investigation of a series of models in which the form and number of steps were systematically varied. In general, the longitudinal steps were found to decrease resistance at high speeds by reducing the area in contact with the water, but to increase resistance at low speeds where the bottom is wetted out to the chines. One longitudinal step on each side of the keel was superior to two longitudinal steps, except at high speeds and very light loads. Spray strips fitted along the steps reduced both the resistance and spray if they were set at the proper angle. This investigation is described in Technical Note No. 574.

Various methods of artificial ventilation of the step were investigated on two typical hull forms, one having straight V sections and one having chine flare on both forebody and afterbody. In both cases the chines aft of the step were clear of the water at the hump speed and above. When the chines were clear the step was ventilated by air flowing in from the sides and the introduction of additional air through ducts or slots produced no further change in resistance or trim. In the case of the form with chine flare, natural ventilation was delayed at speeds below the hump speed and artificial ventilation through ducts aft of the step resulted in an appreciable reduction in resistance and trim. The results of this investigation have been published in Technical Note No. 594.

Tests of models of representative flying-boat hulls.—The hull of the U. S. Navy PB–1 flying boat, which was built by the Boeing Aircraft Company in 1925, had two transverse steps very close together and a long extension carrying the tail surfaces. The forebody was much like that of the NC hull, from which it was apparently derived. Comparisons of its water performance as obtained in the N. A. C. A. tank with that of the NC hull and the Sikorsky S–40 hull are presented in Technical Note No. 576.

A model of the hull of the British Singapore II–C flying boat was investigated in the N. A. C. A. tank in response to suggestion of the Director of Research, British Air Ministry. This investigation made it possible to determine the hydrodynamic characteristics of a typical British hull form over an extensive range of loadings and speeds. It was found that the Singapore hull had higher resistance at the hump speed and lower resistance at higher planing speeds than the American hull with which it was compared. The results of this investigation, together with a comparison with similar results obtained in the British R. A. E. tank with the same model, are presented in Technical Note No. 580.

A large model of the hull of the British Short Calcutta flying boat was made from lines supplied by the British manufacturers and investigated in the N. A. C. A. tank. The form is the immediate predecessor of the Singapore hull, and is representative of British flying-boat design in 1928. The results of these tests, together with calculated comparisons of its take-off performance with that of typical American forms, are published in Technical Note No. 590.

Trim-angle indicator.—The importance of holding a seaplane at the trim angles that would give least resistance during the process of take-off was described in Technical Note No. 486, issued in 1934. In that publication there is described and illustrated a trim indicator for showing the pilot of a seaplane the trim angle at which the craft is traveling. Several versions of this type of trim-angle indicator have since been constructed and tested in service. It has been found that if a pilot has a trim-angle indicator and the information obtained from tank tests of the hull as to the trim angles that give least resistance during the take-off, it is possible for him regularly to take off in much shorter time than he requires when no such instrument and data are available. The pilot of a heavily loaded amphibian operating in the tropics reported that he attributed the uniformly successful operation of his craft, especially the ease with which it took off in smooth water, to the use of a trim-angle indicator that had been supplied by the Committee. In another case the use of a trim-angle indicator by a test pilot is credited with so greatly improving the take-off characteristics that a seaplane which at first appeared very unsatisfactory gave very good performance.

REPORT OF COMMITTEE ON POWER PLANTS FOR AIRCRAFT

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

ENGINE POWER

The recent demand of aircraft designers for engines of increased power output has been fulfilled by the supplying of radial air-cooled engines developing 1,500 horsepower during take-off. This large increase in power has been obtained by increasing the number of engine cylinders and by designing the engines to take the greatest possible advantage of the antidetonating quality of the improved fuels now available for aircraft engines. These large engines will be used in aircraft designed to transport greater loads at increased speeds over present airways. The several investigations of the Committee on the cooling of air-cooled engines have indicated that it will be possible to cool satisfactorily engines of even greater power.

Engine performance with high octane fuels.—The greater percentage of the recent increase in power of aircraft engines is due to the use of fuels having increased antidetonating quality. An investigation to determine the maximum engine performance with fuels having a range of octane numbers from 87 to somewhat greater than 100 has been in progress at the Committee's laboratory during the past year, under the cognizance of the Subcommittee on Aircraft Fuels and Lubricants, and will be described in the report of that subcommittee.

Valve overlap.—The power of aircraft engines may be increased by removing the exhaust gases from the cylinder clearance volume. An efficient method of removing the exhaust gas is to operate with a large valve overlap and low boost pressure. At the request of the Bureau of Aeronautics of the Navy Department, the Committee is determining on a single-cylinder test engine the performance and optimum valve overlap to give efficient scavenging of a radial air-cooled fuel-injection engine operating at a maximum speed of 2,200 r. p. m.

The results indicate that satisfactory scavenging can be obtained with a valve overlap of 130°. From the tests on the single-cylinder engine it was found that as the boost pressure was increased the gain in power with the two-valve cylinder was slightly less than that obtained in previous tests with a cylinder having four valves. The results showed that an engine operating with valve overlap would develop 25 percent more power at the same cylinder temperature than an engine operating with normal valve timing. The tendency to detonate was reduced so that the engine with valve overlap, for the one fuel tested, showed an increase in brake mean effective pressure of 25 percent without detonation as compared with the normal valve timing.

The 2-stroke-cycle engine.—Increased power output can be obtained from a given engine displacement by operation on the 2-stroke cycle instead of on the 4-stroke cycle. The availability of improved fuels having increased antiknock values has renewed the interest in the 2-stroke-cycle spark-ignition fuel-injection engine. An investigation has been conducted to determine the optimum location of the fuel-injection valve and the best arrangement of fuel-valve orifices for injecting the fuel into the engine cylinder. Favorable results have been obtained in a limited series of tests, and the research program is being continued to obtain information on the operating characteristics of this type of engine as affected by speed, scavenging pressures, and induction and exhaust conditions. With fuel of 100 octane number, scavenging pressure of 3 pounds per square inch, and a speed of 1,650 r. p. m., the single-cylinder engine developed an indicated mean effective pressure of 166 pounds per square inch, the corresponding fuel consumption being 0.37 pound per horsepower-hour. A maximum indicated mean effective pressure of 193 pounds per square inch has been developed with a fuel consumption of 0.44 pound per horsepower-hour. A positive valve-operating mechanism for this engine is being developed that will permit the maximum engine speed to be increased from 1,800 to 2,500 r. p. m.

Air intercoolers.—An analysis has been made of data from laboratory tests for the purpose of selecting the most desirable intercooler for various operating conditions—the cooling, drag, pressure drop through cooler, and weight of core being considered. On the basis of this analysis, a program of tests for intercoolers has been prepared that includes both full-scale tests in a wind tunnel and tests of promising cores in the engine laboratory.

COMBUSTION RESEARCH

A study of combustion both in spark-ignition and in compression-ignition engines has been undertaken with the object of obtaining new knowledge concerning the combustion phenomena. The problem of detonation in internal-combustion engines is being attacked with the aid of high-speed schlieren photographs to indicate the temperature variations in the front and rear of the combustion zone following ignition.

Ignition lag in compression-ignition engines.—The investigation of the effect of air temperature and density on the auto-ignition and combustion of Diesel fuel with a constant-volume bomb has been extended. Very little reduction in ignition lag is possible for the particular fuel under test by the use of temperatures and pressures in excess of those attained in compression-ignition engines. The combustion process, however, is more satisfactory at densities corresponding to considerable boost. A concentration of combustion products several times greater than that corresponding to the residuals in a compression-ignition engine is capable of definitely increasing the ignition lag. Technical Report No. 580 has been published giving the results of this investigation.

Compression-ignition engine with air flow.—The investigation of the fuel-spray and flame formation occurring in a compression-ignition engine having air flow that was set up by a displacer on the piston crown has been described in Technical Report No. 588.

Detonation in engines.—With a schlieren set-up and a high-intensity electric spark as the light source, by means of which 10 photographs are taken at rates up to 2,000 pictures a second with an exposure interval for each picture of approximately one-millionth second, photographs have been obtained that show clearly the depth of the combustion zone and also the burning of the end gases in normal combustion. No evidence has been obtained of any sonic wave preceding the combustion front. Such waves were artificially produced in the chamber and, although their effect on the combustion front was visible, they did not cause the charge to detonate. Even with very severe detonation, the combustion reaches all, or nearly all, the way across the combustion chamber before the detonation occurs. The results of this investigation are being prepared for publication.

An apparatus has been constructed and is being used for preliminary tests of the detonation of gasoline-air mixtures. The combustible mixture is prepared in a reservoir heated to a temperature below the auto-ignition point but sufficiently high to vaporize all the fuel. A portion of this mixture is then admitted by means of a poppet-valve mechanism to an evacuated tubular bomb heated to a temperature such that auto-ignition of the charge will occur after a relatively long time. If this mixture is spark-ignited at one end in such a way that the normal flame can traverse the tube within this lag period, no detonation occurs. On the other hand, when the spark is so applied to the mixture that the flame travels only a large portion of the tube length, then severe vibrations, presumably due to detonation, are set up in the optical pressure indicator attached to the tube at the end opposite the sparking end.

Analysis of engine cycle.—The calculated ideal engine cycle does not include consideration of the actual combustion process, so that the results depart considerably from those obtained from engine tests. In order to obtain better correlation between theoretical and experimental results, a study of the spark-ignition engine cycle was made and a thermodynamic cycle set up closely approximating the actual operating cycle. From a consideration of this cycle, equations for the cycle characteristics, such as indicated horsepower and fuel consumption, maximum cylinder pressure, and point at which the maximum cylinder pressure occurs in the cycle, were written as functions of three combustion parameters that specify the rate, the completeness, and the position in the cycle at which combustion occurs. The variation of the combustion parameters with engine operating conditions was obtained from indicator cards. The cycle characteristics calculated from the combustion parameters agree closely with those obtained in the engine tests.

Air flow in cylinders.—An investigation has been started to determine the effect of air flow on combustion in spark-ignition engines. The air flow is set up by shrouds placed on the inlet valves. Preliminary tests have shown that with an orderly swirl in the combustion chamber the entire combustion front is rotated, but that there is little apparent effect on the combustion velocity.

FUEL CONSUMPTION

Any reduction in the fuel consumption of engines used in long-range or transport aircraft can be utilized to increase the useful load or the range of the aircraft. Large savings in fuel have resulted from the use of mixture indicators by commercial operators. The improvement in cylinder cooling has progressed to such a point that aircraft engines are capable of operating at mixtures leaner than are accurately indicated by commercial mixture indicators. The use of fuels of high octane number has also resulted in an appreciable reduction in fuel consumption.

Mixture distribution.—The results obtained from an investigation of the distribution of fuel to each cylinder of a single-row radial air-cooled engine by chemically analyzing the exhaust gases have been published as Technical Note No. 583.

Fuel distribution.—The use of a fuel-injection system instead of the conventional carburetor requires that additional air flow be set up within the cylinder to assist in mixing the fuel and air. A study has been started to determine the effect of air movement on the distribution of the fuel spray during the suction and compression strokes. The apparatus consists of a glass cylinder clamped between the jacket and the cylinder head of an N. A. C. A. single-cylinder test engine. The piston side thrust is taken on the steel liner, and a dummy piston screwed in the main piston moves in the glass cylinder with very small clearance. The air flow is made visible by goose down introduced with the inlet air and is recorded by high-speed motion pictures taken at a rate of 2,400 frames per second. Tests have been completed with a pent-roof cylinder head in which the inlet valves were shrouded to give different degrees of air movement. With the shrouds arranged to give a tangential swirl, the photographs show that the tangential swirl persists throughout the compression stroke. With the shrouds arranged to direct the air parallel to the cylinder diameter, a decided vertical swirl is produced. With the shrouds radially arranged, a general indiscriminate air movement similar to that obtained without shrouds is obtained. The data are being prepared for publication.

Decreased fuel consumption.—A study of the fuel-consumption characteristics of modern air-cooled engine cylinders at various values of engine speed and torque has been completed. The determination of these characteristics was made on two single-cylinder air-cooled test engines having compression ratios of 5.6 and 6.9, respectively. The results showed that to secure best fuel economy an engine should be operated at high torque and at 65 percent of rated speed. Increasing the compression ratio from 5.6 to 6.9 decreased the fuel consumption but did not change the air-fuel ratio that produced maximum power or minimum fuel consumption. A report is being prepared giving the results of this investigation.

