

THIRTY-THIRD ANNUAL REPORT
OF THE
NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

1947

INCLUDING TECHNICAL REPORTS
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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 Thirty-third Annual Report of the Committee covering the fiscal year ended June 30, 1947.

HARRY S. TRUMAN.

THE WHITE HOUSE,
FEBRUARY 25, 1948.

Letter of Submittal

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
Washington, D. C., February 20, 1948.

DEAR MR. PRESIDENT: In compliance with the provisions of the act of Congress approved March 3, 1915 (U. S. C. Title 49, Sec. 243), I have the honor to submit herewith the Thirty-third Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1947.

The Committee's activities reflect the fact that aeronautical science is still undergoing a technical revolution which started during World War II with the advent of new means of aircraft propulsion. The new developments assure sufficient power to achieve flight of piloted aircraft at supersonic speeds. Extensive scientific research is necessary to develop fully the possibilities of such new engines as the turbo propeller, the turbojet, the ram jet, and the rocket. Concurrent with their development, it appears that basically new shapes of airplanes may be required for safe and efficient flight at supersonic speeds. Wings must be thinner, stronger, and lighter, and probably must be swept back sharply so that in plan form they may resemble arrows. The stability and control of such aircraft at supersonic speeds and at low speeds necessary for take-off and landing present whole new fields for scientific research.

The recent trend of world events makes it increasingly evident that the efforts of the United States to promote peace will be strengthened by leadership in air power. Air power requires an air force in being, supported by an adequate aircraft industry, with constant progress built upon the foundation of advanced scientific research.

Leadership in research, essential to supremacy in the air, can be attained by any nation willing to make the effort. We must make whatever effort is necessary to assure that leadership for the United States.

Respectfully submitted.

JEROME C. HUNSAKER,
Chairman.

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



GEORGE W. LEWIS
RESEARCH CONSULTANT TO THE COMMITTEE AND PAST DIRECTOR OF
AERONAUTICAL RESEARCH

Dr. George W. Lewis

Past Director of Aeronautical Research

Effective September 1, 1947, Dr. George W. Lewis resigned as Director of Aeronautical Research and was appointed Research Consultant to the Committee. He was succeeded as Director of Aeronautical Research by Dr. Hugh L. Dryden, formerly Associate Director of the National Bureau of Standards.

Dr. Lewis assumed the direction of the Committee's research activities in 1919 with the title Executive Officer, and in 1924 he was appointed Director of Aeronautical Research. He was awarded the Daniel Guggenheim Medal in 1936 for "outstanding success in the direction of aeronautical research and for the development of original equipment and methods." In 1937 he was appointed by President Roosevelt as plenipotentiary delegate of the United States to the Inter-American Technical Aviation Conference in Lima, Peru. He delivered the Wilbur Wright Memorial Lecture before the Royal Aeronautical Society in London in 1939 on the subject, "Some Modern Methods of Research in the Problems of Flight." He was awarded the Spirit of St. Louis Medal of the American Society of Mechanical Engineers in 1945. He has been active in scientific and engineering societies, and has served on a number of boards of award for aeronautical medals, contests, and trophies. He has been honored by election to the National Academy of Sciences, by the award of two degrees of Doctor of Engineering, and by a Life Membership in the National Aeronautic Association. He served as an official emissary of the United States Government in inspecting aeronautical research activities in various European countries, notably Germany and Russia, before the war.

At a meeting of the NACA Executive Committee held on August 11, 1947, at which the resignation of Dr. Lewis as Director of Aeronautical Research was announced, the members unanimously adopted the following testimonial:

DOCTOR GEORGE WILLIAM LEWIS
DIRECTOR OF AERONAUTICAL RESEARCH

Resolved, That the members of the National Advisory Committee for Aeronautics do adopt and approve the following tribute to Doctor Lewis.

Since November 1919, Doctor Lewis has directed the activities of the Committee in the exercise of its prescribed function to "supervise and direct the scientific study of the problems of flight with a view to their practical solution." He entered

the service of the Committee a year after the Armistice of World War I, at a time when the organization had only one small wind tunnel and a staff of 43 employees, and at a time when the people generally felt that "the war to end wars" had been won, and disarmament was the national policy. At that time the major European nations had surpassed the United States in contributions to aeronautical science, civil and commercial aviation were virtually non-existent, and the potential military significance of aircraft had been barely demonstrated.

With great executive and professional ability, with patience and understanding, Dr. Lewis has inspired young physicists, engineers, and mathematicians entering the Committee's service, and has developed a research staff of outstanding technical competence numbering to date about 6,000 employees, including many recognized leaders in specialized branches of aeronautical science. He developed the Committee's three major research stations with a plant value of about 90 million dollars. With broad vision of the growing research needs of aviation and with high professional courage, he pioneered in the design and construction of novel research equipment and is responsible for the introduction of new methods of flight research and for the original use of variable density wind tunnels, full-scale wind tunnels, refrigerated wind tunnels, free-flight wind tunnels, gust tunnels, and high-speed wind tunnels. He also pioneered in the design and construction of new facilities for propeller research, seaplane research, structural research, and power plant research.

Under his inspiring leadership, the Committee's research organization has won the confidence and respect of the military services, of the aircraft industry, and of the aeronautical world, and made scientific and technical contributions of inestimable value to the national security.

We are particularly happy that Dr. Lewis will be able to continue his invaluable advice and assistance as Research Consultant.

Resolved further, That the Chairman be authorized to present this Testimonial to Dr. Lewis with our heart-felt thanks for all he has done for the Committee and our congratulations for 28 years of exceptionally meritorious service to his country.



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National Advisory Committee for Aeronautics

Headquarters, 1724 F Street NW, Washington 25, D. C.

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 49, sec. 241). 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.

JEROME C. HUNSAKER, Sc. D., Massachusetts Institute of Technology, *Chairman*

ALEXANDER WETMORE, Sc. D., Secretary, Smithsonian Institution, *Vice Chairman*

HON. JOHN R. ALISON, Assistant Secretary of Commerce.
VANNEVAR BUSH, Sc. D., Chairman, Research and Development Board, Department of National Defense.
EDWARD U. CONDON, Ph. D., Director, National Bureau of Standards.
DONALD B. DUNCAN, Vice Admiral, Deputy Chief of Naval Operations (Air).
R. M. HAZEN, B. S., Chief Engineer, Allison Division, General Motors Corp.
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THEODORE C. LONNQUEST, Rear Admiral, Assistant Chief for Research and Development, Bureau of Aeronautics, Navy Department.

EDWARD M. POWERS, Major General, United States Air Force, Deputy Chief of Staff, Matériel.
ARTHUR E. RAYMOND, M. S., Vice President, Engineering, Douglas Aircraft Co.
FRANCIS W. REICHELDERFER, Sc. D., Chief, United States Weather Bureau.
CARL SPAATZ, General, Chief of Staff, United States Air Force.
ORVILLE WRIGHT, Sc. D., Dayton, Ohio.
THEODORE P. WRIGHT, Sc. D., Administrator of Civil Aeronautics, Department of Commerce.

HUGH L. DRYDEN, Ph. D., *Director of Aeronautical Research*

JOHN F. VICTORY, LL.M., *Executive Secretary*

JOHN W. CROWLEY, JR., B. S., *Associate Director of Aeronautical Research*

E. H. CHAMBERLIN, *Executive Officer*

HENRY J. E. REID, D. Eng., Director, Langley Memorial Aeronautical Laboratory, Langley Field, Va.

SMITH J. DEFRANCE, B. S., Director, Ames Aeronautical Laboratory, Moffett Field, Calif.

EDWARD R. SHARP, LL. B., Director, Flight Propulsion Research Laboratory, Cleveland Airport, Cleveland, Ohio

TECHNICAL COMMITTEES

AERODYNAMICS

POWER PLANTS FOR AIRCRAFT

AIRCRAFT CONSTRUCTION

OPERATING PROBLEMS

SELF-PROPELLED GUIDED MISSILES

INDUSTRY CONSULTING

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.

AMES AERONAUTICAL LABORATORY,
Moffett Field, Calif.

FLIGHT PROPULSION RESEARCH LABORATORY,
Cleveland Airport, Cleveland, Ohio

Conduct, under unified control, 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

THIRTY-THIRD ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Washington, D. C., November 24, 1947.

To the Congress of the United States:

In accordance with the act of Congress, March 3, 1915 (U. S. C. title 49, sec. 241), which established the National Advisory Committee for Aeronautics, the Committee submits herewith its thirty-third annual report for the fiscal year 1947.

The urgency of the aeronautical research program stems from its relation to the national defense. The most powerful military weapon of today, the atomic bomb, is largely dependent for its effectiveness upon aircraft capable of delivering the bomb to its target in the face of intelligent opposition.

An adequate national program of aeronautical research and development is essential to national security. Aeronautical development is still in the technical revolution inaugurated during the war through the application of new forms of propulsion systems—the turbo-propeller, the turbo-jet, the ram-jet and the rocket engine—and through their application to aircraft in an effort to achieve flight at supersonic speeds.

The turbo-prop provides means for attaining relatively good fuel economies and high power outputs without the complication inherent in the high-powered reciprocating engine. The turbo-jet provides means for attaining high power outputs in small packages at speeds above which the propeller becomes inefficient. The ram-jet provides means for attaining relatively good fuel economies at speeds one and a half times that of sound or higher. The rocket provides means for realizing tremendously high powers in a small engine and for realizing powers independent of altitude.

Of these four basic engine types only the turbo-jet and the rocket are at present used for service airplanes and the rocket only for assisted take-off. Much research and development is required to bring all these engines to the state of usefulness of which they are inherently capable. Our military aviation program either for man-carrying aircraft or for guided missiles is predicated on the use of these engines. Their development through adequate research must be carried forward.

Flight at supersonic speeds by practical, manned airplanes is the goal of research and development in this country and elsewhere. There is no scientific reason why such a goal cannot be attained. It will be attained by the nation or nations that make the required effort. Speed is the most valuable single characteristic of military aircraft. Superior speed is virtually essential to supremacy in the air and to our national security. During the war the top speed of our fighters was 400 to 450 miles per hour, of our bombers 250 to 325 miles per hour. Now both fighters and bombers which will fly faster are in service. The present world speed record of 650 miles per hour is 83 percent of the speed of sound. These speeds are not enough if we are to maintain air supremacy. We must assure that this nation acquires the basic research knowledge which will make possible the higher speeds.

In time of peace scientific research is the first line of defense. The country that leads in aeronautical research will be able to construct the best aircraft. An adequate research and development program necessitates fundamental scientific research, applied research, and engineering development. The United States has been outstanding and has rapidly taken the leadership in applied research and in development, but it has contributed less than its due proportion to pure science. On the applied research and development of the immediately preceding years rests the success of our aircraft, and this applied research and development in turn rests on the preceding basic research.

Fundamental research requires time. Wars are fought with weapons based on fundamental principles discovered during the years of peace. Money invested in research buys that irreplaceable commodity—time.

Research conducted with the objective of improving military aircraft is applicable to civil aviation. In general the research results are first applied to military aircraft and after further practical experience and development to civil aircraft. Such a procedure is sound both from the standpoint of passenger safety and of economical operation. The basic objectives of both military and civil aviation are the same—to carry greater loads faster and farther. Consequently the

basic research is the same for both. There are differences in certain fields—passenger comfort, combat speeds, maneuverability and so forth. Research in these special fields must be directed toward the particular use of the airplane.

Because of the great costs and manpower requirements of modern aeronautical research and development there is greater need than ever before for nation-wide teamwork in planning the country's aeronautical future. This need for teamwork led to the statement of the National Aeronautical Research Policy, dated March 21, 1946, which defines the relationship between various governmental agencies and the aircraft industry with regard to aeronautical research and development. This policy was approved by the Army Air Forces, Navy Bureau of Aeronautics, Civil Aeronautics Administration, NACA Industry Consulting Committee, and the NACA. The Committee's field of activity is fundamental research in the aeronautical sciences directed toward solution of the problems of flight. Research of the NACA is not considered complete until results are tested by sufficient practical application. NACA research does not include the development of specific aircraft or equipment.

To assist in the discharge of its duties and in the determination of present and future research needs, the Committee has established an Industry Consulting Committee and standing technical committees on aerodynamics, power plants, operating problems and construction. The members of these committees serve as such without compensation and are specially qualified representatives of the government agencies concerned, and experts from private life.

The committees recommend, prepare, and review the research programs. Although most of the problems so recommended for investigation are assigned to the Committee's laboratories, certain problems are assigned to other governmental agencies when it is to the advantage of the Government to do so, and other problems are assigned by research contracts to scientific and educational institutions in order to utilize the special skills and facilities available at such institutions.

Large gains in quality of aircraft performance are possible of accomplishment through intensive efforts; these gains are beyond and above the normal rate of progress in other fields in which the technology is relatively stable and advances are made more slowly.

National security requires that expenditures for aeronautical research and development be expanded.

The Committee submits the following recommendations for action by the Congress:

1. That the membership of the National Advisory Committee for Aeronautics be increased from fifteen to seventeen to permit the appointment by the President of two additional members from the ranks of science. These additional members are needed in order to strengthen the voice of science in the deliberations of the Committee and to provide members who will be available to assume responsibilities of scientific leadership and, particularly to serve as chairmen of major technical committees.

2. That, paralleling the action of the Congress at its last session with respect to the Army, the Navy, and the Air Force, the National Advisory Committee for Aeronautics be authorized to pay not exceeding \$15,000 a year for 15 positions on its staff. This increase in pay above the present ceiling of \$10,000 a year for a limited number of positions is required in order to secure or retain the services of outstanding scientists and to improve the service at all levels by inducing outstanding personnel in the lower grades to make a career of Government service.

3. That the Congress make available special funds for the construction or modernization of research facilities the need for which in the rapidly-advancing science of aeronautics could not be foreseen at the time of the preparation of the regular annual estimates. It is proposed that such funds be available for starting without delay any urgent project which has the approval of the NACA and the Director of the Bureau of the Budget, within the limits of the authority the Congress may see fit to grant, and subject to the requirement that the NACA report fully to the Congress on the expenditure of such funds.

It is estimated that this authority will save some 8 to 18 months' time in the development and application by the military services and the aircraft industry of new design factors that will improve the performance and military effectiveness of America's aircraft; and that it will not cost any additional money but, on the contrary, will actually effect minor savings.

Respectfully submitted.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
J. C. HUNSAKER, *Chairman.*

Part I

TECHNICAL ACTIVITIES

Research of the National Advisory Committee for Aeronautics is conducted for the most part at its three laboratories—Langley Memorial Aeronautical Laboratory, Langley Field, Va.; Ames Aeronautical Laboratory, Moffett Field, Calif.; and Flight Propulsion Research Laboratory, Cleveland, Ohio. A station has been established at Wallops Island, Va., as a branch of the Langley laboratory for conducting research on models in flight in the transonic and supersonic range. A second station has been established at Muroc Lake, Calif., for research on transonic and supersonic airplanes in flight.

In addition to the research conducted at these five establishments, research is also contracted for by the Committee at the National Bureau of Standards, at various universities and at various nonprofit but privately operated research organizations.

In order to carry out effectively its functions of conducting the supervising, the National Advisory Committee for Aeronautics has established a group of technical committees and subcommittees. The organization of these committees includes representation from the Department of National Defense, from various other governmental agencies concerned with aeronautics, and representatives from civil life. All members are chosen because of their particular knowledge in a specific field of the aeronautical sciences. These technical committees act as coordinating agencies, providing effectively for the interchange of ideas and for the prevention of duplication in the field of aeronautical research. There are six main committees under the National Advisory Committee for Aeronautics:

1. Committee on Aerodynamics.
2. Committee on Power Plants for Aircraft.
3. Committee on Aircraft Construction.
4. Committee on Aircraft Operating Problems.
5. Special Committee on Self-Propelled Guided Missiles.
6. Industry Consulting Committee.

The original purpose of the Special Committee on Self-Propelled Guided Missiles was to coordinate and recommend NACA research related to self-propelled guided missiles. A review was made of NACA work

in progress and a research program was recommended. The original program has been completed, and NACA research in this field has evolved primarily into the study of high-speed aerodynamics, stability and control, and propulsion. The original purpose of the special committee was considered fulfilled, and the special committee has recommended that it be dissolved.

The Industry Consulting Committee consists of representatives from industry. The purpose of this committee is to advise the NACA on the problems in aeronautical research in which the aviation industry is most interested.

The research conducted by the Committee results either from recommendations of its main committees and subcommittees or from the requests originating from the Department of National Defense, and other branches of the Government.

The research conducted by the Committee can be described most easily by referring to the various phases of the work that come under the cognizance of the different committees and subcommittees.

Most of the work done in the Committee's laboratories is of a classified nature and consequently can be referred to only briefly in this unclassified annual report.

AERODYNAMIC RESEARCH

Because of the many related but specialized phases of aerodynamic research, the Committee on Aerodynamics is assisted by Subcommittees on High-Speed Aerodynamics, Stability and Control, Internal Flow, Vibration and Flutter, Propellers for Aircraft, Helicopters, Seaplanes, and the Special Subcommittee on the Upper Atmosphere. The main function of the committee during the past year has been to review the proceedings and recommendations of these subcommittees with a view to their proper coordination in an overall program for aerodynamic research.

The programs directly under the cognizance of the various subcommittees are discussed in other parts of this report. There are, however, a number of investigations with which the Aerodynamics Committee has been directly concerned. These investigations are reviewed in the sections immediately following.

COMMITTEE ON AERODYNAMICS

Airfoils

As an aid to design, recent data for the NACA 6-, 7-, 00-, 14-, 24-, 44-, and 230-series airfoils, obtained both in wind-tunnels tests and in flight, have been collected and insofar as possible correlated in a Wartime Report, NACA ACR L5C05. The general method used to derive the basic thickness forms for NACA 6- and 7-series airfoils and their corresponding pressure distributions are presented together with data and methods for rapidly obtaining the approximate pressure distributions for NACA airfoils. The report also includes an analysis of the aerodynamic characteristics of the airfoils, data on high-lift devices, and discussions of problems associated with lateral-control devices, leading edge air intakes, interference, and surface condition. The data indicate that the effects of surface condition on the lift and drag characteristics are at least as large as the effects of airfoil shape. As a consequence, airfoils permitting extensive laminar flow, such as the NACA 6-series airfoils, have much lower minimum drag coefficients than earlier types of airfoils only if the wing surfaces are sufficiently smooth and fair. It is shown that the NACA 6-series airfoils have favorable critical-speed characteristics and present no unusual problems associated with the application of high-lift and lateral-control devices.

Because of the important influences of surface roughness and surface irregularities on wing drag, available data, principally obtained from tests in the Langley two-dimensional low-turbulence tunnels, on the drag characteristics of practical-construction wings have been summarized in Technical Note 1151. The data presented show that the construction irregularities usually existing with production wings are such that the differences in drag usually associated with airfoils of different series are not obtained. In fact, it appears that where spar joints, de-icer boots, or surface unfairnesses occur in regions of normally laminar flow, the section drag coefficients may in some cases be twice as great as those for the smooth and fair basic airfoils. It was found that combinations of glazing, painting, and minor repairing of the surfaces of production wings were usually sufficient to produce section drag characteristics approaching those for the fair and smooth basic airfoils. Distortion due to aerodynamic loading was found to cause important increases in section drag for one case investigated.

The trailing-edge cusps which are characteristic of the NACA 6-series sections present a difficult structural problem for airfoil sections less than about 12 percent thick, particularly if the point of minimum pressure is far forward. In order to facilitate wing construction,

a new series of sections, designated the NACA 6A-series, was designed without these cusps. Basic thickness forms of NACA 6-series sections were derived with the position of minimum pressure at 30-, 40-, and 50-percent chord and with thickness ratios varying from 6 to 15 percent and are presented in Technical Note 1368. The results of an investigation in the Langley two-dimensional low-turbulence pressure tunnel of a number of these airfoils indicate little difference in the aerodynamic characteristics of NACA 6- and 6A-series airfoils.

High-Lift Devices

A considerable amount of research has been done in the past to provide efficient high-lift flaps. The recent trend toward the use of thin sections for high-speed airplanes has necessitated the continuance and intensification of this research. As a part of this program, an investigation was conducted in the Langley low-turbulence tunnel to determine the optimum maximum lift positions of double slotted flaps for the NACA 63-210, 64-208, 64-210, 641-212, 65-210, 66-210, and 1410 airfoils at a Reynolds number of 2,400,000. Maximum lift coefficients as high as 3.0 were measured on configurations incorporating the NACA 641-212 and 1410 airfoils. The maximum lift coefficient decreased as the position of minimum pressure was moved to the rear or as the airfoil-thickness ratio was decreased. Increasing the Reynolds number from 2,400,000 to 6,000,000 increased the maximum lift coefficient in all cases, but above 6,000,000, generally, the increase had little effect or decreased the maximum lift coefficient.

In order to extend the range of information about flaps suitable for use with thin wing sections, an NACA 65 (112)-111 airfoil section equipped with a 35-percent-chord slotted flap was tested in the Langley two-dimensional low-turbulence tunnels. A correlation of the Reynolds number results so obtained indicated that the maximum section lift coefficient increased with increase in Reynolds number up to about 13,000,000 and generally decreased with increase in Reynolds numbers between 13,000,000 and 25,000,000. Leading-edge roughness was found to cause approximately the same decrement in maximum section lift coefficient regardless of whether the flap was extended or retracted.

Wing Characteristics

A study of available foreign and American data relating to Reynolds number effects on the maximum lift coefficient of swept-back wings has been made by the Langley full-scale tunnel staff. The data show that at low Reynolds numbers higher maximum lift coefficients were obtained for moderately swept-back wings than for unswept wings of similar plan form. At high Reynolds numbers, however, increasing the sweepback decreased

the maximum lift coefficients. A smaller rate of increase of the maximum lift coefficient with Reynolds number was measured for the swept-back wings than that for similar unswept wings in the critical range of Reynolds number. Increasing the Reynolds number resulted in decreasing the maximum lift coefficient for the two wings of approximately triangular plan form that were investigated.

A method for calculating wing characteristics at subsonic speeds by lifting-line theory, using nonlinear section-lift data, is described in Technical Note 1269. In order to minimize the time involved in calculation and to enable a relatively inexperienced person to follow the procedure, simplified computing forms are given and their use is illustrated by a detailed example. The method is also applicable to the use of linear section-lift data, with a subsequent reduction in computing time as compared with most existing methods.

The characteristics of three wings of aspect ratio 9 and of NACA 64-210 and 65-210 airfoil sections, with and without washout, were calculated from two-dimensional airfoil data. These calculated characteristics are in excellent agreement with experimental characteristics determined in the Langley 19-foot pressure tunnel.

An investigation has been conducted in the Langley 19-foot pressure tunnel to determine the maximum lift and stalling characteristics of two thin wings equipped with several types of flaps. Split, slotted, and double-slotted flaps were tested on one wing which has NACA 65-210 airfoil sections and split and double-slotted flaps were tested on the other, which had NACA 64-210 airfoil sections. Both wings had zero sweep, an aspect ratio of 9, and a ratio of root to tip chord of 2.5. At a Reynolds number of 4,400,000 each type of flap increased the maximum lift coefficients of the two wings by increments which were approximately proportional to the flap-neutral value of 1.21 and 1.35 for the NACA 65-210 wing and the NACA 64-210 wing, respectively. The values of maximum lift coefficient for the wings with full-span double slotted flaps were 2.48 and 2.76, which values represent increments of 105 percent of the flap-neutral values. The addition of a representative fuselage or leading-edge roughness was more detrimental to the NACA 64-210 wing, but its values of maximum lift coefficient were still consistently higher than those of the NACA 65-210 wing.

