

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

1948

INCLUDING TECHNICAL REPORTS
NOS. 892 to 921



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CONTENTS

	Page
Letter of Transmittal.....	V
Letter of Submittal.....	vii
Thirty-Fourth Annual Report.....	1
PART I. TECHNICAL ACTIVITIES.....	3
AERODYNAMIC RESEARCH.....	3
PROPULSION RESEARCH.....	22
AIRFRAME CONSTRUCTION RESEARCH.....	32
OPERATING PROBLEMS RESEARCH.....	41
RESEARCH SPONSORED IN SCIENTIFIC AND EDUCATIONAL INSTITUTIONS.....	44
COORDINATION OF RESEARCH AND DISTRIBUTION OF RE- SEARCH INFORMATION.....	44
PART II. COMMITTEE ORGANIZATION.....	53
PART III. FINANCIAL REPORT.....	58
TECHNICAL REPORTS.....	59

TECHNICAL REPORTS

No.	Page	No.	Page
892. Damping in Pitch and Roll of Triangular Wings at Supersonic Speeds. By Clinton E. Brown and Mac C. Adams, NACA.....	59	907. Equations for the Design of Two-Dimensional Supersonic Nozzles. By I. Irving Pinkel, NACA.....	293
893. Velocity Distributions on Two-Dimensional Wing-Duct Inlets by Conformal Mapping. By W. Perl and H. E. Moses, NACA.....	69	908. Stability Derivatives of Triangular Wings at Supersonic Speeds. By Herbert S. Ribner and Frank S. Malvestuto, Jr., NACA.....	317
894. On Similarity Rules for Transonic Flows. By Carl Kaplan, NACA.....	83	909. Laminar-Boundary-Layer Oscillations and Transition on a Flat Plate. By G. B. Schubauer and H. K. Skramstad, National Bureau of Standards.....	327
895. Analysis of Variation of Piston Temperature with Piston Dimensions and Undercrown Cooling. By J. C. Sanders and W. B. Schramm, NACA.....	89	910. Summary of Drag Characteristics of Practical-Construction Wing Sections. By John H. Quian, Jr., NACA.....	359
896. Pressure-Sensitive System for Gas-Temperature Control. By Richard S. Cesaro and Norman Matz, NACA.....	99	911. Lifting-Surface-Theory Aspect-Ratio Corrections to the Lift and Hinge-Moment Parameters for Full-Span Elevators on Horizontal Tail Surfaces. By Robert S. Swanson and Stewart M. Crandall, NACA.....	379
897. Knocking-Combustion Observed in a Spark-Ignition Engine with Simultaneous Direct and Schlieren High-Speed Motion Pictures and Pressure Records. By Gordon E. Osterstrom, NACA.....	107	912. The Interdependence of Various Types of Autoignition and Knock. By H. Lowell Olsen and Cearcy D. Miller, NACA.....	395
898. A Unified Theory of Plastic Buckling of Columns and Plates. By Elbridge Z. Stowell, NACA.....	127	913. Experiments on Stability of Bunsen-Burner Flames for Turbulent Flow. By Lowell M. Bollinger and David T. Williams, NACA.....	411
899. A General Small-Deflection Theory for Flat Sandwich Plates. By Charles Libove and S. B. Batdorf, NACA.....	139	914. Effect of Centrifugal Force on the Elastic Curve of a Vibrating Cantilever Beam. By Scott H. Simpkinson, Laurel J. Eatherton and Morton B. Millenson, NACA.....	417
900. The Use of Source-Sink and Doublet Distributions Extended to the Solution of Boundary-Value Problems in Supersonic Flow. By Max. A. Heaslet and Harvard Lomax, NACA.....	157	915. Extension of Useful Operating Range of Axial-Flow Compressors by Use of Adjustable Stator Blades. By John T. Sinnette, Jr., and William J. Voss, NACA.....	425
901. Analysis of Effect of Basic Design Variables on Subsonic Axial-Flow-Compressor Performance. By John T. Sinnette, Jr., NACA.....	173	916. Correlation of the Drag Characteristics of a Typical Pursuit Airplane Obtained From High-Speed Wind-Tunnel and Flight Tests. By James M. Nissen, Burnett L. Gadeberg, and William T. Hamilton, NACA.....	453
902. Subsonic Flow Over Thin Oblique Airfoils at Zero Lift. By Robert T. Jones, NACA.....	195	917. The Effects of Aerodynamic Heating and Heat Transfer on the Surface Temperature of a Body of Revolution in Steady Supersonic Flight. By Richard Scherrer, NACA.....	463
903. Theoretical and Experimental Data for a Number of NACA 6A-Series Airfoil Sections. By Laurence K. Loftin, Jr., NACA.....	203	918. Theoretical Motions of Hydrofoil Systems. By Frederick H. Imlay, NACA.....	473
904. Estimation of F-3 and F-4 Knock-Limited Performance Ratings for Ternary Blends Containing Triptane or Other High-Antiknock Aviation-Fuel Blending Agents. By Henry C. Barnett, NACA.....	225	919. Accuracy of Airspeed Measurements and Flight Calibration Procedures. By Wilber B. Huston, NACA.....	499
905. Full-Scale Investigation of the Aerodynamic Characteristics of a Typical Single-Rotor Helicopter in Forward Flight. By Richard C. Dingeldein and Raymond F. Schaefer, NACA.....	249	920. The Development and Application of High-Critical-Speed Nose Inlets. By Donald D. Baals, Norman F. Smith, and John B. Wright, NACA.....	535
906. Determination of Stresses in Gas-Turbine Disks Subjected to Plastic Flow and Creep. By M. B. Millenson and S. S. Manson, NACA.....	277	921. Theoretical Symmetric Span Loading at Subsonic Speeds for Wings Having Arbitrary Plan Form. By John DeYoung and Charles W. Harper, NACA.....	593

Letter of Transmittal

To the Congress of the United States:

In compliance with the provisions of the Act of March 3, 1915, as amended, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Thirty-fourth Annual Report of the Committee covering the fiscal year 1948.

HARRY S. TRUMAN.

THE WHITE HOUSE.

APRIL 5, 1949.

Letter of Submittal

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Washington, D. C., March 30, 1949.

DEAR MR. PRESIDENT: In compliance with the Act of Congress approved March 3, 1915, as amended (U. S. C. 1946, Title 50, Sec. 153), I have the honor to submit herewith the Thirty-fourth Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1948.

The Committee's research programs during the past year were conducted in an atmosphere of urgency as a consequence of the fact that the speed of sound has been repeatedly exceeded by a special research airplane. This achievement was the culmination of an effort, in cooperation with the armed services, to verify theoretical and laboratory predictions. It may be the most significant event in aeronautics since the first flight of the Wright brothers, and will certainly influence plans for national security.

The new problems of flight at very high speeds are complex and difficult. Special aerodynamic and propulsion problems are encountered in each of the three speed regimes: supersonic, transonic, and subsonic. Satisfactory solutions to these problems must be combined in the high-speed airplane to permit stable, controllable, and efficient flight at all speeds. Aerodynamic information recently obtained, together with improved jet propulsion power plants, gives assurance that continued scientific research can provide the engineering knowledge necessary for the design of tactical airplanes to operate at the higher speeds now required.

The importance of superior airplanes to implement the policy of the United States to preserve peace has been dramatically emphasized by the Berlin Air Lift. Continuation of American leadership in the air depends to a greater extent than ever before upon scientific research. A vigorous program of aeronautical research, experimentation, and development should be prosecuted by scientific, military, and industrial agencies, coordinated as provided for in the approved National Aeronautical Research Policy.

Respectfully submitted,

JEROME C. HUNSAKER,
Chairman.

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

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 50, sec. 151). Its membership was increased to 17 by act approved May 25, 1948 (Public Law 549, 80th Congress). The members are appointed by the President, and serve as such without compensation.

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

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HON. JOHN R. ALISON, Assistant Secretary of Commerce.

DETLEV W. BRONK, Ph. D., President, Johns Hopkins University.

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JAMES H. DOOLITTLE, Sc. D., Vice President, Shell Union Oil Corp.

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WILLIAM LITTLEWOOD, M. E., Vice President, Engineering, American Airlines, Inc.

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EDWARD M. POWERS, Major General, United States Air Force, Assistant Chief of Air Staff-4.

JOHN D. PRICE, Vice Admiral, United States Navy, Deputy Chief of Naval Operations (Air).

ARTHUR E. RAYMOND, M. S., Vice President, Engineering, Douglas Aircraft Co., Inc.

FRANCIS W. REICHELDERFER, Sc. D., Chief, United States Weather Bureau.

HON. DELOS W. RENTZEL, Administrator of Civil Aeronautics, Department of Commerce.

HOYT S. VANDENBERG, General, Chief of Staff, United States Air Force.

THEODORE P. WRIGHT, Sc. D., Vice President for Research, Cornell University.

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 Aeronautical Laboratory, Langley Field, Va.

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

EDWARD R. SHARP, Sc. D., Director, Lewis Flight Propulsion Laboratory, Cleveland Airport, Cleveland, Ohio

TECHNICAL COMMITTEES

AERODYNAMICS
POWER PLANTS FOR AIRCRAFT
AIRCRAFT CONSTRUCTION

OPERATING PROBLEMS
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 AERONAUTICAL LABORATORY,
Langley Field, Va.

LEWIS FLIGHT PROPULSION LABORATORY,
Cleveland Airport, Cleveland, Ohio

AMES AERONAUTICAL LABORATORY,
Moffett Field, Calif.

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-FOURTH ANNUAL REPORT OF THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Washington, D. C., November 29, 1948.

To the Congress of the United States:

In accordance with the act of Congress approved March 3, 1915 (U. S. C. title 50, sec. 151), which established the National Advisory Committee for Aeronautics, the Committee submits herewith its thirty-fourth annual report for the fiscal year 1948.

Last year it was stated that flight at supersonic speeds by practical, manned airplanes is one of the major goals of research and development in this country and elsewhere, and that this goal could be attained by any nation that would make the effort. A first, most important step in this direction was taken in October 1947 when the USAF X-1 airplane was first flown at a speed greater than that of sound. This airplane and the Navy D-558 are examples of the especially designed, constructed, and instrumented research airplanes of a cooperative project among the NACA, the military services, and the aircraft industry. This achievement may be the most significant event in aeronautics since the Wright brothers' first flight, and certainly is one to influence our future concept of national security.

Although flight at supersonic speeds is now a reality, it cannot yet be considered practical. The flights of the X-1 airplane represent virtually only laboratory accomplishments in view of the elaborate supporting efforts that are involved and the special nature of the airplane. The technical importance of these flights and others in the high subsonic region made by the D-558 airplanes resides in the scientific information that is being obtained about the problems of flight at high speeds.

The quantitative data obtained from these flights, and the reports of the Air Force and NACA pilots who have flown at supersonic speeds, have given an unforeseen stimulus to aircraft designers. Fear of an unknown sonic barrier has been dispelled by a better knowledge of the problems of transonic flight. Moreover, it now appears possible to build aircraft which can be safely controlled within the transonic region. The stimulus of the X-1 accomplishment is known to have extended to other countries, and it must be presumed to have a world-wide effect.

These events are of considerable military significance. Speed is the most valuable single characteristic of aircraft, particularly military. Superior speed is essential to supremacy in the air.

Because of these considerations, an adequate program of aeronautical research and development on problems of high-

speed flight is essential to national security. The Committee feels the necessity for accelerating its efforts to accumulate scientific data and design information as quickly as possible. This is especially necessary now since all of our present military aircraft can enter the transonic speed region in dives, and improved models of more refined design and increased power will encounter flight conditions for which basic design information is still lacking.

The same need for acceleration of effort is evident in the power-plant field. To attain transonic and supersonic speeds much more propulsive thrust is required from the engine. The turbojet with afterburner and the ram jet each offer great possibilities, and research on both should be accelerated. Research must be accelerated to insure that the special fuels on which these engines operate and their special metals of construction can be supplied in sufficient quantities to meet requirements in an emergency.

An adequate program means fundamental scientific research, applied research, and engineering development. These require time. The current performance of our aircraft rests on the applied research and engineering development of the immediately preceding years, and this applied research and development, in turn, rests on preceding scientific research.

The law provides that the National Advisory Committee for Aeronautics shall "supervise and direct the scientific study of the problems of flight, with a view to their practical solution," and authorizes the Committee to "direct and conduct research and experiment in aeronautics." In meeting this responsibility the Committee endeavors to assess the current status of development of aircraft, civil and military, piloted and pilotless; to anticipate the needs for scientific research and engineering data so far as possible; and to provide staff and facilities to obtain the desired information at a rate determined by consideration of the national interest.

The research of the NACA is directed toward the over-all objective of acquiring new scientific knowledge essential to assure American leadership in aeronautics. The immediate objective is to solve, as quickly as possible, the most pressing problems attendant on high-speed flight. Beyond this immediate objective, the Committee continues to direct its research to the needs of military, commercial, and private aviation to obtain the scientific information to permit flight at increasing speeds to be accomplished in a safer and more economical manner.

As a consequence of the similarity of the basic objectives of both military and civil aviation—to carry greater loads faster, farther, and more economically—scientific 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.

The great costs and manpower requirements of modern aeronautical research and development require teamwork in planning the country's aeronautical future. The relationship between various governmental agencies and the aircraft industry with regard to aeronautical research and development is defined by the National Aeronautical Research Policy. Under the terms of this policy, the Committee's activity is directed toward the solution of the scientific problems of flight. Research of the NACA is not considered complete until results are tested by sufficient practical application, but NACA research does not include the design or development of specific aircraft or equipment.

To assist in discharging its duties and in determining research needs, the Committee has established standing technical committees on aerodynamics, power plants, operating problems, and construction. The members of these committees, serving as such without compensation, are especially qualified representatives of the Government agencies concerned and experts from private life. The Committee has also established an Industry Consulting Committee to advise it as to general research policy, especially with regard to the needs of industry.

The committees recommend 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 special skills and facilities that may be available there. The sponsored research projects in universities also inherently assist the educational process in providing aeronautical scientists and engineers.

Aviation has progressed to the frontier of supersonic flight where intensive research effort will result in unprecedented gains in aircraft performance. National security requires that these potential gains be realized.

The Committee is saddened to report the death on July 12, 1948, of Dr. George William Lewis, who had served as Director of Aeronautical Research from November 6, 1919, to September 1, 1947. A tribute to the accomplishments of Dr. Lewis was contained in the preceding annual report, following his resignation as Director of Aeronautical Research.

Parts I, II, and III of the annual report present a résumé on the scientific activities of the Committee, the technical publications issued, and the Committee's financial report.

Respectfully submitted,

JEROME 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 Aeronautical Laboratory, Langley Field, Va.; Ames Aeronautical Laboratory, Moffett Field, Calif.; and Lewis Flight Propulsion Laboratory, Cleveland, Ohio. A subsidiary station is located 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 subsidiary station is located at Muroc Lake, Calif., for research on transonic and supersonic airplanes in flight. The laboratory at Cleveland was renamed the Lewis Flight Propulsion Laboratory on September 28, 1948, at the Second Annual Inspection in memory of Dr. George William Lewis, past Director of Aeronautical Research of the National Advisory Committee for Aeronautics.

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 coordinating aeronautical research, 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 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 five 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. Industry Consulting Committee.

The research conducted by the Committee results either from recommendations of its main committees and subcommittees or from the requests originating within the Department of National Defense and other branches of the Government. The information coming from these investigations is presented in the Committee's technical publications and also in special technical conferences. These conferences have the important advantage of transmitting quickly and efficiently the latest information in a particular field of research directly to the engineers and designers working in that field. During the past year a series of technical conferences was held at the Committee's three main laboratories with representatives of the military services and the aircraft industry covering the subjects of aerodynamics, aircraft structures, and aircraft power plants.

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. Since it is mostly of a classified nature it can be referred to only briefly in this unclassified annual report.

AERODYNAMIC RESEARCH

Progress in aerodynamic research during the past year has been more rapid perhaps than in any other year since the Wright brothers' first powered flight. While the recent successes in transonic and supersonic flight research are generally expected to lead to successful military airplane and missile designs capable of useful performance at such speeds, these results have really served to point out the tremendously large number of detailed technical problems which must be solved through additional highly specialized research and development.

The Committee on Aerodynamics, assisted by the Subcommittees on High-Speed Aerodynamics, Stability and Control, Internal Flow, Propellers for Aircraft, Helicopters, and Seaplanes and the Special Subcommittee on the Upper Atmos-

phere, has reviewed research in progress by the NACA and other agencies and recommended problems that should be investigated, including relative priorities in a number of cases.

The historic flights of this period in excess of the speed of sound have provided an additional stimulus in the design of high-speed aircraft which has resulted in a tremendous increase in the demand for detailed technical data to provide a sound basis for transonic-aircraft design. It was apparent to the Committee on Aerodynamics that additional detailed research throughout the transonic speed range would be required to meet this demand. Accordingly, at its May 7, 1948, meeting, the Committee on Aerodynamics recommended the appointment of a special subcommittee to con-

sider the immediate needs of the aircraft designers and to recommend the direction and concentration of effort in the NACA's limited transonic-research facilities. The Executive Committee concurred in this recommendation, and a special subcommittee on the Research Problems of Transonic Aircraft Design was appointed on May 28, 1948. The subcommittee undertook an intensive study of the situation during June and July, arriving at specific recommendations that, with the concurrence of the Aerodynamics Committee and the Executive Committee, are being implemented at the Committee's laboratories.

COMMITTEE ON AERODYNAMICS

Airfoils

Because of considerable interest in modified NACA four-digit-series airfoil sections, theoretical pressure distributions were calculated and experimental aerodynamic characteristics were determined in the Langley two-dimensional low-turbulence pressure tunnel for a selected group of these sections. The results of this investigation, reported in Technical Note 1591, indicate that, when the modification consisted of moving the maximum thickness to 40 percent chord without changing the leading-edge radius, the maximum lift characteristics very closely approximated those of smooth NACA 64-series low-drag sections of corresponding thickness and camber. Minimum drag coefficients were, however, higher than those of corresponding NACA 64-series airfoils. When the leading-edge radius was then reduced to a quarter of the normal value, the maximum lift coefficients were about 35 percent lower than those of NACA 64-series sections of corresponding thickness and camber; but minimum drag coefficients were about the same as those of corresponding NACA 64- and 66-series sections. Increases in the trailing-edge angle resulting from rearward movement of the position of maximum thickness caused sharp decreases in the lift-curve slope and pronounced forward movement of the aerodynamic center.

In order to provide data for the design of small personal-type aircraft, the aerodynamic characteristics of six airfoil sections of interest in this connection were studied at low Reynolds numbers in the Langley two-dimensional low-turbulence tunnel. A comparison of the results obtained with the previously existing data for higher Reynolds numbers showed that the minimum drag coefficient of each of the smooth airfoils increased progressively as the Reynolds number was reduced from 9,000,000 to 700,000, and that the magnitude of this effect increased with thickness ratio. Decreasing the Reynolds number also caused a reduction in the maximum lift coefficient of all the airfoils both in the smooth condition and with rough leading edges.

An NACA 66^(w)-210 airfoil with a special mean-camber line designed to produce a high critical Mach number was investigated at low speeds in the Langley two-dimensional low-turbulence pressure tunnel. In Technical Note 1633, by the use of data previously obtained in the Langley low-turbulence tunnel and high-speed data obtained in the Ames 1- by 3½-foot high-speed tunnel, the aerodynamic characteristics

of this airfoil were compared at both low and high speeds with those for the NACA 66-210, $\alpha=1.0$ airfoil. The high-speed data indicated that the airfoil with the special mean line had a drag-divergence Mach number at the design lift coefficient slightly higher than that of the NACA 66-210, $\alpha=1.0$ airfoil section, but this increase was not so great as that shown by calculations, based on low-speed data, of the critical Mach numbers.

In an effort to improve the maximum lift and stalling characteristics of moderately thick airfoils, modifications of the contour very near the leading edge have been investigated at the Ames Laboratory. The study was initiated using an NACA 63₁-012 section and various leading-edge radii. In addition, the effects of a nose flap have been investigated. The modifications to the airfoil section contour did not produce the desired improvement in maximum lift and stalling characteristics. However, studies on this problem are being continued.

High-Lift Devices

As an aid to the designer, available data on plain, split, and slotted flaps were collected and analyzed. The effects of each of the variables involved in the design of the various types of flap were examined and, in cases where there were sufficient data, optimum configurations have been deduced.

In order to extend the range of data available on slotted flaps on thin airfoils, the aerodynamic characteristics of an airfoil approximating an NACA 65₍₁₁₎ A111 section and equipped with an 0.35-chord slotted flap were determined in the Langley two-dimensional low-turbulence tunnels for Reynolds numbers ranging up to 25,000,000 and reported in Technical Note 1463. The optimum flap deflection and the optimum location of the flap leading edge were found for the different Reynolds numbers. In general, increasing the Reynolds number delayed the stall to higher section angles of attack and also caused a more gradual stall for both the flap-retracted and the flap-deflected configurations.

For the very thin wings that are desirable for high-speed flight, reasonable maximum lift and stall characteristics require not only trailing-edge flaps but also leading-edge flaps or similar devices capable of effectively increasing the nose camber. An NACA 65A006 airfoil equipped with a drooped nose flap and a plain trailing-edge flap was investigated at high Reynolds number and low Mach numbers in the Langley low-turbulence pressure tunnel. The results of the investigations indicated that at Reynolds numbers up to 9,000,000 the optimum combination of drooped nose and plain trailing-edge flaps investigated increased the maximum section lift coefficient.

A further investigation was conducted in the Langley two-dimensional low-turbulence pressure tunnel to determine the effect of leading-edge flaps on the maximum lift coefficient of an NACA 64-009 airfoil and to compare the results with data obtained from previous investigations of similarly shaped flaps on an NACA 64₁-012 airfoil. The investigation included tests of two 10-percent-chord leading-edge flaps, one designed to extend by sliding forward along the upper surface and the other to hinge at the center of the airfoil leading-

edge radius and deflect from the lower surface. The flaps were tested on the plain airfoil and on the airfoil with a trailing-edge split flap deflected 60° . The results, presented in Technical Note 1624, indicate that the upper-surface leading-edge flap was, in general, a more effective high-lift device than the lower-surface leading-edge flap, especially when used alone on the plain airfoil; however, with rough leading edges, the two flaps were about equally effective. Either type of flap causes a forward shift in the aerodynamic center at high angles of attack.

Wings

The wings of aircraft designed to fly at transonic Mach numbers are, in general, characterized by thin airfoil sections and in most cases also by low aspect ratio and considerable sweep. The maximum lift coefficients normally obtainable with such wings are low. A number of investigations have therefore been conducted by the NACA laboratories with the objective of improving the characteristics of wings of various plan forms appropriate for use in high-speed aircraft. The available results of these investigations, together with pertinent two-dimensional data on the development of thin sections with high section lift coefficients, have been reported. The correlation between the characteristics of swept and unswept wings has also been briefly indicated. The principal conclusions of this study are that maximum lift coefficients in the neighborhood of 1.3 to 1.6 (depending on the angle of sweep) can be obtained with the best combinations of split flaps and leading-edge devices investigated and that, insofar as maximum lift is concerned, the importance of the airfoil section decreases as the sweep increases and as the thickness of the airfoil decreases. The drag at high lift coefficients is shown to be of great importance in determining the power-off rate of descent or, alternatively, the amount of power required for landing. Leading-edge high-lift devices are shown in most cases to be effective in improving the aerodynamic characteristics of the wings in the high-lift range.

An investigation has been conducted in the Langley 19-foot pressure tunnel at a Reynolds number of about 7,000,000 to determine the characteristics of various trailing-edge flaps and stall-control devices on a 37° -sweptback wing of aspect ratio 6, having NACA 64-series airfoil sections. A combination of a half-span leading-edge device and a half-span split or double-slotted flap produced acceptable lift coefficients.

A number of investigations at high Reynolds numbers to determine the effects of high-lift devices on the aerodynamic characteristics of wings utilizing 10-percent-thick, circular-arc airfoil sections have been conducted in the Langley full-scale tunnel. The wings investigated include a trapezoidal wing, a rectangular wing, and a sweptback wing. In general, the landing characteristics of the wings indicated that the inherently high gliding and sinking speeds are alleviated by the use of drooped nose flaps or extensible leading-edge flaps and aggravated by trailing-edge flaps. The longitudinal stability of the unswept wings was satisfactory, and lift characteristics could be satisfactorily calculated from theory.

An investigation has been conducted in the Langley 19-foot pressure tunnel on a 42° -sweptback wing with NACA 64₁-112

airfoil sections to study devices for increasing the maximum lift and improving longitudinal stability. A combination of leading-edge flaps or slats over the outer portion of the wing and trailing-edge split flaps over the inner portion of the wing produced a reasonable maximum lift coefficient and longitudinally stable characteristics at the stall.

Theoretical calculations reported last year indicated that a wing of the highest possible aspect ratio with sweepback of 60° or 65° should be capable of attaining flight efficiencies at Mach numbers up to 1.5 which are comparable with those of fighter airplanes flying at subsonic speeds. A coordinated program was undertaken at the Ames Laboratory to determine the aerodynamic characteristics of a 63° -sweptback wing throughout the speed range available in the various facilities. The Ames 7- by 10-foot wind-tunnel section has investigated various controls and lift-increasing devices on a semispan model of this configuration. Tests of the 63° -sweptback wing in the Ames 12-foot pressure tunnel have indicated only minor effects of compressibility at the highest Mach number tested.

Of the wing plan forms suitable for flight at moderate supersonic speeds, triangular wings combine the structural efficiency of low aspect ratio and high taper with the aerodynamic efficiency of a highly sweptback leading edge. Consideration of the available low-speed data on low-aspect-ratio pointed wings has indicated that the landing and take-off problems, especially with respect to stability and control, may be less severe than those encountered with the more efficient supersonic plan forms combining high sweep with high aspect ratio. As part of a general program of systematic research on a wing of triangular plan form at the Ames Laboratory, tests have been made in the 12-foot pressure wind tunnel of a triangular wing of aspect ratio 2. The tests were conducted at constant Reynolds numbers of 3,500,000 and 5,300,000 for various Mach numbers and at a constant Mach number of 0.18 at Reynolds numbers up to 27,500,000.

Results of these studies indicated that no serious longitudinal stability problems would be encountered in flight with such a wing at the highest Mach number reached. The lift-to-drag ratios at the landing condition were very small and, for the configuration which was tested, it is indicated that a landing without power would not be feasible.

In the study of a general triangular-wing design at the Ames Laboratory, pressure distributions have been obtained over the wing surface in an effort to reach a better understanding of the flow phenomena controlling the wing characteristics. The effects of adding a vertical tail and a fuselage having a fineness ratio of 12.5 to the basic wing have also been determined. A clearer picture of the problems associated with the use of such wings now exists, but the best manner of overcoming these problems remains to be determined.

For flight at Mach numbers above about 2, wing sweep, which is beneficial in delaying the effects of compressibility as long as the wing is swept behind the Mach cone, is no longer structurally feasible because of the large amount of sweep requisite to the attainment of subcritical flow over the wing. Calculations have shown that, at these Mach numbers, a very thin sharp-edged wing without sweep may be superior

in performance to a swept wing which is not swept behind the Mach cone. To investigate the characteristics of such a straight wing at high subsonic speeds, tests have been made in the Ames 12-foot pressure tunnel of a wing of aspect ratio 4 and taper ratio 0.5 with a very thin supersonic airfoil section. Tests were conducted on this model for several constant Reynolds numbers over a range of Mach numbers. At low speeds, data were obtained at Reynolds numbers up to 10,000,000.

As is usually the case with unswept wings, the aerodynamic center of the wing moved forward with increasing Mach number at Mach numbers below the critical. Because of the combination of low aspect ratio and extremely small wing-thickness ratio, the total movement of the aerodynamic center was small for the Mach number range.

The characteristics of three unswept wings with aspect ratio of 10 and thick root sections, determined experimentally in the Langley 19-foot pressure tunnel, are presented and compared with calculated results in Technical Note 1677. The airfoil sections used were of the NACA 44 series, 230 series, and low-drag 64 series. For the flap-neutral smooth-model condition, excellent agreement was obtained between the calculated and experimental characteristics in most cases. No definite trend was observed which would indicate that the degree of correlation obtainable depends on the airfoil section within the range of variables investigated. In a similar comparison, 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 were also found to be in excellent agreement with experimental characteristics determined in the Langley 19-foot pressure tunnel. This work was reported in Technical Note 1422.

In order to help correlate wind-tunnel and flight investigations, a study was made in the Langley full-scale tunnel of the effects of time rate of change of angle of attack, idling propeller operation, and Reynolds number on the maximum lift coefficient of a single-engine fighter-type airplane. This study is reported in Technical Note 1639. Airplane rotation in pitch increased the maximum lift coefficient, as did propeller operation, even with the propeller idling at a negative thrust coefficient. The wind-tunnel results were compared with flight-test measurements of the maximum lift coefficient of the same airplane. Exact agreement was found for the flaps-up configuration; with flaps down, the wind-tunnel maximum lift coefficient was 0.09 below that obtained in flight, which represents a difference of 2 miles per hour in the stalling speed.

Boundary-Layer Investigations

The characteristics of the boundary layer on an NACA 0009 airfoil equipped with plain sealed flaps have been investigated and are reported in Technical Note 1574. This work was performed primarily for the purpose of defining as completely as possible the flow conditions on models that had previously been used to obtain control-surface force and

moment data and will be used for developing the theory of boundary-layer effects on control surfaces.

In Technical Note 1479 the boundary-layer momentum equations for the three-dimensional flow of a fluid with variable density and viscosity are presented in a form similar to the momentum equation for two-dimensional flow. The equations can be reduced to Prandtl's three-dimensional momentum equations for a fluid with constant density and viscosity. When the flow becomes two-dimensional, Von Kármán's momentum equation results. For the flow of a fluid with constant density and viscosity in a convergent or divergent channel, the equations reduce to those of Kehl.

In Technical Note 1644 the laminar flow of a slightly viscous incompressible fluid that issues from a slit and passes over a flat plate is investigated in a region far enough from the slit for the boundary-layer equations to be valid. The partial differential equation for the boundary layer is reduced to a third-order nonlinear ordinary differential equation, which is integrated by numerical means for the required boundary conditions. The solution gives the velocities at points in the fluid and the surface friction at points on the plate.

As a continuation of the study of the boundary-layer and stalling characteristics of airfoil sections, an NACA 63-009 section has been investigated at the Ames Laboratory. This investigation is part of a long-range program to provide a better understanding of the mechanism of separation of air flow from a surface and the stalling of airfoils. Detailed measurements of the boundary layer indicated that the stall resulted from the failure of a separated laminar layer to re-attach itself to the airfoil surface. There was some indication that this phenomenon is similar to the boundary-layer flow associated with the critical Reynolds number of cylinders. The stall was abrupt, but the loss in lift was not large. After the stall, totally new flow conditions were set up. The flow about the stalled airfoil was suggestive of that about very thin or sharp-edged sections (flat plates) prior to their maximum lift. Circulation apparently was lost and lift was due primarily to the dynamic effects of the air stream.

A comparative study of boundary-layer flow at transonic and low speeds is reported in Technical Note 1623. It was found that a significant portion of low-speed boundary-layer theory could be extended for application to transonic flows.

Basic studies have been made of the possibility of obtaining, through boundary-layer control, extensive laminar boundary layers on airfoils with corresponding low drag coefficients. In order to obtain an indication of the stabilizing effect of area suction toward keeping the boundary layer laminar, an NACA 64A010 airfoil having permeable surfaces was investigated in the Langley two-dimensional low-turbulence tunnel at Reynolds numbers of 2,000,000, 4,000,000, and 6,000,000. Although the surfaces of the airfoil model tested had many waves and irregularities of contour, the data corroborated qualitatively the theoretically predicted stabilizing effect of area suction on a smooth flat plate. The suction quantity required for the wavy airfoil investigated, however,

was much greater than the theoretical value for a smooth flat plate.