Mixture-ratio indicators.—With transport aircraft maximum range is obtained by operating the engines at the air-fuel ratio giving minimum specific fuel consumption. The Committee is investigating the more promising types of mixture-ratio indicators suitable for aircraft. The use of these instruments is limited, however, to air-fuel ratios from 15 to 9. Since aircraft engines under cruising conditions are already operating at air-fuel ratios of approximately 18, there is need for an improved instrument that will include the full-range of mixture ratios. An investigation has been started to determine possible methods of operating such an instrument.

Exhaust-gas analysis.—As most commercial instruments for indicating air-fuel ratio depend upon one or more constituents of the exhaust gases, it is important in connection with the development of such an instrument to know the correlation of these constituents with air-fuel ratio. The most reliable method of determining this correlation is by chemical analysis of the exhaust gases. An investigation to determine the correlation for a number of engines and a range of engine-operating conditions has been completed, and the results are in process of publication as Technical Report No. 616.

ENGINE COWLINGS

The N. A. C. A. cowling.—The results of the comprehensive investigation carried out with full-scale models of the N. A. C. A. cowlings in the N. A. C. A. 20-foot wind tunnel have been published in Technical Reports Nos. 592, 593, and 594. The effect of cowlings on the cooling characteristics of a Pratt & Whitney Wasp S1H1–G engine is reported in Technical Report No. 596.

Nose-slot cowling.—The preliminary results obtained with the nose-slot cowling in the wind tunnel have been described in Technical Report No. 595. This cowling is characterized by the fact that the exit opening discharging the cooling air is not, as usual, located behind the engine but at the foremost extremity or nose of the cowling. This nose-slot cowling is inherently capable of producing two to three times the pressure head obtainable with the normal type of cowling, because the exit opening is located in a low-pressure field. Thus identical conditions of cooling can be obtained at correspondingly lower air speeds. In general, the efficiency is found to be high, owing to the fact that higher velocities may be used in the exit opening.

Investigation of the nose-slot cowling has been extended to include flight tests on the XBFC–1 airplane. A two-slot design with an adjustable nose section controllable from the cockpit has given very good results. This cowling compares very favorably with the original installation of the conventional N. A. C. A. cowling. Greater pressure is available for cooling on the ground, while the top speed of the airplane is increased 8 miles per hour. This investigation is being continued to improve the ground cooling further and to eliminate some conditions of local heating caused by the change in direction of the air flow. In the second design of the nose-slot cowling tightly fitting baffles were used. These baffles were much superior to the service-type baffles, lowering the temperature of the cylinder heads 40° and requiring the expenditure of only one-fifth the power.

The in-line air-cooled engine.—With increase in the power output of the air-cooled in-line engine the difficulties of obtaining satisfactory cooling and low drag have increased. The Committee is investigating the problems connected with the cowling and cooling of a 6-cylinder in-line air-cooled engine. In the in-line engine the opening available for the entrance of the cooling air is quite small, so that the air must enter at relatively high speed. The air must be turned through 90° in order to flow over the engine cylinders. Owing to the relatively high velocity, it was found that 30 percent of the available pressure was lost in turning the air before it entered the cylinder baffles. The energy required for cooling was therefore high compared to the energy required in the radial engine.

A new cowling has been constructed that will insure a smooth flow of air over the cowling. Enlarged openings and passages on the air-entrance side of the cylinders will be used to reduce the turning loss of the air. From the results obtained in the tests on this cowling a supplementary investigation will be planned.

ENGINE COOLING

Aircraft engines must be operated at approximately one-half the rated power and with lean mixtures to obtain maximum range. Any improvement made in the cooling of air-cooled engines can be utilized in operating the engine at higher power output during take-off and in cruising with leaner mixtures.

Fin dimensions.—An analysis has been made to determine the best proportions for metal fins for given rates of heat flow, consideration being given to the minimum pressure drop across the fins, the minimum power required for cooling, and the minimum weight of the fins.

This investigation has shown that: A considerable improvement in the heat transfer of conventional aluminum fins is possible by the use of correctly proportioned fins; correctly proportioned aluminum fins will transfer more than 2.25 times as much heat as steel fins for the same weight and pressure drop; the best fin proportions for maximum heat transfer for a given fin weight and pressure drop are also best for obtaining a high heat transfer for a given power expenditure in cooling.

As a result of the investigation of fin dimensions it was found that, for a given width of fin and velocity, there was an optimum spacing below which the heat transfer rapidly decreased. In order to determine the cause of this decrease, an investigation has been started in which the type of flow of air around large-scale model cylinders is determined by means of smoke-flow pictures. A hot-wire anemometer is also used to determine the change from laminar to turbulent flow. The effect of cylinder diameter, fin space, and fin width on the type of flow is being determined.

Heat-transfer coefficients.—The calculation of the heat flow from air-cooled finned surfaces depends upon the experimentally determined heat-transfer coefficients. An investigation to determine the surface heat-transfer coefficients of closely spaced fins from wind-tunnel tests with and without baffles and with blower cooling has been described in Technical Note 602.

An investigation has been made to determine the heat-transfer coefficients of closely spaced aluminum-alloy fins having a width of 1.22 inches and copper fins having a width of 3 inches. The primary object of these tests was to determine whether the heat transfer as calculated from a theoretical equation checked the experimental values for finned surfaces constructed of metals having different thermal conductivities. The optimum fin spacing with wide fins was also investigated.

Cylinder baffles.—A study has been completed of the aerodynamics of cooling air-cooled engine cylinders with baffles. The air passage was recognized to be a venturi and was studied from this point of view. The use of a baffle approximating the best venturi possible under the conditions imposed by a radial air-cooled engine resulted in an improvement of 20 percent in cooling on a model cylinder. When the results of this study were applied in the baffling of a modern 2-row radial engine the cooling on the head was improved 28 percent.

Further work is in progress on the problem of improving the cooling by changing the cylinder contour. An attempt is being made to overcome some of the difficulties in constructing a good venturi in the conventional circular engine cylinder. Although the study is being made for convenience on a model simulating the barrel of the cylinder, the results are applicable to the head of the cylinder. Since 80 percent of the heat is dissipated through the head, and since contour changes are more easily made on the head than on the barrel, the results will be applied to the head of the cylinder.

Blower cooling.—The results of an investigation on a cylinder with fins 1.22 inches in width and with spacings varying from 0.022 to 0.21 inch have been published in Technical Report 587. The cylinders were enclosed in jackets and cooled with air supplied by a blower. The results showed that maximum cooling was obtained with a fin spacing of 13 fins per inch and that the heat-transfer coefficient was not sensitive to the fin spacing for values near the maximum, whether more or less. With 11 or 16 fins per inch the heat transfer was 95 percent of that obtained with a fin spacing of 13 fins per inch.

The results of the investigation to determine the effect of fin width, fin spacing, entrance and exit areas of the jacket around the cylinder, separator plates, and fillets on the pressure drop and power required to force air around finned cylinders at air speeds from 15 to 230 miles per hour have been prepared for publication and will be released as Technical Note 621. An analysis has been made of the losses occurring around the cylinder. As a supplement to this work, some miscellaneous tests are being made to determine the effect of certain special jacket and baffle designs on the heat transfer and pressure drop of finned cylinders.

Cylinder-temperature correction factors.—The results of an investigation to determine the effect of engine power, weight velocity of the cooling air, and atmospheric temperature on the cylinder temperatures of a Pratt & Whitney 1535 engine under flight conditions have been published in Technical Note 584.

The study of the factors for correcting cylinder temperatures of air-cooled engines to a standard atmospheric temperature has been extended to include the correction factors for various flight and test conditions, such as level flight, climb, take-off, airplane stationary on ground, and conditions of constant mass flow of cooling air and of constant velocity of cooling air. The correction factors range from approximately a change in cylinder temperature of 0.6° to 1.1° per degree change in atmospheric temperature, the value of the factor depending on the flight or test condition. A report covering this work is being prepared.

Heat transfer.—The study of the cooling of air-cooled engines has been continued. A report has been prepared and will be published as Technical Report 612, presenting an analysis in which equations for the rate of heat transfer from the engine gases to the cylinder and from the cylinder to the cooling air, as well as equations for the average head and barrel temperatures, as functions of the important engine and cooling variables, are obtained. Data obtained in tests of single-cylinder engines of cylinders from Pratt & Whitney 1535 and 1340–H engines for checking the analysis and for providing the empirical constants in the equations for these cylinders are presented in the report. An illustration of the application of the equations to the correlation of cooling data obtained in flight tests of a Grumman Scout (XSF–2) airplane is also given in the report.

An investigation of the effect of turbulence in the cooling air stream on the cooling of the Pratt & Whitney 1535 cylinder showed that in some cases the turbulence caused an increase of as much as 30 percent in the heat-transfer coefficient of the fins for the same pressure drop across the cylinder. These data are included in the report.

Further cooling tests have been made on a cylinder from a Wright 1820–G engine for obtaining the constants of the heat-transfer equations for this engine.

Radiators.—A study of radiator design has been undertaken. The entrance and exit conditions are being studied with a view to improving their aerodynamic performance. The study has revealed that 50 percent of the power required to cool a radiator is lost in the exit of the air from the radiator tubes in the conventional honeycomb tube radiator. The results show that an important part of this loss can be avoided. Further, the diameter and length of tubes for the minimum power to cool is being determined. The results will give the optimum dimensions for several operating conditions and installations.

COMPRESSION-IGNITION ENGINES

The compression-ignition engine is of particular interest as a power plant for transport aircraft because of its inherently low fuel consumption. The criticism previously made of the compression-ignition engine was that it could not produce the necessary high power outputs for take-off and that the weight of the engine would be excessive because of the high maximum cylinder pressures. The results obtained by the Committee in tests of single-cylinder engines with the N. A. C. A. displacer-type combustion chamber showed that the boosted performance of this compression-ignition engine was equal to that obtained from the latest type of air-cooled engines operating with fuel of 100 octane number. Under take-off conditions the maximum cylinder pressures developed in conventional air-cooled engines have been found to equal those in the compression-ignition engine. The two types of engines should therefore weigh approximately the same.

Prechamber type of combustion chamber.—The results of the investigation of the prechamber type of combustion chamber for compression-ignition engines have been published in Technical Report 577.

Integral type of combustion chamber.—The investigation of engine performance at 2,500 r. p. m. with a displacer piston and a vertical-disk form of combustion chamber has been continued. In order to accommodate the increase in the engine rotative speed from 2,000 to 2,500 r. p. m. the air induction and exhaust systems were altered and development work conducted to determine the proper air-flow passages and the arrangement of fuel sprays in the combustion chamber. Test results showed that with existing fuel-injection equipment the injection period was too long, as evidenced by late burning and a smoky exhaust. Even without the correct rate of fuel injection an indicated mean effective pressure of 260 pounds per square inch was developed at 2,500 r. p. m. for a boost pressure of 10 pounds per square inch. The corresponding specific fuel consumption was 0.42 pound per indicated horsepower-hour.

Altitude performance.—An investigation of the performance of a compression-ignition engine under altitude conditions has been completed, and the results showed the Diesel engine to be under no handicap when compared with the carburetor engine. Tests were conducted at pressure altitudes up to 30,000 feet and at temperature and pressure conditions up to 14,000 feet. Boosted performance was also determined at constant inlet-air temperature from boost pressures of 0 to 10 pounds per square inch over a range of exhaust pressures corresponding to altitudes from 0 to 19,000 feet. The scope of the research was expanded to include the investigation of the effect of single variables of temperature and pressure of the inlet air and exhaust back pressure. A report presenting the results of the work is in process of publication.

Single-cylinder and multicylinder engines.—An air-cooled compression-ignition cylinder having a push-rod-valve mechanism suitable for use on a radial engine has been designed by the Committee and is being supplied by the Bureau of Aeronautics, Navy Department, for investigation. The cylinder has the displacer form of combustion chamber developed by the Committee and will be used to investigate its adaptation to air-cooled cylinders. Information will also be obtained on the factors of multicylinder compression-ignition engine performance and the problem of air-cooling a compression-ignition engine cylinder.

The 2-stroke-cycle engine.—The investigation of the 2-stroke-cycle compression-ignition engine has been continued, and tests have been made to determine the effect of the shape of the inlet ports on engine performance. A cylinder liner providing 62 inlet ports, each of 11/32-inch diameter arranged in three staggered rows and drilled at an angle of 56° from the radial, has been tested for several length-diameter ratios of the ports. Best performance was obtained when the length-diameter ratio was 0.7 and was approximately equal to that with the eight large rectangular ports previously used. Work is in progress to determine the effect of varying the timing and duration of exhaust on engine performance.

Fuel-injection rates.—The results obtained from the investigation of the rates of discharge from a single-cylinder fuel-injection pump connected to two injection valves have been published in Technical Note 600.

