FORTY-FIRST ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1955

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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 Forty-first Annual Report of the Committee covering the fiscal year 1955.

DWIGHT D. EISENHOWER.

THE WHITE HOUSE,
JANUARY 23, 1956.

Letter of Submittal

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 17, 1955.*

DEAR MR. PRESIDENT:

In compliance with the act of Congress approved March 3, 1915, as amended (U. S. C. title 50, sec. 151), I submit herewith the Forty-first Annual Report of the National Advisory Committee for Aeronautics for 1955.

The Committee's research programs during the past year were largely concentrated upon the scientific problems of supersonic flight with a view to their practical solution. This required advancing the frontiers of knowledge of obscure phenomena by means of new techniques of research and analysis and by the creation and use of novel facilities for experimental exploration and verification. Application of the new knowledge has been dramatically successful in some important instances, but the unknown is still of vast extent.

Especially significant are the problems involved in the use of atomic energy for aircraft propulsion and in the development of intercontinental ballistic missiles. Indeed, our national security may well depend on the intensity and competence of our research to solve such problems.

There is evidence to indicate that our present position of leadership in the air has been challenged by a potential enemy. To maintain, at manageable cost, the necessary air power of requisite quality demands continuous research to anticipate the requirements of tomorrow's weapons.

Respectfully submitted.

JEROME C. HUNSAKER,
Chairman.

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

National Advisory Committee for Aeronautics

Headquarters, 1512 H 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.

FORTY-FIRST ANNUAL REPORT

OF THE

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON, D. C., *November 17, 1955.*

To the Congress of the United States:

In accordance with act of Congress, approved March 3, 1915, as amended (U. S. C. title 50, sec. 151), which established the National Advisory Committee for Aeronautics, the Committee submits its Forty-first Annual Report for the fiscal year 1955.

In the 10 years since World War II, practical progress in aeronautics has been more rapid than in any like period since man learned to fly. There have been several scientific "break-throughs", notably in jet propulsion and high-speed aerodynamics. Now, however, further progress depends on the solution of extremely baffling problems requiring new knowledge of the laws of nature which govern flight at the higher speeds and altitudes envisioned. The magnitude of these problems is exceeded only by the importance of the possibilities that can be realized by their solution.

The decisions we make now regarding the extent of our research effort may well determine whether the United States may maintain its present position of world leadership in the air.

When the NACA was established in 1915, "to supervise and direct the scientific study of the problems of flight, with a view to their practical solution", a compelling reason for its creation was the fact that in the United States, birthplace of the airplane, aeronautical progress had been so slow that several other nations had gained leads over the United States. Even then, when the potential value of the airplane both in war and peace was but dimly seen by the public, the importance of aeronautics and what had to be done to advance it was recognized by the Congress.

In the years that followed World War I, definite leadership in aeronautics was regained by the United States. This continuing achievement has been the result of a partnership in which the Congress, the military air services, the aircraft industries, and the NACA have joined. As its part, the NACA undertook research to provide basic information which talented designers in industry used in developing superior airplanes, both civil and military.

How successful this team effort has been was emphasized by the recent public disclosure of the discovery and experimental verification of a new aerodynamic concept known as the Area Rule, and of its prompt use by the aircraft industry. It is a simple method of reducing the sharp increase in drag heretofore associated with transonic flight, and has already led to gains in speed of more than 100 miles per hour by supersonic airplanes. Richard T. Whitcomb, Aeronautical Research Scientist at the NACA Langley Aeronautical Laboratory, has just been awarded the Collier Trophy "for discovery and experimental verification of the area rule, a contribution to basic knowledge yielding significantly higher airplane speed and greater range with same power."

This accomplishment, described in more detail on page 2 of this report was the result of research begun in 1951 as the first major project made possible by the new transonic wind tunnels. It is important to recall that when the NACA requested and received from the Congress in 1946 funds for these transonic wind tunnels, there could be no guarantee that there would come so early and so large a gain from their use.

By mid-1952, the validity of the new design concept had been sufficiently verified by intensive wind tunnel research to warrant confidential disclosure to the military services and to the manufacturers of high-speed airplanes. The military services had already committed hundreds of millions of dollars in contracts for supersonic airplanes. From the standpoint of national security, it was imperative that such heavy investments provide superior airplanes. The timely availability of the Area Rule concept and its prompt application by industry assured to the military services airplanes with much superior supersonic capabilities.

Today, problems associated with a nuclear engine suitable for aircraft propulsion and with an intercontinental ballistic missile are perhaps the most pressing. An airplane powered by a nuclear engine would have range limited only by the endurance of the crew. An intercontinental ballistic missile traveling at speeds from 10,000 to 15,000 miles an hour would be extremely difficult to intercept. Only seconds would elapse between the time such a missile could be detected and the time it would reach its target.

At a time when the world is searching for the means to an enduring and honorable peace, it is vital that we in the United States maintain our qualitative lead in aeronautics and the resulting economy of effective air power. We will do well to remember that to maintain such a lead depends on the vigor and skill with which we press our fundamental and applied research.

We should also keep in mind that with each advance in speed, problems requiring scientific investigation multiply, become more complex and difficult, and their study and solution more costly. The potential advantages to the cause of world peace if America first solves these problems are obvious.

Respectfully submitted.

JEROME C. HUNSAKER,
Chairman.

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Part I—TECHNICAL ACTIVITIES

THE NACA—WHAT IT IS AND HOW IT OPERATES

One of the major functions of the National Advisory Committee for Aeronautics since its establishment in 1915 by the Congress has been the coordination of American aeronautical research. Through the makeup of both the Main Committee and its 29 technical subcommittees, the NACA embraces the several military and civil government agencies concerned with aeronautics and includes members from scientific institutions and the aviation manufacturing industries.

In the performance of its principal responsibility, which is scientific laboratory research in aeronautics, the NACA serves the needs of all departments of the Government. The President appoints the Main Committee, and its 17 members, who serve without pay, report to him. They establish policy and plan the research programs to be conducted by the 7,500 scientists, engineers, and supporting personnel who make up the staff of the NACA.

Assisting the Committee in the determination and coordination of research programs are 6 major and 23 subordinate technical committees, with a total membership of more than 400. The members are selected because of their technical ability, experience, and recognized leadership in a special field. They also serve without compensation, in a personal and professional capacity. They provide material assistance in the consideration of problems related to their technological fields, review research in progress both at NACA laboratories and in other organizations, recommend research projects to be undertaken, and assist in the coordination of research programs.

Membership of the technical committees and subcommittees, as well as of the Industry Consulting Committee, is listed in Part II of this report, beginning on page 61.

Coordination of research is also accomplished through frequent discussions by NACA technical staff personnel with the staffs of research organizations of the aircraft industry, educational and scientific institutions, and other aeronautical agencies. The NACA maintains a west-coast office to further liaison with the aeronautical research and engineering staffs of that geographical area.

During the 40 years since its organization as an independent Federal agency, the NACA has sought to assess the current status of development of aircraft, both civil and military; to anticipate the research needs of aeronautics; to develop the scientific staff and special research facilities required; and to acquire the needed information as rapidly as may be consistent with the national interest.