Boundary-Layer Investigations

In Technical Note 1384, a concise nonmathematical review of boundary-layer literature is presented. The contents of the paper, although insufficient for the solution of specific problems, are sufficient for an introduction to the subject of boundary layers. A list of refer-

ence papers is given from which the detailed knowledge necessary for the solution of specific problems can be obtained.

Sinusoidal waves, commonly called laminar boundary-layer oscillations, have been observed in the laminar boundary layer of a rotating disk. These oscillations appeared in a narrow range of Reynolds number below the Reynolds number of transition. Their frequency was approximately a constant times the angular velocity of the disk. This work is reported in Technical Note 1227.

Suction-slot design for the control of turbulent boundary layers has been investigated (Technical Note 1292) with regard to effectiveness both in improving external flow and in minimizing the suction power required. It was found that the boundary layer behind the slot was determined only by the quantity of air removed, provided the slot inlet had rounded edges. The total-pressure losses through the slot were found to be minimized by rounding the inlet edges, inclining the slot, slightly diverging the walls, and providing sufficient slot width for an inlet-velocity ratio of 0.6. The losses remained, however, unaccountably high.

An exploratory investigation of the NACA 64₁-A212 airfoil section equipped with a leading-edge slat, a double slotted flap, and a boundary-layer-control suction slot at 0.40 chord was conducted in the Langley two-dimensional low-turbulence tunnels to study the application of boundary-layer control to wing sections in combination with other high-lift devices. The results of this investigation, which covered a range of Reynolds numbers from 1,000,000 to 6,000,000 over a flow coefficient range from 0 to 0.03, are reported in Technical Note 1293. In general, the maximum section lift coefficient increased and the minimum section drag coefficient decreased with increasing flow coefficients. At a Reynolds number of 3,000,000, and a flow coefficient of 0.03, deflection of the leading-edge slat alone to the optimum position increased the maximum lift coefficient from 1.77 to 2.46; deflection of the double slotted flap alone increased the maximum lift coefficient to 3.12, and deflection of both the leading-edge slat and the double slotted flap increased the maximum lift coefficient to 3.86. For all combinations of high-lift devices tested, the decrease in maximum lift coefficient caused by leading-edge roughness at a Reynolds number of 6,000,000 and a flow coefficient of 0.025 was less than that caused by roughness on the corresponding configuration without boundary-layer control.

The preceding investigation was extended to find the effects of boundary-layer control on the aerodynamic characteristics of the thick NACA 654-421 airfoil section with a boundary-layer control suction slot at 0.45 airfoil chord and a 0.32-airfoil-chord double slotted flap.

Tests were made over a range of flow coefficient from 0 to 0.03 at Reynolds numbers of 1,000,000 and 2,200,000. In the smooth condition at a Reynolds number of 2,200,000, increasing the flow coefficient from 0 to 0.015 increased the maximum lift coefficient from 1.22 to 2.43 with the flap retracted and from 3.07 to 3.81 with the flap deflected. Further increase in flow coefficient resulted in little increase in lift coefficient. In general, between Reynolds numbers of 1,000,000 and 2,200,000, for the range of flow coefficient investigated, increasing the Reynolds number tended to increase the maximum lift coefficient below a flow coefficient of 0.015 and to decrease the maximum lift coefficient between flow coefficients of 0.015 and 0.030. With the flap retracted, increasing the flow coefficient decreased the minimum section drag coefficient and maintained low drag coefficients to high lift coefficients. The drag coefficients equivalent to boundary-layer-control power were greater, however, than the reduction obtained within the range investigated. These results are reported in Technical Note 1395.

The experimental investigation of the stalling and boundary layer-flow characteristics of two NACA 63-series low-drag airfoils, one 18-percent thick and the other 12-percent thick, has been completed at the Ames Laboratory. The results indicated that for the 18-percent-thick wing it should be possible to obtain an appreciable increase in maximum lift through the use of boundary-layer control applied to the rear of the airfoil. This thick airfoil shows a progressive stalling of the flow from the trailing edge forward as the angle of attack for maximum lift is approached. Calculations of the shape parameter of the boundary layer as it varies along the chord for various angles of attack show very good agreement with previous work. Plots of shape parameter along the chord at various angles of attack indicate that the most effective position for the location of the boundary-layer suction slot is near 50-percent wing chord.

In contrast to the 18-percent-thick wing, the boundary-layer surveys on the 12-percent wing show that the shape parameter of the boundary layer never reaches a separation value as the stall is approached. The stalling of the flow over this wing originates at the nose of the airfoil. Analysis of these data indicates that boundary-layer control cannot be used effectively in increasing the maximum lift of the thin wing if the slot is located on the aft portion of the airfoil. In order to improve the maximum-lift coefficient of thin wings through boundary-layer control, it is necessary to provide some means of eliminating the laminar separation which occurs near the leading edge and which results in the complete stalling of the flow over the airfoil.

A new model of the 12-percent-thick airfoil section has been designed and constructed that can incorporate suction slots located near the wing leading edge and on the after portion of the airfoil. Suction slots near the wing leading edge are at present installed on the model and tests are proceeding. Preliminary results indicate that laminar separation has been eliminated or delayed to a higher angle of attack; but the optimum slot location for elimination of the laminar separation has not as yet been determined.

The evolution of the new NACA airfoil sections, such as the NACA 6-series airfoils described in the report summarizing airfoil characteristics depended to a great extent upon the use of testing equipment which provided flow conditions similar to those in flight. Two of the prime requisites for this testing equipment were high Reynolds numbers and low airstream turbulence. Because of the effectiveness of the Langley two-dimensional low-turbulence pressure tunnel in accomplishing these objectives, Technical Note 1283 has been published to give a description of this wind tunnel and a history of the work done at the Langley Memorial Aeronautical Laboratory leading to the achievement of a remarkably low level of airstream turbulence. Emphasis is given to the factors considered and to the physical reasoning which led to the design of the turbulence reducing screens located in the entrance cone of the tunnel. The types of investigations to which the tunnel is suited and the methods of obtaining and correcting data are also discussed.

A similar development, the Ames 12-foot low-turbulence pressure wind tunnel, is discussed in another section of this report.

Extensive tables and charts giving the boundary-induced upwash for yawed lifting lines in closed circular wind tunnels are presented in Technical Note 1265. By suitable combinations of the data, this information can be applied to straight or swept wings, either yawed or unyawed. The data cover a range of both positive and negative sweep angles and also a range of span-diameter ratios.

An investigation, reported in Technical Note 1244, was made to determine the effects of tunnel-wall boundary layer on the load distribution of a wing protruding from the tunnel wall. The results indicated that the boundary layer had a very small effect on total wing lift but that some error in pitching moment particularly for swept wings at high angles of attack, may result from alteration of the load distribution in the vicinity of the tunnel wall.

Recognizing the need for an accurate and simple method for calculating the growth of boundary layers at high speeds, a summary report has been prepared at the Ames laboratory on the results of a theoretical in-

vestigation. The procedures in this report are limited to supercritical Mach numbers.

Aerodynamic Loads on Airplanes

The NACA, in cooperation with the Air Force and the Navy, has begun a long-range investigation of the problems of high-speed flight for conventional and swept-wing airplanes. The United States Air Force and the Navy assumed responsibility for procuring the research airplanes. A number of aircraft are involved in this program, each design varying in certain fundamental parameters including sweep, wing planform, aspect ratio, and power plant. The initial airplanes of this series, the XS-1 and D-558-1, have completed their acceptance tests and are already carrying out research flights at Muroc Air Base.

The XS-1 research airplane was built by the Bell Aircraft Co. under contract to the United States Air Force. It is a single-place airplane of conventional arrangement, having an aspect ratio of 6, and is powered by a liquid oxygen and alcohol rocket engine.

The D-558-1 research airplane was constructed by the Douglas Aircraft Co. under contract to the Bureau of Aeronautics, Navy Department. This airplane is also a single-place aircraft of conventional arrangement, having an aspect ratio of 4, and is powered by a turbojet engine.

Provisions have been made in each airplane in the course of its construction for NACA research instrumentation.

A major function of the research airplanes is to provide information on aerodynamic loads.

Some basic load information has been obtained up to a Mach number of 0.8 on the XS-1 airplane. Horizontal-tail-load data indicate good agreement with values predicted by wind-tunnel tests. The wing-span loading shows no appreciable movement of the center-of-pressure up to a Mach number of 0.8 and the maximum-lift-buffet boundary has the same general shape as that determined on airplanes such as the P-51D. Calibrated electrical strain-gage systems installed on the spars and skin at the roots of the wing and horizontal tail are being used to measure aerodynamic shear forces and bending moments. Later pressure recording instrumentation will be installed for determining wing and tail chordwise loadings.

Preparations have also been made for instrumentation of the D-558-Phase I research airplane for loads measurements. Strain-gage systems and pressure distribution methods are being used for measurement of wing and tail loads. The data obtained complement those being obtained with the XS-1 and together these two research airplanes will provide a complete picture of the aerodynamic loading problem encountered by conventional airplanes operated at transonic speeds.

Aerodynamic Loads on Wings

Considerable theoretical work has been carried out in the past year directed toward making it possible to predict accurately the loads which will occur on wings and other lifting surfaces. A detailed investigation was carried out at the Ames laboratory which dealt with three-dimensional lifting surfaces of various planforms at subsonic and supersonic speeds. The subsonic research was preceded by a theoretical approach to the solution of the differential equations involved. Under the basic assumptions of linearized supersonic theory it was discovered that methods which had previously been applied by mathematical physicists to the wave equation in two space dimensions could be carried over after some modification to the solution of aerodynamic problems. Technical Note 1412, dealing with these methods, discusses the loadings over triangular, trapezoidal, and rectangular planforms, with specified loads and prescribed camber lines. The loading over a yawed triangular wing is also treated.

A method for calculating wing characteristics at subsonic speeds by lifting line theory using non-linear section lift data is described in Technical Note 1269. Distribution of the wing lifting load may be calculated by this method except for wings of low aspect ratio or for wings having large amounts of sweep.

The loading of swept wings has received considerable attention during the past year. The effects of sweepback on loading have been investigated on a comprehensive group of wing planforms, including wings of various sections, aspect ratios, taper ratios, and wings swept forward as well as backward. Experimental span load measurements were compared with those determined by Falkner's method, and it was found that the theory gives a fairly accurate estimate of the span load distribution on a swept wing, except that the load is somewhat underestimated at the tip and somewhat overestimated at the root. This results in a theoretically determined wing bending moment which is somewhat smaller than would actually be experienced. A study was also made of the accuracy and speed with which three different methods could be used to compute the distortion of the span loading of a wing as a result of the angle of sweep. Experimental loads determined for five wings were compared with the span loading predicted by the methods developed by Falkner, Mutterperl, and Weissinger.

Further investigation, reported in Technical Note 1351, covering the span loading on wings having moderate amounts of sweepback and sweepforward, showed that available methods for predicting the span load distributions gave results which were in good agreement with experiment at low and moderate angles of attack. The results also indicated the possibility of large shifts

in the aerodynamic centers of swept wings at high lift coefficients. By means of the Weissinger method for computing span loading of wings, a study has been completed by the Ames Laboratory of the effect of wing sweepback. Some 175 wings were investigated in this study. The results, presented in Technical Note 1491, are in the form of curves which permit the designer knowing only the geometry of a wing, to determine its loading characteristics.

In extending span load investigations to swept wings having high aspect ratios, tests have been made in the Langley 8-foot high-speed tunnel of a high aspect ratio wing, first unswept, then with varying amounts of sweepback and sweepforward.

Pressure distribution measurements are also being made on model wings and bodies by the NACA wing-flow method in order to gain a more detailed insight into the nature of aerodynamic loads at transonic speeds.

Straight wings have not been neglected in the determination of air loadings. The effects of compressibility on many wing sections have been studied, and several reports issued, among them Technical Note 1211, treating five supersonic airfoils and two subsonic airfoils at Mach numbers from 0.3 to 0.9. Wing pressure distributions have also been studied at high lift coefficients and at high Mach numbers. The model in this case was a tapered wing having NACA 230 series sections. A comparison presented in Technical Note 1390 of measured and calculated chord-wise pressure distributions for several stations along the span showed satisfactory agreement for purposes of structural design up to the critical Mach number.

Several flight investigations of aerodynamic loads were also conducted. In extensive dive tests of the XP-51 airplane, studies were made of the pressure distribution measurements over the wing at high Mach numbers. Spanwise load distributions were also determined in flight tests of a YP-80A airplane and compared with computed spanwise values.

Wind tunnel measurements of the airload distribution of a canard-type airplane are reported in Technical Note 1295. Two combinations of lifting surface and fuselage, representing appreciable variation of lifting surface span relative to fuselage diameter, were obtained by removing separately the wing and stabilizer of the model. The results showed that for the configurations tested the spanwise loadings on the combinations agreed fairly well with the loadings calculated by the Lennertz method. With particular reference to triangular wings, Technical Note 1183 presents a simple method utilizing linearized theory for calculating the loading of such wings at supersonic speeds.

As a phase of load studies on wings, studies have also been made of the loads on control surfaces. Tech-

nical Note 1386 presenting the results of an investigation of drooped ailerons on NACA low-drag airfoils, includes the results of pressure distribution measurements over such ailerons for various control locations and deflections as an aid in aileron and flap design.

A detailed knowledge of the airloads over the component parts of double-slotted flaps is required by aircraft structural designers, since a large part of the total lift is carried by these relatively thin surfaces. In order to provide such information for one representative double-slotted flap, a low-speed high Reynolds number investigation was conducted to determine the airloads over a double-slotted flap on an NACA low-drag airfoil section.

Tests of a wing section equipped with a double-slotted flap were conducted in the Langley two-dimensional low-turbulence tunnel to determine the effect of a skirt extension of the slot entry on the lower surface. Aerodynamic loads were determined for the flap and vane with the best skirt extension installed.

Investigations conducted on the P-51D airplane have yielded particularly useful information on the loads imposed on the wing in maneuvering flight. In this investigation the true maximum lift coefficients were measured in abrupt and gradual stalls, and the buffeting boundary was determined in abrupt pull-ups to high Mach numbers. These boundaries determine the maximum loads which would normally be encountered in maneuvering flight with this airplane.

The loads imposed on airplane wings by atmospheric gusts have also been a subject of much research. In the past it has been possible to treat airplanes as rigid structures in the computation of gust loads. With the advent of larger and more flexible airplanes operating at higher speeds, the effects of structural elasticity become important, and it is necessary to determine methods for calculating and evaluating the effects of dynamic response. A method has been developed for predicting the dynamic response of airplane wings to gusts by considering only the fundamental mode of wing bending, and tests have been made in the gust tunnel to verify the method. Calculations have also been made to determine the changes in the aerodynamic response of airplane wings brought about by changes in gust and airplane parameters. The gust tunnel tests served to show that the method is of sufficient accuracy to predict the increment in load for conventional airplanes. The test results also emphasize the need for including aerodynamic damping in calculations of dynamic response of airplane wings. Technical Note 1320 presents the results of these calculations, including the effects of gradient distance, the overstress possible from the usual design gust, the seriousness of repeated gusts, and the effects of change in forward

velocities. Additional work on methods of calculating dynamic response has resulted in an improved method of calculation which has been summarized in Technical Note 1321. An easily evaluated solution of the equations presented is possible, permitting the determination of the response to any forcing function. Satisfactory agreement was found in a comparison of calculated response with experimental results. This method is quicker and more rational than methods previously developed and permits the determination of the entire time history of the dynamic response.

The elasticity of the wing structure is an important factor in that the twist of the wing under the load imposed by the deflection of the control surface may be such as to neutralize or even reverse the effectiveness of the control in obtaining the desired reaction of the airplane. The effects of a spoiler-type lateral control device on the spanwise variation of section twisting moments of an NACA 230-series wing were determined from pressure distributions obtained in the Langley 19-foot pressure tunnel at a Reynolds number of 7,350,000 and a Mach number of 0.25. The results of the investigation, reported in Technical Note 1298, show that the maximum wing twisting moment contributed by the spoilers was obtained at a station approximately 25 percent of the wing semispan inboard of the spoiler. It appears that spoiler-type lateral-control devices will produce smaller wing twisting moments than conventional ailerons.

Aerodynamic Loads on Tails

Considerable information of importance in the determination of the loads occurring on tails has been obtained in the course of studies of airplane wings. The investigation previously reported in the Langley 8-foot high-speed tunnel on a model of a high-aspect ratio wing included a study of the downwash angles of the flow behind that wing, and investigations have been conducted in the Langley 7- by 10-foot tunnel of the downwash angles of flow behind swept wings of various plan forms. Some results are presented in Technical Note 1378. Again the importance of a thorough knowledge of the loads occurring on tail surfaces and control surfaces is pointed out in Technical Note 1296. The effects of surface covering deformation were explored extensively and it was shown that, if deformation could be prevented over a relatively small part of the control surface near the trailing edge, any deformation that occurred ahead of the rigid portion would produce only very small effects on hinge moments.

At Langley tests of a full-scale semispan horizontal tail surface for a jet-propelled fighter airplane have been conducted in the 16-foot high-speed tunnel to determine the variation of the chordwise and spanwise pres-

sure distributions with Mach number. Surface irregularities were found to cause appreciable distortion of the pressure distribution. By elimination of the surface irregularities it is estimated that the critical speed of the tail surface could be raised from a Mach number of 0.77 to 0.80. Reasonable agreement between the calculated and experimental root-bending moment coefficient was obtained up to a Mach number of 0.68.

As a result of flight tests, a report, Technical Note 1122, has been written describing approved methods for estimating the vertical tail loads encountered during various maneuvers. Charts were developed for predicting the sideslip angles in rolling pull-outs. A rolling pull-out is a maneuver which may be encountered particularly in combat flight, and in which large angles of sideslip may be developed, a condition which may be critical for vertical tail design. A simplified expression for computing the maximum vertical tail load was also derived. Since the variation of airplane yawing moment with angle of sideslip may not be linear, an approximate method for treating these cases was developed, which appears to be generally applicable. Another investigation compared the estimated tail loads obtained by simple methods requiring known sideslip and rudder angles with measured values of the loads actually encountered in flight tests.

Technical Note 1394 also contributed to knowledge of the factors which affect the loads and load distribution on the vertical tail surfaces in maneuvers. In the case of rudder kicks the significant loads were found to be the "deflection load" resulting from an abrupt control deflection and the "dynamic load" consisting of load corresponding to the new static equilibrium condition for the rudder deflected, plus a load due to transient overshoot. The critical loads on the rudder were associated with the deflection load and those on the fin with the dynamic load. In fishtail maneuvers it was found that the pilot tended to deflect the rudder in phase with the natural frequency of the airplane. At the condition of resonance the maximum loads on the fin and rudder were approximately 90° out of phase. The maximum loads measured in fishtailing maneuvers were of the same order of magnitude as those arising from a rudder kick in which the rudder was returned to zero at the time of maximum sideslip.

Frequently buffeting loads arising from irregularities of flow streaming off the airplane wing are superimposed on the load which the horizontal tail must carry in order to maneuver the airplane. In connection with the dive tests on the XP-51 airplane, previously reported, studies were made of the airflow behavior over the wing by means of photographs of wool tufts attached to the wing surface. Studies of the buffeting boundary of the P-51D airplane also contributed to

the knowledge of the loads which must be carried by the horizontal tail.

Aerodynamic Loads on Fuselages and Airplane Components

The Ames laboratory has completed an analysis applying the linear perturbation theory to the determination of subcritical pressure distributions over bodies of revolution at zero angle of attack.

As a part of a general investigation of the aerodynamic loads on cockpit enclosures, surface static pressures have been measured over various cockpit canopies of airplanes in the Langley full-scale tunnel. The results of these investigations show the effects of canopy position, yaw, lift coefficient, and propeller operation on canopy-load distribution. The results indicate that the greatest aerodynamic forces on a canopy occur when the airplane is operating at high speed with the canopy closed and that they are in the outward direction. For all attitudes the effect of opening the canopy is to reduce the external-internal pressure differential and, therefore, to reduce the outward forces.

SUBCOMMITTEE ON HIGH-SPEED AERODYNAMICS

Ames 12-Foot Wind Tunnel

The Ames 12-foot wind tunnel, which was dedicated in July 1946, has been placed in operation during the year. This wind tunnel is a low-turbulence tunnel designed so that the density of the air can be varied from one-sixth of an atmosphere to 6 atmospheres. Low turbulence is achieved by means of 8 fine-mesh screens installed in the largest diameter of the wind tunnel, where the area is 25 times that of the 12-foot-diameter test section. The wind tunnel is of the single-return type. The low turbulence of the tunnel, coupled with the ability to obtain a wide range of Reynolds and Mach numbers, makes it a very useful piece of research equipment.

Wings, Bodies, and Wing-Body Interference

The Ackeret iteration process has been utilized to calculate the effect of compressibility at high subsonic speeds on the moment acting on an elliptic cylinder at small lift coefficients. The expression for the pitching moment was derived and showed a first-step improvement in the Prandtl-Glauert rule. The lift force was also derived and showed a second-step improvement in the Prandtl-Glauert rule. With these results it was possible to calculate both the effect of Mach number and the thickness of the cylinder on the location of the center of pressure. This work was reported in Technical Note 1218.

A simple approximate method has been determined

for the calculation of isentropic irrotational flows past symmetrical airfoils, including mixed subsonic and supersonic flows. The method is based on the choice of suitable values for the curvature of the streamline in the flow field. If a satisfactorily accurate estimate of the curvature of the streamline may be made in the portion of the flow being investigated the general method appears applicable to any subsonic- or supersonic-flow problem, which would provide a simple means of calculating conditions in the field of an airfoil. The method may also be applied to bodies of revolution. This investigation was reported in Technical Note 1328.

The analogy between water flow with a free surface and two-dimensional compressible gas flow has been investigated with the aid of water-channel apparatus. Tests were made to determine the flow about circular cylinders of various diameters at subsonic velocities extended into the supersonic range (Technical Note 1185). Reasonably satisfactory agreement of pressure distribution and fields of flow were found between the water and air flow about corresponding bodies.

Several thin sharp-leading-edge airfoils and airfoils with small leading-edge radii were investigated in the Langley rectangular high-speed tunnel. Flow phenomena were observed associated with the small leading-edge radius which has important bearing on the aerodynamic characteristics at transonic speeds of airfoils of this type, which are being considered for some applications. Comparative results show that subsonic drag of the sharp-leading-edge sections was higher than for those airfoils with rounded leading edges. These results were reported in Technical Note 1211.

A theoretical study was made of the lift and drag characteristics of symmetrical wedge-shaped airfoil sections at supersonic speeds as effected by sweep-back outside the Mach cone (Technical Note 1226). Those portions of the wing in two-dimensional flow were treated to determine the effects of sweep-back, Mach number, and thickness ratio. It was shown that under some conditions sweep-back outside the Mach cone increased the lift-drag ratio.

It was known that for a given thickness ratio, neglecting skin friction, the symmetrical diamond-shaped airfoil had the lowest drag at supersonic speeds. In Technical Note 1371 consideration was given to the skin friction drag of two dimensional supersonic airfoils. It was shown that the laminar boundary layer was more stable on biconvex airfoils, than on the diamond-shaped airfoil. Consequently, the curved airfoil had more laminar flow and hence lower viscous drag and also a lower total drag at certain Reynolds numbers and Mach numbers.