The increase in rotative speeds of the compression-ignition engines has resulted in inferior performance of the fuel-injection equipment. Special apparatus has been constructed whereby accurate and convenient determination of injection rates has been made for a group of available fuel pumps, plungers, and cams in various combinations. The tests included variations of engine speed and quantity of fuel injected for the several injection-system combinations. Results indicated the unsuitability of any available injection equipment to give satisfactory introduction of the fuel charge into the cylinder at engine speeds in excess of 2,000 r. p. m. and the urgent need for further injection-system tests and development.

Fuel-injection pumps.—An improvement in the performance of several compression-ignition engines has resulted from changes in the rate of fuel injection. A knowledge of the rate of injection of the various fuel-injection systems has been obtained only after investigation of their characteristics. A unit type of injection system was investigated to obtain a direct control over the injection rate by variation in the cam outline. A cam-operated injection pump was closely coupled to the injection valve, and the effect of changes in orifice diameter, injection-tube length, throttle setting, pump speed, type of injection valve, and cam outline was studied.

The cam outline directly controlled the injection rate during the first five pump degrees of injection for a large orifice diameter and a differential-area valve. After this time interval, leakage at the pump affected the control. An open nozzle in combination with a ball-check valve reduced the initial rate of discharge to about half that of the differential-area valve. This rate increased with fuel quantity to a maximum at cut-off. With the differential-area valve, the rate of injection reached a maximum a few degrees after the beginning of injection and an increase in fuel quantity did not increase this rate. An increase in pump speed decreased the maximum rate and increased the period in degrees. Increase in injection-tube length had less effect on the open-nozzle valve. Secondary discharges were not obtained under any operating conditions with short injection tubes, but were obtained with increase in tube length under operating conditions in which a high initial pressure wave was obtained. The orifice diameter materially affected the injection rate, owing primarily to the high leakage rate at the injection pump. The maximum rate decreased with decrease in orifice diameter. With a suitable pressure seal at the pump and a relatively large orifice diameter in a differential area valve, the rate of discharge should be controllable by the cam outline for the unit-type injector.

Fuel and combustion accelerators.—The efficiency of the compression-ignition engine at increasing loads is reduced by late burning during the power stroke. Some evidence has been presented that the problem of eliminating the late burning may not be entirely the mechanical process of fuel and air mixing but one also of overcoming chemical retardants. The use of chemical combustion accelerators in the fuel has been suggested as a possible means of overcoming this handicap. A tetranitromethane Diesel oil dope has been obtained and tested in various percentages in the standard laboratory fuel. The small improvement in performance (2 to 3 percent) was considered economically undesirable. A sample of a second combustion accelerator has been ordered for test. A program is also under way to determine the relative merits of combinations of fuel oil and alcohol in various percentages, particularly with respect to more complete utilization of the air charge.

Fuel investigation.—The correlation of engine-performance data requires a knowledge of the heat of combustion of the fuel used. The determination of this factor and the distillation characteristics of the fuel make possible the recognition of changes in fuels due to aging or replacement. The heating values of five samples of Diesel fuel used by the Committee for engine testing have been determined. The values found vary from 19,790 B. t. u. to 19,930 B. t. u. per pound.

The smoky exhaust obtained with compression-ignition engines operating at air-fuel ratios richer than the theoretical (15 pounds of air to one pound of fuel) indicates that considerable fuel is wasted in unburned carbon. An investigation is being made to determine the amount of this carbon and its variation with air-fuel ratio. The method used is to determine the actual hydrogen-carbon ratio of the fuel from complete combustion tests and the apparent hydrogen-carbon ratio from exhaust-gas analysis, the difference in the two values being the carbon in the exhaust. The actual hydrogen-carbon ratio of five samples of Diesel fuel oil representative of the fuels used during the past two years by the Committee has been determined. The values found varied from 0.160 to 0.161.

INSTRUMENTS

Fuel flowmeter.—Flight testing of the electrical type of indicating fuel flowmeter which has been developed by the Committee has been conducted by the Materiel Division of the Army Air Corps. The fuel flowmeter is being altered to incorporate desirable changes indicated as a result of the flight tests.

High-speed camera.—The design of a high-speed motion-picture camera to photograph combustion at rates up to 40,000 frames per second has been completed, and construction of the camera has been started. The operating principle of the camera has been checked by means of a mock-up of the camera.

Fuel-injection pressure indicator.—A piezo-electric pick-up unit has been adapted to a fuel-injection valve to obtain instantaneous values of the fuel pressure at the discharge orifice. The pressures are shown on a cathode-ray tube. Photographic records are made of these instantaneous pressure traces. The rates of fuel discharge calculated from the pressure records show a very close agreement with the rates measured on the rate-of-discharge apparatus. This unit allows a rapid determination of rates of fuel discharge and of any cyclic variations in the discharge.

NATIONAL BUREAU OF STANDARDS

Phenomena of combustion.—A spherical explosion vessel with central ignition and auxiliary apparatus for obtaining simultaneous records of flame travel and pressure development has been constructed. The bomb consists of two flanged hemispheres, about 10 inches in diameter, clamped together on a short ring of glass which affords a view of the flame in a narrow, vertical center-section of the bomb.

The progress of the flame as it spreads from the central spark gap is photographed on a film which is carried on a drum rotating at a known speed on a vertical axis. The movement of the film under the lengthening image of the narrow flame section produces a time-displacement record of the flame front.

Six diaphragm pressure indicators, designed with a view to securing high accuracy throughout the pressure range of the explosion, are mounted on the bomb. Each indicator is set to close an electric contact the instant some predetermined pressure is reached in the bomb. When the contact is closed a neon lamp of high intensity is lighted, which photographs on the rotating film as a line beside the flame trace. In addition to the six lamps corresponding to the six indicators, there is a lamp which flashes 1,000 times a second under the control of a tuning fork and a lamp which burns continuously to provide a reference line for the measurement of flame displacements. The film thus contains all the information necessary for plotting time-displacement and time-pressure curves for the explosion.

Formulas have been developed for calculating from these curves (1) the "transformation velocity" or fundamental speed at which the flame front advances into and transforms the unburned charge; and (2) the "expansion ratio" or ratio of the volume of burned gas to the volume of the same mass of gas before explosion at constant pressure. Experiments will be conducted with this apparatus to investigate the separate effects of charge composition, temperature, and pressure on transformation velocity and expansion ratio.

Some experiments were made in which a cylindrical glass bomb was used with no pressure indicator to determine the effect of water vapor on the period of subnormal flame velocity just after the occurrence of the spark. In equivalent mixtures of carbon monoxide and oxygen saturated with moisture at atmospheric pressure this delay period is very short and high-film speeds must be used to detect it. Constant flame velocity is attained much more slowly when the moisture content is reduced below about one percent by volume. The cause of the delay is not known and it is hoped that new information concerning it will be obtained with the spherical bomb.

A brief mimeographed circular outlining the combustion experiments which have been conducted at the Bureau in engines, soap bubbles, and bombs, and containing a list of published reports on these experiments has been prepared for distribution to visitors and to others interested. A mimeographed bibliography containing 162 references on high-speed pressure indicators, classified according to type, is also available.

Investigation of piston cooling.—As the output of aircraft engines is raised the problem of heat dissipation from the piston head becomes increasingly serious. A program has been outlined for determining the heat flow in suitable test specimens under conditions similar to those encountered in service by aircraft-engine pistons. Preliminary static experiments showed greatly improved heat transfer for a hollow steel specimen with internal cooling over a solid aluminum specimen of approximately equal strength, size, and weight.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Engine performance with iso-octane fuels.—As mentioned in the report of the Langley Memorial Aeronautical Laboratory above, an investigation is being conducted at that laboratory to determine the maximum engine performance with fuels having octane numbers ranging from 87 to somewhat greater than 100. In this investigation the engine performance has been determined with the N. A. C. A. high-speed single-cylinder test engine having a cylinder bore of 5 inches and a stroke of 5.75 inches. The tests have been made at an engine speed of 2,500 r. p. m. and a coolant temperature of 250° F. The desired octane number of the fuel has been obtained by using commercial iso-octane blended with a gasoline having an octane number of 18. For octane numbers greater than 100, tetraethyl lead has been added to the iso-octane.

Tests have been completed with fuels of 87, 91, 95, and 100 octane number as determined by the C. F. R. method. In addition, tests are almost completed on the iso-octane with 1 cubic centimeter of tetraethyl lead. The limiting performance of these fuels has been determined at maximum power and at best fuel economy for both incipient and audible knock. The results show that as the inlet-air temperature is increased for any one compression ratio the effectiveness of the fuels of higher octane number appreciably decreases. Only at the lower inlet-air temperatures are the greatest increases in performance realized for the fuels of higher octane number. The tests have shown that the power of the engine does not vary as the inverse square root of the inlet-air temperature, but as an approximately lineal function.

Stability of aviation oils.—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, has been extended to include laboratory tests of the stability of oils in an apparatus in which the oil flows in a thin film down the walls of a heated cylinder and thus simulates engine conditions. The investigation of this method is not yet completed, but the data obtained thus far indicate a correlation between the results of these tests and the results of tests which have been made in a Pratt and Whitney Hornet engine.

An investigation of the stability of compounded oils has been initiated in cooperation with the Subcommittee on Aircraft Fuels and Lubricants, and the effect of a number of compounding materials on the stability of the base oil has been studied. The results of this investigation will serve as a basis for the choice of compounded oils to be used in connection with the study of wear and oiliness characteristics of aviation engine lubricating oils.

Oil acidity and bearing corrosion.—The investigation, conducted by the National Bureau of Standards in cooperation with the Bureau of Aeronautics of the Navy, of the effect of increase in oil acidity during service on the corrosion of master-rod bearings has been continued. Study of oils in the apparatus for forming acids in oils has indicated that this apparatus can be used to produce changes in the acidity of oils similar to changes which occur during service in aviation engines. It has been found desirable to construct additional apparatus for use in this investigation and this apparatus is being designed.

Aviation engine wear.—The investigation of the relative wear with different oils in actual aircraft engines, carried out at the National Bureau of Standards in cooperation with the Bureau of Aeronautics and certain petroleum organizations, has been continued throughout the fiscal year. The assembly of the operating equipment for engine control and absorption of power is essentially completed. Considerable precautions have been taken to insure reproducibility of operating conditions. Special fixtures for use with the precision instruments required for measuring the engine parts are under construction.

Wear and oiliness characteristics of aviation engine lubricating oils.—The investigation of the oiliness and wear characteristics of mineral and compounded lubricating oils, conducted by the National Bureau of Standards in cooperation with the Army Air Corps and the Bureau of Aeronautics, was continued throughout the fiscal year. An apparatus for determining the differences in piston-ring and cylinder-wall wear with various oils and compounding agents under conditions approximating those of actual engine operation has been completed, and preliminary tests are in progress. Construction of a second wear apparatus of different type has been begun. The design and construction of a machine for the study of oiliness as related to friction in master-rod bearings is under way.

REPORT OF COMMITTEE ON AIRCRAFT MATERIALS

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

Weathering of aircraft structural sheet metals—light alloys.—The series of atmospheric exposure tests of aluminum-alloy sheet materials was completed during the spring of 1937 after four years' duration at three test sites, typical of conditions prevailing at a tropical marine, a temperate marine, and an inland location. The results amply confirm the tentative conclusions announced in last year's report concerning the most corrosion-resistant types of alloys and satisfactory coating treatments for all alloys of this general kind. A report intended for publication summarizing the essentials of the test and the important facts established is in progress.

Preparations are approaching completion for a new series of tests. This series, which is on a somewhat smaller scale than the two previous ones, will be conducted at only one location, a marine one. Hampton Roads Naval Air Station is the site selected. Both aluminum and magnesium alloys are included in the program of tests scheduled, which are intended primarily for investigating the effects of riveting, welding, and contact between unlike metals, as well as the merits of newly developed protective surface treatments. The manufacturers of these materials are cooperating actively in the preparations, and this will insure that the industrial aspects of the problem will receive the careful consideration they deserve.

Corrosion-resistant steel.—The trend toward the use in aircraft of corrosion-resistant steel in thin sheet form has led to the inauguration of a similar program on this type of material. Deterioration of this material, if it occurs, takes place in a different manner from that of the light alloys, and the inspection and testing procedure must be correspondingly different. In both programs the effect of continuous exposure to the marine atmosphere as well as intermittent exposure to sea-water (the so-called "tide-water" tests) is to be determined.