The stalling characteristics of some moderately thick airfoils are characterized by a relatively low maximum lift and an abrupt loss of lift at angles of attack greater than that for maximum lift. The failure of these airfoils to produce greater lift without an abrupt loss of lift beyond maximum lift is attributed to complete laminar separation occurring very near the leading edge of the airfoil. In an attempt to improve these conditions, control of the boundary layer very near the leading edge of an NACA 63₁-012 airfoil was attempted at the Ames Laboratory. Suction was applied to slots of various widths and locations. The results indicated that the optimum slot location is downstream of the point of minimum pressure and in the immediate vicinity of the laminar separated bubble at maximum lift. Slot width is of considerable importance. The maximum section lift coefficient of the airfoil tested was increased from 1.38 to 1.84 with boundary-layer suction, and further gains appear possible. This investigation has been reported in Technical Note 1683.

An investigation has been conducted at Reynolds numbers ranging from 1,000,000 to 6,000,000 in the Langley two-dimensional low-turbulence tunnels to determine the effectiveness of boundary-layer control by suction and of suction-slot location in increasing the maximum lift and decreasing the drag of a thick airfoil section equipped with a double-slotted flap. The results of this investigation are presented in Technical Note 1631. At a Reynolds number of 6,000,000, deflecting the flap increased the maximum section lift coefficient of the smooth airfoil from 1.4 to 3.4, and boundary-layer control at 0.65 chord further increased the value to 4.2. Boundary-layer control by means of a single suction slot at 0.65 chord also resulted in a section total-drag coefficient, including an allowance for the boundary-layer-control power, lower than that of the plain airfoil. The maximum section lift-drag ratio of the airfoil with flap retracted and leading-edge roughness was more than doubled by the use of boundary-layer control and that for the smooth airfoil was increased by nearly 40 percent.

In the Langley full-scale tunnel, studies were made of the lift and stalling characteristics of a 47°-sweptback-wing and fuselage combination equipped with several high-lift and stall-control devices and, also, equipped with boundary-layer suction slots near the midchord of the outboard portion of the wing.

Experiments have been made in the application of boundary-layer control to sweptforward wings at the Ames Laboratory. A wing has been tested alone and also in combination with a fuselage. Detailed studies of the progression of stall have been made and various wing leading-edge devices have been designed to overcome the leading-edge-type stall which is not readily amenable to boundary-layer control. The usefulness of boundary-layer-control devices on the sweptforward wing will be investigated.

The question frequently arises as to whether the additional weight of boundary-layer-control equipment is justified by the improved aerodynamic characteristics or whether the

high maximum lift coefficients thus attainable are actually useful in take-off and landing. In Technical Note 1597, a performance analysis has been made to determine whether boundary-layer control by suction might reduce the minimum take-off distance of a four-place or five-place liaison-type airplane below that obtainable with conventional high-lift devices.

The analysis showed that, unless the wing aspect ratio is made considerably larger than the present typical values, the total take-off distances could not be appreciably reduced by boundary-layer control although the ground-run distance is reduced. The stalling speed for a given maximum airplane speed was reduced 20 to 25 percent for all configurations by application of boundary-layer control.

Research Techniques and Instrumentation

The closed-wind-tunnel phenomenon of choking and the wall-constriction effects in the subsonic Mach number range where supersonic flow appears were studied by means of the hydraulic analogy. For this investigation, flow fields were obtained about several symmetrical airfoils at zero lift in a water channel. With the approach of choking, the flow was found to approach the one-dimensional form. Thinning of the wall boundary layer in the region of the model appreciably increased the choking Mach numbers, but critical speed, position of maximum thickness, and ratio of maximum thickness to chord had little effect.

With increased emphasis placed on aerodynamic investigations conducted in closed wind tunnels, the need for constant improvement in the accompanying interpretation of the data is self-evident. Of particular importance is the problem of determining the constraining effect of the tunnel walls on the flow past bodies mounted in the tunnel and the corresponding modification of the pressure distribution. Recently developed conformal-mapping methods were applied by the Lewis Laboratory to the calculation of the constraining effect of the tunnel walls on the ideal zero-lift flow past arbitrary symmetrical airfoils. The results were compared with those of the conventional first-order image theory, of Goldstein's second-order image theory, and of a stream-filament theory with approximate allowance made for the curvature of the streamline. This information is contained in Technical Note 1642.

The average low-speed jet-boundary constriction correction was experimentally determined for a large model spanning a closed circular tunnel. The model and tunnel were approximately one-eighth scale of a typical full-scale wind-tunnel installation. The variation of the local constriction with spanwise and chordwise location was also experimentally determined. A comparison with existing theory was made for the constriction correction and the induced-curvature correction that results from lifting action. This investigation is reported in Technical Note 1638.

An investigation of the effects of fuselage interference on the readings of pitot tubes, extending various distances forward from the noses of fuselages, is reported in Technical Note 1496. Comparison of measured and calculated interference increments showed that available calculation pro-

cedures were quite reliable. The interference was found to be strongly influenced by the shape of the fuselage nose.

The recent rapid advances in aerodynamic research have resulted to a large extent from the development and perfection of a number of new research techniques. In practically all such cases, the success of these new techniques in recording the data with a high degree of accuracy and under extremely difficult conditions had been made possible through intensive research on these specialized instrumentation problems.

The basic techniques for obtaining data from rocket-powered models by means of telemetering and tracking have been well-established during the past few years, and the aerodynamic research program on rocket-powered models has now entered a period of planned expansion. As a consequence, during the past year effort has been concentrated on improving all technical aspects of the instrumentation and on increasing the number of instrumented models for the research program. Also, to meet future needs, research efforts have been aimed at increasing the range and accuracy of the telemeter and tracking equipment.

In order to increase the effective range of operation of the telemeter system, efforts have been made to improve the radiating efficiency and radiation patterns in antenna design. A telemeter receiving antenna has been developed giving circular polarization and a gain of 12 decibels. This antenna is servo-operated from the SCR-584 radar unit and effectively increases the power output of the telemeter by a factor of approximately 10, thereby increasing the range by a factor of approximately 3 to 1.

A new optical tracking technique employing the open-sight principle has made it possible to track high-acceleration test vehicles with the SCR-584 radar which formerly could not be tracked. In addition, night firing experiments have been carried on in which small lights have been placed on the models. This method of tracking has been found quite satisfactory and may be employed in the future. For improvement of daylight tracking, experiments have been conducted with smoke and with flares. The results with the smoke have been promising, but it is not certain at the present time whether this method will be used as a regular procedure.

An M-9 parallax computer has been adapted as a tracking aid for use with the SCR-584 and the Doppler radar unit. In setting up the radar equipment, it is necessary for the Doppler unit to be placed 200 to 300 yards away from the SCR-584, and the parallax computer improved the accuracy of this tracking arrangement.

Further work on wire resistance strain-gage balances for wind tunnels has resulted in the evolution of two general types, of which a number of balances have been built: Internal balances for sting-mounted models and external balances for semispan models. Three-component sting balances, which were reported in the last annual report, have operated successfully during the year. As a result of experience gained with these balances, several six-component balances were designed and are now under construction. Miniature sting balances have been built for 1-inch-diameter models used in the Langley 9-inch supersonic tunnel. For this installation, a

two-component balance was used to measure lift and pitching moment, and a rolling-moment balance was put into use with slip rings for measurement of damping coefficients at rolling speeds up to 10,000 revolutions per minute. A large balance of the semispan type, measuring four components of load, was used extensively in the Langley two-dimensional low-turbulence pressure tunnel. Several small five-component semispan balances were constructed for use in small supersonic tunnels and for use with the "bump" technique in larger tunnels.

The humid atmosphere that prevails in the Atlantic coastal region has long been one of the major sources of trouble in the use of wire strain gages at the Langley Laboratory and the Wallops Island testing station. However, continuous research has resulted in improved techniques of cementing and moisture-proofing and these results of research, coupled with increased operational knowledge and close attention to detail, have made it possible to improve the over-all quality of strain-gage instrumentation considerably. In addition, during the past year, methods of temperature-compensating have been developed to permit balances to operate through temperature changes of 100° F. with zero shifts of 1 percent or less.

The performance of balances used in the wing-flow method has been improved by more closely matching the lag of all the recording galvanometer elements on each balance as well as by improving strain-gage techniques and temperature compensation.

A miniature hinge-moment balance which has been developed, although standard commercial strain gages were used, fits in a space $\frac{1}{8}$ inch thick or less. Used on a semispan model in the Langley 9- by 12-inch supersonic blow-down tunnel, the balance gave excellent data on control forces at supersonic speeds.

Improvements to the standard NACA V-G flight recorder have been made which include the use of liquid damping in place of the former friction type and the addition of a temperature-compensation mechanism to the airspeed linkage. The Air Force and Navy have ordered a number of these instruments for their own use.

A compact flight analyzer has been developed to provide records of airspeed, altitude, and acceleration for continuous periods up to 200 hours.

Two new types of wing-flow balances have been constructed for the measurement of forces on small models in the transonic range. Both balances employ spring-type pivots throughout and are designed to record three components of force. One balance employs synchronous transmitters for remote recording; whereas the other contains an optical system which allows direct recording.

The miniature inductance pressure gage has been further developed and tested to the point where it can be used to measure air-flow phenomena at frequencies from static to 2,000 cycles per second and pressure ranges from 1 pound per square inch to 100 pounds per square inch full scale. Only $\frac{1}{4}$ inch thick and $\frac{3}{8}$ inch in diameter, these gages have been used to make time-history measurements of pressure behind rotating propellers in the Langley 16-foot high-speed

tunnel and to measure high-frequency pressure and stream-angle fluctuation in several tunnels.

An indicating tachometer with an accuracy of 1 part in 6,000 has been developed for propeller dynamometer research. A magnetic drag disk assembly with a range of 600 revolutions per minute indicates the difference in speed between the propeller being tested and a highly accurate tuning-fork-driven reference motor.

The adaptation of a crystal pressure gage and high-speed photographic equipment to the time-history measurement of a shock wave traveling down a blast tube has produced quantitative data on pressure distribution through shock waves.

The hot-wire anemometer has been further developed and refined so that measurements of turbulence as low as 0.04 percent at frequencies up to 5 kilocycles can be made quickly and accurately at airspeeds up to a Mach number of 0.6. It has been used for several measurements, such as a survey of the boundary layer in a jet of the Langley induction aerodynamics laboratory at Mach numbers up to 0.6 and studies of turbulence behind axial-flow blowers.

A technique for studying the aerodynamics of simple bodies of revolution in the transonic and hypersonic ranges has been developed in which the body being tested is fired as a projectile. The technique has proved to be most useful. One application at transonic speeds has been the study of the interference effects of wind-tunnel walls. This was carried out by firing projectiles through a chamber representing the test section of the wind tunnel. Precise measurements of velocity and simultaneous photographs of the shock-wave pattern permitted a rapid survey of proposed arrangements for improving the flow in transonic wind tunnels. In the hypersonic range, the technique is proving useful as a means of rapidly surveying the flow at Mach numbers of 7 and more. The velocity of the projectile and the conditions in the test chamber can be determined with a precision that is not yet attainable in wind tunnels.

An instrument of particular interest to the United States Air Force Air Weather Service has been developed which is intended to eliminate human judgment in reporting the intensity and frequency of gusts encountered in flight. The instrument, known as a turbulence indicator, operates from the airplane's pitot-static head to measure small increments in forward velocity of the airplane resulting from gusts. The turbulence indicator counts the number of gusts that result in a speed change greater than 10 feet per second and records the magnitude of the strongest gust encountered in any period of time. The instrument has been tested in flight on a B-29 airplane by the Air Weather Service and satisfactory performance was obtained.

Instrumentation for the measurement of low absolute pressures has been supplemented with the development of a miniature Pirani-type gage, an optical indicating manometer, and small optical recording manometers. The Pirani gage is the size of a grain of wheat and is useable over a pressure range of 0.01 to 3 millimeters of mercury absolute and has been constructed for use as a laboratory standard in calibrating other gages within this range. The small optical recorders employ

nesting-type aneroids and have been used successfully for measuring absolute pressures over a range of 0.1 to 20 millimeters of mercury.

In order to provide a means of investigating heat transfer in supersonic flow, a small electrically heated surface provided with heat guard rings has been devised. The unit consists of two rhodium first-surface mirrors that are placed back to back with fine resistance wire wound around the edges to act as a heat-flow barrier. The rhodium surfaces are so arranged that they serve both for heating and for temperature measurement and the temperature-sensitive surface may be mounted flush with the wall of a tunnel or nozzle in which heat transfer is to be investigated.

For investigations of atmospheric turbulence, a single-channel balloon-borne telemeter has been developed which records the low values of acceleration encountered by the balloon as it ascends into the upper atmosphere. At the present time, the range of the accelerometers is $\pm 1\frac{1}{2}g$ centered about a 1g reference. The telemeter allows 2 hours of flight time and a range of more than 100 miles and has an accuracy of approximately 5 percent.

Techniques and equipment were developed for making vibratory strain measurements on propellers. Successful applications were made on a pusher-propeller investigation in the Langley 16-foot high-speed tunnel, and on both the rotor and stator blades of the compressor of the Langley 4-by-4-foot supersonic tunnel when it was put into operation.

Instrumentation was provided for measurement of the vibration and noise level of existing tunnel structures; the data obtained are to be used for improved designs for future wind-tunnel shells.

Wire-strain-gage wing-twist and wing-bending recorders were developed for wing-deflection measurements on supersonic aircraft. The initial unit was used to measure wing twist in a P-47.

Dynamic instrumentation was developed and used for recording linear and angular motions and linear and angular accelerations of seaplane models in tests of rough-water landings.

Complete instrumentation was provided for helicopter investigations in the Langley full-scale tunnel, including a large number of strain gages mounted in the blades which provided data, through slip rings, on bending and twisting stresses. Blade-motion data were also transmitted through slip rings, and other data were provided by a three-component strain-gage balance.

SUBCOMMITTEE ON HIGH-SPEED AERODYNAMICS

Wings at Transonic Speeds

Continuing investigations of NACA low-drag airfoil sections at high subsonic speeds have considerably narrowed the range of geometric variables to be considered in the selection of airfoils for high-speed aircraft.

For reasons other than aerodynamic, the removal of the cusped trailing edges of NACA low-drag sections has been considered desirable, and investigations have been conducted

on cusped and straight-sided airfoils to determine the effects of cusp removal on the high-speed aerodynamic characteristics of the section.

The Langley annular transonic tunnel, which consists of an annular duct in which a two-dimensional airfoil may be rotated at high speeds, was put into operation during the past year. Pressure-distribution measurements on an NACA 6-series airfoil have been made in this tunnel at transonic speeds and have been compared with results of wind-tunnel and free-fall experiments.

Experimental check of part of the Kármán transonic similarity rule has been made by means of the freely falling body technique using a series of NACA low-drag airfoils. Theoretically, the similarity rule has been extended in Technical Note 1527 to include the effects of variable specific-heat ratio.

Free-flight investigations, using the rocket-powered-model method, of wing characteristics as influenced by various geometric variables are continuing. Investigations to determine the effects of aspect ratio, taper, and sweep on wing drag previously reported have been extended during the past year to include the effects of airfoil profile and thickness ratio. Both round- and sharp-leading-edge airfoils were included in the program.

Two triangular wings of differing airfoil section have been extensively investigated over a wide range of subsonic and supersonic Mach numbers in the Ames 1- by 3½-foot transonic tunnel.

A theoretical study has been made to gain insight into the effects of sweepback on boundary layer and separation phenomena. The idealized case of an infinitely long airfoil moving obliquely with respect to the air stream was considered, and the results indicated that as in the case of nonviscous flow the axial component of motion of the airfoil exerts no influence on the boundary layer and on separation. For this idealized case, then, the boundary layer and separation phenomena are related only to the lift coefficient and Reynolds number based on the crosswise component of velocity. This work was reported in Technical Note 1402.

Supersonic Wing Theory

Considerable effort has been expended over the past few years to develop and explore theories for wings at supersonic speeds. As a result most interesting lifting-surface configurations can now be treated at least approximately by the small-disturbance theories. Contributing to this body of theory during the past year were studies of the drag at zero lift of tapered and untapered sweptback wings for the case of Mach lines ahead of the line of maximum thickness, as reported in Technical Notes 1449 and 1672. Calculations were also made in Technical Note 1543 to determine the effect on the zero-lift drag of section-thickness location on swept-back wings.

A method for determining lift distribution for thin three-dimensional wings of fairly general plan form mentioned in the last annual report has been simplified and extended in Technical Notes 1484 and 1585. The extended method for determining the pressure distribution led to the

development of a graphical method which has been found to be particularly useful for plan forms whose edges are curved. This graphical method was reported in Technical Note 1676.

Another generalized wing theory has been developed in Technical Notes 1412 and 1515 for calculating the velocity distribution over lifting surfaces, which removes the limitations of previously developed conical-flow-field analyses. Extension of this method, as reported in Technical Note 1620, permits the calculation of downwash behind wings. Further, it has been shown in Technical Note 1621 that the general theory could be applied directly to the solution of two-dimensional unsteady-lift problems, such as the calculation of the effects of gusts on the load distribution.

Consideration of the extremely high velocities encountered by missiles of the V-2 type in the dense air near the ends of their trajectories led to the development of a method for estimating the pressures on aerodynamic shapes at high Mach numbers in dense air. Bodies of revolution at zero angle of attack and two-dimensional profiles may be treated.

Wings at Supersonic Speeds

Inasmuch as the wing theory mentioned in the preceding paragraphs does not consider the effects of viscosity and is not valid even in the nonviscous case unless the wings considered are thin and at small angles of attack, experiment is necessary to determine viscous and large perturbation effects. Two comprehensive investigations have been conducted in the Ames 1- by 3-foot supersonic tunnel to determine experimentally the characteristics of a number of wings and provide checks against the linear theory. In one investigation a series of approximately 30 wings were investigated to determine the effects of taper, aspect ratio, and sweep. The other investigation involved a detailed study of the pressure distribution on the surfaces of a highly swept untapered wing. One result of both of these investigations was to place additional emphasis on the importance of Reynolds number effects at supersonic speeds.

Maximum Lift at High Speeds

Flight and wind-tunnel investigations at subsonic and supersonic speeds reported during the past year have provided considerable knowledge of the variation of maximum lift of wings with Mach number. Buffet boundaries have been established and the qualitative and quantitative differences between buffet boundaries and maximum lift are now much more clearly understood. The investigations reported during the past year made use of the Langley 16-foot high-speed tunnel, the research airplanes of the Muroc Flight Test Group, and the Langley 9-inch supersonic tunnel.

Bodies and Wing-Body Interference

Research on the drag of bodies at transonic speeds has been conducted by means of the freely falling body method described in previous annual reports. Results are now available for a series of bodies of varying fineness ratio and location of maximum diameter. Other classes of bodies have

been investigated by means of the rocket-powered-model method. The pressure distribution over a body of revolution at transonic speeds, difficult to measure by the free-flight methods, has been contributed by the NACA wing-flow technique. From this pressure-distribution investigation insight was gained into the mechanism of the drag rise incurred in going through Mach number 1.0.

Generalized investigations of wing-nacelle and wing-fuselage interference at high subsonic and transonic speeds have been conducted. An investigation in the Langley 16-foot high-speed tunnel, reported in Technical Note 1593, determined the optimum location of a representative nacelle in an unswept thin wing. At transonic speeds, an investigation was undertaken by means of the freely falling body technique to determine the drag interference between a slender fuselage and a sweptback wing as influenced by the location of the wing with respect to the maximum diameter of the body. The effect of a large fillet at the juncture of a swept wing and slender body at transonic speeds also was studied.

A detailed study of the effects of external stores, such as fuel tanks and bombs, on drag and buffeting at high speeds has been carried out in the Langley 7- by 10-foot high-speed tunnel.

Complete Configurations

A number of complete airplane and missile configurations have been investigated at transonic and supersonic speeds, both in free flight and in wind tunnels. From tests in the transonic region some general research results have been obtained which help in pointing the way to design considerations which should result in desirably small force and moment changes near Mach number 1.0.

Research Techniques and Equipment

Modifications to the test section of the Ames 16-foot high-speed tunnel to permit higher speeds were completed during the past year. Test Mach numbers up to about 0.95 are now possible.

Until recently the technique of making shock waves visible at high speeds belonged exclusively to the wind tunnel. An investigation at the Ames Laboratory during the past year demonstrated the feasibility of flow visualization in flight, using a shadowgraph technique with the sun as the light source. By use of the technique developed it is possible to render visible wing and pilot-canopy shock waves. Following this investigation a fighter airplane was fitted with schlieren apparatus which was successful in obtaining a cross-section view of the supercritical chordwise flow over the wing.

The problem of model-support interference in supersonic wind tunnels has been studied in the Ames 1- by 3-foot supersonic tunnel. Insight was gained into the effects of the support system on the drag of bodies of revolution in this investigation and a satisfactory method for correcting test results for interference effects was evolved.

Coordination of Supersonic Aerodynamic Research

Consideration by the military services and civilian research agencies of the research needs and current activities in the field of supersonic aerodynamics resulted in a cooperative effort to coordinate research being conducted in this field by the various agencies. This effort is aiding materially in avoiding unnecessary duplication and in pointing up neglected problems. It is the current plan to continue this study from time to time as required.

SUBCOMMITTEE ON STABILITY AND CONTROL

The Subcommittee on Stability and Control has continually studied the advances in its field and the needs for further research. To answer the stability and control problems recommended for study by the subcommittee and those resulting from previous laboratory research, extensive investigations have been conducted in the NACA's wind tunnels, in flight, and analytically.

In addition to flight tests of special research aircraft, three special techniques, developed and reported over the past several years, have been employed to answer problems that occur in the important transonic regime. Two of the techniques used to obtain aerodynamic data in the transonic range are the wing-flow method and the wind-tunnel bump. These techniques make use of the high-velocity region that exists over a curved surface when the main-stream velocity is very high but less than the speed of sound. Velocities over the curved surfaces reach Mach numbers of the order of 1.1. In flight the wing of an airplane provides the high-speed region required for such tests. The model to be investigated is mounted on the wing surface, dimensioned and positioned so that it is in the high-velocity region. In high-speed wind tunnels, a curved surface is mounted on one side of the tunnel. This bump produces a field of high velocities over its surface and investigations similar to those made by the wing-flow technique are conducted.

The third technique makes use of rocket models. The configuration under investigation is propelled in free flight by means of rockets. Throughout the flight of the model, aerodynamic data are telemetered back to the ground and recorded. Data are obtained not only through the transonic range but also well into the supersonic region.

Stability and control research and some results by the use of these newer specialized techniques as well as by conventional means will be discussed in the following sections.

Longitudinal Stability

Some triangular wings appear to have stability and control characteristics that would be suitable for flight at both subsonic and supersonic speeds. One triangular plan form already extensively studied in the high-speed facilities of the Ames Laboratory has been investigated in the 7- by 10-foot wind tunnel to determine its subsonic stability and control characteristics. This wing had an aspect ratio of 2 and a thin double-wedge section. The tests were made with the wing alone, with controls, and with the wing in combination with a fuselage and in the presence of a ground board. Tests

on this triangular wing with two fuselage configurations were also made at supersonic speeds in the Ames 1- by 3-foot tunnel.

An exploratory investigation to obtain a survey of the flying characteristics at low speed of models with low-aspect-ratio triangular wings has been conducted in the Langley free-flight tunnel. Four models having triangular-planform wings with 53°, 63°, 76°, and 83° sweepback and five models having these same wings with the tips cut off were used in this investigation.

A correlation of available two-dimensional airfoil data to determine the effects of compressibility on the location of the section aerodynamic center at low lift coefficients has been made. The results indicate that there are large forward or rearward movements of the aerodynamic center with Mach number. Thickness ratio appears to be an important controlling parameter.

An investigation was made in the Langley 300-mph 7- by 10-foot tunnel of an airplane model having a 42.8°-sweptback wing and having sweptback horizontal and vertical tails to determine the low-speed stability and control characteristics of the arrangement. This investigation determined the effects on longitudinal stability of wing vertical location, fuselage size, horizontal-tail location, and stall-control vanes on the wing.

A 42°-sweptback NACA 64-112 wing equipped with inboard split flaps and outboard leading-edge flaps was investigated in the Langley 19-foot pressure tunnel, alone and in combination with a fuselage and horizontal tail. Results for the wing-alone tests show that at small distances above the ground the nature and magnitudes of the ground interference effects were, in general, comparable to those obtained on unswept wings; the longitudinal stability at the stall was not materially affected by the presence of the ground. Results with the fuselage and tail installed show that the tail did not appreciably alter the direction of the final break in the pitching-moment curve of the model in the stalling range; the effect of the tail on the pitching-moment characteristics was not altered appreciably by the relative wing-fuselage height.

A comparison of downwash angles by direct measurement and by calculation from horizontal-tail moment data was made possible by an investigation in the Langley 19-foot pressure tunnel with a high-wing, six-engine-pusher, powered model. The results indicated that the average values of downwash obtained from air-stream surveys in the plane of the elevator hinge line were approximately 1° to 2° greater than the effective values obtained from force and moment data. An empirical formula was developed by which average values of downwash angle obtained from air-stream surveys could be made to agree satisfactorily with effective values of downwash.

Downwash angles have been measured at probable tail locations behind a high-aspect-ratio wing with various amounts of sweep and mounted on a fuselage. The wing had an NACA 65-210 airfoil section; in addition, the straight wing was swept back and swept forward 30° and 45°. This

investigation was conducted in the Langley 8-foot high-speed tunnel. The tests indicate that although the downwash characteristics behind the swept wings are similar to those of the straight wing, the changes in downwash were delayed by sweep. This delay corresponded to the delay in critical Mach number associated with the sweep.

An investigation was made in the Langley 300-mph 7- by 10-foot tunnel to determine the low-speed stability and control characteristics of a complete model equipped with a V-tail. Tail dihedral angles of 35°, 47°, and 55° were tested and the results compared with results of tests of a conventional-tail arrangement used with the same wing-fuselage combination. The results of this study, present in Technical Note 1478, indicated that the 47° V-tail was the best of those tested and contributed 40 percent more longitudinal and directional stability and 90 percent more dihedral effect than the conventional tail despite the fact that the V-tail had only about 12 percent greater area than the conventional tail.

An investigation was made in the Langley 300-mph 7- by 10-foot tunnel of a complete model with a sweptback V-tail and a sweptback wing to determine its low-speed stability and control characteristics. Comparisons were made with the results of investigations of the same tail panel with zero dihedral (horizontal tail) on the same wing-fuselage combination. The results indicated that for the same contribution to stability, a V-tail configuration similar to the one tested will probably require less area than a conventional-tail assembly.

The large tailless airplane model investigated in the Langley full-scale tunnel last year and reported in the last annual report has been converted to a tail-boom airplane model and investigated in the Langley full-scale tunnel in order to obtain a direct comparison of the performance possibilities of the two types of airplanes. This comparison is reported in Technical Note 1649.

A wind-tunnel investigation has been made in the Langley 7- by 10-foot tunnel to determine the effects of unsymmetrical horizontal-tail arrangements on the power-on static longitudinal stability of a single-engine single-rotation airplane model. The results of this investigation have been reported in Technical Note 1474.

Flight investigations have been made in the Langley free-flight tunnel to determine the dynamic lateral stability and controllability of a model having an unswept wing with an aspect ratio of 2 over a range of dihedral angles and vertical-tail areas. The results of these investigations were compared with a similar series of tests on a conventional model having a wing with an aspect ratio of 6 and are reported in Technical Note 1658. The flight characteristics of the low-aspect-ratio model were not so satisfactory as those of the conventional model.

An investigation was made by the NACA wing-flow method to determine the longitudinal stability and control characteristics at transonic speeds of a semispan airplane model having a 45°-sweptback wing and tail. Measurements

were made of lift and angle of attack for trim for several stabilizer and elevator settings. Additional tests were made to investigate the effects of transition wires mounted on the wing and tail of the model, the effect of increasing the boundary-layer thickness on the test surface, and the effectiveness of a wing flap having a sweepback of 45° .

An investigation was made in the Langley high-speed 7-by-10-foot tunnel to determine the longitudinal stability and control characteristics of an unswept semispan airplane model and an airplane model having a 45° -sweptback wing and tail at transonic speeds. The transonic-bump technique was utilized to obtain aerodynamic data up to a Mach number of 1.2.

An investigation at the Ames Laboratory of a 45° -sweptback wing of aspect ratio 4.5 with stall-improvement devices indicated that fences parallel to the wind stream on the upper surface of the wing would improve the longitudinal characteristics of the wing below the stall, but would not improve the characteristics at the stall. The use of split flaps gave only a slight increase in maximum lift and no improvement in the longitudinal characteristics at the stall, while chord-extension flaps gave sizable increases of maximum lift coefficient but caused nonlinear lift and pitching-moment characteristics.

The problems of obtaining longitudinal stability for airplanes designed to fly in the transonic range have been reviewed. The results of investigations on the transonic bump and by the wing-flow method as well as low-speed investigations were analyzed. It was shown that large amounts of sweepback on both the wing and the horizontal tail can delay significantly the Mach number at which critical trim changes occur and can greatly reduce the trim and stability changes when they are encountered. It was also found that satisfactory longitudinal stability characteristics in the landing condition for airplanes having sweepback of 45° could be obtained by utilizing various stall-control devices. Optimum arrangements for such devices, however, must be determined experimentally.

As part of a general investigation of the effects of Mach numbers on longitudinal stability and control characteristics, tests were made on two different aircraft to evaluate the use of a negatively deflected flap designed to reduce or alleviate the nose-down change in trim experienced by high-speed straight-wing aircraft above the critical speed.

An investigation of the reduction in static longitudinal stability of airplanes with increasing Mach numbers up to that for lift divergence was completed. It was shown that the reductions in static longitudinal stability became more pronounced and might reach serious proportions when the wing aspect ratio or tail lengths were decreased. In order to minimize the effects of compressibility on static longitudinal stability, it was found that the rate of change of downwash angle with angle of attack must be kept to a minimum value.

Existing basic dynamic-longitudinal-stability equations are for the fixed-control case and for the incompressible speed

range. In a study at the Ames Laboratory, these equations were extended to include the effect of changes in the coefficients with speed as well as angle of attack. The effect of a free elevator control was also investigated. Thirty-eight trace records, each a solution of the equations of motion for a particular airplane flight condition, were obtained from a differential analyzer. It is planned to compare these results with those obtained by simpler methods to ascertain the importance of including the variation of the coefficients with Mach number.

Lateral and Directional Stability

The low-speed yaw characteristics of a 42° -sweptback circular-arc wing equipped with extensible round-nose leading-edge flaps and split flaps were investigated in the Langley 19-foot pressure tunnel. The effective dihedral increased to a maximum at moderate lift coefficients, and then decreased with further increase on lift. With leading-edge flaps, the effective dihedral continued to increase with lift coefficient in a manner similar to that for a comparable round-nose-airfoil configuration. In general, tests with a fuselage showed that the effect of the fuselage on effective dihedral was similar to that of an unswept wing when the flaps were deflected; but, with flaps neutral, the fuselage effect was reversed except in the low-lift range. Air-stream surveys showed that a vertical tail would be more effective on a low-wing airplane of this type than on a corresponding high-wing airplane.

An investigation was made in the Langley 300-mph 7-by-10-foot tunnel of an airplane model having a 42.8° -sweptback wing and a sweptback horizontal and vertical tail to determine the low-speed stability and control characteristics of the arrangement. A series of modifications, including lowering the wing, incorporating a smaller-fineness-ratio fuselage, and increasing the vertical-tail size, were made in order to improve the aerodynamic characteristics of the original model configuration.