Calculations of the supersonic wave drag at zero lift have been made for families of tapered and untapered

wings swept behind the Mach lines, and the sum of the results presented in NACA Technical Note 1319. For a given taper ratio and aspect ratio appreciable reduction in wave drag coefficient with increasing sweepback was found. For a given angle of sweepback wave drag decreased with increasing aspect ratio when the wing was swept well behind the Mach lines. When the Mach lines approached the leading edge the low aspect ratio wings had lower drag coefficients. The calculations for wings on the basis of equal root bending stress showed that the increased aspect ratio associated with wing taper reduced the drag coefficient when the wing was swept well behind the Mach lines and increased the drag coefficient when the Mach lines approached the leading edge; similar comparisons on the basis of constant aspect ratio showed that when the wing was swept behind the Mach lines an increase in the taper resulted in an increase in the drag coefficient, and when the Mach lines approached the leading edge, resulted in a decrease in the drag coefficient.

A simple method utilizing linearized theory was found for calculating the lift and induced drag of triangular wings at supersonic speeds. The slope of the lift curve was found to depend only on the ratio of the leading-edge angle to the Mach number. An appreciable suction force on the leading edge was indicated when the leading edge was behind the Mach line. This work was reported in Technical Note 1183.

A theoretical investigation of the aerodynamic coefficients of two-dimensional supersonic biplane wings indicated that for a given thickness ratio the biplane can have greater lift-drag ratios than the monoplane if friction is neglected. Definite conclusions regarding the relative merits with friction considered could not be drawn due to the lack of experimental data or friction-drag coefficients at supersonic speeds. The maximum friction drag for which the biplane would retain its superiority was estimated, however. This investigation was reported in Technical Note 1316.

A theoretical method has been formulated to evaluate the lift distribution on thin three-dimensional wings at supersonic speeds (Technical Note 1382). The method has been applied to calculate the pressure distribution and to evaluate portions of the flow field in the vicinity of the wing tips at supersonic speeds. The effects of yawing thin pointed wings and related plan forms at supersonic speeds have also been evaluated by the method in Technical Note 1429.

Technical Note 1487 has been prepared, dealing with a theoretical study of the effects of aspect ratio and taper on the pressure-drag of unswept wings at zero lift. On the basis of this investigation nondimensional charts have been derived which permit a rapid estima-

tion of the drag coefficient of any wing at any Mach number.

The Langley Flight Research Division has continued drag measurements at zero lift in the important transonic speed range by means of the freely falling body method described in the previous annual report. In addition to airfoil tests to extend the results reported last year, preliminary results have been obtained on the transonic drag characteristics of wing-body combinations which appeared promising for use as transonic or supersonic aircraft.

Unfavorable interference effects between body and swept wings has been expected on theoretical grounds, since at the juncture of a swept wing with a body the beneficial lateral displacement of the streamlines is ordinarily prevented. There is however, a possibility of shaping the surface of the body at the juncture to accommodate the displacement of the streamlines for a particular lift coefficient and thus to minimize the flow disturbance when the wing is operating at this lift coefficient. In this connection a method for the calculation of the streamline pattern about a swept wing was developed in the Langley Stability Analysis Section. The method and specific examples of the subsonic flow patterns about two particular airfoils are presented in Technical Note 1231. Experimental confirmation is required.

Wind Tunnel Tests of Specific Airplanes

The lift and drag characteristics of the D-558-1 research airplane, with several wing and tail planform configurations, were determined from a preliminary investigation of a model of the airplane in the Langley 8-foot high-speed tunnel at high subsonic Mach numbers.

An experimental investigation was conducted in an Ames supersonic tunnel to determine the aerodynamic characteristics of a fighter airplane. Measurements were made of the lift and drag characteristics, longitudinal and directional stability, and elevator effectiveness.

Aerodynamic Heating

An analytical investigation was made to determine the amount of cooling required to maintain the surface temperatures of a body of revolution at a given value in steady, supersonic flight (Technical Note 1300). An approximate method was developed for determining the cooling requirements in the region of laminar boundary layer on a body of revolution as a function of Mach number, altitude, size, and surface temperature. The method was applied to an example body at Mach numbers up to 3 and altitudes within the lower constant-temperature region of the atmosphere (40,000 to 120,000 feet). For thin, fair bodies, the body length

for a completely laminar boundary layer was estimated as about 50 feet for Mach numbers of about 3 and altitudes of about 100,000 feet. Cooling requirements were found to increase rapidly with increasing Mach number.

High-Speed Boundary Layers and Shock Waves

The large influence of viscous effects at supersonic velocities became apparent during a recent investigation on an airfoil. In order to visualize the flow within the viscous boundary layer, an adaptation of the liquid-film method developed in England by Grey was used. This method utilizes the fact that the rate of evaporation of a liquid from the surface of a model is generally much greater where the boundary layer is turbulent than where it is laminar. The technique employed consisted of, first, coating the model to be tested with dull black lacquer. Immediately prior to installation in the tunnel, the model was given a thin coat of a liquid mixture composed of glycerin, alcohol and a liquid detergent, the glycerin being the actual evaporating agent. With the model mounted in the wind tunnel for testing, force measurements and visual or photographic observations of the boundary layer, as indicated by the liquid film, were made simultaneously. The method allows the determination of the point of transition from laminar to turbulent boundary layer, the position of laminar separation and the areas of separated or reverse flow on wing surfaces. To date, the method has been applied to bodies of revolution, wings, and wing-body combinations, and has been a valuable aid in the interpretation of force measurements.

The theoretical work on the stability of the laminar boundary layer in a compressible fluid, first presented in Technical Note 1115, has been continued and more recent developments reported in Technical Note 1360. It was shown in that report that the Reynolds number at which the laminar boundary layer became unstable to small disturbances was influenced markedly by conditions of heat transfer through the boundary layer. Withdrawing heat from the fluid through the solid surface was found to increase the stability of the laminar layer to disturbances—that is, to increase the Reynolds number at which the boundary layer became unstable—and that conduction of the heat to the fluid through the solid surface has the opposite effect. It was further shown that at supersonic Mach numbers when the rate at which heat is withdrawn from the fluid through the solid surface exceeds a certain critical value the laminar boundary layer is completely stable at all Reynolds numbers. Calculations show that for a free-stream Mach number greater than 3, approximately, the boundary layer flow for thermal equilibrium (where the heat conducted from the flow through the solid surface balances the heat radiated from the surface) is com-

pletely stable at all Reynolds numbers, if the free-stream flow is nonturbulent. Some experimental confirmation of certain of the low-speed conclusions is available; for example, the result that heating a surface (heat conduction to the fluid) causes a reduction in the Reynolds number for transition to turbulent flow has been experimentally observed.

There is experimental evidence that channel flows involving shock-free deceleration through the speed of sound are unstable. An analysis, presented in Technical Note 1225, of nonviscous, unsteady channel flows has been made to gain some insight into this apparent instability, to provide some information on the factors determining the minimum shock intensity for stable flow, and to study in general the formation and motion of shock waves in channel flow. From this study it was concluded that smooth transonic deceleration is unstable to compression pulses or waves coming from the rear of the channel.

SUBCOMMITTEE ON STABILITY AND CONTROL

The Subcommittee on Stability and Control is concerned with all problems affecting the flying and handling qualities of aircraft. With the advent of propulsion units capable of developing thrust sufficient for flight at supersonic speeds there have been radical changes in the basic configuration of aircraft, involving sweepback, low aspect ratio, and new types of airfoils and control surfaces. These changes in configuration have introduced new problems in stability and control over the entire speed range which must be solved before such aircraft can be flown with safety. The research facilities of the Ames and Langley laboratories are therefore extensively engaged in attacks on these problems. Some of the currently completed research in this field forms a part of the present annual report.

Longitudinal Stability

The problems of static longitudinal stability and control and the diving tendencies at high speeds of airplanes having unswept wings have been analyzed by the Ames Aeronautical Laboratory. The analysis covers the effects of compressibility on both the stick-fixed and stick-free characteristics of airplanes up to high subsonic Mach numbers. A further study of the problem of stability and control at high subsonic speeds includes a current analysis of the effects of wing aspect ratio and tail location.

With the objective of determining further the feasibility of predicting flight characteristics with reasonable accuracy, from tests of small-scale three-dimensional airplane models, an investigation has been conducted to determine longitudinal stability and con-

control characteristics of a scale model of a jet airplane in the Ames 1- by 3½-foot high-speed wind tunnel.

As a further aid in the determination of the stability and trim characteristics of complete airplanes, downwash angles have been measured behind a model of a high-aspect-ratio wing at points near the probable tail location at high subsonic Mach numbers in the Langley 8-foot high-speed tunnel.

A further study of downwash behind swept wings was made in the Langley 7- by 10-foot tunnel to determine effects of wing planform. The results presented in Technical Note 1378 indicated that the maximum rate of change of downwash with angle of attack occurred in the regions normally occupied by the horizontal tail. In general, the rate of change of downwash with angle of attack was reduced by lowering the tail to the extended chord line or by increasing the tail length.

In connection with a basic research study of the low-speed stability and control problems associated with swept wings, investigations are being conducted in the Langley free-flight tunnel on several proposed United States Air Forces and Navy swept-wing airplanes that are considered typical of current design trends. Both tailless and conventional designs having sweepforward and sweepback (including triangular planform) are being investigated for the purpose of determining, and finding solutions for, the low-speed stability and control problems of practical design swept-wing airplanes.

A preliminary investigation made in the Langley 300-mile-per-hour 7- by 10-foot tunnel to determine the low-speed characteristics in pitch of a 60° sweptback, tapered, low-drag wing of aspect ratio 2.55 is reported in Technical Note 1284. Because of undesirably large changes in the pitching-moment characteristics of the 60° swept wing, several modifications were made to the wing in an attempt to improve these characteristics. The maximum-lift coefficient of the sweptback wing was about the same as that of the wing with panels rotated to give an unswept planform. Decreasing the aspect ratio of the swept wing from 2.55 to 1 improved the pitching-moment characteristics, particularly in the high-lift coefficient range.

In order to determine the effect of Reynolds number at low speeds on the wing configurations for high speeds, a series of investigations have been conducted in the Langley 19-foot pressure tunnel, the Langley full-scale tunnel, and the Ames 40- by 80-foot wind tunnel. Wing planforms incorporating various airfoil sections and both sweepforward and sweepback have been studied. In a part of the program the effects of a fuselage on the characteristics of the wing configurations have been investigated. The investigations also included

tests of extensible leading edge flaps and various trailing edge flap combinations. A combination of leading edge flaps or slats over the outer portion of the wing and trailing edge slat flaps over the inner portion of a sweptback wing produced a reasonable maximum-lift coefficient and longitudinally stable characteristics at the stall.

The characteristics of a moderately sweptback wing with various arrangements of lift and trim flaps were investigated and have been reported in Technical Note 1352. The results of flap lift increments and flap spans and chords necessary for trim were generally in good agreement with predictions based on an earlier analytical investigation. The experimental results indicated that under some conditions it may be advantageous to locate the lift flap some distance forward of the wing trailing edge.

Experimental research on the stability and control characteristics of various airplane configurations under conditions simulating rolling, yawing, and pitching motions is being performed by means of the rolling and curved-flow facilities of the Langley stability tunnel. The information obtained should provide a basis for a marked improvement in the accuracy with which airplane motions can be predicted. Tests reported in Technical Note 1309 have established the validity of the rolling-flow method for determining characteristics in roll. The investigation shows that important changes may occur in the rolling characteristics of swept wings at high lift coefficients. These changes are not easily predictable by theory, since they seem to be associated with the break-down of potential-flow characteristics.

The results of tests made to determine the effect of wing-tip tanks on lateral maneuverability are presented in Technical Note 1317. This report shows that the use of some wing-tip tank arrangements on straight wings may cause appreciable losses in lateral maneuverability. Tanks located below the wing tips are shown to cause a smaller loss in lateral maneuverability than tanks located out from the wing tips.

An investigation reported in Technical Note 1351 of the span loading on wings having moderate amounts of sweepback and sweepforward showed that available methods for predicting the span-load distributions gave results which were in good agreement with experiment at low and moderate angles of attack. The results also indicated the possibility of large shifts in the aerodynamic centers of swept wings at high lift coefficients.

An investigation was made in the Langley 7- by 10-foot tunnel to determine the effect of wing position, power, and full-span flaps on the longitudinal stability and control characteristics of a single-engine airplane. The results of the longitudinal-stability investigation

with a low-wing model are reported in Technical Note 1239 and the high-wing-model results are presented in Technical Note 1339. Deflecting the flaps on the low-wing model increased the longitudinal stability slightly. The effect of power on longitudinal stability was small except for an erratic effect with single slotted flaps and at very high lift coefficients with double slotted flaps. With the wing in the high position, flap deflection generally decreased the stability slightly. The stability was appreciably higher for all flap conditions with power-off for the high-wing model than for the low-wing model, but the effects of power were generally destabilizing.

Lateral and Directional Stability

Tests made on specific aircraft models during the war indicated the need for a rational method for the prediction of the lateral stability of aircraft. Existing information on the effects of various airplane components on lateral stability needed considerable analysis for proper evaluation, and appeared to be inadequate.

An analysis of existing information on dihedral effect has been undertaken at the Ames laboratory with a view toward evolving a satisfactory method for the estimation of the dihedral effect of a complete airplane. This study indicated the need for additional analytical and experimental information for both straight and swept-back configurations.

An investigation was made in the Langley 7- by 10-foot tunnel to determine the effect of wing position, power, and full-span flaps on the lateral stability and control characteristics of a single-engine airplane. The results of the lateral stability investigation with the low-wing model are reported in Technical Note 1327 and the high-wing model results are presented in Technical Note 1379. Power decreased the dihedral effect on the low-wing model regardless of flap condition and the double-slotted-flap configuration showed the most marked decrease. Raising the wing to the high position slightly increased the effective dihedral, power-off with flaps neutral, and decreased the directional stability somewhat, power-off for all flap conditions.

General stability and control research was continued at the Langley full-scale tunnel with an investigation of the factors that affect the rate of change of rolling moment with yaw for a typical fighter-type airplane. The separate effects of propeller operation, of the wing-fuselage combination, and of the vertical tail on the effective dihedral of the airplane were determined.

As a portion of a program to study the characteristics of swept wings at large scale, a study has been made in the Ames 40- by 80-foot wind tunnel of the damping in roll of swept wings. Five large-scale wings were tested on the rolling stand. Using the experimental results as a basis, a theoretical procedure was developed to pre-

dict the damping-in-roll characteristics of swept wings which appears as good as that used in the case of unswept wings. From these results it would appear that the designer can satisfactorily find the damping-in-roll of his swept-wing design without additional experimentation.

Recent stability calculations have indicated that it is necessary to include product of inertia terms in the lateral stability equations in order to determine accurately the damping of the lateral oscillation. When the effects of product of inertia are taken into account the problem of attaining satisfactory lateral stability with highly swept wings does not appear as serious as had previously been expected. A systematic investigation with several models in the Langley free-flight tunnel has provided a comprehensive check of the calculations and has indicated conclusively the need for inclusion of effect of product of inertia in lateral stability calculations. The results of this study are reported in Technical Note 1370.

An investigation to determine the effect of geometric dihedral on the aerodynamic characteristics of a 40° swept-back wing of aspect ratio 3 has been completed in the Langley free-flight tunnel and reported in Technical Note 1169. The results of this investigation indicated that for low and moderate lift coefficients, changes in geometric dihedral from -10° to 10° resulted in a change in the effective dihedral that was about 75 percent as great as that obtained for an unswept wing of aspect ratio 6. For dihedral angles outside the range of -10° to 10°, changes in geometric dihedral produced approximately one-half the change in effective dihedral as for dihedral angles between -10° and 10°.

As a continuation of the Langley free-flight tunnel research on swept wings, tests have been made to determine the low-speed static stability and damping-in-roll characteristics of three wings having 42° sweepback and aspect ratios of 5.9, 3, and 2, and two wings with 38° sweepforward and aspect ratios of 5.9 and 3. The results of these tests, reported in Technical Note 1286, showed that decreasing the aspect ratio reduced the damping in roll and tended to eliminate the longitudinal instability at the stall of the sweptback wings. Sweepforward produced a maximum value of negative effective dihedral approximately one-half of the positive value produced by sweepback.

Two flight investigations in the free-flight tunnel with models having 42° and 62° sweepback have been made to study the dynamic stability and control characteristics of swept wings. The results of the tests are presented in Technical Notes 1287 and 1282 for the 42° and 62° sweptback models, respectively. In general, both models exhibited the same stability and control characteristics. The dynamic longitudinal stability

was unsatisfactory at intermediate lift coefficients although force test results had indicated satisfactory static stability over this range. The poor flight behavior was believed to be associated with the change in airflow over the wing that caused abrupt changes in the variation of wing pitching moment and model flight-path angle with lift coefficient. The lateral oscillation was predominantly a rolling motion and was fairly well damped over the entire lift range. The very large rolling moment due to sideslip affected the controllability adversely, particularly when the directional stability was low. These results indicated that dihedral and tail design will in some cases be determined more from considerations of controllability than of dynamic lateral stability. Aileron control became weaker with increasing lift coefficient and in the case of the 62° sweptback model was inadequate to maintain satisfactory control at high lift coefficients. At the stall the models dropped without pitching or rolling off which can be accounted for by the fact that these sweptback wings maintained some damping in roll at the stall in contrast to unswept wings which usually auto-rotate at the stall.

A theoretical investigation was made in the Langley Stability Analysis Section to determine the effect of variations in the lateral-stability derivatives, wing loading, altitude, and radii of gyration on the lateral stability boundaries. The results of the investigation indicated that an airplane with a high wing loading designed for high-speed and high-altitude flight would be laterally stable if the moments of inertia, the location of the principal longitudinal axis of the airplane, and the value of the damping in roll derivative C_p were properly selected. Inclination of the principal longitudinal axis of the airplane above the flight path at the nose caused a large stabilizing shift in the oscillatory stability boundary but did not affect the spiral stability boundary. A more complete analysis of this investigation is reported in Technical Note 1282.

Controls

Significant results have been obtained from several control-surface investigations conducted in the Ames 16-foot wind tunnel covering the effects of sweep, trailing-edge contour, and fabric distortion on the hinge moments and effectiveness of control surfaces at high subsonic Mach numbers. An extensive investigation was conducted of control surfaces having shielded and unshielded horn balances. The results of the several investigations emphasize the pronounced and often adverse control-surface characteristics at high speeds which can be caused by relatively small irregularities of control-surface contour, by excessive trailing-edge angle, and by some types of aerodynamic balances.

Analytical studies have been made on the effects of control-surface characteristics on the high-speed longitudinal stability and control of airplanes.

The effects of variations in airfoil thickness-chord ratio and in flap chord upon the effectiveness of plain trailing-edge flaps in controlling lift at speeds approaching that of sound have been investigated in the Ames 1- by $3\frac{1}{2}$ -foot high-speed wind tunnel.

An investigation reported in Technical Note 1228 was made in the Langley two-dimensional low-turbulence pressure tunnel to study the two-dimensional characteristics of a control surface suitable for application to a large modern airplane. The tests were made of a 10.7-percent-thick symmetrical tail section equipped with a 40-percent-airfoil-chord flap designed for use as either a rudder or elevator and incorporating a 20-percent-flap-chord tab. Results indicated the importance of sealing the tab nose gap because of a resultant increase in tab hinge-moment effectiveness and flap lift effectiveness. Sealing the flap nose gap was also beneficial in that it eliminated sharp irregularities in the flap hinge-moment characteristics and large increases in drag that were caused by flow of air through the gap.

Research has continued on the factors that affect the hinge moments of control surfaces and on improved methods of designing control surfaces to obtain satisfactory characteristics. (See Technical Note 1296.) A considerable amount of data on the characteristics of tabs having various aerodynamic balances has been published in Technical Note 1403. Analysis of the results indicated that certain types of balance could be used to advantage on the spring tabs of large airplanes. The use of lifting-surface theory, which has been shown to provide a reliable basis for predicting the hinge moments of finite-span control surfaces from section characteristics, has been extended in Technical Note 1275 to the case of a partial-span elevator.

A collection and analysis of wind-tunnel data on the characteristics of isolated tail surfaces with and without end plates were made and the results are presented in Technical Note 1400. It was found that the values of the lift-curve slope and the elevator lift-effectiveness parameters computed by use of lifting-surface-theory equations agree within about 10 percent of the measured values. For elevators with no cut-outs, a majority of the hinge-moment parameters computed by lifting-surface-theory equations show good agreement with the measured values. The increase in lift-curve slope resulting from tip-located double end plates was determined to be dependent upon the square root of the area of the end plate divided by the airfoil span.

As a part of the program being carried out to correlate section and finite-span data on control surfaces hav-

ing various overhang and trailing-edge balances, tests were made in the Langley 4- by 6-foot vertical tunnel of a plain and a balanced flap having three different trailing-edge angles on a tapered semispan wing of NACA 0009 section. Analysis of the data showed good agreement between the measured values of the lift and hinge-moment parameters and the values calculated from two-dimensional data by lifting-surface theory. The results of this investigation were reported in Technical Note 1248.

An improved method of predicting the control forces of spring-tab ailerons from wind-tunnel data is described in Technical Note 1333. This method does not require that the variations of the aileron and tab hinge-moment coefficients be linear nor does it employ any lengthy process of successive approximations.

One study consisted of a collection of the available test data on lateral controls with full-span flaps. Lateral-control effectiveness and hinge-moment data obtained from two-dimensional, three-dimensional, and flight tests have been collected and included the characteristics of spoiler devices and ailerons with retractable flaps. A discussion is given of the characteristics of the lateral-control devices considered and of the application of the data to specific airplane designs.

A further study, made in the Langley 300 mile per hour 7- by 10-foot tunnel to determine the effect of span, spanwise location, and chordwise location of spoilers on the lateral-control characteristics of a tapered semispan wing has been reported in Technical Note 1294. The results of the investigation indicate that the variation of rolling-moment effectiveness with spoiler span have a trend similar to that for ailerons on a geometrically similar wing. The spanwise yawing-moment effectiveness for ailerons and spoilers showed the same trend with spanwise location; but the spoilers gave favorable yawing moments.

Control surfaces for wing plan forms being considered for supersonic flight have received some attention. At the Ames Laboratory wind-tunnel and wing-flow tests have been made to determine the effectiveness of various types of hinged control surfaces on a wing of triangular plan form.

At the Langley laboratory the 7- by 10-foot tunnel sections have tested various control arrangements on a triangular wing at transonic speeds, with special tunnel apparatus.

In an effort to develop suitable lateral-control devices which permit the use of full-span flaps, an investigation was conducted to determine the practicability of drooped ailerons on NACA low-drag airfoils. The results of this investigation are presented in Technical Note 1386. Section aerodynamic characteristics of an NACA 66 (215-216) ($\alpha=0.6$) airfoil with a slotted

aileron of normal profile and modified nose shape are presented for various aileron locations, hinge centers, and aerodynamic balances. The report also includes the results of pressure-distribution measurements over the ailerons for various control locations and deflections for use as an aid in aileron and flap design. Also included in the report are extensive computations made to determine the lateral-control characteristics of three hypothetical airplanes of widely different sizes assuming drooped ailerons similar to those for the two-dimensional model. These computations indicate that the drooped ailerons can be applied successfully to airplanes with spans ranging from 45 to 141 feet.

Flying Qualities

During the past year, further progress has been made in the extension of flying-qualities investigations into the transonic speed range. Acceptance tests have been completed on the United States Air Forces Bell XS-1 airplane. The object of these tests was to demonstrate the structural integrity of the airplane and to prove that its stability and control characteristics were satisfactory up to a Mach number of 0.8. NACA personnel participated in the tests by evaluating records obtained from NACA recording instruments installed in the airplane, NACA telemetering equipment, and radar tracking equipment. The tests were made in a series of 26 flights with two XS-1 airplanes, and in 14 of these flights, the rocket motor was operated.