Surface treatment for improving the durability of magnesium.—The ultimate aim in this investigation is to produce a tightly adherent surface film, highly impervious to corrosive agents, particularly chlorides, to which paint and other applied coatings will adhere over long periods of time without peeling or flaking. Anodic treatment in a dichromate-phosphate bath by the method developed in cooperation with the Bureau of Aeronautics, according to repeated laboratory tests at the National Bureau of Standards, continues to be the preferred method for the surface treatment of magnesium and its alloys. Studies on the improvement of the anodic treatment have been continued, and the

38548—38——4

results have indicated certain modifications by which further improvement appears possible. "Sealing" of the pores in the anodic film after it has been formed is important to produce a highly impervious film. This may be accomplished either by chemical means or by immersion in a hot oil or resin bath. Tests along this line are continuing. Initial cleaning before anodic treatment is also important in obtaining a film on the treated specimen of superior resistance. Tests on paint adherence as affected by the sealing treatment and other surface characteristics are in progress in the laboratory and on the outdoor exposure rack.

Sub-zero temperature and aircraft metals.—The original program, undertaken in cooperation with the Bureau of Aeronautics, has been completed and a report rendered, copies of which are available to all interested Government agencies. The only important adverse effect of low temperature, down to −80° C., is the decreased impact resistance of ferritic steels, which is in marked contrast to the aluminum alloys and the austenitic steels. Study of the factors responsible for this lowered impact resistance of ferritic steels is being continued with the aim of reducing and possibly eliminating the effect by suitable initial heat treatment of the steel. The investigation has been extended to include a study of the impact resistance at low temperatures of welded joints in steel members.

Elastic properties of high-strength aircraft metals.—The elastic properties of metals which owe their high-strength properties to strengthening by cold working are only nominal and vary greatly with the precision of the method used for their determination. An outstanding example is austenitic steel, such as 18–8 stainless steel, which because of its high corrosion resistance is favored for many important uses in aircraft. The method used in this work is essentially an "over-load" or "proof-stress" method, consisting in the determination of yield strength after various degrees of cold working by stretching immediately prior to testing. A rise in proof stress with increase in prior cold work is indicative of an improvement in the material, and vice versa for a decrease in proof stress. A report summarizing this phase of the work will be forthcoming shortly. Hysteresis measurements, such as those which may be obtained in the ordinary tensile-testing machine, are now in progress.

Structural changes in aircraft metals occurring as a result of service stressing.—The principal aim in this investigation is expressed in the question, Does continued fatigue-stressing below the endurance limit adversely affect aircraft metals? The widely used aluminum propeller alloy, 25S, is the material used in this study. A variety of approaches to the problem have been made, some of which were abandoned at early stages for more promising ones. The project is still in the stage of attempts to detect *significant* changes (other than crack formation and propagation) in physical properties, microstructure, and X-ray diffraction pattern as results of continued repeated stressing in the range of maximum fibre stress from 5,000 to 26,000 pounds per square inch. Up to the present no nondestructive method of inspection has been found which shows a significant difference between the metal not stressed and the same metal after it has been subjected to fatigue stressing. Special mention may be made of the failure to detect a lowering of impact resistance which could be attributed to prior fatigue stressing.

Propeller materials.—The possible deleterious effect of fabrication defects on the endurance properties of steel used in hollow steel propellers merits serious study. Also, the influence on the endurance of propellers of surface coatings, such as chromium plating as a finish, should not be overlooked.

The fatigue limit of such steel is approximately one-half of the tensile strength, which is considered to be normal for this material. Determinations of the fatigue limit of sound weld metal showed this to be about 60 percent of that of the parent metal. Scaling and surface decarburizing, such as may be present accidentally on the inside of the welded structure and cannot be removed, reduced the fatigue limit to one-half that of the polished steel, i. e., not much below that of the weld metal. The effect of accidental defects in the weld is variable; such defects may cause a very sharp reduction in the fatigue limit of the weld metal.

The effect of chromium plating varies with the condition of the steel and thickness of the plating. Specimens of normalized steel (previously polished) bearing relatively thick coatings showed no significant reduction in fatigue limit and a thinner coating had only a slightly greater effect. On specimens of the same steel in quenched-and-tempered condition, however, a reduction in fatigue limit was noted, which appeared to be of more significance and was greater for a very thin coating than for a coating ten times as thick, the plating in each case being applied directly to the previously polished steel. The use of a nickel "under coat," in accordance with commercial usage, prior to plating the quenched-and-tempered steel, gave similar results. The subject is receiving further study.

Further study of the unusual structural features previously reported for aluminum-alloy propeller blades has failed to show that any practical significance can be attached to them.

Miscellaneous.—The fact is well established that the corrosion resistance of many of the aluminum alloys which are strengthened by heat treatment is dependent in large measure upon the control of the conditions of heat treatment. A simple rapid test to determine in advance of service whether structural materials of this kind have been suitably heat-treated so as to develop maximum corrosion resistance should serve a very useful purpose. A study is being made of a proposed method, the essential feature of which is a determination of the solution potential of the material under consideration.

A relatively inexpensive method of preparing small fittings of unusual shape is to use transverse sections of an extruded shape of the proper size and contour. A study of extruded aluminum fittings made in this manner is under way, with a two-fold purpose, namely, (a) the improvement of such fittings with respect to certain features which have not proved entirely satisfactory under all service conditions, and (b) the determination of the practical significance of certain suspected structural features.

The need for a certain degree of ductility in a structural member, as in an aircraft assembly, is well recognized. The amount and the manner in which it is specified are, however, matters on which difference of opinion exists. Determinations of the ductility of various structural steels under various conditions of stress application have been continued, in cooperation with the Bureau of Aeronautics of the Navy. Interpretations as to the practical significance of differences in this property observed under various conditions are yet to be made.

SUBCOMMITTEE ON MISCELLANEOUS MATERIALS AND ACCESSORIES

The problems under the cognizance of this subcommittee during the past year which are being investigated at the National Bureau of Standards include the development of a flexible substitute for glass and the development of substitutes for linen webbing and silk shroud lines for parachutes. Consideration has also been given to the possibilities of plastics as a material for aircraft structures and to the adequacy of thermal and acoustical insulation.

Development of flexible substitute for glass.—Commercial and experimental transparent plastics which have been investigated to determine their suitability for aircraft windshields and windows include cellulose acetate, acrylate resins, cellulose nitrate, ethylcellulose, vinyl chloride-acetate, vinyl acetal, glyceryl-phthalate, styrene, phenol-formaldehyde, and cellulose acetobutyrate.

The tests included light transmission, haziness, distortion, resistance to weathering, scratch and indentation hardnesses, impact strength, dimensional stability, resistance to water and various cleaning fluids, bursting strength at normal and low temperatures, and flammability.

The two types of transparent plastics which are now in use on aircraft, namely, cellulose acetate and acrylate resin, were found to have certain defects which, it is believed, can be overcome in part by suitable modification of the composition and processing of the material.

Cellulose-acetate plastic was found to have excellent impact strength, bursting strength, and flexibility, but the commercial products tested varied considerably in resistance to weathering and were all subject to marked shrinkage in one year's time. The shrinkage produces warping and sets up strains in the plastic sheets, which cause them to craze and crack. These strains are believed to be the cause of the spontaneous cracking of cellulose-acetate windshields after they have been in service for six months or longer. This is particularly true of windshields which are exposed to low temperatures, as by ascent to high altitudes, as additional strains are thereby introduced in the windshield because of thermal contraction. Considerable variation was observed in the weathering resistance between cellulose-acetate sheets received from different manufacturers and also between different lots of the material from the same manufacturer.

The acrylate-resin plastic was found to be remarkably transparent, more stable to light and weathering, and more resistant to scratching than cellulose acetate, but its impact strength and flexibility are much poorer. Surface crazing of the acrylate resins was noted after one year's exposure on the roof and also after storage for a similar period. It is claimed, however, that a method of processing has been developed which eliminates this tendency to craze. Further tests on modified samples of both cellulose acetate and acrylate resins are in progress to determine whether more uniformly durable products than have been on the market to date can be made available to the aircraft industry.

Certain of the other materials, which are not now commercially available, appear very promising.

Tests for impact resistance were developed on a scale commensurate with service conditions. Soft rubber balls, five inches in diameter, loaded to weigh three pounds, were fired from guns at the Naval Proving Grounds. The muzzle velocity was approximately 300 feet per second. No material, whether plastic or laminated glass, was found able to withstand a direct hit with such a projectile. The experimental pieces were, of course, limited as to weight and thickness by practical considerations of airplane design. It was therefore concluded that the windshield alone cannot be regarded as a protection against ducks.

Substitute for linen webbing.—An all-cotton webbing which meets the requirements for breaking strength, weight, width, and thickness contained in U. S. Army Specification No. 15–11–D for linen webbing has been produced commercially. While the construction is not identical with that of the Type-G webbing, the cotton webbing appears to be a satisfactory substitute.

Substitute for silk shroud lines.—Attempts to make shroud lines from some material other than silk have not been successful to date. Whether cotton or rayon was used, the strength-weight ratio of the line has not equalled that obtainable with silk. Experiments are being continued to obtain information on the effect of variations in the construction of the line.

Development of plastic material for aircraft structures.—A survey of the literature on this subject was completed and a report presented to the Committee. The report contains data on density, tensile and compressive strengths, modulus of elasticity, fatigue, energy absorption, corrosion, and methods of fabrication. The Committee is now studying this report with a view to deciding whether or not to go further into the matter.

Materials for acoustical and thermal insulation.—A report bringing together some of the information available on this subject has been presented to the Committee. Plans have been made to ascertain the practical importance of this subject, and upon the answer to this question will depend future developments.

REPORT OF COMMITTEE ON AIRCRAFT STRUCTURES

LANGLEY MEMORIAL AERONAUTICAL LABORATORY

Applied loads on airplane structures—gust loads.—Coordinated measurements of acceleration and air speed on transport airplanes have been continued during the past year, and the total flying time represented on the records has been extended to over 30,000 hours. The maximum accelerations previously recorded have not, however, been exceeded and the maximum effective gust velocities for normal transport operations remain at ±35 feet per second.

Gust research.—The measurements of gust intensities and gradients on light airplanes, begun last year, have been continued and the data greatly extended. The new results do not invalidate the previous tentative conclusions, that in stable atmospheric conditions with large wind gradients, vertical gust velocities of the order of 30 feet per second are reached in a horizontal distance of about 100 feet and that the gust gradient increases with decreasing gust intensity.

Surveys of cumulus types of clouds indicate, in general, stronger downward-acting than upward-acting gusts. On one occasion a downward gust of 53 feet per second, which reached maximum intensity in a distance of 53 feet, was experienced.

Gust tunnel.—During the past year an apparatus for catapulting dynamically scaled models through artificial gusts has been developed to the point of satisfactory operation. In this apparatus the model is launched into a condition of steady glide, following which it flies through an air jet whose angle relative to the flight path can be controlled. The model carries a small optically recording accelerometer, and as it flies through the gust the acceleration is recorded and synchronized with external photographic measurements of the speed, path angle, and attitude angle.

Although this equipment is not ideally suited to the investigation of some of the important fundamental problems of unsteady flow, it can be used and was designed for the direct determination of the effects of changes in the several airplane and gust variables on the airplane motion and wing loads. This function is justification for the equipment in view of the rapid trend toward larger transport airplanes, to which the statistical data obtained on past and present types of airplanes do not apply.

Gust-relief devices.—A preliminary analytical study of the merit of two devices for reducing accelerations due to gusts has been made. The more effective arrangement appears to be a trailing-edge flap operated by a small vane located somewhat ahead of the wing. This arrangement responds more quickly and reduces the acceleration further than the other device studied, which was simply a mass-overbalanced flap.

Load distribution.—The results of a previously reported investigation of the span-load distribution on wings with partial-span flaps have been published as Technical Report No. 585. This report includes a simple set of computing forms for determining the distribution by the Lotz method with sufficient harmonics retained for good precision. The work on wings with partial-span flaps has been extended to include the calculation of the angle of zero lift, the pitching moment, and the induced drag. Wing models are now being constructed for investigation to provide data for comparison with the calculations.

Several pressure-distribution tests have been made in the 7- by 10-foot wind tunnel of wings with various flap arrangements, including Fowler flaps with chords 30 and 40 per cent of the wing chord.

Several reports describing investigations conducted prior to this year have been issued and include a report on pressure-distribution measurements on an O-2H observation airplane in flight (Technical Report No. 590), a report presenting an empirical method for determining tip corrections to the theoretical span-load distribution (Technical Note No. 606), and a report on the theoretical span loading and moments of tapered wings produced by aileron deflection (Technical Note No. 589).

