

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

1950

INCLUDING TECHNICAL REPORTS
NOS. 951 to 1002



UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1951

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Letter of Transmittal

To the Congress of the United States:

In compliance with the provisions of the act of March 3, 1915, as amended, establishing the National Advisory Committee for Aeronautics, I transmit herewith the Thirty-sixth Annual Report of the Committee covering the fiscal year 1950.

HARRY S. TRUMAN.

THE WHITE HOUSE,
JANUARY 22, 1951.

Letter of Submittal

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Washington, D. C., November 13, 1950.

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-sixth Annual Report of the National Advisory Committee for Aeronautics covering the fiscal year 1950.

The Committee's research programs during the past year were directed primarily to the acquisition of scientific data to enable the United States to accelerate exploitation of the possibilities of supersonic flight, and to extend generally the frontiers of aeronautical knowledge. Superior air power in possession of the United States is probably the most effective deterrent to widespread aggression.

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 from 12 to 15 by act approved March 2, 1929, and to 17 by act approved May 25, 1948. The members are appointed by the President, and serve as such without compensation.

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

JOHN W. CROWLEY, JR., B. S., *Associate Director for 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

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AERODYNAMICS

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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

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SEPTEMBER 1, 1950



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 CORNELL UNIVERSITY

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

WASHINGTON, D. C., *October 19, 1950.*

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 its thirty-sixth annual report for the fiscal year 1950.

For the third time in its history the Committee is conducting its program of scientific research in an atmosphere of world crisis. When the NACA was established in 1915, the airplane had just begun to be recognized as a military instrument. In World War II, the airplane was used so effectively as to alter previous concepts of warfare, and to demonstrate the necessity for supremacy in the air.

There is no more effective deterrent to widespread aggression than superior air power in being. The United States is spending billions to strengthen its air power. It is mandatory that the aircraft procured be superior in performance and military effectiveness. To do otherwise would not provide the maximum national security for the large sums of public funds expended. The qualitative superiority of our air weapons is dependent upon the degree to which we exploit scientific and technological talent. Here the United States has no monopoly.

In manpower and money, the research and development necessary to insure maximum performance is small relative to the total effort. We are in a sustained international contest with stakes so great we dare not lose.

The world now has the means and the incentive for supersonic flight. The challenge to American science and industry is to maintain our present lead in this race. We can succeed only by the vigorous prosecution of research on the critical problems requiring solution before we can exploit the military advantages of supersonic speed.

The immediate need is for reliable information concerning aerodynamic forces in the transonic range, where the laws governing subsonic and supersonic speed interplay in a manner now imperfectly understood. In our high-speed research airplane program, the military

services, the aircraft industry, and the Committee, participating as a development team, are making substantive progress.

Research suggests that further investigation of certain basic problems should give opportunities to improve both airplanes and missiles operating in all speed ranges. These problems lie in the fields of aerodynamic efficiency, stability, control, maneuverability, aeroelasticity, aerodynamic heating, and many others. For example, in the field of stability and control is the problem of matching the dynamics of the airplane with the capacities of human and automatic pilots, and of matching the aerodynamic characteristics of missiles with those of automatic control and guidance systems. Much precise information of this kind is required for new designs.

The speed, range, and load-carrying capacity of both military and civil aircraft are closely dependent upon the performance of the propulsion system. The achievement of practical supersonic flight is made possible by the postwar revolution in aircraft power plants based on jet propulsion. The new power plants require great improvement to realize the aircraft performance now aerodynamically possible. Vigorous research is necessary to improve fuel economy, reduce specific weight and critical material content, improve ignition and combustion at high altitude and low temperatures, increase operating temperatures, and improve automatic controls and augmentation on all types of power plants.

Construction problems now being studied include aeroelasticity, aerodynamic and impact loads, structural efficiency, vibration and flutter, and new materials. Operational problems such as prevention of ice formation, fire prevention, effects of atmospheric turbulence, and means for emergency escape from high-speed aircraft, are under active investigation, as are problems peculiar to rotary-wing aircraft and to seaplanes.

Research to improve military aircraft is ultimately applied to civil aviation when proved to be thoroughly practical by experience, but there are differences in emphasis, because safety, comfort, and economy are relatively more important in civil airplanes. Special

research is required on these subjects. Investigations are also in progress seeking to improve the safety and utility of light airplanes, such as might be privately owned and operated.

During World War II, the Committee curtailed its programs of basic research in order to concentrate on applying available scientific knowledge to the immediate improvement of aircraft scheduled for war production. This course was mandatory in view of the limited manpower and research facilities then available, but it was at the expense of the advancement of knowledge of the scientific problems of flight. Although some adjustment is required in the event of emergencies, it must not occur again to the degree effected during World War II. To do so will undermine the research foundation upon which our future development program must be built. This is of even greater importance today than in prior years due to the decreased flow of fundamental research from European scientists and laboratories, and the probable extended prolongation of international tensions.

To make large supersonic wind tunnels available for the development problems of the aircraft industry, a Unitary Wind Tunnel Plan was jointly drafted in 1946 by the military services and the Committee. This plan was designed to provide adequate postwar facilities, to eliminate duplication of effort, and to keep down over-all cost. In 1949, the plan was authorized by law, and in 1950 funds were appropriated for construction of some of the wind tunnels authorized. An important part of the plan, not yet implemented, is the University Wind Tunnel Program which is designed to insure a continuing supply of young men competent to participate in research programs utilizing facilities of the Committee, of industry, and of other laboratories.

Intensive cultivation of some areas of research has continued to yield specific data of immediate help to designers. Frontiers of knowledge have been advanced in other areas by exploratory research potentially important to future air operations, civil and military.

In general, difficult research problems are attacked from several sides. Wind tunnel experiments, power plant tests, mathematical-physical analyses, flight research and sometimes unpredictable inventions may all be applied to a single problem. Such a problem may arise from current operational experience or it may stand as a bar to desired progress toward better performance. Often the real technical problem is so dimly perceived as to require exploratory research for its clear formulation before a definite program of investigation and experiment can be planned with any hope of useful results.

Effective discharge of the Committee's statutory responsibility "to supervise and direct the scientific study of the problems of flight with a view to their practical solution" is dependent on some seven thousand men and women who comprise the Civil Service staff of our laboratories. The year's work has gone well because the Committee has had their effective support of its policies and directives. The Committee takes satisfaction from this continued evidence of good leadership and high morale.

Parts I, II, and III of this annual report present a résumé of the scientific activities of the Committee, a description of the Committee's organization and membership, and the financial report for the fiscal year 1950.

Respectfully submitted.

JEROME C. HUNSAKER,
Chairman.

Part I—TECHNICAL ACTIVITIES

RESEARCH ORGANIZATION AND PROCEDURES

COMMITTEE LABORATORIES

Research of the National Advisory Committee for Aeronautics is conducted largely 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 speed ranges. At Muroc Lake, Calif., is located the NACA High-Speed Flight Research Station for research on transonic and supersonic airplanes in flight. The total number of employees, both technical and administrative, at these five stations and headquarters in Washington was 7,286 at the end of the fiscal year 1950.

TECHNICAL COMMITTEES AND RESEARCH COORDINATION

In carrying out its function of coordinating aeronautical research the Committee is assisted by a group of technical committees and subcommittees. The members of these committees are chosen for their particular knowledge in a specific field of aeronautics. They are selected from other Government agencies concerned with aviation including the Department of Defense, from the aircraft and air transport industries, and from scientific and educational institutions. These committees provide for the interchange of ideas and prevention of research duplication except where parallel efforts are desired. There are four technical 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 Operating Problems.

Each committee is supported by three to eight technical subcommittees.

In addition to the four technical committees, there is an Industry Consulting Committee established to assist the main Committee in formulation of general policy. Membership of this Committee as well as the technical committees and subcommittees is listed in Part II of this report.

Research coordination is further effected through discussions between Committee technical personnel and the research staffs of the aviation industry, educational and scientific organizations, and other aeronautical agencies. The Research Coordination Office is assisted by a west coast representative who maintains close contact with the aeronautical research and engineering staffs of that geographical area.

RESEARCH SPONSORED IN SCIENTIFIC AND EDUCATIONAL INSTITUTIONS

Since 1916 an important segment of the NACA research program has been the research projects that it has sponsored outside its own facilities. The NACA has continued to utilize the vast research talents and facilities of universities, other Government research agencies, and various nonprofit scientific institutions to find solutions for aeronautical problems by sponsoring research projects at the various organizations. By thus using the reservoir of available specialized talent in mathematics, physics, and engineering for research on important aeronautical problems, it is possible to complement the research carried on in NACA laboratories. The NACA prefers to have interested groups submit a proposal of their own choosing for aeronautical research. Such a proposal is thoroughly reviewed by the NACA, and if the review indicates that an original attack upon an important problem is to be undertaken by competent personnel at a reasonable cost to the Government, a research contract may be negotiated. At the completion of a contract, the contractor submits a report which, if suitable, is reviewed and edited for publication and then given distribution to insure maximum usefulness and availability of the information. Not only does this program provide additional research information but also it has the desirable advantage of training university students in practical research techniques.

During the fiscal year of 1950, the NACA has sponsored projects in many sections of the field of aeronautics. Theoretical and experimental investigations of compressible flows at subsonic, transonic, supersonic, and hypersonic velocities are being sponsored by the NACA together with projects on helicopter research, boundary-layer shock-wave interaction and other

boundary-layer flow investigations, the nature of pure turbulence, and research techniques in low-density flows. The investigation of the thermal and physical properties of gases over a wide range of pressures and temperatures is continuing, as are the investigations of personal-aircraft operations, the projects on heat transfer, and the investigations of icing-rate meters and strain gages for aerodynamic research. Many structural problems such as column buckling, design of pressurized cabins, theoretical solution of stress in rectangular plates, biaxial stresses in aluminum alloys, the effect of concentrated mass on the flutter characteristics of an airplane, characteristics of stiffened sheets with compound curvature, properties of stiffened web beams, the strength of honeycomb cores for sandwich construction, side loading of sandwich sheets, the effect of temperature on heat-resisting adhesives, and others are being investigated under NACA sponsorship. Problems involving aircraft structural materials—their physical properties, uses, and mechanisms of failure—are under investigation at various institutions. Work is continuing under NACA sponsorship on the development of ceramic coatings for high-temperature-resisting materials, on development of high-temperature alloys for turbine blades, and on various bearings and lubricants. These various research projects are described in somewhat greater detail under the headings of the committees and subcommittees concerned with each project.

During this year, the NACA has sponsored new research on fundamental aeronautical problems at the National Bureau of Standards, Armour Research Institute, Brown University, Battelle Memorial Institute, Polytechnic Institute of Brooklyn, California Institute of Technology, University of California, Carnegie Institute of Technology, University of Cincinnati, Cornell University, University of Florida, Forest Products Laboratory, Georgia Institute of Technology, Harvard University, Johns Hopkins University, Illinois Institute of Technology, University of Illinois, Massachusetts Institute of Technology, University of Michigan, University of Minnesota, Mount Washington Observatory, New York University, University of Notre Dame, Pennsylvania State College, Princeton University, Purdue University, Stanford University, Syracuse University, Agricultural and Mechanical College of Texas, University of Virginia, and University of Washington.

RESEARCH INFORMATION

Research results obtained in the Committee's laboratories and through research contracts are distributed in the form of Committee publications. Formal Reports,

printed by the Government Printing Office, contain unclassified information and are available to the general public from the Superintendent of Documents. Technical Notes, released by the Committee in limited numbers, also contain unclassified research results of a more or less interim nature and are distributed to interested organizations throughout the country. Frequently, research results which will ultimately be published in Report form are issued initially as Technical Notes in the interest of speedy dissemination of data to American technical people and organizations. Translations of foreign material are issued in the form of Technical Memorandums.

In addition to unclassified publications the Committee prepares a large number of reports containing classified research information. For reasons of national security, these reports are controlled in their circulation. From time to time the classified reports are examined to determine whether it is in the national interest to declassify them. If it is found desirable to declassify the reports, they may be published as unclassified papers.

Another important means of transmitting quickly and efficiently the latest information in a particular field of research directly to designers and engineers working in that field is the holding of technical conferences from time to time at an appropriate NACA laboratory. Several conferences of this nature were held during the past year.

The Office of Aeronautical Intelligence was established in 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 Defense, aircraft manufacturers, educational institutions, and other interested people. 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.

AERONAUTICAL INVENTIONS

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 an 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 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.

* * * * *

The following detailed summary of research, completed during the fiscal year 1950, is organized to reflect the areas of research over which each technical committee and related subcommittee has cognizance.

AERODYNAMIC RESEARCH

Experimental flights with piloted aircraft at transonic and supersonic speeds have been made with increased frequency during the past year. While these flights to low-supersonic speeds are possible for short periods of time only, and with certain other limitations, it has been clearly demonstrated that aircraft operations will be conducted throughout the entire transonic range where previously it was considered that such operation was only a possibility. Information is becoming available to permit the development of airplanes capable of further penetration of the transonic and low-supersonic speed ranges with fewer operational limitations. With continued emphasis on transonic research, large as well as small military airplanes may be expected to be developed for efficient operation through the transonic speed range.

It is most important to recognize, however, that the limited successes already realized through intense research on transonic phenomena have served to point up effectively many detailed problems which remain to be solved by continued research.

The scope of the detailed problems requiring further investigation is extremely broad and includes all phases of transonic and supersonic stability, control, maneuverability, performance, unsteady air flows, and a number of other difficult problems. These problems are similar in nature to those studied in the development of subsonic aircraft, but are considerably more difficult because of the inherent complexities of transonic air flows. Since theoretical studies of the physical phenomena of transonic air flows have been seriously hampered by the general inability of mathematics to express completely the motion of the air as it concurrently obeys the different laws governing subsonic and supersonic flows, it is

necessary to rely to a very large degree on experimental studies.

The concerted research effort on transonic and supersonic phenomena is complemented by studies of related problems at low speeds such as landing and take-off of the new and unconventional high-speed configurations. It is necessary likewise to continue subsonic research to assist in achieving improvement in the performance of more conventional airplanes and of helicopters and seaplanes. Fundamental research on very high supersonic or hypersonic air flows and the development and improvement of highly specialized research techniques and equipment are also required to provide a sound basis for future aeronautical progress.

The NACA is aided in the review of the aerodynamic research activities of the Committee's laboratories and the integration of research programs in this broad area of work by the Committee on Aerodynamics and its subcommittees. Specialized consideration is given to research programs and accomplishments in the related fields of aerodynamics by the Subcommittees on Fluid Mechanics, High-Speed Aerodynamics, Stability and Control, Internal Flow, Propellers for Aircraft, Helicopters, and Seaplanes, and the Special Subcommittee on the Upper Atmosphere.

The practice of holding technical conferences with representatives of the military services and the aircraft industry was continued during the past fiscal year. A technical conference on aerodynamic problems of transonic airplane design, propellers, and research airplanes was held at the Langley Laboratory in the fall of 1949. Another technical conference on supersonic aerodynamics was held early in 1950 at the Ames Laboratory.

In the sections which follow, a description is given of some of the Committee's recent work in aerodynamics.

COMMITTEE ON AERODYNAMICS

Airfoils

As an aid in the selection of wing sections for small

personal types of airplanes, the two-dimensional aerodynamic characteristics of 15 NACA airfoil sections in

both smooth- and rough-surface conditions were determined at relatively low Reynolds numbers in the Langley two-dimensional low-turbulence tunnel (Technical Note 1945). Ten airfoils of this group were NACA 6-series sections varying in thickness ratio, design lift coefficient, and position of minimum pressure. The other five were NACA 4- and 5-digit sections. A number of the airfoils were tested with and without a split flap. An interesting result of this investigation was that although the 6-series airfoils with smooth surfaces have lower drags than conventional airfoils at high Reynolds numbers the difference disappears at low Reynolds numbers.

In order to evaluate the effects of the basic chordwise distribution of thickness on the stalling characteristics of thin, cambered airfoils, an investigation at low speed was undertaken of several two-dimensional airfoils in one of the Ames 7- by 10-foot wind tunnels. The airfoil sections were cambered for design lift coefficients of 0.3 and 0.8, and the basic thickness distributions investigated were the NACA 0010 and 64A010. The results show that in the Reynolds number range of these tests the NACA four-digit-series sections developed greater maximum lift both with and without split flap than the corresponding NACA 64A-series sections for all conditions tested. For the sections cambered for an ideal lift coefficient of 0.3, the stall was primarily due to separation of flow from the leading edge; whereas for the sections cambered for an ideal lift coefficient of 0.8, the stall was the result of a combination of leading-edge and trailing-edge separation.

Some of the effects on airfoil characteristics of variation of maximum thickness have been determined at subsonic speeds in the Ames 1- by 3½-foot wind tunnel. The airfoils consisted of symmetrical NACA four-digit-series sections, ranging in thickness from 4- to 10-percent chord. The results showed progressive improvement in the aerodynamic characteristics of the airfoils at high subsonic Mach numbers as the maximum thickness-chord ratio was reduced.

High-Lift Devices

In the design of supersonic aircraft, consideration is being given to the use of thin airfoils having a sharp leading edge. Such airfoils exhibit favorable characteristics at supersonic speeds; however, their characteristics at low speeds are such that unless modified, high speeds will be required for landing. Several wind-tunnel studies have therefore been made of sharp-edged airfoils equipped with high-lift devices designed to improve the low-speed performance of such airfoils.

Technical Notes 1934, 2018, and 2172 present the results of one such study in the Ames 7- by 10-foot wind tunnel. These results indicated that the maximum

lift characteristics of a sharp-edged, modified double-wedge airfoil may be considerably improved by the use of a flap on the leading edge of the airfoil. Tuft studies, made of the airfoil both plain and with the nose flaps installed, led to a more complete understanding of the action of the nose flaps in improving the stalling characteristics of the airfoil.

A similar study was made in the Langley two-dimensional, low-turbulence tunnel using a two-dimensional sharp-edged biconvex airfoil equipped with various leading-edge slats and drooped-nose-flap configurations and a plain trailing-edge flap. This study showed that the maximum lift of such a wing may be considerably increased by the installation of a properly positioned leading-edge device.

The large pitching-moment increments associated with deflection of certain types of trailing-edge high-lift devices have made it difficult to obtain trim during landing or take-off. As a guide in the selection of high-lift devices, therefore, a survey was made of available two-dimensional data on trim changes near maximum lift resulting from the deflection of various types of leading- and trailing-edge high-lift devices. This survey indicates that the use of extensible leading-edge devices with nonextensible or fixed-hinge type trailing-edge devices seems to offer the best combination of high lift and low pitching-moment increments.

Wings

The incorporation of large amounts of sweepback into wing plan forms to improve their high-speed performance introduces large stability changes at low speeds. A study has been made in one of the Ames 7- by 10-foot wind tunnels of the possibilities of improving the longitudinal stability of a 63° swept wing by the use of camber and twist. An uncambered and untwisted 63° sweptback wing showed a large change of stability at a relatively low lift coefficient because of flow separation from the leading edge of the tip portion. The introduction of camber and twist delayed the leading-edge separation to higher lift coefficients where large variations of stability resulted from excessive spanwise flow within the boundary layer which reduced the lift effectiveness of the tip portion.

Among the studies to improve the low-speed characteristics of high-speed wings is that made in the Ames 40- by 80-foot wind tunnel using a triangular wing of aspect ratio 2 having thin, NACA four-digit airfoil sections. The results obtained on this wing differed only slightly from those obtained on other low-aspect-ratio triangular wings having either thick subsonic-type or thin supersonic-type airfoil sections. At a reasonable angle of attack for landing, the lift coefficient was such that a high landing speed would be required. Also

the low lift-drag ratio indicated that power would be required for landing.

In an attempt to improve the low-speed characteristics of the wing, a combination of leading-edge and trailing-edge flaps was used to produce the effects of camber and twist. Significant increases in the lift coefficient for landing and the lift-drag ratio were obtained. Even with the improvements, it is doubtful, however, if landings without power could be made safely.

Since the characteristics of wing plan forms suitable for high-speed flight are likely to be greatly affected by Reynolds number, a knowledge of these effects is necessary to a full appreciation of the results of small-scale research on such wings. In order to evaluate these effects, a semispan model of a full-span triangular wing previously tested in the Ames 40- by 80-foot wind tunnel was tested in the Ames 7- by 10-foot wind tunnel. The results of the tests from both facilities were in good agreement.

Much of the work in the large-scale low-speed wind tunnels is directed toward understanding and improving the low-speed and stalling characteristics of high-speed wings. In the Langley two-dimensional low-turbulence pressure tunnel an investigation was made to determine the effect of sweep, taper ratio, and aspect ratio on the low-speed aerodynamic characteristics of nine semispan wings with and without split flaps through a large range of Reynolds numbers. The results indicated that increases in sweep angle increased the maximum lift coefficient of the plain wings but decreased the maximum lift coefficient of the wings with half-span split flaps. Reynolds number effects were most pronounced for the more highly sweptback wings at low to moderate lift coefficients.

The effect of variation in leading-edge and trailing-edge flap span on the longitudinal aerodynamic characteristics at low speed of two 45° sweptback wings of aspect ratios 5.1 and 6.0 has been determined in the Langley 19-foot pressure tunnel. Variation in the spanwise extent of split and double-slotted trailing-edge flaps was found to have an important effect on the stability at high angles of attack of the wings with leading-edge flaps. Trailing-edge flaps of greater than 0.5 semispan caused instability; whereas flaps of 0.3 semispan improved stability. A similar investigation in the Langley 19-foot pressure tunnel of the low-speed longitudinal characteristics of a 50° sweptback circular-arc wing of aspect ratio 2.84 has also been made. This investigation led to results similar to those obtained on the 45° sweptback wings.

An investigation was made in the Langley full-scale tunnel of the low-speed longitudinal characteristics of a wing-fuselage combination having a 47.5° sweptback

wing with various extensible leading-edge-flap and plain trailing-edge-flap arrangements. Satisfactory static longitudinal stability was obtained for all configurations employing extensible, partial-span, leading-edge flaps.

A study of the stalling characteristics of swept wings in the Langley full-scale tunnel showed that the separation vortex emanating from the apex of swept-back wings having sharp leading edges has considerable influence on the spanwise and chordwise pressure distributions. The vortex extends spanwise near the wing leading edge at low angles of attack and is gradually swept inboard with increasing angle of attack, with corresponding effects on the stability characteristics of the wings at low speeds. Deflecting a full-span drooped-nose flap on a wing swept back 47.5° was shown to increase the angle of attack at which the separation vortex was formed.

An investigation was conducted in the Langley 19-foot pressure tunnel of leading-edge chord extensions on two 50° sweptback wings with circular-arc and NACA 64-series airfoil sections. Several configurations varying in span, spanwise location, and chord of the leading-edge extensions were tested. The results of this investigation showed that short-span chord extensions are very effective in improving the longitudinal stability characteristics of wings with vortex-type flow.

A study in the Langley full-scale tunnel of a wing with leading-edge sweepback decreasing in two steps from 45° at the root to 20° at the tip indicated a large amount of static longitudinal stability near maximum lift except for configurations with full-span leading-edge flaps installed, for which case the stability was marginal. The lateral stability and aileron effectiveness measured on this wing were generally similar to results obtained on unswept wings. Surface pressures were also measured in order to determine the spanwise load distribution of the wing.

As part of a program to study the effects of adding nacelles to wings at both high- and low-subsonic speeds, a study has been made of the effect of nacelle location on the aerodynamic characteristics of a 35° swept wing at low speeds. The nacelle was mounted in several positions in relation to the wing-chord plane and at several span positions, and the interference effects on the maximum-lift and pitching-moment characteristics of the wing as well as the ram-pressure recovery for the nacelle were determined.

Boundary-Layer Investigations

The University of Michigan has made measurements by the hot-wire technique of the velocity profiles in the turbulent boundary layer on the upper surface of a 25°

sweptback semielliptical wing model. Pressure distributions were measured, and studies of the position of transition from smooth to turbulent flow by a camphor-evaporation technique were also made (Technical Note 1946).

In the Langley two-dimensional low-turbulence pressure tunnel, investigations of laminar boundary-layer control by continuous suction through a porous surface have been made in order to determine the effectiveness of this method at large Reynolds numbers (Technical Note 2112). Full-chord laminar flow was maintained on an NACA 64A010 airfoil up to a Reynolds number of approximately 20,000,000. At this Reynolds number, the combined wake and suction drag was about 38 percent of the drag of a smooth and faired NACA 64A010 airfoil without boundary-layer control.

Laminar boundary-layer control by suction through closely spaced spanwise slots as a means of extending the laminar boundary layer is also being studied in the same facility. In the initial phase of this investigation, described in Technical Note 1961, it was found that, for a relatively small expenditure of suction power, substantial increases in the extent of the laminar layer on a smooth airfoil could be obtained up to a free-stream Reynolds number of 7,000,000. These increases in the extent of the laminar layer could not be achieved at higher Reynolds numbers, however, because of unknown disturbances in the boundary layer which require further study.

An investigation was made in an effort to improve the maximum lift coefficient of an NACA 65₂-018 airfoil section by the use of suction through slots spaced so as to delay separation at the leading edge and trailing edge. The investigation, at a Reynolds number of 1,000,000, showed that both leading- and trailing-edge separation could be delayed by this method; however, the effectiveness of the narrow leading-edge slot was limited to a relatively small range of angle of attack because of the movement of the separation point.

A study of the relative effectiveness in increasing the maximum lift coefficient of an NACA 65₂-415 airfoil section by means of suction through a slot located at 60 percent chord together with a double-slotted flap and by means of suction through a slot on the upper surface of a plain flap was made at Reynolds numbers of 1,000,000 to 6,000,000 in the Langley two-dimensional low-turbulence tunnel. The investigation (Technical Note 2149) showed that for a given expenditure of suction power, the combination of the 60-percent-chord slot and double-slotted flap was the more effective in increasing the maximum lift coefficient.

The study of boundary-layer control by use of porous material at the leading edge of swept wings has been

continued at the Ames 40- by 80-foot wind tunnel. Results were obtained which allowed correlation with existing theories and which pointed the way toward extension of the theory to include sweep and three-dimensional effects.

An investigation of boundary-layer control by suction through leading-edge slots was conducted in the Langley full-scale tunnel on a wing-fuselage configuration having 47.5° sweepback. The results indicate that, with suction through leading-edge slots, it is possible to eliminate the longitudinal instability that occurs in the high lift range for the plain wing.

An analysis has been made to determine the effect on the landing characteristics of a liaison-type airplane of the increases in maximum lift coefficient that are possible with the use of boundary-layer control by suction. The analysis (Technical Note 2148) covered a wide range of airplane wing loading, horsepower, and aspect ratio. The results indicated that for a specified airplane maximum speed the total landing distance over a 50-foot-obstacle could be reduced from 25 to 40 percent by the use of boundary-layer control. Similar decreases in ground run and stalling speed were shown to be possible.

SUBCOMMITTEE ON FLUID MECHANICS

The solution of the problems of flight at all speeds requires continuous research into the mechanics of fluid motion for discovery of laws and principles and for guidance of applied research along fruitful paths. The NACA has continued to devote substantial effort to such basic research on a variety of aerodynamic problems.

Viscous Flows

Emphasis has continued to increase on the study of viscous-flow phenomena, particularly for the high-speed aerodynamics regime. Investigations were made during the past year to study the stability of laminar boundary layers. One investigation conducted at the Ames Laboratory involved determination of the effect of cooling on the transition from laminar to turbulent flow in the boundary layer on a 20° cone at supersonic speeds. The experimental results were in qualitative agreement with existing theory in indicating a delayed transition with increase in cooling. This work was reported in Technical Note 2131.

An analysis was made in Technical Note 1929 of the stability of the laminar boundary layer between parallel streams of an incompressible fluid. Calculations based on this analysis indicated that flow instability occurs at a much lower Reynolds number for the free boundary

layer between streams than for the boundary layer on a flat plate without pressure gradient.