Longitudinal stability and control measurements have been made up to a Mach number of approximately 0.8. The stick-fixed and stick-free static longitudinal stability was slightly positive up to the maximum speed tested. The variation of elevator angle and elevator force with normal acceleration in turns and pull-ups was satisfactorily stable. The static directional stability was high at all speeds. All controls were effective up to the highest test speed.

One XS-1 airplane has been assigned to the NACA and a formal research program to obtain aerodynamic data at transonic speeds has been started.

As previously mentioned, the D-558-1 research airplane has been constructed by the Douglas Aircraft Co. under contract to the Bureau of Aeronautics, Navy Department, for use by the NACA in a cooperative program for the exploration of airplane stability and control characteristics and air loads at transonic speeds. This airplane is a single-place aircraft of conventional arrangement and is powered by a turbo-jet engine. The acceptance tests of this airplane were conducted at Muroc Air Base, Calif. NACA observers witnessed these tests, and at their conclusion, two airplanes were assigned to the NACA for comprehensive study.

As an extension of previous research under clear

weather conditions, an investigation was also made of the flying and handling qualities requirements of transport aircraft under blind landing conditions. The importance of complying with current requirements for handling qualities was demonstrated.

A general investigation of servo-mechanisms for use in powering aircraft control surfaces is being conducted in order to determine the effects of various booster parameters on the handling qualities of airplanes. The chief aim of this investigation is to furnish designers with quantitative requirements for control boosters in general. A theoretical analysis of various possible servo-mechanisms was made. This analysis indicated that satisfactory performance could probably be obtained with a control booster which produced a control-surface velocity proportional to the error in position between the control surface and the control stick. In order to check these theoretical results a bench set-up of this booster system was built that simulated flight conditions as closely as possible. The desired motion characteristics were obtained by building the booster system around a variable-displacement pump, the displacement of which could be controlled normally with negligible force. The bench tests indicated that the booster should be satisfactory in all respects. The application of this type of booster mechanism for control of large airplanes and also for control of airplanes operating in the transonic speed range was considered.

During the past year the Flight Research staffs of the Ames and Langley laboratories have undertaken and reported on the determination of the handling characteristics of nine military airplanes. These investigations established the lateral, directional, and longitudinal stability and control characteristics and the stalling characteristics of the airplanes. In a number of cases where deficiencies in the handling characteristics were found, the investigations were extended to provide satisfactory improvement.

Another investigation continuing the work on correlation of the handling characteristics of an airplane measured in flight with those measured on a small-scale model in the Ames 7- by 10-foot wind tunnel has been completed using a high-powered carrier-based dive bomber. The results of this investigation demonstrated again that wind-tunnel tests can show the unsatisfactory conditions of flight, but that better results would be obtained in tests of large scale models.

Spinning

The design requirements for airplane tail surfaces that would provide effective control for satisfactory recovery from fully developed spins of personal-owner-type light airplanes have been determined from an analysis of the characteristics of approximately 60

models previously tested in the Langley spin tunnels. Although these models did not represent actual personal-owner aircraft, they had proportions of mass and dimensional characteristics representative of many airplanes in the personal-owner category. The results of the analysis are presented in Technical Note 1329 which gives an empirical relationship between a tail-design parameter, relative density, and relative mass distribution of the airplane required for satisfactory recovery.

Free-spinning-tunnel tests were performed with a model of a typical fighter-type airplane with 0° and 40° sweepback in the wings to obtain an indication of the effect of sweepback on the spin and recovery characteristics. The results of the tests, presented in Technical Note 1256, indicated that for this model with a tail design considered unsatisfactory as regards spin recovery, sweeping the wings back 40° improved the recovery characteristics appreciably, but that with a tail design considered satisfactory as regards spin recovery, sweeping the wings back had little effect on the recovery characteristics.

To supplement the existing published data on hinge moments of elevators and rudders in spins, hinge-moment measurements were made throughout a range of spinning attitudes on a specific tail configuration mounted on a fuselage. The results of the hinge-moment measurements for balanced elevator equipped with trim tabs and for a balanced rudder are presented in Technical Note 1400. It was found that the elevator hinge moments had normal variation with angle of attack, yaw, and deflection but because of the high angles of attack in spinning attitudes, the elevators had a strong up-floating tendency indicating that push forces would be generally required for all elevator deflections. The elevator balance was not effective in reducing the force required to push the elevator to neutral, but the trim tabs were quite effective in this respect. The rudder balance appeared to be effective in reducing the rudder pedal forces, but the rudder became overbalanced at angles of attack greater than 40°.

Tests were conducted in the Langley 15-foot free-spinning tunnel to determine the effect of horizontal tail position on the hinge moments of an unbalanced rudder in attitudes simulating spinning conditions. It was found that a low rearward position of the horizontal tail gave the smallest hinge moments, whereas a high forward position of the horizontal tail gave the largest hinge moments. Rudder hinge-moment coefficients were shown to decrease with an increase in angle of attack for all horizontal tail positions. It was found that the rate of change of rudder hinge-moment coefficient with rudder deflection was not appreciably affected by the horizontal tail position except in very

flat spins. These results are presented in Technical Note 1337.

In addition, the characteristics of 11 specific military designs were either determined by tests or analysis. Where deficiencies in the spinning characteristics of these designs were found, changes to remedy the deficiencies were investigated and recommended to the military services.

Specific Models

A number of manufacturers' models were investigated in the wind tunnels of the Ames and Langley laboratories for the military services in order to determine the stability and control characteristics of these models. A number of interesting points were brought out through these tests.

An investigation of a $\frac{1}{4}$ -scale powered model of a proposed 175,000-pound, 290-foot-span, all-wing cargo airplane has been made in the Langley full-scale tunnel to provide data for an estimation of the flying qualities of tailless airplanes.

An analytical investigation has been made to determine the relative performance of tailless and conventional airplanes in order to determine whether there is sufficient promise of better performance by tailless airplanes to justify further research on the flying qualities of this type of airplane. Inasmuch as there has been considerable interest in tail-boom type airplanes having only a wing, booms and tails, this type of airplane has also been included in the performance comparison.

In the analysis certain assumptions were made regarding weight, drag and stability which have not been wholly confirmed. The findings must therefore be considered as tentative pending confirmation by additional research. The principal conclusion drawn from this analysis was that large all-wing tailless airplanes may have better performance characteristics than their equivalent conventional airplane or tail-boom airplanes for certain types of missions.

An investigation was conducted on the effect of engine skew on the lateral stability and control characteristics of a single-engine airplane. The results of the investigation, which were made in the Langley 7- by 10-foot tunnel using a $\frac{1}{5}$ -scale model, have been reported. The analysis indicated that the skewed thrust axis was an effective method of overcoming inadequate rudder control for power-on flight at low speeds and that it also had a pronounced effect on aileron deflection required for trim particularly with flaps deflected.

An investigation reported in Technical Note 1210 has shown that slipstream rotation can result in asymmetric forces on a fuselage, even in the absence of wing

and tail surfaces. A fuselage in pitch, for example, experiences a lateral force and a yawing moment, each proportional to the angle of attack. Tests made with various fuselage-propeller combinations yielded results which were in fair agreement with an approximate theory.

Force tests have been made in the Langley free-flight tunnel of two isolated vee-tail surfaces to provide an experimental verification of a simplified vee-tail theory. A summary of these data was first presented in NACA Wartime Report L-212. Because of the recently increased interest in vee tails, the complete force-test results including moment data not previously given have been presented in Technical Note 1369.

SUBCOMMITTEE ON INTERNAL FLOW

New types of power plants for current and proposed high-speed airplanes and self-propelled missiles require the internal handling of many times the quantity of air used by reciprocating engines. Since inefficient handling of large quantities of air would result in serious reductions in the performances of the aircraft, the Subcommittee on Internal Flow has concerned itself during the past year with the aerodynamic problems affecting the efficiency of internal flow systems.

Although internal aerodynamics is a field closely related to the usual external aerodynamics of aircraft, it is characterized by its own special problems, which in many instances require special consideration. Accordingly, the NACA's Langley, Ames, and Cleveland laboratories have undertaken specialized studies of internal flow phenomena in order to provide a basis for practical design of efficient internal flow systems for aircraft.

Wing Inlets

In current airplane designs wing inlets are of considerable interest. To determine the velocity distribution on arbitrary two-dimensional wing-duct inlet shapes, the conformal-mapping method of the Cartesian mapping function was applied. An assumed form of an actual wing-duct inlet was analyzed. The effects of the leading-edge stagger, inlet-velocity ratio, and section lift coefficient on the velocity distribution were included in the study.

From the foregoing study and tests of a number of wing leading-edge air intakes an empirical design method has been developed whereby satisfactory wing leading-edge air intakes may be designed. Ordinates are derived for the inlet section of a given airfoil from empirical formulae involving only the given airfoil ordinates and a desired inlet height. Using this em-

pirical formula, satisfactory section characteristics have been obtained for wing inlets of several heights for an NACA 63-012 airfoil section. These models were tested in one of the 7- by 10-foot wind tunnels at the Ames laboratory.

Studies have also been made of specific wing leading-edge inlets. One such investigation was carried out in the Langley propeller research tunnel on wing-leading-edge inlets located between the inboard and outboard nacelles of a four-engine airplane. The wing with the originally proposed inlets installed was found to have much lower maximum lift coefficients and critical Mach numbers than those for the basic wing. Inlets with satisfactory maximum lift, critical Mach number, and pressure-recovery characteristics were developed for each of two versions of the airplane. Extensive tests were also conducted to study the effects of propeller operation (both right and left-hand) on the maximum lift coefficient and the total pressures in the ducting.

Side Inlets

Air inlets located on the sides of bodies have received considerable attention. One such study of a series of NACA submerged inlets in an 8- by 36-inch wind channel has been completed at the Ames laboratory. This investigation was concerned with the effect of various changes in inlet configuration upon the merits of the submerged inlet.

A further investigation of practical applications of NACA submerged air intakes covering typical application for both turbo-propeller and turbo-jet engine installations was undertaken. These wind tunnel investigations pointed out many basic design factors.

Tests of submerged inlets have also been made to determine scale effects of this type of installation.

As a part of the duct-inlet problem, an investigation has been conducted in the Ames 7- by 10-foot wind tunnels on a fully submerged inlet with a cascade of airfoils inclined to the airstream to turn and diffuse the entering air. This type of inlet is intended to further reduce the amount of internal ducting, and, in addition prevent the entrance of foreign material into the ducting system and engine. The cascade was installed in the side of a $\frac{1}{4}$ -scale fighter fuselage model.

Nose Inlets

Because of the simplicity of design and the relative ease of aerodynamic analysis, nose inlets are employed in many aircraft designs.

A part of the nose inlet studies conducted at the Laboratories was an investigation of two sharp-edge supersonic inlets with conical central bodies, at low air speeds, in the Langley propeller-research tunnel. This investigation was undertaken to obtain preliminary informa-

tion concerning the characteristics of such inlets in the subsonic flight regime.

A special problem encountered in the design of fuselage air inlets of the central-body type for high-speed airplanes is the avoidance of compression shocks on the surfaces ahead of the air inlets. The avoidance of such shocks will reduce boundary-layer separation and the resulting unstable inlet flow and large losses in pressure recovery. Studies have indicated that shaping the central body so that velocities on this surface are below stream values at all points ahead of the inlet will minimize the effects of compression shocks in both the subsonic and transonic flight regimes. A low-speed investigation of simple annular inlets conducted in the Langley propeller research tunnel indicated that by the use of a conical-nosed body the desired substream surface velocities can be obtained over the ranges of angle of attack and inlet-velocity ratio useful for high-speed flight.

An annular transonic inlet configuration, modified by the installation of a canopy and a nose-wheel fairing into a twin side-inlet configuration, has been investigated in order to study problems involved in applying such an inlet to a fighter-type airplane.

Research efforts at Cleveland and Langley Laboratories have been directed toward the determination of the pressure recovery characteristics of various types of supersonic nose inlet arrangements. One extensive investigation concerned itself with a series of diffusers utilizing various combinations of convergent-divergent sections. This investigation indicated that appreciable pressure losses were unavoidable with this type of diffuser. The maximum theoretical recovery was limited by starting restrictions, and additional limitations were found to exist due to the comparative instability of the flow caused by pressure fluctuations in the system. Subsequent researches have indicated methods of reducing the inherent losses in this inlet system.

Inasmuch as the inherent starting limitations of the convergent-divergent diffuser can be avoided by resorting to external compression of the supersonic airstream, experimental and theoretical investigations were conducted to determine the effect of several parameters on the pressure recovery of the external compression diffuser (spike diffuser).

As part of the analytical study of spike diffusers, a design criterion has been determined for reducing to a minimum the value of the drag produced by the external supersonic compression.

Nacelles

During the past 2 years the laboratories have conducted research on various phases of the aerodynamic design of high-speed bombers. As a part of this pro-

gram, nacelles have received considerable attention. Design principles developed through basic studies of wing-nacelle combinations at the Ames laboratory and the Langley laboratory have been extensively applied in current high-speed jet-propelled bomber designs.

General Studies

As a guide in assessing the importance of air-intake design in determining the efficiency of jet-propelled aircraft, a study has been initiated to evaluate the effect of pressure recovery on jet-engine performance. So far the investigation has been confined to a single typical jet-engine type. The effect of pressure recovery on the net thrust of this engine has been determined. In the next step, the engine was fitted to a representative fighter airplane and the effect on the airplane's performance of varying pressure recovery was computed.

In many cases the flow of gases through engines can be predicted with useful accuracy by means of a one-dimensional approximation to the real three-dimensional flow pattern. A method of calculation has been devised to solve one-dimensional flow problems in which friction, change in composition, changes in heat content, or changes in mass flow may be taken into account for either constant or variable specific heat. The method is described in Technical Note 1419.

A supercharger inlet elbow has been designed to provide uniform velocity at the outlet with a minimum pressure loss through the bend. Flow studies were made to determine the effects of a vane installed normal to the plane of the bend, and on this bend in combination with an impeller shaft housing, to determine the outlet velocity distribution and total pressure loss through the elbow. The results of these tests and tests of a carburetor placed in the system are reported in Technical Note 1148.

The thrust developed by a turbo-jet propulsive unit is sharply reduced by pressure losses in the air induction system. Under certain operating conditions, however, inlet screens with their consequent pressure loss are required to prevent damage to the power plant from ingestion of foreign particles. An investigation of a turbo-jet inlet screen designed for low pressure loss and adequate protection has been made at the Langley induction aerodynamics laboratory.

As part of the basic problem of flows through ducting involving deceleration through the speed of sound, an analysis (Technical Note 1225) of nonviscous unsteady channel flow was made. From this study it was concluded that smooth transonic deceleration is unstable to compression pulses coming from the downstream direction.

A chart method for the rapid determination of mass-flow coefficients and associated flow parameters from

pressure surveys in internal flow systems has been developed and is presented in Technical Note 1381. For isoenergetic flows the point mass-flow coefficients are conveniently evaluated from easily measured station static pressure and total pressure-loss coefficients. The charts presented cover a wide range of the determining parameters through the complete range of subsonic Mach numbers. The equations have also been evaluated for flows to which mechanical or thermal energy has been added, such as in flows behind propellers and radiators.

SUBCOMMITTEE ON VIBRATION AND FLUTTER

With the advent of flight at transonic speeds, problems of flutter and of vibration have become increasingly important and more complex, the emphasis placed on this work being reflected in an increase in the scope of investigations conducted. The purpose of these investigations is to furnish the designer of airplanes and missiles with information concerning flutter throughout the subsonic, transonic and supersonic speed ranges, and particularly in the transonic range in which no theory is fully adequate at present.

Airfoil Flutter

At the Ames laboratory flight, wind tunnel, and analytical investigations of high-speed flutter have been continued with promising results. Additional equipment has been developed and perfected for conducting further research into the interaction of boundary layer, shock-wave location and travel, and control-surface hinge-moments.

An extensive program of flutter model testing has been under way at the Langley laboratory during the past year. These investigations were conducted in the Langley flutter tunnel for high subsonic Mach numbers and on freely falling bodies and rockets for Mach numbers in the transonic range. The results have shown the effects of current trends in wing-planform design on the flutter characteristics of wings and controls.

The velocity potential, lift force, moment, and propulsive force on a two-dimensional airfoil in a stream of periodically varying angle of attack have been derived on the basis of nonstationary incompressible potential-flow theory which includes the effect of the continuous sheet of vortices shed from the trailing edge. Application of these results was made in an analysis of the variation with frequency of the propulsive force on an airfoil in an oscillating stream and in analysis of the problem of forced vibrations of an airfoil in an oscillating stream with consideration of the stiffness of the airfoil and the position of its torsion axis. It was shown

that, when the torsion axis of the airfoil is ahead of the quarter-chord point, the amplitude of the vibrations is generally not large, but when the torsion axis is behind the quarter-chord point certain conditions exist under which dangerous amplitudes of vibration may occur. This work is reported in Technical Note 1372.

The forces and moments on a two-dimensional airfoil executing harmonic motions in a pulsating stream have been derived on the basis of nonstationary incompressible potential flow theory with the inclusion of the effect of the continuous sheet of vortices shed from the trailing edge. An assumption as to the form of the wake is made with a certain degree of approximation. A comparison with previous work applicable only to the special case of a stationary airfoil is made by means of a numerical example, and the excellent agreement obtained shows that the wake approximation is quite sufficient. The results obtained are expected to be useful in considerations of forced vibrations and flutter of rotary-wing aircraft for which the lifting surfaces are in air streams of variable velocity. This work is reported in Technical Note 1326.

In Technical Note 1383, a theoretical study, based on the linearized equations of motion for small disturbances, is made of the air forces on wings of general plan forms moving forward at a constant supersonic speed. The boundary problem is set up for both the harmonically oscillating and the steady conditions. Two types of boundary conditions are distinguished, which are designated "purely supersonic" and "mixed supersonic". The purely supersonic case involved independence of action of the upper and lower surfaces of the airfoil, and the analysis is mainly concerned with this case. A discussion is first given of the fundamental or elementary solution corresponding to a moving source. The solutions for the velocity potential are then synthesized by means of integration of the fundamental solution for the moving source. The method is illustrated by applications to a number of examples for both the steady and the oscillating cases and for various plan forms, including swept wings and rectangular and triangular plan forms.

Flutter of Turbine and Compressor Blades

Flutter problems are not limited to the wings and tail surfaces of airplanes but are also encountered by the blades of turbines and compressors. Earlier work on the effect of lift coefficient on flutter of ducted fans indicated that a given fan blade would have the maximum flutter speed when the aerodynamic center of pressure coincided with the blade-section center of gravity. This theory indicated that high flutter speeds could be obtained at the high lift coefficients, if the fan blade sections were cambered properly. Tests reported in Tech-

nical Note 1330 show that high cambered blades had high flutter speeds at high lift coefficients.

These tests also showed that the greatest danger of flutter for a highly loaded blade occurs at the Mach number at which the local velocity on the upper blade surface becomes sonic. As the speed was increased beyond the critical Mach number, the flutter disappeared.

SUBCOMMITTEE ON PROPELLERS FOR AIRCRAFT

The steadily increasing operational speeds of modern aircraft have resulted in the need for additional research on those factors affecting the efficiency of propellers at very high speeds. The advent of the gas turbine power plant has required that further emphasis be given to such research at this time.

Propeller Theory

As a result of an investigation carried on at Langley, an isosceles triangle twisted into a screw surface about its axis has been proposed as a propeller for transonic flight. The purpose of such a design is to obtain the drag reduction associated with large sweepback in a structurally practicable configuration. A mathematical theory for such a propeller, presented in Technical Note 1303, indicates a net efficiency of the order of 80 percent at a Mach number of 1.1.

The selection of an efficient propeller for application to a light airplane design can be accomplished by the use of charts presented in Technical Note 1338. The charts are prepared for power values from 50 to 300 horsepower, airspeeds from 50 to 200 miles per hour, propeller diameters from 6 to 10 feet, and blade numbers from 2 to 8 for wide values of propeller rotational speed. The application of the results is demonstrated by three examples.

Propeller Experiments

Tests of an NACA 4-(5) (08)-03 two-blade propeller have been made in the Langley 8-foot high-speed tunnel to extend the Mach number range above that of previous tests of this propeller.

An investigation of two two-blade propellers of very high solidity was also carried out in the Langley 8-foot high-speed tunnel.

One means of increasing the power absorption capacity of existing blade designs is the addition of trailing-edge extensions, and a flight investigation was made on a P-47D-28 airplane to determine the effects of such an extension.

In connection with its research on the effects of shape of propeller shank sections, the NACA has made an investigation of the effect of compressibility on the flow over thick airfoil sections.

As part of the overall program of the NACA to reduce the noise produced by aircraft, a review was made of the literature available on the effect of distance on airplane noise and published as Technical Note 1353. This study showed that, for the range of frequency radiated from a propeller, atmospheric absorption was negligible and that the sound energy could be predicted by the inverse square law. In addition, a considerable amount of work was done to determine the range of practical application of propeller noise theory. This work culminated in flight tests of a light airplane equipped with a propeller designed to effect large reductions in the propeller noise level. A report on these flight tests is being prepared.

The investigation of noise from 2-, 4-, and 7-blade propellers, reported in Technical Note 1354, resulted in good agreement with the Gutin theory for rotational noise in the Mach number range from 0.5 to 0.9. At low tip Mach numbers the noise was greater than predicted because of the vortex noise of the propeller.

Charts presented in Technical Note 1358 for determining the loudness of light airplane propellers were prepared in an effort to aid the designer in the choice of a quieter propeller. These charts give the loudness level at distances of 300 and 1,000 feet for various numbers of blades, propeller diameters, rotational speeds and power ranges. These same variables are considered in Technical Note 1338 which presents charts for determining the efficiency of a light airplane propeller.

SUBCOMMITTEE ON HELICOPTERS

The experimental and analytical investigations of the fundamental factors that affect the performance, flying qualities, and reliability of helicopters have been continued during the past year. The object of this work was to provide and interpret the fundamental information required for proper guidance of helicopter development so that the unique potentialities of rotary-wing aircraft might be fully realized in rescue, commercial, and military applications.

Flight Investigations

The effect of rotor-blade stalling on the power absorbed by a rotor was determined in flight and the results of the investigation published in Technical Note 1250. The flight measurements checked the calculations made by the weighting curve method in that it was found that stalling materially reduces rotor efficiency before the operating limitations due to vibration and loss of control were reached. It was also found that calculation of the operating conditions corresponding to an angle of attack of the retreating blade tip of approximately 12° is a useful approach in determining the conditions for optimum performance

of current rotors, as well as in limiting the applicability of theoretical treatments that omit allowances for stalling losses.

Safety and design considerations make the autorotative condition important to the helicopter designer inasmuch as the helicopter rotor becomes, in effect, an autogiro rotor in the event of power failure. Flight tests were therefore conducted on a helicopter in the autorotative condition and the results published in Technical Note 1267. It was found that good agreement between theoretical and experimental autorotative performance was obtained and that the same theory could satisfactorily predict the performance of a rotor in both the power-off and power-on flight conditions. The theory could thus be used in extending the available rotor data from one condition to another. It was shown that significant improvements in gliding performance appear possible with improved blade contour and surface condition.

Basic data on helicopter rotor-blade motion were obtained by photographic observations of the behavior of a rotor blade in flight. The measurements were analyzed by means of existing theory and the results published in Technical Note 1266. Values of measured flapping, feathering, and in-plane motion were compared with theoretical calculations, and agreement was found good enough to render the theory useful in such problems as the estimation of control displacement for trim, the determination of the static stability of the rotor, and in designing the stop settings and bearing positions of the rotor hub. A basis for design of a simple service torquemeter, consisting of a mechanical device for measuring the mean blade-drag angle, was suggested by the test results, in that the mean drag angle was found to be a simple function of the rotor torque and revolutions per minute over a wide range of conditions. Data on blade twisting and distortions imposed by aerodynamic and inertia forces in flight, which are essential to studies of blade stresses and rotor vibration, were also obtained.