The NACA research programs have had both the long-range, all-inclusive objective of acquiring the new scientific knowledge essential to assure American leadership in aeronautics and the immediate objective of solving, as quickly as possible, the most pressing problems, thus to give effective support to the Nation's current aircraft construction program.

Most of the problems to be studied are assigned to NACA's research centers: the Langley Aeronautical Laboratory in Virginia, where research is conducted on aerodynamic, structures, hydrodynamic, and other problems; the Ames Aeronautical Laboratory in California, which concentrates on aerodynamic research; the Lewis Flight Propulsion Laboratory in Ohio, which is concerned primarily with powerplant problems; and the High-Speed Flight Station in California, where specially designed, specially instrumented research aircraft are used in full-scale research on transonic and supersonic problems. Aerodynamic problems in the transonic and supersonic speed ranges are studied, using rocket-powered models in free flight, at the NACA research installation located at Wallops Island, off the Virginia coast.

The NACA also sponsors and finances a coordinated program of research at 25 nonprofit scientific and educational institutions, including the National Bureau of Standards. By this means, scientists and research engineers, whose skills and talents otherwise might not be available, contribute importantly to the Government's program of aeronautical research. Promising students also receive scientific training which makes them useful additions to the country's supply of technical manpower.

During the fiscal year 1955, the following institutions participated in the NACA's program of contract research:

National Bureau of Standards
Battelle Memorial Institute
Polytechnic Institute of Brooklyn
California Institute of Technology
University of California
Carnegie Institute of Technology
Case Institute of Technology
University of Cincinnati
Columbia University
Cornell University
Franklin Institute
Georgia Institute of Technology
Johns Hopkins University
Lightning & Transients Research Institute

Massachusetts Institute of Technology
University of Michigan
University of Minnesota
University of Oklahoma
Purdue University
Syracuse University
University of Washington
University of Wisconsin
Stanford University
Stevens Institute of Technology
New York University

Proposals from such institutions are carefully screened to assure best use of the limited funds available to the NACA for sponsoring research outside its own facilities. Similarly, results from these projects are reviewed to maintain the quality of this part of the NACA program. Reports of the useful results are given the same wide distribution as other NACA publications.

During the fiscal year, most of the NACA technical subcommittees reviewed proposals for research projects from outside organizations or gave attention to reports from completed contracts. Reports covering results of sponsored research totaled 42 during fiscal year 1955.

Research information, including that obtained in the Committee's laboratories and elsewhere under NACA sponsorship, is distributed in the form of Committee publications. Reports and Technical Notes, containing information that is not classified for reasons of military security, are available to the public in general. Translations of important foreign research information are published as Technical Memorandums.

The NACA also prepares a large number of reports containing information of classified nature. These, for reasons of national security, are closely controlled as to circulation. When it is found possible at a later date to declassify such information, these reports also may be given wider distribution.

Current announcement of NACA publications is contained in the NACA Research Abstracts. This service, in addition to telling of NACA publications, makes note of important research reports received from abroad.

In addition to other means of making research information readily available, the NACA each year holds a number of technical conferences with representatives of the aviation industry, universities, and the military services. Attendance at these meetings is restricted, because of the security classification of the material presented, and the subject material is focused upon a specific field of interest.

AREA-RULE CONCEPT STEMMED FROM INTENSIVE TRANSONIC RESEARCH

The work begun early in 1951 which led to expression of the area rule and its subsequent useful development was but one facet of a many-sided research attack which the NACA was waging at its Ames and Langley Laboratories on the problem of transonic drag. Richard T. Whitcomb's assignment, in essence, was to make initial use of the new and, at the time, unique transonic wind tunnel at the Langley Aeronautical Laboratory in an effort to obtain a better understanding of the sharp drag rise which occurred as an airplane neared the speed of sound.

Already, application of the area-rule concept to the design of Air Force and Navy aircraft has resulted in performance gains of as much as 25 percent. Because Whitcomb's accomplishment was one segment of a long-range program, it may be in order to relate his investigations in context with other transonic research which had been undertaken.

The problem of transonic drag has been known for many years. (The drag rise, sometimes called pressure drag, is the difference between the drag level above the speed of sound and the drag level at subsonic speeds where the drag is due primarily to skin friction.) Unfortunately, in these years, the principal aerodynamic research tool, the conventional wind tunnel, was limited by choking phenomena at or very near the speed of sound—where the drag rise was sharpest. Consequently, the task, first, of defining the magnitude and the nature of the problem and, second, of seeking solutions, was made much more difficult.

Once the possibility of faster-than-sound flight had been definitely established, in 1947 by the rocket-powered X–1 research airplane, it became imperative that solutions be found for the drag-rise problem if supersonic speed was ever to be attained by airplanes with useful range and load-carrying capabilities. The development, over a period of years, of several techniques utilizing special research airplanes, falling bodies, rocket-powered models, and so forth to study problems in the transonic area was traced in the NACA's Fortieth Annual Report, 1954, beginning on page 3.

Using these techniques, fairly substantial progress was made in reducing transonic drag rise. The means employed were relatively obvious. The thickness ratio of wings was reduced. Wings with a large degree of sweepback and with low aspect ratio were adopted. Work was done also to develop optimum fuselage shapes for flight at such speeds.

In these years intensive experimentation was also conducted in an effort to determine the best combination of wing and fuselage forms. Rocket-powered models, fired from the NACA's Wallops Island, Va., field station, provided a quick and relatively inexpensive means to carry on this work. From it came a number of wing-body combinations with very low drag rise in the transonic range. Unfortunately, the models with the lowest drag rise were largely impractical from the standpoint of use in the design of tactical military airplanes.

Nonetheless, the aerodynamic progress which was made, coupled with the successful development of turbojet engines of the 10,000-pound-thrust class, made possible flight through the transonic range to low supersonic speed. For the designer, the transonic drag rise remained so large as to compromise seriously the ability of an airplane to perform a useful military mission. At this point, with the transonic-drag-rise problem seemingly still far from solution, numerous designs for supersonic airplanes proved to be incapable of reaching faster-than-sound speeds. Use of the rocket-powered-model technique enabled determination of the magnitude of the drag rise at transonic speeds of such designs and resulted in very considerable savings of both time and money.

Whereas several techniques enabled measurement of the drag rise in the transonic range, it was not until the 8-foot transonic wind tunnel was put into operation at the Langley Laboratory that it became possible to undertake systematic study of the problem. For the first time, it was possible to study visually the interferences of flows over the various components of the airplane with one another which, it was found, were associated to a large extent with the large amount of drag rise. Further work in the tunnel showed plainly that these interferences were sources of large and erratic drag-rise characteristics which could not be explained in terms of model configuration factors such as thickness ratio, sweep, and the usual body considerations.

In the research on flow interference at transonic speeds, systematic investigation was made of the drag-rise increments of numerous wing-body combinations. At subsonic speeds the pressure drag due to thickness of the fuselage or wings is negligible as long as the shapes are sufficiently well streamlined to avoid flow separation. Near the speed of sound, however, the drag becomes sensitive to the shape and arrangement of the bodies.