The contribution of a centrally located vertical tail to the directional stability of a typical fighter-type airplane was investigated in the Langley propeller-research tunnel. The results obtained point out the inadequacies of current design methods and show that more accurate methods must treat separately the contributions of the vertical tail itself, the fuselage area above the stabilizer, and the fuselage area below the stabilizer.

The results of a number of recent lateral-stability investigations conducted by the NACA were summarized. Illustrations are given of some of the effects on dynamic lateral stability of a few of the more important aerodynamic and mass characteristics such as the effective-dihedral parameter, the directional-stability parameter, the damping-in-roll parameter, mass distribution, and relative density. The problems associated with the "snaking" oscillation encountered recently by several high-speed airplanes are discussed. Some of the important factors affecting the values of the stability

derivatives used in dynamic-lateral-stability calculations for airplanes with low-aspect-ratio swept wings were indicated and a method was suggested for estimating the effects of scale and roughness on the stability derivatives.

The effects of steady rolling on the dynamic longitudinal and directional stability of an aircraft have been studied theoretically and the results have been published in Technical Note 1627. Simplifying assumptions have been made with regard to the longitudinal and lateral motions of the airplane in order to obtain a solution which shows the principal effects of the rolling motion.

An investigation has been made in the Langley free-flight tunnel to determine the effects of the sloshing of fuel in partly filled, un baffled tanks on the dynamic stability of a free-flying model. The results show that the sloshing of the fuel in the tanks caused small-amplitude, high-frequency lateral oscillations which caused a rough lateral motion when superimposed on the normal Dutch roll oscillation.

The causes of undesirable directional oscillations of airplanes, usually called "snaking," and various rudder modifications designed to alleviate this condition were investigated. It was found that the rudder-fixed oscillations were predictable using present theory and that the snaking or low damping was attributed to the hinge-moment characteristics of the rudder.

Rotary Stability Derivatives

The rolling- and curved-flow facilities of the Langley stability tunnel are being utilized to investigate the rolling, yawing, and pitching stability derivatives of wings and complete airplane configurations. These investigations show that, for a model representative of current design practice for high-speed airplanes, the wing is the most important contributor to all rolling and yawing derivatives except the yawing moment and lateral force due to yawing. Further test results, reported in Technical Note 1669, show that the effects of sweep on both the yawing and the static stability derivatives depend very largely on the aspect ratio. The effects of sweep on these derivatives generally tend toward zero as the aspect ratio approaches zero. The effects of variation in taper ratio on the static and yawing stability derivatives were shown in Technical Note 1671 to be of about the same importance for 45°-sweptback wings as for unswept wings.

An approximate method based on strip theory for predicting the stability derivatives of wings of arbitrary plan form, but with zero dihedral, has been presented in Technical Note 1581. The analysis shows that the process of evaluating the stability derivatives from known load distributions is more difficult for swept wings than for unswept wings. The analytical methods of Technical Note 1581 were extended to include the effects of dihedral on the static and yawing stability derivatives in Technical Note 1668. The analysis was supplemented by tests of a 45°-sweptback wing with various dihedral angles. The test results were in fair agreement with the calculations and showed that, of the various

static and yawing stability derivatives, only the rolling moment due to sideslip and the rolling moment due to yawing were appreciably affected by dihedral.

The low-speed damping-in-roll and static-stability characteristics of some low-aspect-ratio triangular wings and unswept wings were measured in the Langley free-flight tunnel and the results of these investigations were reported in Technical Note 1468. The sweepback of the triangular wings varied from 53° to 83° and the aspect ratios varied from 3 to $\frac{1}{6}$. The aspect ratio of the low-aspect-ratio unswept wings varied from 3 to $\frac{1}{2}$. A few wings of higher aspect ratio were included for comparison. The unswept wings showed no consistent variation in damping in roll with lift coefficient; whereas the triangular wings in general showed a reduction in damping in roll with increasing lift coefficient and in some cases became unstable before maximum lift was reached. The damping in roll decreased with aspect ratio. Experimental values of damping in roll were generally smaller than the theoretical values.

In Technical Note 1566 the damping coefficients in pitch and roll have been calculated for triangular wings of any aspect ratio at supersonic speeds. The damping coefficients were found to be a function of the ratio of leading-edge angle to the Mach angle; for wings having leading edges ahead of the Mach cone, the damping coefficients were constant. The method utilized a previously developed technique in which the airfoil was represented by a doublet distribution or what may be considered a bound vortex distribution. The relation between the two was derived in the analysis as a contribution to the general lifting-surface theory.

The analysis of the stability derivatives of low-aspect-ratio triangular wings at subsonic and supersonic speeds given in Technical Note 1423 was extended to apply to triangular wings having large vortex angles and traveling at supersonic speeds. All the known stability derivatives of the triangular wing at supersonic speeds are summarized for convenience and presented with respect to both body axes and stability axes. The results of this investigation, which are presented in Technical Note 1572, are limited to Mach numbers for which the triangular wing is contained within the Mach cone from its vortex.

A preliminary experimental investigation of the effect of a jet exhausting from the rear of a fuselage on the dynamic damping characteristics of the fuselage has been made. A body having a fineness ratio of 6 was tested in conjunction with three sizes of vertical tails. The experimental results showed no consistent effects of jet operation on the damping of the fuselage or fuselage-tail combinations for the range of variables investigated.

Controls

An investigation was made in the Langley 7- by 10-foot wind tunnels to determine the aerodynamic section characteristics of an NACA 0009 airfoil with plain flaps having chords of 25 and 50 percent of the airfoil chord. The flaps were tested independently and in combination. The results

of the investigation, which are reported in Technical Note 1517, indicated that the larger flap would provide greater lift increments but would lose lift effectiveness at higher deflections and at a lower angle of attack than would the smaller flap.

A series of five flat-plate models of aspect ratio 2.0 with 25-percent-chord flaps have been investigated at Mach numbers from 0.5 to 1.1 to gain information on the effect of sweepback on flap effectiveness. An unswept model had the highest flap effectiveness at subsonic speeds.

An analysis has been made of the low-speed lift, rolling, and pitching effectiveness of flap-type control surfaces on swept wings as determined from numerous wind-tunnel investigations, and methods for calculating these characteristics have been developed. Two methods are presented in Technical Note 1674 which may be used satisfactorily to calculate the effectiveness of flap-type controls on swept wings having from 0° to 60° sweep of the wing leading edge, aspect ratios from 2.5 to 6.0, and taper ratios from 0.4 to 1.0.

An extensive collection of the lift and hinge-moment characteristics of control surfaces up to a Mach number of 0.9 was assembled from available high-speed wind-tunnel data. The importance of using flat-sided control surfaces and maximum-thickness locations forward of the 40-percent chord line are stressed.

An analytical and experimental investigation of the effect of plan-form changes on the hinge-moment characteristics of control surfaces has been under way for some time. The experimental portion of the program consists of a study of the characteristics of a series of tail surfaces having aspect ratios of 2 to 6 with various amounts of sweepback. The test results have been reported and will be useful in establishing satisfactory methods for the prediction of control-surface characteristics for swept plan forms.

The lifting-surface theory has been used to study low-speed hinge-moment parameters and the results of this study were compared with experiment and reported in Technical Note 1506. This report shows that for 35° -sweptback wings viscous effects appear to be so great that the theory is in poor agreement with experimental measurements.

An investigation has been conducted in the Langley 300-mph 7- by 10-foot tunnel of a 51.3° -sweptback semispan wing with a raked tip and a sealed plain aileron of various spans. Each aileron span was investigated with several trailing-edge angles. The rolling-moment, yawing-moment, hinge-moment, and aileron-seal-pressure characteristics were determined for each of the configurations. The results of this investigation indicated that variation of the aileron geometric characteristics on the swept wing produced effects similar in trend to, but differing in magnitude from, the corresponding effects produced on unswept wings.

A straight-sided plain aileron was investigated on a wing with 30° and 45° sweepback and sweepforward in the Langley 8-foot high-speed tunnel. The wing when unswept had an aspect ratio of 9.0. The results of the investigation show that the severity of the large changes in rolling-moment and

aileron hinge-moment coefficients observed for an unswept wing as a result of compression shock was reduced, and the speeds at which such changes occurred were delayed to higher Mach numbers by 30° of sweepback and sweepforward. The configurations with 45° of sweepback and sweepforward had rolling-moment and hinge-moment characteristics which, for the speeds covered, were not materially affected by a change in Mach number.

An investigation was conducted in the Langley two-dimensional low-turbulence pressure tunnel to determine the effects of a forward movement of the transition point on the section characteristics of a 12-percent-thick low-drag airfoil section with a 24-percent-chord sealed plain aileron. The results, as presented in Technical Note 1582, showed that fixed transition at either 0.30 chord or at the airfoil leading edge resulted in decreased aileron effectiveness and a decrease in the negative rate of change of aileron section hinge-moment coefficient with section angle of attack and with aileron deflection. Shifting the position of transition from approximately 0.50 to 0.30 chord generally caused larger changes in the aileron characteristics than those caused by shifting transition from 0.30 chord to the airfoil leading edge. Leading-edge roughness decreased the maximum section lift coefficient by about 0.3; whereas roughness at 0.30 chord generally caused no significant change in the maximum section lift coefficient.

At the Ames Laboratory, tests were conducted on a wing having sweep angles of 0° and 45° and equipped with an aileron. For the wing unswept, there was a loss in aileron effectiveness as the Mach number was increased. For the swept wing, the aileron did not lose effectiveness with increasing Mach number.

As a part of an investigation in the Langley high-speed 7- by 10-foot tunnel of lateral controls suitable for use with full-span flaps, aileron and high-lift characteristics of a 20-percent-chord straight-sided aileron and a 25-percent-chord full-span flap were obtained. These data are presented in Technical Note 1473. The straight wing, tested as a semi-span model, had an NACA 65-210 section, an aspect ratio of 5.76, and a taper ratio of 0.57. The tests were made at Mach numbers up to 0.71. The lift, drag, and pitching moment were determined with the flap retracted and deflected and the aileron rolling, yawing, and hinge moments were measured.

An analysis of the principal results of recent control-surface research pertinent to transonic flight has been made. Available experimental data on control surfaces of both unswept and sweptback configurations at transonic speeds were used to indicate the control-surface characteristics in the transonic speed range. A design procedure for controls on sweptback wings based on low-speed experimental data was developed. The results of the analysis indicate that no serious problems resulting from compressibility effects would be encountered provided the speeds were kept below the critical speed of the wing and the trailing-edge angle was kept small. Above the critical speed of the wing the be-

havior of the controls depended to a large extent on the wing sweep angle.

The Langley Pilotless Aircraft Research Division has made extensive use of freely flying rocket models to provide data on the transonic and supersonic characteristics of controls. Experimental and theoretical studies of various controls for use on triangular wings are reported in Technical Notes 1600, 1601, and 1660. Technical Note 1600 indicates that triangular tip controls on triangular wings are very effective and that there are no adverse changes in effectiveness in the transonic range. The experimental and theoretical results for the triangular tip controls show excellent agreement at all Mach numbers for which the theory is applicable. Less agreement is shown for constant-chord trailing-edge controls on triangular wings, however, probably because of body interference and boundary-layer effects which are undoubtedly much larger for these controls than for the triangular tip controls. The experimental variation of control effectiveness with Mach number and wing apex angle shows excellent agreement with theory and provides a means of accurately estimating the characteristics of configurations other than those investigated.

Previous rocket-model studies of the effects of wing sweep, taper, thickness, and aspect ratio on aileron effectiveness have been continued and extended to higher speeds and include the effects of airfoil section profile and the characteristics of spoilers.

An exploratory investigation has been performed in the Langley 300-mph 7- by 10-foot tunnel to determine the optimum location for a spoiler lateral-control device on a 42°-sweptback wing having an aspect ratio of 4.01 and a taper ratio of 0.625. Spoilers having a projection of 10 percent of the local wing chord were investigated at various spanwise and chordwise locations and skew angles. The variation of rolling effectiveness with spoiler projection was determined for one of the more satisfactory spoiler arrangements. As reported in Technical Note 1646, a spoiler consisting of a group of segments located near the wing trailing edge, slightly inboard from the wing tip, and skewed with reference to the wing so as to be perpendicular to the free-stream air flow gave the most satisfactory rolling-effectiveness characteristics.

An investigation was performed in the Langley high-speed 7- by 10-foot tunnel to determine the lateral-control characteristics of plug and retractable ailerons on a thin low-drag semispan wing equipped with a 25-percent-chord full-span, slotted flap. Various modifications of the basic plug and retractable ailerons were investigated through a Mach number range from 0.13 to 0.71. A comparison of the plug-aileron and the retractable-aileron data obtained in this investigation with plain-aileron data previously obtained on the same wing indicated more desirable characteristics for the spoiler-type ailerons. A report on this investigation is available as Technical Note 1663.

An analysis, based on wind-tunnel data, has been made to determine the relative merits of spring-tab-aileron and

of spoiler-pilot-aileron lateral-control systems. Spring-tab-aileron control arrangements both with and without an interconnection between the ailerons were considered. The analysis reported in Technical Note 1441 indicated that for a given control force the spring-tab aileron will provide slightly greater rolling effectiveness at high speeds, whereas the spoiler-pilot-aileron system is superior at low speeds. When the ailerons of a spring-tab-aileron control system exhibit upfloating tendencies, the arrangement in which the ailerons are interconnected is preferable.

An analysis of methods used in the determination of the lift characteristics of wings at supersonic speeds has led to the indication that these methods are applicable also to the determination of the characteristics of control surfaces. Technical Note 1554 presents the results of calculations of control characteristics on swept wings at supersonic speeds by the method of superposition of conical-flow solutions. With this method it was possible to obtain solutions for control surfaces with hinge lines and trailing edges operating in the subsonic regime. The theory was applied to the estimation of hinge-moment and effectiveness characteristics of elevators and ailerons.

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. 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.

A theoretical study has been made of the effectiveness of tabs for balancing control-surface hinge moments at supersonic speeds. This investigation showed that in general for thin airfoils conventional geared tabs do not provide, at supersonic speeds, the advantages they offer at subsonic speeds.

An investigation was made to determine the effectiveness of constant-chord trailing-edge elevators. It was found that, for the configurations investigated, Ackeret's theory could be used to give a fair prediction of the lift and pitching moment resulting from a control deflection.

A limited stability and control study was made and reported of a triangular-wing airplane. The major purpose of the investigation was to define the safe operating ranges—that is, angles of attack and sideslip—during the critical take-off and landing periods.

Experimental investigation of automatic stabilization systems has been delayed by the development of new improved research vehicles for conducting supersonic flight studies. Analytical studies, however, have continued. One of these investigations provides an analysis of the displacement-response, flicker-type automatic pilot. This analysis clearly delineates the capabilities and limitations of the displacement-flicker system and provides design charts by which the applicability of such an automatic pilot to any specific problem may be rapidly determined.

Flying Qualities

In addition to the flying-qualities studies to be discussed in this section, the NACA laboratories have conducted extensive flying-quality investigations of many current military-aircraft types. These particular studies are reported in a following section on specific aircraft.

To aid in the evaluation of light aircraft, flight measurements of the flying qualities of five personal-type airplanes were investigated and the results presented in Technical Note 1573. The investigation included studies of stability, controllability, and stalling characteristics. Stability about the three axes was generally satisfactory for all five airplanes, although the degree of stability varied considerably between airplanes. Adverse yaw was considered objectionable on the airplanes which had low directional stability. The dihedral effect was positive and generally within desirable limits for all the airplanes tested. The bank accompanying sideslip was favorably large even at low speeds for all airplanes. The pitching moment due to sideslip was generally desirably small at small angles of sideslip, although at large angles of sideslip an appreciable nosing-down tendency was measured on several of the airplanes. The control surfaces of all the airplanes were satisfactorily effective in producing changes in attitude and angular velocity about their respective axes. Stalling characteristics were considered good for all five airplanes although the ensuing instability was considered objectionable. Ailerons were ineffective in maintaining lateral control in a power-on stall in any of the airplanes. Stalls from turning flight were possible with power on at all speeds in three of the airplanes tested but were generally impossible above a certain airspeed with power off because of insufficient elevator control. Small fixed wing-tip slots on one of the airplanes were found to have no measurable effect on its flying qualities or stalling characteristics.

To determine the necessity of changes or additions to existing handling-qualities requirements to cover the case of instrument approaches with large airplanes, a flight investigation was conducted on a four-engine transport airplane. It was found that no changes in the requirements were necessary.

The satisfactory flying-quality requirements for airplanes as specified by the NACA have served as a basis for similar requirements of the Navy and Air Forces. A better understanding of these requirements and of the factors involved in obtaining satisfactory flying qualities has been made possible by the publication of Technical Note 1670, Appreciation and Prediction of Flying Qualities. The material in this report is based on lecture notes for a training course for research workers engaged in airplane stability and control investigations.

Spinning

A study of the design and mass characteristics of several airplanes was made to determine the basic factors which influence the spin in such a manner as to make the spinning

motion a series of violent rolling and yawing oscillations. Technical Note 1510 presents a chart showing an empirical relationship between a side-area moment factor and mass distribution. This relationship separates a region for which steady spinning motions were obtained from a region for which violent oscillatory motions were obtained.

The effects of landing flaps and landing gear on the spin and recovery characteristics of airplanes have been determined from an analysis of the results of spinning investigations of 58 models and are presented in Technical Note 1643. The results indicate that generally an adverse effect on recovery characteristics was obtained when the flaps were in an extended position during the spin. Extension of the landing gear usually had a negligible effect on the spin-recovery characteristics.

An investigation has been conducted in the Langley 20-foot free-spinning tunnel on a research model, representative of a trainer or a four-place cabin airplane, with varied moments of inertia. The results of this investigation are reported in Technical Note 1575. The investigation was made for eight different wing arrangements and four different tail arrangements, including twin tails. The results indicated that uniformly decreasing the moments of inertia led to steeper spins, higher angular and vertical velocities, and faster recoveries. Adding weight at the center of gravity up to 50 percent of the basic weight did not seriously alter the recovery characteristics but led to higher rates of descent and rotation. The twin-tail configuration was a very favorable arrangement as regards spin recovery.

In addition to the general spin investigations, spin studies of 10 specific military-airplane configurations were made. Not only were normal recovery characteristics investigated, but also the effects on spin characteristics of loading, flaps, air brakes, protuberances, and wing-tip tanks were determined for the various designs. In some cases, the inverted-spin characteristics were studied.

In connection with spinning studies, stable spin-recovery parachutes have been investigated at the Langley Laboratory in both the spin tunnel and free-flight tunnel. The results indicate that the stable parachute, unlike the unstable parachute, can be safely towed by the aircraft. Thus it is possible to check out the operation of the parachute and release mechanism in normal flight before making spin tests. The stability of the parachutes was found to be primarily a function of the porosity of the fabric.

Procedure for pilot escape from spinning airplanes has been determined by means of investigations in which pilot escape was simulated from 21 airplane models spinning in the Langley 20-foot free-spinning tunnel. The results in general showed that the pilot should bail out on the outboard side. For the types of airplanes investigated, the centrifugal force acting on a pilot during a spin would probably not prevent him from leaving the cockpit.

An investigation of the stability of models of the jettisonable nose sections of several research airplanes has been conducted in the Langley 20-foot free-spinning tunnel. Each

model nose section tumbled about an approximately horizontal axis. The installation of suitable fins together with sufficient forward location of the center of gravity prevented the tumbling and caused the models to descend in a stable nose-down attitude.

Specific Designs

In addition to investigations at the request of the Services of many military airplanes and missiles, the NACA laboratories have made general investigations with these aircraft and with the special research airplanes. These specific investigations have yielded useful design and performance information which in many instances has resulted in design changes. In addition to this direct use of the information obtained, these investigations have provided valuable general aerodynamic information.

A complete investigation of the flying qualities of a propeller-driven fighter-type airplane was made to determine the lateral, directional, and longitudinal stability and control characteristics and stalling characteristics. The lateral and directional-stability studies were made with two vertical-tail assemblies.

An evaluation of the handling qualities of a jet-powered fighter airplane was completed. This study included determination of the lateral and directional stability and control characteristics of the airplane, as well as the stalling characteristics.

It has been indicated that the use of sweepback will materially alleviate trim and stability difficulties as well as delay the force break in the transonic speed range, although sweepback is known to add to low-speed flight difficulties. In order to study the effects of moderate sweepback on the low-speed flying qualities of an airplane, a flight investigation has been made with an airplane having a wing sweptback 35°. Measurements were made of the lateral, directional, and longitudinal stability and control characteristics and the stalling characteristics without slots on the wing and also with slots along 40 and 80 percent of the span of the sweptback wing panels. A 1/4.5-scale model of this airplane was tested in the Langley 300-mph 7- by 10-foot tunnel, and therefore a comparison of the flight and lower-scale wind-tunnel measurements could be made. Results of the investigations to determine the lateral and directional stability and control characteristics with the 40-percent-span slots on the wing have been reported in Technical Note 1511. The results of investigations to determine the longitudinal stability, stalling, and lift characteristics of the airplane without slots and with slots along 40 percent of the span are reported in Technical Note 1679.

Two D-558-1 transonic research airplanes were turned over to the NACA by the Bureau of Aeronautics, Department of the Navy, for transonic-flight investigations. One airplane was instrumented for stability and control studies and the other for pressure-distribution measurements.

During the past year progress has been made in transonic-flight research with the X-1 airplane at the Muroc Air

Force Base by joint effort of the NACA and the United States Air Force, which culminated in the attainment of supersonic flight. With this airplane, valuable stability and control data, as well as other aerodynamic information, are being obtained. Research is being conducted with two X-1 airplanes. One airplane is being used in a cooperative program between the United States Air Force and NACA, in which program the flying is done by Air Force pilots and the data are obtained from NACA instrumentation and analyzed by NACA personnel. The other airplane is being operated by the NACA. In general, the flight investigations indicated that the handling qualities of both airplanes were satisfactory in the flight range from minimum speed to a Mach number of about 0.8, and that the airplane should be satisfactory for use as a research vehicle. The stalling characteristics were considered satisfactory with stall warning in the form of buffeting. The flight investigations have been continued over a wider speed range.

In addition to the aforementioned studies, the NACA laboratories have made extensive subsonic, transonic, and supersonic studies of a number of specific airplane and missile configurations. The purpose of these investigations varied from studies of the static and dynamic stability and control characteristics of the basic aircraft to effects of high-lift and stall-control devices, dive controls, power, buffeting, wing-tip tanks, and many other items.

SUBCOMMITTEE ON INTERNAL FLOW

Experience gained in design studies and in actual operation of new aircraft has further emphasized the need for detailed research on air inlets, exits, and associated duct problems through the subsonic and into the supersonic regime.

The results of reviews of these internal-flow problems by the Subcommittee on Internal Flow and the laboratories of the NACA have governed the course of extensive laboratory investigations in this field. These investigations, reported here with some of their results, have contributed directly to the improvement of the performance of aircraft designed for subsonic and supersonic flight.

Nose Inlets

The nose inlet still remains an important inlet type for reciprocating, turbojet, and turboprop installations and for certain ram-jet applications.

To determine the characteristics of nose inlets suitable for high subsonic speeds, a preliminary investigation was conducted in the Langley propeller-research tunnel. This investigation covered cowling-spinner combinations based on the NACA 1-series nose inlets resulting in a systematic family of approximately ellipsoidal spinners. Information was obtained on the effects of spinner location, spinner shape, inner-cowling lip shape, and operation of a propeller. From this information, charts have been prepared from which spinner proportions and rates of internal flow for inlets with good pressure-recovery characteristics can be selected for

high critical speeds. In the course of this investigation, data were also obtained on the effects of spinners and propellers on cowlings characteristics which facilitate selection of NACA 1-series cowlings for use with spinners of other shapes.

In connection with the spinner-cowling investigation, compressible-flow equations relating inlet-velocity ratio to the surface pressures on the cowling and spinner have been derived.

Supersonic nose inlets have received continued attention. One study indicated that high inlet efficiency could be obtained at a Mach number of 1.85 with a nose inlet having a central body that continuously decelerated the entering air stream. Studies on this particular type of inlet have continued in an attempt to improve the drag characteristics of the inlet without impairing the recovery characteristics.

Because the combustion process in a ram jet may affect the efficiency of the inlets and hence the net thrust obtainable, an investigation of the importance of this interaction was undertaken.

Wing Inlets

Although the simple nose inlet presents the most straightforward inlet design problem other types of inlets have to be resorted to as design compromises. One compromise, wing-leading-edge inlets, is of particular interest for many airplane and missile designs.

At the Ames Laboratory, studies of an empirical design method for wing-leading-edge inlets on straight wings have continued. It has been found possible to predict the effect of lift and inlet-velocity ratio on the pressure distribution of the ducted section aft of the inlet.

To provide design information for leading-edge inlets on swept wings a program has been initiated at the 7- by 10-foot wind tunnel of the Ames Laboratory on a 45°-swept-back wing. The inlets in this investigation were derived by a modified version of the method developed for straight wings.

Side Inlets

The side inlet for both subsonic and supersonic flight has received considerable attention. This type of inlet has the advantage of allowing the inlet to be placed near the engine, and thus avoiding long lengths of ducting and associated duct losses.

Some recent results obtained with NACA submerged inlets show the effects of changes in the geometrical design parameters on pressure recovery, pressure distribution, and drag.

An investigation has been made of submerged inlets at large scale based on design principles developed at small scale. It was found that, if the design principles determined at small scale were carefully observed, inlet efficiencies equal to or better than those measured at small scale could be realized.

Tests were conducted with a 0.3-scale model of a generalized fighter airplane up to high subsonic speeds over an angle-of-attack range to determine the characteristics of the inlets

in a practical application. The inlets were placed on each side of the fuselage above the wing at various distances behind the wing leading edge and the air flow into the inlets was varied.

The effect of tractor-propeller operation on ram pressure-recovery characteristics of submerged inlets has been investigated. It was found that for good recovery careful attention must be given to the design of the blade shanks. As might be expected, it was found that the ram recovery increased with increasing thrust coefficient.

The major problem to overcome in designing suitable supersonic side inlets is to minimize the interaction between the boundary layer and the rate of compression of the flow inside the diffuser. To study the merits of schemes to accomplish the desired flow characteristics several investigations were undertaken.

Nacelles

Preliminary results of investigations of nacelles on a sweptback wing at the Ames Laboratory have been obtained. This investigation included a study of the effect of nacelle position with respect to the wing and the effects of air flow through some of the nacelles.

Two pusher nacelles were investigated in the Langley two-dimensional low-turbulence tunnels. Large reductions in drag were obtained by modifications to the nacelle inlet and the internal-flow system. The nacelle as finally developed had relatively low external drag.

Ground-stand investigations of a radial air-cooled engine installation were conducted at the Langley Laboratory to determine means for improving its pressure-recovery distribution in the ground-cooling condition. The pressure-recovery distribution obtained with the originally installed underslung "C" cowling was not improved appreciably by the use of any of three alternate sets of propeller cuffs or by the use of inlet vanes. A small improvement in the over-all cooling characteristics at high powers and engine speeds was obtained by the installation of a symmetrical cowling.

General Studies

A study of the importance of pressure recovery to the performance of the jet aircraft was completed and has been published as Technical Note 1695. It was found that the pressure-recovery efficiency of an airplane air-induction system is best represented by ram-recovery ratio. The analysis indicates the necessity of high ram-recovery ratios for attaining optimum performance. It is also shown that the importance of high pressure recovery will increase as airplanes are developed which have higher drag-divergence Mach numbers and which utilize more powerful jet engines.

A study has been made at the Lewis Laboratory of air ejectors, frequently used in turbojet-engine exhaust-nozzle configurations to pump cooling air through the engine cooling system at static and low-speed flight conditions. This study consisted of a systematic experimental investigation of the performance of air ejectors having pumping capacities required for current aircraft designs.

SUBCOMMITTEE ON PROPELLERS FOR AIRCRAFT

During the past year, research efforts to increase the efficiency of propellers at very high forward speeds have been intensified. The results obtained from the various investigations are of special importance in the successful application of propeller-turbine power plants.

Propeller Theory

A theoretical investigation has been made which resulted in a method for obtaining, by means of Theodorsen's propeller theory, the radial load distribution on a propeller blade which will give maximum propeller efficiency for any design condition.

Propeller Experiments

A program was begun at the Langley Laboratory to determine propeller-blade section characteristics by measuring the pressure distribution over the propeller blade under actual operating conditions.

In order to determine the effects on propeller efficiency of the use, in the design stages, of airfoil data obtained under different test conditions, calculations of propeller efficiencies have been made utilizing data for several NACA 16-series propeller airfoils obtained in different tunnels.

In an effort to improve the operating performance of shank portions of propeller blades, investigations have been made to determine the effects of propeller-shank thickness ratio on over-all propeller efficiency. Comparisons were made of wind-tunnel results for similar sets of blades differing in shank configuration. The conclusions reflect the importance of designing propellers for minimum energy losses and of using efficient airfoil sections along the entire length of the blade. In addition to these wind-tunnel tests, flight investigations were made of a propeller with shanks representative of those used for application on slender-nose airplanes. These shanks are characterized by rapid transition from thin airfoil sections to round roots immediately outside of the spinner. As reported in Technical Note 1414, thrust losses due to shank drag were high, corresponding to an efficiency loss of about 9 percent at a forward Mach number of 0.7 and power coefficient of 0.17 per blade. Loss in thrust due to shanks was a function primarily of airplane Mach number and was relatively independent of power loading. When part of the shank sections of this propeller were covered, by increasing the diameter of the spinner by a factor of 19 percent, shank losses were reduced by 60 percent of their value with the smaller spinner.

The effects of thickness distribution along the blade have been investigated by comparing the performance of a number of propellers having blade-section maximum thickness ratios from 6 to 12 percent of the chord.

In order to evaluate the combined effects of blade-section camber and compressibility on propeller performance, comparisons have been made of a number of related propellers

over a range of blade angle and airspeed. The results indicate that increasing the design camber over what are considered conventional values shows promise for certain applications.

An investigation was conducted in the Langley propeller-research tunnel to determine the efficiency at low tip speeds of two 10-foot-diameter six-blade dual-rotating propellers differing only in pitch distribution (Technical Note 1634). Propeller forces were determined by both dynamometer measurements and wake surveys, and an analytical method using two-dimensional data was used to calculate the efficiency, blade loading, thrust, and torque characteristics of both propellers over a wide range of operating conditions. The calculated results were found to be in good agreement with the experimental results.

The effect of thrust-axis inclination is becoming important in the structural design of propellers because of the variation in blade loading throughout each revolution. An analysis based on simple geometry and calculations based on the analysis are presented in Technical Note 1721. Calculations show excellent agreement with a limited number of flight investigations in which the maximum and minimum thrust loadings on the right and left sides of the propeller disk were measured in relation to the thrust-axis angle of attack.

Investigations reported in Technical Note 1654 were conducted to determine the way in which the noise patterns from multiple propellers combine. Sound measurements for the zero-air-speed condition in the tip Mach number range from 0.87 to 0.89 are presented for three different dual rotating propellers operating side by side in the same plane of rotation; the results obtained are compared with a theoretical analysis of the problem and excellent agreement is found.

Sound from a four-blade dual-rotating propeller was found to fluctuate approximately between that of a two-blade single-rotating propeller and a four-blade single-rotating propeller when the propellers are absorbing the same power at the same tip speeds. The amount of fluctuation was found to depend on the angle of overlap with respect to the observer. By correct phasing of the components of a dual-rotating propeller in flight, the sound reaching the ground in a given direction can be reduced by a small amount.