An experimental investigation was conducted at the Lewis Laboratory involving the measurement of pressures and densities within the laminar boundary layer on a flat plate in a supersonic stream. The immediate purpose of this investigation, which was reported in Technical Note 2110, was to study the application of the two techniques, an interferometer and a pressure probe, to the measurement of boundary-layer characteristics. The presence of density gradients in the boundary layer required detailed analysis of corrections necessary to evaluate the interferometer data. With these corrections satisfactory agreement was found between results from pressure probes and interferograms.

A general integral form of the boundary-layer equation has been derived from the Prandtl partial differential boundary-layer equation. This derivation is reported in Technical Note 2158. The general integral equation obtained is valid for either laminar or turbulent incompressible boundary-layer flow and contains the Von Kármán momentum equation, the kinetic-energy equation, and the Loitsianskii equation as special cases. In an attempt to obtain a practical method for the calculation of the development of the turbulent boundary layer, use was made of the experimental finding that all the velocity profiles of the turbulent boundary layer form essentially a single-parameter family. The general equation is thereby changed to a simple one from which an equation for the space rate of change of the shape parameter of the turbulent boundary layer can be obtained. The present lack of precise knowledge concerning the surface shear and the distribution of the shearing stress across turbulent boundary layers prevents the attainment at this time of a thoroughly reliable method for calculating the behavior of turbulent boundary layers.

Technical Note 2045 presents an analysis based on empirical equations of the development of the turbulent boundary layer along plane surfaces with pressure gradient. Numerical tables were computed with the aid of this analysis from which rapid estimations can be made of turbulent boundary-layer development along surfaces such as the walls of supersonic nozzles and test sections.

An analysis was made and equations were developed at the Lewis Laboratory for the prediction of velocity distributions for fully developed turbulent flow in smooth tubes for both incompressible and compressible flow without heat transfer. Experimental velocity distributions were made in order to check the analysis and to determine values for the constants appearing in the equations. This work was reported in Technical Note 2138.

Compressible Flows

The formidable mathematical difficulties involved in the development of theory for the transonic speed regime makes necessary a many-sided attack. The problem of describing the flow about a simple sharp-edged airfoil at slightly supersonic Mach numbers for which a detached shock appears in the flow ahead of the airfoil was investigated at the Ames Laboratory during the past year. By the use of the hodograph method together with suitable techniques of numerical analysis, it was found possible to calculate the flow field forward of a finite wedge. These results were applied to the determination of pressure distribution and drag of a double-wedge airfoil at zero lift for a range of flight speeds just above Mach number 1.

In another study, presented in Technical Note 2130, an analysis carried out within the framework of the Von Karman transonic similarity theory was made of the flow phenomena in the vicinity of thin airfoils at transonic speeds. The analysis, which was based on the integral form of the continuity equation, resulted in fairly simple methods for the approximate calculation of the velocity distribution, shock location, and pressure drag for symmetrical airfoils in the transonic speed range.

In a theoretical investigation carried out at the Langley Laboratory, the particular integrals of the second-order and third-order Prandtl-Busemann iteration equations for the flow of a compressible fluid have been obtained. The assumption was made that the Prandtl-Glauert solution of the linearized or first-order iteration equation for two-dimensional subsonic flow is known. The forms of the particular integrals derived for subsonic flow are readily adapted to supersonic flows. This work was reported in Technical Note 2159.

Theoretical investigations of compressible flows by educational institutions under contract to the NACA have been continued. Several such investigations have been carried out by Syracuse University. From one of these studies a transformation theory of systems of partial differential equations was developed. This transformation theory allows construction of classes of pressure-density relations depending on any number of parameters for which the equations governing the flow can be transformed into essentially simpler form, namely, into the Cauchy-Riemann equations in the subsonic region, into the system corresponding to the wave equation in the supersonic case, and finally into the form corresponding to the Tricomi equation in the transonic region. This theoretical development is presented in Technical Note 2065.

A method of computing velocity and pressure distributions along wing profiles, under the assumption of

the simplified density-speed relation outlined in Technical Note 1006, was extended in Technical Note 2056 to the case of a nonsymmetrical profile and a flow with circulation. The shape of the profile, the speed of the undisturbed flow, and a parameter determining the angle of attack may be prescribed. The problem is reduced to a nonlinear integral equation which can be solved numerically by an iteration method.

In a related study, a simple computational method was developed for obtaining circulatory flows around given airfoils to a high degree of accuracy for flows satisfying the linear pressure-density equation of state. The method, which is presented in Technical Note 2057, depends not on an integral equation but on a transformation from the hodograph to the physical plane involving the determination of an arbitrary analytical function.

In a fourth study carried out at Syracuse University, the results of which have been reported in Technical Note 2058, a method for continuation of a gas flow across the sonic line was developed. Simple sufficient conditions were given under which a two-dimensional study of the compressible flow can be continued analytically across the line of Mach number 1. Methods for the numerical computation of the flow were described.

Experimental measurements have been made in the Langley Laboratory annular transonic tunnel of the pressures on several thin airfoils at Mach numbers near 1.0. Comparisons between the measured pressure distribution and that predicted by the method of Guderley were made for a double-wedge airfoil at a Mach number of 1.0. For other airfoils elementary analyses were made comparing the measured pressures in the supersonic region on the airfoil with those calculated assuming simple Prandtl-Meyer flow.

A simple method has been developed at the Lewis Laboratory for estimating the location and form of detached shock waves ahead of blunt bodies at supersonic speeds. This method, the development of which was reported in Technical Note 1921, was also used to estimate the drag of bodies with detached shock waves and to estimate the mass flow and drag of nose inlets at supersonic speeds. The method was applied in Technical Note 2115 to the estimation of wave drag and pressure distribution for a variety of open-nosed bodies of revolution at several supersonic Mach numbers.

A newer method for calculating the flow in the vicinity of open-nosed bodies at supersonic speeds was reported in Technical Note 2116. This method provides a simple procedure for determining the pressure distribution over the forward portions of open-nosed bodies, and in addition yields formulas for determining the variation in angle and strength of the initial shock wave with distance ahead of the body.

Experimental measurements were made at the Langley Laboratory of the detached shock waves in front of cones and spheres at Mach numbers from 1.17 to 1.81. The experimental data obtained with an interferometer were compared with theoretical predictions. The data were also correlated to obtain equations that describe the shape of the shock waves. This work was reported in Technical Note 2000.

The development of theoretical methods for handling unsteady flows involving moving shocks and other discontinuities was discussed in the Thirty-fifth Annual Report. During the past year, the theory of such intermittent flows and of such intermittent flow devices as shock tubes has been extended at the Langley Laboratory to include the effects of fluid viscosity. Marked reductions in the calculated pressure ratio across the reflected wave are shown to result from the inclusion of wall friction terms in the theory. Calculated values of the pressure ratio with the friction terms included are in closer agreement with experiment. Because of the similar nature of the attenuation of the hydraulic jump traveling in a channel, the theoretical method has also been developed for this phenomenon. These theoretical developments are reported in Technical Note 1942.

Gas Dynamics

In the Thirty-fifth Annual Report, aerodynamic research at very low densities was discussed, and some of the problems of research technique were mentioned. It was noted that the phenomenon of afterglow had shown promise as a method for visualizing very low density flows. Questions have been raised, however, as to whether excitation of the gas molecules had an important effect on the aerodynamic phenomena being observed. To answer these questions a study was made of the viscosity and the rate of heat release of the nitrogen gas which has been employed extensively in afterglow experiments. It was found from this study that the viscosity did not vary measurably as the result of the excitation. The heat release due to the decay of the afterglow was rather appreciable, but occurred at such a relatively slow rate that no important aerodynamic effects would be expected to result in the flow regions of interest.

In spite of difficulties of technique, research on certain aerodynamic phenomena has been successfully carried out utilizing the low-density equipment available. The drag and temperature-rise characteristics of an unheated transverse cylinder in a high-speed free-molecular flow field have been measured in the Ames low-density wind tunnel. The temperature of the cylinder exceeded the stagnation temperature of the stream as predicted by a theoretical study. The measured drag of the cylinder agreed well with predicted theoretical

values. In these experiments the Knudsen number (ratio of mean free molecular path to cylinder radius) varied from 4 to 18.5; Mach number from 0.55 to 2.75; and Reynolds number from 0.005 to 0.95. The tests have served to indicate that available theory for free-molecular flow may be adequate for predicting aerodynamic forces on bodies flying at very high altitudes.

The aerodynamics of high-supersonic-Mach-number or hypersonic flows are being studied at the three NACA laboratories. Some of this research is discussed in other parts of this annual report. At the Langley Laboratory a mechanical analogy for hypersonic low-density flow was developed which may prove useful in the study of aerodynamic phenomena at Mach number of 5 and greater. In essence, the analogy involves the use of a large number of very small glass beads, which are approximately analogous to gas molecules of certain types. The "molecules" are accelerated by the force of gravity and allowed to impinge on the model. The resulting flow pattern may be observed visually or photographed with simple techniques. The theory of the analogy has been derived and some of the limitations of the analogy have been formulated.

Aerodynamic Heating and Heat Transfer

The knowledge of aerodynamic heating and heat-transfer phenomena has become of increasing importance as airplane and missile flight speeds have increased into the supersonic region. An analytical study has been made at the Langley Laboratory of the aerodynamic heating problem at high supersonic speeds for two-dimensional flows with laminar boundary layers. As a result of this analysis, it was shown that, if a laminar boundary layer can be maintained in the presence of the injection of fluid into the boundary layer, the aerodynamic heating can be reduced substantially by the injection of a small amount of coolant through a porous surface. The coolant injection acts in two ways to decrease aerodynamic heating: First and most important, the boundary-layer velocity profile is altered in such a manner that the rate at which heat is conducted to the surface is reduced; and second, the coolant absorbs an amount of heat which is a function of the difference in temperature between the surface and the coolant. The analysis, which is reported in Technical Note 1987, includes calculations of the cooling requirements and the equilibrium surface temperatures for flat plates and for flat porous surfaces with several rates of fluid injection at Mach numbers from 5 to 15 and at altitudes from sea level to 200,000 feet.

Experimental data have been obtained at the Ames Laboratory on the temperature recovery factor for the cases of laminar, transitional, and turbulent flow on a flat plate at a Mach number of 2.4. The experiments,

reported in Technical Note 2077, were conducted for a range of Reynolds numbers of 235,000 to 6,750,000. The recovery factor for a laminar boundary layer was found to be 0.881. The corresponding value for a fully developed turbulent boundary layer following natural transition varied from 0.897 to 0.884 along the plate.

In another investigation at the Ames Laboratory, reported in Technical Note 1975, the temperature recovery factors for a body of revolution were measured at Mach numbers of 1.5 and 2.0. The recovery factor was found to be the same at both Mach numbers and was independent of body shape. The theoretical values of recovery factor—that is, the square root of the Prandtl number for laminar boundary layers and the cube root of the Prandtl number for turbulent boundary layers—were found to be in good agreement with experimental values.

Heat-transfer measurements were made in the Ames Laboratory 1- by 3-foot supersonic tunnel at a Mach number of 2 on a cooled 20° cone with a laminar boundary layer. These results were reported in Technical Note 2087. It was found that, although the uniform-temperature test region on the cone was preceded by an abrupt change in surface temperature, the experimental results and the theory for uniform surface temperature were in agreement over the rear 60 percent of the test region. These results were also in agreement with data previously obtained on a heated model. An extension of this work to the case of a parabolic body of revolution to determine the magnitude of the effects of the body shape and of longitudinal pressure gradients was reported in Technical Note 2148. Local rates of heat transfer were measured at Mach numbers of 1.5 and 2, and the results indicated that because of compensating effects the heat-transfer characteristics of the test body can be predicted by employing the theoretical relationships normally used for conical bodies.

Research Equipment and Techniques

The usefulness of the rocket technique for aerodynamic investigations at high speeds has been extended during the past year by the development of a number of new instruments. One new instrument with an extremely low time constant is used for measurement of missile skin temperature under rapidly changing high-speed flight conditions.

SUBCOMMITTEE ON HIGH-SPEED AERODYNAMICS

Previous research has pointed broadly to types of airplane and missile configurations which would be expected to fly well and efficiently at transonic and supersonic speeds. Research has continued an attempt

to define more precisely the most efficient configurations of the major aircraft components and their combinations to develop analytical methods and obtain systematic experimental information for use in the design of high-speed aircraft, and to explore new ideas and methods for future reductions in drag and increase in lift. With these aims research has been conducted over a wide range of speeds in wind tunnel and flight on wings of various types, fuselages, wing-wing and wing-body combinations, and on complete models of generalized and specific airplanes and missiles.

Airfoils and Wings at Transonic Speeds

Extensive experimental studies of airfoil sections have been made at high-subsonic speeds in the Langley rectangular high-speed tunnel and the Ames 1- by 3½-foot tunnel. The effects on the airfoil aerodynamic characteristics of variations in section thickness, chordwise location of the maximum thickness, leading-edge radius, and amount and type of camber have been determined. Some of the results obtained are included in Technical Note 2096.

A new basis for the design of airfoil sections having favorable drag characteristics at supercritical speeds has been proposed. The procedure consists essentially in determining the shape of the airfoil section which at the design lift has a minimum local velocity at the airfoil crest (the highest point on the airfoil surface). An application of this procedure to the design of cambered airfoil sections has been made.

Aerodynamic and structural demands in the current designs of missiles and airplanes have turned attention to low-aspect-ratio wings. The lifting-line theory used in the past for analysis of wings of relatively high-aspect ratio has been modified to produce a wing and wing-body theory applicable to the case of low-aspect-ratio wings. There are indications that the theory will provide a good first approximation to the aerodynamic forces in the transonic speed range. One investigation reported in Technical Note 1992 presented spanwise and chordwise load distribution, lift, and induced drag for a family of low-aspect-ratio plan forms.

An extensive investigation has been conducted at the Langley Laboratory using the transonic-bump technique to determine the transonic aerodynamic characteristics of a series of wings having NACA 65A-series airfoil sections. Wing variables investigated included a range of sweep angle, aspect ratio, taper ratio, and thickness.

Wings having the same configuration as some of those included in the transonic-bump study mentioned in the preceding paragraph have been investigated in flight at large Reynolds numbers using the rocket-propelled-model method. The objective of this investigation was

to obtain information regarding the drag at zero lift at large scale.

Many sweptback wings are susceptible even at moderate lift coefficients to flow separation on the upper surface beginning near the leading edge, particularly when the wing sections are thin and have small leading-edge radii. Efforts have been made to improve the aerodynamic characteristics of such wings through the use of cambered wing sections, increased leading-edge radii, and wing twist to reduce the angle of attack of outboard sections. Such refinements of design appear to be necessary in many instances in order to provide efficient sweptback wings having satisfactory longitudinal stability characteristics at the higher lift coefficients. The effects of wing section camber on swept-wing characteristics have been experimentally determined in a series of investigations in the Ames 12-foot pressure tunnel. Six sweptback wing models having different amounts of camber were tested through a range of Mach numbers at a constant Reynolds number and at a constant low Mach number over a range of Reynolds numbers. The effects of combined twist and camber on a sweptback wing have been determined in the Ames 12-foot tunnel over a similar range of test conditions, and on another swept-wing model at high-subsonic speeds on the transonic bump of the Ames 16-foot high-speed tunnel. The effects of local wing section changes have also been investigated on a basically uncambered swept wing through modification of the forward portion of the wing sections to provide a larger leading-edge radius and a small amount of camber concentrated near the leading edges.

Fences located at various positions on the upper surface of swept wings have been found to be effective in some cases as low-speed stall-control devices. A study of the effects of such fences on the aerodynamic characteristics of moderately sweptback wings in the low lift range at transonic and supersonic Mach numbers has been conducted at the Langley Laboratory.

Investigations of triangular wings have continued. An experimental investigation was made by the rocket-powered-model technique of a series of thin triangular wings having different airfoil sections. A comparison of the experimental data was made with calculations based on linearized theory.

Wings at Supersonic Speeds

The study of the supersonic pressure distribution and wave drag of sweptback wings at zero lift has been extended by means of linearized theory to include the combined effects of plan-form taper and curvature of profile. This study was made at the Langley Laboratory and is presented in Technical Note 2009. Comparisons have been made of the pressure distributions and

the wave drag calculated by this method with the results of a simplified method based on formulas for untapered plan forms with symmetrical parabolic-arc sections. In addition, a comparison of the wing wave-drag coefficient has been made with the results obtained from formulas for geometrically similar sweptback and tapered wings with rhombic sections.

The determination of the load distribution on thin wings at supersonic speeds by lift cancellation techniques is described in Technical Notes 2145 and 2147. These methods are more easily applied for some wings than previous methods. An experimental investigation has been made at the Lewis Laboratory to determine the validity of theory in predicting pressures in the vicinity of sharp plan-form edges.

An approximate method of calculating pressures within the tip region of a rectangular wing having a symmetrical circular-arc profile has been developed at the Langley Laboratory. By use of this method it is possible to determine the pressures in the vicinity of wing tips with a higher degree of accuracy than with the usual linearized methods.

In Technical Note 1944 the reversibility theorem introduced by Munk was extended to prove that the lift-curve slope of thin wings in either subsonic or supersonic flow is not changed by reversing the direction of flow over the airfoil. It was also shown that wing reversal does not change the thickness drag or the values of certain stability derivatives.

Methods have been developed for calculating the downwash behind thin wings at supersonic speeds. The approximate method reported in Technical Note 1925 was used to prepare charts for estimating the downwash behind rectangular, trapezoidal, and triangular wings. These results, presented in Technical Note 2141, are in excellent agreement with those obtained by more exact but more laborious methods. Other methods developed from linearized theory enable calculations of the velocity potential and the downwash for wings of arbitrary plan form. General expressions evolved from these methods are reported in Technical Note 2135.

The rolling-up of the trailing vortices associated with low-aspect-ratio wings is of importance in predicting the downwash behind such wings. A study has therefore been made which furnishes predictions of the rolling-up and displacement of the trailing vortex sheet and the development of the cores of the rolled-up vortices at both subsonic and supersonic speeds.

The zero-lift drag of two series of thin, low-aspect-ratio wings has been experimentally determined by use of the rocket-powered-model technique. In the first series of investigations made to determine the effect of trailing-edge thickness, the airfoil sections were modi-

fied over their rearward portions to have several different values of trailing-edge thickness. In the second series of investigations made to determine the effect of type of airfoil section, tests were conducted on a rectangular wing having circular-arc, double-wedge, and slab-sided profiles.

The effect of Reynolds number and Mach number on the characteristics of a sweptback wing mounted on a slender body has been studied in the Ames 6- by 6-foot supersonic wind tunnel. A range of Reynolds numbers extending to 4,000,000 was covered.

The need for experimental studies of the supersonic aerodynamic characteristics of wings with control surfaces has been apparent, especially since shock and boundary-layer interaction effects are not considered by present theory. A fundamental investigation was conducted in the Langley 9-inch supersonic tunnel to study the flow over a rectangular wing having a symmetrical circular-arc profile and a 30-percent-chord trailing-edge flap.

Results of a theoretical investigation of the mutual interference between the two halves of a cruciform wing have been reported by the Ames Laboratory. It has been known that the damping in roll and the rolling moment due to differential deflection of the two halves of one of the sets of wings of a cruciform wing arrangement are seriously affected by the interference of the other set of wings. Previously, no theoretical analysis of this problem had been made because of the complex mathematical treatment necessary in the general case. It was found, however, that by utilizing a certain low-aspect-ratio-wing theory, it was possible to reduce a difficult three-dimensional problem to one of two dimensions in which classical conformal transformation methods could be used to solve the problem.

Bodies and Wing-Body Interference

Interest in bodies of revolution, particularly in the supersonic speed range where the body often becomes a major configuration component, has led to extensive investigations of their aerodynamic characteristics. An analysis has been made at the Langley Laboratory to study the effects of compressibility on the pressure coefficients over several bodies of revolution for the zero-lift case by comparing experimentally determined pressure coefficients with those calculated by linearized equations.

The Langley Laboratory has conducted a series of tests at large scale by the rocket-propelled-model method to develop low-drag bodies. Drag measurements at zero lift were obtained at transonic and supersonic speeds on fin-stabilized parabolic bodies of revolution having a fineness ratio of 6. The investigation has

more recently been extended to include models having higher fineness ratios.

An investigation of a slender, fin-stabilized body of revolution has been conducted in the Lewis 8- by 6-foot supersonic tunnel, the Ames 1- by 3-foot supersonic tunnel, and the Langley 4- by 4-foot supersonic tunnel, and in flight by the rocket-propelled-model method over a wide range of Mach number and Reynolds number. Comparisons have been made of the results obtained in the different facilities, and experimental results have been compared with theoretical predictions.

An analysis has been made of the flow over the base of a body of revolution. The calculation of base drag by semiempirical methods resulting from this analysis enables the effects of Mach number, Reynolds number, forebody shape, and type of boundary-layer flow to be taken into account. Experimental measurements conducted at Mach numbers of 1.5, 2.0, and 3.0 are reported in Technical Note 2137 and show satisfactory agreement with the analysis; the results conclusively demonstrate the importance of viscous effects in determining the base pressure at supersonic velocity.

Experiments to measure the drag of cone-cylinder bodies over a wide Mach number range were conducted in the new Ames supersonic free-flight tunnel. A 60° conical-nose body was tested at Mach numbers between 1.5 and 8.0, and 30° and 90° conical-nose bodies were tested at Mach numbers from 1.5 to 3.7.

Several investigations concerned with the interference between wings and bodies have been made. The effects of such interference on the load-distribution, lift, pitching-moment, side-force, and yawing-moment characteristics of a configuration having a circular body with either a single wing or a cruciform wing are given in Report 962.

The general investigation mentioned in the preceding section conducted on the transonic bump of the Langley 7- by 10-foot tunnel to determine the effects of variations in wing geometry also included tests to determine the interference effects of a body of revolution simulating an aircraft fuselage.

The interference effects between the wings and bodies, as well as the characteristics of the wings alone and the bodies alone, must be known in order to predict the lift and pitching moment of wing-body configurations, particularly those having small wings relative to the bodies. Experiments were conducted in the Ames 1- by 3-foot supersonic wind tunnel to measure the lift and pitching-moment interference of six wing-body combinations having triangular wings of varying aspect ratio.

The pressure distribution over a sweptback wing in the presence of a fuselage has been determined in the Langley 4- by 4-foot supersonic tunnel. Comparison

has been made between the experimental lift and drag coefficients and those predicted by theory.

The effect of nacelles mounted on a sweptback wing has been determined in the Ames 12-foot tunnel at high-subsonic speeds. A primary objective of the investigation was to determine the extent to which a nacelle mounted on a swept wing nullifies the benefits of wing sweep.

The effects of several external store configurations on the aerodynamic characteristics of a $\frac{1}{40}$ -scale model of a high-speed airplane have been investigated in the Langley 7- by 10-foot high-speed tunnel. The external store configurations included inboard underwing and wing-tip installations. The effect of wing tank location on the drag and trim at transonic speeds has been studied by the Langley Laboratory using rocket-powered swept-wing models.

Complete Airplane and Missile Configurations

Drag and performance data for several complete airplane configurations, including a swept-wing airplane, three thin-straight-wing airplanes, and a triangular-wing configuration, have been obtained by the Langley Laboratory using rocket-powered models. Models of other current high-speed airplanes have been tested in the Langley 4- by 4-foot supersonic tunnel and in the Ames 16-foot high-speed tunnel.

A number of supersonic guided-missile configurations have been investigated in flight by the rocket-propelled-model method and in several wind-tunnel facilities, which include the Ames 1- by 3-foot supersonic tunnel, the Langley 9-inch supersonic tunnel, and the Ames 16-foot high-speed tunnel.

Research Equipment and Techniques

Two new supersonic wind-tunnel facilities were placed in operation at the Ames Laboratory during 1950. One of these, the 10- by 14-inch supersonic wind tunnel, can be operated continuously at airspeeds up to about seven times the speed of sound. In the other facility, the supersonic free-flight wind tunnel, models are launched from guns and fly at high speed through the test section in the direction opposite to that of the supersonic air flow. Using this technique, a wide range of Mach numbers and Reynolds numbers can be covered. The aerodynamic data are obtained in this facility from photographic records of the model behavior in flight.

The instrumentation problem for the supersonic free-flight tunnel was especially severe. A system has been developed to obtain an accurate time base for the photographic recording chronograph used in this tunnel. This technique is responsible for time measurements made to date, which have an accuracy of $\frac{1}{10,000,000}$ second. An electronic chronograph has been built and

tested which will extend the accuracy of time measurements possible in free-flight and ballistic research to $\frac{1}{100,000,000}$ second.

A new facility at the Langley Laboratory for attaining hypersonic Mach numbers by firing high-speed projectiles through very low temperature media is described in Technical Note 2120. Shadowgraphs of flows about bodies at Mach numbers up to 6.8 were obtained with equipment which consisted of a rifle with a muzzle velocity of 4,200 feet per second and a chamber containing air at -300°F .

In connection with experimental research at very low densities where aerodynamic forces are small, drag forces of 10-milligram magnitude have been measured with an accuracy of 1 percent by means of a special balance.

A project has been carried out at the Langley Laboratory which involved the design, construction, and testing of a low-cost high-speed tunnel facility suitable for use by educational institutions for student training and basic compressible-flow research. The equipment consists of compressors and a storage tank supplying dried compressed air alternately to an induction tunnel having a 4- by 16-inch test section and capable of Mach numbers ranging from 0.4 to 1.4 and to a blow-down tunnel having a 4- by 4-inch test section capable of supersonic Mach numbers up to about 4.

The general features required for the design of a water channel for studying high-speed flows are discussed in Technical Note 2008. Suggestions are made concerning types of auxiliary equipment and an evaluation is made of some of the limitations involved in the application of the hydraulic analogy.

As part of an investigation of the problem of making accurate airspeed measurements in flight at transonic speeds, a study was made at the Langley Laboratory on the position error of static-pressure orifices. The NACA wing-flow method was used to test a scale half-model of a representative high-speed airplane; four static-pressure orifices were located on the top of the fuselage between the projection of the wing trailing edge and the vertical fin. Tests were made at zero angle of attack over a wide Mach number range.

Three methods have been developed by the Langley Laboratory for the calibration of airspeed installations on airplanes at transonic and supersonic speeds. One method, reported in Technical Note 1979, involves the use of radar-phototheodolite tracking equipment. A second method, described in Technical Note 2046, makes use of measurements of total pressure, static pressure, and temperature. The third method, described in Technical Note 2099, makes use of measurements of acceleration and attitude angle together with the measurements required for the second method. The

accuracy is determined principally by the accuracy of the measurements of normal and longitudinal accelerations and of the attitude angle. Measurements of temperature need not be so precise as those for the method of Technical Note 2046.

SUBCOMMITTEE ON STABILITY AND CONTROL

High-speed flight experience with piloted and pilotless aircraft and continued analytical as well as experimental studies have clearly indicated the need for more detailed investigations in the field of stability and control. Problems of immediate concern involve an understanding of the stability characteristics of individual aircraft components, as well as component combinations. Detailed studies of control surfaces, high-lift devices, and the factors affecting over-all static and dynamic stability and control characteristics of high-speed aircraft have also received attention, particularly in the transonic speed range. Research related to automatic stability and control of aircraft received greater attention, as did studies directed at a more precise definition of flying and handling qualities for piloted aircraft. Stability and control problems associated with high-speed flight were investigated through the utilization of the special NACA research airplanes, as well as current service airplanes.

Longitudinal Stability

A study was conducted in the Langley 19-foot pressure tunnel to investigate the maximum lift and longitudinal stability characteristics of an airplane configuration employing sweptforward wings. The model investigated had an aspect ratio of 5.8 with 35° of forward sweep. The study included an investigation of the effects of nose flaps, trailing-edge flaps, and horizontal-tail position.