From the visualization of flow patterns, which the transonic tunnel permitted, came the formulation of the essential elements of the area rule. The next step was to devise critical experiments which would enable clear-cut proof-testing of the concept.

These critical experiments required enlargement of the research program to include comparisons of the drag-rise increases of wing-body combinations with those of their comparable bodies of revolution (the cross-sectional area of a model's wing was wrapped around the body of revolution which otherwise had the same cross-sectional area along the axis as the model fuselage). Study of schlieren photographs showed that the farther away from the models, and comparable bodies of revolution, the more closely the observed shock patterns resembled each other. In other words, although there were found to be differences of flow near the wing-body combinations and their equivalent bodies of revolution, these differences diminished rapidly farther away from the models.

The generally close similarities of the total or effective flow fields for the wing-body combination and the comparable body of revolution in the regions producing the main portion of the shock losses suggested that the energy losses associated with the shocks for the two configurations should be similar. Since the drag rise for thin low-aspect-ratio wings is due primarily to shock losses, the drag rise for the combination should be approximately the same as that for the equivalent body of revolution.

As one part of the research program, drag-rise increases were measured at a Mach number of 1.03 for 15 models of as many swept-, delta-, and straight-wing-body combinations. Comparison was then made with the drag-rise increments of their comparable bodies of revolution. With a single exception (for which a complete explanation has yet to be found) there was general qualitative agreement between the drag-rise increases of the models and of their comparable bodies of revolution.

A final step in the development of the new concept was the reasoning that the drag rise would be held to a minimum near the speed of sound if the wing-body combination were reshaped so that its area distribution would be similar to that for a smooth body of revolution with the highest possible fineness ratio. Again use of the transonic wind tunnel made possible verification of the validity of the reasoning process.

It soon became apparent that the fineness ratios which could be used were considerably less than that required for minimum total drag because of such considerations as airplane stability and structural weight. No less, such matters as the dimensions of the elevator of an aircraft carrier imposed practical limitations on the length of a Navy fighter airplane.

Further development of the area-rule concept resulted in learning how to insure minimum drag rise by adding to an existing wing-body combination (as well as subtracting area) to obtain a more favorable area distribution. In the case of the Convair F–102A, for example, the fineness ratio was improved by lengthening the nose, and area was added to the fuselage aft of the wings. These changes were in addition to pinching in the fuselage at the wing roots in the manner which has been variously and popularly described as "Marilyn Monroe," "coke bottle," and "wasp waist."

With the area rule clearly stated and experimentally proven, a next step was to develop the theory which would provide an adequate understanding of the phenomena. At this point, it occurred to the researchers that the essence of the area-rule idea might have existed in the body of linear theory which had been developed over the years, and this, in fact, was soon shown to have been the case. For example, in the 1947 doctoral thesis by Wallace D. Hayes at the California Institute of Technology, on linearized supersonic flow, there were mathematical expressions showing that the wave drag of a system of wings and bodies depended on the longitudinal area distribution of the system as a whole and that calculation of the wave drag could be simplified to that of a slender body of revolution. Work on linearized supersonic flow which resulted in somewhat similar indications was also done by W. T. Lord and G. N. Ward of Great Britain, Ernest W. Graham, and others. Because of the limitations of the theory at transonic speeds, it was not felt to be of significance.

Since the first work establishing the area rule, much study has been devoted at the Ames and Langley Laboratories both to attaining maximum benefits from its application and also to establishing its limitations.

The area rule permits ready application of the store of available information about theoretically optimum bodies to the design of airplanes having similar characteristics of optimum drag rise. The simplicity of the rule minimizes the detailed analysis which previously was required whenever such effects of wing geometry as thickness, sweep, and aspect ratio were involved because such analysis was always clouded by the effects of other variables which could not be eliminated. Finally, and perhaps most important, it has brought realization that the airplane's wing and fuselage must be designed together.

Already, the results of this effort have given the designer a powerful, simple, and useful tool in eliminating a major portion of the transonic-drag-rise increase.

AERODYNAMIC RESEARCH

Extensive experimental and theoretical research in the field of aerodynamics has continued in the research facilities of the NACA to further the understanding of the basic factors important in the selection of optimum aircraft configurations for high-speed flight. One important result of this work is the transonic area rule, some details of which are discussed in the section on High-Speed Aerodynamics. In addition to generalized aerodynamic research, a large number of investigations have been undertaken at the request of the military services to assist in the development of specific military aircraft; besides providing particular aerodynamic information on specific problems of special interest, these programs often indicate new general problems on which basic research studies are initiated.

The laboratories have made increased use of ground and flight simulators and electronic computing equipment to complement their wind-tunnel and flight studies of various aerodynamic problems; special attention has been given to the use of such equipment in the study of airplane pitch-roll coupling, a dynamic stability problem of concern in high-speed airplane design. The development of new and improved analytical and theoretical techniques for the estimation of various aerodynamic parameters of an aircraft configuration and its components has also continued.

One relatively new field in which progress has been made is that dealing with vertical-takeoff aircraft. Significant research has been done on various means for achieving vertical takeoff and landing without importantly compromising the high-speed capability. The stability of several promising arrangements has been extensively studied.

Assistance on broad aerodynamic problems has been given to the NACA by the Committee on Aerodynamics and its technical subcommittees on Fluid Mechanics, High-Speed Aerodynamics, Stability and Control, Internal Flow, Propellers for Aircraft, Seaplanes, and Helicopters. In past years, it has been indicated that special NACA conferences, attended by representatives of the military services and many of their contractors, were effective means of disseminating newly acquired NACA research results. During the past year a conference of this type on automatic stability and control of aircraft was held at the Ames Laboratory.

Some of the recent unclassified aerodynamic work undertaken by the NACA is briefly described in the following paragraphs.

FLUID MECHANICS

Boundary-Layer Research

In recent years, with the advent of laminar airfoils and with the observations of laminar boundary layers at Reynolds numbers as high as 50×10^6, the ability to estimate reliably viscous-flow and heat-transfer effects for a laminar boundary layer has become increasingly important. A completely general solution of the laminar-boundary-layer equations which include effects of compressibility, pressure gradient, and heat transfer has been extremely difficult because of the mathematical complexities involved. However, for a particular class of pressure gradients, the velocity and temperature profiles are similar at each streamwise station and a mathematical solution can be obtained. Such a solution is presented in Technical Note 3325. The results of this solution are applied in Technical Note 3326, which provides an approximate method for calculating the characteristics of the compressible laminar boundary layer with arbitrary pressure gradient and heat transfer. A related theoretical study of the effect of pressure gradient, wall temperature, and Mach number on laminar-boundary-layer characteristics has been conducted by the Polytechnic Institute of Brooklyn Aeronautical Laboratories under the sponsorship of the NACA. The results of the study are given in Technical Note 3296.

Although boundary-layer theory has advanced to the stage where it is now possible to predict with some confidence the behavior of the laminar and turbulent boundary layers on a flat plate at moderately high Mach numbers, the determination of the overall behavior has lagged because of a poor understanding of the intermediate transition region. A series of transition studies in high-speed flows has been conducted at the Lewis Laboratory. Results of two of these studies are presented in Technical Notes 3509 and 3267, wherein recovery temperatures and transition locations are analyzed.