Fuel tank vents.—During a dive from high altitudes the pressure changes rapidly on the outside of an airplane. Unless the venting tubes to the fuel tanks and plugs are of the correct size, a pressure difference may be built up that will be sufficient to collapse the fuel tanks or plugs.

The Committee has been requested by the Bureau of Aeronautics, Navy Department, to investigate these pressure differences for a range of diameters and lengths of vent tubes. Apparatus has been assembled in the laboratory that makes possible the rapid determination of the pressure difference between a tank of given volume and the atmosphere during a dive. The laboratory tests have been made at constant temperature, as calculations show that this does not introduce an appreciable error.

Tests have been made for terminal velocities of 300, 400, and 500 miles per hour for dives starting at 10,000 to 40,000 feet altitude with float and tank volumes from 10 to 60 cubic feet. Several lengths of vent tubes 1.5 inches in diameter and 0.75 inch in diameter have been investigated. Pressure differences of 10.5 pounds per square inch have been recorded with a tube 0.5 inch in diameter and 12 feet long.

Stressed-Skin Design—stress analysis of beams with shear deformation of the flanges.—The rapidly increasing size of aircraft structures is forcing designers to rely increasingly, for economic reasons, on mathematical stress analysis rather than on static tests. It is well known that the classic methods of analysis are not always sufficiently accurate and efforts are being made to correct these methods.

As a step in this direction, the bending action of box beams such as airplane wings has been examined. It has been realized for some time that the flanges of such beams deform sufficiently under shear stress to alter the stress distribution materially. The mathematical theory of this action has been developed to the point of practical applicability and has been partially verified by tests. Further tests are under way to determine under what conditions the theory can be used without modification and, for cases in which modifications are necessary, to lead over into the range of the classic engineering theory of bending.

Strength of stiffeners.—A theory for primary failure of straight centrally loaded columns has been published as Technical Report No. 582. In the report the theory for twisting failure of open-section stiffeners, as presented by Herbert Wagner (Technical Memorandums Nos. 807 and 784), has been elaborated to include the twisting failure of open-section stiffeners attached to a skin, with stresses carried above the elastic range. An illustrative computation of the column curve for the twisting failure of an I-section skin-stiffener combination is also included.

Work is being continued on the twisting failure of other types of stiffener sections, notably the Z section and the U section, with and without flanged edges. Consideration is being given to the manner of shift of the axis of rotation in twisting failure, both in and above the elastic range, in order to establish the extent of refinement necessary for practical application.

Besides the study of twisting failure, which is a primary failure, the local failure of various types of stiffener sections is being investigated, and the theoretical strength curves are being compared with such experimental data as become available from time to time.

Stability of structural systems.—A report has been prepared and published as Technical Note No. 617 dealing with the stability criterion for structural systems. The Hardy Cross method of moment distribution is employed. In order to simplify the application of the stability criterion, detailed tables are given for the ready evaluation of the stiffness and carry-over factors. Sample problems are also included to illustrate the use of the method.

NATIONAL BUREAU OF STANDARDS

Tubes under loads other than torsion.—Considerable time has been spent during the year in revising and bringing into conformity with latest Navy Department specifications a report which has been written on the fixation of struts; that is, the column strength of tubing elastically restrained at the ends. This report is now completed and will be published by the National Advisory Committee for Aeronautics as a technical report. It gives the column strength of chromium-molybdenum steel, 17ST aluminum alloy, stainless steel, and heat-treated chromium-molybdenum-steel tubing, and suggests a method by which planar trusses that are continuous at the joints may be analyzed and designed for stability. Two numerical examples are given.

In order to determine the minimum ratio of slenderness below which thin tubes fail by crinkling rather than as columns, and to determine the crinkling strength, tests of short tubes must be made under axial load. The crinkling strength under axial load of relatively short specimens of round 17ST aluminum-alloy tubing has been determined for values of the diameter-thickness ratio approximately from 15 to 100. Work is in progress and has been almost completed to determine the crinkling strength of chromium-molybdenum-steel tubing.

The modulus of rupture of round 17ST aluminum-alloy tubing has been determined for values of the diameter-thickness ratio approximately from 15 to 100. This has been done under third-point loading with the load applied (1) in such a way that failure occurred in the free length between loads, and (2) in such a way that failure occurred under a load. The latter method of loading simulates practical conditions occasionally encountered under which the load is applied through a compression member tending to dent the tube. Two empirical formulas involving the tensile yield strength of the tube material and the dimensions of the tube were derived to describe the modulus of rupture for the two series of tests.

The modulus of rupture obtained with the first method of loading does not depend to any marked extent on the position of the loading points, and the empirical formula for this method of loading may be used with safety whenever the maximum bending moment occurs in the free length of tube between loading points (including supports). The results are conservative for all other cases except in those relatively few instances in which the load is applied through a compression member tending to dent the tube. Under these conditions the empirical formula obtained from the tests with the second method of load should be used. The results of the second series of tests can be extended rationally to apply to other than third-point loading.

Work is in progress and has almost been completed to determine the modulus of rupture of round chromium-molybdenum-steel tubing under the same conditions of test as obtained for the 17ST aluminum-alloy tubing.

Determination of elastic constants on stainless-steel sheet material.—A study was made of the elastic properties of stainless-steel sheet of three thicknesses (0.007, 0.016, and 0.022 inch) in order to determine effective values of Young's modulus and of Poisson's ratio which could later be used in calculating stresses from the deformation under load of a model structure of this material.

The variation of Poisson's ratio and of Young's modulus with stress, sheet thickness, direction of rolling, and prestressing was measured by cutting tensile specimens in the direction of rolling and at right angles to that direction and measuring the ratio of transverse strain to axial strain with a set of four pairs of Tuckerman optical strain gages suitably placed to eliminate the effects of nonuniformity of stress distribution.

The values of Poisson's ratio were found to range from about 0.2 to 0.3. On the 0.007-inch specimen the Poisson's ratio in the direction of rolling was about 0.27, while at right angles to that direction it was only about 0.21. In some cases a considerable difference in values was found for the second run as compared to the first, showing the effect of prestressing on the elastic properties of the material.

Large variations in the value of Young's modulus with direction of rolling, sheet thickness, and stress were also found. In the case of the 0.007-inch specimens tested in the direction of rolling the Young's modulus dropped from around 28.5 10^6 pounds per square inch at a stress of around 5,000 pounds per square inch to a value less than 26.0 10^6 pounds per square inch at a stress of around 30,000 pounds per square inch.

The test results indicated the anisotropy of the stainless-steel sheet material. Stresses determined from strain measurements on a model constructed from such material would be subject to a probable error of several percent due to the variations in elastic properties alone.

Flat plates under normal pressure.—Experimental work was confined to tests of circular plates under normal pressure. The stress-strain curve of the material in the center of the plate was derived from the measured strains and the measured contours under load for two of the plates. In both cases the stress-strain curve obtained was found to differ from the tensile stress-strain curve of a coupon cut from the plate in that the stress continued to rise after passing the knee of the stress-strain curve; the mechanism of yielding in bilateral tension seemed to be different from that in straight tension.

The experimental work was paralleled by an extension of Stewart Way's analysis of clamped circular plates of medium thickness under normal pressure to greater deflections than the deflections of 1.2 times the thickness of the plate to which Way carried his tables. The deflections in the present plates amounted to about four times the plate thickness before yielding became appreciable. With the derivation of the curves of maximum stress and of deflection at the center of this order it will be possible to make an instructive comparison between the observed and the calculated deformation of circular flat plates, which it is hoped will lead to an understanding of the yielding in the rectangular plates also.

Inelastic behavior of duralumin and alloy steels in tension and compression.—The investigation of stress-strain curves of sheet material in tension and compression has been continued. A large number of tensile and "pack" compressive tests have been made on specimens cut with and across the direction of rolling from sheet ranging in thickness from 0.032 to 0.081 inch. Stress-strain curves have been obtained for aluminum alloys 17ST, 24ST, 24SRT, Alclad 17ST, and Alclad 24 ST. The difference in yield strength in compression as compared to tension was found to be of the order of 10 to 15 percent. The data suggest that the compressive yield strength of sheet material in the direction of rolling can, in general, be approximated roughly by the tensile yield strength at right angles to that direction, and vice versa.

The accuracy of the pack compression test was investigated by comparing the stress-strain curves obtained on solid specimens of cold-rolled steel, aluminum alloy, and brass 0.7 by 0.7 inch in section, with stress-strain curves from pack compression tests on packs built up from leaves cut from the same bar stock. The two sets of stress-strain curves were found to agree within ±2 percent.

The pack compression tests on 24SRT aluminum alloy had shown a value of Young's modulus which was consistently higher by about 3 percent than the Young's modulus in tension. This difference could not be ascribed to errors in the compression tests. Preliminary tests indicated it to be due to a continuous increase in the slope of the stress-strain curve in passing from small tensile stresses through zero to small compressive stresses.

Tubes with torsional loads.—The report on torsion tests of 61 chromium-molybdenum-steel tubes and of 102 17ST aluminum-alloy tubes was completed and will be published as Technical Report No. 601 of the National Advisory Committee for Aeronautics.

A comparison of the empirical formulas proposed in this report with the torsional strength of tubes of 17ST and 51SW aluminum alloy as tested at the Aluminum Research Laboratories showed close agreement, although the tubes tested by the Aluminum Research Laboratories were considerably shorter and in the case of the 51SW material had considerably different mechanical properties than the tubes tested at this Bureau. The agreement may be ascribed to the use in the empirical formulas of ratios involving the tensile properties of the tube material.

Beams and stressed-skin research.—The program on wing beams has been continued with the completion of tests under axial load, transverse load, combined axial and transverse loads, of eight wing-beam specimens of aluminum alloy with an I-type section having tilted flanges. Failure in these beams occurred by local instability of one of the flanges. The measured strains and deflections are being analyzed with the help of compressive stress-strain curves for the flange material which were obtained by the pack method. Failure of the combined-load specimens occurred at a flange stress calculated from the loads which ranged from 34,700 to 36,400 pounds per square inch.

The analysis of the data obtained on the two sheet-stringer panels tested in end compression at the National Bureau of Standards has been completed. Comparison with the results of similar tests at the Navy Model Basin on panels of the same design showed good agreement for the load carried by the sheet at failure. The load carried by stringers at failure was found to be about 10 to 20 percent lower for two of the specimens tested at the Model Basin. This relative loss in strength is probably due to the difference in end restraint, the flat end condition used at the Model Basin providing less restraint against buckling than the casting of the ends in Wood's metal used at the National Bureau of Standards.

The measured strain distribution in the sheet of the two panels tested at the National Bureau of Standards and the measured buckle shape were compared with the deformation calculated from approximate theories developed by S. Timoshenko, by J. M. Frankland, and by K. Marguerre. None of the approximate theories was found to agree accurately with observed deformations. The deflections of the buckled sheet were best described by Timoshenko's theory, the axial strains were about equally well described by all three theories, the transverse strains were best described by Frankland's theory, and the sheet load was best described by Marguerre's theory.

The analysis of the deformation of the stringers in the sheet-stringer panels was confined to a series of plots of deformation against deformation over load in accordance with Southwell's method. If the deformation plotted leads to an instability of the type to which Southwell's relation applies, all points will lie on a straight line with a slope equal to the elastic buckling load. Excellent straight lines could be obtained for some of the stringer twists as measured by the rotation of pointers mounted on the stringer, the slope of the lines being in close agreement with the observed buckling load. The agreement was less satisfactory for plots of other deformations. The lack of general agreement is not surprising, since a proof for the validity of Southwell's method has been given so far only for the column failure of beams under eccentric axial load and under certain combinations of axial and transverse loads.

Eighteen sheet-stringer panels are being fabricated at the Naval Aircraft Factory for the investigation of the effect on the compressive strength of such panels of rivet spacing and spot-spacing. The panels will be 12 and 18 inches long and will consist of three Z-type stringers fastened to the sheet by rivets or spots spaced an amount ranging from ½ to 4 inches. The spacing between stringers, the sheet thickness, and the spacing between rivets or spots will be varied to explore the effect of rivet spacing on both the buckling of the sheet between rivets and on the effective width of the sheet between stringers.

Airplane vibration.—Close cooperation was maintained with the Bureau of Aeronautics of the Navy Department in its program on airplane vibration. The National Bureau of Standards participated actively in a number of conferences at which methods were discussed for recording the readings of vibration pick-ups and of strain pick-ups mounted on various portions of an airplane in flight.