The effects of changes in airfoil section and wing-tip tanks on the longitudinal stability characteristics of a rigid straight wing typical of current high-subsonic-speed designs were investigated in the Langley high-speed 7- by 10-foot tunnel from low speeds to high-subsonic speeds.

Consideration of the use of triangular wings for high-speed application led to a series of investigations. In the Langley high-speed 7- by 10-foot tunnel the aerodynamic characteristics of a modified triangular wing in combination with a fuselage were obtained for a range of high-subsonic speeds. To obtain some insight regarding the effects of Reynolds number, tests were made with the flow transition fixed and free. At the Ames Laboratory, a triangular wing of aspect ratio 2, equipped with a constant-chord flap, was investigated by the wing-flow method as part of a general research

program at that laboratory on this wing configuration. A comparison of these data with those from conventional large-scale wind-tunnel investigations substantiated the validity of the plan-form characteristics measured in the wing-flow study.

A study was made in the Langley 19-foot pressure tunnel to determine the effects of fuselage afterbody shape, split flaps, and variations in the span of leading-edge flaps on the contribution of the horizontal tail to the stability of an airplane configuration with a swept-back wing. Surveys were also made to determine the nature of the flow field in the vicinity of the tail.

At the Ames Laboratory extensive surveys were made in the 6- by 6-foot supersonic tunnel to determine the downwash and sidewash characteristics in the flow field behind cruciform wings. These surveys were made in connection with a general program to investigate the characteristics of cruciform-wing missiles.

The time-dependent downwash behind a wing undergoing a linear change in angle of attack with time in a supersonic stream was studied analytically in the Langley stability analysis section. The method of analysis employed an extension of a solution of the linearized potential equation for unsteady flow, and the results are applied to the calculation of the contribution of the horizontal tail to the pitching moment and lift due to normal acceleration of an airplane. The investigation was reported in Technical Note 2042.

The use of the canard or tail-first configuration has been suggested as a possible means of alleviating stability and control problems in high-speed flight. As a step in the evaluation of this type, an investigation of the longitudinal stability and control characteristics of a canard airplane was made at the Langley Laboratory utilizing the wing-flow method. The distinguishing features of this configuration, in addition to the unconventional wing-stabilizer arrangement, were the triangular plan form of the stabilizer, which was also the longitudinal control surface, and the 45° sweptback wing of aspect ratio 4.1. In addition to this study, an investigation of the low-speed static stability and control characteristics of a canard model was conducted in the Langley free-flight tunnel.

An investigation was conducted in the Ames 6- by 6-foot supersonic tunnel to determine the longitudinal and lateral stability and control characteristics of a canard-type missile. Included in this study was an investigation of the interference effects of the various missile components.

An investigation was conducted in the Langley free-flight tunnel to determine the longitudinal stability and control characteristics of a fighter-type airplane when closely coupled to the tail of a bomber such as might be done for in-flight refueling purposes.

Conventional straight-wing aircraft usually experience rather large trim changes in many cases associated with decreased control effectiveness in the transonic flight range. One method suggested for minimizing these effects is to accelerate rapidly through the speed range where these trim changes occur. An analytical investigation of this flight technique was made at the Ames Laboratory.

Lateral and Directional Stability

The application of the Laplace transformations to the solution of both the lateral and longitudinal equations of motion for an airplane in free flight has been presented in Technical Note 2002. The method outlined in this paper was used at the Langley Laboratory in an analytical study of the lateral motions of a high-speed airplane. The results of this study are presented in Technical Note 2129. The method presented in Technical Note 2002 permits the calculation of the free motion of an aircraft following any initial condition or the forced motion following the application of constant external forces and moments. These forced motions can be used to obtain the response to any arbitrary forcing function by means of Duhamel's integral.

An analytical study was made, and reported in Technical Note 2013, of the applicability of experimental stability derivatives to the prediction of the lateral disturbed motions of an airplane in flight. In this study, use was made of the static and rotary derivatives measured in the Langley stability tunnel on a 1/6-scale model of a fighter airplane with a 35° swept wing. A comparison of the calculated motions with flight results showed good agreement for lift coefficients less than 0.8.

An investigation was made at the Ames Laboratory to determine the effect of wing incidence on the lateral stability characteristics of a variable-incidence wing in combination with a thin body. The wing was of a modified triangular plan form and the wing-body combination was similar to that of several guided missiles.

An experimental investigation of the effects of various external store installations on the lateral stability and control characteristics of a model of a tailless airplane with a sweptback wing was made in the Langley high-speed 7- by 10-foot tunnel.

A series of experimental investigation of the effects of various airplane components on the low-speed static stability parameters of complete models were conducted in the Langley stability tunnel. The results of one of these investigations to determine the effect of the horizontal tail on the characteristics of a model having 45° sweptback wing and tail surfaces are reported in Technical Note 2010. These results indicate that at any given angle of attack the effectiveness of the vertical

tail is dependent on the longitudinal as well as the vertical location of the horizontal tail with respect to the vertical tail.

Technical Note 2168 contains the results of an investigation to determine the effects of vertical tail size and tail length and of fuselage shape and fineness ratio on the aerodynamic characteristics of a model with 45° sweptback wing and tail surfaces. In this study, the effects of wing and fuselage interference on the vertical-tail effectiveness were also evaluated.

As one phase of a general study of the relative merit of single- and twin-vertical-tail configurations on fighter airplanes with sweptback wings, an investigation was made in the Langley free-flight tunnel to determine the effects of tail configuration on the dynamic stability characteristics of a model of a swept-wing fighter airplane. The model was tested with twin tails located approximately one-half way out on the wing and also with a single vertical tail mounted on the rear of the fuselage.

Some recently proposed airplane designs have incorporated fuselages having a relatively flat cross section with the major cross-sectional axis horizontal. In order to obtain information on which to base estimates of the directional stability of such fuselages, an investigation was conducted in the Langley free-flight tunnel in which the static stability characteristics of several such fuselages having high fineness ratios were determined.

Rotary Stability Derivatives

Airplane configurations and operating conditions associated with high-speed flight are characterized by difficult problems of dynamic stability and response in all speed ranges. Comprehensive practical methods of evaluating the rotary stability derivatives are essential to the designer in attempting to solve these problems. The NACA has conducted extensive theoretical and experimental studies, with emphasis on high-speed configurations and operating conditions, to develop such methods.

The Langley Laboratory made a theoretical evaluation, based upon linearized supersonic-flow theory, of the lateral force and yawing moment due to combined angle of attack and rolling for a series of thin, sweptback, streamwise-tip wings of arbitrary sweep and taper. The analysis and results, presented in Technical Note 2122, are valid for a range of supersonic speeds for which the wing is contained between the Mach cones springing from the wing apex and from the trailing edge of the root section of the wing. The analysis for the case where the Mach cone from the wing apex is rearward of the leading edge and the Mach cone from the trailing edge of the root section is either forward or rearward of the trailing edge is reported in Technical

Note 2156. Design charts are presented in both reports which permit rapid estimation of the lateral force and yawing moment due to rolling.

A theoretical evaluation of the lift-curve slope and damping-in-roll derivative for a series of thin wings was made at the Langley Laboratory. The results, presented in Technical Note 2114, are applicable to wings of arbitrary taper ratio in which the leading edge is sweptback, whereas the trailing edge is either sweptback or sweptforward, and the tips are yawed with respect to the free-stream direction. The range of speeds covered is such that the components of the stream velocity normal to the leading and trailing edges are supersonic. The results of the investigation are presented in the form of generalized design curves for rapid estimation of the lift-curve slope and the damping-in-roll derivative. Methods for calculating the pressure distribution and damping in steady roll at supersonic Mach numbers of thin flat sweptback wings having subsonic leading edges were developed at the Ames Laboratory and are reported in Technical Note 2047.

The lift and damping in roll have been evaluated by the Langley Laboratory for families of thin sweptback tapered wings with raked-in and cross-stream wing tips. Equations were derived for wings that are wholly contained within a boundary formed by the Mach lines. The analysis is presented in Technical Note 2048, together with a series of design charts which permit rapid estimation of the lift-curve slope and of the damping-in-roll derivative.

An analysis based on linear theory was made of the effect of a body on the damping in roll of wings having supersonic leading edges. This analysis, presented in Technical Note 2151, indicates that cylindrical bodies having diameters up to 35 percent of the wing span have little effect on the damping in roll. Larger bodies decrease the damping.

The damping in roll at supersonic speeds of a complete guided-missile configuration and its components was determined both theoretically and experimentally at the Ames Laboratory. The sum of the damping derivatives of the components was appreciably greater than that of the complete configuration because of the effect of the wing downwash on the damping of the tail. An approximate method to correct this effect on all similar configurations was derived.

A collection of the available linear-theory calculations of damping-in-roll, lift, and pitching-moment derivatives of various wing plan forms at supersonic speeds was published in Technical Note 1977.

A new method of estimating the rolling moment due to yawing for subsonic speeds has been developed and reported in Technical Note 1984. The method is semi-empirical in that it provides for experimentally deter-

mined correction factors to be applied to the theory. Comparisons of experimental and estimated values of this factor for 22 different wing configurations and 8 complete models indicate that this method provides a substantial improvement over existing theoretical methods of estimation.

Research studies of the derivatives associated with yawing, rolling, and pitching motions have been continued with the rolling- and curved-flow facilities of the Langley stability tunnel. The effects of various vertical-fin arrangements on the low-speed yawing stability derivatives of a triangular-wing model were measured over a large range of angle of attack in the Langley 6- by 6-foot curved-flow test section. An investigation was made of the pitching derivatives of wings of triangular and modified triangular plan forms, and the measured values of the damping-in-pitch parameter were compared with those predicted for a typical airplane having a conventional arrangement of wing and horizontal tail.

Research was conducted in the Ames 6- by 6-foot supersonic wind tunnel on the dynamic longitudinal stability of triangular wings at supersonic speed. The damping in pitch was evaluated over a range of supersonic Mach numbers by analysis of the transient oscillation of a spring-restrained model, and the results were compared with those predicted by theory.

An investigation was made in the Langley high-speed 7- by 10-foot tunnel by the free-roll method to determine the effect of wing-tip-mounted tanks on the rolling characteristics of a sweptback wing. The effects of various tank configurations on the damping in roll and the aileron effectiveness were determined.

A simplified method for obtaining free-flight measurements of damping in roll by use of rocket-powered models has been developed by the Langley pilotless aircraft research division. A systematic series of tests is being conducted with this technique to determine the effects of changes in wing geometry on the damping-in-roll derivative at transonic and supersonic speeds, and some studies of the effect of airfoil section and aspect ratio have been reported.

Controls

The range of airspeeds over which current and projected aircraft designs are required to operate has increased the need for and the importance of detailed studies of control characteristics.

At the Ames Laboratory a program has been completed comparing low-speed experimental lift and hinge-moment parameters of control surfaces on wings with and without sweepback with values of these parameters computed by several theoretical procedures. A theoretical method involving adjustments to the sec-

tion values of lift and hinge-moment parameters for the effects of induced angle of attack and induced camber for a finite aspect ratio appears to give satisfactory comparison with experiment. Although the method is based on lifting-surface theory, it can be easily applied through the use of design charts.

One specific low-speed investigation of plain flaps on a swept wing has been conducted in the Langley 300-mph 7- by 10-foot tunnel. The purpose of this investigation was to determine the lateral control characteristics of the flaps which were 25 percent of the wing chord and located at various spanwise stations on a low-aspect-ratio 45° swept wing. It was found that the rolling effectiveness at low angles of attack could be predicted by the method outlined in Technical Note 1674.

As part of the preceding program to determine flap design criteria for wings, other studies have been made in the Langley 300-mph 7- by 10-foot tunnel of a 25-percent-chord plain flap on an unswept untapered wing with an aspect ratio of 3.13. The results of this investigation are reported in Technical Note 2080. It was found that existing theoretical and empirical methods for predicting the lift effectiveness of the flaps for various spans gave satisfactory agreement with experimental results.

At the Langley Laboratory a study has been made of means of reducing the control forces associated with high-speed heavily loaded airplanes. One means of reducing the hinge moments, particularly at low speeds, is through the use of horn balances. To provide information on horn balances at high speeds, an investigation was conducted in the high-speed 7- by 10-foot tunnel on a low-aspect-ratio sweptback wing having a 25-percent-chord flap with various horn balances. Information was obtained through a Mach number range on the incremental rate of change of hinge-moment coefficient with angle of attack and elevator deflection.

Investigations at transonic speeds of effectiveness and hinge-moment characteristics of trailing-edge controls with conventional subsonic balances have been made by the wing-flow technique at the Langley Laboratory. Results obtained with one beveled trailing-edge full-span control on a 35° sweptback wing model indicated that the degree of balance varied considerably both with Mach number and Reynolds number. In conjunction with this investigation, the characteristics of a beveled trim tab were obtained over a range of tab deflections.

As part of a coordinated program at the Ames Laboratory to furnish data for the design of horizontal tails, the aerodynamic characteristics of three tails, having 0°, 35°, and 45° of sweepback have been investigated in the 12-foot pressure tunnel. Elevator, stabilizer,

and tab effectiveness as well as elevator tab hinge moments were measured. These tests provide the designer with much detailed information concerning tail design.

For missiles it is often desirable to have three or more wing panels mounted at the same longitudinal station on the fuselage with individual control surfaces on each panel. To determine the effects of wing proximity on aileron rolling effectiveness, an investigation was performed in the Langley high-speed 7- by 10-foot tunnel using a free-rolling-model testing technique.

As part of a general lateral-control research program, investigations in the transonic and low-supersonic regimes have been conducted by the Langley pilotless aircraft research division through the use of rocket-propelled models. The rolling effectiveness of ailerons located at various spanwise stations on a series of straight and swept wings was investigated as part of this program.

In the supersonic range, an extensive investigation of the characteristics of flap-type controls on a highly sweptback wing has been made in the Ames 6- by 6-foot supersonic wind tunnel over a range of Mach numbers. For the wing plan form investigated, it was found that the controls, although adequate for lateral control, would be inadequate for providing longitudinal trim in case the wing was applied to a tailless design. The results of this investigation have been compared with calculations using linearized theory.

In the Langley 9-inch supersonic tunnel, tests of a rectangular wing having a 30-percent-chord trailing-edge flap were made at several Reynolds numbers. These data have been compared with available theory.

An investigation has been made in the Langley 9- by 12-inch supersonic blow-down tunnel of a tail-surface design for a specific missile. Of concern in this investigation were the aerodynamic characteristics of the tail and elevator, including elevator hinge moments.

Plain flaps have also been investigated in the Langley 9- by 12-inch supersonic blow-down tunnel. These tests were conducted on a low-aspect-ratio swept wing having a double-wedge airfoil section. The flaps investigated had various chords, spans, and spanwise locations. The results of this investigation have been compared with supersonic theory.

In the Langley 24-inch high-speed tunnel, studies were made to determine the time lag between the deflection of the control and the development of the aerodynamic forces on the wing at supersonic speeds. This information is useful in the determination of control response characteristics.

In addition to the more familiar flap controls, spoiler controls have been under study as a possible means of meeting the stringent control demands throughout the

operating ranges of current and anticipated aircraft designs.

In the Langley 19-foot pressure tunnel, a series of ailerons and spoilers have been investigated on a 35° sweptforward wing having an aspect ratio of 5.8.

A series of plain and step spoilers on a sweptback wing were also investigated in the 19-foot tunnel at a Reynolds number of 6,800,000. In this study spoiler projection as well as span was varied for a series of spanwise and chordwise locations in combination with various high-lift and stall control devices. From this series of tests optimum locations for both types of spoiler controls were obtained.

Another device that has been investigated in an attempt to provide adequate lateral control for transonic and supersonic flight is the deflectable wing-tip aileron. This aileron consists of the entire tip of the wing and is deflected about a spanwise axis approximately normal to the plane of symmetry. This type of control has been investigated on a low-aspect-ratio 45° sweptback wing in the Langley 300-mph 7- by 10-foot tunnel. The control in the case of the tailless airplane could also be used as an elevator. Results of this investigation indicate that this type of control compares favorably with conventional controls.

In the Langley free-flight tunnel the dynamic lateral control characteristics of a model having stepped plug ailerons on a 38° sweptback wing with an aspect ratio of 3 and a taper ratio of 0.5 have been investigated. The control characteristics of the plug ailerons were compared with those for flap-type ailerons on the same model. The results of this study are reported in Technical Note 2089, and show that the controllability of the model was more satisfactory with the plug ailerons than with conventional ailerons in the high lift range.

In the Langley 300-mph 7- by 10-foot tunnel plain and stepped spoiler ailerons have been investigated on a sweptback wing. This investigation was primarily concerned with the effects of spoiler span and spanwise location on rolling effectiveness. The optimum spoiler-aileron spanwise location was found to depend on both spoiler and wing configurations. The results of this study were correlated with the values calculated by available methods for predicting the effectiveness of flap-type ailerons.

The transonic characteristics of spoilers have been investigated on the Langley high-speed 7- by 10-foot tunnel bump. In one series of investigations data were obtained on flap-type and spoiler-type ailerons on a series of wings through the transonic range. The wings utilized in this investigation had an aspect ratio of 4.0, and 0°, 35°, and 60° of sweep. The spoiler and flap-type ailerons were also investigated on a 60° sweptback wing having an aspect ratio of 2.0.

Rocket-powered-vehicle experiments have been conducted by the Langley pilotless aircraft research division to investigate hinge-moment and control characteristics of all-movable-tip ailerons on a swept-back triangular wing. This type of control has also been investigated on straight and swept wings.

The effectiveness of a tip aileron on a triangular planform wing with raked-in tip was measured at supersonic Mach numbers in the Ames 1- by 3-foot supersonic wind tunnel. The effectiveness of this aileron has been compared with the theoretical effectiveness of a triangular wing-tip control.

The characteristics of all-movable-tip controls on pointed wings with leading-edge sweepback of 60° and trailing-edge sweepforward of 0° and 30° have been investigated in the Langley 9- by 12-inch supersonic blow-down tunnel. In addition to determining the characteristics of the complete wing configuration, normal-force and hinge-moment measurements were made for the control surfaces.

Automatic Stability and Control

Work in this field has been intensified in view of the dependence of missiles on automatic stabilization and control equipment, and of the improvements in flying qualities of piloted airplanes which appear possible through the use of such equipment. Theoretical studies of means to increase the damping of the lateral oscillatory motions of airplanes by use of servomechanisms have been extended, and basic stabilization and control problems of guided missiles have been studied both theoretically and through the use of rocket-powered research vehicles.

A method has been derived by the Langley Laboratory to determine the effect of time lag in an automatic-stabilization system of an airplane on the damping and period of the lateral oscillatory mode of motion. The method is based on an analytical-graphical procedure. The critical time lag of the airplane autopilot system is shown to be readily obtainable from the frequency-response analysis. The motions calculated for an airplane-autopilot system by this method, presented in Technical Note 2005, were in excellent agreement with those calculated by a step-by-step procedure.

A theoretical investigation was made by the Langley Laboratory to determine the effect on the lateral oscillations of a typical high-speed airplane of an automatic damping system sensitive to yawing accelerations. The results, reported in Technical Note 2006, indicated that lateral oscillations can be satisfactorily damped through the use of this control. The main advantages of a control of this type are that the time lag in the automatic control is not a critical factor and that the control does not oppose the forces applied by the pilot

in any steady maneuvers. For the case investigated, it was found that satisfactory damping could be obtained if the automatic control had a time lag of from 0.10 to 0.28 second. Because of the assumption of a constant time lag in the automatic control, the theoretical analysis predicts that the automatic control will introduce a higher-frequency mode of motion, which becomes unstable with increasing time lag, in addition to the existing lower-frequency Dutch roll mode of motion, which becomes more stable with increasing time lag.

Rocket-powered-vehicle experiments were conducted by the Langley Laboratory with a supersonic missile configuration to investigate automatic stabilization. Information on the aerodynamic stability derivatives and performance also was obtained during flight tests directed at the development of design methods for roll stabilization systems.

An analytical investigation was made by the Langley Laboratory of a nonlinear automatic pilot utilizing a mechanical linkage with a dead spot. Comparison of these analytical results with the results of roll-simulator tests of the actual autopilot indicated limitations in applying linear methods of analysis to systems which have nonlinear components.

An analysis was made at the Langley Laboratory of the stability of a system composed of a subsonic canard airframe and a canted-axis-gyroscope automatic pilot. The analysis was based on calculations of the airframe frequency response and laboratory measurements of the autopilot frequency response. The results, reported in Technical Note 2004, show that this method of analysis will dictate system adjustment to obtain the desired transient response.

In conjunction with automatic-stabilization investigations, the Langley Laboratory has presented a method in Technical Note 1964 for the determination of the frequency-response characteristics of airframes which utilizes the transient output to a known but arbitrary input. Flight-test data obtained by simple methods, such as control pulsing of rocket-powered models, may be reduced by this method to give the frequency response.

Flying Qualities

Unusual configurations employed on many modern airplanes in the interest of increased performance have intensified flying-qualities problems. Emphasis has continued on investigations directed at defining in quantitative terms the dynamic airplane characteristics which are conducive to safe, comfortable, and effective flight of various classes of airplanes over the ever-widening operating ranges of airspeed and altitude and on means of obtaining satisfactory flying qualities without seriously compromising the performance.

A method of automatically varying the effective dihedral of an airplane in flight has been developed at the Ames Laboratory, and was employed to determine the tolerable range of effective dihedral on a conventional fighter airplane. It was found that small amounts of negative dihedral and values of positive effective dihedral greater than 20° could be tolerated by the pilots at both landing-approach and cruising speeds. In fact, at landing-approach speeds an effective dihedral sufficiently high to produce oscillatory instability could be tolerated. This investigation is reported in Technical Note 1936 and in Report 948.

The flying qualities of a conventional transport airplane were measured by the Langley Laboratory as a preliminary phase of an investigation to determine any additions or revisions to the flying-qualities requirements necessitated by problems associated with instrument landing approaches.

The effects of elevator power-boost characteristics on the flying qualities of a medium bomber airplane were investigated in tests involving a booster installed by the Langley Laboratory. The effects of variations in pilots' control-force gradients and in the maximum rate of control motion supplied by the booster system were determined. The results indicated that some deviation from the currently specified elevator control-force gradients might be permissible, and that rates of control motion lower than those normally employed would be acceptable.

Experience has indicated that reduction in pilot-applied rudder-pedal force to the point of zero or slightly unstable force variations in steady sideslip would result in a marked deterioration in handling characteristics. This point was studied in flight tests at the Ames Laboratory of a conventional fighter airplane equipped with the normal rudder and with a rudder which was modified to give virtually no force variation in steady sideslip.

A preliminary flight investigation was made at the Langley Laboratory of the effect on the flying qualities of a fighter airplane of artificially induced changes in directional damping. The results indicated that the present requirements for damping of the classical Dutch roll oscillation generally were adequate for airplanes with moderately effective dihedral.

A study is being made by the Langley Laboratory of the ability of pilots to control simulated oscillatory airplane motions. As part of this study, the effects of variations in directional oscillation period and damping and in rudder control effectiveness have been investigated by use of a swivel-chair apparatus which simulates the directional motions and control characteristics of an airplane.

An investigation was conducted in the Langley free-flight tunnel to compare the longitudinal flying qualities of a model under conditions of constant thrust with those under constant power. The results, presented in Technical Note 2075, showed that reductions in constant-thrust static stability caused a decrease in the longitudinal steadiness (the reaction of the airplane to disturbances at essentially constant airspeed). When the constant-thrust static margin was reduced to zero, the flight behavior became very poor. For a given value of constant-thrust static margin, however, no reduction in longitudinal steadiness was noticeable as the constant-power static margin was reduced. Even with negative values of constant-power static margin, good flight behavior was obtained as long as the constant-thrust static margin was adequate.

Rocket-model techniques developed by the Langley Laboratory have been utilized to investigate the flying qualities of various airplane configurations at transonic speeds. Data have been reported during the past year on a tailless triangular-wing fighter and on a thin-straight-wing airplane-type model.

A theoretical analysis has been made at the Langley Laboratory of means of improving the uncontrolled motions of personal airplanes to the point that such airplanes could be made to fly uncontrolled for an indefinite period of time without getting into dangerous attitudes, and for a reasonable period of time (1 to 3 minutes) without deviating excessively from their original course. The results of this analysis, presented in Technical Note 1997, indicated that the uncontrolled motions of a personal airplane could be made safe as regards spiral tendencies and could be greatly improved as regards maintenance of course without resort to an autopilot. Analysis indicated that, although most present-day personal airplanes possess a slight degree of positive spiral stability, they can easily get into dangerous attitudes and deviate excessively from the original course in uncontrolled flight because of out-of-trim moments and insufficient spiral stability. In order to insure even reasonably satisfactory uncontrolled motions, these out-of-trim moments must be almost entirely eliminated by trimming the airplane in flight, and by keeping control-system friction low or using some mechanical system to provide positive centering of the control. Spiral stability can be increased by increasing tail length and/or increasing the vertical-tail area and dihedral angle simultaneously without adversely affecting the flying qualities of the airplane.

In order to determine the more effective maneuver for correcting the lateral displacement of a large transport airplane from the runway during the final landing approach, the amount of possible correction was cal-

culated by the Langley Laboratory for coordinated turns with limited bank angle and for level sideslips. These calculations showed that, for all distances from the end of the runway, coordinated turns are the more effective maneuver. At 2,000 feet from the end of the runway, the correction possible in turns is roughly twice that in sideslips, and this ratio increases as the distance from the end of the runway increases. At distances of less than 1,300 feet from the end of the runway, the amount of correction with either maneuver is almost negligible, being of the order of 20 feet or less.

An analysis was made at the Langley Laboratory of the lateral response to atmospheric turbulence of two airplanes, one of conventional and the other of high-performance design. The nature and reasons for differences in the gust response characteristics were determined.

At the Ames Laboratory the lateral motions of several proposed high-performance airplanes in response to various gusts and control motions were computed by means of an electronic analog computer. These airplane motions were examined in the light of recent flight experience on dynamic lateral behavior in order to uncover possible undesirable dynamic characteristics and to investigate means of eliminating such difficulties.

Spinning

Airplane spinning characteristics and control movements required to bring a spinning airplane back to a normal flight attitude are still of considerable interest to airplane designers. Although spinning for most airplanes is an inadvertent maneuver, the airplane must be designed so that a pilot can bring the craft under normal control within prescribed rotational limits once corrective measures are taken. Spinning and associated problems have been under continuous study in the Langley 20-foot free-spinning tunnel.

As a means of evaluating the test techniques and methods of interpreting the results of model tests in the Langley free-spinning tunnel, the results of spin-tunnel model tests of 60 specific designs have been compared with the results of full-scale spin tests. This correlation study has been reported in Technical Note 2134. These data show that the models satisfactorily predict full-scale spin and recovery characteristics for approximately 90 percent of the configurations investigated. Generally, in the spin the models lost less altitude per revolution, spun at smaller angles of bank, and approached a 45° angle of attack less closely than did the actual airplanes. Predictions of emergency-recovery parachute sizes based on results of the model tests were found to be somewhat conservative.

With controls free, rudders and elevators usually tend to float away from neutral. This floating tendency

is a function of the type of control surface employed and can affect the spin-recovery characteristics of an airplane. Tests were conducted on a series of rudders and elevators to learn more about these floating characteristics in spinning attitudes. The results of this study, particularly pertinent to designers of light airplanes, are presented in Technical Note 2016. The study indicates that the floating characteristics of horn-balanced rudders can be readily adjusted to aid in spin recovery; plain rudders generally tend to float with the spin; and plain-overhang-balanced, horn-balanced, and beveled-trailing-edge elevators tend to float in an up position in spins. The study also shows that beveled-trailing-edge elevators tend to float closest to the neutral, usually from an up position.