Wind-Tunnel Investigations

As part of a general helicopter research program intended to provide designers with fundamental rotor information, the forward-flight performance characteristics of a typical single-rotor helicopter have been investigated in the Langley full-scale tunnel. The data, which are given in Technical Note 1289, are presented in a series of charts which facilitate the rapid estimation of the forward-flight performance of helicopter rotors having physical characteristics similar to the rotor tested. The results indicate that large savings in the power required for flight would result

from the use of smooth rotor blades and that additional smaller savings in power would result from operation at lower rotational speeds.

Blade motions of the PV-2 helicopter rotor have been studied in the Langley full-scale tunnel. The flapping and feathering motions of the rotor blades were subjected to harmonic analysis and the Fourier coefficients have been summarized in a convenient set of charts from which the motions for such a rotor may be readily obtained for a range of flight conditions. The theory in common use was found to predict accurately the coning angle and the longitudinal component of the equivalent flapping; fair agreement for the lateral component of the equivalent flapping, however, requires that the theory take into account the fact that the inflow across the rotor disk increases from front to rear.

Analytical Studies

An extension of previous work on the theory of self-excited mechanical oscillations of hinged rotor blades has been published. Previously published papers cover the cases of three or more rotor blades on elastic supports (such as landing gear) having equal or unequal support stiffness in different directions and the case of one or two blade rotors on supports having equal stiffness in all horizontal directions. The missing case of one or two blades on unequal supports has now been treated in Technical Note 1184. This report completes the combinations of support elasticity and number of blades which the ground-vibration studies have been planned to cover. The results show the existence of ranges of rotational speed at which instability occurs (changed somewhat in position and extent) similar to those possessed by the two-blade rotor on equal supports. In addition, the existence of an infinite number of instability ranges which occurred at low rotor speeds and which did not occur in the cases previously treated is shown.

A theory has been developed in preliminary form and reported in Wartime Report L-692 which seems capable of predicting the aerodynamic instability phenomena of a two-blade "see-saw-type" helicopter rotor. In particular, the theory indicates the possibility of unstable vibrations even with the chordwise center of mass at or ahead of the 25-percent-chord position. The stability condition for oscillatory motion is expressed in terms of a small number of composite parameters that are evaluated from the moments of inertia, angle settings, and aerodynamic parameters of a blade. Computed stability results for different coning angle settings, center-of-mass positions, and control-system stiffnesses for one value of blade density and aspect ratio are presented in a chart. It is found that, in addition to parameters analogous to those occurring in wing-flutter theory, the present theory requires the use of a

parameter that represents an unstabilizing effect due to the difference between the moments of inertia in flapping and in rotation.

In order to facilitate solutions of the general problem of helicopter selection, the aerodynamic performance of rotors is presented in Technical Note 1192 in the form of charts showing relations between primary design and performance variables. By the use of conventional helicopter theory, certain variables are plotted and other variables are considered fixed. Charts constructed in such a manner show typical results, trends, and limits of helicopter performance. Performance conditions considered include hovering, horizontal flight, climb, and ceiling. Special problems discussed include vertical climb and the use of rotor-speed-reduction gears for hovering.

A tentative list of standard symbols for helicopters was prepared in answer to the interest in standardization shown by the armed services and the rotary-wing industry. The symbols listed were limited to those most generally used in helicopter aerodynamics studies, inasmuch as the specialized symbols necessary in vibration, stress, and stability work remain to be developed and standardized.

Current Developments

The NACA helicopter test tower was placed in operation. The work done to date is of a preliminary nature dealing with the calibration of the tower. The tower is 40 feet high and powered with a 1,500 horsepower engine. It is instrumented to obtain the average aerodynamic rotor forces as well as transient forces. The test tower is designed for the purpose of obtaining the aerodynamic rotor characteristics for the hovering and near-hovering cases and has been located in a relatively isolated area in order to minimize interference effects from other objects. The construction of the driving head is such that various types of rotors may be used.

SUBCOMMITTEE ON SEAPLANES

Aerodynamic Characteristics

Seaplane research has been directed toward reducing the aerodynamic drag of seaplanes without imposing penalties on the hydrodynamic characteristics.

Recent research on seaplane hulls has brought to light a number of ways that they may be improved both aerodynamically and hydrodynamically. These studies have indicated that increasing the length-beam ratio in such a manner that the hydrodynamic performance remained unchanged resulted in smaller frontal area. Wind-tunnel tests (Technical Note 1305) verified the predicted decrease in drag and showed that no appreciable change in stability resulted from the increased

length-beam ratio. A study of the hull structure indicated that a favorable reduction in structural weight would be expected with an increase in length-beam ratio. These trends show that increased performance in the form of range, speed, and payload can be expected from seaplanes designed with higher length-beam ratio hulls.

Rough Water Characteristics

In the past the theory of the impact of seaplanes landing in rough water has been confined to the first impact despite the fact that larger loads are often imposed at later impacts because of the difficulty of predicting mathematically the dynamic behavior and contacting conditions during subsequent bouncing. Powered dynamic models have proved a useful tool in determining the behavior and impact accelerations during this latter phase of the landing. Tests showed that for each seaplane there was a critical wave length which produced the maximum impact loads and further that the length was independent of wave height. A long afterbody was found to materially reduce the maximum impact loads encountered during a landing.

In order to test the validity of an impact theory developed by the NACA in recent years (Technical Note 1325), single impact tests were made on an approaching wave with a prismatic float. The theory was verified by agreement between the impact loads obtained from this form of float and those computed from the theory. The combination of the theory and the dynamic history obtained from the dynamic models will lead to a more complete understanding of the complex relations between the many factors involved in the rough water operation of seaplanes.

Specific Model Tests

Dynamic models of several flying boats being built for the Navy were tested to provide design information and flight handling characteristics before the flight tests. Factors investigated during these and other general tank tests include the effect of varying the step depth, plan form, afterbody keel angle, deadrise, reversed-type longitudinal steps, wing-tip floats, and spray strips. These factors increase the understanding of hydrodynamic phenomena and provide information making possible better seaplane designs.

SPECIAL SUBCOMMITTEE ON THE UPPER ATMOSPHERE

Standard Atmosphere

Recent developments in aeronautics and ordnance, particularly high-altitude missiles, have demonstrated the need for information concerning the characteristics of the upper atmosphere. In view of the need for

standard values on which to compare the performance characteristics of aircraft, missiles, and prime movers, the NACA, upon recommendation of the Committee on Aerodynamics, appointed a Panel on the Upper Atmosphere in 1946. This panel recommended tentative standard values for the atmosphere to altitudes of 100,000 feet extending the tables from the limit of 65,000 feet given in Technical Report No. 218. The tentative standard values were adopted by the NACA and are published as Technical Note 1120. In April 1946 this panel was superseded by the Special Subcommittee on the Upper Atmosphere.

The subcommittee has reviewed the limited information available concerning the temperature and composition of the upper atmosphere. On the basis of existing data obtained by the use of balloons at altitudes up to about 125,000 feet and of indirect measurements obtained at greater heights by various techniques such as sound-range and meteor observations, recommendations regarding temperature-height and composition-height relationships to altitudes of 120 kilometers (about 400,000 feet) were made by the subcommittee. These recommendations cover three arbitrary sets of temperatures: (1) tentative standard temperatures, (2) probable minimum temperatures, and (3) probable maximum temperatures.

The recommendations were adopted by the NACA and two sets of tables of the properties of the upper atmosphere, in the metric and British systems of units and based upon the tentative standard temperatures, were prepared by the Langley laboratory and were published as Technical Note 1200. The probable minimum and probable maximum temperatures have been included to indicate the possible range of variation of temperature and have proved useful for estimating the limits of performance of aircraft and missiles.

Because the values published in Technical Note 1200 are tentative and as such are subject to revision after a sufficient number of reliable direct measurements are available, the Subcommittee is continuing its activity until such time as it may be able to recommend with certainty final extensions of the tables of the NACA standard atmosphere.

The subcommittee is continuing to serve as a medium for the interchange of information on research in progress or proposed and also as an advisory body for the formulation and coordination of programs of research on problems of physics of the upper atmosphere.

PROPULSION RESEARCH

Propulsion systems for high-speed aircraft have introduced many problems which must be thoroughly

investigated in order to establish a sound basis for increasing the power output, efficiency and operating life of these systems. Knowledge of a basic nature is needed on which to base design of engine components and from which to draw a better understanding of the processes that take place in the engines. Outstanding improvements have been made in weight reduction, in power output, and in operating life between engine overhauls, but there is still a need for further substantial improvement in these factors.

The Flight Propulsion Research Laboratory has been aided in its program by the Committee on Power Plants for Aircraft and its seven subcommittees. For the sake of convenience the results of this program are presented herein according to committee and subcommittee fields of interest. Research has been conducted by educational institutions under contract to the NACA and the results of these researches are included.

As a means of bringing the findings of NACA research to the aircraft industry with a minimum of delay, a series of conferences on specific phases of the research have been held at the Flight Propulsion Research Laboratory during the past year. At these conferences significant NACA research results were presented on compressors, turbines, combustion, ram jets, high-temperature materials and means of de-icing for aircraft propulsion systems. These conferences were attended by representatives of Government agencies and Government contractors working in the particular field.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Altitude Performance of Gas-Turbine Engines

An investigation of a turbojet engine incorporating an axial-flow compressor was made over a range of simulated altitudes and ram-pressure ratios; the effect of changes in altitude, ram-pressure ratio, and tail-pipe nozzle area on the performance of the engine, the compressor, and the turbine were determined. In addition, an investigation of a gas turbine propeller engine over a wide range of engine speeds, engine powers, and altitudes gave information on engine performance, windmilling characteristics, pressure and temperature distributions, and compressor, turbine and combustion chamber performance. Analyses have been made to enable extrapolation of performance data from one altitude to another. To date these analyses have shown promise, but have not eliminated the necessity of obtaining complete experimental results.

Ram Jet Engines

The ram jet engine continues to show promise for propulsion at high speeds, and the research is continuing. An investigation has been conducted on a rectangular ram jet designed for installation in an aircraft wing, and research was also directed at extending and improving the performance of the cylindrical ram jet configuration.

Thrust Augmentation of Turbojet Engines

Means of supplying turbo-jet engines with extra power for take-off and for emergency maneuvers are still under investigation, and research has continued on various methods of thrust augmentation, with a view to obtaining further increases in total thrust.

Engine Cooling

Experiments have been directed to determine ways and means of cooling the inner walls of rocket combustion chambers and nozzles in order to prolong rocket-motor life when propellants of high-energy release are used. Experiments have been initiated in which quantitative heat-transfer data for internal films of the sort used to cool rocket motors are being determined.

An investigation of a 12-cylinder liquid cooled reciprocating engine to determine the effect of engine exhaust pressure on cylinder temperatures and heat rejections was conducted in connection with investigations of compound-engine performance. It was found that an increase in exhaust pressure had only a small effect on cylinder temperature and heat rejection when manifold pressure was held constant, but resulted in appreciable increase in cylinder temperature and heat rejection when engine charge air was held constant.

In order to check the generality of cooling correlation methods previously obtained from a 12-cylinder liquid-cooled reciprocating engine of 1,710-cubic-inch displacement, a similar investigation was conducted with a 12-cylinder liquid-cooled engine of 1,650-cubic-inch displacement. The coolant-flow distribution, the cylinder temperature at various locations in the head and the barrel, and the heat rejections to the coolant and the oil were determined over wide ranges of all of the engine and coolant conditions. The data that have been analyzed and correlated indicate trends similar to those obtained for the engine of 1,710-cubic-inch displacement and verify the generality of the correlation method.

Engine Stresses and Vibration

Among the power plant components that were investigated were compressor and turbine disks, compressor and turbine blades, and shafts supported on three

or more journal bearings. A method was developed for calculating the stress in disks, which have complicated physical profiles, variable temperatures, and physical properties along the different radii of the disks. (See Technical Note 1279.) The method previously developed for calculating stresses in disks was applied (Technical Note 1334) to a study of the effects of temperature distribution and elastic properties of materials on gas-turbine-disk stresses. It was found that the critical stresses in the rim could be relieved by relatively small changes in temperature distribution at this location.

Vibrating blades were investigated (Technical Note 1204) to determine whether strain gages placed at the locations of the high stress as determined under non-rotating conditions would indicate with validity the highest stresses occurring under operating conditions; it was analytically and experimentally shown that they would.

An experimental investigation was made of gas-turbine-disk stresses due to the different rates of expansion of the component parts of the disk. It was shown that the use of gas-turbine disks consisting of a central region of carbon steel and a rim region of high-temperature alloy can result in residual tensile stresses at the rim as a result of the lower coefficient of expansion of the high-temperature alloy. This tends to aggravate the rim-cracking problem.

Measurement of vibratory stresses in gas-turbine blades is reported in Technical Note 1174. It was shown that stresses in turbine buckets can be studied by means of high-temperature wire-resistance strain gages.

An investigation of the strain rosette, consisting of three or more wire strain gages oriented at definite angles to each other and ordinarily used to determine the complete state of strain in a region of complex stress, is reported in Technical Note 1133. It was desired in this investigation to determine the effect of minor misalignments on the component strain. It was analytically and experimentally shown that misalignments ordinarily expected in such strain rosettes could not produce principal errors in many regions of complex stress. The error is directly proportional to the shear strain; therefore, such misalignments should be especially avoided in fields of pure shear.

Engine Controls and Auxiliaries

An investigation was made of the relations between spark timing and basic factors in engine operation, flame-front travel, and cylinder pressure rise (Technical Note 1217) in a reciprocating engine in order to determine an effective means of maintaining maximum-economy spark timing with varying engine operating conditions. Data obtained in this investigation showed

that maximum-economy spark timing occurred when the crank angle of maximum rate of pressure rise was 3° A. T. C. and that the crank angle of maximum rate of pressure rise and the travel of the flame front were directly related.

Methods of accurately dividing the fuel flow to the cylinders of the Otto-cycle internal-combustion engine have been investigated. A simple and accurate system has been designed, whereby fuel flow is maintained constant independently of the resistance of the discharge nozzles. This system permits considerable latitude in the choice of fuel nozzles or atomizers. The advantages of accurate distribution of fuel include improvements in engine cooling and in specific fuel consumption.

Fuel distribution in aircraft gas-turbine type engines was investigated for the purpose of improving distribution characteristics for a range of fuel-flows and in particular for low fuel flows. A system was devised which gave marked improvement in fuel distribution.

SUBCOMMITTEE ON AIRCRAFT FUELS AND LUBRICANTS

Effect of Fuel Characteristics on Combustion in a Turbojet Engine

Because of the complexity of the hydrocarbon mixtures used as fuels for aircraft engines the analytical investigations of the components of these mixtures have been continued. Knowledge of the exact composition of the fuels investigated in combustion research is desirable and also makes it possible for that research to be more systematically planned. Several investigations have also been conducted to evaluate the effects of fuel volatility and chemical composition of fuels on combustion efficiencies. These studies have been made at simulated altitude conditions in single-combustor installations and sea-level conditions in a full-scale turbojet engine. As a corollary investigation preliminary results have been obtained on the effect of fuel-nozzle characteristics on turbojet-combustor performance.

Rocket Propellants

Several combinations of liquid rocket propellants have been investigated in thrust rating rocket motors. Work has been initiated on the development of a fuel rating rocket motor for use as a research tool for determining the relative performance of various rocket propellants. As a preliminary step, an analysis has been completed on the relative merits of various combinations of rocket propellants. The bases of comparison are specific impulse and volume specific impulse. The handling properties of some of the most promising propellants are also being investigated.

High Energy Fuels

Aircraft designed for flight at high speeds have thin wings. This feature places a rigid limitation on the amount of space available in the airplane for fuel storage. This restriction on fuel capacity in high-speed aircraft suggests the use of fuels having high-energy content per unit volume. During the past year an investigation of compounds of this type has been initiated and the first step in this study consisted in calculating the heat content for a number of possible compounds that might be used as fuels.

Effect of Chemical Structure of Fuels on Combustion Power

The investigation of the influence of the chemical structure of fuels on knock-limited performance of reciprocating engines was continued. Additional fuels were prepared (Technical Notes 1163 and 1164) for determining the knock-limited power that could be developed in order to obtain a complete picture of the influence of structure on the engine performance of aromatic hydrocarbons, aromatic amines, and ethers. Similar investigations are under way in connection with jet-engine combustion research.

Fuel Knock Sensitivity

In order to extend further the knowledge of the variation of the knock-limited performance of a fuel with engine operating conditions, investigations have been made of several high-performance fuel blends in single-cylinder engines and in flight. The results of these studies show clearly the extent to which fuels differ in their responsiveness to changes in engine conditions. Some operating conditions appear to have greater effects than others on the knock-limited performance of a given fuel. The relative effect of six engine variables on the knock-limited performance of two fuels is presented in Technical Note 1117, which shows the influence of exhaust back pressure on knock-limited performance to be an important factor in compound-engine performance. An investigation of the effect of compression ratio and spark advance on knock-limited performance and fuel consumption of full-scale multi-cylinder engines has shown the extent to which an engine using high-performance fuel gains in fuel economy when operated at a high compression ratio.

Use of Low-Volatility Fuel in a Reciprocating Engine

As part of a general investigation of a typical two-row radial air-cooled engine used in bomber and transport type airplanes, an investigation was conducted to determine if low-volatility fuel (sometimes called safety fuel) could be successfully used in this engine.

The study was limited to three methods of injecting safety fuel. They are an injection impeller, an impinging-jet nozzle bar, and a standard injection-carburetor nozzle bar. The fuels used in this investigation had performance ratings and heating values equivalent to those of aviation gasoline. The injection impeller gave better mixture and temperature distributions, better over-all engine performance, and a lower specific fuel consumption when using low volatility fuel than did the nozzle bar or the standard nozzle bar. (See Technical Note 1413). From the standpoint of fuel distribution, power output, and fuel economy engine operation using low-volatility fuel was comparable with that using gasoline; however, the mixture and temperature variations were slightly larger with the low-volatility fuel. Cold starting with low-volatility fuel requires the use of an auxiliary fuel of a higher volatility.

SUBCOMMITTEE ON COMPRESSORS

Inducer Impeller

Investigations have been conducted on various centrifugal impellers in accordance with a program to determine the effect of several variables upon centrifugal-compressor performance. This program included the investigation of the effects on performance of changing the division of work between increase of angular velocity and increase of radius of rotation in an impeller. Several impellers consisting of radial-bladed sections were investigated with the same inducer section. The results of this investigation showed an improvement of 6 to 7 percent in efficiency at the higher tip speeds when the amount of work resulting from the angular acceleration was increased with respect to the work of compression resulting from the increased radius of rotation. (See Technical Note 1216.)

Blade Loading

An investigation was conducted on centrifugal impellers to determine the effect of blade curvature on impeller performance. (See Technical Note 1313.) Impellers having elliptical, parabolic, and circular blade curvatures were investigated. The impeller with the elliptical blade curvature had the highest peak adiabatic efficiency for equivalent tip speeds below 1,400 feet per second; the impeller with the parabolic blade curvature had the highest peak adiabatic efficiency at equivalent tip speeds of 1,400 and 1,600 feet per second. The highest maximum specific capacity up to an equivalent tip speed of 1,500 feet per second was obtained with the impeller having a circular blade curvature.

Centrifugal Compressor Performance

Experimental investigations of centrifugal impellers over a range of inlet-air temperatures have shown that the measured efficiency of the compressor always deteriorated to some extent when the inlet-air temperatures were reduced. This phenomenon not only prevented the prediction of compressor performance over a range of altitudes, but made the accuracy of the results obtained by standard techniques doubtful. An investigation to determine the source of this discrepancy disclosed the fact that the largest part of the observed efficiency variations were caused by heat transfer between the environment and the compressor collector and the outlet pipe. By measuring the outlet temperature in the compressor diffuser instead of in the outlet pipe, the observed discrepancies were reduced to a negligible value.

Surging

The operating range over which a compressor, suitable for gas-turbine-engine application, can deliver a stable air flow is limited for maximum flow by the occurrence of a sonic velocity in the compressor passages and for minimum flow by the compressor surge point. When operating at high compressor speeds, the maximum flow is very close to the minimum flow and the desired operating conditions of peak efficiency and pressure ratio are therefore also very close to the surge point. The danger of surging while the engine is operating at the point of peak performance is then a distinct possibility.

Experiments have been conducted on three compressor units to determine the conditions that cause surging in compressors and to determine the effect of various installations and operating conditions on the character of the velocity and pressure variations occurring during surging. (See Technical Note 1213.) In addition, a simplified analysis was made to determine how instability of flow may occur in a compressor. An examination, based on this analysis, was made of several possible methods of inhibiting the occurrence of surging. A surge inhibitor that recirculated air from the compressor discharge to the inlet was investigated. At the high speeds, the inhibitor increased the stable operating range of the compressor, and, in addition, increased the peak efficiency 5 percent and increased the peak pressure ratio 17 percent.

Diffusers and Scrolls

A report has been prepared on a method for designing vaneless diffusers. (See Technical Note 1426.) The suitability of a design for a given impeller is determined by two design parameters: The ratio of throat width to diffuser-inlet width; and the rate of area ex-

pansion through the diffuser. Optimum values of these variables for one particular mixed-flow impeller were experimentally found to be 0.72 for the throat-to-inlet width and 6° for area expansion rate.

Friction coefficients were determined for three vaneless diffusers. (See Technical Note 1311.) Except at the diffuser entrance where highly turbulent mixing occurs, values for diffuser friction coefficient agreed well with the values for turbulent flow in smooth pipes. Magnitudes of the friction coefficient at the diffuser entrance were approximately three times the pipe values.

Cascade Theory

A new method has been developed for calculating the potential flow in two-dimensional cascades of airfoils. (NACA Technical Note 1252.) The method considers directly the influence on a given airfoil of the rest of the cascade and evaluates this interference by a rapidly converging iterative process. The calculations are very accurate and considerably simpler to perform than those of previous methods. The method can also be readily adapted to the design of cascades for desired types of airfoil pressure distributions. In order to show its use in design, NACA Technical Note 1254 has been published giving in detail three examples of the design of thin-airfoil cascades.

A number of comparisons have been made between theoretical and experimental lift coefficients and pressure distributions on airfoils in cascade in NACA Technical Note 1375. It was found that the discrepancies between theoretical and experimental values are generally larger than has been found for isolated airfoils, especially when there is a large pressure rise across the cascade. Some of the discrepancy has been attributed to the characteristically low aspect ratios of the experimental cascades. Modifications of the calculation procedure, in which the lift coefficient was arbitrarily forced to duplicate the experimental value, resulted in greatly improved agreement between the pressure distributions.

Blade Design

A blade-element theory for axial-flow compressors has been developed and applied to the analysis of the effects of basic design variables on compressor performance. Charts have been developed that permit rapid calculation of a wide variety of design conditions. The possible gains in useful operating range obtainable by use of adjustable stator blades are easily computed by means of the charts. An exact solution of the problem of designing an airfoil with a prescribed velocity distribution on the suction surface in a given uniform flow of a perfect incompressible fluid has been obtained. (See Technical Note 1308.) It was found that the ve-

locity distribution at any angle of attack other than design conditions may be computed from the initial data before the solution for the shape is obtained, if a solution exists for the prescribed initial data.