In connection with the Committee's program to reduce noise emanating from aircraft, a study was made of the factors affecting the design of quiet propellers. The paper which describes the results of this study constitutes a review of acoustic, aerodynamic, and structural considerations. It is concluded that to obtain a quiet propeller the rotational speed must be reduced to about one-half the conventional speed. Such speed reduction requires a propeller of about four times the conventional area. It is shown from theoretical considerations that, for a given propeller diameter, if the number of blades is increased, no penalty in aerodynamic efficiency will result. It is also shown, when flutter speed is used as a criterion, that by using a lighter material

for blade construction the quiet propeller need not be heavier than the conventional propeller.

As an aid in the design of propeller shanks and cuffs, the flow speeds and directions in the vertical plane of symmetry of six NACA 1-series cowling-spinner combinations and one NACA 1-series nose inlet were measured in the Langley propeller-research tunnel.

SUBCOMMITTEE ON HELICOPTERS

The increasing use of helicopters, both by the military services and by commercial operators, has accentuated the necessity for developing means of improving the flying and handling qualities of this type of aircraft. During the past year, the Committee has intensified its research on the basic problems involved in obtaining satisfactory stability and control characteristics for helicopters.

Flight Investigations

Flight-performance measurements were made on a twisted, plywood-covered helicopter rotor in various flight conditions, in order to obtain reliable data with which to check the rotor theory that had already been published by the NACA. An analysis of the test results, published in Technical Note 1595, showed that rotor theory can be used to predict adequately the performance of helicopters in various steady-flight conditions. By comparing the test results with performance measurements on a fabric-covered rotor, the analysis of Technical Note 1595 also showed the importance of smooth, rigid-blade surfaces for obtaining maximum performance.

The effects of rotor-blade twist on helicopter performance in the high-speed and vertical-autorotative-descent conditions were investigated in flight and the results reported in Technical Note 1666. It was found that the use of negative blade twist appears to be an effective means for increasing the maximum speed of the helicopter as limited by blade stall and for reducing the performance losses due to stall at a given thrust coefficient and tip-speed ratio. The investigations also showed that negative blade twist had little effect on the power-off performance of the rotor in the vertical-descent and forward-flight conditions.

Analytical Studies

As a first step in establishing a set of flying- and handling-qualities requirements for helicopters similar to those previously established for the airplane, a discussion of some fundamental concepts of helicopter stability and control was prepared. This paper also includes a discussion of several lines of development which appear to warrant consideration.

In view of the current interest in large, slow-moving load-carrying helicopters, methods for the improvement of rotor hovering performance are necessary. One means for accomplishing this improvement, which involves designing the rotor blades with proper amounts of twist and plan-form taper,

was investigated theoretically in Technical Note 1542. The results of the analysis indicated that substantial improvements in hovering payload could be achieved by small amounts of linear twist and taper.

The high tip speeds of helicopter rotors appear to offer a useful application of jet power, particularly for the large load-lifting type of helicopter. To evaluate the merits of the various types of jet power plants available, a theoretical study was made of the hovering performance of a helicopter powered respectively by a ram jet, pulse jet, and Nernst turbine in which the air is compressed by the centrifugal pumping action in the hollow rotor blade and mixed with fuel at the blade-tip burners.

Bibliographies and Summary Reports

Direct contact with designers and research workers in the rotating-wing field has indicated the need for bringing to their attention all of the available technical literature. Accordingly, as an aid in obtaining such material and in order to acquaint the rotating-wing industry and the various Government agencies charged with the design, evaluation, and procurement of helicopters with the work done by the NACA in the field of rotating-wing aircraft, a bibliography of NACA papers issued in that field was released.

Also, in order to facilitate the application of miscellaneous airfoil data to the problems of the helicopter designer, a discussion of a number of the problems most frequently arising was published. A reference list of published reports on airfoil section characteristics (or their application) which experience had shown to be useful in connection with these helicopter problems was included in the paper.

SUBCOMMITTEE ON SEAPLANES

Length-Beam Ratio

Seaplane research has been focused sharply on the possible methods of developing operational seaplanes which will have minimum air drag consistent with acceptable hydrodynamic characteristics. Increasing the length-beam ratio of the hull of a flying boat by maintaining constant the product of length squared and beam has been a promising direction of development and extensive investigations have been conducted on hulls of high length-beam ratio.

Wind-tunnel tests of model hulls mounted on a wing had shown that the air drag was reduced when the length-beam ratio was increased from 6 to 15. In order to determine the extent of wing interference, tests were made of the hulls without the wings. The results (Technical Note 1686) confirmed the previous conclusion that increasing the length-beam ratio reduced the air drag.

To investigate the effect on structural weight of use of a high-length-beam-ratio hull, a mathematical analysis was carried out; it was concluded that a weight saving would result with no reduction in strength.

Because of the advantages of reduced air drag and reduced structural weight, the series of length-beam-ratio hulls were investigated in the towing tank to determine their hydrodynamic characteristics. The spray in the vicinity of the propellers and flaps was slightly better on high-length-ratio hulls, but the spray around the horizontal tail was slightly worse. It was concluded that the over-all spray was of about the same severity. Hydrodynamic stability and resistance measured on complete dynamic models (Technical Note 1570) were practically unchanged by increasing the length-beam ratio.

Unconventional Seaplanes

An airplane is designed primarily to fly and devices used for taking off and landing are secondary to the primary design purpose. In some airplane designs, the landing gears are so greatly subordinated to the flight missions that any workable arrangement is permissible. With the philosophy of this design practice in mind, research has been directed toward providing a means of seaplane take-off and landing which will not penalize the flight characteristics.

Step Depth

The step on a seaplane must be deep enough to prevent skipping on landing and yet not so deep as to cause unnecessary air drag. An empirical formula has been devised (Technical Note 1571) from a series of model tests for computing the depth of step necessary from the length of the afterbody and the afterbody keel angle. A comparison of this formula with the results of other model investigations and flight tests shows it to predict accurately the depth of step required.

Small Twin-Float Seaplanes

Because of the large number of low-powered twin-float seaplanes encountering take-off difficulties, an analysis of the take-off resistance was made (Technical Note 1524). The resistance at the high Froude numbers encountered near the take-off speed was found to be critical for take-off. Based on previous experience, methods of reducing this resistance were suggested.

SPECIAL SUBCOMMITTEE ON THE UPPER ATMOSPHERE

Standard-Atmosphere Tables

The Special Subcommittee on the Upper Atmosphere has reviewed the tentative standard upper atmosphere that was established from indirect measurements and released as Technical Note 1200, in the light of high-altitude temperature and pressure measurements becoming available from soundings by V-2 and other high-altitude rockets. Although direct measurements have now been made, they are still few in number and are open to some question owing to uncertainties that exist in the methods of measurement. For these reasons,

it has appeared inadvisable to attempt any revision of the tentative standard at this time. The subcommittee is continuing its efforts to provide an accurate extension to extreme altitudes of the NACA standard atmosphere.

Surface-Temperature Rise in the Free-Molecule Regime

At the extreme altitudes encountered during flight of sounding rockets and missiles, the atmosphere can no longer be considered as a continuum, and account must be taken of the individual motions of the molecules composing the atmosphere. Using the methods of kinetic theory, calculations have been made by the Ames Laboratory of the temperature of uncooled flat plates traveling at high speed in the upper atmosphere. This work is reported in Technical Note 1682. The calculation may be extended to bodies of arbitrary shape by considering them to be comprised of a number of flat plates. The amount of cooling required to maintain several specified body temperatures is included in the calculations.

PROPULSION RESEARCH

The propulsion requirements of high-speed aircraft and guided missiles have led to the consideration of many possible forms of power plants in addition to the reciprocating-engine and propeller combination. Among these are the turbojet, the turbopropeller, the compound engine, the ram jet, and the rocket. Research problems have multiplied accordingly. These new forms of power plants for aeronautical applications are capable of marked improvement through continued research. NACA efforts in this field have been assisted by the Committee on Power Plants for Aircraft and its seven subcommittees. Most of the research discussed in this section has been conducted at the Lewis Flight Propulsion Laboratory, formerly called the Flight Propulsion Research Laboratory. Research has also been conducted by the National Bureau of Standards and 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, conferences on specific phases of the research have been held at the Lewis Flight Propulsion Laboratory during the past year. At these conferences significant NACA research results were presented on fuels and engine stress analyses. These conferences were attended by representatives of Government agencies and Government contractors working in the particular field.

During the year the former Subcommittee on Aircraft Fuels and Lubricants recommended that the subject of lubricants be assigned to another group. It was accordingly assigned to the then Subcommittee on Lubrication, Friction, and Wear. As a result, the names of both subcommittees were changed, becoming the Subcommittee on Aircraft Fuels and the Subcommittee on Lubrication and Wear, respectively.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Altitude Performance of Gas-Turbine Engines

During the past year the full-scale gas-turbine power-plant altitude facilities of the Lewis Flight Propulsion Laboratory were increased by the addition of two altitude test chambers. These facilities have proved very useful in providing research information which previously could be obtained only in the altitude wind tunnel or in flight.

Investigations have been conducted in the Lewis altitude wind tunnel to determine the operational and performance characteristics of several turbojet engines. The effects of variations in altitude, ram-pressure ratio, and tail-pipe-nozzle area on the engine performance and operational characteristics and on the engine-component performance were evaluated.

The study of methods of generalizing the data so that performance of a turbojet engine could be extrapolated from one operating condition to another was continued. In general, the engine-performance data for one turbojet engine generalized satisfactorily over the range of altitudes investigated; whereas, the performance of a second engine could be estimated only to an accuracy of about 9 percent over a range of altitudes. The generalization of data for a third engine did not afford satisfactory performance estimation because of variations in compressor and turbine efficiencies with altitude.

Thrust Augmentation of Turbojet Engines

The performance and operating characteristics of 10 different types of tail-pipe burner were investigated on a blower test rig. The results of this investigation served as a basis for the selection of burner design. In addition to establishing a simple low-pressure-drop system of fuel injection and flame holders, methods of controlling the temperature distribution in the burner were investigated. The use of different fuels was also studied. A method of obtaining satisfactory ignition was developed.

An investigation was conducted in the altitude wind tunnel of the thrust augmentation of a turbojet engine having an axial-flow compressor. These investigations evaluated the thrust increases obtainable with tail-pipe burning in a tail-pipe burner which did not increase the over-all dimensions of the engine and in an over-size tail-pipe burner with simultaneous water injection into the engine inlet and the combustion chambers.

Flight investigations were made with water-alcohol mixtures injected into the compressor inlets to determine the mixture ratio and the injection rate for optimum thrust augmentation for a range of flight speeds and altitudes.

Ram Jets

Flight investigations have been made using several different ram jets. Starting characteristics, operating limits, and combustion efficiency were determined for a 20-inch-diameter ram jet over a range of flight conditions. At high altitudes, it was found that the adverse effects on combustion efficiency of low pressures and temperatures were

greater for low fuel-air ratios than for approximately stoichiometric mixtures. A flight investigation has been made of a rectangular ram jet incorporating a V-shaped gutter-type flame holder. The combustion efficiency decreased markedly with increasing altitude, but rough engine operation was encountered only when the fuel-air ratio approached either the lean or rich operating limits at altitudes above 20,000 feet. Free-flight investigations at supersonic speeds of a series of 16-inch-diameter ram jets were made by releasing the unit from an airplane at high altitude and utilizing the engine thrust and force of gravity for acceleration.

Investigations of ram jets in the altitude wind tunnel have been directed toward the determination of configurations for optimum engine performance. The effect of flame-holder geometry on combustion-chamber performance in the 20-inch-diameter ram jet has been evaluated.

A study of ram-jet performance characteristics indicated that optimum performance over a wide range of operating conditions required a variable exhaust-nozzle-outlet area. A 20-inch ram jet with an adjustable exhaust-nozzle plug to vary the outlet area was investigated in the altitude wind tunnel. In general, the performance of the engine was improved by the use of a nozzle plug.

An analytical method that gives two independent means of evaluating the total-temperature ratio across a ram jet without direct measurement of the outlet temperature was developed. Tests of a 20-inch ram jet over a wide range of operating conditions verified the results of the analysis. Inasmuch as the thrust of a ram jet depends on the total-temperature ratio across the engine, this analysis provides the basis for two general types of fuel-metering control.

Stress and Vibration Research

Among the power-plant components that were investigated were the disks and the blades of conventional and supersonic compressors and of the conventional gas turbine.

An investigation (Technical Note 1667) was conducted to determine the influence of strength and ductility on room-temperature burst characteristics of solid disks, disks with large central holes, and disks with small central holes. Ductility varied from 3.4 to 52.8 percent conventional elongation. For all designs, disk strength increased with increasing tensile strength and the ratio of disk strength to tensile strength was found to be relatively independent of ductility.

An experimental investigation was made of the distribution of residual stresses in an over-speeded thin flat disk with a central hole by the nondestructive method of X-ray diffraction. Stresses were measured on the surface along the disk radius in the radial and in the tangential directions after some plastic deformation under rotating stresses. The apparent operating stresses in a 3-S aluminum disk as determined by the measurement of the residual stresses in those directions showed the occurrence of high local stress gradients and variations, particularly near the center hole.

Several analytical methods exist for the determination of frequencies in the various modes of vibration of turbine blades, but most of these methods are lengthy. A short method of calculating the frequencies of axial-flow-compress-

sor blades in the first three bending and torsional modes was tested by comparison with experimental measurements on actual blades and was found to predict frequencies correctly within 10 percent. Because the variation in geometry of axial-flow-compressor blades is limited, mode constants determined experimentally from one set of blades may be used to predict the frequencies of other sets of blades if the variation in geometry is within the limitations set forth in the analysis.

A theoretical investigation was made of the effect of centrifugal force on the flutter of blades. It was found that centrifugal force can decrease the critical flutter speed as much as 60 percent.

The effect of aerodynamic hysteresis on the critical flutter speed at stall was investigated. A mathematical analysis was made to determine whether the aerodynamic-hysteresis theory can be correlated with the available experimental data. Good agreement was obtained.

Experimental vibration measurements were made on supersonic axial-flow-compressor blades as mounted in a wind tunnel and when functioning as a true compressor powered by an electric-drive motor. The effects of flow velocity, centrifugal tension, tip speed, angle of attack, and shrouds were investigated. A series of tests was also undertaken in the wind tunnel to evaluate various blade thicknesses and their effect on natural frequencies and vibration amplitudes.

Vibratory stresses were measured by wire resistance strain gages in the blading of a 10-stage axial-flow compressor under normal operating conditions. The effects of speed and order of vibration on both frequency and stress amplitude were determined. It was found that the lower the order or higher the speed, the higher was the stress level; however, no destructive vibrations were detected. The change in damping coefficients with the application of the instrumentation and the amplitude necessary to cause failure were experimentally determined.

Thrust Control of Turbojet Engines

An analysis was made, using engine-component operating data, which indicated that the thrust of a turbojet engine can be fully controlled by an inlet throttle or a variable exhaust nozzle or both with the engine operating at a constant speed. This result is particularly significant because it presents a means of varying propulsive thrust far more rapidly than can be obtained with current variable-engine-speed systems. Rapid thrust control is a very important requirement for high-speed maneuverability as well as for safety.

Control of Ram Jets

Although the ram jet is unique in both design and flight application, its practicability as a power plant for either guided missiles or piloted supersonic aircraft will depend to a great extent upon the development of satisfactory control systems that will permit the engine potentialities to be fully exploited. An analysis was made to determine the fundamental control requirements and parameters for the ram jet in order to provide a rational basis for the development of ram-jet control systems.

Temperature Sensing and Control

Both the gas-turbine- and the ram-jet-type engines are temperature limited; that is, they are operated at temperatures only slightly below the maximum temperature that can be withstood by the engine materials. It is therefore necessary that controls be provided to maintain the engine temperatures at the high levels required for peak engine efficiency and at the same time to prevent the temperatures from exceeding safe limits even for brief periods.

Because conventional temperature-sensing and control systems were considered inadequate to meet satisfactorily either current or future gas-turbine-engine control requirements, an investigation was instituted to study various new temperature-sensing and control systems. A new pressure-sensitive, temperature-control system was evolved, which offers much promise in providing accurate high-response-rate temperature signals up to temperature levels of approximately 3,000° F.

Operation During Starting

The starting of gas-turbine engines has been investigated to determine basic causes of overheating, which leads to failure of various engine parts during this important phase of operation. Results of the investigation indicate that excessive fuel-flow rates at the low rotative speeds incident with starting were causing extremely high temperatures, resulting in failure of certain engine parts. It was found that hot starts could be eliminated by improving fuel atomization at low flow rates. Use of lower fuel-flow rates with improved atomization resulted in controlled temperatures during the starting cycle. Improved atomized fuel sprays also permitted ignition of the engine burners at lower rotative speed, with a resultant reduction in required starter input energy of approximately 50 percent.

Fuel Distribution

A new type fuel system for gas-turbine engines, comprised of variable-area atomizing nozzles and a distribution control, has been investigated to determine characteristic performance of both the engine and the fuel system. The variable-area fuel nozzles were found to produce finely atomized sprays over a much wider range of fuel-flow rates than conventional fixed-area fuel nozzles. Peak fuel pressures were also reduced to approximately one-half the value of those now in current use. The fuel-distribution control was found capable of regulating fuel-flow rates to each nozzle within ± 2 percent of the average value. A fuse valve in the distribution control functioned perfectly to eliminate fuel flow to any nozzle line that had ruptured. This feature would permit an engine to continue in operation at near maximum output after several fuel lines had been severed through breakage or battle damage. A break in any fuel-nozzle line of current fuel systems will cause immediate engine failure and introduce a serious fire hazard.

Reciprocating-Engine Cooling—Air Cooled

An investigation of the types and the locations of pressure tubes and thermocouples satisfactorily used by the NACA in

multicylinder-engine cooling investigations was made. The advantages and the disadvantages of the various types of pressure tube and thermocouple were evaluated with regard to reliability, durability, and ease of installation. The results are reported in Technical Note 1509.

Piston Cooling

An investigation was made of the coefficients of heat transfer at the surfaces of pistons and of the effects of piston dimensions on piston temperature distribution. Conflicting ideas in the literature on the use of thick or thin piston crowns to avoid overheating of the piston result from lack of information on coefficients of heat transfer at piston surfaces.

Temperature distributions within a piston were determined by hardness surveys of the piston, which was composed of an age-hardened aluminum alloy. From these data surface coefficients of heat transfer were determined. These coefficients of heat transfer were then used in a theoretical analysis of the effects of crown thickness, ring-belt thickness, and undercrown cooling on temperatures throughout the piston. The analysis reconciled the previously conflicting opinions. With low rates of undercrown cooling encountered by early investigations, thickening the crown decreases crown temperature with little increase in ring-belt temperature. With high rates of undercrown cooling achieved by oil sprays, thin crowns reduce both crown and ring-belt temperature. In the latter case, very little heat is dissipated through the piston rings or lands.

Effect of Valve Overlap on Engine Performance

An investigation was conducted to determine the effect on the performance of a two-valve air-cooled aircraft cylinder of increasing the valve overlap from the conventional value of 40° to 130°. With the 130° valve overlap, nearly complete clearance-volume scavenging was obtained with a consequent increase in power output of approximately 20 percent over that obtained with no scavenging (Technical Note 1475). Despite the increased power output with the 130° valve overlap, the cooling effect of the scavenging air was sufficient to prevent any increase in the exhaust-valve-seat temperature.

Heat Transfer From High-Temperature Surfaces to Fluids at High Heat-Flux Densities

An investigation has been instituted to obtain surface-to-fluid heat transfer and associated pressure-drop information at high surface temperatures and heat-flux densities in which case the temperature gradients of the fluids at the surface are severe, making the extrapolation of existing data to these conditions doubtful. As part of the general program, an investigation was made with air flowing through an electrically heated Inconel tube at average surface temperatures up to 1,700° R. The results indicated that correlation of the heat-transfer data by conventional methods, wherein the physical properties of the air were evaluated at the average bulk temperature, resulted in a reduction of Nusselt number of about 25 percent for an increase in average surface tem-

perature from 680° to 1,700° F. at constant Reynolds number. A good correlation of the data for the entire temperature range was obtained, however, when the physical properties of the air were evaluated at the average surface temperature and the Reynolds number was modified by substituting the product of air density evaluated at the average surface temperature and velocity evaluated at the average bulk temperature for the conventional mass flow per unit cross-sectional area.

SUBCOMMITTEE ON AIRCRAFT FUELS

Effect of Turbojet-Fuel Characteristics on Combustion in an Engine

Investigations over a range of altitudes have shown that the boiling range of the fuel and the predominant types of hydrocarbon present in the fuel have an important bearing upon the performance of the turbojet engines in which the fuels are used. These fuel variables influence the starting characteristics of the engine at altitude conditions, the combustion efficiency, the altitude operational limits, and the quantity of carbon that will deposit in the engine. The influence of fuels on these parameters has been investigated in both tubular and annular combustors from turbojet engines. The investigations have shown that at simulated high-altitude conditions one type of hydrocarbon fuel will give a combustion efficiency markedly greater than another type of hydrocarbon fuel. It has also been shown that the altitude operational limits that can be attained with a combustor are influenced by the fuel. Differences of several thousand feet in simulated-altitude operational limits have been obtained with two different fuels in the same combustor. As part of these investigations studies have been continued to determine whether fuels available in sufficient quantity in time of national emergency will operate satisfactorily in aircraft gas turbines. On the advice of the NACA Subcommittee on Aircraft Fuels the military services tentatively indicated a fuel for aviation gas turbines which would permit maximum utilization of available crude oil for conversion to aircraft gas-turbine fuel in time of national emergency. The performance of such a type of fuel has been investigated in several current types of turbojet power plants under altitude conditions.

Method of Fuel Injection

The manner in which the fuel is introduced into the combustion chamber has a great influence on the efficiency of the combustion process. The research reported in Technical Note 1618 indicated the extent to which at low fuel flow the combustion efficiency of a tubular combustor was improved by changing the fuel spray in such a manner that the fuel was more efficiently distributed in the primary combustion zone.

Molecular Structure and Chemical Composition

Turbojet engines and ram jets require a rapid energy release in a short combustion chamber. Therefore, it is desirable to utilize fuels with a rapid rate of flame propagation. A study of the changes in rates of flame propagation attained when the molecular structure of hydrocarbon fuels

is varied is reported in Technical Note 1609. In quiescent fuel-air mixtures, fuels with a triple carbon-to-carbon bond gave considerably faster rates of flame propagation than fuels with single carbon-to-carbon bonds.

The hydrocarbon types present in actual turbojet fuels are extremely numerous and complex. Suitable methods have not yet been developed for the characterization of the components of such fuels, and research is being continued on new methods for their chemical and physical analysis. A spectroscopic method for the analysis of naphthalene components in mixed fuels is reported in Technical Note 1608. A rapid method for the determination of aromatic hydrocarbons in complex mixtures is described in Technical Note 1641.

High-Performance Reciprocating-Engine Fuels

Research was conducted on the knock-limited performance of fuel components necessary to produce fuels above a performance number of 115/145. The manner in which both paraffinic and aromatic blending agents perform in a full-scale single-cylinder engine is reported in Technical Notes 1374 and 1416. It was shown that the knock-limited performance of paraffinic blends could be predicted from the performance of the pure components. However, aromatic hydrocarbons did not follow the blending relation derived for paraffins. Small-scale single-cylinder-engine evaluation of high-performance paraffins and olefins is reported in Technical Note 1616.

The knock rating of high-performance aviation fuels by comparison with leaded blends of heptane and isooctane has been considered as needing improvement. A number of rating systems have been suggested but some have not been completely evaluated. The results of an investigation to determine a suitable fuel-rating system are reported in Technical Note 1619. It was concluded that a heptane-triptane system is a satisfactory fuel-rating system but the standard rating engine must be changed before extremely high performance fuels can be satisfactorily rated.

The interest in reciprocating engines compounded with a turbine has created considerable interest in the influence of high exhaust manifold pressures on the knock-limited performance of fuels. An investigation of this problem was conducted on a full-scale single-cylinder engine as reported in Technical Note 1617. At most operating conditions the knock-limited performance of the fuels investigated decreased regularly with increasing exhaust manifold pressure.

SUBCOMMITTEE ON COMPRESSORS

Research results obtained on turbine cooling and high-temperature materials for gas-turbine engines show that substantial increases in turbine-inlet gas temperatures are feasible. The turbine expansion ratio for gas-turbine engines must increase with increasing turbine-inlet temperatures if full advantage is to be taken of the large gains in performance obtainable with increased turbine-inlet temperature. Because pressure on the downstream side of the turbine is for the most part fixed by the pressure of the

atmosphere surrounding the engine, the compressor must supply a higher pressure ratio to correspond with the larger expansion ratios required by higher turbine temperatures. Good progress has been made during the past few years in increasing the pressure ratio per stage of both axial- and centrifugal-type compressors. The supersonic compressor embodies a completely new concept in the field of efficient mechanical compression, and experimental models have been operated successfully with encouraging results. The evolution of high-performance compressor types is being pursued by theoretical and experimental investigations.

Axial-Discharge Mixed-Flow Compressor

An axial-discharge mixed-flow compressor was investigated in order to study the possibilities of combining the compactness, reliability, and wide operating range of a centrifugal compressor with the high flow capacity per unit of frontal area that characterizes the axial-flow compressor. The flow capacity per unit frontal area for this axial-discharge impeller was found to be much greater than that for current types of mixed-flow compressors for which data were available but was somewhat less than that for the best axial-flow compressors. This axial-discharge mixed-flow compressor exhibited a wide operating range over the entire speed range and the performance was in close agreement with that predicted by the theoretical design.

Centrifugal-Compressor Performance

Several investigations were conducted to determine the performance of large centrifugal-type compressors that are components of turbojet engines, and to increase the fundamental knowledge of flow through this type of compressor. A centrifugal compressor with a single-entry impeller and a vaned collector was investigated over a wide range of operating conditions and the effectiveness of the component parts of the compressor was evaluated. An analysis of static-pressure variation along the direction of flow in the compressor showed that the maximum-flow limitation of the compressor was caused by flow separation in the entrance region of the vaned-collector passage. On the basis of this analysis, an alteration of the vaned collector was made to provide a large entrance flow area, which resulted in a 25 percent increase in weight flow and improved over-all efficiency at the operating speed of the compressor. Pressure losses were also shown to originate in the inlet region of the impeller at high flow rates.

A method of compressor-performance augmentation by means of water injection into the impeller was investigated on two large double-entry centrifugal compressors. Water injection resulted in an increase in total-pressure rise and an increase in weight flow. Although the compressors were physically similar, the surge characteristics were differently affected by water injection, and it is therefore necessary to consider the effect on surge characteristics when matching the turbine and the compressor using water injection in a turbojet engine.

Diffusers and Collectors for Centrifugal Compressors

Examination of a large amount of data on compressor performance with both vaned and vaneless diffusers using the same impeller suggested the possibility of combining desirable characteristics of the two types of diffuser, thus increasing the adaptability and performance of centrifugal compressors. The vaneless diffuser has the advantage of a wide operating range, but has a considerably larger diameter than a vaned diffuser for equivalent energy conversion.

Further study of the data on vaneless diffusers with a conventional collector ring indicated that the decrease in compressor efficiency with reduction in vaneless-diffuser diameter was approximately proportional to the loss encountered at the juncture of the vaneless diffuser and the collector ring. The inlet losses of the collector ring could be attributed to the increase in kinetic energy at the collector inlet associated with a decrease in vaneless-diffuser diameter. It appeared that the substitution of a diffusing scroll collector for the collector ring might reduce the inlet kinetic-energy losses to a point where a small-diameter vaneless diffuser could be efficiently employed.

A family of diffusing scroll collectors was therefore designed for a mixed-flow impeller and a small-diameter vaneless diffuser. It was found that for the range of scroll-collector geometry and surface conditions investigated there was a negligible difference in compressor performance. A representative vaneless-diffuser and scroll-collector combination was therefore used in a comparison of over-all compressor performance with the same impeller and various diffuser-collector combinations. The results showed that the performance of a 20-inch vaneless diffuser and scroll collector is approximately the same as that of a 34-inch vaneless diffuser and collector ring. Also, the 20-inch vaneless diffuser and scroll collector had a higher efficiency and pressure coefficient than a 17-inch vaned diffuser and collector ring (Technical Note 1568).

The effect on diffuser performance of the passage curvature of two vaneless diffusers designed with a 6° equivalent-cone divergence along a logarithmic-spiral path was investigated in combination with two mixed-flow impellers. It was found that the large difference in passage curvature of the two vaneless diffusers made no appreciable difference in diffuser performance at the peak compressor efficiency (Technical Note 1490).

Collectors for Axial-Flow Compressors

An investigation was conducted to determine the effect of size and number of outlet pipes on the performance of collectors used experimentally for the investigation of axial-flow compressors. The size and the number of outlet pipes had no appreciable effect on the static-pressure distribution at the collector inlet. It was found that in a collector with a sudden expansion at the inlet, which resulted in large pressure losses, the ratio of cross-sectional outlet-pipe area to collector-inlet area had to be greater than 2.0 to prevent choking of the flow in the outlet pipes.

With the exception of the smallest outlet cross-sectional area investigated, the principal total-pressure losses occurred

at the collector inlet. When two different outlet configurations of the same total flow area were compared, the total-pressure-loss factor was smaller with one outlet pipe than with two (Technical Note 1607).

Surging in Axial-Flow Compressors

Compressor operation at low air flows for a given speed is limited by unstable flow conditions, commonly called surge. In axial-flow gas-turbine engines, the compressor surge problem becomes critical because the range of compressor operating flows is so small that the engine operating point is very close to the compressor surge point. An investigation has been conducted to determine the surge characteristics of a 10-stage axial-flow compressor. All the stages started surging at approximately the same time and, although the end of surge was not clearly defined, all stages appeared to stop surging at approximately the same time. As the compressor speed was increased, the amplitude of pressure fluctuation increased and the frequency decreased. The frequency of fluctuation was practically unaffected by inlet-air pressure but the amplitude increased as the pressure was increased.

Effect of Reynolds Number on Axial-Flow Compressors

An investigation was made to determine the effect of Reynolds number on the performance of a multistage axial-flow compressor by varying inlet-air pressure and temperature. The peak values of adiabatic temperature-rise efficiency and pressure ratio were found to decrease as the inlet-air pressure was reduced at constant inlet-air temperature. The indicated effect of inlet-air temperature was small as compared with inlet pressure effects because the range of Reynolds numbers covered by varying the inlet-air temperature was much smaller than that obtained by varying the inlet-air pressure. The peak values of the performance parameters increased as the inlet Reynolds number was increased with the exception of the equivalent weight-flow parameter, which was only slightly affected by inlet conditions.

Effect of Mach Number on Axial-Flow Compressors

An investigation was conducted to study the influence of high relative inlet Mach number on the performance of a highly loaded axial-flow-compressor rotor-blade row designed for axial subsonic inlet velocity. Detailed flow measurements were taken both upstream and downstream of the rotor-blade row to investigate blade-section performance and the over-all pressure ratio and efficiency. The results at the mean-radius section of the blade showed that low-speed two-dimensional cascade data can be used to predict rotor-blade section performance with a fair degree of accuracy. The blade row had good efficiency with a slight decrease in efficiency as the relative Mach number was increased to a value of 0.82; above that Mach number the efficiency decreased rapidly. The over-all total-pressure ratio was extremely high in comparison with the stage pressure ratio being obtained in current axial-flow-compressor designs.

Supersonic Compressors

An axial-flow compressor rotor operating with supersonic velocities relative to the rotating blade row has been investi-

gated in air to determine performance characteristics in air and to check the performance obtained from an aerodynamically similar rotor operated in Freon-12 at lower rotating speeds. The rotor blades were designed on the basis of studies with supersonic diffusers and cascades. The 24-inch diameter rotor was machined from a solid steel forging with the shroud integral with the blading and was investigated over a wide range of rotor speeds. The general performance closely paralleled that obtained from the rotor operated at lower speeds in Freon-12, and the detailed flow measurements indicated that theoretical supersonic performance characteristics were closely approached.