An important part of the program is the development of dynamic-strain pick-ups suitable for attachment to the structural parts of an airplane. In connection with this work a number of special strain pick-ups have been built by the Sperry Gyroscope Company which embodied a principle of inertia compensation suggested by William M. Bleakney, of the Engineering Mechanics Section of this Bureau. A description of this principle has appeared in the Journal of Research of the National Bureau of Standards for June 1937 under the title "Compensation of Strain Gages of Vibration and Impact," by William M. Bleakney. Three of the experimental pick-ups built by the Sperry Gyroscope Company were tested for compensation and for ruggedness of construction on a device subjecting them to accelerations up to 50 times gravity with negligible strain. Compensation for inertia forces adequate for present applications was obtained on one of these after a number of small adjustments had been made. The calibrations also suggested a number of changes in the design of the gage which would probably improve its operation.

A second type of strain pick-up on which considerable work was done at the Bureau is the strain pick-up of the carbon-resistance type developed by A. V. deForest. Static and dynamic calibrations were made on 20 carbon resistance strips, 5 of them of the "granular" type used at the Hamilton Standard Propeller Company, and the remaining 15 of the so-called "Ess-strip" type. A report describing the results of these tests in detail has been forwarded to the Bureau of Aeronautics of the Navy Department. The report gives quantitative results for the effect of frequency, strain amplitude, time under load, and temperature on the calibration of a number of these strain pick-ups.

The best dynamic characteristics were found for the gages of the "Ess-strip" type. These gages showed a resistance amplitude that was nearly proportional to the strain amplitude up to strains of 0.001 (corresponding to stresses of about 10,000 pounds per square inch in aluminum alloy). The calibration factor calculated by dividing the constant of proportionality by the direct-current resistance of the gage was independent of frequency between 30 and 100 cycles per second within ± 10 percent, independent of temperature between $-10°$ C. and 40° C. within ± 10 percent, independent of time for one day within ± 5 percent and for 40 days within ± 9 percent.

The static calibration tests, which were confined to gages of the "Ess-strip" type, gave calibration factors ranging from 40 percent below to 35 percent above the dynamic calibration factors. The effect of temperature variations and of time under load were found to be sufficient to render this type of strain gage very much inferior to accepted gages such as the Tuckerman optical strain gage or the Huggenberger extensometer in those cases where static strains on a large structure are to be measured.

The dynamic calibrations of "Ess-strips," which were made by attaching the gage to a propeller blade and then vibrating this blade in resonance, had indicated the need for a calibrator that would subject the strips to uniform sinusoidal strains of sufficient amplitude and of a frequency that could be varied over a wider range than the restricted number of resonance frequencies (30 to 100 cycles per second) that could be set up in the propeller blades. A device was accordingly designed for calibrating dynamic-strain gages up to 8 inches in length by subjecting them to uniform sinusoidal strains up to 0.001 at frequencies ranging from 10 to 200 cycles per second. This device is now being constructed.

Strength of riveted joints in aluminum alloy.—The investigation described in Technical Note 585 of the National Advisory Committee for Aeronautics has been extended to joints in which combinations of the following alloys were used: rivets, A17ST, 53SW, 53ST, and 24ST; and sheet, 24ST, 24SRT, and Alclad 24ST.

In accordance with the suggestions of manufacturers, tests have been made to determine whether the results previously obtained on 0.25-inch rivets are applicable to rivets of other sizes. Single shear and double shear tests made so far on rivets ranging from 3/32 to 5/16 inch in diameter indicate that for practical purposes there is no difference between the results obtained on the various sizes. The driving stress required to form a flat head of a given size was found to increase slightly with the diameter of the rivet, but this tendency was not observed for button heads.

Tests to determine the effect of aging upon the driving stress required to form the head, the shearing strength of rivets of the various alloys, and the mechanical properties of rivet wire are being carried out.

To supply information needed by the industry on riveted joints of the flush type, specifications for joints to be made by manufacturers have been prepared and distributed. Several sets of specimens have been received, and these are now being tested. Other flush riveted specimens are being made at this Bureau.

A set of fixtures has been constructed for driving rivets by means of a pneumatic hammer in a manner which minimizes the personal element in the heading process.

Investigation of fatigue resistance of fabricated structural elements of aircraft.—The fatigue test on the rear upper wing beam of a BF2C-1 airplane was followed by a similar test on the front beam of the same wing cell. The test was carried to failure at a nominal stress amplitude of about 5,700 pounds per square inch, as compared to a nominal stress amplitude of about 8,500 pounds per square inch for the first test. After about

2,900,000 cycles one flange parted with a sharp report at a section where a rib attachment had been riveted to the flange. Several other cracks were found in the same flange, and a large crack was found in the web just outside one terminal attachment. Comparison of the stress history with the endurance curve of similar material indicated a stress concentration factor of about 3.7. This is considerably higher than the stress concentration factor of about 3 derived for the first test, and indicates that the fatigue limit of the fabricated structure may be well below one-third the fatigue limit of the material, perhaps as low as a nominal stress of 4,000 pounds per square inch.

Two complete sets of BF2C–1 wings have been supplied by the Navy Department for the fatigue tests. The wing beams have been removed from these wings, and a method of cutting them has been devised which will give eight wing-beam specimens of sufficiently uniform section for the tests. It is planned to test these specimens at different amplitudes of nominal stress in order to obtain a sufficient number of values of stress against cycles to failure to draw a S–N curve for the fabricated wing beam, which may then be compared with the S–N curve of the wing-beam material. The first of these eight specimens is being set up for test in the fatigue machine.

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 law provides that the members shall include two representatives each from the War and Navy Departments and one each from the Smithsonian Institution, the Weather Bureau, and the National Bureau of Standards, together with not more than eight additional persons "who shall be acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." One of these eight is a representative of the Bureau of Air Commerce of the Department of Commerce. 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 21, 1937, Dr. Joseph S. Ames was reelected Chairman for the ensuing year and Dr. David W. Taylor was reelected Vice Chairman.

Dr. Joseph S. Ames resigned as Chairman of the Executive Committee in April 1937, a position he had filled continuously since October 9, 1919. At the meeting held on April 22, 1937, Dr. Willis Ray Gregg, Chief of the Weather Bureau, was elected to fill out Dr. Ames' unexpired term as Chairman of the Executive Committee. At the meeting held on October 21, 1937, Dr. Gregg was elected Chairman of the Executive Committee for the ensuing year and Dr. William P. MacCracken Vice Chairman of the Executive Committee. Dr. David W. Taylor had served as Vice Chairman of the Executive Committee since that position was created in 1927. He remains Vice Chairman of the main Committee.

During the past year there was one change in the membership of the main Committee. Dr. Fred D. Fagg, Jr., who had succeeded Honorable Eugene L. Vidal as Director of Air Commerce of the Department of Commerce, was, on April 23, 1937, appointed by the President to succeed Mr. Vidal as a member of the National Advisory Committee for Aeronautics.

The executive offices of the Committee, 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 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 1,475 new submissions. It conducted the necessary correspondence and granted interviews as requested by the inventors. Approximately six 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

In continuation of the plan initiated as a result of recommendation of the Federal Aviation Commission, a special allotment of $25,000 was made available from the Committee's funds during the fiscal year 1937 for aeronautical research in educational institutions. Under this allotment eleven contracts were made during the year with five universities and technical schools, for 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 made the preceding year have been published by the Committee, while others have supplied information of value as a basis for further research either at the Committee's laboratory or elsewhere. The papers received under contracts which have been published by the Committee include one technical report and three technical notes. In addition, one paper has been issued in advance confidential form to American manufacturers.

COOPERATION WITH THE AVIATION INDUSTRY

The Committee, in the preparation of its program of research, makes provision for the requirements of the aviation industry as to problems to be investigated, both in connection with design and operation. The aircraft manufacturers and operators bring their problems to the Committee's attention as they arise, either by correspondence or by personal contacts and informal conferences. Advantage is taken by the Committee of every opportunity to obtain suggestions and recommendations from representatives of the industry as to investigations which are of particular importance to them. When the need arises in connection with any particular problem of the industry it is the policy of the Committee to call a special conference, or, as previously stated, to establish a special subcommittee, including in either case representation from the industry.

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 aeronautics. 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.

Some of the subjects on which results have been released in this manner during the past year are the prevention of ice formation on propellers; the characteristics of related forward camber airfoils, from tests in the variable-density wind tunnel; the characteristics of tapered wings having N. A. C. A. mean lines; the characteristics of tandem air propellers, as investigated by Stanford University under contract with the Committee; wing-fuselage interference, including in the first report a comparison of conventional and airfoil-type fuselage combinations, and in the second report the characteristics of thirty combinations, from tests in the variable-density wind tunnel; transparent plastics for use on aircraft, as investigated by the National Bureau of Standards for the Committee; tricycle-type landing gears, including three phases of the subject—first, accelerations in landing, second, factors affecting the geometrical arrangement; and third, the stability of castering wheels; and the characteristics of tapered wings with ordinary ailerons and partial-span split flaps, as determined in wind-tunnel investigation.

Annual research conference.—As an important aid in keeping in close contact with the problems and needs of the aviation industry, the Committee holds each May at its laboratories at Langley Field an aircraft engineering research conference with representatives of aircraft manufacturers and operators. This conference was initiated in 1926, and has two principal purposes, as follows: First, to enable representatives of the industry to obtain first-hand information on the Committee's research facilities and the results obtained in its investigations; and, second, to afford them an opportunity to present to the Committee their suggestions for investigations to be included in the Committee's research program.

Owing to the large number of those who desired to attend, the conference for the past two years has been held on two days, the same program of discussions and demonstrations being followed both days. The dates of the 1937 conference were May 18 and 20.

Acting under authorization of Dr. Joseph S. Ames, Chairman of the National Advisory Committee for Aeronautics, who was prevented by illness from being present, Honorable Edward P. Warner, a member of the Committee and Chairman of the Committee on Aerodynamics, served as Chairman of the conference on May 18; and on May 20 Dr. Willis Ray Gregg, Chairman of the Executive Committee of the National Advisory Committee for Aeronautics, was Chairman. The Committee was represented on both days by officers and members, and on May 18 also by its Committees on Aerodynamics and Power Plants for Aircraft, and on the 20th by its Committee on Aircraft Structures and Materials and Subcommittee on Structural Loads and Methods of Structural Analysis.

At the morning session each day the principal investigations under way at the laboratory, both in aerodynamics and power plants, were explained by the engineers in charge of the work, and charts were exhibited showing some of the results obtained. The guests were then conducted on a tour of inspection of the laboratory and the research equipment was shown in operation.

In the afternoon six simultaneous conferences were held for the discussion of six different subjects, namely, airplane performance and design characteristics, aerodynamic efficiency and interference, cowling and cooling research, aircraft-engine research, seaplanes, and rotorplanes. At these conferences the results of the Committee's researches were presented in further detail, and suggestions were submitted by the representatives of the industry for problems to be added to the Committee's program. Each of these suggestions, according to its nature, was referred to the Committee on Aerodynamics, the Committee on Power Plants for Aircraft, or the Subcommittee on Structural Loads and Methods of Structural Analysis and was considered by that committee in the preparation of the research program being carried on under its cognizance.

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, during the past year there has been a major change in the organization of the Committee's standing technical committees. The Committee on Aircraft Structures and Materials, which was one of the three principal technical committees, and two of its subcommittees, the Subcommittee on Structural Loads and Methods of Structural Analysis and the Subcommittee on Research Program on Monocoque Design, were discharged, and two new standing committees, the Committee on Aircraft Materials and the Committee on Aircraft Structures, were established, each with a status coordinate with that of the Committee on Aerodynamics and the Committee on Power Plants for Aircraft. The Subcommittee on Metals Used in Aircraft and the Subcommittee on Miscellaneous Materials and Accessories were retained as subcommittees of the new Committee on Aircraft Materials.

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

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

COMMITTEE ON AERODYNAMICS

Hon. Edward P. Warner, Chairman.
Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.
Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.
Dr. L. J. Briggs, National Bureau of Standards.
Theophile dePort, Matériel Division, Army Air Corps, Wright Field.
Lt. Comdr. W. S. Diehl, United States Navy.
Dr. H. L. Dryden, National Bureau of Standards.
Lt. Col. O. P. Echols, Air Corps, United States Army, Matériel Division, Wright Field.
Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.
Lt. Comdr. L. M. Grant, United States Navy.
Dr. Willis Ray Gregg, United States Weather Bureau.
Lawrence V. Kerber, Bureau of Air Commerce, Department of Commerce.
Delbert M. Little, United States Weather Bureau.
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.
Dr. David W. Taylor.
Dr. A. F. Zahm, Division of Aeronautics, Library of Congress.