The development of blading for subsonic axial-flow compressors was continued. High Mach number cascade-tunnel tests of the 65-series blade profiles gave important information on the high-speed performance of those profiles. By showing the maximum operating Mach numbers which can be used without serious compressibility losses, this work permits design for maximum stage pressure rise without decrease in efficiency due to compressibility effects. Tests of a highly loaded isolated rotor in a low-speed test blower, reported in Technical Note 1388, showed that pressure rise per stage can be increased with no decrease in efficiency by using blades more highly cambered than those given in the design charts of Technical Note 1271.

Pressure Distribution on a Rotating Blade

A preliminary investigation has been made of the pressure distribution about the mean-radius section of the rotating blades of a single-stage axial-flow compressor at a blade Mach number of 0.35. A 24-cell pressure-transfer device used in obtaining the pressure data is described and the accuracy of these data is established by several independent methods. The results reported in Technical Note 1189 indicated that the maximum suction pressure for the thin low-camber rotor blades tested (stagger, 70°, and solidity, 0.86, at mean-radius section) was only slightly greater than for the isolated airfoil of the same section. The lift-curve slope for the rotor blades was much lower than that estimated from theoretical calculations for a comparable two-dimensional cascade; this fact indicated the necessity of using experimental cascade data to determine the blade angle settings. Stalling of the flow in the compressor was found to originate at the root and tip sections of the blade owing to the effects of casing boundary layers, improper blade twist, and large clearances.

Multistage Compressors

The NACA has investigated the performance of several multistage axial-flow compressor components of turbo-jet engines. Complete performance data including interstage survey data were obtained in these investigations.

SUBCOMMITTEE ON TURBINES

Nomenclature

The Subcommittee on Turbines recognized the need for standard turbine symbols to facilitate the exchange of technical information and to provide a basis

for comparison of results obtained by various investigators. The Subcommittee has prepared a list of suggested standard symbols and definitions for turbine research and the list will be available shortly as NACA Technical Note 1508, Suggested Symbols and Definitions for Turbines.

Design and Performance

In the development of better turbines, an effort is being made to devise more reliable turbine-design methods. It is highly desirable to develop methods that will allow accurate prediction of the efficiency, gas flow, and power capacity of the turbine. If adequate methods of design are available, the development of turbines having the optimum characteristics for a given application will be greatly simplified. A single-stage cold-air experimental turbine is currently in use in an investigation of a series of blades to determine the effect of changes in the turbine-blade shape parameters.

Of fundamental importance in gas-turbine design is a knowledge of the effect of the Mach number and the Reynolds number of the working fluid on the turbine performance. Mach number may be studied by observing performance variations over a range of pressure ratios across the turbine; Reynolds number effect appears as turbine-performance variation with changes of the turbine-inlet pressure or temperature or both. Such an investigation is being conducted using a representative gas turbine.

An investigation has also been conducted on a turbine suitable for use as an aircraft accessory drive. A series of different nozzle designs were investigated to determine the effect of pressure ratio and turbine speed upon turbine efficiency. In order to determine the true output of the nozzle-and-turbine combinations, the power losses of the unit due to windage and mechanical friction were evaluated.

Turbine Cooling

Turbine-cycle analysis has shown that moderate increases in thermal efficiency and substantial increases in engine power would result from increasing turbine-inlet temperatures. The rapid deterioration of strength of available blade materials at high temperatures make it necessary to pay particular attention to cooling the blades when inlet gas temperatures above 1,500° F. are used. In order to explore the possibilities of turbine cooling, experimental investigations are being conducted as well as analytical studies. Instrumentation has been developed for the measurement of turbine-rotor temperatures and this instrumentation has been used in a flight investigation. (See Technical Note 1159.)

SUBCOMMITTEE ON LUBRICATION, FRICTION, AND WEAR

Sliding Friction

An experimental investigation that provides fundamental data and information on the effects of high velocities on friction has been completed. The empirical results show that friction decreases appreciably with an increase in sliding velocity for both dry and boundary-lubricated surfaces. The decrease in friction is attributed to high surface temperatures, which result in physical changes in the surface materials, and to the formation of chemical compounds on the surfaces. One of the chemical compounds was identified as ferrous oxide (FeO). The results also indicated the possibility of a correlation, under certain conditions only, of friction and wear.

In connection with the problem of the mutual adaptation of rubbing surfaces, the results of electron and X-ray diffraction studies of run-in have associated the occurrence of specific surface conditions with desirable or undesirable running properties of sliders operating under steady or changing loads. Results of the investigations indicated that one of the principal variables observed on surfaces that had been run-in was the presence of isolated and mixed oxides of iron. By association, it is thought that the presence of ferrous oxide (FeO) and ferrosferric oxide (Fe_3O_4) is beneficial to slider surfaces and that the presence of ferric oxide (Fe_2O_3) is not beneficial. (See Technical Note 1432.) An electron-microscope study of run-in surfaces, which indicated physical changes to surfaces of sliders as the result of elevated temperatures and high surface pressures, is described in Technical Note 1132.

As another phase of this problem a study of metal transfer was conducted by the Massachusetts Institute of Technology under contract to the NACA. This study was made possible by a technique employing radioactive materials, made available through the cooperation of the Atomic Energy Commission, as a means of quantitatively measuring metal transfer. The results showed that metal is more readily transferred from a soft steel to a hard steel than the reverse. Nitrided and chromium plated surfaces were also studied. (See Technical Note 1355.)

Fretting Corrosion

The term fretting corrosion is generally applied to the corrosion phenomena observed at the contact surfaces of machine parts subject to vibration. Fretting corrosion damage appears to be worse, other things being equal, the better the original fit of the surfaces. For this reason the fretting corrosion problem has been par-

ticularly troublesome in the aircraft industry where dimensional tolerances are small. An investigation of this problem was conducted at the Massachusetts Institute of Technology under contract to the NACA. The results indicate that chemical action between the surfaces is of primary importance and that oxide films give no protection but rather increase the rate of fretting. Most metal oxides are extremely hard, so when trapped between the vibrating surfaces they act as abrasives. The rate of wear under fretting conditions is determined by the relative hardness of the oxides and parent metals.

Lubrication

A preliminary investigation of lubrication with so-called extreme-pressure additives is being conducted and a study of the reactions with steel of compounds containing chemical groups used in these lubricant additives has been completed. (See Technical Note 1207.) The products formed by chemical reaction at elevated temperatures were analyzed by reflection electron diffraction, and the additive reactivities were in agreement with predictions based on knowledge of the chemical reactivity of the groups and linkages studied. The compound formation observed in the investigation supported the theory of boundary lubricant additive action, which states that additives form compounds of low shear strength at metal surfaces and prevent seizure when no fluid film is present.

Bearings

The results of an investigation of load capacity of aluminum-alloy bearings as determined under rotating loads are reported in Technical Note 1108. All the alloys had a load capacity in excess of 6,000 pounds per square inch. It was shown that these alloys are susceptible to sudden seizure and that chemical composition, particularly with respect to iron content, is one of the most critical variables.

SUBCOMMITTEE ON COMBUSTION

Effect of Operating Variables on Performance of Gas-Turbine Combustors

Investigations have been continued to evaluate the performance of various gas-turbine combustors as influenced by the operating variables or inlet conditions, of the combustors. Generalized information on the effect of inlet-air temperature, pressure, and velocity and fuel-air ratio on combustion efficiency and altitude operational limits was obtained in a sufficient variety of combustors so that a fairly complete and comprehensive picture of this phase of combustion research has been obtained.

On typical aircraft gas turbines the turbine entrance conditions are dependent on combustion chamber exit

conditions. In the interest of obtaining favorable turbine operation, the pressure drop through the combustor should be low, the temperature and velocity profiles at the combustor outlet should be as even as possible, and afterburning should be kept to a minimum. The effects of the operating variables on these combustor performance characteristics as well as on fuel-injection characteristics and the condition of the combustion chamber liners were investigated. This knowledge provides the basis for research and development on gas-turbine combustors. The results of one of these investigations is reported in Technical Note 1357.

Effect of Design on Gas-Turbine Combustor Performance

The performance of several gas turbine combustion chambers was investigated for the purpose of determining the effect of the design geometry on combustor performance and characteristics. The design variables considered were shape of cross section, area of cross section, length or length-to-diameter ratio, and shape and secondary air-inlet spacing of the combustion chamber flame tube or basket. The characteristics observed were stability of operation, combustion efficiency, temperature distribution at the combustor outlet, pressure drop, size and weight, ease of ignition, and carbon formation.

Combustion in the Primary Zone of a Gas-Turbine Combustor

The unique requirement of aircraft gas-turbine combustors to release a great amount of heat in a small space and in a short time presents a difficult problem in the technique of establishing stable, efficient flames. Consequently, an attempt was made to isolate the combustion process in the primary or burning zone of a gas-turbine combustor for separate study by means of a 2-inch-diameter experimental burner. The effect on performance of various methods of introducing turbulence in the primary zone, as well as the effect of the inlet-air conditions, was determined. The performance criteria examined were combustion stability, flame length, and combustion efficiency. Because air turbulence is one of the important factors in achieving efficient and stable combustion at unusually high rates of energy release, the effect of turbulence on combustion has been receiving further intensive experimental study. One part of the general program on this topic that was completed is a series of experiments on the stability of bunsen-type flames with turbulent flow. This work is reported in Technical Note 1234.

General Combustion Studies

Concurrent with other research on ram jets an exploratory investigation of the effect of operating vari-

ables, or inlet conditions, on the performance of a ram jet was made. As another aspect of the basic problem of converting heat energy to useful thrust, preliminary investigations have been made of fundamental behavior of combustion under high pressure conditions in a liquid-fuel rocket. The problems of ignition of rocket engines have been investigated for the various propellant combinations.

A motion picture camera that will take photographs at the rate of 400,000 frames per second was developed to record combustion phenomena such as autoignition, pre-ignition, and knock in the reciprocating engine. (See Technical Note 1405.) High-speed photography techniques are also being employed to study combustion in turbojet, ram jet and rocket engines.

Calculations for the performance of ram-jets, rockets, or other propulsion devices where the temperatures encountered in combustion are sufficiently high to induce dissociation are extremely laborious. As an aid to such calculations, charts for determining the reaction temperature and gas composition for fuel-oxidant mixtures having the elements carbon, hydrogen, oxygen, and nitrogen in the temperature range from 3,600° to 9,000° R. were compiled including dissociation effects.

The study of the theory of combustion-chamber pressure losses and the applications of this theory to the analysis of the performance of turbo-jet engine combustion chambers and to the determination of gas temperatures in ram jet nozzles by means of pressure measurements was continued. Technical Note 1180 presents some of the results of this study.

Nomenclature

The Subcommittee on Combustion recognized the need for standard combustion symbols to facilitate the exchange of technical information and to provide a basis for comparison of results obtained by various investigators. They have prepared a list of suggested standard symbols for combustion research. This list, entitled "Proposed Symbols for Combustion Research," has been distributed to persons in industry and in universities concerned with combustion problems, and will be available as Technical Note 1507.

SUBCOMMITTEE ON HEAT-RESISTING MATERIALS

Theory of Solids

The fatigue type of failure has been successfully analyzed by the use of rate-process and dislocation theory, and the endurance limit of materials at room temperature has consequently been determined in parameters defined in terms of the physical properties of materials. A relation has been established between

the creep and fatigue mechanisms of failure. A qualitative analogy of the dislocation process has been set up utilizing a lattice composed of bubbles, and the resultant action under stress has been studied by motion pictures. The NACA method of analysis of stress-rupture failures was successfully applied to four high-temperature alloys of gas-turbine significance.

Crystal Structure and Phase Relations

The crystal structures of six representative cast heat-resisting alloys have been determined by X-ray diffraction methods. The main phase of each alloy was found to be of face-cubic symmetry and the values of the lattice parameters ranged from 3.5525 to 3.5662 Å. The possible phase changes with temperature of 10 wrought high-temperature alloys were investigated by means of an elevated temperature X-ray diffraction unit, by a dilatometer, and by hardness measurements. Only the chromium-nickel base alloy 19-9W-Mo manifested a discernible phase transition at temperatures up to 1,800° F. In an attempt to better understand the mechanisms of failure a study was made of the effects of alpha and gamma radiation on an aluminum alloy. With sources of 100-millicuries strength, no discernible effects were noted in the elevated temperature creep properties or the age hardenable characteristics at low and room temperatures.

Evaluation of Alloys

Contract research at the University of Michigan has been continued in this field. Turbine disk forgings have been investigated and their physical properties reported in Technical Note 1230, and other reports to be available shortly. This same investigation has produced results on high-temperature properties of several sheet materials and cast materials. (See Technical Notes 1465, 1314, and 1380.) All of the results show that the effects of heat treatment and other processing variables can influence the physical properties of the alloys more than changes in composition. Creep and stress rupture data are presented for the alloys at one or more temperatures between 1,200° F. and 1,800° F.

Ceramics

A combustion chamber lined with ceramic material supplied by the National Bureau of Standards showed excellent refractory properties in a range of temperatures of combustion up to nearly the stoichiometric temperature of gasoline and air. Linings of this type are one means of increasing combustion chamber life. Coatings have also been found effective in protecting molybdenum metal instrument probes in ram-jet engines. Despite molybdenum's high melting point of

approximately 4,700° F. it cannot be used at elevated temperatures without protection from oxidation.

In the investigation of materials for use at elevated temperatures in gas turbines, an experimental investigation of the tensile properties of a sillimanite refractory material was made (Technical Note 1165). It was found that the strength-density ratio of this material compared very favorably with that of high-temperature metals. It was also found that the tensile strength of the material actually increased at high temperature and that the tensile strength at low temperature was improved by heat transfer. Because of these encouraging results, turbine blades were constructed of a similar material of a sillimanite base and were mounted in a specially constructed turbine wheel for investigation under operating conditions. Successful operation was obtained up to a gas temperature of 1,725° F. and a tip speed of 520 feet per second (Technical Note 1399).

Research performed for the NACA at the National Bureau of Standards produced some interesting elevated temperature properties for several ceramic bodies. On the basis of strength-weight ratio these bodies compared favorably with alloys and, in fact, were superior as the temperatures approached 2,000° F.

SUBCOMMITTEE ON PROPULSION SYSTEMS

Comparative Performance of Several Engine Cycles

An analysis was made to determine the relative performance characteristics of the compound engine, the turbine-propeller engine, the turbojet engine, the turbo-ram-jet engine, the ram jet engine, and the rocket engine. The theoretical investigation included a comparison at both subsonic and supersonic flight speeds of the load-range characteristics of aircraft powered with these engine types. It is shown that the compound engine, which has the greatest weight per unit thrust and also the lowest specific fuel consumption, gives the longest range. As the speed is increased, the increased engine weight seriously reduces the disposable load that the airplane is capable of carrying and hence decreases the range. As the speed is increased it is therefore necessary to progress to engine types that provide successfully greater thrust per unit weight generally at the cost of an increased specific fuel consumption and hence decreased range. The results of this study are reported in Technical Note 1349.

Compound Engine

The compound engine, which generally consists of a reciprocating engine in combination with one or more exhaust-gas turbines appears more efficient than the conventional geared or turbo-supercharged engines. Analyses have been made (based on experimental data

obtained in studies of component performance) of various types of compound power plant over wide ranges of engine and flight operating conditions. The analyses have considered power plants utilizing turbines of the conventional steady-flow type and the intermittent-flow (blow-down) type.

Exhaust Process Analysis

Changes in exhaust-valve design and engine operating conditions affect the exhaust process of the reciprocating engine. An effective exhaust process is particularly important when consideration is given to compounding reciprocating engines with exhaust-gas turbines. An analysis of the factors that affect the exhaust process of a four-stroke-cycle reciprocating engine was made (Technical Note 1242) in order to provide means of evaluating exhaust-valve-design changes or variation in engine operating conditions as a means of improving the exhaust process. The analysis permits the estimation of the exhaust pressure near the end of the exhaust stroke. This estimated cylinder pressure is indicative of the adequacy of the exhaust-valve size and timing.

Experimental investigations of the effect of exhaust pressure on the performance of several reciprocating engines have been completed, and satisfactory methods of correlating the data have been found. The results show that, in general, an increase in exhaust pressure results in a decrease in engine power and charge-air flow becomes greater as the valve overlap is increased. The results of the investigations have been reported in Technical Notes 1220, 1232, and 1367.

Jet Propeller

A theoretical analysis has been made of a propeller powered by gas jets issuing from the tips of the blades. In the propeller considered, air is drawn through the hub and passes through the hollow blades to the tips where burners heat the air and expel it through tangential nozzles in the blade tips.

A jet-operated propeller would be very light as compared with the conventional reciprocating engine and propeller. Analysis shows, however, that the fuel consumption would be several times as great. (See Technical Note 1155.) The practical application of a jet-operated propeller depends therefore on the saving in weight and simplicity of manufacture compensating for the high fuel consumption.

AIRFRAME CONSTRUCTION RESEARCH

COMMITTEE ON AIRCRAFT CONSTRUCTION

The NACA research program on airframe construction has been conducted by the Langley Memorial Aero-

nautical Laboratory and supplemented by a considerable number of research contracts with universities and other non-profit scientific organizations. The increasing flight speeds have introduced numerous new problems in this field, and it has become necessary to review constantly the research program so as to take full advantage of all new developments. During the past year the Committee on Aircraft Construction has aided the NACA in this review and in the establishment of an adequate program. The results of this program are presented herein according to subcommittee fields of interest.

SUBCOMMITTEE ON AIRCRAFT STRUCTURAL DESIGN

With the increasing speed of aircraft, the aerodynamic and performance requirements of the airplane are tending more and more to influence the structure of the airplane. The wing must be thin to minimize drag and control difficulties, and it must have high torsional stiffness to prevent flutter and to maintain effective control. These aerodynamic and performance requirements result in a wing structure with a relatively thick skin, and methods must be found to utilize this thick skin as efficiently as possible so as not to increase the weight unnecessarily.

With the increasing size of aircraft, the flexibility of the structure becomes of importance even though the airplane may not be of an extremely high speed type. The more flexible the structure, the greater will be the deformation under given loads. The deformation may affect not only the aerodynamic characteristics, but also the distribution of stresses. It is therefore desirable that these deformations be limited where possible, and that methods be available for the accurate calculation of their magnitude. With an accurate knowledge of the deformations, then proper account can be taken in both aerodynamic and structural calculations.

The Langley Memorial Aeronautical Laboratory has been actively engaged during the past year studying the structural problems of high-speed aircraft. Research has also continued on the study of stiffened thin-skin construction, although at a decreased rate of effort because the problems of stiffened thin-skin design have been extensively treated as compared to some of the problems introduced by the higher flight speeds. In addition to these two major fields of effort, numerous individual problems which effectively contribute to the efficient design of aircraft structures, have been studied. Some of these individual problems are sufficiently basic to be applicable to either high- or low-speed flight.

Wing Stiffness of High-Speed Aircraft

The wings of high-speed aircraft are subject not only to strength but also to certain stiffness requirements, for the wing stiffness affects the flutter speed, the aileron effectiveness, the divergence speed, and other characteristics. The conventional methods of beam analysis yield stiffness results of uncertain accuracy because of the effects of cut-outs, shear lag, and restrained cross-sectional warping. Relatively refined stress theories have been developed for the stress analysis of such wings, and these theories have now been applied to permit a more accurate determination of the wing stiffness. Bending as well as torsional deflections are considered for wings without or with cut-outs (Technical Note 1361).

Minimum-Weight Design of Multiweb Wings

Because of the small thickness of thin high-speed wings, some designers are considering the use of a type of construction that employs a number of shear webs with no intermediate stiffening of the skin (multiweb wing). Accordingly, a method was developed for the determination of the buckling stress of a multiweb wing in bending; and design charts based on this method were developed for the minimum-weight design of multiweb wings of 24S-T aluminum alloy sheet, extruded 75S-T aluminum alloy, and extruded O-1HTA magnesium alloy. These charts will be helpful in designing wings of the multiweb type for a wide range of design requirements (Technical Note 1323).

Buckling of Curved Plates and Shells

The current emphasis on aircraft designed for very high speed has required the use of thin wings with thick skins and relatively few stiffening elements. In such construction a very large percentage of the load is carried by the skin, and thus ability to predict accurately the behavior of the skin under load has become very important. As a part of the program designed to fill this need, an investigation was initiated to provide the designer with more information on the buckling strength of curved sheet than had been available in the past. This investigation was primarily theoretical, making use of a new approach to the problem of determining the buckling loads of curved plates and cylinders under simple or combined stresses with various edge conditions. All theoretically computed results were checked against the available experimental data, and where necessary semi-empirical corrections were introduced for use in design. The results of the investigation are embodied in curves convenient for practical use in a series of eight NACA Technical Notes (Technical Notes 1341 to 1348).

Swept Wings

For some very high speed aircraft the wings are swept back in order to delay the effects of compressibility. This change in the wing structure introduces different stress distributions from those that would occur in a conventional wing structure, especially near the root of the wing, and present methods of stress analysis are therefore not adequate. An experimental investigation of the stress distribution in a swept back box beam under bending and torsional loads has been conducted.

Vibration and Flutter of Wing Structures

A knowledge of the vibration characteristics of aircraft structures is of fundamental importance to an understanding of the action of the structures under suddenly impressed loads. Most of the existing methods for determining the coupled modes and frequencies of airplane wings are lengthy and cumbersome to apply. Also, the methods have been developed for the nonswept wing, and cannot, in general, be applied to the swept wing. A study was therefore made with the view of developing a method which was quick to apply, easily understood, and which would apply to the swept wing. Such a solution has been found through use of the energy method in conjunction with power series. The important features of the method are that the nonswept wing is covered (the case of zero sweep) and that most types of vibration, either cantilever or free-free, uncoupled as well as coupled, can be found directly from the same set of characteristic equations.

Sandwich Panels

A type of construction that is of considerable interest at the present time is sandwich construction, that is, a low density core material with a high density layer of material on either side of the core. The high density material may be either plywood or metal. A panel made by this construction has the advantage of being very stiff for a given weight of panel because the load carrying material is displaced at a distance from the neutral axis of the panel. This type of construction may have considerable advantage in applications where stiffness is most important. A theoretical study of the buckling of sandwich panels has been made and a general small deflection theory for flat elastic sandwich plates has been developed.

An investigation of sandwich-type shells has also been conducted by the Massachusetts Institute of Technology under the Committee's sponsorship. The investigation has resulted in the development of a theory for small bending and stretching of sandwich-type shells, including the effect of transverse shear deforma-

tion and the effect of transverse normal stress deformation.

Skin-Stiffened Panels

A significant contribution during the past year has been the development of a new type of design chart which eliminates the laborious computations heretofore necessary to find the most efficient design of a longitudinally stiffened wing compression panel. Charts of this type for several stiffener sections and materials have been developed (Technical Note 1339).

A study to understand better the buckling action of Z-stiffened panels where the flange width of the Z-stiffener is small as compared to the web width has been conducted. This study was conducted on lipped Z-columns, since the physical action taking place during the failure of a lipped Z-column is similar to the action taking place during failure of a Z-stiffened panel. This study resulted in a theory which is in good agreement with experiment (Technical Note 1335).

A survey of the problem of the flat plate under normal pressure has been conducted, with the purpose of extracting from the literature as much useful information as possible for the aircraft designer. The survey included a general discussion of the flat plate under normal pressure, a discussion of existing solutions, consolidation of previous work into design data, and a review of the stiffened flat-plate problem. This survey was conducted by the California Institute of Technology under the Committee's sponsorship.

An investigation has been conducted by Brown University under sponsorship of the Committee on the bending of rectangular plates with large deflections. The theoretical analysis includes membrane stresses of curvature which were usually neglected in the classical theory of bending of thin elastic plates under lateral loads. Specific problems of uniformly loaded plates with boundary conditions which approximate the riveted sheet-stringer panels were solved.