SUBCOMMITTEE ON TURBINES

Substantial improvements in turbojet and turbine-propeller engines are obtainable if the permissible turbine-inlet temperatures and the expansion ratios across the turbine are increased. Great care must be exercised, however, to assure that these higher temperatures and expansion ratios are accompanied by adequate service life and low engine weight. Considerable effort is therefore being expended in turbine research to devise means that will yield the highest performance gains without sacrificing compactness, light weight, and reliability.

Suitable cooling of the turbine blades and other critical engine parts by circulating air or water as a coolant permits sustained high-temperature operation. Experimental results indicate that considerable gains can be obtained using this scheme, but much basic research remains to be done before the fundamentals are clearly understood. Circulation of coolant inside the turbine blades requires that thicker blade shapes be used, which in turn leads to a completely new approach to the technique of blade design.

Design and Performance

Although partial-admission steam turbines have long been in general use, little application of this technique is known to have been made to gas turbines which have relatively high pressure ratio per stage. Partial admission is one possible method that could be used to obtain efficient part-load operation or power regulation. In order to determine the effects of partial admission of gases to the nozzle periphery on turbine performance, an investigation was conducted on a representative single-stage turbine. It was found that efficient turbine performance could be obtained up to a blocked nozzle arc of 180°. When the nozzle annulus was blocked further, marked losses in efficiency occurred. A method was also developed by which the over-all turbine efficiency and power output for any degree of admission can be evaluated if the performance at full admission is known.

The effect of inlet conditions and pressure ratio on the adiabatic efficiency of a radial-flow turbine has been determined. It was found that the turbine efficiency increased as the Reynolds number was increased at a given blade-to-jet speed ratio.

Matching

The performance of a turbine component designed to match the NACA eight-stage axial-flow compressor was in-

vestigated with cold air. The interaction and the matching of the turbine with the NACA eight-stage compressor were computed with the combination considered as a turbojet engine; the over-all performance of the engine was then determined. The internal aerodynamics was studied to the extent of investigating the performance of the first stator ring and its influence on turbine performance. For this stator, the stream-filament check on velocity distribution permitted efficient sections to be designed, but the design condition of free-vortex flow with uniform axial velocities was not obtained. The actual air flow was 0.964 of the design value at design pressure ratio and speed, and was 0.98 at design speed and enthalpy drop. Rotative speed for optimum efficiency (0.875) was 180 revolutions per second as compared with the design speed of 134 revolutions per second when an efficiency of 0.823 was obtained (Technical Note 1459).

In order to understand the operation and interaction of turbojet-engine components during engine operation and to determine how component characteristics may be used to compute engine performance, a method of analyzing and estimating performance of such engines was devised and applied to the study of the characteristics of a turbojet engine. The applicability of component calibration was determined by correlating turbine performance obtained from engine experiments with that obtained by the simpler procedure of separately calibrating the turbine with cold air as a driving fluid. The turbine characteristic curves of weight flow and total-pressure ratio checked with the results from cold-air component calibration, though some discrepancies in efficiency were noted. The system of analysis was also applied to prediction of the engine and component operation during engine acceleration and to estimates of the performance of the engine and components when the exhaust gas was used to drive a power turbine (Technical Note 1701).

Turbine Cooling

Analysis has shown that large increases in specific power output along with a decrease in specific fuel consumption can be obtained by increasing the turbine-inlet temperature while simultaneously maintaining optimum pressure ratio in a turbine-propeller engine. The net horsepower output per pound of air is approximately doubled by increasing the gas temperature from 1,500° to 2,500° F. By providing cooling for the blades, turbines can be built to withstand these higher temperatures. Turbine cooling has an additional advantage, particularly in applications where the very high gas temperatures are not needed, in that less costly metals can be used in place of present types of high-temperature alloys.

Fundamental heat-transfer data are being obtained to determine the best possible means of cooling turbines. Analytical investigations have been extended to provide a theoretical analysis of the radial-temperature distribution through a turbine with and without cooling fins on the rim. The results showed that the addition of cooling fins on the rim permits only a slight increase of effective gas temperature. A three-dimensional study indicated the type

of temperature gradients to be expected in a section of the rim surrounding a blade root and may be applied to determinations of rim thermal stresses.

Experimental investigations have been conducted on the high-temperature operation of liquid-cooled blades in a static heat-transfer research unit and in a liquid-cooled turbine. The results of this investigation showed that a liquid-cooled turbine wheel of a high-conductivity material, such as aluminum alloy, can be satisfactorily operated at gas temperatures appreciably higher than those now in use.

SUBCOMMITTEE ON LUBRICATION AND WEAR

Sliding Friction and Run-In

An experimental investigation, reported in Technical Note 1578, was conducted to identify the roles of solid surface films in the various mechanisms of sliding and lubrication involved under three conditions: (1) In the mating and compatibility of boundary-lubricated slider surfaces, (2) in the action of extreme-pressure lubricants, and (3) in the operation of slider surfaces not supplied with fluid lubricants. Molybdenum disulfide was shown to be a very effective solid-film lubricant under conditions of high sliding velocities and extreme surface loads. Other results indicated that chlorine components were more effective extreme-pressure lubricant additives than were sulfur compounds. The observed friction trends favored the theory of the action of extreme-pressure lubricants, which states that the film material, formed by reaction of the lubricant additive with a surface, melts under extremely high temperatures or pressures and in that case the friction force will involve only shearing of a liquid film.

Extreme-Pressure Lubricants

Analysis of the mechanism of action of extreme-pressure additives led to a theory that the relative speed between sliding surfaces might exceed the rate at which an effective chemical reaction could occur. Evidence tending to confirm the theory was obtained in an investigation of lubricants at high sliding rates. The experimental evidence, obtained with a sulfur-type additive, showed that the critical sliding velocity, above which effective lubrication cannot be maintained, is unaffected by additive concentration or surface loads (Technical Note 1720).

Bearings

A theoretical analysis of the effects of bearing acceleration on several performance characteristics of slider and journal bearings has been made (Technical Note 1730). Equations are presented that establish fundamental relationships and show the effects of temporal acceleration on pressure distribution and on load capacity. The equations show that the factor most important in establishing the effects of acceleration on bearing performance is the ratio of acceleration to speed. When this ratio is high, the effects of acceleration are great; when it is low, the effects are slight.

SUBCOMMITTEE ON COMBUSTION

Effect of Operating and Design Variables on Performance of Gas-Turbine Combustors

Investigations have previously been directed toward obtaining a comprehensive picture of the influence of operating variables, or inlet conditions, on the performance of various gas-turbine combustors. With a knowledge of these effects as a background, increased emphasis has been placed on experimental research aimed at providing design rules and design criteria for gas-turbine combustors. This research has been particularly aimed at determining the effect of pressure drop, location, size, and area of air holes in the flame tube, and fuel nozzles on the efficiency and the altitude operational limits of gas-turbine combustors. A most significant finding in this research was that, by introducing some of the combustion air through properly distributed liner holes in part of the liner length, altitude operational limits and combustion efficiency at altitude were markedly improved. Redistribution of the air entering the flame tube of the liner of a gas-turbine combustor to improve its altitude operational limits frequently adversely affects the outlet temperature distribution. A particular outlet temperature distribution is required to avoid turbine-blade failure, and increased emphasis is being placed on the problem of outlet temperature distribution.

Effect of Operating and Design Variables on the Performance of Ram-Jet Combustors

As a basis for research and development on the operation and the design of ram jets, the effect of operating variables such as altitude and flight speed must be known for the combustion-chamber design. Experimental research has been conducted on both rectangular and cylindrical ram-jet combustors with particular emphasis on the effect of inlet-air temperature, pressure, and velocity and fuel-air ratio on the operational limits of the combustor, on the efficiency of combustion, and on the flame length. This research thus far has covered only a limited number of the ram-jet combustor configurations that must be studied.

As in the case of research on gas-turbine combustors, a search for design rules that are required in the development of ram-jet combustion chambers has been undertaken. This research includes the systematic variation of flame-holder design and fuel-injector design with the effect of these variations on operating limits, efficiency, and flame length being noted. The relation between combustion phenomena and ram-jet diffuser design has also been studied.

Liquid Propellants for Rocket Engines

The determination, evaluation, and perfection of propellant systems that can be used for the desired application and that will give the maximum thrust per unit weight flow and per unit volume flow of propellants have been undertaken. A theoretical investigation of the performance to be expected from a large number of propellant combinations has been continued. This theoretical investigation has necessitated the preparation of charts and methods for the thermo-

dynamic computations that are involved. Charts for the computation of equilibrium composition of chemical reactions in the carbon-hydrogen-oxygen-nitrogen system at temperatures from 2,000° to 5,000° are presented in Technical Note 1653. The more promising propellant combinations revealed in the theoretical study are being experimentally evaluated with regard to their handling properties and their performance in actual rocket engines. Experimental propellant evaluation has been conducted in small-scale rocket engines. Propellants investigated offer the possibility of greatly increasing the range of rocket-propelled vehicles as compared with alcohol and liquid-oxygen propellant.

Rocket-Engine Design

If high-energy propellants are to be burned in rocket engines, ways and means of cooling the chamber and the nozzle of the rocket engine must be found in order to prevent destruction of the engine when it is subjected to the extremely high temperatures resulting from the high-energy propellants. Jacketing of the rocket engine and nozzle with a coolant fluid is frequently insufficient. Other means of protecting the wall of the engine from the heat of the combustion products are being investigated.

Research has been conducted with different rocket-engine sizes and with different fuel-injection devices in order to determine the smallest and lightest possible rocket engine for a given thrust. High-speed photographs of the fuel-injection process and the subsequent combustion in the rocket engine have been made as an aid in this research.

General Combustion Studies

In order to gain an insight into the basic combustion processes so that a rational application of combustion to aircraft propulsion devices can be made, various fundamental projects are underway. In one such project, a flowing stream of premixed fuel and air was burned on the downstream side of a turbulence-promoting plate. The total open area in this plate, as well as the number of holes for any one open area, was systematically varied and combustion efficiency, flame length, and combustion stability were measured.

The chemical reactions encountered in the combustion process are being investigated. Part of this study was the determination of the potential required to accelerate electrons to the point where they would rupture various chemical bonds in fuel molecules that were being studied. This research is a first phase of the project in which it is intended to analyze a flame for the molecular species existing therein.

Further research on combustion phenomena in the reciprocating engine as studied with high-speed photography is reported in Technical Notes 1408 and 1614. Autoignition and knock have been shown to be separate and distinct phenomena. The high-speed camera was used to take simultaneously direct and schlieren photographs of combustion and in another project was used to record the ultraviolet spectrum in the reciprocating-engine combustion chamber.

Combustion Charts With Diluent Addition

Diluents and refrigerants are used in turbine engines to provide power augmentation for special needs. The use of

diluents requires a change in fuel rate to permit attainment of the required operating temperatures. A series of charts have been prepared to aid in the calculation of fuel requirements with the following diluents: Water, alcohol, carbon dioxide, ammonia, liquid nitrogen, and liquid oxygen, or combinations thereof. (See Technical Note 1655.)

SUBCOMMITTEE ON HEAT-RESISTING MATERIALS

Identification of Microconstituents

Many of the constituents of heat-resisting alloys have as yet not been identified and it is necessary as the first step in evaluating the importance of alloying elements to identify the various forms in which they appear within the alloys. The research on identifying these microconstituents, so-called because many of them appear in minute quantity, has been continued. The presence of columbium carbide and isomeric chromium carbide ($Cr_{23}C_6$), previously reported, has revealed the presence of titanium carbide and nitride, columbium nitride, isomeric chromium carbide (Cr_7C_3), and two mixed carbides of the type M_4C and $M_{23}C_6$ where M designates a pair of metallic elements, one each from chromium, nickel, or iron, and from molybdenum or tungsten, respectively. Results of this investigation on 20 heat-resisting alloys are presented in Technical Note 1580.

Evaluation of Materials

Contract research at the University of Michigan has been continued in this field. Turbine-disk forgings of Timken alloy, 19-9DL alloy, and CSA alloy have been studied (see Technical Notes 1531, 1532, and 1533, respectively) and data on creep and stress-rupture properties have been obtained up to temperatures of 1,200° F. Additional data have been obtained on disk forgings of Inconel X alloy, S-816 alloy, and low-carbon N-155 alloy up to temperatures of 1,500° F.

The research at the University of Michigan has included an investigation of the effects of various processing variables on low-carbon N-155 alloy, representing a typical heat-resisting alloy. Wide ranges in properties of most of the better alloys developed for gas-turbine service have been due to the influence of heat treatment and processing conditions on properties. The treatments used have been of more influence than wide ranges in chemical composition. It is expected that the trends shown in this investigation for the various treatments will hold for other alloys.

Consideration continues to be given to the problem of substituting lower-alloyed materials for those containing large percentages of scarce elements such as cobalt, columbium, and tungsten. The subcommittee is very active on this problem and is assembling data that will be of use in planning future study of it.

Analysis of Operating Conditions and Failures

A finite-difference method was developed for determining the effect of plastic flow and creep on the stress distribution in gas-turbine disks (Technical Note 1636). This method was used to compute the stresses in an operating gas-turbine

disk based on measured temperature distributions. It was found that the high temperature gradients on the cooled face of the disk produce compressive stresses at the rim that exceed the elastic limit of the rim material. Plastic flow in compression results in residual tensile stresses that are the cause of rim cracking of welded disks.

An analytical investigation was made to determine the centrifugal-stress distributions in six turbine blades representative of current design practice. Operating-temperature data were available for one type of blade and it was shown by means of the stress analysis that the critical stress region occurred at a location approximately half way between the base and the tip of the blade. Service failures that have occurred in this region corroborate the analysis.

An investigation was conducted to determine the vibration phenomena that occur in service operation of turbine blades. Through the use of high-temperature wire resistance strain gages, the blade vibrations were observed and evaluated in terms of modes, frequencies, stress range, and probable sources of excitation. The frequencies of the principal vibrations were found to be related to the number of nozzle blades and combustion chambers.

An investigation was made under accelerated operating conditions of the life of turbine blades of a currently used high-temperature alloy. This investigation indicated that most of the blade failures were probably caused by fatigue. No significant differences were found between broken and unbroken blades with respect to chemical composition, epsilon-phase distribution, or carbide-mesh distribution. It should be pointed out that the conditions of test and the engine employed in the evaluation can influence the type of failure considerably.

The operating temperatures of the critical components of turbojet engines and their correlations with gas temperatures were determined. An interesting result of this program was the determination of large temperature gradients in the gas stream from the burner, which result in large temperature gradients along the nozzle blades and the turbine blades. These gradients can accelerate the failure of components they affect.

The application of ceramics to turbine blades has been continued. Blades of a high-beryllia ceramic developed by the National Bureau of Standards have been operated for 50 hours at various tip speeds up to 737 feet per second and a turbine-inlet gas temperature of 1,800° F. Thermal shock resistance, however, is still a limiting factor in the use of ceramics in turbines.

Protective Coatings

Corrosion or oxidation is one of the chief mechanisms whereby some high-temperature materials fail. Under the sponsorship of the NACA the National Bureau of Standards is working on the development and evaluation of protective coatings for some of these materials. Coatings for molybdenum have been further improved over that reported last year and a number of service tests of coated molybdenum parts have been encouraging. A part of this research is reported in Technical Note 1626.

Coating materials have different affinities with the base materials that they are designed to protect. A study was made of the chemical reaction at high temperature of 61 compounds used in coatings with a number of heat-resisting alloys. This study included an evaluation of the effect of atmosphere on the reactions. Of the compounds investigated the alkalies, lead compounds, and some of the alkaline earths gave the most pronounced attack. (See Technical Note 1731.)

SUBCOMMITTEE ON PROPULSION SYSTEMS

Analyses of Gas-Turbine Engines

Analyses have been made to determine the pressure ratios and temperatures which must be used in gas-turbine-engine cycles in order to achieve maximum efficiency and power. Results of the studies indicate that maximum power can be realized with the use of very high maximum cycle temperatures, accompanied by considerable increases in compressor pressure ratio for both the turbojet and turbopropeller engines. Maximum aircraft range is obtained with pressure ratios considerably less than those necessary for maximum efficiency and the corresponding optimum temperature. Large increases in engine weight which are experienced with the use of very high pressure ratios necessitate this reduction in compressor pressure ratio in order to achieve maximum aircraft range. Gas-turbine-engine analyses indicate an urgent need for turbines which will withstand the higher cycle temperatures.

Comparative Performance of Several Engine Cycles

A comparison of the theoretical performance of a ducted-fan engine with that of a turbojet engine and a turbopropeller engine was made. The ducted-fan engine consisted of an axial-flow turbojet engine modified by the addition of a fan in a concentric duct around the basic turbojet engine. Power to drive the fan was obtained from the turbine of the basic engine by increasing the pressure drop across the turbine in the same manner that power for the propeller in the turbopropeller engine is made available. Comparison of the performance of the ducted-fan engine with the turbojet and turbopropeller engines indicated that the ducted fan has superior performance characteristics for a very limited range of operation. In general, for flight Mach numbers below 0.6 the turbopropeller engine appeared advantageous, and for flight Mach numbers above 0.6 the turbojet engine has the greatest flexibility. At a flight Mach number of 0.6 and with ratios of payload to gross weight of 0.3 or less, maximum airplane range is obtained with the ducted-fan engine.

Turbopropeller

A theoretical thermodynamic analysis was made of the performance of the turbine-propeller engine. The performance of the basic engine and the basic engine modified by the addition of intercooling, reheating, and regeneration, including the effects of flight speed, jet thrust, altitude, and variations of the working fluid, was determined. Charts to aid

in computing compressor and turbine work and temperature change, engine performance, and gas states were also developed. When the performance of the four engines was compared, it was found that reheating and intercooling increase the specific power output of the basic engine. Regenerator effectiveness must be greater than 0.50 in order to lower the minimum specific fuel consumption of the basic engine. The analysis is reported in Technical Note 1497.

Thrust Augmentation of Jet-Propelled Aircraft

Analytical and experimental investigations of various methods of thrust augmentation for turbojet engines have been made. Results of the analytical investigations indicate that tail-pipe burning and tail-pipe burning plus water injection are the most efficient means of obtaining large increases in thrust of a turbojet engine. Increases in thrust for turbojet-powered aircraft are also obtainable with rocket-engine assist as well as from bleed-off cycles in which air is bled from the basic turbojet engine at the compressor outlet and burned at stoichiometric fuel ratios in an auxiliary burner. Air bled from the basic engine is replaced by water which is injected into the engine combustion chamber. This latter method of thrust augmentation involves increases in specific liquid consumption from two to four times as large as the increases with tail-pipe burning and water injection. Much larger increases in thrust are available from the use of liquid-propellant rocket assist but entail even greater specific liquid consumptions.

Spark-Ignition Compound Engine

Theoretical investigations are continuing on the performance of various compound power plants consisting of a spark-ignition reciprocating engine, one or more turbines, compressors, and various geared arrangements so that the excess power of a turbine driven by the exhaust gas is returned to the crankshaft of the engine. Performance of several compound power plants, using the experimental data for (a) 18-cylinder radial aircraft engines with different nominal valve overlaps (62° and 40°), (b) the 62° -valve-overlap engine modified with 40° -valve-overlap cams, and (c) a 12-cylinder liquid-cooled engine, has been computed. The calculations, in general, give the optimum performance of these combinations for various engine operating and flight conditions and show the increased performance of the compound engine over the conventional reciprocating engine. The results of these investigations are reported in Technical Notes 1447, 1500, 1602, and 1612.

Compression-Ignition Compound Engine

Research is being conducted on compound engines of the gas-generator type consisting of a compressor, a two-stroke-cycle compression-ignition engine, and a turbine that is driven by the gases from the engine. In this power plant, the reciprocating element serves only to drive its own supercharging compressors and to furnish gas for driving the turbine that supplies the power to drive the propeller.

An analysis of the gas-generator-type power plant which has been completed indicates that it should be capable of operating with a brake specific fuel consumption of 0.32

pound per horsepower hour. The analytical studies indicate that this type of power plant should have an installed specific weight comparable to that of a typical turbopropeller engine. This performance should be obtainable with limiting values of cylinder pressure and turbine-inlet temperature that are compatible with reliable engine operation.

Thermodynamics

A method of calculation that permits a rapid and simple semigraphical solution of one-dimensional compressible-flow problems that involve friction, change in composition, changes in heat content, or changes in mass flow for either constant or variable specific heat has been developed. The method is reported in Technical Note 1419.

AIRFRAME CONSTRUCTION RESEARCH COMMITTEE ON AIRCRAFT CONSTRUCTION

The Committee on Aircraft Construction has undergone a number of changes in organization designed to give a more complete coverage of the problems under its cognizance and to emphasize further certain fields of research. The primary changes have been made to bring about a more concerted attack on those problems combining aerodynamic and structural variables. For this purpose a new subcommittee was appointed, the Subcommittee on Aircraft Loads, and the Subcommittee on Vibration and Flutter was shifted from the Committee on Aerodynamics to the Committee on Aircraft Construction. The Subcommittee on Aircraft Structural Materials was appointed to consider research on all materials, metallic or otherwise, pertinent to aircraft structures. The Subcommittee on Aircraft Structures is concerned primarily with the behavior of structures under given loads, either static or dynamic.

Because of these changes in organization considerable effort has been spent by the Committee on Aircraft Construction and its subcommittees in reviewing present programs and recommending new research. In addition to those portions of the program that are carried out in NACA laboratories, a considerable amount of research is performed by university and other nonprofit scientific laboratories under contract to the NACA. The results of this supplementary research are presented herein as a part of the complete program divided according to the subcommittee fields of interest.

SUBCOMMITTEE ON AIRCRAFT STRUCTURES

Research in the field of aircraft structures has been actively pursued during the past year by both the Langley Aeronautical Laboratory and a number of universities studying under contract with the NACA. The achievements of the past year indicate the trend toward higher-speed aircraft although a number of studies have been sufficiently basic to apply equally well to the lower-speed aircraft.

Strength of Curved Plate

As part of a broad program on the strength of curved sheet, a method was recently developed for determining the theoretical buckling stresses of unstiffened cylindrical shells under various loading conditions. This theory has now been

extended to include stiffened shells, and the particular case of curved rectangular panels in axial compression reinforced by a centrally located chordwise stiffener of zero torsional stiffness has been treated in detail (Technical Note 1661). Because a panel of moderate or large curvature buckles in compression at a stress considerably below the theoretical value, a method has been suggested to aid in determining a critical stress for use in design.

Aircraft Shell Structures

Work on methods for calculating the stresses in aircraft shell structures has continued. A report on stresses in cambered box beams has been published (Technical Note 1466). A previously published approximate theory was reasonably accurate for wings, very approximate for fuselages, and practically inapplicable to single-web beams. The new theory covers all these cases in a more satisfactory manner.

Present designs of aircraft for transonic speeds call for wings with large angles of sweep. In order to investigate the problems that might be encountered in the design of such wings, a box beam representing the main structural component of a full-span two-spar 45°-swept wing with ribs normal to spars was subjected to symmetrical tip loading and its stresses and distortions were measured (Technical Note 1525). The investigation revealed that the stress phenomena peculiar to sweep are confined to that portion of the wing near the fuselage, the stresses in the outer portion being given with reasonable accuracy by the standard formulas for straight wings. The major effect of sweepback on the stresses is to cause a concentration of normal stress and vertical shear in the rear spar. The investigation indicated that deflections may be estimated by considering the outer portion of the wing as a cantilever and superimposing on the cantilever distortions rigid-body movements due to flexibility of the inboard portion to which the cantilever is attached.

An investigation was conducted by the Polytechnic Institute of Brooklyn to determine whether built-up narrow rectangular box beams subjected to pure bending are liable to failure by torsional instability. A numerical procedure was developed for the calculation of the torsional-instability buckling load. In the analysis the ribs of the beam were assumed to be rigid. The procedure was applied to a test box beam which failed by torsional instability as predicted by theory.

A series of torsional tests were made at the University of Notre Dame on stiffened structural specimens having the cross section of a D-tube. The stiffeners consisted of ribs and stringers. A design chart was developed for that type of structure taking into account the skin thickness, rib spacing, and stringer spacing.

The Polytechnic Institute of Brooklyn has investigated the instability problem of monocoque cylinders. Two closely related numerical methods which employ operations tables have been developed and used in the calculation of the buckling load of a monocoque cylinder subjected to pure bending. They are based on the assumption of a simplified structure which includes only the most highly compressed portion of the cylinder. The buckling loads of three cylinders with

widely different characteristics were calculated by these methods. Reasonable agreement with experiment was obtained.

The Polytechnic Institute of Brooklyn investigated eight stiffened cylinders in pure bending having either long bottom cut-outs or a series of side cut-outs. A strain-energy theory similar to one developed earlier at the Polytechnic Institute of Brooklyn was established for the reinforced monocoque cylinders having the symmetric cut-out on the compression side and buckling according to general instability patterns. The difference between the present and the earlier theories is the use of the axial wave length as an additional parameter whose value was determined from a minimum condition. The theory was applied to four cylinders and fair agreement was found between theory and experiment.

Methods of Analysis

A large number of problems in elastic stability and vibrations are not amenable to exact theoretical solution, and hence recourse must be had to approximate theoretical methods. The approximate methods of Rayleigh-Ritz and Galerkin, which are generally used, very often lead to extremely tedious calculations; furthermore, the accuracy of the final results obtained usually remains in doubt. The Lagrangian multiplier method is a modification of the Rayleigh-Ritz method that not only may reduce the labor involved in solving a given problem but also provides information on the accuracy of the results obtained. In the calculation of a buckling stress, for example, the method may be used to obtain upper and lower limits to the true buckling stress; furthermore, these limits may be made as close as desired. A report has been prepared (Technical Note 1558) to describe new applications of the Lagrangian multiplier method. By means of elementary examples, the paper shows how the method may be used to obtain buckling stresses of (a) clamped plates in shear and (b) plate-stiffener combinations.

Buckling of Flat Plate Under Shear

A knowledge of the buckling stresses of flat rectangular plates in shear is useful in the design of thin-web spars. Two papers have been prepared to provide the designer with more accurate theoretical data on shear buckling stresses than have been previously available. In one paper (Technical Note 1559) the shear buckling stresses of clamped rectangular plates are presented. The results given are the averages of upper and lower limits obtained by the Lagrangian multiplier method and are known to be within 1¼ percent of the exact theoretical buckling stresses. In another paper (Technical Note 1566) the shear buckling of flat plates continuous over unyielding line supports is discussed. Calculations made by means of the Lagrangian multiplier method show the fallacy of the usually made assumption that a plate over equally spaced line supports behaves as if it were simply supported at the supports when it buckles in shear.

Buckling of the stressed skin of a wing under applied shear loads results in a reduced torsional stiffness and a

reduced aerodynamic fairness of the wing. The problem of determining the shear stress at which the reinforced skin of the wing buckles is of particular importance in the case of high-speed airplanes which are normally subject to flutter and control problems. The wing panels of high-speed aircraft are usually narrow and reinforced by relatively few stiffeners. Investigations were made, accordingly, to determine the shear buckling load of long plates reinforced by one and by two longitudinal stiffeners. In addition, a theoretical solution was obtained of the problem for any number of stiffeners. The results of the tests and the theory were compared and found to be in fair agreement (Technical Note 1589).

Instability of Columns

A column supported at points along its length by other structural members may be elastically restrained against rotation and deflection by the supporting members. In the determination of the buckling load of such a column the elastic restraint may be considered to be due to deflectional and rotational springs at the points of support. The problem of the buckling of a column on equally spaced deflectional and rotational springs has been analyzed theoretically and the results are presented in nondimensional forms by means of charts that may be used in design (Technical Note 1519).

The compressive buckling strength of outstanding flanges reinforced by bulbs was investigated by the National Bureau of Standards. The strain-energy method was used and flanges having 10 shapes and a range of lengths were studied. The results were checked for some cases by computations based on a differential-equation method. The edge of the flange opposite the bulb was considered clamped, and the loaded ends were considered simply supported. The results were analyzed to determine which shape of flange gave the greatest support to the structure to which it was attached.

Diagonal Tension

While the theory of diagonal tension in flat webs, such as spar webs, has been undergoing continuous development in the past decade, no corresponding efforts had been made to improve the theory for curved webs. The information was badly needed for fuselage design, but there appeared to be little hope of success until the theory for flat webs was reasonably well in hand. In 1946, it was felt that the knowledge of flat webs was advanced well enough to justify starting a series of investigations on cylinders in torsion. The theory for flat webs was generalized by introducing a curvature parameter and was found to be capable of representing the cylinder results quite well (Technical Note 1481).

Existing methods for designing the intermediate uprights of (flat-web) diagonal-tension beams are strictly applicable only when no external load is applied to the upright. In the actual structure, some external load is often applied. A design method applicable to such cases was developed and checked experimentally (Technical Note 1544).

Gas-tank bays and other openings in the wings are often provided with detachable covers. These covers usually carry only chordwise stiffeners, and the nature of the attachment is such that the cover is loaded essentially in shear. Although the cover appears to act as a diagonal-tension field with a curved web, the design methods developed for beams with curved webs are not directly applicable because there are no beam flanges. A series of strength investigations was run on specimens simulating covers, and it was found that their strengths could be predicted by the theory of flat diagonal tension (Technical Note 1635).

Stiffened Panels

The increasing speed of aircraft and the accompanying trend toward thinner and thinner wings has imposed new design requirements for the wing in addition to the usual strength requirements. The skin thickness tends to be established by torsional-stiffness requirements of the wing, as for aileron effectiveness or flutter. Space inside the wing tends to be at a premium which restricts the height of the skin stiffeners, and the stiffener spacing becomes restricted by requirements of providing a smooth wing surface. Previous design procedures for skin-stiffener panels, since they were concerned primarily with the selection of the lightest panel to carry the wing bending load, required lengthy calculations in order to take these additional restrictions into account. A new type of design chart has therefore been devised which permits the designer to see at a glance what effect the additional restrictions have on the panel design. A longitudinally stiffened compression panel design can be selected directly from these charts either for minimum weight or to meet restrictions on stiffener height and spacings with the least weight penalty. These charts have been presented for 75S-T aluminum-alloy material and one stiffener shape (Technical Note 1640).

The conventional stiffened-skin aircraft structures are joined together by riveting, and the strength of the structure is determined in part by the strength of the riveting. In order to develop an accurate criterion for determining the diameter and pitch of rivets used for attaching stiffeners to skin, an investigation has been carried out on the effect of riveting on the strength of longitudinally stiffened compression panels. Two preliminary parts of this investigation have been reported (Technical Notes 1421 and 1467) which indicated that, except for very long structurally inefficient panels, panel strength always increased with either an increase in the diameter or a decrease in the pitch of the rivets.

The fabrication of skin and stiffeners in one integral unit by extrusion or some other process would not only greatly simplify the construction of wing compression panels but also offers possibility of achieving a smooth, highly efficient structure by eliminating the deleterious effects of riveting stiffeners to skin. Accordingly, a structural evaluation was made of such an extruded panel manufactured by the Dow Chemical Co. of magnesium alloy (Technical Note 1518). The results showed that this panel had structural characteristics which lay approximately midway between those for

the best equivalent 24S-T and 75S-T aluminum-alloy panels fabricated in the usual manner by riveting.

A method has been developed by which the local buckling strength of a panel having longitudinal Z-section stiffeners can be predicted if the strength of riveting stiffeners to skin is adequate to approach that for integral construction like that of an extruded panel. This method (Technical Note 1482) is based on the existing theory for predicting the elastic critical stress of a structure composed of a series of plate elements. The elastic theory is extended into the high stress (plastic) range by the use of the secant modulus in place of the elastic modulus (Technical Note 1480) and the empirical relationship developed therein between the critical stress and average stress at failure is assumed to apply to panels. The method is shown to give good agreement with test data.