In current airplane designs the use of external fuel tanks has raised questions regarding the effects of these tanks on spin characteristics and the possibility of the tanks striking the airplane if jettisoned in a spin. These effects were investigated for models of 11 specific airplanes in the Langley free-spinning tunnel. The results of this investigation showed that, for the designs where it might be necessary to jettison the tanks to aid spin recovery, the tanks would clear all parts of the aircraft.

For some airplane designs, it has been found that the available controls cannot insure effective spin recovery, and parachutes have proved an effective emergency aid. The results of a spin-tunnel investigation to determine the effect of minimizing the opening shock of the parachute on spin-recovery characteristics have been reported in Technical Note 2051. This study indicates that the effectiveness of spin-recovery parachutes is not impaired by the installation of a shock absorber in the parachute towline, provided the shock absorber does not appreciably extend the time required for the development of the steady load of the open parachute. It was also found that increasing the fabric porosity of the parachute canopy decreased the parachute opening shock load, whereas increasing the towline length increased the parachute opening shock load.

In addition to these correlation and generalized studies, many specific configurations have been investigated in the Langley 20-foot free-spinning tunnel. In one study the spin and recovery characteristics of a current high-speed airplane were determined. The effects of rudder movement and rudder configurations, in conjunction with movement of the elevator for spin recovery, were studied, as were modifications to the vertical tail and the installation of external wing tanks.

Another specific investigation was concerned with the effects of a single vertical tail and twin vertical tails and the effects of mass distribution on the spin-recovery characteristics of a fighter-type airplane. The study

showed that neither tail allows effective spin recovery when the mass distribution is chiefly along the wings; for mass distribution along the fuselage, either tail proved satisfactory.

The effect of a single vertical tail and dual vertical tails on the spin and recovery characteristics of a triangular-wing-airplane configuration has also been investigated in the spin tunnel. In addition to the effects of changes in vertical-tail design, the effects of various loadings were investigated.

Specific Design Studies

At the request of the armed services and other Government bodies, the NACA has undertaken studies of specific airplane and missile designs. These investigations were undertaken to supply urgently needed information and with a view to amplifying current research programs in both the airplane and missile fields. In addition to these specific investigations, the NACA has continued its studies at its High-Speed Flight Research Station, Edwards Air Force Base, Muroc, California, with the special research airplanes developed in cooperation with the Air Force, the Bureau of Aeronautics, Navy Department, and industry. Included in this group of special research airplanes are the Douglas D-558-I and -II, the Bell X-1, and the Northrop X-4.

In the case of the D-558-I airplane, a detailed study of the rolling characteristics of the ailerons was made over a range of high subsonic speeds.

Tests of the D-558-II airplanes have been made to determine the static and dynamic lateral stability and control characteristics and the static longitudinal characteristics of the configuration, including stall characteristics.

During the past year, flight tests of the X-1 research airplane were conducted to obtain detailed information on the trim characteristics as well as detailed data on lateral control characteristics at high Mach numbers. The results of flight tests to determine the dynamic lateral stability characteristics have been correlated with the results of analytical studies.

Useful data on the general flying and handling qualities and control characteristics of the X-4 airplane were obtained by the NACA during the Air Force and contractor's flights through the use of NACA instrumentation. Also included was some information on the stall characteristics of the airplane.

At the Ames Laboratory, an F-86 airplane has undergone extensive flight studies to determine static and dynamic stability and control characteristics in the high-speed range. The investigations have yielded much useful information related not only to this airplane but

to general problems associated with high-speed flight.

Tests at transonic speeds have been conducted by the Langley Laboratory utilizing the wing-flow method to determine longitudinal stability characteristics of a moderately sweptback supersonic airplane configuration. Lift, pitching-moment, and rolling-moment characteristics of the semispan model, as well as stabilizer hinge moments and downwash characteristics at the tail, were measured.

The characteristics of a model of a swept-wing tailless airplane were also investigated at the Langley Laboratory by the wing-flow method. The purpose of this investigation was to determine the longitudinal stability and control characteristics of this airplane configuration in the transonic speed range. This investigation covered the effects of speed brakes and ailerons on the model's stability characteristics.

In the transonic and low supersonic speed regimes, the Langley pilotless aircraft research division has continued to employ the rocket-model technique to obtain stability and control data on current high-speed airplane designs.

Model tests of a current fighter were conducted in the Langley high-speed 7- by 10-foot tunnel to determine the lateral and directional stability characteristics. In addition to the experimental studies, the dynamic lateral stability characteristics of the airplane were investigated analytically.

A comprehensive wind-tunnel study has been made in the Langley 4- by 4-foot supersonic tunnel of the stability and control characteristics of a model of a 40° sweptback wing airplane. The study included measurements of static longitudinal as well as static lateral and directional stability and control characteristics.

Missile configurations have also been under study in the Committee's wind tunnels. At subsonic speeds, static longitudinal stability and control characteristics of one specific design have been investigated in the Langley stability tunnel. Another low-speed investigation of a specific missile was conducted in the Langley full-scale tunnel to evaluate static stability and control characteristics.

Full-scale studies of a missile have been made at the Ames Laboratory. It was the purpose of this investigation to aid in the development of satisfactory low-speed stability and control characteristics. This study included consideration of aeroelastic effects on the longitudinal stability and control characteristics.

Specific missile studies in the transonic and low-supersonic ranges have been conducted at the Langley Laboratory utilizing both the free-fall and the rocket-model techniques. These studies included canard configurations as well as triangular-wing configurations

Data on the longitudinal and lateral characteristics have been obtained.

In the Langley 9-inch supersonic tunnel another specific missile configuration was studied. The static stability characteristics of the configuration were determined for several wing-body combinations.

Research Equipment and Techniques

Solution of the dynamic-stability problems of modern aircraft having unusual configurations and greatly increased relative density and the application of rational design procedures to servomechanism installations in these aircraft require precise knowledge of the dynamic-response characteristics of the airplane. These response characteristics in turn are dependent upon the accurate evaluation of inclination of the principal axes and moments of inertia of the aircraft.

Because of the large errors inherent in the methods previously used for the determination of these characteristics and since the inclination of the principal axes was not directly measured by these methods, a new method has been used for determining the moments of inertia and the inclination of the principal axes. A simple system of pivots and springs is used to measure the moment of inertia about the pitching and rolling axes, and a torsional pendulum is used to measure the moment of inertia about the yawing axis. This torsional pendulum is suitable for accurate measurements of inclination of the principal axes by a "null" method wherein the airplane attitude corresponding to zero rolling motion during oscillations in yaw is indicative of the inclination of the principal axes of the airplane.

SUBCOMMITTEE ON INTERNAL FLOW

An important consideration in high-speed aircraft design is the efficient handling of the large volumes of air required by current and future turboprop, turbojet, and ram-jet propulsion systems. To achieve this end, the study of internal-flow problems has been the subject for a number of investigations conducted at the NACA laboratories during the past year, which have contributed to a greater understanding of air-inlet, exit, and associated duct characteristics through the subsonic and into the supersonic speed range.

Nose Inlets

Research has been conducted at both the Ames and Langley Laboratories to supply information for use in the design of air intakes suitable for turbine-propeller types of power-plant installation. These investigations have thus far been concerned with so-called spinner cowlings (cowling and central body rotate with the

propeller). The internal-flow characteristics of one such configuration have been investigated at subsonic speeds over a wide range of the flow parameters. The pressure-rise and leakage-loss characteristics of the rotating cowling were determined and a method was derived for determining the pressure-rise characteristics. Another recent investigation of a similar configuration in which the cowling was tested in a stationary position with propeller-blade shank fairings installed in the inlet passage has shown that a high-efficiency internal flow can be maintained up to high-subsonic Mach numbers.

Research on nose inlets at high-subsonic and transonic speeds has been extended to include an investigation of a series of NACA nose inlets to determine the effect of a protruding central body. Such characteristics as the Mach number for supercritical drag rise and the minimum inlet-velocity ratio for unseparated central body flow were determined.

Investigation of nose inlets at supersonic speeds has continued at the Langley Laboratory to study a method of varying the cross-sectional area of an inlet to permit more efficient operation over a range of mass flow rates.

An investigation at supersonic speeds of a series of perforated convergent-divergent inlet-diffuser configurations has been conducted at the Lewis Laboratory. A range of contraction ratios utilizing various perforation distributions was studied to determine peak total-pressure recoveries, relative mass flows, perforation flow coefficients, and shock stability of the combinations.

One problem associated with air-inlet design is the unsteady flow or pulsations that result from subcritical operation of a supersonic inlet or from rough burning in a ram-jet engine. These pulsations lower the efficiency of the air induction system and create structural problems. The pulsations associated with the rough burning of a ram-jet engine have been the subject for a recent investigation at the Lewis Laboratory. The effect of these pulsations on the performance of a ram-jet inlet were determined from supersonic wind-tunnel tests. Instantaneous measurements of the amplitude and frequency of the oscillations were made and the mean inlet efficiencies determined.

Side Inlets

Because of the possibility that in certain aircraft types the nose inlet cannot be used because of the need for carrying radar equipment or guns in the fuselage nose section, the side inlet for both subsonic and supersonic flight has received considerable attention. Side inlets that have been studied include the scoop, partially submerged, and fully submerged or flush type of inlet.

A preliminary low-speed investigation has been made at the Langley Laboratory on a new type of submerged inlet consisting basically of an air scoop within a depression or dimple in the fuselage surface. A number of detailed variations in the design were studied, including the application of boundary-layer control to remove the fuselage boundary layer ahead of the inlet.

Research on submerged inlets at the Ames Laboratory during the past year has been concerned principally with investigations of the flow field in the vicinity of the inlet. Measurements have been made of the boundary-layer growth along the ramp surfaces for both parallel- and divergent-wall inlets and of the vortex originating from the side walls of the divergent-wall inlets. Tests of these two submerged-type inlets were conducted at subsonic and transonic speeds.

Because the performance of a submerged inlet is dependent on the inlet location on the body, a low-speed investigation was made in the Ames 40- by 80-foot wind tunnel of a more rearward position on a body than those which had previously been studied.

Another recent investigation of a submerged inlet has been conducted in the transonic speed range by utilizing the NACA wing-flow technique. The variation with Mach number of ram-recovery ratio was determined for various mass-flow ratios.

Since submerged inlets may be suitable for use in turboprop installations, results have been obtained on the effects of a propeller slipstream on submerged-inlet characteristics.

Several comparative studies of various types of inlets have been made during the past year. One such investigation has been conducted with an NACA submerged inlet and a conventional scoop inlet at transonic speeds by utilizing the transonic-bump technique. Drag and air-induction characteristics were determined over a range of angle of attack.

A comparative study has been conducted in the Ames 8- by 8-inch supersonic tunnel on three types of supersonic inlets. Drag and pressure-recovery characteristics of a twin-scoop inlet configuration were compared with those obtained for two types of nose inlets at various mass-flow ratios and angles of attack.

Supersonic aircraft powered with air-breathing engines will require satisfactory air-inlet operation not only at the design supersonic speed but also at subsonic speeds to insure adequate performance in take-off, climb, and cruising conditions. Since the optimum-design requirements for subsonic and supersonic inlets are generally conflicting, compromises may be necessary. Initial studies of the subsonic characteristics of supersonic inlets have been conducted on a scoop type of inlet whose geometry was derived from supersonic tests. In this

subsonic investigation, pressure distribution, pressure recovery, and drag were measured for a wide range of angle of attack, angle of sideslip, and mass-flow ratio. Boundary-layer measurements were made on the fuselage in front of the scoop, and flow visualization techniques were utilized for observing the flow patterns.

Several current high-speed aircraft utilize twin air intakes to duct the flow into a common plenum chamber. Flow instability and flow reversal have been found to occur for certain flow conditions in such systems. The determination of the factors influencing these unsteady flow phenomena has been the subject for a recent study conducted at the Ames Laboratory. The results, published in Technical Note 2049, indicate that the flow instability and flow reversal are functions of the static-pressure-recovery characteristics at the juncture of the two ducts.

Wing Inlets

Research has continued on wing leading-edge inlets. A practical method for determining the profile coordinates of an air inlet in the leading edge of an airfoil has been formulated at the Ames Laboratory. The usefulness of this method has been demonstrated by an analysis of the results of a wind-tunnel investigation of leading-edge inlets on an unswept wing.

The application of leading-edge inlets to swept wings has also been the subject for a recent experimental investigation. Pressure distribution, ram-pressure recovery, and wake-survey measurements have been made on an inlet in the leading edge of a swept wing which completely spanned the wind-tunnel test section. The validity of the technique for simulating infinite aspect ratio has been previously substantiated from experimental tests of a plain swept wing mounted across a wind tunnel in this manner. These results have been published in Technical Note 2160.

Ducts and Duct Elements

One of the problems connected with the design of internal-flow systems is the prevention of total-pressure losses due to boundary-layer separation from the duct walls. A recent investigation has been conducted at the Langley Laboratory to study the interrelation of boundary-layer growth and diffuser performance in full-scale internal-flow systems at Reynolds numbers and Mach numbers characteristic of those encountered in high-speed flight. Total- and static-pressure surveys were made at the inlet and exit and the velocity profiles obtained in conical diffusers for two inlet-boundary-layer conditions.

In another experimental study of diffusers conducted at the Langley Laboratory, the aerodynamic characteristics of two types of annular diffusers of the same

area ratio but with different angles of divergence have been determined at high subsonic inlet velocities. Pressure distributions across the inlet and exit and along the diffuser wall were determined for two diffusers having differing angles of divergence.

Jets and Jet Exits

In designing jet-propelled aircraft, a knowledge of the spreading characteristics of the jets is important since the location of the tail surfaces and other components must be sufficiently far removed from the jet stream to avoid excessive heating and structural damage. Recent investigations have been made at the Lewis Laboratory to determine the boundaries of single and twin jets discharging through convergent nozzles into quiescent air. The surveys were made for several internal-jet pressures and temperatures and for several spacings of the twin jets. The effects of humidity were also investigated.

Although the tail surfaces can be placed so as to be well above the jet streams for the flight condition, the jets may be deflected from the runway during take-off in such a manner as to impinge on parts of the aircraft structure. A full-scale-engine investigation has been conducted at the Lewis Laboratory to determine the temperature and pressure distributions in the wake of two adjacent, parallel jets impinging on the ground.

Research is continuing on air ejectors to determine their characteristics when used as air pumps and as thrust-augmentation devices. An analysis has been made to determine the nature of ejector action and the source of its thrust. This analysis, reported in Technical Note 1958, showed that ejector augmentation of the thrust generated in a primary-jet passage is created largely by pressure forces on the surface of the converging secondary passages preceding the mixing zone.

An experimental investigation of the entrainment and thrust-augmentation characteristics of ejectors which incorporate annular nozzles has been carried out at Stanford University under an NACA contract. The results, reported in Technical Note 1949, showed that ejectors with annular nozzles and nondivergent mixing tubes have negligible thrust-augmentation capabilities, despite the possession of entrainment characteristics substantially identical with those of the conventional ejector with central nozzle. The combination of divergent mixing tubes with annular nozzles was found to result in very substantial improvement of both entrainment and thrust-augmentation characteristics.

Investigation of air ejectors for pumping engine-cooling air has continued at the Lewis Laboratory. Ejector configurations including variable-area primary-jet nozzles and two concentric cooling-air shroud configurations have been investigated.

SUBCOMMITTEE ON PROPELLERS FOR AIRCRAFT

High-Speed Propellers

The procurement of design information for improved propellers for high-speed aircraft is a primary objective of NACA propeller research. The broad program has included theoretical, analytical, and high-speed wind-tunnel investigations.

An extensive investigation of several single-rotation propellers has been conducted over a wide range of blade angle, forward speed, and propeller rotational speed in the Langley 8-foot high-speed tunnel to establish the effects of sweep, blade-section camber and thickness ratio, and advance ratio. The results of the investigation also give an insight into the type of propeller blade loading most suitable for high-speed propellers. In addition to force tests, wake surveys were made for two of the related propellers.

Force tests have also been conducted in the Langley 8-foot high-speed tunnel to determine the characteristics of a dual-rotating propeller at high speeds.

Flight studies of the effects of blade power loading on climb and high-speed propeller efficiency were continued during the past year with tests of a three-blade propeller on a radial-engine airplane. The results, which were reported in Technical Note 2022, showed that large efficiency gains accrued from raising the blade power coefficient from 0.06 to 0.16 at an airplane level-flight Mach number of 0.7 and at propeller-tip Mach numbers above unity. These increases were shown to be caused primarily by a reduction in profile-drag losses due to operating the blade sections nearer to the condition of maximum lift-drag ratio as the blade power coefficient was increased. In climb, an increase in power loading was shown to reduce efficiency as a consequence of increased induced drag losses. Profile-drag losses were of secondary importance in climb except where blade stall was encountered.

Analytical and theoretical studies of high-speed propellers also have been conducted. An analytical investigation has been made to ascertain the probable maximum efficiency levels of propellers operating at high-subsonic flight speeds. The results show the effect of blade-section thickness and operating advance ratio on propeller efficiency.

As propeller research is extended into the transonic speed range, conventional incompressible theory is unable to explain many phenomena which occur. To serve as a starting point for the development of a suitable theory, the axial momentum theory has been derived for a compressible fluid in Technical Note 2164. The results indicate that the flow pattern in compressible flow is considerably different from the flow pattern in

incompressible flow and that these differences may have important effects on propeller operation.

Blade Sections

An extensive investigation is being conducted in the Langley 16-foot high-speed tunnel to determine propeller blade-section characteristics by measuring the pressure distribution over several propeller blades under operating conditions at tip Mach numbers up to 1.2. These studies will provide important basic information for the design and performance prediction of propellers operating at high subsonic and transonic speeds.

Vibration and Flutter of Propellers

Data have been obtained on the aerodynamic excitation of first-order vibration occurring in a representative three-blade propeller having its thrust axis inclined to the airstream in the Langley 16-foot high-speed tunnel. Calculated values of the section aerodynamic exciting force and the first-order vibratory stresses were compared with experimental values for the tilted propeller. The comparison provided a basis for judging the operating conditions for which the vibration characteristics of a tilted propeller can be calculated.

Another propeller vibration investigation has been conducted with a twin-engine, fighter-type airplane in the Ames 40- by 80-foot tunnel. Flow-field measurements were made at one of the propeller planes before the propellers were installed. The oscillatory air loads and vibratory stresses were measured when the propellers were operated at several angles of inclination. A preliminary analysis of the results, presented in Technical Note 2192, showed that both the oscillatory air load and the vibratory stress could be predicted with good accuracy by use of existing theory.

The flutter speed and flutter frequency were obtained at the Langley Laboratory for a one-blade wooden propeller operating at zero forward velocity and at a range of pressures and blade-angle settings. Results of the investigation are reported in Technical Note 1966. The maximum experimental flutter speeds, which were substantially lower than predicted by classical flutter theory, were in the vicinity of zero aerodynamic moment and increased considerably in this region with decreasing air density. The flutter frequency was found to approach the natural torsional frequency of the propeller at both large positive and negative blade angles. Additional details concerning this study are presented in the section on the Subcommittee on Vibration and Flutter.

Propeller Noise

Sound-pressure measurements at static conditions are reported in Technical Note 2024 for five shrouded pro-

pellers and are compared with those for an unshrouded propeller of the same diameter operating at approximately the same power and rotational speed. The maximum total sound pressure produced by a two-blade shrouded propeller was found to vary approximately from one-half to twice as much as that for a comparable unshrouded propeller, depending on flow conditions at the shroud surface.

SUBCOMMITTEE ON SEAPLANES

Hydrodynamics

Hydrodynamic studies in the Langley tanks have continued to provide research data to aid in the development of high-speed water-based airplanes which will have a minimum of aerodynamic penalty for hydrodynamic performance. Tests were made on unorthodox shapes as well as some of the more orthodox hulls incorporating high length-beam ratio and long afterbodies. Studies were made to evaluate the effects of a number of auxiliary lifting devices for use in water operation and fundamental data concerning their behavior were obtained.

Landing Loads

Hulls of high length-beam ratio not only reduce air drag in flight but also fortunately reduce landing impact loads as well. Tests were made in the Langley impact basin of such a hull incorporating 30° dead rise. The impact results were reported in Technical Note 2015 and pressure distributions were reported in Technical Note 2111. It was found that the instantaneous pressures for a given draft, trim, and location on the bottom are directly proportional to the square of the velocity normal to the keel.

A smooth-water full-scale landing investigation was conducted for the purpose of comparing measured and calculated wing bending moments during hydrodynamic impact. The results of this investigation were reported in Technical Note 2063.

SUBCOMMITTEE ON HELICOPTERS

The increasing practical application of helicopters has emphasized the need for research information which will permit the development of machines having improved performance and satisfactory flying and handling qualities. The research effort of the NACA has been directed at supplying this information. Theoretical, flight, wind-tunnel, and helicopter test-tower studies are being made at Langley of such problems as the development of helicopter rotor airfoils, autorotation of jet-powered rotors, helicopter stability and control, and vibration.

Rotor-Blade Sections

In order to simplify the construction of small metal helicopter rotor blades, consideration is being given to the use of a blunt, thick trailing edge. The aerodynamic penalties resulting from the use of this thickened trailing edge have been studied using a two-dimensional model of a modified NACA 0012 airfoil. The results are presented in Technical Note 2074. Tests were made at Reynolds numbers of 3,000,000 and 6,000,000 to determine the lift, drag, and pitching-moment characteristics of three airfoil sections formed by removing successively large portions of the rear of the airfoil section. The results indicated that the minimum drag coefficient increased for both smooth and rough surface conditions; with increasing trailing-edge thickness, however, the maximum lift coefficient remained nearly constant for the smooth condition and increased slightly for the rough condition. The position of the aerodynamic center was found to move rearward with increasing trailing-edge thickness.

One of the more promising of the airfoil sections designed specifically for helicopter rotors, the NACA 8-H-12, has been investigated in the Langley two-dimensional low-turbulence pressure tunnel at Reynolds numbers from 1,800,000 to 11,000,000. The data, presented in Technical Note 1998, indicated no unusual scale effect on lift, drag, or pitching moments in either the smooth or rough leading-edge conditions.

Rotor Performance

The autorotative rates of descent of conventionally powered helicopters with normal disk loadings have proved to be satisfactory to the pilot from the standpoint of safety and controllability. The autorotative performance of helicopters powered by rotor-blade-tip jet units, however, presents a problem because of the high rates of descent resulting from the relatively high drag of the jet units when they are inoperative. In order to obtain more quantitative information concerning the effects of the power-off drag of the tip jet, the autorotative performance of a hypothetical tip-jet-powered helicopter was calculated for several values of jet-unit power-off drag coefficient. The analysis and the results are published in Technical Note 2154. It was concluded that the power-off drag of ram-jet units of current design could cause a marked increase in the minimum rate of descent of helicopters, but that the effects of the power-off drag of pulse-jet units giving power or thrust equal to the ram-jet units would be less severe because of their greater ratios of net power-on thrust to power-off drag.

Stability and Control

Because of the increased demand for improvements in the flight characteristics of helicopters, particularly the handling qualities, a major effort has been exerted toward the establishment and fulfillment of satisfactory flying-qualities requirements. The problem was investigated by obtaining flight-test measurements and corresponding pilots' opinions of the forward-flight longitudinal flying-qualities characteristics of several single-rotor helicopters. The comparison obtained formed the basis for defining satisfactory longitudinal flight characteristics. The conclusions reached as a result of these tests were expressed in the form of tentative flying-qualities requirements. The results of the investigation are presented in Technical Note 1983.

The flight investigations also showed the importance of a stability parameter known as rotor damping, the moment produced by the rotor per unit angular pitching or rolling velocity, on the handling qualities of the helicopter. The subject was investigated theoretically and the results indicated that present-day helicopters with conventional control systems tend to have low damping at high speed and in climbs and can even experience negative damping in certain maneuvers, and that high-speed, high-powered helicopters and certain types of convertible aircraft would have prohibitive amounts of negative damping. The analysis, together with an experimental check of trends shown with varying flight conditions, was published in Technical Note 2136, which also contained suggestions for the avoidance of negative damping through special design features. The investigation also disclosed the fact that the assumption that the rotor force vector is at all times perpendicular to the tip-path plane during rolling or pitching may give highly misleading results when applied to the calculation of rotor characteristics.

Most of the published literature on helicopter stability is written for the specialist in stability theory. For the nonspecialist, an explanation of the fundamental ideas underlying helicopter stability in terms of the basic physical parameters rather than of specialized mathematics has been prepared and is presented in Technical Note 1982. Three primary helicopter-rotor stability parameters that influence the flying qualities of helicopters are discussed in fundamental terms. Static stability of the helicopter and the stick-fixed oscillation in hovering and forward flight are also discussed in the same fashion because of their influence on flying qualities.

The results of flight tests made by the Navy of a tandem-rotor helicopter representative of a present

helicopter design indicated that it was directionally unstable at small angles of yaw. To study and find means for increasing the directional stability of this helicopter, force tests have been made in the Langley free-flight tunnel on a model of a fuselage-pylon combination which was representative of the tandem-rotor configuration. The investigation included force tests of the model with the original tail and with various modifications to the tail.

An aerodynamic servocontrolled rotor system in which auxiliary airfoils mounted outboard on the blades are used to twist the blades in order to achieve pitch control has been investigated on the Langley helicopter tower. The results, published in Technical Note 2086, indicated that satisfactory performance and control characteristics could be obtained by using the aerodynamic type of servocontrol, although approximately 6.5 percent more hovering power was required as compared with a conventional rotor of the same diameter and solidity.

Vibration

A theoretical analysis of the frequency and damping characteristics of the free modes of vibration of balanced, fixed-ended, and hinged elastic rotor blades in hovering and in vertical flight has been made by the Polytechnic Institute of Brooklyn under NACA sponsorship. This study, presented in Technical Note 1999, is further discussed under the section on the Subcommittee on Vibration and Flutter.

The frequency and damping characteristics of the coupled flapping and lagging oscillations of helicopter blades in hovering have also been derived for the general case in which the lagging (vertical) hinge axis is offset from the flapping hinge axis, while both hinge axes are inclined. The analysis and the numerical examples indicate that significant increases in the damping of the lagging motions, which ordinarily border on

instability, can be obtained by suitable inclinations of the hinge axes, especially of the lagging axis. Offsetting the flapping and lagging hinge axes tends especially to increase the natural lagging frequency.

Research Equipment and Techniques

A suitable hot-wire anemometer was devised and installed in a helicopter where it has been in use for 1 year. This instrument indicates the forward component of airspeed, whether positive or negative, and is particularly suitable for the very low airspeeds which are encountered near hovering.

SPECIAL SUBCOMMITTEE ON THE UPPER ATMOSPHERE

Study of the semidiurnal oscillations of barometric pressure of the atmosphere a number of years ago led to the development of theoretical relations for the calculation of the free periods of oscillation of the atmosphere. In order to provide a measure of the accuracy of the tentative standard temperature profile of the upper atmosphere presented in Technical Note 1200, a theoretical study of the compatibility of the tentative standard temperature distribution with the observed free periods of oscillation of the atmosphere, through use of the previously noted theory of atmospheric tides, is being made at the Massachusetts Institute of Technology under NACA sponsorship. In addition, a study using the theory of atmospheric tides is being made at the Institute for Advanced Study of the oscillations of an atmosphere in which the temperature increases linearly with height above 80 kilometers. The research completed so far as the Institute for Advanced Study indicates that the classical tidal theory may be inadequate for this purpose in that it apparently fails to take into account satisfactorily the variation of density in the atmosphere with increasing height.