When thick plate is used in aircraft structures the stresses may be so high that buckling of the plate will occur under plastic conditions. Consequently, as thicker plate is being considered for high speed aircraft, the plastic buckling of the plate is becoming of considerable importance. An investigation has been conducted by Brown University under the Committee's sponsorship on the plastic buckling of a rectangular plate under edge thrusts. The fundamental equations were developed on the basis of a new set of stress-strain relations for the behavior of a metal in the plastic range. The equation for the buckling of a simply compressed plate together with typical boundary conditions was developed and the results applied to calculating the buckling loads of various sections.

When a cut-out is made in the sheet elements of an

airplane structure, the interrupted stresses are forced to detour around the opening. As a consequence there is a concentration of stress near the edges of the cut-out requiring that a reinforcement be added. During the past year research has been completed on the reinforcement of rectangular and circular cut-outs in flat panels. In the case of rectangular cut-outs (Technical Note 1176) three types of coaming stringer were used: without reinforcement, with riveted reinforcement, or with integral reinforcement. It was found that the measured strains, which are proportional to stress, were in good agreement with a previously published theory for cut-outs with unreinforced coaming stringers.

In the case of circular cut-outs (Technical Note 1241) strain surveys were made around four reinforced cut-outs in an axially loaded tension panel. The results obtained showed the distribution of stringer and shear stresses in the panel and bending stresses in the reinforcing rings. From these results empirical methods were derived for estimating the maximum stringer stresses in the panel and for approximating the longitudinal stresses in the stringers and rings at the transverse center line of the cut-outs.

A study of reinforcement rings and frames in plane and curved sheet has been sponsored by the Committee at the Brooklyn Polytechnic Institute. The particular problem treated was the arrangement, by an inverse method, of the reinforcement in such a way that it was as nearly as possible equivalent to the part of the structure which had been cut out. Both circular cutouts in plane sheets and rectangular cutouts in thin-walled cylindrical shells were treated.

When a load is applied along the flange at the edge of a flat stiffened panel, some of the load is transmitted to the various stiffeners by the sheet, which is placed in shear by the action. An electrical computer has been constructed for the solution of this type problem, based on an electrical analogy. Several shear-lag and bolted-joint problems have been solved analytically and also by use of the computer (Technical Note 1281).

Diagonal Tension in Beam Webs

The shear webs inside of wings are often of the incomplete diagonal tension type. During the past year a previously published method for strength analysis for this type of beam has been revised, extended, and published. From this study a set of formulas and graphs covering all aspects of strength analysis were worked out, experimental data were obtained and the accuracy of the formulas were compared with the data. Revisions of some formulas have resulted in improved agreement with experimental stresses and with more rigorous theory, particularly with low ratios of applied shear to buckling shear. The scope of the experimental evi-

dence has been greatly increased, compared with previous work on this problem (Technical Note 1364).

As one part of the study of incomplete diagonal tension beams, strength tests were made of a number of 24S-T and Alclad 75S-T aluminum alloy shear webs to determine the effect of rivet or bolt holes on the shear strength. Data were obtained for webs which approached a condition of pure shear stress as well as for webs with well-developed diagonal tension. This study indicated that at the ultimate load the shear stresses on the cross section were nearly constant for all values of the rivet factor investigated if the other properties of the web were not changed (Technical Note 1177).

The engineering theory of incomplete diagonal tension in plane webs has been generalized in order to make it applicable to curved webs. Comparisons were made between calculated and experimental results for a number of stiffened cylinders subjected to torsional loads and the results show that theory predicts the stresses to about the same accuracy for curved webs as for plane webs. The failing stresses in the stringers in curved webs were predicted conservatively in all cases.

Stiffened Shells

Experimental data on stresses in reinforced circular cylinders obtained during the war indicated the inadequacy of the elementary theory of bending and torsion when applied to the relatively flexible shell structures used in airframe construction. The best theories presented became tedious and unwieldy when extended to nonuniform cylinders. Study of the problem led to the development of a recurrence formula for the stress analysis of reinforced circular cylinders loaded in the planes of their rings. In contrast to the elementary engineering analysis, deformation of rings and sheet were considered. The recurrence formula method enables the stress analyst to find the shear flows and direct stresses in the sheet, as well as the shear forces, axial forces, and bending moments in the rings.

In order to reduce the amount of computation involved in the stress analysis of relatively long reinforced cylinders an approximate method of analysis was developed. This approximate solution is suitable for the stress analysis of cylinders loaded at rings located two or more bays from external restraints (Technical Note 1219).

Additional work on this subject led to the development of charts for stress analysis of a reinforced circular cylinder. These charts facilitate the determination of the shear flows and direct stresses in the sheet of the cylinder as well as the shear forces, axial forces, and bending moments in the rings. Separate charts were prepared for each of three basic loading condi-

tions; a concentrated radial load, a concentrated tangential load, and a concentrated bending moment (Technical Note 1310).

With the increasing size of aircraft fuselages, a problem that has become important is that of the general instability failure. In this type of failure, the skin, stiffeners and reinforcing rings fail simultaneously. Consequently, it is important to be able to predict when a general instability failure may occur. Research has been conducted on this subject for a number of years with significant results being obtained: However, the problem has not as yet been adequately solved. During the past year an investigation was conducted under a research contract with the Brooklyn Polytechnic Institute on the general instability of monocoque cylinders, and resulted in a revised strain energy theory to assume a more general deflected shape at buckling. The theory was applied to four test cylinders with reasonable accuracy.

An experimental investigation was also conducted by the Brooklyn Polytechnic Institute on 18 cylinders with various skin thicknesses loaded under pure bending. The purpose of this investigation was to establish the critical value of a design parameter, above which failure would occur by general instability, and below which it would not occur by general instability.

The Brooklyn Polytechnic Institute has also investigated, under the Committee's sponsorship, the stresses in and the general instability of monocoque cylinders with cut-outs. A number of cylinders have been prepared and tested, and methods have been developed for the calculation of the stresses in the cylinders.

Investigations have been conducted at both Brooklyn Polytechnic Institute and University of Michigan on methods of stress analysis for fuselage rings.

Box Beams

The basic load carrying structure of many aircraft wings is a box of approximately rectangular cross section consisting of the front and rear spars and the top and bottom skins of the wing. This box is stressed by both bending and torsional loads. In the case of torsional loading the determination of the stress distribution in the box is a relatively simple problem, provided that the cross section of the box is not constrained in any manner against warping. In this case the Bredt formula for thin-walled torsion tubes is applicable. If some restraint is offered to warping as is always the case near the root of a wing, a set of secondary stresses is introduced in the box. In order to study the effect of wing taper on these secondary stresses, a special investigation was undertaken. Recurrence formulas were developed for use in calculating these secondary stresses and the results obtained by this method of computation have been compared with experimental data from tests

performed on tapered box beams. The results show good agreement between experimental and calculated values (Technical Note 1297).

SUBCOMMITTEE ON AIRCRAFT METALS

The majority of the research in the field of metals for airframe use has been carried out by research contracts with universities and other nonprofit scientific organizations. This research has complemented the program on materials for power plants discussed earlier.

Magnesium-Cerium Forging Alloys

While magnesium-cerium forging alloys have not been widely used in the past, they have been investigated experimentally, and the available data indicated that these alloys in the wrought condition possess an unusual combination of low density and relatively high mechanical properties for elevated temperature service up to at least 600° F. An investigation has been conducted under a research contract with Battelle Memorial Institute to improve the elevated temperature tensile properties and resistance to creep of these alloys. A large number of experimental compositions have been prepared by adding various alloying elements to the magnesium-cerium base, and from them the relative benefits of the alloying elements have been determined.

Effects of Corrosion

The United States Air Force, the Bureau of Aeronautics and the NACA sponsored a cooperative program at the National Bureau of Standards on the effects of salt water and atmospheric exposure on the corrosion rate of aircraft structural alloys. This program has been quite extensive and has extended over a number of years, with significant results being obtained as the program progressed. That phase of the program on the exposure of spotwelded aluminum alloy panels has been completed and includes the results of tests of 191 panels some of which were exposed to the weather and in the tidewater for periods up to 36 months. This work has proved particularly valuable in preparing specifications for protection and care of aircraft structures.

Fracture of Metals

Investigations leading to knowledge of the conditions under which metals will fracture have broad scientific and engineering interest. The importance of this subject to aircraft designers stems from two objectives: (1) To design parts that will not fracture during fabrication; (2) to design aircraft structures that will not fracture in service. As higher strength materials are used in order to provide lighter weight structures, it becomes increasingly important to have

detailed knowledge of the factors affecting their fracture strength, and a number of investigations on this subject have been completed during the past year.

The effects of circumferential notches on the fracturing characteristics of tensile test bars of 24S-T aluminum alloy were investigated by the Case Institute of Technology. Two variations in notch contour, that is notch radius and notch depth, were studied. The fracture stress for mildly notched bars was found to increase with increasing transverse tension, or increasing triaxiality, while the ductility decreased correspondingly. The effects of triaxial stress states, produced by circumferential V-type notches, on the fracturing characteristics of 24S-T, 75S-T, and 24S-TS6 aluminum alloys were also investigated by the Case Institute of Technology.

An investigation has been conducted at Pennsylvania State College in which the yield strength, ultimate strength, ductility, and plastic stress-strain relations of 24S-T aluminum alloy subjected to biaxial stresses were determined. Tubular specimens were used for the investigation and the biaxial stress states were produced by applying axial tensile loads in combination with internal pressures.

The effect of combined stresses on the fracture strength of 75S-T aluminum alloy has been investigated by the University of California. The combined stress states were obtained, as in the previously mentioned investigation, by applying axial loads and internal pressures to thin-walled drawn tubes. It was found that the alloy ruptures in substantial agreement with the critical shear stress law for fracture. The effects of other factors on the fracture strength of the 75S-T aluminum alloy were also discussed in the results of the investigation.

An investigation has also been conducted by the University of California to determine the relationship between stresses and plastic strains of wrought aluminum alloys for three types of loading, tension, compression, and torsion. A secondary objective was to identify which assumptions of an ideal theory of elastoplasticity are invalid for these alloys. It was found that universal stress-strain curves as predicted by the theory were not obtained with wrought aluminum alloys. The observed disagreement between theory and experiment was attributed to the invalidity of the assumptions of isotropy, constancy of volume, continuity of the metal, and linear stress-infinitesimal plastic strain relations. Fair correlation between the theory and experimental facts, however, was obtained with a cast and solution heat-treated magnesium alloy which behaved isotropically during plastic deformation. Correlation with some of the aluminum alloys was obtained for the compression and torsion data when

shear stresses were plotted as functions of effective strain, but no theoretical justification is available at present for this anomaly.

SUBCOMMITTEE ON NONMETALLIC AIRCRAFT MATERIALS

The NACA research in the field of nonmetallic aircraft materials has been concentrated upon materials which appear to have promise in primary and secondary structural applications. The majority of the research in this field, as in the case of aircraft metals, has been carried out by research contracts with universities and other nonprofit scientific organizations.

Adhesive-Adherent Systems

The fundamentals of adhesion have not been studied extensively in the past, and the experimental work has been concerned largely with the development and use of adhesives for industrial purposes including the aircraft industry.

During the past year the strength properties of various adhesive-adherent combinations have been determined as one phase of a longer range investigation of the nature of adhesion conducted by the National Bureau of Standards. The results of these tests give an indication of the specific attraction between the various materials and hence lead to a better understanding of the nature of adhesion. The results will also be instrumental in the selection of adhesion-adherent systems for the fundamental studies of adhesion that are still in progress.

Laminated Plastics

A knowledge of the effects of temperature on the strength properties of laminated plastics is becoming especially significant for high speed flight applications because the surface temperatures of aircraft increase with increasing speed. An investigation at the National Bureau of Standards sponsored by the NACA provided results of Izod impact and flexural tests on some selected laminated plastics, containing as the reinforcement: glass fabric, asbestos fabric, rayon fabric, cotton fabric, and high strength paper. During the past year, tests have been completed on the tensile and compressive properties of these same materials and throughout the same temperature range, that is, -70° to 200° F.

Sandwich Materials

An investigation has been conducted on the mechanical properties of paper-base honeycomb structures by the Forest Products Laboratory. Ten different resins were used in the investigation, and the mechanical properties included tension, compression and shear. As a result of the investigation it was found that the com-

pressive strength and tensile strength of the resin-impregnated paper honeycomb structures were lower than those of balsa wood, and that the modulus of rigidity, shear stress at proportional limit and shear strength compare favorably with the corresponding properties of balsa wood.

OPERATING PROBLEMS RESEARCH

With the expanded air traffic of the postwar years, the problems of safety of aircraft operation have been greatly emphasized. To effect the largest possible margin of safety to the passengers as well as to the flight crew, not only must the aircraft and power plant be well designed, but the flying technique must be such that safety is insured under all weather and operating conditions.

Problems of research relating to aircraft operations are carried on under the cognizance of the Committee on Operating Problems and its two subcommittees, the Subcommittee on Meteorological Problems and the Subcommittee on Deicing Problems.

COMMITTEE ON OPERATING PROBLEMS

Speed Control of High-Speed Transport

The modern high-speed transport airplane is aerodynamically clean and capable of inadvertently exceeding its maximum safe flying speed during descent. The importance and significance of this possibility were investigated in cooperation with an air carrier engaged in transcontinental and overseas operations. From a statistical analysis of data taken during a large number of flights, it was indicated that the probability of exceeding the airplane placard "never-exceed" speed is substantially greater than the probability of exceeding the critical Mach number of the airplane. Further, the probability of exceeding the "never-exceed" speed is sufficiently great so that the problem may be one of direct concern in the analysis of aircraft loads and the planning of operational techniques.

Ditching

The tremendous increase of overseas flying both during and since the war has focused attention to the problem of ditching, or the forced landing of landplanes on water. During the past year, in the continuation of an extensive program, dynamic models of four long-range military aircraft have been studied in the NACA towing tanks and by means of an outdoor catapult to determine and predict the ditching characteristics of the service airplane and to recommend ditching procedures which would provide minimum hazard to the crew as well as to the airplane.

Several of the large transport aircraft planned or

in use by the air lines also are currently being studied to determine their ditching characteristics.

Flying and Handling Qualities of Transport Aircraft

In cooperation with the air lines, the NACA has been conducting investigations of the flying and handling characteristics of transport aircraft to determine whether design requirements should be revised in light of the use of radio and radar blind-landing systems. The investigation thus far has substantiated the belief that present flying and handling requirements are satisfactory and that no special requirements are necessary to insure safe and easy operations with the various blind landing systems. The importance of complying with the flying qualities requirements has been reemphasized and in this particular investigation the necessity of taking special care to keep the friction in the control system to a minimum has been noted.

Cabin Heating, Cooling, and Ventilating

The problem of pilot and passenger comfort has been rendered much more difficult since sustained high-speed flight has become common. The modern high-speed, high-altitude airplane experiences heating due to solar radiation and aerodynamic or frictional heating on the airplane surface. Results of preliminary investigations indicate that cooling of the cockpits of proposed transonic and supersonic aircraft will be a major problem.

SUBCOMMITTEE ON DE-ICING PROBLEMS

Perhaps the greatest hazard to the regular operation of aircraft under all weather conditions is the danger of the formation of ice over critical regions on the surface of the airplane and in the various air ducts. Not only can ice formations seriously affect the performance, but under certain conditions can render the aircraft uncontrollable or cause stoppage of the engines.

The Committee's icing research program has been conducted at the Ames and Cleveland laboratories by using as research tools actual airplanes completely instrumented and flying in regions of natural icing. In addition, the Cleveland laboratory for the past several years has conducted wind-tunnel icing-research programs directed toward the elimination of the hazard of icing. During the year a technical conference was held at the Cleveland laboratory at which the latest research results obtained at the Committee's laboratories in the field of aircraft ice protection were presented to representatives of other Government agencies and the aircraft industry.

Thermal Ice Prevention

Results of previous research pointed to the possibility of utilizing waste heat from exhaust gas to prevent ice

formation on airplane surfaces. Extensive analytical and experimental investigations have proved the economic feasibility and the operational superiority of this method of ice prevention, and as a result, provisions for thermal ice prevention have been included in all new transport designs to be operated both by the services and by the airlines.

The comprehensive investigation of the fundamentals of thermal ice protection for airplane wings, empennages, windshields, and propellers has been continued. In general, this investigation consists of the determination of the meteorological conditions which produce icing conditions and the derivation of methods for the computation of the minimum heating requirements for ice prevention in these conditions. A thermally protected icing-research airplane was flown through natural icing conditions in regions covering a large portion of the United States to study and evaluate experimental installations and analytical techniques. Special meteorological equipment was developed and used to measure the important icing parameters, such as the amount of free water present in the atmosphere and the size of the cloud water drops. In addition, experimental apparatus such as electrically heated airfoil models, windshields, and propellers were used to establish basic heating requirements.

Meteorology

Data have been obtained during the flight research program on the physical characteristics of icing clouds and the meteorological processes producing these clouds. Analysis of these data has resulted in tentative specifications of the most probable maximum and the normal or typical icing condition. (Technical Notes 1391, 1392, 1393, and 1424.) These data also have provided an indication of the manner of formation of icing clouds, which is of considerable value in the forecasting of potential icing hazards to aircraft.

Wings and Empennages

In order to compute the heat required for the prevention of ice accretions on airfoil surfaces, it is important to determine the area over which water will impinge on the aircraft and the amount of ice that will be deposited. A method for the calculation of this information has been derived and checked by tests on electrically heated airfoil models (Technical Note 1397). This method is sufficiently reliable to permit generalized calculations to be made of any practical configuration with relatively little labor.

Windshields

As part of the over-all ice prevention program thermal methods of preventing ice formation on windshields have been studied. The double pane type of heated windshield has been proved to be satisfactory as have

various other internally air and electrically heated configurations. Empirical results from investigations of the various configurations have served as a guide for the development of a rational method for the design of windshield ice-prevention equipment. This method takes into account radiation, evaporation of impinging water, convection of heat to the surrounding air, as well as the characteristics of air and water paths in the vicinity of the windshield (Technical Note 1434).

Propellers

The large thrust losses associated with propeller icing make the problem very real and urgent. The requirements for propeller icing protection have been investigated for both externally and internally electrically heated blades as well as for hot-gas internally heated blades (Technical Note 1084). The theoretical and experimental results have established the hot-gas requirements for gas-heated propeller blades. The heat required for effective propeller protection is a fraction of the engine waste heat available. The power required for protecting propellers electrically, utilizing blade-heating elements attached externally to the blades or placed internally in the blades has also been studied (Technical Notes 1084 and 1178).

Jet Engine Inlets

The necessity of keeping jet engine inlets free from ice is of major importance since even partial blocking of the air intake may seriously impair the performance or even cause stoppage of this type of engine. Further, should ice enter the compressor serious structural damage might result. In view of the seriousness of this problem, an extensive program is being carried out both in flight and in the icing-research tunnel in order to develop means for the protection of these engines against icing.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

A detailed knowledge of the structure of the atmosphere is essential to the safe and efficient design and operation of all aircraft. Much of the information to be obtained is of a statistical nature and involves analyses of data obtained from large numbers of flights of aircraft over an extreme range of meteorological conditions.

During the past year, the NACA in cooperation with the United States Weather Bureau, the Air Force and the Navy, in the Thunderstorm project, has continued an investigation of turbulence associated with thunderstorms. This project is a continuation of one begun last year and is directed toward the elimination of the hazards presented by thunderstorms to the safe operation of aircraft. Fully instrumented airplanes have explored a number of thunderstorms up to altitudes of

30,000 feet. Valuable data on the structure and intensity of gusts and associated meteorological conditions in relation to airplane behavior and structural design have been obtained. Analysis of the large amount of data recorded during the flights is extremely time consuming and consequently not yet complete, but preliminary results indicate that good correlations between predicted and observed effects have been obtained which will aid to establish safe and valid design and operation criteria (Technical Note 1253).

The NACA has continued its analysis of data recorded in airplanes operated by several of the air lines and equipped with V-G and other special NACA recording instruments as well as in specially equipped research airplanes to obtain a clearer picture of gust structure and atmospheric turbulence under ordinary operating conditions. These data are important in determining the effects of gust structure and turbulence on airplane life and performance and also in devising means for the alleviation or circumvention of turbulence. Information obtained in the Langley gust tunnel under controlled conditions is correlated with these data in order to establish rational load factors to increase the life and safety of aircraft (Technical Notes 1320, and 1321).

UNIVERSITY RESEARCH

The NACA maintains a program of sponsored or contract research at educational and scientific institutions so that the skills and talents of the nation's aeronautical research scientists and technical facilities can be utilized to the fullest extent in connection with the Government's intensified aeronautical research program. By this means, eminent scientists, not otherwise available to the Government, contribute to the planned program and unique facilities are brought to bear on the solution of important research problems. A byproduct of this program is the training in research of promising students to serve as useful additions to the country's scientific manpower.

It has been possible under this program to engage some of the nation's foremost aerodynamicists, mathematicians, physicists, chemists, and engineers in the study of the complex phenomena existing in connection with the design and operation of modern aircraft and power plants. The fields covered in the contract research program embrace practically all the fields included within the framework of the subcommittees, and some of the work has been described in earlier sections of this report.

In the field of theoretical high-speed aerodynamics, new classes of mathematical equations have been developed in an effort to solve the complex problems arising in the study of transonic and supersonic flows and

existing methods have been investigated in order to extend their utility. The problem of flutter of high-speed aircraft has been studied in order that reliable estimates of the flutter characteristics may be made for aircraft in the design stage. The determination and prediction of flutter characteristics is exceedingly complex and involved mathematically so that only scientists with a high degree of training and understanding can appreciate the problems and hope to effect solutions. The effects of heat and turbulence on the characteristics of jet flows have assumed primary importance and these problems have been investigated through the use of university research facilities and personnel specially qualified in these fields. The characteristics of swept-back and low-aspect-ratio wings have been studied in university wind tunnels. Other aerodynamic research problems including boundary-layer effects, rotating-wing theory, aircraft noise reduction, and aircraft and missile stability have been successfully attacked in the contract research program.

Much of the increase in efficiency and endurance of jet engines is attributed to advances resulting from studies of heat-resisting alloys conducted under the sponsorship of the NACA. This research has occupied an important position in the over-all program as improved high-strength heat-resistant alloys offer the most promise for further increases in the performance of jet engines.

Educational institutions have always been prominent in the field of aircraft structural design and stress analysis and work of this type has been actively pursued as part of the committee's contract research program. New theories and methods for the design and analysis of specialized structures have resulted from research carried out under contract. Other researches include the investigation of promising new structural alloys and nonmetallic materials and the study of the fatigue life of aircraft structures. Further detailed discussions of the programs conducted under contract are included in the subcommittee discussions.

In summary, the contract research program of the NACA constitutes an important part of the over-all NACA research picture and serves to help fill in gaps and round out the program of the Nation to maintain this country's leadership in the field of aeronautics.

COORDINATION OF RESEARCH AND DISTRIBUTION OF RESEARCH INFORMATION

Coordination of aeronautical research is accomplished partially through the activities of the NACA technical committees and subcommittees. Inasmuch as the members of these committees consist of representatives from

the different Government organizations as well as those from civil life the Committee is in a particularly advantageous position to be advised on the work being conducted on aeronautics. The membership of the committees is such as to discourage duplication of research effort except where such duplication is desirable. At the meetings of these technical committees and subcommittees the members report on activities in their field that will be of interest to the NACA. In addition, they review the research being conducted by the NACA and make recommendations as to its continuance, to any changes desirable in the research program, and to any additional fields of research in which knowledge is necessary and on which work is not being done.