The efficient design of a chordwise stiffened wing requires a knowledge of the buckling stress of the stiffened compression skin. Accordingly, a theoretical analysis has been made of the compressive buckling of a simply supported plate having equally spaced stiffeners transverse to the direction of loading; the torsional as well as the flexural stiffnesses of the stiffeners have been taken into account. Charts have been prepared (Technical Note 1557) which relate the buckling stress to the properties of the plate and stiffeners. The charts cover the range of practical stiffener spacing (from zero to one-half the plate width) and are applicable to plates having four or more stiffeners.

Plastic Buckling and Bending

The calculation of the critical compressive stress of columns and of structures made up of plates is an important problem in aircraft design. Formulas for the critical compressive stress have been worked out for a multitude of cases of both columns and plates, but these formulas are accurate only if the buckling takes place within the elastic range of the material. In present-day designs, most buckling occurs above the elastic range. The usual method of handling this problem is to retain all the formulas derived for the elastic case, and to try to discover an effective, or reduced, modulus of elasticity which will give the correct result when inserted into these formulas.

An analysis was made (Technical Note 1556) to determine the proper reduced modulus on the basis of the deformation theory of plasticity for a number of different structural elements under compressive load. Included in the analysis are columns, flanges, and plates of various aspect ratio and type of support. The theoretical critical shear stress of an infinitely long plate in the plastic region has been treated in a parallel fashion (Technical Note 1681). The agreement between theory and available experimental data in each case is very satisfactory.

Stanford University has conducted an investigation of pure bending in the plastic range. Rectangular beams and I-beams of aluminum alloy 75S-O were tested in pure bending with the plane of loading at angles of 0°, 30°, 60°, and 90° to the minor principal axis of the cross section.

Determination of Plate Compressive Strengths

In designing the flat or nearly flat plate compressive elements of the airplane structure, a knowledge of their buckling and ultimate stresses is important. A convenient vehicle for the experimental study of these properties is the local-instability test of the H-, Z-, and C-section column which is made up of plate elements. The results of an extensive series of such investigations on a number of different shapes and materials have been summarized in Technical Note 1480 where a correlation is shown between the buckling stress-strain curve and the compressive stress-strain curve.

The results of compressive-strength investigations cannot in general be used directly for design purposes, because the compressive properties of the material used for the investigations ordinarily differ from the standard values from which the design is to be made. Methods of adjusting the plate-investigation results to account for this difference in material properties have been developed (Technical Note 1564).

Bolted Joints

The investigation of bolted joints started in the preceding year was continued. The investigations previously confined to joints with two and three bolts in line were extended to joints with five and nine bolts in line. A recurrence formula for calculating the stresses in such joints was developed. Special, more rapid solutions were also developed by using finite-difference equations and by using the differential equations used in the shear-lag theory; the former are applicable to joints with fairly large numbers of bolts (Technical Note 1458).

SUBCOMMITTEE ON AIRCRAFT LOADS

Distribution of Loads on Wings and Control Surfaces

Aerodynamic considerations in some cases now dictate the use of wings which are sweptback. Although theoretical methods are available for determining the load distribution over these wings, the methods up to now have been for the most part very laborious. There has existed therefore a need either for shortening the methods to be used or for presenting results for a wide variety of wing shapes in chart form. Both approaches have been utilized during the past year. From the standpoint of shortening the methods, a simple approximate method for obtaining spanwise lift distributions over swept wings has been derived. In addition, charts have been prepared presenting the distributions used, and a method has been developed that allows for the inclusion of first-order compressibility effects.

An indication of the relative accuracy of several available methods for computing wing loading has also been obtained. This was possible through a comparison of span loading measured in flight at high Mach numbers on the wing of a jet-propelled airplane and the span loading as calculated by several methods. Theoretical studies of span load distribution have been extended to wings of various sweep, aspect ratio, and taper, and the results have been presented in Technical Notes 1476 and 1491.

Experimental research on load distribution on wings conducted in the past year includes extensive pressure-distribution measurements on large-scale triangular-shaped wings to provide data for estimating critical load conditions. In addition, chordwise pressure distributions have been measured in the Langley 16-foot high-speed tunnel on a wing at speeds ranging from a Mach number of 0.20 to 0.60 and angles of attack ranging from small negative values up to stalling angles. The data obtained are presented in Technical Note 1696; an analysis and discussion of the data are presented in Technical Note 1697. Pressure distributions have also been measured at high subsonic Mach numbers in the Langley 8-foot high-speed tunnel on a thin wing of high aspect ratio which included an aileron. The measurements were made with no sweep and with various amounts of sweepback and sweepforward.

Considerable information has been obtained concerning the loads to be expected on wing flaps of various kinds. In the Langley 19-foot pressure tunnel, pressure distributions have been determined over an extended leading-edge flap mounted on a 42°-sweptback wing.

The pressure distributions over drooped nose flaps on a 42°-sweptback wing having circular-arc airfoil sections were also determined in the Langley 19-foot pressure tunnel. In particular, the effects of the deflection and span of these flaps and the effects of deflecting split trailing-edge flaps on the pressures over the drooped nose flap were determined. The drooped nose flap on the circular-arc airfoil was further investigated in the Langley two-dimensional low-turbulence tunnel. Here the aerodynamic loads and moments were determined on a drooped nose flap and a plain trailing-edge flap on a symmetrical circular-arc airfoil section. Airfoil lift, flap normal force, flap chord force, and flap hinge-moment characteristics were determined for various deflections of the flaps either individually or in appropriate combinations.

The use of thinner wing sections and swept wings in the achievement of high speeds of flight no longer permits the assumption that the airplane is a rigid structure. The interplay of aerodynamic and structural characteristics resulting from the deflection of wings or control surfaces has been termed "aeroelasticity." Aeroelastic phenomena include aileron reversal, elevator reversal, wing divergence, and changes in effective dihedral. A number of investigations related to this subject have been conducted during the last year. In one investigation the loss of rolling effectiveness due to wing twist was measured in flight on a fighter-type airplane, and the results were compared with calculated results. The computed rolling velocity showed good agreement with experimental values throughout the range of Mach number covered by the flights. Extrapolation of the flight data indicated that aileron reversal would occur at a Mach number which agreed well with that obtained from calculations. From the standpoint of prediction of aeroelastic effects, a method was developed in Technical Note 1541 for calculating the effect of wing flexibility on the rolling moment due to sideslip for wings of various aspect ratios and taper ratios, when different shapes of the bending deflection curve

are insignificant, the main factor being the amount of wing-tip deflection. An accurate method for calculating wing-tip deflection has been derived, and is also presented in this report. The conclusions reached indicate that the effect of wing flexibility on the rolling moment due to sideslip is large enough to be of appreciable significance in the design of large airplanes having low load factors. The report contains charts that simplify the design calculations required. In addition, a series of charts have been prepared for determining preliminary values of span load, shear, bending moment, and accumulated torque across the span of swept wings having various taper ratios. The use of the charts permits results which are sufficiently accurate for preliminary design work and eliminates much laborious calculation.

In an investigation of the possibility of reducing the probability of wing failures due to overloading, an analytical investigation was undertaken to determine the feasibility of incorporating controlled failure points as safety valves for the primary airplane structure.

Distribution of Loads on Tails

Effort has been continued along both experimental and theoretical lines to provide information on tail loads in maneuvering flight. A comprehensive flight investigation, reported in Technical Note 1483, was conducted to determine the loads on the horizontal tail surface of a fighter-type airplane. In this investigation the differences between upper- and lower-surface pressures were measured to obtain the horizontal-tail load throughout the speed range of the airplane in level and in accelerated flight. Effects of engine power and sideslip angle were determined. The data were utilized in such a manner as to determine the major parameters affecting the tail load and the extent of their effect. Flight results indicated that an accurate knowledge of certain tail-load parameters will permit the accurate prediction of the tail load. The parameters required are the pitching-moment coefficient, the location of the aerodynamic center, and the pitching angular acceleration. In sideslip the upwind tail surface was found to experience an up load relative to the downwind tail surface which increased linearly with angle of yaw. The dissymmetry of load was found to be mainly on the stabilizer and not on the elevator. The conditions of critical design for tail-up loads are shown to occur at high values of pitching angular acceleration in combination with high positive load factors and medium speed. For tail-down loads the combination of high negative load factors and maximum speed was critical. The downward tail-load increment causing pitching angular acceleration was confined principally to the elevator surfaces.

The tail loads encountered in an abrupt pull-up and push-down maneuver are treated in Technical Note 1539. This is the concluding report of a series comparing calculated horizontal tail loads with loads actually measured in flight. In general, it was shown that, if the elevator motions are correctly estimated and reasonable estimates of the aerodynamic characteristics of the airplane are made, the agreement between calculated and measured horizontal-tail loads is good. Information on the accuracy with which vertical-tail loads

may be computed from knowledge of sideslip angle and rudder angle has been obtained through the comparison of predicted loads with vertical-tail loads as actually measured in flight. In addition, the problem of ascertaining the maximum vertical-tail loads which occur in transient and steady-state fish-tailing maneuvers has been reported in Technical Note 1504. The results indicate that a maneuver with rudder oscillating and aileron fixed appears the most useful as a criterion for vertical-tail loads.

In addition to loads normally imposed as a result of maneuvers, the tails of airplanes are also subject to what have been termed "buffeting loads." When a boundary of angle of attack defined by maximum lift or by what has been termed the "buffet boundary" is exceeded at high load factor, the ensuing flow breakdown generates large vibratory forces termed "buffeting" that are superimposed on the quasi-steady forces acting on the airplane. The phenomenon of buffeting is not yet fully understood, and the nature of the loading conditions associated with buffeting can be determined only by consideration of the complete airplane in flight. Accordingly, measurements of tail buffeting were conducted in flight on a fighter-type airplane. The results of the measurements reported in Technical Note 1719 indicate that at least up to Mach numbers of 0.8 the most severe buffeting loads are encountered at the lower speeds when buffeting occurs coincidentally with the attainment of maximum lift coefficient on the wing. The investigation showed that as the Mach number increased the loads decreased, at least up to the highest speed investigated. The results indicated that the frequencies of the buffeting loads tended to correspond to the frequencies of the main parts of the structure regardless of Mach number.

Considerable data on wing and tail loads have been obtained in flight using the X-1 airplane. The buffet boundary of the airplane has been established and the magnitude of the buffet loads has been determined.

Gust Loads

One of the problems associated with the use of swept wings is the prediction of gust-load factors. In order to provide information pertinent to this problem, investigations of a 45°-sweptback-wing model with and without fuselage and of an equivalent straight-wing model were conducted in the Langley gust tunnel. A comparison of the results of the investigations and calculations indicated that the gust load on airplanes with swept wings is dependent on the lift-curve slope of the equivalent straight wing multiplied by the cosine of the angle of sweep and that it is also dependent on the effect of the gradual penetration of the gust. The results also showed that the maximum acceleration increment in a gust for an airplane with sweptback wing would be much less than that for the same airplane with an equivalent straight wing. The results of this investigation are reported in Technical Note 1528.

In the determination of the design gust-load factor for an airplane, an important parameter is the slope of the lift curve. In order to determine the influence of the use of low-drag wings on this parameter, tests were made in the Langley

gust tunnel on a model having a wing of low-drag section with smooth surface, and, later, with roughness applied to the leading edge to simulate a conventional section. The results of the investigations, which are reported in Technical Note 1632, indicate that, within the limits of accuracy and precision required for present gust-load calculations, the low-drag and conventional airfoil sections show the same slopes of the lift curve while traversing gusts with gradient distances up to at least 12 chord lengths. For gust-load calculations, it is indicated that the section slope of the lift curve of all airfoils should be assumed to have a value of approximately 6.0 per radian and that a simple correction for aspect-ratio effects should be applied to obtain the slope of the lift curve for finite wings.

Aerodynamic Heating

With the attainment of supersonic speeds, consideration must be given in the design of aircraft to the heating of the aircraft by air passing around it. In this connection, a comparison was made between the time history of skin temperature measured on the nose of a V-2 rocket and the temperature computed by using Eber's experimental relation for heat-transfer coefficient for conical bodies under supersonic conditions. The agreement obtained was felt to justify the use of Eber's relation in the calculation of skin temperatures under flight conditions. A general method was developed for making such skin-temperature calculations and used to compute the variation of skin temperature with time for a wide range of values of the pertinent parameters. The results showed that by proper selection of the basic parameters the increase of skin temperature during a limited time of flight can be held to structurally permissible values. Methods are given for taking into account, when necessary, the effects of solar heating and the radiation exchanged between the skin and atmosphere. Time histories of skin temperature were also computed for representative flight plans of a typical supersonic airplane to insure that structural difficulties would not be encountered in any proposed flight plan because of aerodynamic heating. The results of the investigation have been reported in Technical Note 1724.

A short and simple method was developed for the determination of transient skin temperature of conical bodies for short-time, high-speed flight. A differential equation was established for this purpose, giving the fundamental relations between the transient skin temperature and the flight history. For the heat-transfer coefficient and boundary-layer temperature, which are needed in the differential equation, Eber's experimental results for conical bodies under supersonic conditions were adapted and summarized in a convenient way. A numerical procedure for solving the differential equation was given. The method is presented in Technical Note 1725.

In addition to the heating problem resulting from the passage of air around an airplane, other problems of thermal stress exist. When an airplane dives at high speeds from a high altitude to a lower, warmer altitude, the outer surfaces are subjected to rapidly changing boundary-layer temperatures as a result of aerodynamic heating and increases in the free-stream temperature while the internal structure

remains relatively cold. These temperature gradients, if of sufficient magnitude, could cause thermal stresses between adjacent components such as the wing ribs and skin. The magnitude of the temperature gradients occurring in the wing of a typical, high-speed fighter airplane has been measured during dives, and an analytical method for predicting the temperature variations in similar wings has been evolved and reported in Technical Note 1675.

Landing Loads

In fundamental research conducted at the Langley impact basin, hydrodynamic impact data for a seaplane hull were obtained to supplement previously reported data. In Technical Note 1516 data from these tests were condensed and compared with theory previously developed and reported. In condensing the data, an approach parameter combining trim and flight-path angle was introduced in combination with load, draft, and time coefficients having interrelation dependent only upon the approach parameter. Some theoretical results showing the effect of chine immersion on the maximum load for narrow-beam hulls were also included.

Data on hydrodynamic pitching moments during landing impact were obtained in the impact basin and compared with generalized results involving a nondimensional moment coefficient. These results were reported in Technical Note 1630. The nondimensional approach parameter was also used in this report.

In Technical Note 1694, extensive application of theory to planing data was made for the purpose of determining downwash, virtual mass, end flow, and Froude's effects, which might be adapted to impact-force calculations. A comparatively simple procedure gave results which agreed with the data over wider ranges than had been investigated in impact.

In continuation of the program for determining landing loads for flexible airframes, a simplified analytical method was derived for predicting the time history of the accelerations along the wing of an airplane. In Technical Note 1690, wing-tip accelerations computed by this method were compared with those measured during landing impacts of a small seaplane. The theoretical and experimental results were in good agreement.

Through the use of various simplifying assumptions, a number of approximate solutions can be obtained to the complex problem of the determination of stresses developed in the landing of an aircraft. In order to determine the nature and magnitude of the errors that are involved when the various simplifying assumptions are made, an investigation of an idealized form of aircraft which was susceptible to exact solution was made. The approximate solutions break the problem into two parts: First, the determination of the landing strut forces and, second, the determination of the stresses from these strut forces. Then the effect of the neglect of the structural elasticity in one or both of these parts is considered. The comparison made with the exact solution indicates that a satisfactory treatment of the landing problem may be obtained from an analysis which assumes

that in landing the aircraft is an elastic structure subject to the forces or accelerations found in a drop test in which a rigid mass is used. The work of this investigation is reported in Technical Note 1584.—

The lift acting on a seaplane during the landing impact affects the maximum acceleration experienced. Solutions for calculating the acceleration were available based on the assumption that the lift equals the weight; however, in rough-water landings, more than one impact may occur and the wing lift may be reduced because of partial stalling after the first impact. A solution of the two-dimensional problem (infinitely long float) was obtained for an arbitrary value of the lift which is useful for writing design specifications. The solution, as well as calculated numerical examples, is presented in Technical Note 1563.

Canopy Loads

In addition to the general fields of load research reported above, certain other specific problems were investigated. For example, as part of a general investigation of the subject, the aerodynamic loads on the canopy of a Navy fighter airplane were measured in flight. The same canopy had previously been investigated in the Langley full-scale tunnel, and thus means were afforded for comparing wind-tunnel and flight results to determine the effect of Mach number and distortion on the canopy load distribution.

SUBCOMMITTEE ON VIBRATION AND FLUTTER

Flutter of Wings and Control Surfaces

The experimental program for obtaining information concerning flutter of aircraft in the transonic speed range has been continued. Additional flutter data have been obtained in investigations of six wings, four unswept and two with 45° sweepback, attached to various bodies and dropped from high altitudes. The data were telemetered from the bodies to recording equipment on the ground.

Initial flight investigations have been made of a high-velocity rocket-propelled vehicle for flutter studies. Unswept wings investigated showed experimental flutter speeds higher than those determined by calculations in which an incompressible flow for a two-dimensional airfoil was assumed. These calculations, nevertheless, have proved very useful in the design of the wings for flutter and as a basis for determining the correction which should be applied to two-dimensional theory.

New low-acceleration rocket-powered vehicles have also been developed for investigating flutter in free flight at transonic and at supersonic speeds. Additional investigations have been made of sweptback wings, using this low-acceleration rocket-propelled vehicle. This work indicated that there was an adverse effect on the flutter speed because of the increased coupling between flexure and torsion associated with effective dihedral for the sweptback condition, but this adverse effect was compensated for by other favorable aerodynamic effects.

A broad program has been undertaken in the Langley flutter tunnel to study the effects of concentrated weights on the

flutter characteristics of cantilever wings. Some of the results are reported in Technical Note 1594, for a straight untapered wing tested with various concentrated weights. The moments of inertia, chordwise positions, and spanwise positions of these weights were varied, and in several of the tests an end plate was installed which was believed to change the effective aspect ratio of the wing. The effects of these variations on the flutter characteristics are presented in a form which may be conveniently used for correlation with concurrent theoretical flutter calculations.

The methods of analysis for determining the modes and frequencies of unswept-wing aircraft are not directly applicable to aircraft with swept wings. An analysis which includes the effect of sweep therefore was needed, and has been developed. Simple power series expansions are made for both the deflection and the twist, and by use of special wing-root coupling conditions and the energy method, characteristic equations for both symmetrical and antisymmetrical vibration are derived. Numerical examples which are susceptible to exact analysis have been prepared and compared with the exact solutions.

Control-surface flutter at transonic speeds has become a serious problem as it tends to make the airplane uncontrollable and to weaken structurally the flutter surface. From wind-tunnel research on parameters contributing to transonic flutter, a pressure-cell technique for conveniently measuring instantaneous pressure distribution on a flutter surface was developed. This technique is applicable to other problems where rapidly fluctuating pressures over a surface are involved. An empirical theory to enable prediction of the frequency of flutter and the corresponding conditions for instability was developed. This theory was used in predicting the flutter frequency of the aileron on a wing having a low-drag airfoil section, and a wing having a conventional airfoil section.

Tab Flutter

An experimental investigation was made of a preloaded spring-tab flutter model to determine the effects on the flutter speed of aspect ratio, tab frequency, and preloaded spring constant. The rudder was mass-balanced, and the flutter mode studied was essentially one of three degrees of freedom (fin bending coupled with rudder and tab oscillations).

Torsional Stiffness and Divergence

The emphasis on the use of sweptback or sweptforward wings for high-speed flight has created widespread interest in the aeroelastic behavior of swept wings. One of the fundamental aeroelastic parameters is the wing divergence speed.

The divergence of wings (or tail surfaces) is an instability phenomenon which results from the interaction of aerodynamic and structural forces. If a wing is given a deflection of arbitrary magnitude, the aerodynamic forces often act in such a way as to increase the deflection, whereas the structural forces always tend to decrease the deflection. Since the aerodynamic forces increase with the flying speed, whereas the structural forces are independent of it, a speed

will often exist at which the two sets of forces are exactly in balance, so that they tend to maintain the given deflection. This speed is known as the divergence speed, since any further increase in speed causes the aerodynamic forces to predominate over the restraining structural forces and tends to increase any deformation until structural failure occurs.

The theory of divergence of unswept wings has reached a considerable degree of refinement. The analysis of the divergence of swept wings, however, is complicated by the fact that, unlike the case of unswept wings, the air forces depend on the bending deformation as well as on the twisting deformations. A theoretical analysis of the divergence of uniform and linearly tapered swept wings is presented in Technical Note 1680. (The tapered wings are assumed to have stiffnesses varying as the fourth power of the chord.) The results of the analysis are presented in nondimensional curves from which the divergence speed can be estimated for a given design. The theoretical results indicate that the divergence speed drops rapidly as sweepforward increases up to about 40°. On the other hand, wings with sweepback beyond a fairly low value cannot diverge at all.

A limited number of wind-tunnel investigations of uniform wings were made to check the theory; agreement between theory and experiment was good.

Failures probably due to flutter were encountered in NACA flight investigations of several rocket-powered drag-research missiles that were intended to attain Mach numbers of about 1.4. A study of the wing failures of these missiles led to a simple semiempirical torsional-stiffness criterion for preventing flutter of uniform swept or unswept missile wings that reach supersonic speeds. Missiles that failed were redesigned in accordance with this stiffness criterion and, subsequently, made successful flights.

Shear Lag and Other Structural Effects

Vibration investigations of airplane wings have shown that discrepancies often exist between observed and calculated natural frequencies of wings. Among the possible sources of these discrepancies are aerodynamic and structural damping, rotary inertia, shearing deflections, and shear-lag effects. In order to determine the importance of the last of these, an investigation in which shear lag is included was made of box beams in bending vibration. This investigation is reported in Technical Note 1583. A procedure is given for determining the modes and frequencies when shear lag is included. Examples show that in some cases shear lag may reduce appreciably the higher mode frequencies even though the fundamental mode is influenced little and that in other cases appreciable reduction in the fundamental mode frequency may even be found.

In the flutter and dynamic analysis of aircraft structures, the determination of the natural modes and frequencies is often of basic importance. Most of the methods of modal determination that have been developed have had certain undesirable features which make them either limited or unwieldy in their application. A method has been developed which is easy and quick to apply and gives results within the range of accuracy with which the physical properties

of the structure (mass, stiffness distribution, and so forth) can ordinarily be determined. The method is based on the principle of the Stodola method and consists of solving the differential equations for vibration by a method of successive approximations. All computations are tabular in form and are easily performed. Higher modes are readily found and special consideration has been given the treatment of various boundary conditions. The frequency is found simply as the square root of the proportionality factor existing between modal deflection curves in successive approximations. This method of frequency and modal determination is given in Technical Note 1522. Given also in this report are a number of examples which illustrate the procedure and indicate the high accuracy which is attainable.

SUBCOMMITTEE ON AIRCRAFT STRUCTURAL MATERIALS

The majority of the investigations on aircraft structural materials have been carried out by contracts with universities and other nonprofit scientific organizations. These investigations have complemented the program on materials for power plants.

Fatigue of Metals

A wartime survey showed lack of complete information on the fatigue properties of sheet materials used in airframe construction. Although a great deal of information was available, it appeared that no material had been investigated fully and that no strictly comparative tests of any extent had been made on different materials under carefully controlled conditions. For example, on any one material, information was generally incomplete (1) on fatigue damage under various conditions and (2) on notch sensitivity with various notches and loading conditions. In comparing materials, it appeared that considerable information was available for some aluminum alloys (notably 24S-T Alclad) in sheet form under axial loading, while information on steel was mostly from rotating-beam tests on round bars. Thus, such materials could not be readily compared in regard to their fatigue behavior in sheet form at mean stresses different from zero.

As part of a broad program designed to mitigate this situation by obtaining basic information on the fatigue properties of several materials, all in sheet form and all tested under reasonably comparable conditions, Battelle Memorial Institute during the past year has completed investigation of the following phases: (1) Selecting samples of three materials of current interest (24S-T and 75S-T aluminum alloys and normalized 4130 steel) and making conventional tests to check the quality of each lot of material; (2) development, by preliminary tests, of suitable means of preparing specimens; (3) obtaining base-line S-N curves for each material over the range from fully reversed stress to stress alternation about a high mean tensile stress; and (4) investigating fatigue damage and fatigue strengthening at two stress levels.

The results of this investigation, of interest in themselves, may also furnish basic information for further studies of the same materials. In view of this, considerable care was taken to evaluate the experimental errors involved and to estimate, as far as possible, the residual "scatter" of test results.

Another phase of the fatigue program which has been completed during the past year was the design and construction of two dual-load fatigue testing machines by the National Bureau of Standards. The outstanding feature of these machines is the ability to change automatically the load amplitude alternately from one to the other of two values with a definite number of load cycles at each. Both values of the load are present on the machine prior to initiation of the test.

Tensile and Compressive Properties of Aluminum-Alloy Sheet

The National Bureau of Standards has conducted an extensive investigation of the tensile and compressive properties of high-strength aluminum-alloy sheet. The properties in both a longitudinal and a transverse direction to rolling were obtained and the results were presented as stress-strain, stress-deviation, and tangent-modulus graphs. The graphs were plotted on a dimensionless basis to make them applicable to material with yield strengths which differ from those of the test specimens. Results have previously been presented for aluminum-alloy R 301 sheet (Technical Note 1010), aluminum-alloy 75S-T Alclad sheet (Technical Note 1385), aluminum-alloy 24S-T Alclad sheet (Technical Note 1512), and aluminum-alloy 24S-T81 Alclad sheet (Technical Note 1513). During the past year results were presented on aluminum-alloy 75S-T sheet and aluminum-alloy 24S-T86 Alclad sheet.

Sandwich Materials

The Forest Products Laboratory has continued investigations on sandwich materials. They have completed an analysis of the compressive strength of a folded type of honeycomb core by the method previously developed (Technical Note 1251) for the corrugated type of honeycomb core. The results of 20 tests showed good agreement with the analysis. These results were compared with data obtained from five tests of the corrugated-type core made of the same sheet material. The two types of core had approximately the same strength which implied that the compressive strengths of honeycomb cores cannot be altered greatly by changing the cell shape.

The Forest Products Laboratory has conducted an investigation to determine the durability of a resin-impregnated, paper, corrugated-type honeycomb-core material when subjected to accelerated weathering exposures of heat and moisture. The effect of these exposures was measured by compression tests of 2- by 2- by 6-inch honeycomb specimens and tensile tests of flat strips of paper (not corrugated).

The Forest Products Laboratory has also investigated and evaluated several methods of forming panels of compound curvature to determine the adaptability of paper honeycomb

cores in such panels. A bowl-shaped construction having glass-cloth facings on a preformed core of paper honeycomb has been made to demonstrate the practicability of one method. Other methods, such as postforming a flat aluminum-faced panel and the use of flat tailored pieces of paper honeycomb, were tried and found to be unsatisfactory.

Transparent Enclosures

The transparent enclosures of modern aircraft must withstand both the temperatures and forces encountered in high-speed flight and the forces imposed by cabin pressurization. They must offer a minimum of vision distortion and should not shatter under impact. The materials available for these enclosures are glass and the transparent acrylic plastics in both laminated and solid sheet form. Because the cost of forming glass severely limits its use, the acrylic plastics are in common use, and the operating requirements are rapidly exceeding the capabilities of this material.

In view of this situation the NACA Subcommittee on Aircraft Structural Materials felt that a program to develop adequate transparent enclosures was necessary. It had been indicated that no conclusive data had been obtained regarding the relative merits of solid and laminated transparent plastic enclosures and that research should clarify this problem. Accordingly the National Bureau of Standards during the past year conducted a survey of the existing information pertinent to the problem to aid in planning future research.

OPERATING PROBLEMS RESEARCH COMMITTEE ON OPERATING PROBLEMS

Of major importance in the work of the Committee on Operating Problems during the past year was the establishment of the Subcommittee on Aircraft Fire Prevention in order that emphasis might be given to the study of fire safety. Continued study has been given by the Subcommittee on Icing Problems and by the Subcommittee on Meteorological Problems to icing and meteorological problems encountered in the operation of aircraft.

Noteworthy results were achieved in studies of aircraft noise and ditching.

Noise

Because the noise created by airplanes is usually objectionable to persons living in the vicinity of airports, it has been a factor in the location of new airports and has caused the abandonment of established ones. In order to investigate this problem, studies were made of both engine noise and propeller noise. An Army liaison-type airplane typifying a 150- to 200-horsepower personal airplane was modified with a muffler and a multibladed, slow-turning propeller. When the modified airplane was flying at 300 feet, the sound level on the ground was reduced from 87 to 67 decibels; therefore this airplane may be even quieter than necessary (Technical Note 1647). The fundamental factors involved in the generation of noise were reviewed and methods were suggested for designing quiet propellers which would be as efficient and no heavier than conventional propellers.

Ditching

Studies of models of landplanes catapult-launched in the landing condition for simulated ditchings are being continued. Several models of military bombers and transports were included in the study. The conventional transport type seems to have good ditching characteristics, that is, a smooth run over the water and low accelerations of about 2g. The bottom of the fuselage was built to scale strength and it was not severely damaged during ditching. This would indicate that the floor of the cabin would be relatively safe for personnel. In general, the transports had better ditching characteristics than the bombers. Although none of the models tested had characteristics severe enough to warrant the use of the NACA hydroflap as a ditching aid, it remains a promising device for eliminating violent dives.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

The effects of atmospheric turbulence and, in particular, the loads imposed on aircraft as a result of such turbulence are of fundamental importance in the safe and efficient design and operation of all aircraft. The effects of atmospheric turbulence are determined for the most part by the statistical analysis of data from large numbers of routine test flights.

The NACA has continued its participation in the U. S. Weather Bureau Thunderstorm Project for which field operations are now complete. The data gathered in this investigation are now being analyzed and will be studied to determine relations for forecasting atmospheric turbulence from other meteorological parameters. In addition, the analysis will also be useful to determine the influence of piloting technique and airplane characteristics on the measurement of effective gust velocity, to evaluate ground radar as a means of detecting and avoiding regions of turbulence, and to devise a simple procedure for adjusting the maximum effective gust velocities for differences in distances over which records are taken.

In analyzing data on the structure and intensity of atmospheric gusts within thunderstorms, questions arise concerning the validity of comparisons between different sets of data on the basis of the maximum gust velocities encountered. Results of simple sampling procedures indicate the observed values of maximum effective gust velocity to be a function of the record distance. A simple procedure has been developed which removes the effect of differences in record distance between two sets of data and allows a direct comparison of the gust velocities.

An analysis of the energy transformations in convective-type clouds gave qualitative relations between the maximum possible gust velocities and the height of convective activity and the horizontal temperature variations. As a result of this analysis, a simplified relation which may be used to forecast the maximum effective gust velocities within convective-type clouds was developed and is reported in Technical Note 1569.

In the past, the influence of piloting technique and airplane characteristics on measurements of effective gust velocity obtained from reactions of an airplane in flight have been assumed to be consistent in sign and magnitude. The statistical analysis of gust data obtained from the Thunderstorm Project to determine possible errors resulting from these assumptions indicates that, for over-all analysis of gust data, airplane and pilot effects will average out. However, for the analysis of individual transverse data, these effects may be of considerable concern. Results of this investigation are reported in Technical Note 1645.