PROPULSION RESEARCH

While aircraft flight at transonic and supersonic speeds has been demonstrated as being feasible, the realization of a useful airplane for flight at such speeds raises many research problems. An important problem is that of providing improved power-plant performance in order that the fuel consumption for such flight speeds may be kept low enough to permit the carrying of a reasonable amount of useful load. This problem has been approached through theoretical and experimental investigations for the purpose of obtaining the most efficient operation of each part of the turbojet engine. The Committee is also exploring the possibility of developing new principles which will permit smaller and

lighter engine components without sacrificing engine performance or, conversely, which will permit much higher performance output from a given size of power-plant element.

Propulsion research pertinent to supersonic guided missiles has been conducted primarily on the problems of the turbojet, the ram-jet, and the rocket power plants. Research has also been conducted on the problems of lower flight speeds involving the turbopropeller and the compound engine.

NACA efforts in the aircraft propulsion 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 with addi-

tional assistance provided by the National Bureau of Standards and by educational and nonprofit institutions under contract to the NACA.

COMMITTEE ON POWER PLANTS FOR AIRCRAFT

Engine Performance and Operation

A method of generalizing turbojet-engine performance in terms of the engine-pumping characteristics was developed. The performance was presented in terms of engine temperature ratios, pressure ratios, and a Reynolds number index in addition to corrected values of air flow, engine speed, and fuel-air ratio. This presentation of the engine performance was independent of the characteristics of the induction or exhaust systems of the propulsive unit. The method facilitated the estimation of propulsive-system performance with varying inlet-pressure losses, inlet temperature, flight speed, or altitude or with heat addition in the tail pipe (Technical Note 1927).

A generally applicable and numerically usable solution of the equations for the equilibrium operating conditions in turbojet engines was made in Technical Note 1956. General trends of the effects of turbine and nozzle dimensions, component efficiencies, permissible gas temperature, flight ram ratio, and pressure altitude are immediately discernible, and if the proper descriptive coefficients for the engine components are known the numerical values of performance characteristics of turbojet engines may be estimated.

An analysis was made of the performance and load-range characteristics of turbojet engines in the transonic speed range for altitudes from 10,000 to 70,000 feet, compressor pressure ratios from 2 to 30, and turbine-inlet temperatures from 1,700° to 2,300° R. The results, which are reported in Technical Note 2088, indicated that for an engine submerged in the fuselage maximum or near-maximum range could be obtained with compressor pressure ratios of 8 to 10. At the lower altitudes and flight speeds, the turbine-inlet temperature had only a small effect on ultimate range. At the higher altitudes and flight speeds, the greatest range was obtained with the highest turbine-inlet temperature.

Current and anticipated aircraft designs impose the requirement for a source of compressed air for purposes of cabin pressurization and air-conditioning, ice protection, and other auxiliary uses. A method of fulfilling this requirement in jet-engine aircraft is by bleeding air from the compressor-outlet diffuser. This system has the advantage of requiring no increase in weight or space; however, bleeding air from the compressor outlet will affect the over-all engine performance.

A method of analysis has been developed for

evaluating the effect on engine performance of bleeding air from the compressor outlet of a turbojet engine. The analysis was based on the matching of experimentally determined performance characteristics of the components of a typical axial-flow turbojet engine. The results were presented as working charts applicable to engines operating in the current range of temperatures and pressure ratios, and were found to check with experimental data (Technical Note 2053).

Experimental data were obtained from an investigation conducted at the Lewis Laboratory to determine the effect of air bleed-off at the compressor outlet on the performance of an axial-flow turbojet engine over a range of flight conditions, engine speeds, exhaust-nozzle areas, and bleed-off air flows. It was found that bleeding a given percentage of the engine air flow from the compressor outlet decreased the thrust and increased the specific fuel consumption by about double the percentage air bleed.

An investigation has been conducted in the Lewis altitude wind tunnel to determine the performance and operational characteristics of a gas-turbine-propeller engine over a range of altitudes and engine speeds. The effects of altitude, engine speed, and turbine-inlet temperature on engine and component performance and the effect of varying the power distribution between the propeller and the jet on engine performance were evaluated. Calculations were also made on the performance characteristics of a ducted-fan power plant utilizing a typical turbine-propeller engine.

An investigation was conducted in an altitude test chamber to determine the performance characteristics of a British turbojet engine. The effects of variations in altitude and ram pressure ratio on engine performance were evaluated over a range of engine speeds.

An atmospheric effect on a gas-turbine engine results directly from the low inlet pressures associated with high-altitude flight. The low pressures reduce the Reynolds number throughout the engine flow passages and result in increased viscous losses. Generalized parameters, which correct the over-all performance variables for Mach number and density variations, do not account for Reynolds number effects on the components.

An investigation of the effect of Reynolds number on the performance of an axial-flow compressor was conducted in the Lewis altitude wind tunnel, using an axial-flow compressor operating in a turbojet engine.

Variations in compressor performance with inlet conditions were obtained by operating the engine over a range of compressor-inlet Reynolds numbers at several compressor Mach numbers. At each compressor Mach number and Reynolds number, data were obtained at two inlet total pressures while the Reynolds number was maintained constant by changing the compressor-inlet temperature. The results obtained indicated that the decrease in compressor efficiency and corrected air flow with a reduction in inlet pressure at each compressor Mach number was caused by a corresponding reduction in compressor-inlet Reynolds number. The change of efficiency with Reynolds number was greater at the lower Reynolds numbers. The performance of two other compressors, each of a different design, indicated similar trends with variation in Reynolds number.

The performance of a specific jet engine was explored without afterburning, at altitudes from 6,000 to over 50,000 feet and ram pressure ratios from 1.03 to 1.6, using fixed-area exhaust nozzles and a variable-area nozzle. Sufficient instrumentation was installed to permit the determination of compressor, combustor, and turbine efficiencies, as well as over-all engine performance. The performance of two types of combustors was also evaluated. High-altitude starting characteristics of the engine were determined with fuels of different Reid vapor pressures. Starting characteristics of an alternating-current ignition system were also determined.

Performance of a turbojet engine with ten afterburner configurations was determined at simulated altitudes. Eight of these configurations were studied in an attempt to obtain adequate shell cooling without sacrificing high-altitude performance. A continuously variable exhaust nozzle was used for all afterburning operation. Both engine and afterburner were controlled by an integrated electronic control.

A knowledge of the effects of atmospheric conditions on engine performance is essential to the prediction of engine performance at a desired flight condition from data obtained at a different flight condition. As part of a broad, general program, the effects of humidity on turbojet-engine performance have been investigated. These effects are generally very small, but under hot humid conditions thrust losses from humidity effects alone may reach four percent. The results of this investigation have been published in Technical Note 2119.

The initial phase of a free-flight investigation of a series of constant-diameter ram-jet engines has been completed. Data on engine thrust, drag, diffuser efficiency, combustion efficiency, and combustion stability have been obtained over a range of free-stream Mach numbers.

An investigation of a full-scale ram-jet engine in an

altitude test chamber at a supersonic flight Mach number of 2.0 and high altitudes was conducted. Included in the investigation was a study of the effects of flameholder geometry on combustion performance.

An investigation was conducted on a single-cylinder, four-stroke-cycle, liquid-cooled test engine, using fuel injection into the engine cylinder and spark ignition, to determine the effect of valve overlap and compression ratio on variation of engine power and specific fuel consumption with exhaust pressure. From data of this investigation, performance calculations were made for a compound power plant, assuming a system in which a steady-flow turbine and compressor are mounted on the same shaft and the turbine power not required for supercharging is returned to the engine crankshaft through gears. The purpose of these calculations was to determine the optimum compression ratio and valve overlap for a compound-engine system consisting of a spark-ignition reciprocating engine and an exhaust gas turbine (Technical Note 2025).

The effects of the engine and coolant variables on the cylinder-head temperatures and coolant heat rejection of a 1650-cubic-inch-displacement, liquid-cooled engine have been extensively investigated and the data have been correlated with the pertinent engine and coolant variables (Technical Note 2069).

SUBCOMMITTEE ON AIRCRAFT FUELS

During the past year research on fuels for turbojet-powered aircraft has been directed toward the achievement of maximum fuel availability, maximum flight range, and maximum engine reliability. The selection of fuels on the basis of these factors has necessarily involved studies intended to show how such fuels might be adapted to current power plants and power plants considered for the future. In these studies, the greatest emphasis has been placed upon combustion-efficiency improvements, the elimination of carbon deposition, and satisfactory starting at sea level and altitude.

Fuel Characteristics

Early investigations conducted in the NACA laboratories indicated the extent to which fuel volatility affects starting and combustion efficiency in engines of current design. Current investigations at the Lewis Laboratory are being conducted to show the influence of volatility of prospective fuels on these factors. The results obtained to date indicate that less-volatile fuels are more difficult to ignite in an engine; however, the ease of starting can be improved by altering the methods of injection.

Studies of combustion efficiency and carbon deposition indicated that Grade JP-3 fuels or low-vapor-pressure fuels derived from JP-3 fuels behaved in a manner

consistent with that of other fuels; that is, combustion efficiency decreased with decrease in volatility and carbon deposition was more severe with fuels of low volatility.

Considerable emphasis is now being placed upon high-density fuels as a possible means of extending flight range. Fuels of this type have high energy contents per unit volume and are being considered for high-speed volume-limited aircraft where fuel storage space is small. In general, high-density fuels tend to form carbon in engines, to burn at low efficiencies, and to be more difficult to ignite. Methods of improving the performance characteristics of these fuels are now being investigated.

Availability of Fuels

For the past several years, the NACA Subcommittee on Aircraft Fuels has been concerned with the problem of selecting the type of fuel that will be available in maximum quantities in the event of a national emergency. As a result of the early deliberation of the subcommittee, the tentative characteristics for a fuel of maximum availability were established. Fuels conforming to these characteristics were later evaluated in engines of current design.

The most critical problem that has arisen to date with the use of this fuel is the loss during high-altitude flight and in rapid climb of the volatile components from the fuel through the aircraft tank vents. The occurrence of these losses has resulted in suggestions that the 7.0-pound-per-square-inch vapor pressure proposed in the tentative specification be reduced. This reduction would cause some reduction in the over-all availability of the fuel. A reduction in the vapor pressure also affects the performance of a fuel in an engine; consequently, investigations have been conducted at the Lewis Laboratory to ascertain the magnitude of these effects.

Smoking Characteristics and Carbon Deposition

Carbon-deposition investigations are difficult and costly to conduct in turbojet engines. An effort was therefore made to develop a satisfactory and economical laboratory method which would permit the prediction of carbon-forming tendencies of fuels. As a result of these studies, a test method was devised that correlated well with engine studies.

Fuel Synthesis and Analytical Chemistry

Concurrently with the engine evaluation of fuels for aircraft power plants, synthesis work was continued to provide, for the engine studies, fuels that are unavailable commercially. The preparation of fuels was restricted to compounds having high densities inasmuch

as these materials offer the greatest promise of high energy content per unit volume. Physical properties of all synthesized materials were determined in the Lewis Laboratory and correlations were found relating physical properties and molecular structure (Technical Note 2081). Relations of this type have been quite useful in the prediction of properties of new compounds and in this way serve as guides for future synthesis projects.

When new synthesis techniques or compounds are developed from this research which are applicable to fields other than aviation the results are published in the chemical journals. Two papers were published in the Journal of the American Chemical Society during the past year, one dealing with the preparation of dicyclic hydrocarbons and the other with the reduction of methylcyclopropylketone to methylcyclopropylcarbinol.

Analytical-chemistry facilities have been used in the past year to devise new procedures for analysis of fuels used in turbojet-powered aircraft. Some of these fuels are sufficiently different from gasoline so that analytical procedures previously developed on gasoline are not suitable for these jet fuels.

Fundamental Fuel Investigations

Through the year, the applied fuel research investigations were supplemented by studies of fundamental fuel characteristics. Flame speeds were determined for a number of pure hydrocarbons that occur in fuels derived from petroleum. The study, though not complete, represents the most extensive investigation of its kind conducted to date.

In addition, one project was conducted to provide a better understanding of the mechanism of flame propagation. This project dealt with the travel of flame through carbon-monoxide-air mixtures and the part played by active radicals in the promotion of combustion.

SUBCOMMITTEE ON COMBUSTION

Effect of Operating and Design Variables on Combustion

Combustion research is closely integrated with fuels research. The fuel is one of the major variables of the problem but there must also be taken into account the many additional variables introduced by gas-turbine and ram-jet engine configurations as well as by the performance and operational requirements. These factors alone introduce many additional combustion research problems. The gas-turbine engine requires that the combustion of the fuel proceed in a stable manner with high efficiency over a wide range of conditions of airplane altitude and speed. The output of hot gas from

the combustion chamber must be closely controlled and stay within given limitations of temperature and velocity. The requirements of the ram-jet power plant are quite similar to those of the gas turbine. Research has been continued toward the objective of improved combustion in turbojet and ram-jet power plants, with emphasis being placed on the design factors that lead to optimum performance.

Studies have been made of the influence of design variables on the performance of turbojet combustors as part of the required effort to achieve stable and efficient combustion at high altitude. One such investigation compared the performance characteristics of two very different can-type combustors and represents a step in the determination of the factors of combustor design that influence the combustion process.

Research investigations have been conducted to determine the optimum method for introduction of air to the combustion zone. The first of these studies was intended to illustrate the effect of primary and secondary air distribution on radial exhaust-gas-temperature distribution. The data obtained indicated that changing the design of the combustor wall will permit control of outlet-temperature distribution. This control of temperature distribution prolongs turbine life and permits more power and efficiency in engine operation.

Subsequent to these investigations, a combustor was designed with these changes and, at the same time, provision was made for proper distribution of dilution air in the combustor. In a performance investigation with this configuration it was found that the new design permitted improved altitude operational limits and improved combustion efficiencies in critical operating ranges. Temperature distribution at the combustor outlet was satisfactory.

Connected-pipe and supersonic free-jet studies of a ram jet were conducted in the Lewis altitude wind tunnel to provide information on the interrelation between supersonic diffusion and combustion. These experiments showed that for low supersonic Mach numbers and for medium altitudes ram-jet pulsations and their undesirable influence on engine performance can be considered negligible.

Investigations have also been conducted to determine the influence of design factors on performance of ram-jet engines. Compact, highly efficient combustors with high heat-release rates are required for effective engines. In such an investigation, three types of flame holders were studied and the relation of the flame-holder position to the fuel-injector position was evaluated.

Because the high temperatures encountered in ram-jet and tail-pipe combustors seriously weaken or even destroy the combustion-chamber walls, techniques of cooling must be carefully investigated. An analytical

study was completed in which temperatures of the combustor walls were determined as a function of the combustor operating conditions and the coolant flow, for combustion chambers cooled with an annular coolant passage around them. In addition, a method for the approximation of temperature distribution in combustion-chamber cooling passages was developed and reported in Technical Note 2067. As part of this problem, it was found that a working chart based upon this method simplifies calculation of pressure drops across the cooling passages.

Another study was made of four combustion-chamber configurations in a large-diameter ram jet. The objective of this investigation was to determine what configuration would provide performance equal to the design requirements for this particular ram jet. One of the configurations permitted smooth operation over a wide range of fuel-air ratios with high combustion efficiency. The magnitude of the fuel-air-ratio range and efficiency fulfilled the design requirements.

One means of increasing turbojet-engine performance is by the use of tail-pipe burners. Projects on tail-pipe burners were concerned primarily with the determination of the optimum tail-pipe-burner configuration. It was found that certain burner designs gave large increases in thrust over the original turbojet-engine thrust.

Effects of Stream Variables on Combustion

An investigation to evaluate a simple, lightweight, internal-regenerative fuel preheating system was conducted. Data obtained at simulated subsonic sea-level flight conditions indicated that useful fuel preheat temperatures were approached within two minutes after burner ignition. Pressure losses caused by introduction of the preheater in the combustion chambers were found to be small.

Kinetics of Rocket-Engine Reaction

Theoretical calculations of rocket performance have been continued and a tabulation of the thermodynamic functions has been published for use in analysis of aircraft propulsion systems (Technical Note 2161).

A theoretical study was made of a method of increasing rocket performance by means of increased chamber pressure and expansion ratio. The results indicated that the increased impulse accompanying an increase in combustion-chamber pressure is almost entirely caused by the increased expansion ratio through the nozzle.

In 1949 the first research program on rocket starting under low-temperature conditions was undertaken in this country. Several propellant-oxidant combinations were found to ignite satisfactorily.

SUBCOMMITTEE ON LUBRICATION AND WEAR

Bearings Research

A preliminary investigation was conducted to determine experimentally the operating characteristics of the three types of turbine roller bearing currently used interchangeably in an aircraft gas-turbine engine. The main difference in the bearing assemblies is in the cage construction. Significant differences exist in the operating characteristics of the bearings investigated. These differences become more apparent at very high speeds. Although all three roller-bearing types are at present used interchangeably in some aircraft gas-turbine engines, a greater factor of safety may result under critical conditions if the turbine roller bearing of these engines was restricted to the one-piece, inner-riding cage-type bearing because of its more reliable performance (Technical Note 2128).

Sliding Friction

A study was made of bearing materials composed of various amounts by weight of molybdenum disulfide (up to 35 percent), silver, and 5-percent copper. The materials investigated were lubricated by a transfer of solid lubricant (molybdenum disulfide) from within the structure of the rider (ball) to the interface between rider and slider. This transfer resulted in the formation of an effective lubricating film (Technical Note 2027).

Decomposition films formed by heating surfaces to which several common synthetic and petroleum lubricants have been applied were studied to determine the effects of such films on friction and load capacity of surfaces. A typical example of the formation of such films is found in the turbojet engine where turbine-bearing temperatures may be high enough to cause decomposition of the lubricant. In general, the films were beneficial to slider surfaces with regard to friction and load capacity when compared with dry, clean, steel surfaces. Friction values with the film materials were in the same general range of values as those obtained in boundary lubrication with the original fluid lubricants (Technical Note 2076).

Fretting Corrosion

An experimental investigation using microscopic observation of the action was conducted to determine the cause of fretting corrosion. The observations and the analysis led to the conclusions that fretting corrosion was caused by the removal of finely divided and apparently virgin material due to inherent adhesive forces. The fretting corrosion of platinum, glass,

quartz, ruby, and mica relegated the role of oxidation as a cause to that of a secondary factor (Technical Note 2039).

SUBCOMMITTEE ON COMPRESSORS

Aerodynamics of Compressors

In attempting to reduce the fuel consumption of turbojet engines at transonic and supersonic flight speeds, the reduction of size and weight of the power plant is important. Reduced size and weight for the same power output can be reflected by reduction of airplane size, thus reducing the thrust required, or by provision of more capacity in the same airplane for additional fuel. Since the compressor and the combustion chamber of the turbojet engine are the principal elements in determining the frontal area and length of the engine, research problems on increasing their output or conversely reducing their size are of direct importance. Compressor research has been continued with emphasis on the aerodynamic problems of compressing air in a compressor of minimum frontal area, minimum length, and minimum complexity.

The theoretical approach to the aerodynamics of compressors has been concentrated on obtaining a working knowledge of the flow phenomena associated with the compressor and its operating conditions. A theory for analysis of the three-dimensional, nonviscous compressible flow in compressors has been developed in which only the average flow conditions are considered in the circumferential direction. The method is being applied to determine the effects of velocity distribution, hub- and tip-radius variation, and compressibility on the flow in a single-stage axial-flow compressor. The results obtained thus far have shown that methods previously used for estimating the meridional streamlines gave results that were approximately correct.

A method has been developed for the analysis of compressible flow in the meridional plane of mixed-flow compressors of arbitrary design (Technical Note 2165). This solution involves the adaptation of the stream-filament theory and numerical integration of the resulting equations that govern the flow. The method was applied to an impeller that had been experimentally investigated and the validity of the theoretical method was shown by the correlation of the analytical and experimental results. Adverse velocity gradients that existed on the impeller hub and shroud surfaces are indicative of flow separation and consequent losses within the impeller passage.

Using the assumption of linearized pressure-volume relation, a solution of the problem of designing cascades for a given turning and prescribed velocity dis-

tribution along the blades in a potential flow of a compressible fluid was obtained (Technical Note 1970). This method has been extended to include the design of cascades with suction slots in the blades for boundary-layer control.

Representative compressor blades of aspect ratios of 1, 2, and 4 have been tested in a low-speed cascade tunnel with solid and porous tunnel walls to determine the effect of tunnel configuration and testing technique on the performance of the blade sections. The results presented in Technical Note 2028 show that, although two-dimensional flow could not be established in any of the solid-wall cascades, two-dimensional flow was obtained in all the porous-wall cascades investigated. The results presented for a typical turbine blade section show no advantage in the use of porous walls for testing cascades through which a pressure drop occurs.

The general theory and method presented in Report 935 for determining two-dimensional compressible flow in turbomachines with sonic flow surfaces have been applied to centrifugal compressors with straight blades (Report 954). The results of this analysis have shown that for straight blades adverse flow conditions existed along the flow path and indicated the desirability of blade designs that incorporate improved velocity distributions.

An investigation of the effect of boundary layer on the losses incurred in an axial-flow compressor stage was conducted in a three-dimensional vortex-generating static cascade. Results of this investigation showed the largest losses to occur at the hub and tip sections of the blade. With a reduction of Reynolds number, the smallest increase in loss was obtained at the hub. The boundary-layer movements determined in the static cascade were found to be similar to those obtained for rotating blades. It was indicated that the effects of centrifuging the boundary layer are of secondary importance.

An investigation has been made to determine the possibilities of obtaining high pressure coefficients by using a constant pressure, high-turning, axial-flow, impulse compressor rotor. Utilizing low-speed cascade-tunnel data, a rotor was designed to produce a turning angle of 75° and a pressure coefficient of 2.40. Low-speed experimental results showed that the rotor approached the design assumptions.

An investigation to determine the performance characteristics of high-pressure-ratio axial-flow compressor stages was made using a complete single stage designed on the basis of the latest available two-dimensional high-speed cascade data. A total pressure ratio of 1.5 for the single stage was obtained at an efficiency of 0.89.

A study of high-mass-flow-capacity inlet stages of

multistage axial-flow compressors was made to determine the effects on performance of high inlet axial velocities. It was found that increased inlet axial velocities resulted in an improved range of operation and increased mass-flow capacity, while maintaining high efficiency and good pressure ratios per stage.

An investigation has been conducted to establish the performance of a high-pressure-ratio multistage axial-flow compressor designed for turbine-propeller engine application. The results indicated that boundary-layer build-up in the latter stages of a high-pressure-ratio compressor of this type adversely affects the compressor performance. Analysis of the data has indicated methods for preventing the deviations from design flow assumptions and for improving compressor performance.

An analysis of interstage flow data obtained from a medium-pressure-ratio multistage axial-flow compressor has indicated the importance of blade wakes and boundary-layer formations on the performance of the compressor. It was found that, because of the design procedures used, the third, fourth, and fifth stages were stalled and that the flow separated at the hub sections when the compressor was operating near the surge point.

A large research compressor, which was designed for obtaining detailed internal-flow measurements in rotating impeller passages, has been investigated at a tip speed of 500 feet per second. Theoretical studies of flow in this impeller indicated an eddy formation on the driving face of the blade; the experimental data, however, showed no evidence of this flow condition. The experimental data indicated that flow separation existed on the trailing face of the blade which resulted in an increase in velocity and piling up of the air on the driving face and a decrease in velocity on the trailing face. The data are being analyzed to determine the factors causing this flow separation and the deviation from design theory.

An investigation of the performance of an axial-discharge mixed-flow impeller in conjunction with supersonic-diffuser cascades has been made. The results of these tests showed that the choking occurred in the diffuser blades at a weight flow considerably lower than the impeller design weight flow, which adversely affected the over-all compressor efficiency and pressure ratio. Deviation from design conditions resulted from the low supersonic Mach numbers and flow distribution at the compressor outlet and boundary-layer build-up in the diffuser.

The potentialities of the supersonic compressor having supersonic flow throughout the rotor have been known; however, the lack of information on the prob-

lems of supersonic turning and diffusion and of interference effects retarded experimental investigation of this compressor type. Recent investigations have added to the knowledge of supersonic diffusion, and preliminary tests of supersonic turning passages have indicated that the basic flow problems can be solved.

An analytical investigation of the performance and of the blade design problems indicated that compression ratios of 6 to 10 per stage can be obtained at reasonable adiabatic efficiencies. An experimental investigation was made at an inlet Mach number of 1.71 of a series of four 90° supersonic turning passages, designed by the method of characteristics. The losses were measured in relation to the inlet stagnation pressure. The smallest loss was obtained in the passage in which separation on the convex surface was minimized by the introduction of a favorable pressure gradient. Tests were also made to determine the mixing losses behind the trailing edges of a two-dimensional cascade of three 90° supersonic turning passages at an inlet Mach number of 1.81. The average turning angle was within 1 percent of the design value. Of the total loss, approximately 5 percent is chargeable to the mixing process downstream of the trailing edges.

An axial-flow compressor rotor designed for supersonic flow throughout the rotor and with a normal shock in the stator was investigated. A high rotor pressure ratio was obtained with uniform flow conditions approaching the design values existing at the inlet to the stator. This favorable air-flow distribution should simplify the stator design problems.

A supersonic axial-flow compressor previously investigated without inlet guide vanes was operated with a set of inlet guide vanes designed to improve the distribution of the inlet air so as to give relatively the same Mach number from hub to tip at the compressor inlet. The use of these inlet vanes resulted in an increase in mass flow, and a decrease in maximum pressure ratio and efficiency. The use of inlet guide vanes increased the flow separation in the compressor and resulted in poorer diffusion behind the normal shock. It was indicated that the unsteady flow field created by the inlet-guide-vane wakes is a significant factor that must be considered in supersonic-compressor design.

Mechanical Aspects of Compressors

The effect of blade-surface finish on the performance of a single-stage axial-flow compressor has been determined using blades having machined and hand-filed finishes. Analysis of the performance data showed the extent to which variations in blade-surface finish had effects on compressor performance. Results of this study will be used in determining manufacturing tol-

erances on blade finishes and should reduce blade-fabrication cost and time.

An investigation has been made to determine the losses in pressure that result from blunt leading edges on supersonic compressor blades.

The vibration characteristics of several symmetrical ball-root-type blades, simulating the mass and the natural frequency of axial-flow-compressor blades, were investigated under various mounting conditions by subjecting them to controlled periodic excitation and centrifugal loading. Looseness of blade mounting reduced vibration amplitude at moderate rotor speeds, but lost its effectiveness as centrifugal force effectively tightened the blades at speeds comparable with normal turbojet-engine speeds.

SUBCOMMITTEE ON TURBINES

Aerodynamics of Turbines

As in the case of the other components of the turbojet engine, research on turbines has been aimed at the solution of problems of improving turbine performance for application to transonic and supersonic aircraft. Turbine research problems also include turbine cooling as well as those of heat-resisting materials which will be discussed in a later section.

A theoretical aerodynamic investigation of the three-dimensional flow in a typical single-stage gas turbine has been conducted to determine the effects of blade loading, radial component of blade force, and compressibility. This analysis is being extended to determine the variation of the state of the gas in the circumferential direction.

The application of the wire-mesh plotting device to predict the flow pattern about a cascade of airfoils in incompressible inviscid flow is discussed in Technical Note 2095. The use of this device for the design of a cascade with a prescribed pressure distribution is also discussed. The results obtained for two typical turbine-blade cascades compare well with experimental data, and several analytical checks of the accuracy of the results are presented.

An experimental study of subsonic turbine blades operating at supercritical pressure ratios necessary for high-power output showed that subsonic turbine blades can be satisfactorily used for high-power output, which results in supersonic velocities at the blade exit. The power output from gas turbines may be increased considerably by the use of supersonic velocities within the machine. In order to evaluate design methods for supersonic turbine blades, three blade profiles have been designed for investigation in a two-dimensional turbine cascade rig.

Thermodynamics of Turbines

A comprehensive research program is being conducted to determine methods of adequately cooling turbine blades. The immediate objective is to eliminate the use of strategic materials from gas-turbine engines. The eventual research objective is to provide methods for building cooled turbines capable of operation at high gas temperatures in order to realize large gains in turbine-engine performance.