Various aspects of the turbulent boundary layer have been investigated in the past year. In Technical Note 3454, the problem of shock-induced turbulent-boundary-layer separation is analyzed by an approximate method. This analysis provides criteria for avoiding separation behind the shock.

Attention has also been directed toward a fundamental understanding of the physical mechanisms involved in a turbulent boundary layer. This research involves measurement of various statistical quantities in the boundary layer. Experimental measurements of all the terms appearing in the momentum equations, such as mean and turbulent shear stress, are presented in Technical Note 3264. These terms are evaluated and analyzed for a flow with progressively increasing pressure gradient. Measurements of the spectra of the longitudinal component of turbulence are reported in Technical Note 3453; the measured spectra are also compared with the different variations predicted from the hypothesis of statistical equilibrium.

In Technical Note 3266, an experimental investigation of fully developed turbulent flow in pipes is presented. Analysis of the turbulent stress tensor shows that the direction of principal stress was oriented nearly parallel to the wall in the region near the wall. The results indicated that the intensity at the center was of a universal nature. Comparison of turbulence measurements obtained using the constant-current and constant-temperature systems of hot-wire anemometry showed good agreement.

The problem of the effect of yaw on the turbulent boundary layer and skin friction of infinite cylinders was investigated experimentally at Cornell University under the sponsorship of the NACA. Results of tests conducted on three flat plates yawed 0°, 30°, and 45° with artificially fixed transition in a low-speed, low-turbulence tunnel are described in Technical Note 3383. These results indicate that the boundary-layer displacement thickness increases in the stream direction at a slightly greater rate on the yawed plates than on an unyawed plate; the effects of yaw on the direction of flow within the boundary layer were generally small.

If a shock wave advances into a stationary fluid bounded by a wall, a boundary-layer flow is established along the wall. An analysis of such a boundary layer, which is important in studies of phenomena involving nonstationary shocks, is presented in Technical Note 3401. Velocity and temperature profiles, recovery factors, and skin-friction and heat-transfer coefficients are tabulated for a wide range of shock strengths.

Skin Friction and Heat Transfer

The design of supersonic airplanes and missiles requires engineering information about heat-transfer coefficients and recovery factors that extend over a wide range of Reynolds numbers. Free-flight tests at supersonic speeds up to a Mach number of 2.5 have therefore been made by the Langley Pilotless Aircraft Research Division to determine the local convective heat-transfer coefficients evaluated from measured skin temperatures on a rocket-propelled fin-stabilized parabolic body of revolution. Skin temperatures were measured by resistance-type thermometers cemented to the inside surface of the body. The experimental heat-transfer values were compared with the results obtained from the V–2 research missile and with several equations for heat transfer in a turbulent boundary layer. The equation for heat transfer on a flat plate in a turbulent boundary layer at subsonic speed was in good agreement with the test results which covered a Mach number range from 1.0 to 2.5.

Other heat-transfer studies up to similar high Mach numbers and Reynolds numbers were made by the Langley Gas Dynamics Branch. Axially symmetric annular nozzles consisting of a constant-diameter outer wall and center bodies shaped to produce supersonic flows were used. The measurements, made along the outer wall, gave essentially flat plate results that were free from wall-interference and corner effects. Test results at Mach numbers of 3.03, 2.06, and 1.62 are reported in Technical Notes 3303, 3374, and 3461, respectively. The experimental heat-transfer coefficients were in good agreement with theoretical analysis and with the V–2 rocket data.

One of the most critical areas affected by aerodynamic heating is in the vicinity of the forward stagnation points on blunt bodies. An analysis of the heat transfer at these points for two-dimensional and axially symmetric blunt bodies is presented in Technical Note 3513. Relations for the heat transfer, obtained from exact solutions to the equations of the laminar boundary layer, are given in terms of the local velocity gradient at the stagnation point.

Structural damage resulting from aerodynamic heating in supersonic flight can be avoided either by utilizing high-temperature materials in aircraft construction or by one of several methods of surface cooling. The method of transpiration cooling, in which the coolant passes through small pores in the aircraft surface into the outside boundary layer, seems promising. In Technical Note 3341, an analysis is presented which indicates that the surface injection associated with transpiration cooling systems produces large reductions in both the heat-transfer and skin-friction coefficients for a turbulent boundary layer on a flat plate. The numerical results are restricted to the case of air blowing into air. The effects of blowing are indicated to be similar for high-speed compressible flow to those for low-speed incompressible flow. In Technical Note 3404, a solution of the equations of the compressible laminar boundary layer is given which includes the effects of transpiration cooling. The effect of several flow parameters on coolant-flow rates is discussed with the aid of representative examples. Analysis indicates that, on a weight-of-coolant basis, transpiration cooling is more effective than other methods studied.

A review has been made of recent advances in the knowledge of heat transfer and skin friction occurring on the surfaces of high-speed aircraft. The subject matter included the following topics: boundary-layer transition, heat transfer and skin friction in laminar boundary layers, heat transfer and skin friction in turbulent boundary layers, and transpiration cooling. The review was presented at the NACA-University Conference held at the Lewis Flight Propulsion Laboratory on October 20, 21, and 22, 1954.

Gas Dynamics

In Technical Note 3318, a further effort is made to clarify the mathematical problem of accurately approximating subsonic compressible flow. Comparisons are made of calculations by the Prandtl-Busemann (small-disturbance) method with calculations by the Janzen-Rayleigh (M^2-expansion) method for the flow about a parabolic cylinder. The small-disturbance method as normally used was found to be unsuitable to the calculation, but when the solution was developed in powers of M as a control parameter the result was identical with that obtained by the M^2-expansion method. It is also shown that the small-disturbance solution, developed in reciprocal powers of the distance from the vortex, agrees with the results of second-order thin-airfoil theory.

Transonic flow past certain two-dimensional bodies has been the subject of several recent analytical studies and the phenomena are well understood; some study has also been made of the similarity rules of axially symmetric transonic flow, but information is not so complete as that for two-dimensional flow. To increase this information, an experimental investigation was undertaken by the California Institute of Technology, under the sponsorship of the NACA, of the transonic flow past cone-cylinder, axially symmetric bodies. In Technical Note 3213, the experimental results are compared with theoretical predictions.

A precise experimental determination of the structure and thickness of the normal shock wave is of fundamental interest in the study of gas dynamics. The profiles and thicknesses of normal shock waves of moderate strength have recently been determined experimentally in terms of the variation of the equilibrium temperature of an insulated transverse cylinder in free-molecule flow. The shock waves of this study, conducted under the sponsorship of the NACA by the University of California, were produced in a steady state in the jet of a low-density wind tunnel at Mach numbers from 1.72 to 3.91. The shock thickness varied from 5 to 3½ times the length of the Maxwell mean free path in the supersonic air stream. A comparison of the experimental results with various theoretical predictions is included in Technical Note 3298.

In Technical Note 3299, solutions corresponding to the reflection of a centered simple wave along a straight wall and along a free streamline of constant pressure are formulated in mathematical terms. Associated problems are of great importance in two-dimensional supersonic-flow theory and apparently have not been previously studied mathematically. This study, undertaken by Brown University under the sponsorship of the NACA, shows that these solutions are simply related to some solutions arising in the theory of linear partial differential equations and to some important theorems predicting "a priori bounds" for special mathematical problems.