SUBCOMMITTEE ON AIRSHIPS

Hon. Edward P. Warner, Chairman.
Starr Truscott, National Advisory Committee for Aeronautics, Vice Chairman.
Dr. Karl Arnstein, Goodyear-Zeppelin Corporation.
Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.
Commander Garland Fulton, United States Navy.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Ralph H. Upson, Ann Arbor, Mich.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Dr. Willis Ray Gregg, United States Weather Bureau, Chairman.
Dr. W. J. Humphreys, United States Weather Bureau.
Dr. J. C. Hunsaker, Massachusetts Institute of Technology.
Dr. George W. Lewis, National Advisory Committee for Aeronautics (ex officio member).
Delbert M. Little, United States Weather Bureau.
Dr. Charles F. Marvin.
Lt. Comdr. F. W. Reichelderfer, United States Navy, Naval Air Station, Lakehurst.
Dr. C. G. Rossby, Massachusetts Institute of Technology.
Maj. B. J. Sherry, United States Army, Signal Corps, War Department.
Eugene Sibley, Bureau of Air Commerce, Department of Commerce.

SUBCOMMITTEE ON SEAPLANES

Capt. H. C. Richardson, United States Navy, Chairman.
Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.
Theophile dePort, Matériel Division, Army Air Corps, Wright Field.
Lt. Comdr. W. S. Diehl, United States Navy.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

Jack T. Gray, Bureau of Air Commerce, Department of Commerce.

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

Lt. Comdr. A. O. Rule, United States Navy.

Starr Truscott, National Advisory Committee for Aeronautics.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Dr. William P. MacCracken, Chairman.

Dr. George W. Lewis, National Advisory Committee for Aeronautics, Vice Chairman.

Lt. Comdr. Rico Botta, United States Navy.

Dr. H. C. Dickinson, National Bureau of Standards.

John H. Geisse, Bureau of Air Commerce, Department of Commerce.

Carlton Kemper, National Advisory Committee for Aeronautics.

Gaylord W. Newton, Bureau of Air Commerce, Department of Commerce.

Maj. E. R. Page, Air Corps, United States Army, Matériel Division, Wright Field.

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

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Dr. H. C. Dickinson, National Bureau of Standards, Chairman.

Lt. Comdr. Rico Botta, United States Navy.

Dr. O. C. Bridgeman, National Bureau of Standards.

Lt. Comdr. James V. Carney, United States Navy.

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, Bureau of Air Commerce, Department of Commerce.

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.

Maj. H. Z. Bogert, Air Corps, United States Army, Matériel Division, Wright Field.

S. K. Colby, Aluminum Co. of America.

Lt. Comdr. C. F. Cotton, United States Navy.

Edgar H. Dix, Jr., American Magnesium Corporation.

Warren E. Emley, National Bureau of Standards.

Comdr. Garland Fulton, United States Navy.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

Jack T. Gray, Bureau of Air Commerce, Department of Commerce.

C. H. Helms, National Advisory Committee for Aeronautics.

J. B. Johnson, Matériel Division, Army Air Corps, 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.

Hon. Edward P. Warner.

SUBCOMMITTEE ON METALS USED IN AIRCRAFT

H. S. Rawdon, National Bureau of Standards, Chairman.

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.

John Vitol, Bureau of Air Commerce, Department of Commerce.

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.

John Easton, Bureau of Air Commerce, Department of Commerce.

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.

Richard C. Gazley, Bureau of Air Commerce, Department of Commerce.

Lt. Comdr. L. M. Grant, United States Navy.

Maj. C. F. Greene, Air Corps, United States Army, Matériel Division, 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).

Eugene E. Lundquist, National Advisory Committee for Aeronautics.

Lt. Comdr. R. D. MacCart, United States Navy.

Prof. Joseph S. Newell, Massachusetts Institute of Technology.

Dr. Walter Ramberg, National Bureau of Standards.

Richard V. Rhode, National Advisory Committee for Aeronautics.

Edward I. Ryder, Bureau of Air Commerce, Department of Commerce.

R. L. Templin, Aluminum Company of America.

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

Hon. Edward P. Warner.

COMMITTEE ON AIRCRAFT ACCIDENTS

Hon. Edward P. Warner, Chairman.

Lt. J. F. Greenslade, United States Navy.

Maj. E. V. Harbeck, Jr., Air Corps, United States Army.

J. W. Lankford, Bureau of Air Commerce, Department of Commerce.

Dr. George W. Lewis, National Advisory Committee for Aeronautics.

Lt. Comdr. A. O. Rule, United States Navy.

J. T. Shumate, Bureau of Air Commerce, Department of Commerce.

Maj. Lowell H. Smith, Air Corps, United States Army.

COMMITTEE ON AERONAUTICAL INVENTIONS AND DESIGNS

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

Dr. Willis Ray Gregg, United States Weather Bureau.

Capt. S. M. Kraus, United States Navy.

Brig. Gen. A. W. Robins, Air Corps, United States Army. Matériel Division, Wright Field.

Dr. David W. Taylor.

John F. Victory, Secretary.

COMMITTEE ON PUBLICATIONS AND INTELLIGENCE

Dr. Joseph S. Ames, Chairman.

Dr. Willis Ray Gregg, United States Weather Bureau, Vice Chairman.

Miss M. M. Muller, Secretary.

COMMITTEE ON PERSONNEL, BUILDINGS, AND EQUIPMENT

Dr. Joseph S. Ames, Chairman.

Dr. David W. Taylor, Vice Chairman.

Dr. Willis Ray Gregg, United States Weather Bureau.

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.

577. Prechamber Compression-Ignition Engine Performance. By Charles S. Moore and John H. Collins, Jr., N. A. C. A.
578. Flight Measurements of the Dynamic Longitudinal Stability of Several Airplanes and a Correlation of the Measurements with Pilots' Observations of Handling Characteristics. By Hartley A. Soulé, N. A. C. A.
579. A Study of the Two-Control Operation of an Airplane. By Robert T. Jones, N. A. C. A.
580. Heat Transfer to Fuel Sprays Injected into Heated Gases. By Robert F. Selden and Robert C. Spencer, N. A. C. A.
581. Measurements of Intensity and Scale of Wind-Tunnel Turbulence and Their Relation to the Critical Reynolds Number of Spheres. By Hugh L. Dryden, G. B. Schubauer, W. C. Mock, Jr., and H. K. Skramstad, National Bureau of Standards.
582. A Theory for Primary Failure of Straight Centrally Loaded Columns. By Eugene E. Lundquist and Claude M. Fligg, N. A. C. A.
583. The Rolling Friction of Several Airplane Wheels and Tires and the Effect of Rolling Friction on Take-Off. By J. W. Wetmore, N. A. C. A.
584. Strength of Welded Aircraft Joints. By W. C. Brueggeman, National Bureau of Standards.
585. Span Load Distribution for Tapered Wings with Partial-Span Flaps. By H. A. Pearson, N. A. C. A.
586. Airfoil Section Characteristics as Affected by Variations of the Reynolds Number. By Eastman N. Jacobs and Albert Sherman, N. A. C. A.
587. Blower Cooling of Finned Cylinders. By Oscar W. Schey and Herman H. Ellerbrock, Jr., N. A. C. A.
588. Fuel Spray and Flame Formation in a Compression-Ignition Engine Employing Air Flow. By A. M. Rothrock and C. D. Waldron, N. A. C. A.
589. An Analysis of Lateral Stability in Power-Off Flight with Charts for Use in Design. By Charles H. Zimmerman, N. A. C. A.
590. Pressure-Distribution Measurements on an O-2H Airplane in Flight. By H. A. Pearson, N. A. C. A.
591. An Analytical and Experimental Study of the Effect of Periodic Blade Twist on the Thrust, Torque, and Flapping Motion of an Autogiro Rotor. By John B. Wheatley, N. A. C. A.
592. Full-Scale Tests of N. A. C. A. Cowlings. By Theodore Theodorsen, M. J. Brevoort, and George W. Stickle, N. A. C. A.
593. Cooling of Airplane Engines at Low Air Speeds. By Theodore Theodorsen, M. J. Brevoort, and George W. Stickle, N. A. C. A.
594. Characteristics of Six Propellers Including the High-Speed Range. By Theodore Theodorsen, George W. Stickle, and M. J. Brevoort, N. A. C. A.
595. Full-Scale Tests of a New Type N. A. C. A. Nose-Slot Cowling. By Theodore Theodorsen, M. J. Brevoort, George W. Stickle, and M. N. Gough, N. A. C. A.
596. Cooling Tests of a Single-Row Radial Engine with Several N. A. C. A. Cowlings. By M. J. Brevoort, George W. Stickle, and Herman H. Ellerbrock, Jr., N. A. C. A.
597. Air Propellers in Yaw. By E. P. Lesley, George F. Worley, and Stanley Moy, Stanford University.
598. Alternating-Current Equipment for the Measurement of Fluctuations of Air Speed in Turbulent Flow. By W. C. Mock, Jr., National Bureau of Standards.
599. Flight Tests of the Drag and Torque of the Propeller in Terminal-Velocity Dives. By Richard V. Rhode and Henry A. Pearson, N. A. C. A.
600. An Analysis of the Factors That Determine the Periodic Twist of an Autogiro Rotor Blade, with a Comparison of Predicted and Measured Results. By John B. Wheatley, N. A. C. A.
601. Torsion Tests of Tubes. By Ambrose H. Stang, Walter Ramberg, and Goldie Back, National Bureau of Standards.
602. Wind-Tunnel and Flight Tests of Slot-Lip Ailerons. By Joseph A. Shortal, N. A. C. A.
603. Wind-Tunnel Investigation of Wings with Ordinary Ailerons and Full-Span External-Airfoil Flaps. By Robert C. Platt and Joseph A. Shortal, N. A. C. A.
604. Pressure-Distribution Measurements at Large Angles of Pitch on Fins of Different Span-Chord Ratio on a 1/40-Scale Model of the U. S. Airship "Akron." By James G. McHugh, N. A. C. A.

605. Résumé and Analysis of N. A. C. A. Lateral Control Research. By Fred E. Weick and Robert T. Jones, N. A. C. A.
606. Electrical Thermometers for Aircraft. By John B. Peterson and S. H. J. Womack, National Bureau of Standards.
607. Spinning Characteristics of the XN2Y-1 Airplane Obtained from the Spinning Balance and Compared with Results from the Spinning Tunnel and from Flight Tests. By M. J. Bamber and R. O. House, N. A. C. A.
608. Stress Analysis of Beams with Shear Deformation of the Flanges. By Paul Kuhn, N. A. C. A.
609. Experimental Investigation of Wind-Tunnel Interference on the Downwash behind an Airfoil. By Abe Silverstein and S. Katzoff, N. A. C. A.
610. Tests of Related Forward-Camber Airfoils in the Variable-Density Wind Tunnel. By Eastman N. Jacobs, Robert M. Pinkerton, and Harry Greenberg, N. A. C. A.
611. Wind-Tunnel Investigation of Tapered Wings with Ordinary Ailerons and Partial-Span Split Flaps. By Carl J. Wenzinger, N. A. C. A.

LIST OF TECHNICAL NOTES ISSUED DURING THE PAST YEAR

No.