In order to attain these objectives, experimental research is under way to determine the heat transfer, coolant flow, and performance characteristics of cooled turbines. Analyses are being simultaneously made of the gas flow about the blade, of the coolant flow through the blade, and of the cooled turbine-engine performance in aircraft installations.

An analysis was made by means of which blade-surface heat-transfer coefficients may be predicted. A system of generalized equations for the laminar boundary layer with heat transfer has been derived. A formula has also been derived for average surface coefficients where the boundary layer is partly laminar and partly turbulent.

Analytical methods for the determination of local values of outside and inside heat-transfer coefficients from measured turbine-blade temperatures have been developed.

The theory for temperature distribution of air-cooled turbine blades has been summarized in a report containing analytically determined equations for obtaining spanwise temperature distribution for air-cooled hollow, insert, and internally finned turbine blades.

An analysis has been made of the air flow through rotating-blade coolant passages of an air-cooled turbine. The simultaneous effects of area change, wall friction, heat transfer, and rotation were included.

Air flow through porous material offers a good possibility for turbine-blade cooling. Generalized boundary-layer equations are being applied and a method is being devised for estimating heat transfer and friction with porous cooling for blade profiles of arbitrary shape for the laminar range.

Liquids, because of their better conductivity, are more effective as coolants than gases. Cooling effectiveness can be further increased by utilizing the large free-convection currents generated by centrifugal forces in rotating turbine blades. A theory for the turbulent boundary layer in natural-convection circulation, which critically affects the designer's choice of coolant-passage diameter-to-length ratio and blade coolant-passage configuration, has been developed.

Experimental data on heat transfer from hot gas to a cascade of cooled impulse blades were correlated by

the Nusselt equation with the fluid properties of the gas based on blade-wall temperature. An average pressure and velocity distribution around the blade was used. All available cascade data were correlated in an identical manner to provide a comparison on a common basis.

An investigation was conducted to determine values of recovery factors at local positions around turbine blades. These values are required to determine the effective gas temperature, or the temperature that must be used for calculating the heat transferred to the turbine blades. Results indicated that for a given local Mach number the recovery factor remained unchanged regardless of the position on the blade.

An investigation is being conducted on an aluminum forced-convection-circulation and a steel natural-convection-circulation water-cooled turbine. Blade-to-coolant heat-transfer coefficients and pumping losses have been determined for both turbines. Pumping losses were found to be small in both turbines. Gas-to-blade-surface heat-transfer coefficients have also been obtained on the aluminum turbine. Correlation of the outside coefficients on the aluminum turbine agreed within 10 percent with static-cascade results and indicated the possibility of using readily obtainable cascade heat-transfer data in designing cooled rotating turbine blades.

Turbine Staging

An experimental investigation of the first stage of a two-stage turbine designed to produce free-vortex flow was undertaken to determine whether the design method produced the expected characteristics and to obtain data for matching the second stage with the first. The results indicated that the radial distribution of total pressure at the stator and rotor outlets was constant, as expected, over the major portion of the radial distance, although the radial distribution of outlet flow angle did not correspond fully to that expected for a free-vortex velocity distribution (Technical Note 2107).

SUBCOMMITTEE ON PROPULSION-SYSTEMS ANALYSIS

Comparative Performance of Various Engine Cycles

The optimum combination of compressor pressure ratio and turbine-inlet temperature was determined by analysis, on the basis of load range, for the turbojet engine in the transonic speed range. Lift-drag and structure-to-gross-weight ratios of the aircraft and the efficiencies of the engine components assumed for the analysis are representatives of the best values obtained either in practice or in laboratory investigations. Effects of the variation, with flight conditions and engine operating variables, on the thrust per square foot of

engine frontal area, specific weight, thrust specific fuel consumption, ultimate range, and range with various pay loads have been analyzed (Technical Note 2088).

Thrust Augmentation

Analytical and experimental investigations of various methods of thrust augmentation of turbojet engines have continued. An analysis of the effect of design and operating variables on the performance of the tail-pipe-burning, water-injection, and bleed-off methods of thrust augmentation was made (Technical Note 2083). In the bleed-off method, air bled from the compressor outlet and burned in an auxiliary burner is replaced by water, which is injected in the engine combustors. Experimental verification of the thrust and liquid consumption, analytically determined, for the bleed-off cycle has been obtained. Methods of analyzing the effects of water injection and the results of an investigation to determine turbojet-engine performance with water injection over a wide range of flight Mach numbers and altitudes are reported in Technical Notes 2104 and 2105. The results showed that the thrust augmentation increases rapidly as the Mach number is increased and decreases as the altitude is increased.

The effect of inlet-air temperature and humidity on thrust augmentation produced by injection of water and alcohol at the inlet of a centrifugal-flow-type turbojet engine has been experimentally investigated. Experimentally observed effects of water injection at the centrifugal-compressor inlet on the compressor performance were used to compute the effectiveness of water injection for augmenting the power of turbine-propeller engines.

An investigation of injection of water and alcohol into the combustion chambers of centrifugal- and axial-flow-compressor-type turbojet engines has been continued.

Heat Transfer

As a part of the experimental program to obtain surface-to-fluid heat-transfer and associated pressure-drop information at high surface temperatures and flux densities, an investigation was conducted to determine the influence of tube-entrance configuration on average heat-transfer coefficients and friction factors. Long approach and short right-angle-edge entrance sections were investigated at average surface temperatures up to 2,000° R and heat flux densities of 150,000 Btu per hour per square foot. These experiments were made at Reynolds numbers above 1,000 with tubes having a length-diameter ratio of 60.

Control Problems

Recent improvements in gas-turbine-engine performance through adoption of afterburners on turbojet en-

gines for thrust augmentation and increased activity in the application of turbine-propeller engines have resulted in a great demand for better controls to relieve the operator of the burden of devoting attention to engine operation. Research on controls for these gas-turbine engines consists of exploration of basic characteristics of engines that result in the need for controls, and studies of how to design control systems that are quick acting, accurate, stable, and safe.

A preliminary investigation was made to determine whether the dynamic characteristics of the engine are simply related to the steady-state operating characteristics (Technical Note 2091).

Inasmuch as high gas temperatures in turbine engines can cause destruction, control systems for this engine must measure the gas temperature. Research on methods of sensing gas temperature has led to the development of the principles of temperature measurement through use of pressure-sensitive systems (Technical Note 2043) and spark-gap breakdown systems (Technical Note 2090). An investigation of the accuracy of pressure-sensing systems for use in controls has resulted in the establishment of engineering design procedures for designing pressure-sensing systems that will follow transient pressures accurately to as high a frequency as desired, and will filter out undesirable pressure fluctuations at all higher frequencies (Technical Note 1988).

In the process of designing a control system, the dynamic characteristics of components planned for the control system must be known. In Technical Note 2109, the experimentally determined dynamic characteristics of a positive-displacement variable-stroke fuel pump are presented.

An investigation of the effects of altitude on the dynamic and control characteristics of a turbine-propeller engine and a turbojet engine with tail-pipe burning has been made in the Lewis altitude wind tunnel. The results showed that the engine dynamic characteristics varied with altitude in accordance with a rationally derived law.

SUBCOMMITTEE ON HEAT-RESISTING MATERIALS

Properties of Heat-Resisting Materials

The current aircraft gas-turbine-blade alloys exhibit considerable nonuniformity in their structures and physical properties. This often results in a very broad life dispersal curve with the first few blade failures occurring as early as a third of the maximum blade life. An investigation was conducted to determine the effects of an aging treatment on the life of a typical cast alloy fabricated into small blades and operated at approximately 1,500° F. and a stress of 20,000 psi

at the blade-failure plane. Twenty blades were aged for 48 hours at 1,500° F. and were compared with thirty-three unaged blades in a type B turbosupercharger spin rig. Aging, which has been reported to harden this alloy and to improve its stress-rupture life, apparently improved the time for initial blade failure, the average life, and the uniformity of the life of the blades tested. The lives of the last blades to fail were not appreciably affected by the aging treatment (Technical Note 2052).

Recent tests have indicated that thermal shock plays an important part in the failure of such heat-resisting alloy parts as nozzle blades. An investigation was undertaken to determine the relative resistance of six cast high-temperature alloys to cracking from thermal shock. The thermal-shock test procedure consisted of a controlled water quench of the symmetrical edge of a uniformly heated, wedge-shaped specimen. The heating-and-quenching cycle produced an elongation or deformation of the quenched edge, with the total elongation increasing with the resistance of the material to thermal shock. Materials having similar thermal properties, such as the coefficient of linear expansion, conductivity, and specific heat, were shown to have widely differing resistance to thermal shock. Metallurgical examination of the alloy structure and study of the nature of crack propagation yielded no correlation between the structural characteristics and resistance to cracking by thermal shock. An analysis of the manner in which the thermal-shock crack formed and progressed into the specimen and an examination of available data on the notch impact strength of cast high-temperature alloys indicated that there might be a relation between notch impact strength and resistance to cracking by thermal shock. The alloys investigated, listed in the order of decreasing resistance to thermal-shock cracking, were S-816, S-590, AMS-5385, 422-19, X-40, and Stellite 6 (Technical Note 2037).

The NACA sponsored investigation at the University of Michigan on the fundamental effects of aging and solution-treating on the creep characteristics of N-155 alloy has been continued. The properties of low-carbon N-155 alloy were obtained from 1,200° to 1,800° F for several typical commercial heat treatments. The data show that there were large differences in strength between the heats of bar stock at test temperature above 1,200° F, except when a 2,200° F solution heat treatment was used. This indicates that the hot-working conditions prior to final treatments have a pronounced effect on the physical properties unless the final heat treatment involves high-temperature solution treatment to minimize variations in the hot-working conditions.

The University of Michigan investigation also included a study of the rupture properties of low-carbon

N-155 alloy and a 20 Cr-20Ni-20Co+2Cb alloy made with a columbium-tantalum ferro alloy. This investigation was conducted as a part of the NACA program on the substitution and conservation of strategic materials.

An investigation was conducted to evaluate the engine service performance of the nozzle blades of columbium (AISI 347) and titanium (AISI 321) stabilized stainless steels. The results indicate that these two steels are interchangeable for such applications. The blade cracks that occurred, for the most part, in the edges of the blades were attributed to thermal stresses and oxidation caused by the exhaust gases. The cracks progressed through the material along the grain boundaries.

As a part of the NACA research program to improve the service life of heat-resisting alloys, an investigation was sponsored at the National Bureau of Standards aimed at developing improved protective coatings for exhaust-gas manifolds and similar high-temperature parts exposed to corrosive gases. The results of preliminary tests of heat exchangers used in supplying heated de-icing air in the B-36 airplane indicate that a three fold improvement in operating life can easily be obtained. In addition, the effectiveness of a ceramic coating in preventing corrosion by lead bromide has been shown. Work on protective coatings for molybdenum has resulted in a coating that will withstand 3,500° F at very low creep rates for approximately a half hour.

Preliminary Studies of the Effect of Radiation on Materials

A theoretical analysis of absorbers whose radioactivity is time-dependent has been completed. Matrix methods were employed as a tool in the analytical determination of the intensity of radioactivity and the amount of heat generated in any portion of a thick absorber. The method was applied to the following three cases: (1) Plane source of monochromatic radiation of a single type at normal incidence to a plane absorber, (2) plane source of polychromatic radiation of a single type at normal incidence to a plane absorber, and (3) plane source of polychromatic radiation of several types at normal incidence to a plane absorber (Technical Note 1919).

Matrix methods have been employed in the solution of absorption problems in which the incident radiation is a known arbitrary function of time. The case of a plane source of polychromatic radiation of several types at normal incidence to a plane absorber was considered. The method was applied to a hypothetical example in which the amounts converted to thermal energy were

found for a time-dependent source (Technical Note 1952).

A theoretical treatment of absorption problems is presented in Technical Note 2108, in which the following cases are simultaneously considered: (a) Radiation is normal to an absorber of which the stations are plane parallel surfaces, (b) radiations are of several polyenergetic types, (c) induced radioactive isotopes decay

to stable atoms in multistep decay processes, and (d) radiations from the absorber affect the time-dependency of the source activity.

In Technical Note 2026 tables are presented for determining the total-absorption coefficients, as well as the intensities and the spectral distribution of gamma rays at any given scattering angle. Only thin scatters are treated and secondary effects are neglected.

AIRFRAME CONSTRUCTION RESEARCH COMMITTEE ON AIRCRAFT CONSTRUCTION

Increased emphasis has been placed by the NACA on a study of the many problems in the field of airframe construction. This emphasis is evidenced in the planning of new facilities to study the structural loads encountered in landing and ground handling of airplanes. Attention directed toward airframe construction problems has also made possible an extension of what had heretofore been considered only aerodynamic studies into a realm of more direct interest to the structural designer. As in the past a considerable amount of the NACA research effort on structural materials and structures was performed under contract by universities and other nonprofit scientific institutions.

Research within the airframe construction field is discussed in the following pages and appears under the appropriate subcommittee heading.

Research Techniques and Instrumentation

It has become possible through the use of high-speed automatic computing machinery to extend greatly the range of theoretical investigations particularly those concerned with the dynamics of the structure. The Reeves Electronic Analogue Computer, more commonly called the REAC, the Bell Relay Computer, and IBM punched card computing equipment have been used by the NACA for this purpose.

Because of the immense amount of computer time and effort required for working up test data, attempts are being made to devise means for incorporating at least part of this work with the measuring instrument itself. Two instruments have already been constructed that effect considerable saving in this respect. One of these is a pressure-distribution manometer that records wing pressure distributions as plots of pressure against chordwise position. These recorded plots are immediately available on the recording medium for preliminary viewing or for manual integration to secure lift and pitching-moment coefficients. Another device is an electrical integrator that plots section lift and moment coefficients against Mach number.

For the statistical study of loads encountered in routine airline operations 75 VG recorders of the oil-damped type have been placed in service. A new instrument which records velocity, normal acceleration, and altitude as a time history (designated the NACA VGH recorder) has been built for use in scheduled aircraft so that operational information and gust-load experience of the aircraft on a time scale can be secured. In order to correlate landing loads of land-based airplanes with airplane vertical velocity at touchdown, a device was built to record the latter quantity. Recording instruments based on free gyroscopes have also been developed which record their attitude to better than 0.1° under dynamic conditions. These recorders are useful to determine the dynamic twist of wings under gust loads. In addition a miniature two-component accelerometer was developed to record landing loads encountered in the hydrodynamic testing of flying-boat models.

SUBCOMMITTEE ON AIRCRAFT STRUCTURES

Stress Distribution

The aerodynamic advantages of sweptback wings in the transonic speed range have established their usefulness in modern airplanes. Such wings require an unconventional construction which has necessitated research on their structural characteristics. Previous work in this field was confined to the study of the stresses and distortions for symmetrical loading conditions. Tests were therefore made of a 45° sweptback box beam under antisymmetrical bending and torque loads. The investigation revealed that the antisymmetrical loading magnified the effects of sweep which were previously observed for symmetrical loads on the same box beam. These effects are a concentration of normal stress and vertical shear stress in the rear spar near the fuselage. An additional feature of the antisymmetrical loading was the appearance of large shear lag effects in the carry-through section, particularly

for bending. The results of this investigation are presented in Technical Note 2054 which also includes a method for calculating the spar deflections.

The sandwich plate used in aircraft construction consists of a lightweight low-stiffness core material between two high-stiffness cover sheets. This low-stiffness core material (which might be, for example, balsa, plastic foam, honeycomb, or corrugated metal sheet) necessitates consideration of the shear flexibility which is usually found negligible in ordinary plate problems. A previous theory which included this effect for flat sandwich plates has been published, but there was a need for an extension of the theory to curved sandwich plates, orthotropic as well as isotropic. Accordingly, a theory was developed which takes into account deflections due to transverse shear, and covers those types of sandwich plates having constant cylindrical curvature, with similar properties on the average above and below the middle surface, and also essentially constant core thickness (Technical Note 2017).

New York University has developed a theory for predicting the stress distribution in rectangular, stiffened plates under axial compression after buckling has occurred. This theory makes a definite contribution in that a considerable improvement in accuracy with no more computational labor has been achieved.

The stress-concentration factors calculated by the theory of elasticity become invalid when the material around the discontinuity is stressed into the plastic range. An investigation has been made to study the effects of a circular hole in a large flat plate loaded in simple tension. The results of this theoretical study, which have been confirmed experimentally, reveal that a very simple equation can be given which will predict the stress-concentration factor when plasticity is considered (Technical Note 2070). The simple form of the equation which was derived only for the case of a circular hole suggests that corresponding formulas be made empirically for other types of discontinuities.

Stability

A general problem that has confronted aeronautical engineers for many years is that of how to design the stiffening members in shell structures where the purpose of the stiffening members is to maintain shape. In such problems the uncertainty lies in how stiff those members should be. Accordingly, in an effort to supply information on this subject as well as to lay ground work for future research, a study was made of the ring stiffness required to hold the shape of a circular cylinder in torsion. The results of the study on ring stiffeners are presented in the form of design charts in Technical Note 1981, together with experimental verification.

Where a curved rectangular panel of skin on the surface of an airplane is bounded by rather heavy stiffeners, the question arises as to whether it might not be advantageous to employ one lightweight stiffener in the middle of the panel to stabilize further the curved plate. This question was studied for the case when shear is applied to the panel. The results of this investigation show the effect of a single additional stiffener, either spanwise or chordwise, on the stability of the curved panel (Technical Note 1972).

Tests have shown that the effect of internal pressure is to raise the buckling stress for curved sheet. No adequate theory, however, existed to explain this effect and predict the magnitude of the increase. Since flight at high altitude necessitates internal pressure in cabins and the lifting air pressures on the surface of wings provide the equivalent of internal pressure inside wings, a fundamental, experimental, and theoretical study was undertaken on the strengthening effect of internal pressure. The results of the investigation show that by use of large-deflection theory the magnitude of the increase caused by pressure may be predicted with good accuracy (Technical Note 2021).

It is known that the usual Euler formula for column strength applies to only very narrow plate columns. The results of a theoretical study which was undertaken show the effect of width of plate on the buckling stress in the transition from very narrow to very wide plate columns (Technical Note 2163).

Most of the sheet used in aircraft structures is clad with a material having superior corrosion resistance but lower yield stresses than the core material. How this cladding material should be taken into account in the stability calculations for plates had been a question only partly answered. Accordingly, this subject was investigated and corrections were obtained. They are given in Technical Note 1986 where supporting experimental evidence is also presented.

The parts of an airplane structure, especially a curved panel with skin on the wing and fuselage, are subjected to combinations of shear and direct stress, and their strength in that condition of combined loading is one of importance to designers. In order to supply information on that subject, a theoretical and critical study of this problem was undertaken based on a theory developed recently for solving curved-plate problems in the elastic range. The results of this study of combined strength of curved plates are presented in the form of charts for five different length-width ratios in Technical Note 1928 where experimental data are also presented to demonstrate the validity of the theoretical curves.

The strength of long flat plates under combined shear and longitudinal compression had been satisfactorily solved for the elastic stress range years ago, but the

question was not answered as to how loading to high stresses where plastic buckling occurred would affect the interaction curve. Accordingly, a study was undertaken of this problem and a deformation type of theory of plasticity was employed which has been found adequate for the buckling of plates in compression alone and in shear alone. The results of this study, presented in Technical Note 1990, confirmed the use of a parabolic interaction curve on plastic buckling which had previously been derived only for buckling in the elastic stress range.

A theory for plastic buckling of plates was developed by the Langley structures research staff some years ago. This theory gave very good results when applied to an isolated plate. In order to check the accuracy of this theory when applied to plate assemblies, a study was made of the compressive buckling stress for H- and Z-sections which were of such proportions as to develop plate instability in the plastic stress range. The theory is presented in Technical Note 1971, together with a comparison with experimental results.

The strength of plates when loaded beyond buckling is a fundamental problem in the strength calculation of aircraft structures. The methods of calculation have been based upon a mixture of empiricism and theory which has developed over a number of years. Theories have always been based on elastic considerations, and an empirical correction factor was introduced to take into account the effects of plasticity in order to make the formulas fit test data. The increasing understanding of plasticity in materials has made possible a more rational attack on this problem. The first case considered is that of a long flat plate or flange hinged along one side edge and free along the other side edge and loaded in compression. The fundamentals of the same theory of plasticity which had successfully predicted the buckling strength of plates in the high stress range were employed. Rotations of the flange as well as the stress distribution in the flange were calculated and found to be in very good agreement with the direct measurement of these values. The results of this theoretical and experimental study are presented in Technical Note 2020.

In an effort to provide large spaces inside wings for removable gas tanks or other purposes and to reduce the weight of internal stiffening structure, a study was made of the use of posts to stabilize the compression skin by connecting it to the tension skin on the other side of the wing. The case studied was that of a box beam where the tension and compression covers were relatively thick plates. The results of this study are presented in the form of design charts (Technical Note 2153). The University of Minnesota has developed a method of designing tension-field beams so that the

webs and uprights are of about equal strength. Charts and tables were prepared to aid the designer to proportion beams economically.

The attachment of stiffeners to the skin surface of the metal covering of airplanes requires a multitude of rivets. In order to reduce the man-hours and costs, it is desirable to reduce the number of rivets to the minimum required for the stiffener to perform its function satisfactorily. This problem has been studied experimentally over a period of several years and a number of papers have been issued presenting the results from time to time. In the past year the results of this extended study have been generalized in the form of a summary report, Technical Note 2139, in which is presented a single curve which takes into account the effect of riveting on the strength of spanwise stiffened compression panels.

An experimental study was made to extend the data on the compressive strength of skin-stiffener panels to the proportions suitable for thin, high-speed wings. Data were obtained for 75S-T6 aluminum-alloy panels with longitudinal Z-section stiffeners, particularly in the range of thicker skins and smaller, more widely spaced stiffeners than had previously been considered (Technical Note 1978).

Vibration Characteristics

Methods of calculating modes and frequencies of aircraft structures ordinarily require a separate and independent calculation for each modification to the structure. As such calculations must be made many times for the many modifications required to meet all operation conditions, a method has been developed to simplify the calculations of these modes and frequencies which allows the effect of the modifications to be obtained directly from the modes and frequencies of the unmodified structure (Technical Note 2132).

Structural Response to Dynamic Loads

When an airplane flies through gusty air or when it effects a landing, transient stresses arise in the structure which may play an important role in the design of the airplane structure. These stresses are, in general, not computable from an applied load as in purely static cases because the load itself depends either wholly or in part upon the motion and deformation of the airplane structure. The physical conditions which describe the problem are the gust of air or the approach to landing governed by piloting technique, combined with the structural and aerodynamic properties of the airplane. Because of the great complexity of the problem, approximations directed toward isolation of the load from elastic deformations have frequently been employed. A method, which is free from this limitation and yet

remains within the realm of practical usefulness, has now been developed for the response to gusts. This method, presented in Technical Note 2060, takes into account the flexibility of the wing in bending and twisting, the fuselage deflection, the vertical and pitching motion of the airplane as a whole, and some of the tail forces. The method employs a matrix-recurrence relation derived from consideration of difference equations. Although the application discussed in the report emphasizes an airplane flying into a gust, the possibilities of applying the method to other transient problems, such as landing impact, are discussed.

SUBCOMMITTEE ON AIRCRAFT LOADS

Steady Aerodynamic Loads on Wings

The subject of load distribution continues to be an important one not only because of the wide variations in wing configurations employed in aircraft and missile design but also because of the extended speed range being considered. The determination of load distribution is further complicated by structure flexibility and the interaction between the relatively large nacelles and fuselages employed in modern aircraft design. Theoretical studies of load distribution have been accelerated because new analytical tools have been adopted and because experimental verification has shown that theoretical studies will provide an adequate and useful solution to many problems.

For wings of relatively high aspect ratio, lifting-line theory was adequate for determining load distribution; however, the aerodynamic and structural demands have turned attention toward low-aspect-ratio wings and, as a consequence, modifications to this method or more suitable theoretical methods were required. Additional emphasis has therefore been placed upon the applications of slender-wing and wing-body theory, and there are indications that this theory will provide a good first approximation to the aerodynamic forces in the transonic speed range for low-aspect-ratio wings. The theoretical results from one investigation of the spanwise and chordwise distribution of loading, the lift, and the induced drag for a family of slender plan forms based on linearized lifting-surface theory are presented in Technical Note 1992. In Technical Note 1973 the virtual-mass concept and Weissinger method were utilized to prepare a number of charts by which span distribution may readily be determined for low-aspect-ratio wings for fairly conventional configuration.

Theoretical studies of the subsonic loadings on wings of arbitrary plan form have been extended to include loadings due to rolling, aileron deflection, and flap de-

flection. Charts, tables, and computational aids which enable the rapid determination of loads over the wing and/or flap when the plan form is defined are presented for the unsymmetrical case in Technical Note 2140. Procedures are given which, within limits of theory, account for the effects of section-lift-curve slope and compressibility. From the theoretically determined loadings, factors such as lift-curve slope, induced drag, spanwise center of load, and, with fair accuracy, aerodynamic-center location can be found.

At flight speeds slightly above the speed of sound the flow about an airfoil section is characterized by a detached shock wave which stands in the stream forward of the leading edge of the airfoil section. Under these conditions the theoretical determination of the forces on the airfoil is seriously complicated by the existence of a region of mixed subsonic and supersonic flow between the airfoil and the detached shock wave; however, methods have been derived for calculating the flow field for the case of the detached shock wave forward of a finite wing.

In order to facilitate application of the theoretical knowledge of wing loading to the design of supersonic aircraft, existing information has been summarized. Technical Notes 1916 and 2007 treat triangular, trapezoidal, and related plan forms at moderate supersonic speeds and fill gaps in previous theoretical work by including the effects of sideslips. Technical Notes 1991 and 2093 consider sweptback wings with interacting leading and trailing edges including the effect of wing taper and tip shape. Lift-cancellation techniques for determining the load distribution on thin wings at supersonic speeds are presented in Technical Notes 2145 and 2147 because these methods are simpler to apply to some wing plan forms than previously developed methods.

Experimental verification of wing load distributions has been obtained throughout the subsonic, transonic, and supersonic speed range for a series of wing plan forms and the results show compressibility effects that are not apparent from linearized theory, but which significantly alter load distributions. Detailed information concerning load distribution has been obtained through extensive measurements of surface pressure over wings, some models being equipped with plain trailing edges and ailerons and an elementary analysis comparing pressures measured on airfoils at Mach numbers near 1 with those computed for Prandtl-Meyer flow indicates good agreement. Large-scale wind-tunnel tests have shown the presence of a separation vortex emanating from the apex of sweptback wings having sharp leading edges which has considerable influence on the wing spanwise and chordwise pressure distribu-

tion. An investigation is reported in Technical Note 1967 which is concerned primarily with comparing over-all loads measured by pressure-distribution or electric-strain-gage techniques and indicates clearly the advantages of each technique.

Airplane and missile flights at either high altitudes or heavy wing loadings require operations at higher angles of attack than have been customary in the past. Consequently, the determination of maximum available lift has become increasingly important. During the past year a series of investigations have been carried out in which the effect of angular velocity on maximum lift at various Mach numbers has been measured up to a Mach number of 0.8. This material has been reported in Technical Note 2061 and indicates that the increase in maximum lift due to pitching angular velocity is small above a Mach number of 0.6. Tests have been conducted at subsonic and transonic speeds to determine the maximum-lift characteristics of sweptback wings; as with unswept wings the results show a large effect of Mach number on the maximum lift. Some data were also obtained in the lower Reynolds number range, thus extending the regime where experimental data are available on the effect of Reynolds number on maximum lift at low Mach numbers.