At present, there exists little quantitative information about the flow in cutouts in aerodynamic surfaces. The equilibrium of the vortex systems existing within the cavity evidently depends on the geometery of the cavity and the parameters of the outside flow, but it is not apparent which features are predominant in determining this equilibrium. The California Institute of Technology, in an investigation sponsored by the NACA, therefore, undertook to provide additional information in this field. In this study, the flow in a rectangular cavity, or slot, in the floor of a wind tunnel is described by pressure and velocity measurements. A report on these results, which includes the effects of varying the depth-breath ratio of the cavity, is given in Technical Note 3488.

The use of auxiliary air injection downstream of a supersonic-wind-tunnel test section reduces the pressure ratio required to start and run the tunnel. The feasibility of such a configuration depends on the effectiveness of injectors in reducing tunnel pressure ratio without excessive increases in total weight flow. The results of an experimental investigation of injector performance, reported in Technical Note 3262, indicate that the tunnels with injectors operated at pressure ratios approximately 20 percent greater than the theoretically predicted values.

By passing shock waves into a supersonic-wind-tunnel test section, instantaneous changes in flow Mach number result. Such a technique would be of value for experimental investigations of transient phenomena. An experimental study of the Mach number changes that can be induced by initiating a high-pressure pulse at the upstream end of a supersonic-wind-tunnel nozzle was recently undertaken at the Lewis Laboratory. The results of the study are presented in Technical Note 3258.

One of the basic problems in combustion aerodynamics is the dynamic effect produced in a medium as a result of heat release; the strength of the pressure waves generated by the heat release and their importance are of particular concern. To provide additional information relating to this problem, an analytical investigation was recently made by The Johns Hopkins University under the sponsorship of the NACA. The results of the study are given in Technical Note 3411. An approximate formula of a linearized solution for the pressure field generated by a moderate rate of heat release is included. Analogies between the pressure waves generated by heat release and those generated by mass release, piston motion, or a two-dimensional body in a supersonic air stream are presented.

Research Equipment and Techniques

The design and construction of a new wind tunnel for heat-transfer studies have been completed at the Lewis Laboratory and the tunnel has been put into operation. The wind tunnel is of the closed-circuit type, having a test-section size of 10 inches by 12 inches, with a Mach number range from 2½ to 6. The wind tunnel is designed to permit testing at air stagnation temperatures up to 1,200° F and duplicate temperatures in actual flight at a Mach number of 4 at approximately 50,000 feet. The wind tunnel will be used for obtaining heat-transfer and aerodynamic data under the air-temperature conditions encountered in flight.

In order to simplify the method of designing supersonic nozzles, a procedure has been published in Technical Note 3322 for computing nozzle shapes for any Mach number directly from tabulated flow parameters and appropriate equations. An existing report gives equations for nozzle shapes starting with radial supersonic flow; this report completes the procedure by providing the method of designing the first part of the nozzle to achieve this necessary radial flow.

Development of hypersonic testing in wind tunnels is hampered by condensation of the air itself at the low temperatures that exist in the test section. In order to determine the nature of the condensation process and to determine the effect of stagnation temperature, pressure measurements and scattered-light measurements were made in two Mach number 7 nozzles at the Langley 11-inch hypersonic tunnel. The results, reported in Technical Note 3302, showed that liquefaction of air occurred very close to the saturation point without a condensation shock, which indicated that liquefaction took place on foreign nuclei such as water and carbon-dioxide particles. The results with various contents of water vapor and carbon dioxide, however, could not be correlated with available condensation theory.

An investigation of a method of obtaining skin-friction coefficients from measurement of the local rate of heat transfer was undertaken by the California Institute of Technology under the sponsorship of the NACA. Technical Note 3268 discusses the possible range of application of the method in low- and high-speed flow and presents experimental data to show that a very simple instrument can be used to obtain laminar and turbulent skin-friction coefficients with a single calibration.

Analysis has shown that photometric measurements in the scattered electromagnetic field produced when a plane light wave passes through a nonabsorbing turbulent gas can be used to define an integral scale and average intensity of the density fluctuations. Although the analysis is rigorously valid only for turbulence characterized by isotropic density fluctuations having an exponentially decaying autocorrelation, experimental data for supersonic turbulent boundary layers have proved to be in good functional agreement with the predictions of the analysis. Thus, a promising new method is available for the detection and measurement of density fluctuations in compressible boundary layers, wakes, and jets. The investigation was reported in a paper presented at the 1955 Joint Meeting of the American Physical Society and the Sociedad Mexicana De Fisica.

HIGH-SPEED AERODYNAMICS

Wing-Body Drag Interference at Transonic Speeds—The Area Rule

In the course of experimental research on the drag caused by interfering pressure fields from aircraft wings and bodies, a fundamental discovery of considerable importance to the performance of high-speed aircraft was made. It was found that at Mach numbers near 1.0 the wave drag of a wing-body combination is dependent primarily on the streamwise distribution of cross-sectional area of the combination. This statement constitutes what has become known as the "area rule." Some of the historical aspects of research leading to this discovery and the subsequent application of the area rule to the design of particular aircraft are related in an earlier section of this Annual Report.

The original research, which was carried out in the Langley 8-foot transonic tunnel by Richard T. Whitcomb, provided the experimental demonstration of the area rule and showed that, by the proper removal of body cross-sectional area in the region of the wing, large decreases in the transonic drag of wing-body combinations could be achieved. Within the range of applicability of the area rule it should be possible in a wing-body combination to eliminate completely the zero-lift component of pressure drag due to the wing and such was demonstrated to be the case.

In a later analysis designed to investigate the range of applicability of the area rule, a comparison was made with the appropriate similarity rule of transonic-flow theory and within available experimental data for a large family of rectangular wings of various aspect ratios and thickness-chord ratios. It was found that for this family of wings the data could be correlated on the basis of the area rule for values of the similarity parameter (aspect ratio times the one-third power of the thickness-chord ratio) less than about 1.0.

In a theoretical study the basic ideas of the slender-body approximation were applied to the nonlinear transonic-flow equation for the velocity potential in order to obtain some of the essential features of slender-body theory at transonic speeds. The transonic area rule and some conditions concerning its validity were found to follow from the analysis.

In another investigation theoretical methods were used to calculate the pressures over a swept wing in the presence of a cylindrical central body and a nearly cylindrical body indented according to the area rule. The investigation showed that the pressure distribution on the wing in the presence of the indented body was closely similar to the pressure distribution on an infinite swept wing.

Airfoils and Wings

Several recent theoretical advances have been combined in Technical Note 3390 to give a second-order theory of airfoil sections in subsonic flow. The surface velocities were calculated for incompressible flow, transformed by the second-order compressibility rule, and then corrected near the leading and trailing edges. A straightforward computing scheme is given for treating any profile, based on a knowledge of its ordinates at designated points. Solutions for a number of airfoils are given and compared with results of other theories and experiment.