In an attempt to determine the proper gust velocity to be used in the design of high-altitude aircraft, gust-velocity data for convective-type clouds at various altitudes were analyzed to show the variation of effective gust velocity with altitude. The analysis indicates that the distribution of effective gust velocity is approximately the same at various altitudes within convective-type clouds. Consideration of these results for altitudes below 34,000 feet indicates that similar results would apply to convective-type clouds at all altitudes within the troposphere. The results of this investigation are reported in Technical Note 1628.

The preliminary evaluation of data obtained from correlating flights through thunderstorms with ground radar echoes from air-mass convective storms (Technical Note 1684) indicates that the gust bumps experienced can be reduced by circumventing the areas of radar echo. This was followed by observations from air-borne radar on routine flights from Seattle to Alaska to determine if advance warnings of gust were feasible. The absence of well-defined radar echoes prevented definite conclusions, but preliminary indications show that turbulent air can exist without radar indications.

If the life of aircraft is to be more exactly known, the important factors of airspeed and gust velocity must be correlated. V-G measurements made on routine trans-Pacific flights prior to and during the recent war have been analyzed (Technical Note 1693). These data support previous indications that airplane speed in regions of turbulent air is a significant factor in the life of aircraft.

SUBCOMMITTEE ON ICING PROBLEMS

The effectiveness of present aircraft is seriously limited by their inability to operate under all weather conditions. One of the serious hazards in the practical all-weather operation of aircraft is the formation of ice on critical surfaces and components. Such ice formations may impair the operation of the aircraft to such an extent that a crash may result.

The program of icing research of the Committee has been carried out at the Ames Laboratory and the Lewis Laboratory. The close of the 1948 fiscal year, however, brought a cessation to the icing-research activities of the Ames Laboratory and henceforth research on aircraft icing will be conducted at the Lewis Laboratory. The experimental research in aircraft icing is accomplished for the most part in the 6- by 9-foot icing-research wind tunnel and by flights of specially equipped airplanes in natural icing conditions.

Meteorology

Special meteorological instrumentation was installed in an icing-research airplane to measure the important physical characteristics of icing clouds. A preliminary analysis of the data obtained during the icing season confirmed and augmented similar data obtained in previous years (Technical Notes 1391, 1392, 1393, and 1424). As a consequence, the tentatively established specifications of the most probable maximum and normal icing conditions presented previously have been placed on a more substantial basis. The data will also serve as a basis for the development of techniques for forecasting aircraft icing conditions.

Propellers

One phase of propeller icing research was directed toward the establishment of a fundamental basis for the determination of blade-heating requirements. Heat flow from the blade surface and temperature rise of the blade were measured at various power conditions in different icing conditions. Inasmuch as cyclic heating of propellers necessitates the tolerance of some ice accretion on the blades during the heat-off period, thrust measurements were made to determine the losses caused by these intermittent accretions for various cyclic-heating conditions.

Wind-tunnel investigations of external rubber blade heaters were conducted to determine power densities for a range of ambient-air temperature. It is shown in Technical Note 1520 that an approximately uniform chordwise distribution of heat on the blade surface resulted in the minimum heat requirements. Also presented in this report is the optimum ratio of heat-on time to heat-off time.

The effects of propeller speed, air temperature, and water concentration on the power requirements and de-icing performance of internal electric blade heaters are presented in Technical Note 1691.

Hot-gas heating of a hollow-steel propeller blade was investigated both theoretically and experimentally and the results are published in Technical Notes 1494, 1586, 1587, and 1588. The experimental investigations indicated that, by confining the heated gas flow to the forward portion of the propeller blade, a more economical distribution of the applied heat was obtained.

In conjunction with the work at the Lewis Laboratory on hot-gas heating of a hollow-steel propeller blade, an investigation was conducted in the Langley 16-foot high-speed wind tunnel to determine the effect on propeller efficiency of internal flow through hollow blades. The results of this investigation (Technical Note 1540) indicate that the flow through tip nozzles having good external design but poor internal ducting caused peak efficiency losses of approximately 1 percent. When the internal flow was heated to approximately 285° F., the peak efficiency losses were again approximately 1 percent. Reasonable agreement was obtained between calculated and measured efficiency losses.

Wings and Empennages

An analysis of the heating requirements for wing and empennage sections for ice protection in specified icing conditions is presented in Technical Note 1472. This analysis provides a fundamental basis for design which has replaced the previously employed empirical methods.

Windshields

A method for calculating the heat requirements for windshield thermal ice prevention and a method for determining the heat required to prevent fog formation on windshield inner surfaces in diving flight have been published in Technical Notes 1434 and 1301, respectively.

Jet Engines

Flight investigations to determine the effect of ice formations on the performance of axial-flow turbojet engines indicated that ice collected on the cowl, spinner, and guide vanes, thus disrupting the air flow in the compressor inlet and in turn causing a substantial reduction in jet thrust. In addition, the tail-pipe temperature became excessively high as a result of the increased fuel flow required to maintain engine speed.

A preliminary investigation of internal water-inertia separation inlets, including a simplified analytical design procedure, has been completed. Results indicate that ram-pressure losses will not be excessive when satisfactory ice protection is obtained by this system. The submerged inlet, also an inertia separation system, has been investigated, and results indicate that in order to be effective the inlet opening must be extremely small with high entrance-velocity ratio and consequently high ram-pressure losses.

Preliminary investigations of the use of hot gases bled from the turbine to heat the inlet demonstrated the method to be practical. Even under severe icing conditions the thrust losses were moderate. In connection with this system of ice protection, studies were made to determine the penetration of a circular air jet directed perpendicularly to an air stream. These studies, reported in Technical Note 1615, related the penetration to the jet diameter, to the distance downstream of the inlet, and to the ratios of the jet and air-stream velocities and densities.

Thermodynamic Properties of Gases

Mollier diagrams have been presented in Technical Note 1715; these diagrams related the thermodynamic properties of air when saturated with water vapor and when in equilibrium with water and ice at low temperatures.

SUBCOMMITTEE ON AIRCRAFT FIRE PREVENTION

Recent critically serious fires in commercial and military aviation have necessitated consideration of possible fundamental research that may reduce the basic causes of fire hazards. The new Subcommittee on Aircraft Fire Prevention was formed for the purpose of identifying specific fire problems for which solutions are most urgently needed, ex-

changing information on aircraft-fire-prevention research, and coordinating the research of the various contributing agencies. It is intended that the fundamental research conducted by the NACA will provide information which is needed to supplement that being provided by these other agencies.

Survey of Aircraft-Fire-Prevention Problem

The results of a preliminary survey of the aircraft fire problem indicate that a significant solution to the problem would require that inflammable materials be made less hazardous or removed from the airplane, that ignition sources be eliminated or isolated, and that the fuel be separated from potential ignition sources within the airplane. The preliminary survey further indicates that the ultimate reduction of the fire hazard will not result from the application of any single improvement but will come from an integration into the airplane design and flight operation of new ideas and methods, many of which remain to be explored. Results of laboratory experiments indicate that the use of low-volatility fuel will reduce the rate at which fire spreads in a crash, although full-scale airplane crash tests are believed necessary before final recommendations can be made. More dependable fire detectors and more dependable methods of using inert gases in interior compartments are needed if the maximum safety from fire in aircraft is to be achieved. As a result of this survey and by recommendations from the Subcommittee on Aircraft Fire Prevention, several investigations have been started.

Investigation of Less Inflammable Lubricants and Hydraulic Fluids

Studies have been initiated to determine the state of development of less inflammable lubricants and hydraulic fluids to establish guides in undertaking research for the discovery of new compounds or additives. It is believed that these guides will assist in reducing the inflammability of aircraft-engine lubricants and hydraulic fluids.

Investigation of Ignition Sources and Inflammability of Aircraft Materials

Work has been started to establish practical concepts and definitions of ignition sources and inflammability and to extend the knowledge of these factors, in order to make possible the maximum reduction of the fire hazard. It is intended to establish practical concepts and definitions through improved design and operation with existing ignition sources and inflammables and through research and development whereby the airplane and its contents may be made less inflammable and ignition sources less hazardous.

Review of Fire Records and Survey of Fire Research

The purpose of a review of fire records and a survey of fire research is to establish the significance of various phases of the aircraft fire problem; to identify ignition sources, inflammables, and conditions which are conducive to the start and spread of aircraft fires; and to evaluate the extinguishability of fires in order to direct efficiently the devel-

opment of remedial measures from existing engineering data and to direct intelligently future research on the fire problem which cannot be eliminated from existing knowledge. The survey of existing and planned research will make possible the necessary coordination of fire-prevention research.

Investigation of the Fundamentals of Aircraft-Fire Extinguishing

Investigation of the chemistry and physics of aircraft-fire extinguishing, with special consideration of the aircraft materials, geometry, and operating conditions, has been started in order that the mechanism of fire extinguishing may be better understood.

RESEARCH SPONSORED IN SCIENTIFIC AND EDUCATIONAL INSTITUTIONS

NACA sponsors a coordinated program of research at the National Bureau of Standards, Forest Products Laboratory, and nonprofit scientific and educational institutions to supplement the work carried on at the Committee's laboratories. By this means, eminent scientists and research engineers, whose highly qualified skills and talents would not otherwise be available for attack on aeronautical problems requiring solution, are able to use their talents to contribute to the Government's planned program on aeronautical research. In addition, promising students assisting in these programs receive scientific training which makes them useful additions to the country's scientific manpower.

This research program is coordinated through NACA committees and subcommittees with aeronautical work as a whole and with the Committee's research in its own laboratories. In this way provision is made for the solution of problems in all of the fields under the cognizance of the committees and subcommittees. It has been possible to engage some of the Nation's foremost aerodynamicists, mathematicians, physicists, chemists, and engineers in the study of the complex phenomena underlying the design and operation of aircraft and aircraft power plants.

These investigations are carried out under the cognizance of the appropriate committees and subcommittees and the results are published as NACA Technical Notes and Reports along with the research from the Committee's laboratories. The details of the work accomplished are reported in the preceding pages under the pertinent committee and subcommittee.

During this year specific investigations of the fundamental problems involved in flight have been studied for the NACA by such institutions as the National Bureau of Standards, Forest Products Laboratory, Aeronautical Research Foundation, University of Akron, University of Alabama, Armour Research Foundation, Battelle Memorial Institute, Polytechnic Institute of Brooklyn, California Institute of Technology, Carnegie Institute of Technology, University of Illinois, Illinois Institute of Technology, State

University of Iowa, Johns Hopkins University, Massachusetts Institute of Technology, University of Michigan, University of Minnesota, New York University, Princeton University, Rensselaer Polytechnic Institute, Stevens Institute of Technology, and Stanford University.

COORDINATION OF RESEARCH AND DISTRIBUTION OF RESEARCH INFORMATION

Coordination of aeronautical research is achieved through the broad structure of NACA technical subcommittees, whose members are drawn from every branch of aviation activity, including other Government agencies. This diversified membership keeps the NACA informed and prevents duplication of research except where parallel efforts are desired. In the various subcommittee meetings, the members report on activities in their field that will be of interest to the NACA, and also review the research being conducted by the NACA and make recommendations on future programs.

The Office of Research Coordination is further assisted by a west coast representative who maintains close contact with the aeronautical research staffs of that geographical area. A number of discussions between NACA personnel and the research staffs of the aviation industry and educational and scientific organizations are coordinated and reported each year through the Coordination Office.

In addition to other activities, the NACA holds each year certain informal conferences at its laboratories with members of the aviation industry, universities, and the military services. The purpose is to examine the research being conducted by the NACA and see that the proper government and private organizations are receiving full benefit from it.

During the past year, the Committee has held 9 technical conferences in which the following subjects were discussed:

1. Aircraft structures.
2. Aircraft loads.
3. Supersonic aerodynamics.
4. Results of X-1 flight research.
5. Propellor controls.
6. Thrust augmentation in turbojet engines.
7. Hydrodynamics.
8. Fuels.
9. University conference on aerodynamics.

Each of these conferences was attended by 100 or more members of Government services and industrial organizations having contracts with the Department of National Defense on projects related to the subjects under discussion. Members of the NACA laboratories' staff presented papers containing the latest research information obtained and the visitors exchanged their views on the Committee's work.

The research results obtained in the Committee's laboratories are distributed in the form of Committee publications. Two of these publications, Reports and Technical Notes, contain information that is not classified and so is available to

the public in general. 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 it is in the national interest to continue the classification. If it is found desirable to declassify the reports, they are then published as unclassified papers.

The Office of Aeronautical Intelligence was established in the early part of 1918 as an integral part of the Committee's activities. 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.

The program of wartime report publication, making available previously classified wartime research results, has been concluded and the last wartime report distributed.

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."

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

- No.
804. Air-Consumption Parameters for Automatic Mixture Control of Aircraft Engines. By Sidney J. Shames.
805. An Analysis of Life Expectancy of Airplane Wings in Normal Cruising Flight. By Abbott A. Putnam.

- No.
806. An Investigation of Backflow Phenomenon in Centrifugal Compressors. By William A. Benser and Jason J. Moses.
807. A Method of Analysis of V-G Records from Transport Operations. By A. M. Peiser and M. Wilkerson.
808. A Method for the Calculation of External Lift, Moment, and Pressure Drag of Slender Open-Nose Bodies of Revolution at Supersonic Speeds. By Clinton E. Brown and Hermon M. Parker.
809. Principles of Moment Distribution Applied to Stability of Structures Composed of Bars or Plates. By Eugene E. Lundquist, Elbridge Z. Stowell and Evan H. Schnette.
810. Analysis and Modification of Theory for Impact of Seaplanes on Water. By Wilbur L. Mayo.
811. Preignition-Limited Performance of Several Fuels. By Donald W. Male and John C. Evvard.
812. Knock-Limited Performance of Several Internal Coolants. By Donald R. Bellman and John C. Evvard.
813. Correlation of Exhaust-Valve Temperatures with Engine Operating Conditions and Valve Design in an Air-Cooled Cylinder. By M. A. Zipkin and J. C. Sanders.
814. A General Representation for Axial-Flow Fans and Turbines. By W. Perl and M. Tucker.
815. Method of Matching Performance of Compressor Systems with that of Aircraft Power Sections. By Robert O. Bullock, Robert C. Keetch and Jason J. Moses.
816. Comparison of Wind-Tunnel and Flight Measurements of Stability and Control Characteristics of a Douglas A-26 Airplane. By Gerald G. Kayten and William Koven.
817. Nitrided-Steel Piston Rings for Engines of High Specific Power. By John H. Collins, Jr., Edmond E. Bisson and Ralph F. Schmidell.
818. An Experimental Investigation of Rectangular Exhaust-Gas Ejectors Applicable for Engine Cooling. By Eugene J. Manganello and Donald Bogatsky.
819. Formulas for Propellers in Yaw and Charts of the Side-Force Derivative. By Herbert S. Ribner.
820. Propellers in Yaw. By Herbert S. Ribner.
821. Effect of the NACA Injection Impeller on the Mixture Distribution of Double-Row Radial Aircraft Engine. By Frank E. Marble, William K. Ritter, and Mahlon A. Miller.
822. Calculations of the Economy of an 18-Cylinder Radial Aircraft Engine with Exhaust-Gas Turbine Geared to the Crankshaft. By Richard W. Hannum and Richard H. Zimmerman.
823. Experimental Verification of a Simplified V-Tail Theory and Analysis of Available Data on Complete Models with V-Tails. By Paul E. Purser and John P. Campbell.
824. Summary of Airfoil Data. By Ira H. Abbott, Albert E. von Doenhoff, and Louis S. Stivers, Jr.
825. Analysis of Wind-Tunnel Stability and Control Tests in Terms of Flying Qualities of Full-Scale Airplanes. By Gerald G. Kayten.
826. A Method for Determining the Camber and Twist of a Surface to Support a Given Distribution of Lift, with Applications to the Load over a Sweptback Wing.
827. Charts for the Minimum-Weight Design of 24S-T Aluminum Alloy Flat Compression Panels with Longitudinal Z-Section Stiffness. By Evan H. Sshuette.
828. Bending and Shear Stresses Developed by the Instantaneous Arrest of the Root of a Moving Cantilever Beam. By Elbridge Z. Stowell, Edward B. Schwartz, and John C. Houbolt.
829. Summary of Measurements in Langley Full-Scale Tunnel of Maximum Lift Coefficients and Stalling Characteristics of Airplanes. By Harold H. Sweberg and Richard C. Dingeldein.
830. A Method for Determining the Rate of Heat Transfer from a Wing or Streamline Body. By Charles W. Frick, Jr., and George B. McCullough.
831. An Analysis of the Dissipation of Heat in Conditions of Icing from a Section of the Wing of the C-46 Airplane. By J. K. Hardy.

No.

832. A Systematic Investigation of Pressure Distributions at High Speeds over Five Representative NACA Low-Drag and Conventional Airfoil Sections. By Donald J. Graham, Gerald E. Nitzberg, and Robert N. Olson.
833. General Theory of Airfoil Sections Having Arbitrary Shape or Pressure Distribution. By H. Julian Allen.
834. Effect of Compressibility at High Subsonic Velocities on the Lifting Force Acting on an Elliptic Cylinder. By Carl Kaplan.
835. Properties of Low-Aspect-Ratio Pointed Wings at Speeds below and above the Speed of Sound. By Robert T. Jones.
836. Bending-Torsion Flutter Calculations Modified by Subsonic Compressibility Corrections. By L. E. Garrick.
837. Standard Nomenclature for Airspeeds with Tables and Charts for Use in Calculation of Airspeed. By William S. Alken.
838. Consideration of Dynamic Loads on the Vertical Tail by the Theory of Flat Yawing Maneuvers. By John Boshar and Philip Davis.
839. Theoretical Lift and Drag of Thin Triangular Wings at Supersonic Speeds. By Clinton E. Brown.
840. Stalling of Helicopter Blades. By F. B. Gustafson and G. C. Myers.
841. Application of the Method of Characteristics to Supersonic Rotational Flow. By Antonio Ferri.
842. Some Effects of Compressibility on the Flow Through Fans and Turbines. By W. Perl and H. T. Epstein.
843. Jet-Boundary and Plan-Form Corrections for Partial-Span Models with Reflection Plane, End Plate, and No End Plate in a Closed Circular Wind Tunnel. By James C. Sivelis and Owen J. Deters.
844. Tank Tests to Determine the Effect of Varying Design Parameters of Planning-Tail Hulls. I—Effect of Varying Length, Width, and Plan-Form Taper of Afterbody. By John R. Dawson, Robert C. Walter and Elizabeth S. Hay.
845. Quantitative Treatment of the Creep of Metals by Dislocation and Rate-process Theories. By A. S. Nowick and E. S. Machlin.
846. Flutter and Oscillating Air-Force Calculations for an Air-foil in a Two-Dimensional Supersonic Flow. By L. E. Garrick and S. I. Rubnow.
847. Critical Combinations of Shear and Transverse Direct Stress for an Infinitely Long Flat Plate with Edges Elastically Restrained against Rotation. By S. B. Batdorf and John C. Houbolt.
848. The Lagrangian Multiplier Method of Finding Upper and Lower Limits to Critical Stresses of Clamped Plates. By Bernard Budiansky and Paj C. Hu.
849. The Effect of Wall Interference upon the Aerodynamic Characteristics of an Airfoil Spanning a Closed-Throat Circular Wind Tunnel. By Walter G. Vincenti and Donald J. Graham.
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851. Thin Oblique Airfoils at Supersonic Speed. By Robert T. Jones.
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854. Compressibility Effects on the Longitudinal Stability and Control of a Pursuit-Type Airplane as Measured in Flight. By William N. Turner, Paul J. Steffen and Lawrence A. Clousing.
855. Relation between Spark Ignition Engine Knock, Detonation Waves, and Autoignition as Shown by High-Speed Photography. By Cearcy D. Miller.
856. The NACA High-Speed Motion-Picture Camera—Optical Compensation at 40,000 Photographs a Second. By Cearcy D. Miller.

No.

857. Analysis of Spark-Ignition Engine Knock as Seen by Photographs Taken at 200,000 Frames per Second. By Cearcy D. Miller, H. Lowell Olsen and Gordon E. Osterstrom.
858. Comparison of Several Methods of Predicting the Pressure Loss at Altitude across a Baffled Aircraft-Engine Cylinder. By Joseph Neustein and Louis J. Schafer, Jr.
859. Measurements in Flight of the Pressure Distribution on the Right Wing of a P-39N-1 Airplane at Several Values of Mach Number. By Lawrence A. Clousing, William N. Turner and L. Stewart Rolls.
860. Analysis of Cooling Limitations and Effect of Engine-Cooling Improvements on Level-Flight Cruising Performance of Boeing B-29 Airplane. By Frank E. Marble, Mahlon A. Miller and E. Barton Bell.
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862. An Investigation of a Thermal Ice-Prevention System for a Twin-Engine Transport Airplane. By Alun R. Jones.

TECHNICAL NOTES¹

1195. Effect of Finite Span on the Airload Distributions for Oscillating Wings. II—Methods of Calculation and Examples of Application. By Eric Reissner and John E. Stevens.
1198. Some Investigations of the General Instability of Stiffened Metal Cylinders. IX—Criteria for the Design of Stiffened Metal Cylinders Subject to General Instability Failures. By Louis G. Dunn.
1259. A Graphical Method for Interpolation of Hydrodynamic Characteristics of Specified Flying Boats from Collapsed Results of General Tests of Flying-Boat-Hull Models. By F. W. S. Locke, Jr.
1262. Effect of Variables in Welding Technique on the Strength of Direct-Current Metal-Arc-Welded Joints in Aircraft Steel. II—Repeated-Stress Tests of Joints in SAE 4130 Seamless Steel Tubing. By C. B. Voldrich and E. T. Armstrong.
1264. Stresses in and General Instability of Monocoque Cylinders with Cutouts. IV—Pure Bending Tests of Cylinders with Side Cutout. By N. J. Hoff, Bruno A. Boley, and Louis R. Viggiano.
1322. The Spot Welding of Dissimilar Aluminum Alloys in the 0.040-Inch Thickness. By W. F. Hess, R. A. Wyant, and F. J. Winsor.
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1366. Effect of Changing Manifold Pressure, Exhaust Pressure, and Valve Timing on the Air Capacity and Output of a Four-Stroke Engine Operated with Inlet Valves of Various Diameters and Lifts. By James C. Livengood and James V. D. Eppes.
1375. Limits of Precision in the Determination of Lattice Parameters and Stresses by the Debye-Scherrer Method. By Hans Ekstejn and Stanley Siegel.
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1436. Stresses in and General Instability of Monocoque Cylinders with Cutouts. VI—Calculation of the Buckling Load of Cylinders with Side Cutout Subjected to Pure Bending. By N. J. Hoff, Bertram Klein, and Bruno A. Boley.
1437. Impact Theory for Seaplane Landings. By S. U. Benscoter.
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1439. Compressive Strength of 24S-T Aluminum-Alloy Flat Panels with Longitudinal Formed Hat-Section Stiffeners Having a Ratio of Stiffener Thickness to Skin Thickness Equal to 1.00. By William A. Hickman and Norris F. Dow.
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1442. Friction at High Sliding Velocities. By Robert L. Johnson, Max A. Swikert, and Edmond E. Bisson.
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1452. An Investigation of Aircraft Heaters. XXVIII—Equations for Steady-State Temperature Distribution Caused by Thermal Sources in Flat Plates Applied to Calculation of Thermocouple Errors, Heat-Meter Corrections, and Heat-Transfer by Pin-Fin Plates. By L. M. K. Boelter, F. E. Romie, A. G. Guibert, and M. A. Miller.
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1463. Investigation of NACA 65₍₁₅₎A111 (Approx.) Airfoil with 0.35-Chord Slotted Flap at Reynolds Numbers up to 25 Million. By Stanley F. Racisz.
1464. Effects of Surface Finish, of Certain Defects, and of Repair of Defects by Welding on Fatigue Strength of 855-T6 Sand-Castings and Effects of Prior Fatigue Stressing on Tensile Properties. By F. M. Howell, G. W. Stickley, and J. O. Lyst.
1465. The Rupture-Test Characteristics of Heat-Resistant Sheet Alloys at 1700° and 1800° F. By J. W. Freeman, E. E. Reynolds, and A. E. White.
1466. Recurrence Formulas and Differential Equations for Stress Analysis of Cambered Box Beams. By Joseph Kempner.
1467. Effect of Variation in Diameter and Pitch of Rivets on Compressive Strength of Panels with Z-Section Stiffeners. Panels of Various Stiffener Spacings that Fail by Local Buckling. By Norris F. Dow and William A. Hickman.
1468. Low-Speed Static Stability and Damping-in-Roll Characteristics of Some Swept and Unswept Low-Aspect-Ratio Wings. By Louis P. Tosti.
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1471. Experimental Investigation of Velocity Distributions Downstream of Single Duct Bends. By John R. Weske.
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1475. An Investigation of Valve-Overlap Scavenging over a Wide Range of Inlet and Exhaust Pressures. By John W. R. Creagh, Melvin J. Hartmann, and W. L. Arthur, Jr.