582. Analysis and Model Tests of Autogiro Jump Take-Off. By John B. Wheatley and Carlton Bioletti, N. A. C. A.
583. Mixture Distribution in a Single-Row Radial Engine. By Harold C. Gerrish and Fred Voss, N. A. C. A.
584. Effect of Several Factors on Cooling of a Radial Engine in Flight. By Oscar W. Schey and Benjamin Pinkel, N. A. C. A.
585. Mechanical Properties of Aluminum-Alloy Rivets. By Wm. C. Brueggeman, National Bureau of Standards.
586. The Reduction of Aileron Operating Force by Differential Linkage. By Robert T. Jones and Albert I. Nerken, N. A. C. A.
587. The Forces and Moments on Airplane Engine Mounts. By Philip Donely, N. A. C. A.
588. Strain Measurements on Small Duralumin Box Beams in Bending. By Paul Kuhn, N. A. C. A.
589. Theoretical Span Loading and Moments of Tapered Wings Produced by Aileron Deflection. By H. A. Pearson, N. A. C. A.
590. Hydrodynamic Tests in the N. A. C. A. Tank of a Model of the Hull of the Short Calcutta Flying Boat. By Kenneth E. Ward, N. A. C. A.
591. Full-Scale Span Load Distribution on a Tapered Wing with Split Flaps of Various Spans. By John F. Parsons and Abe Silverstein, N. A. C. A.
592. A Study of the Factors Affecting the Range of Airplanes. By David Biermann, N. A. C. A.
593. Pressure Drop in Tubing in Aircraft Instrument Installations. By W. A. Wildhack, National Bureau of Standards.
594. Tank Tests of Two Models of Flying-Boat Hulls to Determine the Effect of Ventilating the Step. By John R. Dawson, N. A. C. A.
595. Bending Tests of Circular Cylinders of Corrugated Aluminum-Alloy Sheet. By Alfred S. Niles, John C. Buckwalter, and Warren D. Reed, Stanford University.
596. Full-Scale Wind-Tunnel and Flight Tests of a Fairchild 22 Airplane Equipped with a Zap Flap and Zap Ailerons. By C. H. Dearborn and H. A. Soulé, N. A. C. A.
597. Notes on the Calculation of the Minimum Horizontal Tail Surface for Airplanes Equipped with Wing Flaps. By Hartley A. Soulé, N. A. C. A.
598. Wind-Tunnel Tests of a Clark Y Wing with "Maxwell" Leading-Edge Slots. By William E. Gauvain, N. A. C. A.
599. Charts Expressing the Time, Velocity, and Altitude Relations for an Airplane Diving in a Standard Atmosphere. By H. A. Pearson, N. A. C. A.
600. Discharge Characteristics of a Double Injection-Valve Single-Pump Injection System. By Dana W. Lee and E. T. Marsh, N. A. C. A.
601. The Lateral Instability of Deep Rectangular Beams. By C. Dumont and H. N. Hill, Aluminum Company of America.
602. Heat Transfer from Cylinders Having Closely Spaced Fins. By Arnold E. Biermann, N. A. C. A.
603. A Preliminary Study of Flame Propagation in a Spark-Ignition Engine. By A. M. Rothrock and R. C. Spencer, N. A. C. A.
604. Full-Scale Wind-Tunnel and Flight Tests of a Fairchild 22 Airplane Equipped with External-Airfoil Flaps. By Warren D. Reed and William C. Clay, N. A. C. A.
605. Noise from Propellers with Symmetrical Sections at Zero Blade Angle. By A. F. Deming, N. A. C. A.
606. Empirical Corrections to the Span Load Distribution at the Tip. By H. A. Pearson, N. A. C. A.
607. The Behavior of Thin-Wall Monocoque Cylinders Under Torsional Vibration. By Robert E. Pekelsma, University of Michigan.
608. Free-Spinning Wind-Tunnel Tests of a Low-Wing Monoplane with Systematic Changes in Wings and Tails. I—Basic Loading Condition. By Oscar Seidman and A. I. Neihouse, N. A. C. A.
609. Considerations Affecting the Additional Weight Required in Mass Balance of Ailerons. By W. S. Diehl, Bureau of Aeronautics, Navy Department.
610. Effect of Air-Entry Angle on Performance of a 2-Stroke-Cycle Compression-Ignition Engine. By Sherod L. Earle and Francis J. Dutee, N. A. C. A.
611. The Sonic Altimeter for Aircraft. By C. S. Draper, Massachusetts Institute of Technology.
612. Spinning Characteristics of Wings. III—A Rectangular and a Tapered Clark Y Monoplane Wing with Rounded Tips. By M. J. Bamber and R. O. House, N. A. C. A.
613. The Effect of Curvature on the Transition from Laminar to Turbulent Boundary Layer. By Milton Clauser and Francis Clauser, California Institute of Technology.
614. Fuselage-Drag Tests in the Variable-Density Wind Tunnel: Streamline Bodies of Revolution, Fineness Ratio of 5. By Ira H. Abbott, N. A. C. A.
615. Motion of the Two-Control Airplane in Rectilinear Flight after Initial Disturbances with Introduction of Controls Following an Exponential Law. By Alexander Klemin, New York University.

LIST OF TECHNICAL MEMORANDUMS ISSUED DURING THE PAST YEAR

No.

805. General Considerations on the Flow of Compressible Fluids. By L. Prandtl. Paper presented at Volta meeting in Italy, September 30 to October 6, 1935.
806. The Question of Spontaneous Wing Oscillations (Determination of Critical Velocity through Flight-Oscillation Tests). By B. v. Schlippe. From Luftfahrtforschung, February 20, 1936.
807. Torsion and Buckling of Open Sections. By Herbert Wagner. From the 25th anniversary number of the Technische Hochschule, Danzig 1904–1929.

808. High-Speed Wind Tunnels. By J. Ackeret. Paper presented at the fifth convention of the Volta Congress, Italy, September 30 to October 6, 1935.
809. Tests for the Determination of the Stress Condition in Tension Fields. By R. Lahde and H. Wagner. From Luftfahrtforschung, August 20, 1936.
810. Impact of a Vee-Type Seaplane on Water with Reference to Elasticity. By F. Weinig. From Luftfahrtforschung, May 20, 1936.
811. The Impact on Floats or Hulls During Landing as Affected by Bottom Width. By E. Mewes. From Luftfahrtforschung, May 20, 1936.
812. The Horsepower of Aircraft Engines and Their Maximum Frontal Area. By Michel Precoul. From L'Aéronautique, No. 207, August 1936.
813. The Cetene Scale and the Induction Period Preceding the Spontaneous Ignition of Diesel Fuels in Bombs. By M. N. Michailova and M. B. Neumann. From Comptes Rendus (Doklady) de l'Academie des Sciences de l'URSS, Vol. II (XI), No. 4 (90), 1936.
814. Experimental Studies of the Effective Width of Buckled Sheets. By R. Lahde and H. Wagner. From Luftfahrtforschung, July 20, 1936.
815. Automatic Stabilization. By Fr. Haus. From L'Aéronautique, March 1936.
816. The Gyroplane—Its Principles and Its Possibilities. By Louis Breguet. From Journees Techniques Internationales de l'Aéronautique, November 23–27, 1936.
817. The Stress Distribution in Shell Bodies and Wings as an Equilibrium Problem. By H. Wagner. From Luftfahrtforschung, September 20, 1936.
818. Valve-Spring Surge. By Willy Marti. Federal Polytechnic Institute of Zurich. 1935.
819. Experimental Apparatus for the Study of Propellers. By M. Panetti. From Experimental reports by the Aeronautical Laboratory of the Royal Engineering Institute of Turin, series 1.
820. Some Experiments on the Slipstream Effect. By C. Ferrari. From Experimental reports by the Aeronautical Laboratory of the Royal Engineering Institute of Turin, series 2.
821. On the Actual Loads on Airplane Landing Gears. By S. Shiskin. From Report No. 269, of the Central Aero-Hydrodynamical Institute, Moscow, 1936.
822. Turbulent Boundary Layer of an Airfoil. By K. Fediaevsky. From Report No. 282, of the Central Aero-Hydrodynamical Institute, Moscow, 1936.
823. Experimental Investigation of the Problem of Surface Roughness. By H. Schlichting. From Ingenieur-Archiv, February 1936.
824. The Photoelastic Investigation of Three-Dimensional Stress and Strain Conditions. By G. Oppel. From Forschung auf dem Gebiete des Ingenieurwesens, September–October 1936.
825. The Source of Propeller Noise. By W. Ernsthausen. From Luftfahrtforschung, December 20, 1936.
826. The Scale Effect in Towing Tests with Airplane-Float Systems. By Rudolph Schmidt. From Luftfahrtforschung, July 20, 1936.
827. Helicopter Problems. By H. G. Küssner. From Luftfahrtforschung, January 20, 1937.
828. Ground Effect—Theory and Practice. By E. Pistolesi. From Pubblicazioni della R. Scuola d'Ingegneria di Pisa, series 6, July 1935.
829. Method of Curved Models and Its Application to the Study of Curvilinear Flight of Airships. Part I. By G. A. Gourjienko. From Central Aero-Hydrodynamical Institute, Moscow, Report No. 182, 1934.
830. Method of Curved Models and Its Application to the Study of Curvilinear Flight of Airships. Part II. By G. A. Gourjienko. From Central Aero-Hydrodynamical Institute, Moscow, Report No. 182, 1934.
831. Contributions to the Theory of Incomplete Tension Bay. By E. Schapitz. From Luftfarhrtforschung, March 20, 1937.
832. The Critical Velocity of a Body Towed by a Cable from an Airplane. By C. Koning and T. P. DeHaas. From Rijks-Studiedienst voor de Luchtvaart, Amsterdam, Report A 367.
833. The Apparent Width of the Plate in Compression. By Karl Marguerre. From Luftfahrtforschung, March 20, 1937.
834. The Stability of Orthotropic Elliptic Cylinders in Pure Bending. By O. S. Heck. From Luftfahrtforschung, March 20, 1937.
835. Pressure Distribution on a Wing Section with Slotted Flap in Free Flight Tests. By Georg Kiel. From Luftfahrtforschung, February 20, 1937.
836. The Ground Effect on Lifting Propellers. By A. Betz. From Zeitschrift für angewandte Mathematik und Mechanik, April 1937.
837. Charts for Checking the Stability of Plane Systems of Rods. By K. Borkmann. From Luftfarhrtforschung, February 20, 1937.
838. The Strength of Shell Bodies—Theory and Practice. By H. Ebner. From Luftfahrtforschung, March 20, 1937.

LIST OF AIRCRAFT CIRCULARS ISSUED DURING THE PAST YEAR

No.

205. The Hafner A.R.III Gyroplane (British). From Flight, February 18, 1937.
206. Armstrong Whitworth 27 "Ensign" Commercial Airplane (British). An All-Metal High-Wing Monoplane. From Flight, January 7, and April 1, 1937.
207. Baynes Bee Light Airplane (British). A Two-Seat High-Wing Monoplane. From The Aeroplane, March 17, 1937; and Flight, March 11, and March 18, 1937.
208. The Airspeed "Oxford" Training Airplane (British). A Two-Engine Cantilever Monoplane. From The Aeroplane, June 23, and July 28, 1937; and Flight, April 29, and July 1, 1937.

FINANCIAL REPORT

The general appropriation for the National Advisory Committee for Aeronautics for the fiscal year 1937, as contained in the Independent Offices Appropriation Act approved March 19, 1936, was $1,158,850. A supplemental appropriation of $1,367,000 was made available in the First Deficiency Appropriation Act, fiscal year 1936, approved June 22, 1936, for the same purposes specified in the Committee's regular appropriation act for 1936, to continue available until June 30, 1937, and providing for expenditure of not to exceed $1,100,000 for the construction and equipment of an additional wind tunnel (19-foot pressure tunnel), and not to exceed $267,000 for increasing the length of the seaplane model testing tank and for additional equipment therefor. The total amount available for general expenditure during the fiscal year 1937, therefore, was $2,525,850. The amount expended and obligated was $2,337,638, itemized as follows:

Personal services	$928,337
Supplies and materials	71,788
Communication service	3,053
Travel expenses	14,464
Transportation of things	2,742
Furnishing of electricity	36,258
Repairs and alterations	4,639
Special investigations and reports	80,744
Equipment	381,519
Structures	814,094
Expended and obligated	2,337,638
Unobligated balance	188,212
Total, general appropriation	2,525,850

The appropriation for printing and binding for 1937 was $18,700, of which $18,679 was expended.

The sum of $19,689 was received during the fiscal year 1937 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 $12,073, was deposited in the Treasury to the credit of Miscellaneous Receipts.

The amount of the regular appropriation for the fiscal year 1938 is $1,259,850, as provided in the Independent Offices Appropriation Act approved June 28, 1937. 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 shall 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 $186,-968. The total amount available for general expenditure during the fiscal year 1938, therefore, is $1,899,818. In addition, the amount of $21,000 was appropriated for printing and binding for the fiscal year 1938.

An allotment of $7,350 was received from the State Department for payments during the fiscal year 1937 to employees stationed abroad, on account of exchange losses due to appreciation of foreign currencies, and of this amount $2,866 was paid during the fiscal year to employees of the Committee stationed in the Paris Office, leaving a balance of $4,484 turned back into the Treasury.

Of the allotment of $2,000 for participation in the Greater Texas and Pan American Exposition, which opened at Dallas, Texas, June 12, 1937, the amount of $404 was expended and obligated as at June 30, 1937.

CONCLUDING STATEMENT

The greatly extended use of aircraft for both military and civil purposes has been reflected in an increased activity on the part of progressive nations in extending their aeronautical research facilities. The demands made upon the Committee by the War, Navy, and Commerce Departments for new information are increasing in number and in difficulty with the increase in the speed and size of aircraft. The Committee fully recognizes its enlarged responsibility to make provision not only to take care of research needs arising from current problems, but also to look well into the future and to anticipate the needs that will arise as a result of the trend toward the construction of much larger landplanes and seaplanes.

The Committee is grateful to the President and to the Congress for the earnest consideration and support that have been given to its needs, and urges the continued support of this most fundamental activity of the Federal Government in connection with aeronautics.

Respectfully submitted,

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