Inasmuch as an airfoil intended for supersonic flight must first traverse the subsonic and transonic speed ranges, its force characteristics must be suitable for steady and controllable flight in these speed ranges. To investigate this problem, a series of eight 6-percent-thick airfoils was tested in the Langley rectangular high-speed tunnel. These airfoils included the NACA 0006–63, NACA 16–006, NACA 66–006, three circular-arc airfoils with maximum thickness locations at 30, 50, and 70 percent chord, and two symmetrical wedge airfoils with maximum thickness locations at 30 and 70 percent chord. Pressure-distribution tests were made at Mach numbers up to choking and at angles of attack up to 20°. The Reynolds number range corresponding to the Mach number range varied from 0.7×10^6 to 1.5×10^6 based on a chord of 4 inches. The results of this investigation, which are reported in Technical Note 3424, led to the conclusion that for airfoils of the type tested the variations with Mach number of the lift, drag, and pitching-moment coefficients are generally similar, and there do not appear to be any factors which would prohibit the use of sharp-leading-edge profiles in the speed range of these tests.

The linearized theory of thin wings, which has proved so fruitful for both subsonic and supersonic flows, is known to fail near leading and trailing edges if the component of free-stream velocity normal to the edge is subsonic, and erroneous calculations of the drag result. A simple technique is given in Technical Note 3343 for correcting this failure. Consideration of the flow past parabolas and wedges leads to simple rules for treating round and sharp edges. In this way, rules given previously for round-nosed airfoil sections in incompressible flow are extended to higher approximations, sharp edges, subsonic speeds, three-dimensional wings, and to slender bodies of revolution.

Among airfoil profiles the wedge is of particular interest since its geometric simplicity permits ready formulation of a problem with known boundary conditions in the hodograph plane. Consequently, it has been the subject of considerable theoretical work in the transonic Mach number range. Guderley and Yoshihara obtained theoretical results for a symmetrical double-wedge profile at zero lift at a Mach number of 1 and have recently extended their work to include the lifting condition. In order to provide experimental data for comparison with these theoretical results, tests were made of a 10-percent-thick, symmetrical double-wedge airfoil at Mach numbers up to 1.0 and at angles of attack up to 8° in the Langley 4- by 19-inch semiopen tunnel. These experiments are reported in Technical Note 3306. At zero lift the experimental results are in fair agreement with the theoretical results of Guderley and Yoshihara at a Mach number of 1 and with the results of transonic small-disturbance theories of other investigators in the Mach number range from 0.85 to 1.0. At lifting conditions, a reasonable check was obtained on the value of the lift-curve slope at a Mach number of 1 calculated by Guderley and Yoshihara.

The use of airfoils with appreciable trailing-edge thickness has received little attention prior to the last few years, presumably because of the high drag associated with a blunt trailing edge at low speeds. The characteristics of blunt-trailing-edge airfoils have recently been investigated because of their evident structural advantages, improvement in certain lift and control characteristics at transonic velocities, reduction in profile drag at moderate and high supersonic velocities, and increase in the lift-curve slope at supersonic velocities. An investigation concerned solely with the lift characteristics of blunt-trailing-edge wings in supersonic flow has been undertaken by the Ames Laboratory. The results of this investigation, reported in Technical Note 3504, show reasonable agreement between calculations and experiments over the Mach number range between 1.5 and 3.1. Increasing the trailing-edge thickness increased the lift-curve slope in amounts up to about 15 percent. This effect was greater at hypersonic speeds, where the calculations predict, for example, up to 25-percent greater lift for a fully blunt 5-percent-thick airfoil than for a sharp-trailing-edge airfoil.

The inherently low values of lift-drag ratio and the resultant short ranges characteristic of conventional aircraft configurations operated at supersonic speeds have stimulated research on more efficient shapes for use at these speeds. This research has been directed along two main lines, one, the reduction of the drag at zero lift and, the other, the reduction of the drag due to lift. One of the most promising developments has been the use of twist and camber to reduce the wing drag due to lift for a given plan form. The problem of how best to select the one particular combination of twist and camber that will represent the best compromise for all flight conditions is being studied at the Langley Laboratory. In Technical Note 3317, relations and curves are presented from which a suitable selection may be made, depending on the relative importance of maximum range and top speed. In addition, it is shown that large increases in maximum lift-drag ratio can probably be realized by the use of the proper twist and camber.

The estimation of the drag due to lift for low-aspect-ratio wings has been hampered by the effect of aspect ratio on the variation of profile drag with lift coefficient. An analysis of the drag due to lift of low-aspect-ratio rectangular wings has recently been made and is presented in Technical Note 3324. A discussion of the variation of profile drag with lift also is presented and a method is developed which relates the effect of aspect ratio on the profile drag due to lift to an effective two-dimensional lift coefficient. A simple expression for this "effective" two-dimensional lift coefficient in terms of the aspect ratio is derived and used to correlate experimental values of profile drag due to lift for rectangular wings in the low-aspect-ratio range. A method of utilizing two-dimensional test results, by means of this effective two-dimensional lift coefficient, to estimate the profile drag due to lift of low-aspect-ratio wings is briefly discussed.

Zero-lift drag calculations have generally not been made for tapered wings with curved surfaces because of the difficulty of solving the drag equations. However, the zero-lift wave drag of a particular family of unswept tapered wings with linearly varying thickness ratio and symmetrical parabolic-arc sections has been calculated using linear theory. In Technical Note 3418, the case of the wing with a given root thickness ratio is given primary consideration with the view toward its use for missiles with all-movable fins where the root thickness must be large enough to allow for a rigid attachment to the trunnion and controlling mechanism. By comparing the drag for these wings with that for a corresponding constant-thickness-ratio wing with rhombic sections, it is found that the variable-thickness-ratio wings can be used to advantage with no serious structural penalties if the wings are assumed to have the same given root thickness ratio or the same internal volume.

Of the several published methods for computing the aerodynamic loading over the wing span at subsonic speeds, the Weissinger method with seven control points across the span is one of the easier methods to use and, at one time, appeared to afford the best compromise between labor and accuracy. It has been found, however, that for wings combining high aspect ratio with large amounts of sweepback the seven-point loadings are in error. A simple procedure is presented in Technical Note 3500 to correct these errors for a sizable range of plan forms. These corrected results agree with known accurate results within 1 percent. The lift-curve slope and the method of fairing the loading are also improved.

The shock-expansion method for calculating the pressure distribution on cylindrical wings in supersonic flow has been extended in Technical Note 3499 to tapered wings made up of single-curved (i. e., developable) surfaces. The method applies in regions of the wing where the component velocity normal to the surface rulings is supersonic and the flow is not influenced by the presence of the root or tip. Because of the nature of the flow in such regions, the method can be developed from elementary considerations of infinitesimal plane waves and simple geometry. The result is a pair of ordinary differential equations describing the flow over the surface. These equations can be solved by standard numerical methods for any given wing. Calculations using this method indicate that linear theory cannot be used for accurate prediction of lift distribution even for thin, low-aspect-ratio wings at angles of attack as small as 3°. Experimental measurements that verify this fact were made on a triangular wing having a maximum thickness of 5 percent of the chord and an aspect ratio of 4. The wing was tested at a Mach number of 3.36 in the 1- by 3-foot supersonic wind tunnel of the Ames Laboratory.