- No.
1476. A Comparison of Three Theoretical Methods of Calculating Span Load Distribution on Swept Wings. By Nicholas H. Van Dorn and John DeYoung.
1477. Generalized Performance Comparison of Large Conventional, Tail-Boom, and Tailless Airplanes. By Herman O. Ankenbruck and Marion O. McKinney, Jr.
1478. Wind Tunnel Investigation of the Stability and Control Characteristics of a Complete Model Equipped with a Vee Tail. By Edward C. Polhamus and Robert J. Moss.
1479. Boundary-Layer Momentum Equations for Three-Dimensional Flow. By Neal Tetervin.
1480. Determination of Plate Compressive Strengths. By George J. Helmerl.
1481. Diagonal Tension in Curved Webs. By Paul Kuhn and George E. Griffith.
1482. A Method of Calculating the Compressive Strength of Z-Stiffened Panels that Develop Local Instability. By George L. Galaher and Rolla B. Boughan.
1483. Flight Measurements of Aerodynamic Loads on the Horizontal Tail Surface of a Fighter-Type Airplane. By John Garvin.
1484. Theoretical Lift Distribution and Upwash Velocities for Thin Wings at Supersonic Speeds. By John C. Evvard and Richard L. Turner.
1485. Fatigue Strength and Related Characteristics of Aircraft Joints. II—Fatigue Characteristics of Sheet and Riveted Joints of 0.040-Inch 24S-T, 75S-T, and R308-T275 Aluminium Alloys. By H. W. Russell, L. R. Jackson, E. J. Grover, and W. W. Beaver.
1486. Stress Distribution in a Beam of Orthotropic Material Subjected to a Concentrated Load. By C. B. Smith and A. W. Voss.
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1500. Comparison of Computed Performance of Composite Power Plants Using 18-Cylinder Aircraft Engines With 62° and 40° Valve Overlap. By Samuel J. Kaufman and David S. Boman.
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- No.
1504. Sideslip Angles and Vertical-Tail Loads Developed by Periodic Control Deflections. By Harvard Lomax.
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1506. An Application of Falkner's Surface-Loading Method to Predictions of Hinge-Moment Parameters for Swept-Back Wings. By Arthur L. Jones and Loma Sluder.
1507. Symbols for Combustion Research. By NACA Subcommittee on Combustion.
1509. Cylinder-Temperature and Cooling-Air-Pressure Instrumentation for Air-Cooled-Engine Cooling Investigations. By Michael F. Valerino and Samuel J. Kaufman.
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1512. Stress-Strain and Elongation Graphs for Alclad Aluminum-Alloy 24S-T Sheet. By James A. Miller.
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1520. De-Icing Effectiveness of External Electric Heaters for Propeller Blades. By James P. Lewis.
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- No.
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1537. Apparent Effect of Inlet Temperature on Adiabatic Efficiency of Centrifugal Compressors. By Robert J. Anderson, William K. Ritter, and Shirley R. Parsons.
1538. Analysis of Accuracy of Gas-Filled Bellows for Sensing Gas Density. By Edward W. Otto.
1539. Measurements of the Pressure Distribution on the Horizontal-Tail Surface of a Typical Propeller-Driven Pursuit Airplane in Flight. III—Tail Loads in Abrupt Pull-Up Push-Down Maneuvers. By Melvin Sadoff and Lawrence A. Clousing.
1540. The Effect of Tip Modification and Thermal De-Icing Air Flow on Propeller Performance as Determined from Wind-Tunnel Tests. By W. H. Gray and R. E. Davidson.
1541. The Effect of Wing Bending Deflection on the Rolling Moment Due to Sideslip. By Powell M. Lovell, Jr.
1542. Effect of Rotor-Blade Twist and Plan-Form Taper on Helicopter Hovering Performance. By Alfred Gessow.
1543. Effect of Chordwise Location of Maximum Thickness on the Supersonic Wave Drag of Sweptback Wings. By Kenneth Margolis.
1544. Strength of Thin-Web Beams with Transverse Load Applied at an Intermediate Upright, By L. Ross Levin.
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1547. Tank Tests of Three Types of Afterbodies on a Flying-Boat Model with Basic Hull Length-Beam Ratio of 10.0. By Charlie C. Garrison and Eugene P. Clement.
1548. The Damping Due to Roll of Triangular, Trapezoidal, and Related Plan Forms in Supersonic Flow. By Arthur L. Jones and Alberta Aleksne.
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1551. Fracture Strength of 75S-T Aluminum Alloy under Combined Stress. By E. G. Thomsen, I. Lotze and J. E. Dorn.
1552. Investigation on the Validity of an Ideal Theory of Elasto-Plasticity for Wrought Aluminum Alloys. By E. G. Thomsen.
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- No.
1558. Notes on the Lagrangian Multiplier Method in Elastic-Stability
1559. Buckling Stresses of Clamped Rectangular Plates in Shear. By Bernard Budiansky and Robert W. Connor.
1560. Mechanical Properties of Five Laminated Plastics. By William N. Findley and Will J. Worley.
1562. Calibration of Altimeters under Pressure Conditions Simulating Dives and Climbs. By Daniel P. Johnson.
1563. Effect of Partial Wing Lift in Seaplane Landing Impact. By Stanley U. Benscoter.
1564. Methods of Constructing Charts for Adjusting Test Results for the Compressive Strength of Plates for Differences in Material Properties. By George J. Helmerl.
1565. Buckling in Shear of Continuous Flat Plates. By Bernard Budiansky, Robert W. Connor, and Manuel Stein.
1566. Damping in Pitch and Roll of Triangular Wings at Supersonic Speeds. By Clinton E. Brown and Mac C. Adams.
1567. Simulated-Altitude Investigation of Performance of Tubular Aircraft Oil Coolers. By S. V. Manson.
1568. Design and Performance of Family of Diffusing Scrolls with Mixed-Flow Impeller and Vaneless Diffuser. By W. Byron Brown and Guy R. Bradshaw.
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1572. Stability Derivatives of Triangular Wings at Supersonic Speeds. By Herbert S. Ribner and Frank S. Malvestuto.
1573. Flight Measurements of the Flying Qualities of Five Light Airplanes. By Paul A. Hunter.
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- No.
1587. Investigation of Effectiveness of Air-Heating a Hollow Steel Propeller for Protection against Icing. II—50-Percent Partitioned Blades. By Porter J. Perkins and Donald R. Mülholland.
1588. Investigation of Effectiveness of Air-Heating a Hollow Steel Propeller for Protection against Icing. III—25-Percent Partitioned Blades. By Donald R. Mülholland and Porter J. Perkins.
1589. Effect of Longitudinal Stiffeners on the Buckling Load of Long Flat Plates under Shear. By Harold Crate and Hsu Lo.
1590. Investigation of an Approximately 0.178-Chord-Thick NACA 6-Series-Type Airfoil Section Equipped with Sealed Internally Balanced 0.20-Chord Ailerons and with a 0.05-Chord Tab. By F. Visconti.
1591. Aerodynamic Characteristics of a Number of Modified NACA Four-Digit-Series Airfoil Sections. By Laurence K. Loftin, Jr., and Kenneth S. Cohen.
1592. Compressible Flow Tables for Air. By Marie A. Burcher.
1593. Effects of Nacelle Position on Wing-Nacelle Interference. By Charles H. McLellan and John I. Cangelosi.
1594. Experimental Investigation of the Effects of Concentrated Weights on Flutter Characteristics of a Straight Cantilever Wing. By Harry L. Runyan and John L. Sewall.
1595. Analysis of Flight-Performance Measurements on a Twisted, Plywood-covered Helicopter Rotor in Various Flight Conditions. By F. B. Gustafson and Alfred Gessow.
1597. Analysis of the Effects of Boundary-Layer Control on the Take-Off Performance Characteristics of a Liaison-Type Airplane. By Elmer A. Horton and John H. Quinn, Jr.
1598. Effects of Ice Formations on Airplane Performance in Level Cruising Flight. By G. Merritt Preston and Calvin C. Blackman.
1599. An Investigation of a Thermal Ice-Prevention System for a Cargo Airplane. IX—The Temperature of the Wing-Leading-Edge Structure as Established in Flight. By Bernard A. Schiaff.
1600. Characteristics of Thin Triangular Wings with Triangular-Tip Control Surfaces at Supersonic Speeds with Mach Lines behind the Leading Edge. By Warren A. Tucker.
1601. Characteristics of Thin Triangular Wings with Constant-Chord Full-Span Control Surfaces at Supersonic Speeds. By Warren A. Tucker.
1602. Calculated Performance of 12-Cylinder Liquid-Cooled Engine with Exhaust-Gas Turbine Geared to Crankshaft. By Leland G. Desmon and Ronald B. Doyle.
1603. Application of Statistical Methods to Study of Gas-Turbine Blade Failures. By Charles A. Hoffman and G. Mervin Ault.
1604. Standard Symbols for Helicopters. By Alfred Gessow.
1605. Accuracy of Airspeed Measurements and Flight Calibration Procedures. By Wilber B. Huston.
1606. Cylinder-Head Temperatures and Coolant Heat Rejections of a Multicylinder, Liquid-Cooled Engine of 1710-Cubic-Inch Displacement. By John H. Povolny and Louis J. Chelko.
1607. Effect of Size and Number of Outlet Pipes on Design of Collectors for Rating and Testing Axial-Flow Compressors. By Jason J. Moses and Thomas I. Kazberovich.
1608. Quantitative Analysis of Ternary Mixtures of Naphthalene 1-Methylnaphthalene, and 2-Methylnaphthalene by Ultraviolet Spectrophotometry. By Alden P. Cleaves, Mildred S. Carver and Robert H. Hibbard.
1609. Effect of Hydrocarbon Type and Chain Length on Uniform Flame Movement in Quiescent Fuel-Air Mixtures. By Thaine W. Reynolds and Earl R. Ebersole.
1610. Effect of Screens in Wide-Angle Diffusers. By G. B. Schubauer and W. G. Spangenberg.
1611. Axial Fatigue Tests at Zero Mean Stress of 24S-T and 75S-T Aluminum-Alloy Strips with a Central Circular Hole. By W. C. Brueggeman and M. Mayer, Jr.
- No.
1612. Effect of Reducing Valve Overlap on Engine and Compound-Power-Plant Performance. By David S. Boman and S. J. Kaufman.
1613. A Method for Determining the Aerodynamic Characteristics of Two- and Three-Dimensional Shapes at Hypersonic Speeds. By H. Reese Ivey, E. Bernard Klunker and E. N. Bowen.
1614. Knocking Combustion Observed in a Spark-Ignition Engine with Simultaneous Direct and Schlieren High-Speed Motion Pictures and Pressure Records. By Gordon E. Osterstrom.
1615. Investigation of the Penetration of an Air Jet Directed Perpendicularly to an Air Stream. By Edmund E. Callaghan and Robert S. Ruggeri.
1616. Knock-Limited Performance of Several Branched Paraffins and Olefins. By Russell S. Genco and Isadore L. Drell.
1617. Effect of Exhaust Pressure on Knock-Limited Performance of an Air-Cooled Aircraft-Engine Cylinder. By Albert M. Lord, Orville H. Heinicke and Edward G. Stricker.
1618. Effects of Fuel-Nozzle Carbon Deposition on Combustion Efficiency of Single Tubular-Type, Reverse-Flow, Turbojet Combustor at Simulated Altitude Conditions. By Ralph T. Dittrich.
1619. An Evaluation of Proposed Reference Fuel Scales for Knock Rating. By Henry C. Barnett and Thomas C. Clarke.
1620. The Calculation of Downwash behind Supersonic Wings with an Application to Triangular Plan Forms. By Max A. Heaslet and Harvard Lomax.
1621. Two-Dimensional Unsteady Lift Problems in Supersonic Flight. By Max A. Heaslet and Harvard Lomax.
1622. Analysis and Preliminary Design of an Optical Instrument for the Measurement of Drop Size and Free-Water Content of Clouds. By Willem V. R. Malkus, Richard H. Bishop and Robert O. Briggs.
1623. Some Fundamental Similarities between Boundary-Layer Flow at Transonic and Low Speeds. By Gerald E. Nitzberg and Stewart Crandall.
1624. Two-Dimensional Wind-Tunnel Investigation of an NACA 64-009 Airfoil Equipped with Two Types of Leading-Edge Flap. By F. F. Fullmer, Jr.
1626. A Study of Ceramic Coatings for High-Temperature Protection of Molybdenum. By D. C. Moore, L. M. Bolz, and W. N. Harrison.
1627. Effect of Steady Rolling on Longitudinal and Directional Stability. By William H. Phillips.
1628. An Analysis of the Variation with Altitude of Effective Gust Velocity in Convective-Type Clouds. By H. B. Tolefson.
1629. The Experimental Determination of the Moments of Inertia of Airplanes by a Simplified Compound-Pendulum Method. By William Gracey.
1630. A Generalized Theoretical Investigation of the Hydrodynamic Pitching Moments Experienced by V-Bottom Seaplanes during Step-Landing Impacts and Comparisons with Experiment. By Benjamin Milwitzky.
1631. Wind-Tunnel Investigation of Boundary-Layer Control by Suction on NACA 65-424 Airfoil with Double Slotted Flap. By Stanley F. Racisz and John H. Quinn, Jr.
1632. Gust-Tunnel Tests to Determine Influence of Airfoil Section Characteristics on Gust-Load Factors. By Harold B. Pierce and Mitchell Trauring.
1633. An Evaluation of the Characteristics of a 10-Percent-Thick NACA 66-Series Airfoil Section with a Special Mean-Camber Line Designed to Produce a High Critical Mach Number. By Laurence K. Loftin, Jr., and Kenneth S. Cohen.
1634. Wind-Tunnel Tests and Analysis of Two 10-Foot-Diameter Six-Blade Dual-Rotating Tractor Propellers Differing in Pitch Distribution. By Jean Gilman, Jr.
1635. Strength Tests of Shear Webs with Uprights not Connected to the Flanges. By Charles W. Sandlin, Jr.

- No. 1636. Determination of Stresses in Gas-Turbine Disks Subjected to Plastic Flow and Creep. By Morton B. Millenson and Samuel S. Manson.
1637. Effect of Preignition on Cylinder Temperatures, Pressures, Power Output, and Piston Failures. By Lester C. Corrington and William F. Fisher.
1638. Experimental Investigation of the Jet-Boundary Constriction Correction for a Model Spanning a Closed Circular Tunnel. By Maurice Tucker and Morris D. Rouso.
1639. Investigation of Some Factors Affecting Comparisons of Wind-Tunnel and Flight Measurements of Maximum Lift Coefficients for a Fighter-Type Airplane. By Don D. Davis, Jr., and Harold H. Sweberg.
1640. Direct-Reading Design Charts for 75S-T Aluminum-Alloy Flat Compression Panels Having Longitudinal Straight-Web Y-Section Stiffeners. By Morris F. Dow and William A. Hickman.
1641. A Method for Determination of Aromatics in 150° to 300° C. Fractions of Crude Petroleum by Measurement of Aniline-Point Rise. By Arthur M. Busch, Alden P. Cleaves, and Robert R. Hibbard.
1642. Velocity Distributions on Symmetrical Airfoils in Closed Tunnels by Conformal Mapping. By William Perl and Harry E. Moses.
1643. Effect of Landing Flaps and Landing Gear on the Spin and Recovery Characteristics of Airplanes. By Lawrence J. Gale.
1644. Laminar Flow of a Slightly Viscous Incompressible Fluid that Issues from a Slit and Passes over a Flat Plate. By Neal Tetervin.
1645. A Statistical Analysis of Gust-Velocity Measurements as Affected by Pilots and Airplanes. By Harry Press.
1646. Low-Speed Wind-Tunnel Investigation of Various Plain-Spinner Configurations for Lateral Control on a 42° Sweptback Wing. By Leslie E. Schnelzer and James M. Watson.
1647. Sound-Level Measurements of a Light Airplane Modified to Reduce Noise Reaching the Ground. By A. W. Vogeley.
1648. Tank Tests of $\frac{1}{10}$ -Size Model of a Hypothetical Flying Boat with a Hull Length-Beam Ratio of 9.0. By Marvin I. Haar.
1650. Chordwise and Spanwise Loadings Measured at Low Speed on a Triangular Wing Having an Aspect Ratio of Two and an NACA 0012 Airfoil Section. By Bradford H. Wick.
1651. Supersonic Nozzle Design. By J. Conrad Crown.
1652. Investigation of Axial-Flow Fan and Compressor Rotors Designed for Three-Dimensional Flow. By Abraham Kahane.
1653. Charts for the Computation of Equilibrium Composition of Chemical Reactions in the Carbon-Hydrogen-Oxygen-Nitrogen System at Temperatures from 2000° to 5000° K. By Veal N. Huff and Clyde S. Calvert.
1654. Sound from Dual-Rotating and Multiple Single-Rotating Propellers. By Harvey H. Hubbard.
1655. Thermodynamic Charts for the Computation of Fuel Quantity Required for Constant-Pressure Combustion with Diluents. By Donald Bogart, David Okrent, and L. Richard Turner.
1656. Tests of Six Types of Bakelite-Bonded Wire Strain Gages. By W. R. Campbell.
1657. Effects of Compressibility on the Flow Past Thick Airfoil Sections. By Bernard W. Daley and Milton D. Humphreys.
1658. Lateral Stability and Control Characteristics of a Free-Flying Model Having an Unswept Wing with an Aspect Ratio of 2. By Marion O. McKinney, Jr. and Robert E. Shanks.
1659. Method for Calculation of Pressure Distributions on Thin Conical Bodies of Arbitrary Cross Section in Supersonic Stream. By Stephen M. Maslen.
1660. Characteristics of Thin Triangular Wings with Constant-Chord Partial-Span Control Surfaces at Supersonic Speeds. By Warren A. Tucker and Robert L. Nelson.
1661. Critical Axial-Compressive Stress of a Curved Rectangular Panel with a Central Chordwise Stiffener. By S. B. Batdorf and M. Schilderout.
- No. 1662. Aerodynamic Properties of Slender Wing-Body Combinations at Subsonic, Transonic, and Supersonic Speeds. By John R. Spreiter.
1663. High-Speed Wind-Tunnel Investigation of an NACA 65-210 Semi-span Wing Equipped with Plug and Retractable Ailerons and a Full-Span Slotted Flap. By Jack Fischel and Leslie E. Schreiter.
1664. A Device for Measuring Sonic Velocity and Compressor Mach Number. By Paul W. Huber and Arthur Kantrowitz.
1665. Characteristics of Low-Aspect-Ratio Wings at Supercritical Mach Numbers. By John Stack and W. F. Lindsey.
1666. Flight Investigation of Effects of Rotor-Blade Twist on Helicopter Performance in the High-Speed and Vertical-Autorotative-Descent Conditions. By Alfred Gessow.
1667. Effect of Strength and Ductility on Burst Characteristics of Rotating Disks. By Arthur G. Holms and Joseph E. Jenkins.
1668. Investigation of Effects of Geometric Dihedral on Low-Speed Static Stability and Yawing Characteristics of an Untapered 45° Sweptback Wing Model of Aspect Ratio 2.61. By M. J. Queijo and B. M. Jaquet.
1669. Investigation at Low Speeds of the Effect of Aspect Ratio and Sweep on Static and Yawing Stability Derivatives of Untapered Wings. By Alex Goodman and Jack D. Brewer.
1670. Appreciation and Prediction of Flying Qualities. By W. H. Phillips.
1671. Effect of Taper Ratio on Low-Speed Static and Yawing Stability Derivatives of 45° Sweptback Wings with Aspect Ratio of 2.61. By William Letko and John W. Cowan.
1672. Supersonic Wave Drag of Nonlifting Sweptback Tapered Wings with Mach Lines behind the Line of Maximum Thickness. By K. Margolis.
1673. Tables and Charts of Flow Parameters across Oblique Shocks. By Mary M. Nelce.
1674. Estimation of Effectiveness of Flap-Type Controls on Sweptback Wings. By John G. Lowry and Leslie E. Schnelzer.
1675. Temperature Gradients in the Wing of a High-Speed Airplane During Dives from High Altitudes. By Thorval Tendeland and B. A. Schlaff.
1676. Graphical Method of Obtaining Theoretical Lift Distributions on Thin Wings at Supersonic Speeds. By Clarencé B. Cohen and John C. Ekvard.
1677. Experimental and Calculated Characteristics of Several High-Aspect-Ratio Tapered Wings Incorporating NACA 44-Series, 230-Series, and Low-Drag 64-Series Airfoil Sections. By Thomas V. Bollech.
1678. Theoretical Wave Drag and Lift of Thin Supersonic Ring Airfoils. By Harold Mirels.
1679. Flight Measurements of the Longitudinal Stability, Stalling, and Lift Characteristics of an Airplane Having a 35° Sweptback Wing Without Slots and With 40-Percent-Span Slots and a Comparison with Wind-Tunnel Data. By S. A. Sjoberg and J. P. Reeder.
1680. Divergence of Swept Wings. By F. W. Diederich and Bernard Budiansky.
1681. Critical Shear Stress of an Infinitely Long Plate in the Plastic Region. By Elbridge Z. Stowell.
1682. Heat Transfer to Bodies Traveling at High Speed in the Upper Atmosphere. By Jackson R. Stalder and David Jukoff.
1683. An Experimental Investigation of an NACA 63-012 Airfoil Section with Leading-Edge Suction Slots. By George B. McCullough and D. E. Gault.
1684. A Preliminary Evaluation of the Use of Ground Radar for the Avoidance of Turbulent Clouds. By H. Press and E. T. Binkley.
1685. Linearized Supersonic Theory of Conical Wings. By P. A. Lagerstrom.
1686. Effect of Length-Beam on the Aerodynamic Characteristics of Flying-Boat Hulls without Wing Interference. By John G. Lowry and John M. Riebe.

- No. 1687. Jet Diffuser for Simulating Ram-Pressure Conditions on a Turbojet-Engine Static Test Stand. By Robert H. Essig, H. R. Bohanon and David S. Gabriel.
1688. Load Distributions Due to Steady Roll and Pitch for Thin Wings at Supersonic Speeds. By W. E. Moeckel and J. C. Evvard.
1690. Theoretical and Experimental Wing-Tips Accelerations of a Small Flying Boat During Landing Impacts. By Daniel Savitsky.
1691. Icing and De-Icing of a Propeller with Internal Electric Blade Heaters. By James P. Lewis and Howard C. Stevens, Jr.
1692. Determination of Bending Moments in Pressure-Loaded Rings of Arbitrary Shape when Deflections are Considered. By F. R. Steinbacher and Hsu Lo.
1693. An Analysis of the Airspeeds and Normal Accelerations of Martin M-130 Airplanes in Commercial Transport Operation. By Walter G. Walker.
1694. Analysis of Planing Data for Use in Predicting Hydrodynamic Impact Loads. By Margaret F. Steiner.
1695. Effect of Pressure Recovery on the Performance of a Jet-Propelled Airplane. By Frederick H. Hanson and Emmet A. Mossman.
1699. A Linearized Solution for Time-Dependent Velocity Potentials Near Three-Dimensional Wings at Supersonic Speeds. By J. C. Evvard.
1701. Analysis of the Performance of a Jet Engine from Characteristics of the Components. II—Interaction of the Components as Determined from Engine Operation. By Arthur W. Goldstein, Sumner Alpert, William Deede, and Karl Kovach.
1702. Analytical and Experimental Performance of an Explosion-Cycle Combustion Chamber for a Jet-Propulsion Engine. By M. A. Zipkin and George W. Lewis, Jr.
1705. Experimental Investigation of the Effects of the Plastic Flow in a Tension Panel with a Circular Hole. By George E. Griffith.
1707. Effect of Reynolds Number in the Turbulent-Flow Range on Flame Speeds of Bunsen-Burner Flames. By L. M. Bollinger and D. T. Williams.
1708. Theoretical Characteristics in Supersonic Flow of Constant-Chord Partial-Span Control Surfaces on Rectangular Wings Having Finite Thickness. By Warren A. Tucker and Robert L. Nelson.
1710. Minimum-Weight Design of Simply Supported Transversely Stiffened Plates under Compression. By Alexander Gomza and Paul Selde.
1712. Analytical Method of Determining Transmission of Particles and Radiation through Great Thicknesses of Matter. By A. R. Bobrowsky.
1713. Experimental Study of Effect of Vaneless-Diffuser Diameter on Diffuser Performance. By G. R. Bradshaw and E. B. Laskin.
1718. Influence of Leading-Edge Suction on Lift-Drag Ratios of Wings at Supersonic Speeds. By Clarence B. Cohen.
- 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).
1103. A Ram-Jet Engine for Fighters. By E. Sängler and I. Bredt. From Deutsche Forschungsanstalt für Segelflug E. V., Ernst Udet, Ainring, Oberbayern, 1943; ZWB, UM 3509.
1116. Stability of Plates and Shells Beyond the Proportional Limit. By A. A. Ilyushin. From Prikladnaya Matematika i Mekhanika, N. S. 8, No. 5, 1944, pp. 837-860.
- No. 1125. The Influence of the Diameter Ratio on the Characteristics Diagram of the Axial Compressor. By B. Eckert, F. Pfüger, and F. Weing. From Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren, Technische Hochschule Stuttgart.
1137. The Turbulent Flow in Diffusers of Small Divergence Angle. By G. A. Gourzhienko. From Central Aero-Hydrodynamical Institute, Report 462, 1939.
1138. On the Application of the Energy Method to Stability Problems. By Karl Marguerre. From Jahrbuch 1938 der Deutschen Versuchsanstalt für Luftfahrt, pp. 252-262.
1139. Planing of Watercraft. By Herbert Wagner. From Jahrbuch der Schiffbautechnik, vol. 34, 1933, pp. 205-227.
1159. Wind-Tunnel Measurements on the Henschel Missile "Zitterrochen" in Subsonic and Supersonic Velocities. By Weber and Kehl. Wind-Tunnel Measurements on the Wing of the Henschel Missile "Zitterrochen" in Subsonic and Supersonic Velocities. By Kehl. From ZWB, UM 3122, Oct. 7, 1944.
1165. Coefficient of Friction, Oil Flow and Heat Balance of a Full-Journal Bearing. By P. I. Orloff. From Aeronautical Engineering (Moscow) 9th year, Jan. 1935, pp. 25-56.
1175. Fundamental Aerodynamic Investigations for Development of Arrow-Stabilized Projectiles. By Hermann Kurzweg. From Schriften der Deutschen Akademie der Luftfahrtforschung. No. 1059/43, 1943, pp. 33-71.
1176. Test Report on Three- and Six-Component Measurements on a Series of Tapered Wings of Small Aspect Ratio. (Partial Report: Triangular Wing). By Lange/Wacke. From ZWB, UM 1023/5, Sept. 27, 1943.
1178. Investigation of the Operating Properties of the Leakage Current Anemometer. By Wilhelm Fucks. From Aachen, Feb. 4, 1944; ZWB, UM 1208.
1180. Maintaining Laminar Flow in the Boundary Layer Using a Swept-Back Wing. By Brennecke. From ZWB, UM 3151, Sept. 13, 1944.
1182. The Problem of Torsion in Prismatic Members of Circular Segmental Cross Section. By A. Weigand. From Luftfahrtforschung, Vol. 20, No. 12, Feb. 8, 1944, pp. 333-340.
1185. Systematic Investigations of the Influence of the Shape of the Profile upon the Position of the Transition Point. By K. Bussmann and A. Ulrich. From Technische Berichte und radrücke aus Jahrbuch 1943 der deutschen Luftfahrtforschung Vol. 10 (1943), No. 9, Sept. 15, 1943, IA 010, pp. 1-19.
1186. Comparison of Drop and Wind-Tunnel Experiments on Bomb Drag at High Subsonic Speeds. By B. Göthert. From ZWB, FB 1570, April 17, 1942.
1188. The Elasto-Plastic Stability of Plates. By A. A. Ilyushin. From Prikladnaya Matematika i Mekhanika X, 1946, pp. 623-638.
1189. Theoretical Analysis of Stationary Potential Flows and Boundary Layers at High Speed. By K. Oswattitsch and K. Wieghardt. From Lilienthal-Gesellschaft für Luftfahrtforschung Report S 18/1, pp. 7-24.
1190. Tests of Cascades of Airfoils for Retarded Flow. By Yoshinori Shimoyama. From Transactions of the Society of Mechanical Engineers, Japan. Vol. 3, No. 13, Nov. 1937, pp. 334-344.
1191. Venturi Tube with Varying Mass Flow. By B. Regenscheit. From ZWB, FB 1945, May 19, 1944.
1192. Rotating Disks in the Region of Permanent Deformation. By F. László. From Zeitschrift für angewandte Mathematik und Mechanik, Ingenieurwissenschaftliche Forschungsarbeiten, Vol. 5, No. 4, Aug. 1925, pp. 281-293.
1193. Measurements on Compressor-Blade Lattices. By F. Weing and B. Eckert. From Berichte der Gittertagung in Braunschweig, Institut für Motorenforschung der Luftfahrtforschungsanstalt Hermann Göring, Mar. 27 and 28, 1944.
1195. On the Sound Field of a Rotating Propeller. By L. Gutin. From Physikalsche Zeitschrift der Sowjetunion, Vol. 9, No. 1, 1936, pp. 57-71.

Part II

COMMITTEE ORGANIZATION AND MEMBERSHIP

By act of Congress approved May 25, 1948 (Public Law 549, 80th Cong.), the act of March 3, 1915, establishing the National Advisory Committee for Aeronautics as amended, was further amended to provide for increasing the membership of the Committee from 15 to 17 and to provide further that the Chairman of the Research and Development Board of the National Military Establishment shall be one of the 17 members. The Committee's members are appointed by the President and include, in addition to the Chairman of the Research and Development Board, 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 seven 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 seven members serve for terms of 5 years. The representatives of the Government organizations serve for indefinite periods. All members serve as such without compensation.

In accordance with the act of May 25, 1948, the President, under date of June 25, appointed Dr. Detlev W. Bronk, of the Johnson Research Foundation, University of Pennsylvania (subsequently elected president of Johns Hopkins University), and Dr. James H. Doolittle, vice president of the Shell Union Oil Corp., as two additional members, and reappointed Dr. Vannevar Bush a member in his capacity as Chairman of the Research and Development Board. Upon the latter's resignation from the Research and Development Board, Dr. Karl T. Compton, his successor as Chairman of that Board, was appointed, on November 1, 1948, to succeed him on the Committee.

The death of Dr. Orville Wright on January 30, 1948, brought to a close 28 years of membership on the Committee, during which his sound advice and stimulating views were of great benefit in the councils of the Committee.

Other changes in the Committee's membership since the publication of the last annual report were as follows:

On January 27, 1948, Vice Adm. John D. Price, U. S. N., was appointed a member to succeed Vice Adm. Donald B. Duncan, whom he also replaced as Deputy Chief of Naval Operations (Air).

Following his resignation as Administrator of Civil Aeronautics to become vice president for research of Cornell

University, Dr. Theodore P. Wright was, under date of May 18, 1948, appointed to the vacancy in the Committee's membership caused by the death of Dr. Orville Wright, and as of the same date Hon. Delos W. Rentzel, the new Administrator of Civil Aeronautics, was appointed a member of the Committee succeeding Dr. Theodore P. Wright.

Gen. Hoyt S. Vandenberg, U. S. A. F., Chief of Staff of the Air Force, was appointed a member of the Committee on June 2, 1948, to succeed Gen. Carl Spaatz, his predecessor as head of the Air Force.

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 21, 1948, Dr. Jerome C. Hunsaker was reelected Chairman of the NACA and of the Executive Committee, and Dr. Alexander Wetmore and Dr. Francis W. Reichelderfer were reelected Vice Chairman of the NACA and Vice Chairman of the Executive Committee, respectively.

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 5 principal committees and their 22 subcommittees as organized in 1948 were as follows:

COMMITTEE ON AERODYNAMICS

Dr. Theodore P. Wright, Cornell University, Chairman.
Capt. Walter S. Diehl, U. S. N., Bureau of Aeronautics, Vice Chairman.
Col. George F. Smith, U. S. A. F., Air Matériel Command.
Col. O. J. Rittland, U. S. A. F., Air Matériel Command.
Brig. Gen. Henry B. Saylor, U. S. A., Office of the Chief of Ordnance.
Rear Adm. Malcolm F. Schoeffel, U. S. N., Bureau of Ordnance.
Mr. F. A. Loudon, Bureau of Aeronautics, Department of the Navy.
Mr. Harold D. Hoekstra, Civil Aeronautics Administration.
Dr. Hugh L. Dryden (ex officio).
Mr. Floyd L. Thompson, NACA Langley Aeronautical Laboratory.
Mr. Carlton Bioletti, NACA Ames Aeronautical Laboratory.
Mr. Paul S. Baker, Chance Vought Aircraft, United Aircraft Corp.
Mr. Otto E. Kirchner, American Airlines, Inc.
Mr. L. E. Root, Rand Corp.

Mr. George S. Schairer, Boeing Airplane Co.
 Dr. William R. Sears, Cornell University.
 Dr. Theodore von Kármán, California Institute of Technology.
 Mr. Fred E. Weick, Texas Agricultural & Mechanical College.

Special Subcommittee on Research Problems of Transonic Aircraft Design

Mr. L. E. Root, Rand Corp., Chairman.
 Mr. P. C. Emmons, Bell Aircraft Corp.
 Mr. Benedict Cohn, Boeing Airplane Co.
 Mr. Frank W. Davis, Consolidated Vultee Aircraft Corp.
 Mr. L. B. Rumph, Curtiss-Wright Corp.
 Mr. Harold Luskin, Douglas Aircraft Co., Inc.
 Mr. R. B. Smith, Douglas Aircraft Co., Inc.
 Mr. Charles Tilgner, Jr., Grumman Aircraft Engineering Corp.
 Mr. Phillip Coleman, Lockheed Aircraft Corp.
 Mr. George S. Trimble, The Glenn L. Martin Co.
 Mr. Vernon Outman, McDonnell Aircraft Corp.
 Mr. H. A. Storms, North American Aviation, Inc.
 Mr. Irving Ashkenas, Northrop Aircraft, Inc.
 Mr. C. E. Pappas, Republic Aviation Corp.
 Mr. William Schoolfield, Chance Vought Aircraft Division United Aircraft Corp.
 Capt. Walter S. Diehl, U. S. N., Bureau of Aeronautics.
 Col. J. A. Gibbs, U. S. A. F., Air Matériel Command.
 Mr. R. R. Gilruth, NACA Langley Aeronautical Laboratory.
 Mr. Thomas A. Harris, NACA Langley Aeronautical Laboratory.
 Mr. Robert M. Crane, NACA Ames Aeronautical Laboratory.

Subcommittee on High-Speed Aerodynamics

Mr. Russell G. Robinson, National Advisory Committee for Aeronautics, 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, Ballistic Research Laboratory, Aberdeen Proving Ground.
 Mr. William H. Miller, Bureau of Aeronautics, Department of the Navy.
 Mr. Oscar Seldman, Bureau of Aeronautics, Department of the Navy.
 Mr. George V. Schliestett, Office of Naval Research, Department of the Navy.
 Dr. R. J. Seeger, Naval Ordnance Laboratory.
 Dr. Hugh L. Dryden (ex officio).
 Mr. John Stack, NACA Langley Aeronautical Laboratory.
 Mr. H. Julian Allen, NACA Ames Aeronautical Laboratory.
 Mr. Abe Silverstein, NACA Lewis Flight Propulsion Laboratory.
 Dr. William Bollay, North American Aviation, Inc.
 Dr. Francis H. Clauser, Johns Hopkins University.
 Mr. Harold Luskin, Douglas Aircraft Co., Inc.
 Mr. Mark V. Morkovin, University of Michigan.
 Mr. C. E. Pappas, Republic Aviation Corp.
 Mr. Allen E. Puckett, California Institute of Technology.

Subcommittee on Stability and Control

Capt. Walter S. Diehl, U. S. N., Bureau of Aeronautics, Chairman.
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Part III

FINANCIAL REPORT

Appropriations for 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 Aeronautical Laboratory.....	6,452,350
Ames Aeronautical Laboratory.....	193,700
Lewis Flight Propulsion Laboratory.....	3,282,950
Total appropriations.....	43,449,000

In addition contract authority for construction and equipment of laboratory facilities was provided in the amount of \$2,143,000.

Obligations incurred during the fiscal year 1948 are listed below. The figures shown for salaries and expenses include the costs of personal services, travel, transportation, communication, utility services, contractual services, supplies and equipment, and tort claims.

Salaries and expenses:	
Headquarters Office, Washington, D. C.....	\$652,223
Langley Aeronautical Laboratory.....	13,652,187
Ames Aeronautical Laboratory.....	5,124,140
Lewis Flight Propulsion Laboratory.....	12,753,433
Research Contracts—educational institutions.....	597,755
Transfer to National Bureau of Standards.....	129,884
Printing and binding, all activities.....	79,987
Construction and equipment of laboratory facilities:	
Langley Aeronautical Laboratory.....	6,205,660
Ames Aeronautical Laboratory.....	193,657
Lewis Flight Propulsion Laboratory.....	3,034,923
Total obligations.....	42,423,849
Unobligated balances:	
Salaries and expenses.....	580,378
Printing and binding.....	13
Construction and equipment.....	444,760
Total appropriations.....	43,449,000

Obligations incurred under the contract authority for construction and equipment of laboratory facilities were incurred as follows:

Langley Aeronautical Laboratory.....	\$295,456
Ames Aeronautical Laboratory.....	69,936
Lewis Flight Propulsion Laboratory.....	1,570,889
Total obligations.....	1,936,281
Unobligated balance.....	206,719
Total authorization.....	2,143,000

Appropriations for the fiscal year 1949.—Funds in the following amounts were appropriated for the Committee for the fiscal year 1949 in the Independent Offices Appropriation Act, 1949, approved April 20, 1948:

Salaries and expenses.....	\$37,810,000
Printing and binding.....	95,000
Construction and equipment of laboratory facilities:	
Langley Aeronautical Laboratory.....	4,188,650
Ames Aeronautical Laboratory.....	370,300
Lewis Flight Propulsion Laboratory.....	5,441,050
Total appropriations.....	47,905,000

The amount of \$10,000,000 appropriated for construction and equipment of laboratory facilities includes \$2,143,000 for liquidation of the obligations incurred under the contract authority provided in the appropriation for the fiscal year 1948. The remainder, \$7,857,000, will be available during the fiscal years 1949 and 1950. Additional contract authority for construction and equipment of laboratory facilities in the amount of \$18,200,000 was provided in the 1949 act, for obligation during the fiscal years 1949 and 1950.