Maneuvering Aerodynamic Loads on Wings

The design trend toward higher-performance aircraft and missiles together with the development of aids that permit pilots to withstand greater acceleration forces has increased the severity of maneuver-load design conditions; consequently, effort is being directed along statistical lines to determine the frequency with which loads of various severity are imposed on aircraft as a result of maneuvers. More exact methods for analyzing maneuvers have also been considered and Technical Note 1965 presents two such methods for determining the impressed force from a measured response.

Load distributions resulting from unsteady motions of thin wings at supersonic speeds have been analytically evaluated and presented in Technical Note 2034. The method presented is applicable to a large class of wing plan forms and to arbitrary motions as long as the rate of change of wing attitude is sufficiently small.

A method for calculating the pressure distribution and damping in steady roll at supersonic Mach numbers of thin, flat, sweptback wings having all leading edges subsonic is reported in Technical Note 2047. As an illustrative example the pressure distribution and damping derivative of an untapered sweptback wing were calculated, but, because the method was considered to be laborious in practice, a shorter method was derived which is sufficiently accurate for most applications.

Loads on Tails and Control Surfaces

Supersonic flight has increased tremendously the demands on tails and control surfaces for stabilizing and maneuvering aircraft and missiles. These demands are reflected in increased loads in the control system and increase in booster capacity as well as in increased structural loads in the control surface itself. A coordinated program of research has been pursued to furnish data for the design of tails and control surfaces, including both theoretical and experimental procedures.

Experimentally determined low-speed lift and hinge-moment parameters of control surfaces with and without sweepback have been compared with values computed by several theoretical procedures. The most satisfactory theoretical method was one involving adjustments to the section values of the lift and hinge-moment parameters for the effect of induced angle of attack and induced camber to obtain values for a finite aspect ratio. The necessary information for use of this method is incorporated in design charts which eliminated a need for complete understanding of lifting-surface theory upon which the method is based.

A method has been devised for determining the horizontal-tail loads to be used in design. This method is based on a prescribed maneuver rather than upon the more commonly used criteria of a prescribed elevator motion and is reported in Technical Note 2078. To supplement theoretical methods for determining tail loads, an analysis has been made of available data on angular accelerations which are directly related to horizontal-tail loads. These data which include the maximum angular accelerations encountered in airplanes tested over the past 18 years and simple summaries for deriving angular accelerations are reported in Technical Note 2103.

Experimental data are being obtained by both flight and wind-tunnel tests to supplement theoretical tail-load studies. Flight investigations are currently under way to obtain horizontal- and vertical-tail loads on modern high-speed-type aircraft for various flight maneuvers. The results obtained thus far indicate that the measured loads agree well with those that were predicted from high-speed wind-tunnel data and those computed by available analytical methods. High-speed wind-tunnel investigations have provided information concerning control-surface hinge-moment parameters and loads on tail surfaces of varying sweep as well as information on downwash angles and dynamic-pressure characteristics in the region of probable tail locations.

As part of a general investigation to determine flap design criteria for wings having plan forms suitable

for transonic and supersonic speeds, studies were made on an unswept tapered wing with 0.25-chord plain flap and were reported in Technical Note 2080. Studies of the effects of sweep on this wing configuration indicate that existing theoretical and empirical methods for predicting the lift effectiveness of flaps of various spans agree satisfactorily with experimental results. Additional high-speed wind-tunnel measurements of pressure distributions over plain trailing-edge ailerons show that adverse changes in loading and hinge moments increase considerably at transonic speeds.

Loads on Bodies and Wing-Body Arrangements

Renewed interest in the aerodynamic characteristics of bodies of revolution, particularly in the supersonic speed range where the body becomes a major component of missiles or supersonic aircraft, has led to the formulation of an approximate theory for the prediction of the forces and moments on slender inclined bodies. It is well-known that simple potential theory does not give results which are in good agreement with experiment; consequently, in Technical Note 2044 it is shown that a simple allowance for viscous effects yields pressure distributions which are in reasonable agreement with experiment in both subsonic and supersonic speed ranges. A new method for calculating the flow in the vicinity of open-nosed bodies at supersonic speeds (Technical Note 2116) provides a simple procedure for determining the pressure distribution over the forward portions of open-nosed bodies, and, in addition, yields formulas for determining the variation in angle and strength of the initial shock wave with distance from the body. An analysis has been made of the effects of compressibility on the pressure coefficients about several bodies of revolution by comparing experimentally determined pressure coefficients with corresponding coefficients calculated by the use of the linearized equations of compressible flow. The results show that the theoretical methods predict the changes in pressure coefficients over the central portion, but not near the nose of the body.

Rocket-model-flight, wind-tunnel, and free-fall methods of testing have provided data on the variation with Mach number of the pressure distribution over fuselages and wing-fuselage combinations. Data for the fuselage alone are, over most of the body, in good agreement with a complete linear theory but for many practical afterbody shapes complex higher-order theories are required for accurate prediction of the pressures.

Pressure-distribution measurement and load-coefficient data have been obtained in flight for a conventional front and rear sliding canopy which had previously been tested in the Langley full-scale tunnel. The

principal conclusion of the wind-tunnel tests as to the effect of canopy position, yaw, and power and lift coefficients on the pressure distributions were confirmed by the flight results.

Wing-Body Interference

Present-day airplane and missile designs indicate a pronounced trend toward larger fuselages in combination with wings of lower aspect ratio than have been considered in the past. This trend increases the importance of the wing-body interference on the aerodynamics of the aircraft. The results of an investigation of load distribution, lift, pitching moment, side force, and yawing moment which treats the interference effects between a circular fuselage and either a single or cruciform wing have been presented in Report 962.

In an investigation of the interference effects of large fuselages in combination with low-aspect-ratio wings the wing loads were measured independently but in the presence of the fuselage. Three fuselages providing variation in the ratio of fuselage diameter to wing span were tested in conjunction with an unswept wing having a thin sharp-edged section. Wind-tunnel measurements were also made of the interference effects of a nacelle on a swept wing with provisions for obtaining very complete information on the pressure distribution at high subsonic speeds.

Buffeting

One of the first factors of concern in the study of buffet characteristics of airplanes is the determination of the lift coefficient and Mach number at the onset of buffeting as detected by the pilot or by suitable instruments. A second factor is the relation of the buffet boundaries so determined to some criterion which will define the occurrence of flow separation on some major component which presumably is causing the buffeting. Information on these two points has been obtained from a study of existing flight records which had been originally obtained and analyzed for purposes other than a study of buffeting characteristics. It was found that, in general, the trend of the buffet boundaries indicated that flow separation on the upper surface of the wing was the primary cause of the buffeting. A criterion showing a consistent relation to the buffet boundaries was established.

The wake behind an airfoil in subsonic and transonic flow has been studied using a special electronic survey head which measures the fluctuations of the total pressure and the stream angle in the wake. Flight measurements have also been made of the buffet boundary and peak normal-force coefficients at high Mach numbers and these measurements indicated that, in the Mach number range investigated, the buffet boundary falls

considerably below the maximum available normal-force coefficients.

Aeroelasticity

The requirements of long-range, high-speed, high-altitude operations often result in a relatively flexible airplane compared with previous designs. If sweepback is utilized to increase the operating speeds at high altitudes, the bending of the wing not only affects the spanwise load distribution, but also overshadows the usual spanwise load changes due to the effect of torsional moments on wing twist. Previously strip theory combined with matrices has been employed in calculating the spanwise lift distribution and the attendant changes due to induced twist. The need for a mathematically simple approach which included the aerodynamic refinements contained in lifting-line and lifting-surface theories prompted the development of a method based on a relaxation approach utilizing aerodynamic loadings obtained from Weissinger's simplified lifting-surface theory together with simple beam theory. By this means the aerodynamic spanwise load distribution is expressed in a convenient form which reduces detailed computing involved in extensive aeroelastic calculations for many flight conditions to the calculation for a single set of flight conditions. The method is simplified further by an abbreviated solution to the relaxation process.

As part of the NACA transonic research program a high-speed wind-tunnel test has been undertaken to investigate the aeroelastic characteristics of sweptback wings on a typical fuselage. Data were obtained on forces, moments, downwash, dynamic pressure characteristics, and tuft behavior. The results of this investigation indicate large effects of aeroelastic deformation on the lift-curve slopes and longitudinal stability of the models.

A flight investigation on a modern transport airplane was undertaken in order to determine the effect of the dynamic response of a wing in rough air upon the normal acceleration measured at the airplane center of gravity. During flights in clear-air turbulence simultaneous acceleration measurements were taken at the airplane center of gravity and at several stations along the wing span. In Technical Note 2150 an analysis of the data obtained indicates that the peak recorded center-of-gravity acceleration increments were on the average of 20 percent higher than the true airplane acceleration increments. There appeared to be smaller changes in acceleration with the weight and speed changes involved, but this effect could not be substantiated.

Water-Landing Loads

The need for increasing the speed of modern aircraft has led to the development of seaplane configurations

having high length-beam ratio and low aerodynamic drag. Fortunately the configurations exhibiting low-air-drag characteristics in flight generally show reduced impact loads in landing; nevertheless, hydrodynamic landing data are required. In Technical Note 2015, data from landing tests in the Langley impact basin of a heavily loaded V-bottom hull are presented as nondimensional coefficients varying with the trim and flight-path angle at water contact.

A second phase of the investigation of hydrodynamic pressure distribution on hull bottoms during landing has been reported in Technical Note 2111 where initial impact conditions and maximum experimental pressures are presented together with time histories of the velocities and pressure distributions for several representative landings in the impact basin. It was shown that the instantaneous pressures for a given draft, trim, and location on the hull bottom are directly proportional to the square of the velocity normal to the keel. The results are presented as three-dimensional plots of instantaneous pressures varying with time and are compared with available theory.

A comparison of data from 50-full scale sheltered-water landings with rationalized design specifications for loads and pressures in sheltered-water impacts indicates that the experimental over-all loads were smaller than specified while local forces were of the same order as specified. A smooth-water full-scale landing investigation was conducted for the purpose of comparing measured and calculated wing bending moments during hydrodynamic impact and the results reported in Technical Note 2063 showed good agreement between measured and computed values.

Gust Loads

Although research on gust loads has been carried on for many years and many of the results have been incorporated in design rules, these data have either been issued piecemeal or not published at all; consequently, a compilation of available information on gust loads, which includes all NACA material available on gust loads up to about October 1947, has been issued as Technical Note 1976. The material is arranged according to the three principal phases of the gust-load problem: (1) The determination of the gust structure; that is, the size, shape, intensity, and frequency of occurrence, (2) the reaction of any airplane to gusts of known structure, and (3) the determination of the operating statistics. Additional V-G data obtained from several transport airplanes of a four-engine type during post-war commercial operations on trans-Pacific and Caribbean-South American routes of the same airline have been analyzed and presented in Technical Note 2176.

Past attempts to study the airplane stability parameters most influential in determining the airplane motion in a gust have been hampered by the complexity of the equations of motion and by the time consumed in their solution. It was therefore desirable to develop an analytical method for calculating airplane motions in a gust that would be mathematically practicable, would give reasonably accurate results, and would require only a moderate expenditure of time. Such a method based on a unit-jump or arbitrary forcing function is derived in matrix notation and presented in Technical Note 2035. The solution for the airplane motions for the stick-free condition is modified by neglecting the elevator terms so that the effects under similar stability conditions may be calculated with the stick in a fixed position. If the complete response of the airplane is known, wing and tail load may be readily computed.

For many problems of gust loads it is satisfactory to calculate the loads for a rigid airplane restrained in pitch under the action of a gust. Previous investigations have presented solutions for particular mass parameters and gust shapes, but they have not been considered sufficiently accurate. The equation of motion has therefore been solved for a large range of mass parameters to obtain charts of airplane reactions to specific gusts and to provide a means for obtaining loads on airplane wings for arbitrary gust shapes. The charts are presented in Technical Note 2036 based on two-dimensional unsteady-lift curves and a numerical solution of the equation of motion.

An important phase of gust-load investigations is the development of techniques for estimating the probabilities of encountering the larger gust loads and gust velocities. Technical Note 1926 shows that the statistical theory of extreme values can be used to predict the frequency of encountering the larger gust loads and gust velocities for specific test conditions as well as commercial transport operations. The extreme-value theory provides an analytical form for the distribution of maximum values of gust load and velocity. Methods of fitting the distribution together with a method for estimating the reliability of the predictions are presented. Results obtained by applying the theory of extreme values to available gust-load data indicate that the estimates of the frequency of encountering the larger loads are more consistent with the data and more reliable than those obtained in previous analyses.

By means of the NACA VGH recorders samples of time-history data of airspeed, altitude, and normal accelerations have been obtained from modern airplanes in commercial transport operation. These data extend existing knowledge of the maximum acceleration and airspeed data obtained by means of the NACA

V-G recorder and define the distribution of accelerations experienced in greater detail. The frequency distributions of normal accelerations and of effective gust velocities indicate differences in the gust loads experienced at low and high altitudes, but no conclusions are warranted because of the limited data sample obtained to date.

Inasmuch as bending deflections of sweptback wings are a possible means of gust alleviation, an investigation was made in the Langley gust tunnel to obtain experimental data on the amount of alleviation that might be expected for a representative sweptback-wing configuration. The model used in the investigation had 45° sweptback wings with hinges between the root section and the wing panels. The wing hinges were restrained by torsion springs that allowed the panels to deflect in bending but not in twist. Tests of the model consisted of flights of the model at a forward speed of about 60 miles per hour through a sharp-edge gust of about 10 feet per second with the wings locked in neutral position and then with the wings free to deflect or respond to the loads imposed by the gusts. The results of this investigation reported in Technical Note 1959 indicated that wing flexibility resulted in over-all reduction in gust load of approximately 8 percent for a sharp-edge gust and 14 percent for a 9-chord gust. The effects of pitching motion caused by a forward movement of the aerodynamic center when the wing was deflected were very large and analysis has indicated that the alleviation due to wing bending alone was approximately 20 percent. It appears therefore that, unless adverse pitching motion can be eliminated or reduced, the gain in over-all load reduction will be small. The net reduction in bending moment, however, may be appreciable because the outboard loads are reduced considerably.

Research Equipment and Techniques

Small, fast-response, electrically operated pressure-measuring cells have been developed. These cells are particularly well-suited to studies of the fluctuating pressures during buffeting and flutter since the acoustic response and damping effects normally associated with conventional pressure-measuring equipment are eliminated.

SUBCOMMITTEE ON VIBRATION AND FLUTTER

Flutter of Wings and Control Surfaces

Theoretical studies on flutter characteristics of wings and control surfaces have been extended to provide new analytical tools for predicting flutter. Experimental techniques have also been extended and improved to provide additional data for comparison with the results of theoretical analysis. Good agreement

has been obtained between theory and experiment for oscillating air forces on wings or control surfaces and for the effect of aspect ratio, density, Mach number, and sweep on the flutter characteristics of wings for the ranges of parameters investigated.

Results of an experimental study showing effect of air density (altitude) and Mach number are presented in Technical Note 1989. Two cantilever-wing models were made to undergo flutter through a range of Mach numbers up to 0.82. The testing medium was air or mixtures of air and a gas in which the speed of sound is considerably lower than in air. A wide range of the mass-parameter ratio and of Reynolds number could be achieved. It was shown that for the two wings investigated the effects of compressibility could be accounted for by a simple correction formula.

Wind-tunnel experiments on the effect of aspect ratio and Mach number on the flutter of unswept cantilever wings for a range of aspect ratios and Mach numbers have been conducted and the results examined on the basis of recent theoretical values obtained from two-dimensional incompressible-flow theory.

The aerodynamic theory relating to the flutter characteristics of uniform sweptback cantilever wings has been developed in detail and a comparison of theoretical results with experimental data presented in Technical Note 2121 indicates that the analysis is satisfactory for obtaining the effects of sweep for nearly uniform cantilever wings over moderate length-to-chord ratios. Experimental data have been obtained on the effects of root restraint on the flutter of sweptback cantilever wings including the effects of variably located concentrated masses for wings clamped at the root parallel to the air stream and perpendicular to the wing leading edge.

The program of flutter experiments at high speed with the aid of rocket-powered models is being continued. Experiments have been made on a series of wings at various angles of sweep and aspect ratio, and the experimental results compared with an idealized flutter theory for subsonic flow.

Wing-aileron coefficients for oscillating air forces in two-dimensional supersonic air flow are tabulated in Technical Note 2055 for a range of Mach numbers and ratios of control-surface chord to airfoil chord. These coefficients are directly applicable to oscillating-airfoil calculations. For each combination of chord ratio and Mach number approximately 35 values of reduced frequency are utilized. Both exact and approximate expressions for the tabulated quantities are given, because approximate expressions are useful for extending the tables to lower values of the frequency and for interpolation between Mach numbers. Preliminary experimental data on forces and moments of an oscillating

wing at high-subsonic speeds have also been made and the results compared with the existing theory.

The effect of aspect ratio on the air forces and moments of an oscillating, thin, rectangular wing in supersonic potential flow is treated theoretically in Technical Note 2064. The velocity potential is expanded in powers of frequency of oscillation. Expressions that include the frequency to the third power are given for the velocity potential, the components of total force and moment coefficients, and section force and moment coefficients.

Investigations of the aileron buzz phenomenon have continued and results have been obtained which provide some insight into the fundamental causes of buzz and confirms previous opinions that buzz is not caused simply by buffeting of a control surface by separated flow.

Theoretical and experimental research on flows around and forces on oscillating airfoils of finite span has been successfully completed by the Massachusetts Institute of Technology under the sponsorship of the NACA. Experimental measurements of the aerodynamic reactions on a symmetrical airfoil oscillating harmonically in a two-dimensional flow have been obtained and analyzed. Harmonic motions include pure pitch and pure translation, for several amplitudes and superimposed on an initial angle of attack, as well as combined pitch and translation. The problem of stall flutter has been attacked in two ways. First, numerous experimental observations of stall flutter have been reviewed and various known attempts at its prediction have been examined, compared, and extended; as a result, a semiempirical method of predicting the variations of moment in pitch with airfoil shape, reduced frequency, initial angle of attack, and amplitude of oscillation has been formulated. Second, the aerodynamic reactions on wings oscillating harmonically in pitch and translation in the stall range have been measured, evaluated, and correlated where possible with available published data for the purpose of providing empirical information where no aerodynamic theory exists. In addition to affirming major known effects of Reynolds number, airfoil shape and reduced frequency on the aerodynamic reactions, data on the time-average values in the stall range of both lift and moment have been obtained for the first time. An approximate theoretical method for predicting flows around and forces on an oscillating airfoil of finite span has been reported in Technical Note 1953. A theoretical solution to the three-dimensional nonstationary aerodynamic force has also been obtained by a generalization of one of the known approximate methods for the solution of a two-dimensional problem.

Purdue University, under sponsorship of the NACA, has completed a theoretical investigation of the effect of concentrated masses on wing flutter characteristics and has shown that a harmonic-response function may be used to predict the effect on the wing flutter characteristics of the addition of a rigid mass to an airplane wing.

The chordwise distribution of lift, pitching moment, and flap hinge moment on an oscillating airfoil with a simple hinged flap in two-dimensional compressible flow (subsonic) has been calculated by applying Dietze's method for the solution of Possio's integral equation in Technical Note 2213.

Vibration and Flutter of Propellers

The vibratory stresses resulting from the operation of inclined propellers in nonuniform flow fields were investigated in the Ames 40- by 80-foot wind tunnel. The results presented in Technical Note 2192 are discussed further under the Subcommittee on Propellers for Aircraft.

An investigation of the flutter characteristics of a small one-blade wooden propeller with a Clark Y section is reported in Technical Note 1966. The flutter speed and flutter frequency were obtained with the propeller at zero forward velocity for a range of blade-angle settings and air densities. The highest flutter speeds were found in the vicinity of the angle of zero aerodynamic moment, and the flutter speed increased considerably in this region with decreasing air density. Over the rest of the pitch range the flutter speeds were much lower and varied little with air density. The maximum experimental flutter speed was 63 percent of the approximate theoretical classical flutter speed, which fact indicates that even under ideal conditions an appreciable factor of safety must be observed by designers. The flutter frequency was found to approach the natural torsional frequency of the propeller at both large positive and negative angles of attack.

The aerodynamic excitation of first-order vibration occurring in a representative three-blade propeller having its thrust axis inclined to the air stream has been investigated. The measured section aerodynamic exciting force of a pitched propeller was compared with theoretical values.

Flutter and Vibration of Helicopters

The Polytechnic Institute of Brooklyn, under NACA sponsorship, has completed a theoretical analysis of the frequency and damping characteristics of the free modes of vibrations of balanced fixed-ended and hinged elastic helicopter rotor blades in hovering and vertical flight which is reported in Technical Note 1999. Torsional vibrations, bending vibrations in flapping and in

lagging, and coupling between the flapping and lagging motions were considered. Methods for calculating natural frequencies and logarithmic decrements of the principal modes were developed, and, on the basis of quasi-stationary flow, simple flutter criteria were derived for the stability of the coupled torsional and flapping vibrations.

A study of rotor-blade lagging motions which normally border on instability has also been completed by the Polytechnic Institute of Brooklyn. This project is reported under the Subcommittee on Helicopters.

SUBCOMMITTEE ON AIRCRAFT STRUCTURAL MATERIALS

As in previous years, the majority of investigations on aircraft structural materials have been carried out by contract with universities and other nonprofit and scientific organizations. These investigations have complemented the program on materials for power plants.

Fatigue of Metals

The program on fatigue at Battelle Memorial Institute has been continued. Mention was made of this investigation in the 1948 and 1949 annual reports when it was pointed out that the purpose of the program is to obtain comprehensive information on fatigue properties of several materials commonly used in aircraft production, 24S-T3 and 75S-T6 aluminum alloys and SAE 4130 steel. Results have previously been reported on unnotched specimens and research during the past year has produced fatigue data on the above materials over a considerable range of stress concentration. These concentrations, induced in the specimen by means of holes, notches, and fillets, simulate stress concentration which might be expected to occur in the material of an aircraft in actual operation. As a result of this investigation two reports are being published, one on the fatigue properties of unnotched specimens of 24S-T3 and 75S-T6 aluminum alloys and SAE 4130 steel, the other on the fatigue properties of notched specimens of the same material.

Research in fatigue over the years has brought the gradual realization that fatigue properties are not exact values but are rather statistical quantities. While the wide scatter obtained in fatigue tests may sometimes be attributed to faulty experimental techniques, it has been found that even in extensive testing under rigidly controlled conditions the fatigue properties vary over a wide range. The Carnegie Institute of Technology has undertaken a program of research to study the statistical nature of the fatigue of metals and to evaluate the fundamental factors that affect the variability of fatigue results. Knowledge of the statistical deviation

of the fatigue properties will considerably aid in the proper selection of a factor of safety in engineering application.

Another phase of the fatigue problem is being investigated at the National Bureau of Standards. In this program the effect of continuously varying the loading cycle throughout the fatigue test is being studied. An attempt is being made to correlate the results with current damage theories. This is an important problem in view of the fact that the stresses in aircraft elements during flight vary continuously and this variation is known to affect the fatigue life of aircraft materials. The dual-load fatigue testing machine used in this investigation was described in the 1948 annual report. Results to date have been limited to 75S-T6 clad aluminum-alloy sheet under completely reversed axial loads which varied during testing.

Plasticity

A theory for the polyaxial stress-strain relations of metals in the plastic range based on the concept of slip has been developed by the Langley structures research staff. The new theory seeks to predict the plastic strain that would result from the application in any sequence of arbitrary combinations of stress and requires for this purpose only a knowledge of the uniaxial stress-strain relation for the material. Technical Note 1841 presents the essential features of the new theory. Supplementary research to study further this slip theory and to determine the validity of the various plasticity theories is being conducted at the Pennsylvania State College. The biaxial plastic stress-strain relations of 75S-T6 aluminum alloy were studied during the past year utilizing tension-tension stresses with both constant and varying principal stress ratios and directions. This loading was obtained by simultaneously subjecting a hollow cylinder to axial tension and internal pressure.

Sandwich Materials and Adhesives

The Forest Products Laboratory has continued its investigation of sandwich materials and adhesives. During the past year an investigation was completed on the effect of cell shape on compressive strength of hexagonal honeycomb structures. The dimensions of the cells in the hexagonal honeycomb structure were found to be an important factor in determining the compressive strength of the structure parallel to the flutes. From the results obtained with 35 test specimens a family of curves was obtained by means of which it is possible to estimate the ultimate compressive strength of such honeycomb structures.

Other investigations completed at the Forest Products Laboratory during the past year were the evalua-

tion of several adhesives and processes for bonded sandwich construction of aluminum facings and paper honeycomb cores and the determination of the shear stress distribution along glue lines between skin and cap-strip of an aircraft wing. The results of these investigations are given in Technical Notes 2106 and 2152, respectively.

Another investigation was conducted at the Forest Products Laboratory on the effect of temperatures from -70° to 600° F on the bond strength of clad aluminum lap joints. Tension tests were made on these lap-joint specimens to determine the strength at various temperatures of eight commercial and eight experimental adhesives. Lack of satisfactory resistance to 192 hours of exposure at a temperature of 450° F was evident in all the adhesives tested. The bonding strength of these adhesives was generally not seriously affected by temperatures of -70° F. There was considerable variation, however, in performance of the various adhesives from room temperatures up to 450° F.

Plastics

A survey conducted by the National Bureau of Standards and referred to in the 1948 annual report disclosed that crazing was a major factor contributing to the reduction in the strength of plastics used in windows and canopies of airplanes. An investigation is therefore under way at the National Bureau of Standards in which the factors affecting crazing and strength properties of plastic glazing are being studied. An analysis was made of the results of a series of tensile tests to determine the loss of strength of both ordinary and heat-resistant acrylic plastic sheet due to crazing. In these tests tensile specimens were stress-solvent crazed by stroking the surface with a brush wet with benzene. The specimens were then broken. It was found that crazing caused a reduction in average tensile strength of about 30 to 50 percent.

Investigations were also conducted at the National Bureau of Standards on the effect of some variables in fabrication techniques on the properties of glass-fabric laminated plastics. The variables investigated were molding conditions and fabric finishes. The effects of several molding conditions upon the physical properties of laminates prepared with a Fiberglas fabric and an unsaturated-polyester resin were investigated. The molding variables included pressure, temperature, and time during both precuring and curing operations. It was found that an increase in molding pressure increased the flexural strength, whereas an increase in precure temperature decreased the strength properties of the laminates. Extending the curing time to 48 hours at a temperature of 160° F. improves the strength properties relative to those ob-

served in other cure cycles. The effects of six commercial fabric finishes upon the physical properties of these laminates were also investigated. These finishes included the following types; Three water-repellent, heat-treated, heat-cleaned, and plain. It was found that one of the three water-repellent fabric finishes was superior to the other finishes when both wet and dry flexural strengths were considered.

Stress Corrosion

An investigation designed to further knowledge on the mechanism of stress corrosion is under way at the Armour Research Foundation predicated on the assumption that stress corrosion is an electrochemical process. Studies are being made of the effect of stress on the solution potential of the several phases which might be present in any given alloy. Particular attention is being paid to such substances as inter-

metallic compounds or other phases which might be precipitated in an alloy. By means of a new technique developed at Armour the determination of the effect of stress on the solution potentials of these substances is made possible and measurements of the galvanic current flowing in couples made from these materials and the parent metal matrix can be made.

Titanium

The Langley structures research laboratory has completed an investigation of the compressive properties of titanium sheet at temperatures from room temperature to 800° F. Technical Note 2038 presents results of compressive stress-strain tests over this temperature range. The results show that titanium has good compressive properties which are comparable with those in tension up through 800° F. Marked anisotropy in compression was also noted.