Some aspects of the nature of the flow around delta wings have been studied in a recent experimental investigation. Vapor-screen, pressure-distribution, and ink-flow studies were made at a Mach number of 1.9 on a series of semispan delta-wing models with slender wedge airfoil sections and sharp leading edges. The models had semiapex angles varying from 5° to 31.75°. The results of this investigation, reported in Technical Note 3472, show that separated regions of vorticity existed along the chords of all the wings in the series tested. Concentrated vortex cores were found only on wings of very small semiapex angles. For wings with medium and large semiapex angles the separated vorticity was concentrated in a region extending over the outboard part of the span and lying close to the wing upper surface. The results show that theoretical aerodynamic calculations, such as those in Technical Note 3430, utilizing a single separated vortex pair above the wing upper surface to represent the separated vorticity, can be applied at supersonic speeds for very slender wings.

Bodies

The problem of shaping a body in such a way that its wave drag at supersonic speeds is a minimum is receiving considerable attention. Most of the shapes so far derived have been closed at one or both ends; for nacellelike or ductlike configurations such a restriction is undesirable. The problem of determining the optimum shape for a given volume added to a basic circular cylinder was attacked and solved without the assumption that the body be of small radius but rather that it depart only slightly from a basic circular cylinder. The solution obtained contains the complete range of results from the slender to the two-dimensional (which is approached for cylinders of very large radius). These results, given in Technical Note 3389, indicate that the solution rather quickly loses its similarity to the slender-body-theory solution and approaches the two-dimensional as the radius of the basic cylinder is increased. A reverse-flow theorem for axial symmetry is presented and used to derive a useful relation between the geometry of optimum shapes and the pressure in a combined flow field.

As part of a supersonic research program, the Langley Pilotless Aircraft Research Division has investigated the drag at different Reynolds numbers of a fin-stabilized parabolic-arc body of revolution designated the NACA RM–10. The Mach number range of the tests was approximately 0.9 to 3.3 and the Reynolds numbers, based on body length, were from 14×10^6 to 210×10^6 for the full-scale models and 15×10^6 to 110×10^6 for the half-scale models. The results, reported in Technical Note 3320, indicate that there is, at most, only small effect on total-drag coefficient of the RM–10 configuration at a given Mach number due specifically to changes in Reynolds number. The results showed the base-drag coefficient of the half-scale models to be 25 to 50 percent lower than that of the full-scale model. However, information was insufficient to show whether this difference was due to the difference in Reynolds number at a given Mach number or to differences in internal base configurations and location of the measurement point between the two sizes of models.

The pressure acting on the base of a body moving at supersonic speeds may be of considerable importance since it can produce base drag amounting to more than one-half the total drag of the body. Tests are continuing to determine the factors affecting base drag. In one Langley study, base pressures were measured in flight at Mach numbers from 0.7 to 1.2 on fin-stabilized bodies of revolution with and without rocket chambers and with and without a converging afterbody. Results presented in Technical Note 3372 show that the presence of a "cold" rocket chamber increased the pressure (less suction) over the center portion of the bases. The addition of a convergent afterbody greatly increased the base pressure as measured at both edge and center-line orifices. Base-pressure characteristics of related nonlifting bodies of revolution were investigated experimentally in the Ames 10- by 14-inch supersonic wind tunnel. The tests were conducted at Mach numbers from 2.73 to 4.98 and Reynolds numbers from 0.6 to 8.8 million based on body length. The basic body shape was a 10-caliber tangent ogive with a cylindrical afterbody. The variation of base-pressure coefficient with free-stream Mach number and Reynolds number was determined for laminar-, transitional-, and turbulent-boundary-layer flow. Some effects of body fineness ratio, nose-profile shape, and afterbody shape (boattail) were also included in the investigation. The results of this study, reported in Technical Note 3393, show that the base-pressure coefficient decreased with increasing Reynolds number and increased with increasing free-stream Mach number or fineness ratio.

For application to the analytical study of external stores at supersonic speeds, methods have been developed in Technical Note 3369 for calculating the drag of a body of revolution in a nonuniform flow field, such as the field of the airplane. In addition, the general expression has been obtained for determining the shape of the minimum-drag body of revolution of given volume and length in a given uniform flow. The results, based on linear theory, have been applied to several cases, and it was found that the nonuniformity of the flow field does not affect the shape of the minimum-drag body.

Research Equipment and Techniques

At the Rome meeting of the Advisory Group for

Aeronautical Research and Development of the North Atlantic Treaty Organization in December 1952, it was decided to encourage a program of tests of standard models in supersonic wind tunnels for the purpose of resolving differences among test facilities, techniques, equipment, and data-correction methods. Technical Note 3300 presents test results of the AGARD Calibration Model B, which is a 60° delta-wing—body combination, in the Langley 9-inch supersonic tunnel. Lift, drag, and pitching-moment coefficients were obtained at Mach numbers of 1.62, 1.94, and 2.41 and at a Reynolds number of approximately 3×10^6, based on a body length of 6.8 inches.

A firing-range facility for small-scale supersonic free-flight testing was put into operation at the Ames Laboratory. The range, which had been previously used only as a proof-test facility for the supersonic free-flight wind tunnel, was instrumented with seven spark shadowgraph stations and precise time-measuring equipment. This equipment provides the means for experimental study of stability, drag, and other aerodynamic characteristics of small gun-propelled models in free flight, free of the restraints and supports required in wind-tunnel tests. Initial tests have been concerned with airplane models having wing spans of the order of 3 inches, in flight at transonic and moderate supersonic speeds. The purpose of these tests was to investigate the coupling of longitudinal and lateral motions which are becoming so important on modern high-fineness-ratio airplanes and to evaluate drag rise at transonic speeds under free-flight conditions (no wind-tunnel walls).

A vane-type angle-of-attack indicator that has been developed by the NACA for use at subsonic and supersonic speeds is described in Technical Note 3441. Its usefulness has been demonstrated in numerous tests of rocket-propelled research models. A description of this instrument, a brief history of its development, and a wind-tunnel calibration are given, along with a discussion of the corrections to be applied to the indicated readings.

STABILITY AND CONTROL

Static Stability

In order to reduce the difficulty of correctly predicting the effects of changes in static stability derivatives on airplane behavior and controllability in flight, the NACA has followed a systematic long-term program of flight testing representative new airplane configurations. These tests have been conducted to determine which stability characteristics result in new flying-qualities problems and also to find the source of problems uncovered during initial flight tests of prototypes. For example, pronounced changes in longitudinal trim were encountered on straight-wing jet-propelled fighters at high subsonic speeds. Airplanes with both climbing and diving tendencies were therefore tested to identify the particular static derivatives involved; longitudinal instability (pitch-up) encountered in a high-speed dive pull-out was analyzed in a similar manner and explained by considering the changes in downwash at the tail and elevator effectiveness with angle of attack and Mach number.