In order to further coordinate the aeronautical research efforts and prevent duplication of research, the office of Research Coordination functions in conjunction with a West Coast representative who maintains close contact with the aeronautical research staffs of that geographical area. A number of discussions pertaining to aeronautical research between NACA personnel and the research staffs of the aircraft and engine manufacturers and of the educational and scientific institutions were coordinated and reported through the Committee's coordination office.

In addition to these activities of the Committee, there are numerous informal conferences held between staffs of the NACA laboratories and members of the military or other Government services, with members of industrial organizations, and with members of university staffs. The purpose of these informal discussions is to examine the work being conducted at the Committee's laboratories and so insure that the appropriate Government and private organizations are receiving full benefit of the NACA research.

During the past year the Committee has held eight technical conferences at its laboratories in which the following topics were discussed:

1. Supersonic aerodynamics.
2. Airplanes for private ownership.
3. Gas turbine engine compressors.
4. Gas turbine engine turbines.
5. Combustion.
6. Ram jets.
7. High temperature materials.
8. Ice prevention.

Each of these conferences was attended by 100 or more members from the Government services and those industrial organizations that had contracts with the Department of National Defense on projects related to the subject under discussion. At these conferences the staff of the NACA laboratories presented papers on the latest information being obtained at the laboratories. Following the presentation of the papers the

visitors exchanged their views on the work of the Committee and on any changes that were advisable in the research programs.

The research results obtained in the Committee's laboratories are distributed in the form of Committee publications. Two of these publications, Technical Reports and Technical Notes, contain information that is not classified and so is available to the public in general. The Technical Reports contain information considered to be of major importance. The Technical Notes contain results that are of transitory interest or results which should be made immediately available to a large number of organizations, but which will later be presented in a more complete Technical Report. Translations of foreign material are issued in the form of Technical Memorandums. In addition to these unclassified reports the Committee prepares each year a large number of reports in which the results are of a classified nature. These reports for reasons of national security are controlled in their circulation. From time to time the various classified reports issued by the Committee are examined to determine whether or not it is in the national interest to continue the classification. If it is found desirable to declassify the reports, they are then published in one of the standard NACA forms.

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral part of the Committee's activity. Its functions are the collection and classification of technical knowledge on the subject of aeronautics, including the results of research and experimental work conducted in all parts of the world, and its dissemination to the Department of National Defense, aircraft manufacturers, educational institutions, and others interested. American and foreign reports obtained are analyzed, classified, and brought to the attention of the proper persons through the medium of public and confidential bulletins. Foreign reports are translated and where practical are issued in the form of Technical Memorandums previously mentioned.

To handle efficiently the work of procuring and exchanging reports in foreign countries, the Committee prior to World War II maintained a technical assistant in Europe. It was his duty to visit the governmental and private laboratories in European countries and to procure for the United States not only printed matter, but more especially advance information as to the work in progress and technical data not prepared in printed form. The Office of Technical Assistant in Europe will be reopened as soon as the necessary arrangements can be completed.

The NACA has continued the publication of such

wartime reports as have been declassified, in the War-time Report form mentioned in last year's annual report. The issuance of these wartime reports should be completed during the 1948 fiscal year.

By act of Congress approved July 2, 1926 (U. S. C. title 10, sec. 310-r), an Aeronautical Patents and Design Board was established consisting of the Assistant Secretaries for Air 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 is charged with the function of analyzing and reporting upon the technical merits of aeronautical inventions and designs submitted to any agency of the Government. The Aeronautical Patents and Design 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 volume of aeronautical inventions, designs, and suggestions for the improvement of aircraft received by the Committee has greatly increased. This increase reflects the rapid growth of general public interest in flying which was accelerated during the war period.

Recognizing its obligation to the public in this respect the Committee has continued to accord to all correspondence on such matters full consideration. All proposals received have been carefully analyzed and evaluated and the submitters have been duly advised concerning the probable merits of their suggestions. Many personal interviews have been granted inventors who visited the Committee's offices, and technical information has been supplied when requested.

TECHNICAL REPORTS

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| No. | |
| 752. | On a New Method for Calculating the Potential Flow Past a Body of Revolution. By Carl Kaplan. |
| 753. | Methods Used in the NACA Tank for the Investigation of the Longitudinal-Stability Characteristics of Models of Flying Boats. By Roland E. Olson and Norman S. Land. |
| 754. | Operating Temperatures of a Sodium-Cooled Exhaust Valve as Measured by a Thermocouple. By J. C. Sanders, H. D. Wilsted and B. A. Mulcahy. |
| 755. | Requirements for Satisfactory Flying Qualities of Airplanes. By R. R. Gilruth. |
| 756. | The Induction of Water to the Inlet Air as a Means of Internal Cooling in Aircraft-Engine Cylinders. By Addison M. Rothrock, Alois Krsek, Jr., and Anthony W. Jones. |
| 757. | The Measurement of Fuel-Air Ratio by Analysis of the Oxidized Exhaust Gas. By Harold C. Gerrish and J. Lawrence Meem, Jr. |

- No. 758. Performance of NACA Eight-Stage Axial-Flow Compressor Designed on the Basis of Airfoil Theory. By John T. Sinnette, Jr., Oscar W. Schey and J. Austin King.
759. Derivation of Charts for Determining the Horizontal Tail Load Variation With Any Elevator Motion. By Henry A. Pearson.
760. A Method of Estimating the Knock Rating of Hydrocarbon Fuel Blends. By Newell D. Sanders.
761. Identification of Knock in NACA High-Speed Photographs of Combustion in a Spark-Ignition Engine. By Cearcy D. Miller and H. Lowell Olsen.
762. A Theoretical Investigation of the Lateral Oscillations of an Airplane with Free Rudder with Special Reference to the Effect of Friction. By Harry Greenberg and Leonard Sternfield.
763. Tests of Airfoils Designed to Delay the Compressibility Burble. By John Stack.
764. A Method for Calculating Heat Transfer in the Laminar Flow Region of Bodies. By H. Julian Allen and Bonne C. Look.
765. Exhaust-Stack Nozzle Area and Shape for Individual Cylinder Exhaust-Gas Jet-Propulsion System. By Benjamin Pinkel, L. Richard Turner, Fred Voss and LeRoy V. Humble.
766. Aerodynamic and Hydrodynamic Tests of a Family of Models of Flying-Boat Hulls Derived from a Streamline Body.—NACA Model 84 Series. By John B. Parkinson, Roland E. Olson, Eugene C. Draley and Arvo A. Luoma.
767. The Problem of Longitudinal Stability and Control at High Speeds. By Manley J. Hood and H. Julian Allen.
768. The Flow of a Compressible Fluid Past a Curved Surface. By Carl Kaplan.
769. The Effect of Mass Distribution on the Lateral Stability and Control Characteristics of an Airplane as Determined by Tests of a Model in the Free-Flight Tunnel. By John P. Campbell and Charles L. Seacord, Jr.
770. Jet-Boundary Corrections for Reflection-Plane Models in Rectangular Wind Tunnels. By Robert S. Swanson and Thomas A. Toll.
771. Review of Flight Tests of NACA C and D Cowlings on the XP-42 Airplane. By J. Ford Johnston.
772. Determination of General Relations for the Behaviour of Turbulent Boundary Layers. By Albert E. von Doenhoff and Neal Tetervin.
773. Analysis of Heat and Compressibility Effects in Internal Flow Systems and High-Speed Tests of a Ram-Jet System. By John V. Becker and Donald D. Baals.
774. Effect of Tilt of the Propeller Axis on the Longitudinal Stability Characteristics of Single-Engine Airplanes. By Harry J. Goett and Noel K. Delany.
775. The Theory of Propellers. I—Determination of the Circulation Function and the Mass Coefficient for Dual-Rotating Propellers. By Theodore Theodorsen.
776. The Theory of Propellers. II—Method for Calculating the Axial Interference Velocity. By Theodore Theodorsen.
777. The Theory of Propellers. III—The Slipstream Contraction with Numerical Values for Two-Blade and Four-blade Propellers. By Theodore Theodorsen.
778. The Theory of Propellers. IV—Thrust, Energy, and Efficiency Formulas for Single- and Dual-Rotating Propellers With Ideal Circulation Distribution. By Theodore Theodorsen.
- No. 779. The Effect of Increased Cooling Surface on Performance of Aircraft-Engine Cylinders as shown by Tests of the NACA Cylinder. By Oscar W. Schey, Vern G. Rollin and Herman H. Ellerbrock, Jr.
780. Compressible Potential Flow with Circulation about a Circular Cylinder. By Max A. Heaslet.
781. Wind-Tunnel Procedure for Determination of Critical Stability and Control Characteristics of Airplanes. By Harry J. Goett, Roy P. Jackson and Steven E. Belsley.
782. Wall Interference in a Two-Dimensional-Flow Wind Tunnel, with Consideration of the Effect of Compressibility. By H. Julian Allen and Walter G. Vincenti.
783. Compressibility and Heating Effects on Pressure Loss and Cooling of a Baffled Cylinder Barrel. By Arthur W. Goldstein and Herman H. Ellerbrock, Jr.
784. Intercooler Cooling-Air Weight Flow and Pressure Drop for Minimum Drag Loss. By J. George Reuter and Michael F. Valerino.
785. Preknock Vibrations in a Spark-Ignition Engine Cylinder as Revealed by High-Speed Photography. By Cearcy D. Miller and Walter O. Logan, Jr.
786. Performance of Blowdown Turbine Driven by Exhaust Gas of Nine-Cylinder Radial Engine. By L. Richard Turner and Leland G. Desmon.
787. A Theoretical Investigation of the Rolling Oscillations of an Airplane with Ailerons Free. By Doris Cohen.
788. On the Plane Potential Flow Past a Lattice of Arbitrary Airfoils. By I. E. Garrick.
789. On the Flow of a Compressible Fluid by the Hodograph Method. I—Unification and Extension of Present-Day Results. By I. E. Garrick and Carl Kaplan.
790. On the Flow of a Compressible Fluid by the Hodograph Method. II—Fundamental Set of Particular Flow Solutions of the Chaplygin Differential Equation. By I. E. Garrick and Carl Kaplan.
791. A Theoretical Investigation of Longitudinal Stability of Airplanes with Free Controls Including Effect of Friction in Control System. By Harry Greenberg and Leonard Sternfield.
792. Flight Studies of the Horizontal-Tail Loads Experienced by a Fighter Airplane in Abrupt Maneuvers. By the Flight Research Maneuvers Section—LMAL.
793. Experiments on Drag of Revolving Disks, Cylinders, and Streamline Rods at High Speeds. By Theodore Theodorsen and Arthur Regier.
794. The Flow of a Compressible Fluid Past a Circular Arc Profile. By Carl Kaplan.
795. The NACA Impact Basin and Water Landing Tests of a Float Model at Various Velocities and Weights. By Sidney A. Batterson.
796. An Interim Report on the Stability and Control of Tailless Airplanes. By Langley Stability Research Division—Compiled by Charles J. Donlan.
797. Application of Spring Tabs to Elevator Controls. By William H. Phillips.
798. Effect of Hinge-Moment Parameters on Elevator Stick Forces in Rapid Maneuvers. By Robert T. Jones and Harry Greenberg.
799. Charts for the Determination of Wing Torsional Stiffness Required for Specified Rolling Characteristics or Aileron Reversal Speed. By Henry A. Pearson and William S. Aiken, Jr.

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- No. 1086. Distribution of Structural Weight of Wing Along the Span. By V. V. Savelyev. From Central Aero-Hydrodynamical Institute Report No. 331, 1939.
1087. Strength Investigations in Aircraft Construction Under Repeated Application of the Load. By E. Gassner. From Luftwissen, Vol. 6, No. 2, Feb. 1939, pp. 61-54.
1088. A Camera for Obtaining Profile Photographs of Propellers and Model Airfoils. By R. Kuhl and K. Raab. From Luftwissen, Vol. 5, No. 5, May 1938, pp. 183-185.
1089. Investigation of Flow in a Centrifugal Pump. By Karl Eisner. From Mitteilungen des Hydraulischen Institutes der Technischen Hochschule München, No. 4, 1931.
1090. On the Problem of Stress Corrosion. By L. Graf. From Luftwissen, Vol. 7, No. 5, May 1940, pp. 160-169.
1091. The Effect on the Sperry Directional Gyro in Turning. By Rossello Rosselli Del Turco. From Atti Di Guidonia, No. 18, Oct. 6, 1939, pp. 373-380.
1092. On Laminar and Turbulent Friction. By Theo. Von Karman. From Zeitschrift für Angewandte Mathematik und Mechanik, Vol. 1, No. 4, August 1921, pp. 233-252.
1093. The Further Development of Heat-Resistant Materials for Aircraft Engines. By Franz Bollenrath. From Luftfahrtforschung, Vol. 14, No. 4-5, April 20, 1937, pp. 196-203.
1094. Investigation of the Behavior of Thin-Walled Panels with Cutouts. By A. A. Podorozhny. From Central Aero-Hydrodynamical Institute Report No. 454, 1939.
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1098. The Oscillating Circular Airfoil on the Basis of Potential Theory. Parts I & II. By Th. Schade (Pt. I) K. Krienen & Th. Schade (Pt. II) From Luftfahrtforschung, Dec. 10, 1940, pp. 387-400 (Pt. I) Luftfahrtforschung, Aug. 20, 1942, pp. 282-291 (Pt. II).
1099. Airscrew Gyroscopic Moments. By G. Bock. From Luftwissen, Vol. 8, No. 3, March 1941, pp. 96-97.
1100. Infinitesimal Conical Supersonic Flow. By Adolf Busemann. From Deutschen Akademie der Luftfahrtforschung, 1942-43, pp. 455.
1101. Investigations of Pressure Distribution on Fast Flying Bodies. By G. Stamm. From ZWB, UM 8103, August 18, 1944.
1102. High Speed Measurements on a Swept-Back Wing (Sweep-back Angle $\phi=35^\circ$). By B. Gothert. From Lillienthal-Gesellschaft für Luftfahrtforschung, Report 156, p. 30-40.
1103. Calibration Tunnel for High Speed. By J. Pretsch. From AVA Göttingen.
1104. The Influence of the Jet of a Propulsion Unit on Nearby Wings. By H. Falk. From ZWB, UM 3200, Dec. 28, 1944.
1105. Plane and Three-Dimensional Flow at High Subsonic Speeds. By B. Gothert. From Lillienthal Gesellschaft 127.

TECHNICAL MEMORANDUMS

Large amounts of the material translated from the German are parts of two regular series of reports. Reference will be made to these series of German reports by abbreviations defined as follows:

- ZWB—Zentrale für Wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters
(German Central Publication Office for Aeronautical Reports)
- FB —Forschungsbericht
(Research Report)
- UM —Untersuchungen und Mitteilungen
(Reports and Memoranda)

- No. 1084. Kinetics of Chemical Reactions in Flames. By Y. Zeldovich and N. Semenov. From Journal of Experimental and Theoretical Physics (USSR) Vol. 10, 1940, pp. 1116-1123.

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1110. On Combustion in a Turbulent Flow. By K. I. Shelkin. From *Journal of Technical Physics (U.S.S.R.)* Vol. XIII, Nos. 9-10, 1943.
1111. The Monoplane as a Lifting Vortex Surface. By Hermann Blenk. From *Zeitschrift für angewandte Mathematik und Mechanik*, Vol. 5, No. 1, February 1925.
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Part II

COMMITTEE ORGANIZATION AND MEMBERSHIP

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915, and the membership increased from 12 to 15 by act approved March 2, 1929 (U. S. C. title 49, sec. 241). Its members are appointed by the President and include two representatives each of the Air Force and of the Navy Department, two representatives of the Civil Aeronautics Authority (Civil Aeronautics Act of 1938), one representative each of the Smithsonian Institution, the United States Weather Bureau, and the National Bureau of Standards, together with six additional persons who are "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." These latter six serve for terms of 5 years. The representatives of the Government organizations serve for indefinite periods. All members serve as such without compensation.

During the period since the publication of the Committee's last annual report, for the year 1946, the following changes have occurred in the membership of the main Committee:

Rear Adm. Lawrence B. Richardson, U. S. N., submitted his resignation effective December 1, 1946, because of his retirement from the Navy, and Rear Adm. Leslie C. Stevens was appointed to succeed him.

Also effective December 1, 1946, the President reappointed Dr. Vannevar Bush and Mr. Arthur E. Raymond, members from private life, for 5-year terms.

Vice Adm. Donald B. Duncan, U. S. N., was appointed a member under date of February 24, 1947, to succeed Vice Adm. Arthur W. Radford, upon replacing the latter as Deputy Chief of Naval Operations (Air).

On June 19, 1947, the President appointed Rear Adm. Theodore C. Lonnquest, U. S. N., to succeed Admiral Stevens, transferred to duty away from Washington.

Hon. John R. Alison, Assistant Secretary of Commerce for Air, was appointed a member of the Committee under date of August 25, 1947, as successor to Hon. William A. M. Burden, who resigned from the Committee because of his resignation as Assistant Secretary of Commerce.

In accordance with the regulations governing the organization of the Committee as approved by the President, the Chairman and Vice Chairman are elected annually, as are also the Chairman and Vice Chairman of the Executive Committee.

On October 23, 1947, Dr. Jerome C. Hunsaker was reelected Chairman of the NACA and of the Executive Committee. Dr. Alexander Wetmore was elected Vice Chairman of the NACA, succeeding Dr. Theodore P. Wright, and Dr. Francis W. Reichelderfer was reelected Vice Chairman of the Executive Committee.

SUBCOMMITTEES

Under the main Committee there are standing technical committees, with subcommittees, to prepare and recommend to the main Committee the programs of research, to coordinate research needs, and to act as mediums of interchange of ideas and information, in their respective special fields. In addition, it is the policy of the Committee to establish from time to time special technical subcommittees for the study of particular problems as they arise.

The 6 principal committees and their 20 subcommittees as organized in 1947 were as follows:

COMMITTEE ON AERODYNAMICS

Dr. Theodore P. Wright, Administrator of Civil Aeronautics, Chairman.
Dr. Hugh L. Dryden, National Advisory Committee for Aeronautics, Vice Chairman.
Col. C. K. Moore, U. S. A. F., Air Matériel Command.
Brig. Gen. Donald L. Puff, U. S. A. F., Air Matériel Command.
Capt. Walter S. Diehl, U. S. N., Bureau of Aeronautics.
Mr. F. A. Loudon, Bureau of Aeronautics, Department of the Navy.
Mr. Harold D. Hoekstra, Civil Aeronautics Administration.
Mr. John F. Parsons, NACA Ames Aeronautical Laboratory.
Mr. Floyd L. Thompson, NACA Langley Memorial Aeronautical Laboratory.
Mr. Paul S. Baker, Chance Vought Aircraft, United Aircraft Corp.
Mr. John G. Borger, Pan American Airways System.
Prof. Joseph H. Keenan, Massachusetts Institute of Technology.
Mr. L. E. Root, Douglas Aircraft Company, Inc.
Mr. George S. Schairer, Boeing Airplane Co.
Dr. William R. Sears, Cornell University.
Dr. Theodore von Karman, California Institute of Technology.
Mr. Fred E. Weick, Engineering and Research Corp.

Subcommittee on High-Speed Aerodynamics

Dr. Hugh L. Dryden, National Advisory Committee for Aeronautics, Chairman.
Mr. R. G. Robinson, National Advisory Committee for Aeronautics, Vice Chairman.
Mr. H. L. Anderson, Air Matériel Command, U. S. Air Force.
Col. J. A. Gibbs, U. S. A. F., Air Matériel Command.

Mr. R. H. Kent, Ballistics Research Laboratory, Ordnance Department.
 Mr. F. A. Loudon, Bureau of Aeronautics, Department of the Navy.
 Dr. R. J. Seeger, Naval Ordnance Laboratory.
 Mr. Paul C. Spiess, Civil Aeronautics Administration.
 Mr. H. Julian Allen, NACA Ames Aeronautical Laboratory.
 Mr. John Stack, NACA Langley Memorial Aeronautical Laboratory.
 Mr. Abe Silverstein, NACA Flight Propulsion Research Laboratory.
 Dr. Francis H. Clauser, Johns Hopkins University.
 Mr. Harold Luskin, Douglas Aircraft Co.
 Mr. Vladimir Morkovin, University of Michigan.
 Mr. C. Pappas, Republic Aviation Corp.
 Mr. Allen Puckett, California Institute of Technology.
 Prof. John von Neumann, The Institute for Advanced Study, Princeton.

Subcommittee on Stability and Control

Capt. Walter S. Diehl, U. S. N., Bureau of Aeronautics, Chairman.
 Mr. Melvin Shorr, Air Matériel Command, U. S. Air Force.
 Mr. Joseph Matulaitis, Civil Aeronautics Administration.
 Mr. Harry J. Goett, NACA Ames Aeronautical Laboratory.
 Mr. H. A. Soule, NACA Langley Memorial Aeronautical Laboratory.
 Mr. William M. Harcum, Sperry Gyroscope Co., Inc.
 Mr. E. R. Heald, Douglas Aircraft Co., Inc.
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 Prof. Otto Koppen, Massachusetts Institute of Technology.
 Mr. W. F. Milliken, Jr., Cornell Aeronautical Laboratory.
 Prof. C. D. Perkins, Princeton University.
 Mr. Charles Tilgner, Grumman Aircraft Engineering Corp.

Subcommittee on Internal Flow

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 Col. Paul H. Kemmer, U. S. A. F., Air Matériel Command.
 Mr. Parker M. Bartlett, Bureau of Aeronautics, Department of the Navy.
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 Mr. Abe Silverstein, NACA Flight Propulsion Research Laboratory.
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 Dr. William Bollay, North American Aviation, Inc.
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Part III

FINANCIAL REPORT

Appropriations for fiscal year 1947.—Funds in the following amounts were appropriated for the Committee for the fiscal year 1947 in the Independent Offices Appropriation Act, 1947, approved March 28, 1946, and the Act providing increased pay costs, 1947, approved March 29, 1947:

Salaries and expenses.....	\$27,540,000
Printing and binding.....	75,000
Construction and equipment of laboratory facilities:	
Langley Memorial Aeronautical Laboratory.....	2,990,000
Flight Propulsion Research Laboratory.....	108,000
Total appropriations.....	30,713,000

Obligations incurred during the fiscal year 1947 are listed below. The figures shown are total obligations and include the costs of personal services, travel, transportation, communication, utility services, contractual services, supplies, and equipment.

Salaries and expenses:	
Headquarters office, Washington, D. C.....	\$622,296
Langley Memorial Aeronautical Laboratory.....	11,687,315
Ames Aeronautical Laboratory.....	3,927,356
Flight Propulsion Research Laboratory.....	10,169,438
Research contracts—educational institutions.....	250,120
Transfer to National Bureau of Standards.....	107,584
Printing and binding, all activities.....	74,794

Construction and equipment of laboratory facilities:

Langley Memorial Aeronautical Laboratory.....	\$2,989,633
Flight Propulsion Research Laboratory.....	107,987
Total obligations.....	29,936,523
Unobligated balances:	
Salaries and expenses.....	775,891
Printing and binding.....	200
Construction and equipment.....	380
Total appropriations.....	30,713,000

Appropriations for the fiscal year 1948.—Funds in the following amounts were appropriated for the Committee for the fiscal year 1948 in the Independent Offices Appropriation Act, 1948, approved July 30, 1947:

Salaries and expenses.....	\$33,490,000
Printing and binding.....	80,000
Construction and equipment of laboratory facilities:	
Langley Memorial Aeronautical Laboratory.....	6,452,350
Ames Aeronautical Laboratory.....	193,700
Flight Propulsion Research Laboratory.....	3,232,950
Total appropriations.....	43,440,000 ¹

¹ Plus additional contract authority for construction and equipment of laboratory facilities in the amount of \$2,143,000.