AIRCRAFT OPERATING PROBLEMS RESEARCH

Studies of problems encountered in the operation of aircraft have encompassed investigations of the meteorological factors which impair the performance of airplanes, methods of insuring safe operations during adverse weather conditions, and means of increasing the safety and comfort of airplane flight. The NACA's major effort in this field of research has been concerned with atmospheric turbulence, icing, and aircraft fire. The Langley Aeronautical Laboratory staff has conducted the research on atmospheric turbulence and its effect on aircraft operation. They have also been concerned with problems of aircraft ditching and pilot escape from high-speed airplanes. The research

on icing and aircraft fire has mainly been centered at the Lewis Flight Propulsion Laboratory. However, limited studies of icing have been conducted at the Ames Aeronautical Laboratory. Several universities have participated in this program under contract to the NACA.

The Committee on Operating Problems is responsible for the guidance of the operating problems research program. In this regard it is aided by its subcommittees, the Subcommittee on Meteorological Problems, the Subcommittee on Icing Problems, and the Subcommittee on Aircraft Fire Prevention.

COMMITTEE ON OPERATING PROBLEMS

Effect of Gusts on Operating Practices

As a part of an investigation of world-wide flight conditions along commercial routes, V-G data have been taken on several four-engine-type transport aircraft during postwar commercial operations on trans-Pacific and Caribbean-South American routes of the same airline, and the results analyzed.

The first sample of time-history data of airspeed, altitude, and normal accelerations during transport operations has been obtained at the Langley Laboratory by means of the NACA VGH recorder. These time-history data were obtained from a modern twin-engine transport operating at low altitudes. The data supplement the maximum acceleration and airspeed data obtained by means of the NACA V-G recorder and provide greater detail on operating conditions and practices.

A limited amount of similar VGH data has been obtained on two four-engine transport airplanes during operations at high altitudes. Although differences have been noted in the data obtained from the low- and high-altitude operations, no definite general conclusions are warranted at present because of the limited size of the sample from the high-altitude operations.

Escape Techniques

The low- and high-speed investigations of five airplane jettisonable nose sections that have been proposed as emergency pilot-escape devices at high speeds have been completed. As a result of these investigations, a criterion has been established for the determination of the fin area required for stabilization of these nose sections so that large accelerations normally encountered by the pilot are eliminated.

The motion of a jettisoned nose during and immediately after jettisoning also has been investigated at various speeds. Results of the investigation have established recommendations regarding forcible forward ejection of a fin-stabilized nose, the stability of which can be adversely affected by the nearness of the rear body.

Ditching

In cooperation with the CAA, the ditching characteristics of transport-type aircraft have been under study using dynamic-model techniques for several years and the program is now nearly complete. The recommended procedure was found to be generally similar for these aircraft. The ditching should be made parallel to the crests of large swells, if present, with the wheels up and the flaps down. Contact should be made as smoothly as possible at as low a speed as can be obtained consistent with good control. In general, this class of aircraft behaves rather well when ditched according to the recommended technique and relatively low decelerations are to be expected.

SUBCOMMITTEE ON METEOROLOGICAL PROBLEMS

Turbulence Detection and Measurement

A previous investigation indicated that atmospheric turbulence encountered in air-mass thunderstorms in Florida may be greatly reduced by avoiding regions of radar echo indicated by AN/CPS-1 ground radar equipment. In order to extend this investigation to other regions and to other weather situations, an analysis of data obtained from the 1947 Ohio operations of the thunderstorm project was made. The results of the analysis, reported in NACA Technical Note 1960, indicated that the magnitude and intensity of gusts encountered in air-mass and frontal thunderstorms may be considerably reduced by avoiding storm areas as indicated by ground radar of a 10-centimeter wavelength. The analysis extends the use of ground radar for avoiding regions of severe thunderstorm turbulence in subtropical regions to include thunderstorms in temperate regions. The data also indicate that for turbulence avoidance the ground radar used becomes more effective with increasing altitude up to 25,000 feet and is least effective at 6,000 feet.

Meteorological Characteristics of Clouds

In order to understand more clearly the composition of clouds above freezing temperatures, an investigation of drop-size and liquid-water-content measurements has been initiated. Three methods are being developed for the measurement in flight of cloud-droplet size and

liquid-water content. The first method employs an instrument that by means of a coronal discharge places an electric charge on the droplets and then separates them aerodynamically according to their mass. This instrument is used for the determination of droplet size, drop-size spectrum, and liquid-water content of clouds. The second method employs an instrument known as the cascade impactor, which in the past has been used to sample drop-size distribution in a low-velocity air stream. In order to adapt it for flight use, it is used in conjunction with a diffuser, which reduces the air to a velocity that is suitable for use of the impactor. The third method employs a mass spectrometer for the measurement of water-vapor content and liquid-water content of clouds. Liquid-water content can be measured by vaporizing the cloud droplets, measuring the total vapor content of the heated air, and making a suitable correction for the vapor content of the cloud. A flight model mass spectrometer has been fabricated and is being calibrated in the laboratory prior to flight service use.

SUBCOMMITTEE ON ICING PROBLEMS

Aircraft involved in all-weather operations are subjected to the hazard of ice formation, and studies initiated for the alleviation of this hazard are being continued. Work on the research program was conducted by the Lewis Flight Propulsion Laboratory and the Ames Aeronautical Laboratory.

Meteorological Characteristics of the Icing Cloud

Recommended values of the meteorological factors (Technical Note 1855), necessary to be considered in the efficient design of aircraft ice-prevention systems, are limited in the respect that the probability of encountering the various icing conditions during normal operation has not been analyzed. Consequently, a comprehensive statistical analysis has been made of all available measurements of actual icing encounters.

The properties of supercooled water are being investigated to obtain a more complete understanding of the icing phenomenon as it affects aircraft operations. One phase of this research has been the experimental investigation of the relationship between the spontaneous freezing temperature of supercooled water droplets and droplet size (Technical Note 2142), and a theory for the prediction of the probability of the spontaneous freezing temperature of cloud droplets has been developed.

The study of the meteorological phase of the icing problems has been continued at the laboratories with emphasis on the development of new-type instruments for measuring pertinent meteorological factors involved

in the icing phenomenon. The measurement of cloud-droplet sizes in flight has been accomplished by both a high-speed photographic technique and a droplet-inertia-separation method. The concentration of liquid water within icing clouds can now be obtained by a continuous recorder developed on the principle of ice catch on a moving body. Analysis of recent meteorological data indicates that the frequency and severity of icing conditions are substantially reduced in areas of precipitation and that the most severe icing occurs at or near the top of the clouds. This condition has been investigated, however, only up to altitudes of 20,000 feet.

Particular emphasis on the further development of instruments suitable for installation on transport airplanes for the specific purpose of the procurement of icing meteorological data during routine transport operation has resulted in the installation of two types of icing-rate meters on airline aircraft.

Evaluation of three multicylinder icing-rate meters during icing conditions at the Mount Washington Observatory has been completed.

Wing and Tail Surface Ice Protection

The heat requirement for ice protection on airplane wings and tail surfaces is dependent, among other things, upon the area of the leading edge on which the cloud drops impinge and the rate of impingement. The Ames Laboratory has developed a semiempirical method for calculating area and rate of drop impingement that is based on the results of drop trajectories for five airfoils computed utilizing a differential analyzer. Step-by-step numerical methods of computing this information are available but are tedious and require a knowledge of the flow field ahead of the airfoil. The method requires only a knowledge of the airfoil pressure distribution and shows promise of being applicable to both conventional and low-drag airfoils at speeds of about 400 miles per hour.

A comparison of the requirements for the icing protection of an NACA 65, 2-016 airfoil section in flight and in the icing research tunnel of the Lewis Laboratory indicates good agreement between natural and simulated icing.

Propeller Ice Protection

An investigation has been made to determine the effectiveness of internal spanwise finning at the leading edges of the propeller blade, where the greatest amount of heat is required, in order to reduce the quantity of hot air required to provide icing protection for air-heated propellers. By varying the amount and location of the internal finning and utilizing proper chordwise partitioning of the heated-air passage, local heat-

ing rates can be controlled with a resulting increase in the efficiency of air-heated propeller anti-icing systems (Technical Note 2126).

A comprehensive investigation, analytical and experimental, has been made at the Ames Laboratory of the probable propeller-thrust loss to be expected in icing conditions. A report on the investigation shows that thrust losses due to ice accretions, though not negligible, would probably be lower than generally anticipated. With regard to means of propeller ice protection, the intermittent application of electrical heating has received the most attention but is difficult to analyze because of the transient character of the heat flows involved. An electrical analog has been constructed to simulate blade surface conditions under cyclic heating and will be used to establish heating requirements for intermittently operated propeller heating elements.

Jet Engine Ice Protection

Investigations of inertia-separation-type inlets have been concluded. The data indicate that, although a high percentage (92 percent) of the water droplets can be separated from the air stream before the water reaches the engine, the pressure losses in the inlet duct, caused by the high air velocities required for effective water-droplet separation, limit the practical application of this type of protective system for current turbojet engines.

Surface-heating requirements for jet-engine-inlet guide vanes, which in the absence of a compressor screen constitute the greatest icing hazard, have been determined. Because the heat source necessary for providing the heat requirements may be critical with respect to the performance of a turbojet engine, three methods of guide-vane heating were investigated—the flow of hot air through hollow guide vanes, electrical heating by means of resistance wire embedded in the vanes, and electrical heating by the use of the eddy-current principle. The results of this research indicated that only a small amount of hot air is required to provide adequate icing protection for temperatures as low as -20° F when a properly internally partitioned and finned vane is utilized (Technical Note 2126). Eddy-current heating was shown to be feasible and preliminary results indicated that adequate icing protection could be obtained with only a minute percentage loss in engine power. In general, all three methods of protection had a negligible effect on engine performance although there was a slight weight penalty resulting from the weight of the heating-system components inherent in all methods.

The flight program to determine the effect of natural icing on turbojet-engine performance has been completed. The effect of inlet-guide-vane icing was iso-

lated by installing electrically heated boots on the other engine components, namely the cowl lip, the accessory housing dome, and the front bearing support struts. It was found that guide-vane icing accounted for approximately one-half of the total reduction in engine performance caused by inlet icing. Periodical photographs of the engine inlet, taken during the icing runs, indicated that during prolonged icing runs the inlet icing was characterized by a cyclic growth and shedding of the accretions with the greatest deterioration occurring within the initial few minutes of the encounter.

Further studies of the mixing of jets directed perpendicularly to an air stream for purposes of heating or cooling of the air stream have been undertaken with circular, square, and elliptical orifices at high pressure ratios. The flow coefficients were shown to be independent of the stream velocity provided the correct outlet pressure was used (Technical Note 1947). The penetration of the jets issuing from these orifices was correlated in terms of dimensionless parameters. Greater penetrations were obtained with square orifices and elliptical orifices at low tunnel velocities and low jet pressures than with the other orifices investigated (Technical Note 2019).

SUBCOMMITTEE ON AIRCRAFT FIRE PREVENTION

Further improvement in aircraft safety by reducing the possibility of fire is recognized as an important objective by the aviation industry. Achievement of this aim is of interest to both commercial and military operators. A significant reduction in the fire hazard requires the establishment of fundamental data for design criteria that will result in the best possible fire prevention and personal safety. The NACA aircraft-fire research program, in coordination with research and development by other governmental agencies and the aviation industry, is directed toward this objective.

Survey of Fire Records and Fire Research

A bibliography of aircraft-fire publications has been compiled as an initial phase of the aircraft-fire-prevention program. An analysis of multiengine-transport-airplane fire records covering the 10-year period ending July 1, 1948, has been completed. Results of this analysis show that gasoline was most frequently the initial combustible ignited in flight and ground fires and is considered to be the most hazardous of the combustibles carried. The exhaust system is concluded to be the most hazardous ignition cause for flight fires, ground fires, and crash fires. Engine failures were the most frequent cause of fires occurring in flight.

Basic Mechanisms Involved in Fire-Extinguishing Agents

An analysis of existing data was made with respect to the relative extinguishing effectiveness of different substances and the basic mechanisms involved in the action of extinguishing agents. Five basic actions of fire-extinguishing agents were investigated. It appears from this analysis of existing data that mechanical action, blanketing action, and chain-breaking action are the most important factors in extinguishing by gaseous and liquid agents. Information on the relative extinguishing effectiveness indicates that organic halogen compounds will most probably yield the more powerful extinguishing agents (Technical Note 2102).

Fire Safety Program

Full-scale crash-fire experiments, for the evaluation of fuel volatility and de-energizing of ignition sources, have been started. The equipment for the tests was constructed; a test procedure formulated; the instrumentation planned and constructed; and initial tests were made to evaluate the testing technique. The results indicated that the technique was generally satisfactory and that useful information could be obtained from this type of research.

RESEARCH PUBLICATIONS

TECHNICAL REPORTS

- | No. | No. |
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| 922. Characteristics of Low-Aspect-Ratio Wings at Supercritical Mach numbers. By John Stack and W. F. Lindsey. | 926. Sound-Level Measurements of a Light Airplane Modified to Reduce Noise Reaching the Ground. By A. W. Vogeley. |
| 923. Effect of Afterbody Length and Keel Angle on Minimum Depth of Step for Landing Stability and on Take-Off Stability of a Flying Boat. By Roland E. Olson and Norman S. Land. | 927. Appreciation and Prediction of Flying Qualities. By William H. Phillips. |
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- No. 1200. Measurement of Oil-Film Pressures in Journal Bearings Under Constant and Variable Loads. By A. Buske and W. Rolli. From *Jahrbuch 1937 der deutschen Luftfahrtforschung*, pp. II 67-II 78.
1220. Pressure-Distribution Measurements on the Tail Surfaces of a Rotating Model of the Design BFW-M 31. By M. Kohler and W. Mautz. From ZWB, FB 704, Sept. 30, 1936.
1221. Experimental Flights for Testing of a Reactor as an Expedient for the Termination of Dangerous Spins. By P. Höhler and I. v. Köppen. From ZWB, FB 1027, Feb. 25, 1929.
1222. Investigation of the Model ME 210 in the Spin Wind Tunnel of the DVL. Fourth Partial Report—Model with Long Fuselage and with a Vee Tail. By A. Huffschild. From ZWB, UM 1288, June 15, 1944.
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1227. Moments of Cambered Round Bodies. By Günther Kempf. From Ludwig Prandtl, zum 70. Geburtstage, *Schriften der Deutschen Akademie der Luftfahrtforschung*, Berlin, 1945, pp. 139-151.
1228. Behavior of the Laminar Boundary Layer for Periodically Oscillating Pressure Variation. By August Wilhelm Quick and K. Schröder. From Ludwig Prandtl, zum 70. Geburtstage, *Schriften der Deutschen Akademie der Luftfahrtforschung*, Berlin, 1945, pp. 247-255.
1231. Report on Investigation of Developed Turbulence. By L. Prandtl. From *Zeitschrift für angewandte Mathematik und Mechanik*, Vol. 5, No. 2, April 1925, pp. 136-139.
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1235. Investigation of Conditions of Titanium Carbonization—IV. By G. A. Meerson and Y. M. Lipkes. From *Zhurnal Prikladnoi Khimii*. Vol. 18, Nos. 4-5, 1945, pp. 251-253.
1236. A Class of de Laval Nozzles. By S. V. Falkovich. From *Prikladnaia Matematika i Mekhanika*, Vol. 11, 1947.
1237. On the Motions of an Oscillating System Under the Influence of Flip-Flop Controls. By I. Flüge-Lotz and K. Klotter. From ZWB, UM 1826, Aug. 1, 1943.
1239. Two-Dimensional Motion of a Gas at Large Supersonic Velocities. By S. V. Falkovich. From *Prikladnaia Matematika i Mekhanika*, Vol. 11, 1947.
1242. Theory of Characteristics. By Dr. W. Tollmien. From *Technische Hochschule Dresden*, Archiv No. 44/2, Chapter 2.
1243. Two-Dimensional Potential Flows. By Manfred Schäfer and W. Tollmien. From *Technische Hochschule Dresden*, Archiv No. 44/3, Chapter 3, Mar. 22, 1941.
1244. Rotationally Symmetric Potential Flows. By Manfred Schäfer and W. Tollmien. From *Technische Hochschule Dresden*, Archiv No. 44/4, Chapter 4, Nov. 18, 1940.
1245. Lift Force of an Arrow-Shaped Wing. By M. I. Gurevich. From *Prikladnaya Matematika i Mekhanika*, Vol. 10, 1946, pp. 513-520.
1247. Landing Procedure in Model Ditching Tests of Bf 109. By W. Sottorf. From ZWB, FB 951, 1938.

TECHNICAL MEMORANDUMS ¹

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

ZWB—Zentrale für Wissenschaftliches Berichtswesen der Luftfahrtforschung des Generalluftzeugmeisters (German Central Publication Office for Aeronautical Reports).

FB—Forschungsbericht (Research Report).

UM—Untersuchungen und Mitteilungen (Reports and Memoranda).

No. 1197. Investigations on the Stability, Oscillation, and Stress Conditions of Airplanes with Tab Control. First Partial Report—Derivation of the Equations of Motion and Their General Solutions. By B. Filzek. From ZWB, FB 2000 [pt. 1] Oct. 24, 1944.

1198. Investigations on the Stability, Oscillation, and Stress Conditions of Airplanes with Tab Control. Second Partial Report—Application of the Solutions Obtained in the First Partial Report to Tab-Controlled Airplanes. By B. Filzek. From ZWB, FB 2000 [pt. 2] Nov. 15, 1944.

¹The missing numbers in the series of technical memorandums were released before or after the period covered by this report.

- No. 1251. On the Formation of Shock Waves in Subsonic Flows with Local Supersonic Velocities. By F. I. Frankl. From *Prikladnaya Matematika i Mekhanika*, Vol. 11, 1947, pp. 190-202.
1252. Some Studies on the Flow of a Gas in the Region of Transition through the Velocity of Sound. By I. A. Kiebel. From *Izvestia Akademii Nauk, SSSR*, No. 3, 1947, pp. 253-259.
1253. Flow Measurement by Means of Light Interference. By Th. Zobel. From ZWB, FB 1167, Feb. 1, 1940.
1254. Systematic Model Researches on the Stability Limits of the DVL Series of Float Designs. By W. Sottorf. From *Jahrbuch 1942 der Deutschen Luftfahrtforschung*, pp. I 451-I 465.
1255. Equations of Motion of a Rocket. By F. R. Gantmacher and L. M. Levin. From *Prikladnaya Matematika i Mekhanika*, Vol. 11, No. 3, 1947, pp. 301-312.
1256. The Boundary Layers in Fluids with Little Friction. By H. Blasius. From *Zeitschrift für Mathematik und Physik*, Vol. 56, No. 1, 1908, pp. 1-37.
1257. Vibration of a Wing of Finite Span in a Supersonic Flow. By M. D. Haskind and S. V. Falkovich. From *Prikladnaya Matematika i Mekhanika*, Vol. 11, 1947, pp. 371-376.
1259. Theoretical Investigations on the Efficiency and the Conditions for the Realization of Jet Engines. By Maurice Roy. From France, *Ministere de l'Air, Publications Scientifiques et Techniques* No. 1, 1930.
1265. Amplitude Distribution and Energy Balance of Small Disturbances in Plate Flow. By H. Schlichting. From *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen, New Series*, Vol. 1, No. 4, 1935, pp. 47-78.
1266. Preliminary Results from Fatigue Tests with Reference to Operational Statistics. By E. Gassner. From *Lilienthal-Gesellschaft für Luftfahrtforschung, Bericht* 106, Pt. 1, 1939, pp. 9-14.
1267. Theory of Plane, Symmetrical Intake Diffusers. By Walter Brödel. From ZWB, FB 1475, Pts. 1 and 2, Sept. 20, 1941.
1270. The Gas Kinetics of Very High Flight Speeds. By Eugen Sanger. From ZWB, FB 972, May 31, 1938.
1275. The Solution of the Laminar-Boundary-Layer Equation for the Flat Plate for Velocity and Temperature Fields for Variable Physical Properties and for the Diffusion Field at High Concentration. By H. Schuh. From ZWB, FB 1980, Aug. 18, 1944.
1279. Two-Dimensional Symmetrical Inlets with External Compression. By P. Ruden. From ZWB, FB 1209, Apr. 15, 1940.
1280. Graphical Determination of Wall Temperatures for Heat Transfers Through Walls of Arbitrary Shape. By Otto Lutz. From *Zeitschrift des Vereines deutscher Ingenieure*, Vol. 79, No. 84, August 1935, pp. 1041-1044.
1284. Instrument for Measuring the Wall Shearing Stress of Turbulent Boundary Layers. By H. Ludwig. From *Ingenieur-Archiv*, Vol. 17, No. 3, pp. 207-218.
1285. Investigations of the Wall-Shearing Stress in Turbulent Boundary Layers. By H. Ludwig and W. Tillmann. From *Kaiser-Wilhelm-Institut für Strömungsforschung, Göttingen, Report*.

Part II—COMMITTEE ORGANIZATION AND MEMBERSHIP

The act of Congress approved March 3, 1915, establishing the National Advisory Committee for Aeronautics (U. S. Code, Supplement III, title 50, sec. 151), as amended by act approved March 25, 1948 (Public Law 549, 80th Cong.), provides that the Committee shall consist of 17 members appointed by the President, and shall include "two representatives of the Department of the Air Force; two representatives of the Department of the Navy, from the office in charge of naval aeronautics; two representatives of the Civil Aeronautics Authority; one representative of the Smithsonian Institution; one representative of the United States Weather Bureau; one representative of the National Bureau of Standards; the Chairman of the Research and Development Board of the National Military Establishment; and not more than seven other members selected from persons 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 five years. The representatives of the Government organizations serve for indefinite periods. All members serve as such without compensation.

Under date of February 27, 1950, President Truman appointed Hon. Thomas W. S. Davis, Assistant Secretary of Commerce for Aeronautics, a member of the National Advisory Committee for Aeronautics to succeed Hon. John R. Alison, resigned.

In accordance with law, Hon. William Webster was appointed a member of the Committee March 10, 1950, following his appointment as Chairman of the Research and Development Board of the Department of Defense. Mr. Webster succeeded Dr. Karl T. Compton, whose membership on the Committee was terminated in November, 1949, upon his resignation as Chairman of the RDB.

Vice Adm. John H. Cassady, USN, Deputy Chief of Naval Operations (Air), was appointed a member of the Committee on March 11, 1950 succeeding Vice Adm. John D. Price, USN, relieved upon his transfer to duty away from Washington.

In view of the recent establishment in the Air Force of the post of Deputy Chief of Staff, Development, Maj. Gen. Gordon P. Saville, USAF, who is serving in that capacity, was appointed under date of October

19, 1950, a member of the National Advisory Committee for Aeronautics to succeed Gen. Hoyt S. Vandenberg, USAF.

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 19, 1950, 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.

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Part III—FINANCIAL REPORT

Appropriations for the fiscal year 1950.—Funds and contract authority in the following amounts were appropriated for the Committee for the fiscal year 1950 in the Independent Offices Appropriation Act, 1950, approved August 24, 1949:

Salaries and expenses.....	\$43,000,000	
Construction and equipment of laboratory facilities:		
Funds to continue financing of fiscal year 1949 program:		
Langley Aeronautical Laboratory	\$3,894,200	
Pilotless Aircraft Research Station.....	133,000	
Ames Aeronautical Laboratory	400,000	
Lewis Flight Propulsion Laboratory	2,850,000	
	7,277,200	
Funds to start financing of fiscal year 1950 program:		
Langley Aeronautical Laboratory	\$812,000	
Pilotless Aircraft Research Station.....	638,000	
Ames Aeronautical Laboratory	560,000	
Lewis Flight Propulsion Laboratory	712,800	
	2,722,800	
Total appropriated funds.....	\$53,000,000	
Contract authority for remaining obligations necessary to complete fiscal year 1950 program:		
Langley Aeronautical Laboratory.....	\$6,377,000	
Pilotless Aircraft Research Station.....	373,000	
Lewis Flight Propulsion Laboratory.....	3,250,000	
	10,000,000	
Total contract authority.....	\$10,000,000	

Obligations incurred against the fiscal year 1950 appropriated funds and contract authority are listed below, together with the unobligated balances remaining on June 30, 1950. The figures shown for salaries and expenses include the costs for personal services, travel, transportation, communication, utility services, printing and binding, contractual services, supplies, and equipment.

Salaries and expenses:	
NACA Headquarters.....	\$994,661
Langley Aeronautical Laboratory.....	16,654,315
Pilotless Aircraft Research Station.....	466,407
High-Speed Flight Research Station.....	685,072
Ames Aeronautical Laboratory.....	6,972,769
Western Coordination Office.....	17,404

Salaries and expenses—Continued

Lewis Flight Propulsion Laboratory.....	\$16,013,815
Wright-Patterson Coordination Office.....	9,814
European Office.....	15,267
Research Contracts—educational institutions...	777,885
Services performed by National Bureau of Standards and Forest Products Laboratory...	222,500
Unobligated balance.....	170,091
	\$43,000,000
Total appropriated funds, salaries, and expenses.....	\$43,000,000

Construction and equipment of laboratory facilities:

Funds to continue financing of fiscal year 1949 program:	
Langley Aeronautical Laboratory	\$3,822,188
Pilotless Aircraft Research Station.....	132,971
Ames Aeronautical Laboratory	399,653
Lewis Flight Propulsion Laboratory	2,849,888
Unobligated balance.....	72,500
	\$7,277,200
Funds to start financing of fiscal year 1950 program:	
Langley Aeronautical Laboratory	\$646,679
Pilotless Aircraft Research Station.....	516,572
Ames Aeronautical Laboratory	542,038
Lewis Flight Propulsion Laboratory	658,497
Unobligated balance.....	1,859,014
	2,722,800
Total appropriated funds.....	\$53,000,000

Contract authority for remaining obligations necessary to complete fiscal year 1950 program:

Langley Aeronautical Laboratory.....	\$3,479,612
Pilotless Aircraft Research Station.....	121,084
Lewis Flight Propulsion Laboratory.....	404,247
Unobligated balance.....	1,5,005,057
	\$10,000,000
Total contract authority.....	\$10,000,000

¹These unobligated balances remain available for obligation in the fiscal year 1951.

Funds in the amount of \$75,000,000 were appropriated in the Deficiency Appropriation Act, 1950, approved June 29, 1950, for the construction of wind tunnels authorized in the Unitary Wind

Tunnel Plan Act of 1949 (Public Law 415, 81st Congress, approved October 27, 1949). These funds are available until expended and have been allotted as follows:

Langley Aeronautical Laboratory	\$14,917,000
Ames Aeronautical Laboratory	27,227,000
Lewis Flight Propulsion Laboratory	32,856,000
Total appropriation	\$75,000,000

No obligations were incurred against these funds in the fiscal year 1950, and the full amounts are available for obligation in the fiscal year 1951 and succeeding years.

Appropriations for the fiscal year 1951.—Funds and contract authority in the following amounts were appropriated for the Committee for the fiscal year 1951 in the General Appropriation Act, 1951, approved September 6, 1950:

Salaries and expenses	\$42,500,000
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Construction and equipment of laboratory facilities:

Funds to continue financing of fiscal year 1949 program:	
Langley Aeronautical Laboratory	\$6,000,000
Lewis Flight Propulsion Laboratory	4,000,000
	<u>10,000,000</u>

Construction and equipment of laboratory facilities—Continued

Funds to continue financing of fiscal year 1950 program:

Langley Aeronautical Laboratory	\$2,877,000
Pilotless Aircraft Research Station	373,000
Lewis Flight Propulsion Laboratory	1,750,000
	<u>\$5,000,000</u>

Funds to start financing of fiscal year 1951 program:

Langley Aeronautical Laboratory	\$50,000
Ames Aeronautical Laboratory	450,000
	<u>500,000</u>

Total appropriated funds	\$58,000,000
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Contract authority for remaining obligations necessary to complete fiscal year 1951 program:

Langley Aeronautical Laboratory	\$2,450,000
Ames Aeronautical Laboratory	8,550,000
	<u>\$11,000,000</u>