With the introduction of swept-wing airplanes, the pitch-up problem at high angles of attack at transonic speeds was found to be more severe. The cause of this behavior was an unstable break in the wing-fuselage pitching-moment curve associated with stalling of the wing tips. The observed correlation of the pitch-up behavior with the stall-progression pattern on the wings suggested a number of modifications to the wings in an attempt to delay the occurrence of the tip stall and subsequent pitch-up. Wing boundary-layer fences and vortex-generator arrangements on the wing surface have been found to be the most successful of these modifications.

In designing an airplane to have adequate static longitudinal stability, an important factor to be examined is the location of the horizontal tail with respect to the wing-chord plane. Choice of tail location is usually strongly affected by the downwash behind the wing. Downwash has been predicted in the past by considering the wing as a lifting line with a vortex sheet trailing aft of the wing in a horizontal plane. It was considered that no change occurred in the spanlike distribution of vorticity with downstream position. For swept wings, these assumptions are no longer valid because of changes in spanwise distributions of loading both at the wing and downstream of the wing. To provide the aircraft designer with a means of predicting the downwash in a rapid manner, a method employing influence-coefficient types of computations has been developed and reported in Technical Note 3346. The effects of the rolling up of the vortex sheet as it progresses downstream and the effects of the presence of the fuselage have been accounted for by the application of simple correction factors. Comparison of predicted values with available experimental data shows good agreement.

In addition to longitudinal difficulties, high-speed airplane configurations (having low-aspect-ratio wings, high-fineness-ratio bodies, and short tail lengths) often have lateral-directional-stability problems. To provide data for study of these problems, a review has been made of existing data obtained from investigations of several airplane models which cover many of the geometric arrangements of high-speed airplane components of current interest. This review included a study of the variation of directional stability with angle of attack and Mach number and of the interference effects, associated with vortex flow and shock waves, on vertical-tail effectiveness.

As an aid in evaluating interference effects and to obtain a more complete understanding of the factors contributing to the stability of an airplane, investigations of isolated component parts are also continuing.

For example, a theoretical investigation has been conducted in the Langley Stability Analysis Section in which expressions were derived by means of linearized supersonic-flow theory for the pressures, forces, and moments due to various lateral motions acting on thin isolated vertical tails. Motions considered in the analysis are constant sideslip, steady rolling, steady yawing, and constant lateral acceleration. For the particular cases of half-delta and rectangular vertical tails, detailed charts were prepared which enable rapid estimation of 12 stability derivatives for given values of aspect ratio and Mach number. The results of the investigation are published in Technical Note 3240 for the subsonic-leading-edge condition and in Technical Note 3373 for the supersonic-leading-edge condition.

An investigation has been conducted in the Langley free-flight tunnel to determine the static stability characteristics of several fuselages having a relatively flat cross section and a high fineness ratio. The results, presented in Technical Note 3429, show that, at high angles of attack, for flattened fuselages with the major cross-sectional axis horizontal, a strong sidewash existed which caused these fuselages to be directionally stable for a center-of-gravity position two-thirds the fuselage length behind the nose. This sidewash also caused a vertical tail on these fuselages to be directionally destablishing at small angles of sideslip.

In addition to study of conventional airplane types, investigation of the static stability characteristics of aircraft capable of vertical takeoff and landing are also continuing. A study has been conducted in the Langley 7- by 10-Foot Tunnels Branch for the purpose of developing wing-propeller combinations suitable for such aircraft. One approach to this problem involves rotation of the wing-propeller combination through 90° to allow the propellers to act as lifting rotors during takeoff and landing and as conventional forward-thrust propellers for cruising. The wind-tunnel experiments employed a semispan wing with two large-diameter overlapping propellers. The results, presented in Technical Note 3304, indicate that, although wing stalling may exist at some attitudes, the transition appears feasible and the power necessary for takeoff should be sufficient to sustain the aircraft in all attitudes. A propeller design problem is expected, however, because of direct propeller pitching moments at intermediate angles of attack which correspond to an effective downward movement of the center of thrust equal to about 20 percent of the propeller radius.

Another approach utilizes the redirected-slipstream principle in which the thrust of forward-directed propellers is rotated through large angles by wing flaps and vanes. Results on arrangements of propellers and plain flaps are reported in Technical Note 3307. Additional results on slotted-flap and propeller arrangements are published in Technical Note 3364 and some effects of propeller operation and rotation are given in Technical Note 3360. The most promising results were obtained with an arrangement of propellers, double-slotted flaps, and one auxiliary vane.

In other areas investigations are under way aimed at procuring an understanding of the stability characteristics of missiles.

In one study, slender-body theory has been applied to the calculation of the effects on lift of gaps between the wing and body of a slender wing-body combination. The analysis is applicable to an estimation of missile characteristics wherein the longitudinal control is obtained by variable-incidence wings for which gaps exist at high deflections. The results of the analysis, presented in Technical Note 3224, show that the lift decreases very rapidly with gap size for small gaps and approaches as an asymptote the value of lift attributed to isolated panels of the wing.

Control

As higher speeds typical of those at which current airplanes are designed to fly are achieved, the influence of aeroelasticity on the rolling effectiveness of flap-type ailerons becomes increasingly important. The calculation of aeroelastic behavior in rolling at supersonic speeds is facilitated by a simplified method presented in Technical Note 3370. Calculations based on the simplified method are compared with those based on the very accurate procedure previously given in Technical Note 3067 (reported in the Fortieth Annual Report, 1954) and excellent agreement is found. The simplified method is considered to be applicable to a wide variety of structural configurations and should be suitable for other types of static elastic problems on torsional divergence and center-of-pressure shift.

Other factors affecting the rolling effectiveness of trailing-edge flap-type ailerons have been experimentally studied by the Langley Pilotless Aircraft Research Division using free-flight rocket-propelled models. Wing sweepback has been found to have a beneficial effect in minimizing the abrupt changes in control effectiveness which occur for unswept wings at transonic speeds but causes a considerable decrease in the level of effectiveness at all speeds. Decreasing the aspect ratio of an unswept wing by a factor of approximately one-half causes a twofold increase in the rolling effectiveness. Large trailing-edge angles have a very adverse effect upon the rolling effectiveness of plain flap-type ailerons. Ailerons employing trailing-edge angles in the range of 17° to 21° produce reversed rolling effectiveness at transonic speeds. This condition can apparently be corrected by the simple expedient of using flat-sided ailerons. It has been found that the effectiveness of a given aileron is only slightly affected by the contour of the forward portion of the airfoil.

Several arrangements of flap- and spoiler-type ailerons have also been studied in the Langley full-scale tunnel on a 47.5° sweptback-wing—fuselage model. The results show that moderate-span spoilers produced rolling moments equivalent to half-span, flap-type ailerons, although the spoilers were more detrimental to longitudinal characteristics. Adverse yaw was produced by both types of controls when they were located inboard.

Numerous investigations have been made of various types of lateral-control devices on wings of triangular plan form. Since available data indicate that tip controls are more effective than flap-type controls at transonic and supersonic speeds, the studies of tip controls were extended to low speeds. Quantitative information on the effectiveness as well as the hinge-moment characteristics of two different types of tip controls at low speed and high Reynolds number was obtained in the Langley low-turbulence pressure tunnel on a 60° triangular-wing—fuselage combination.

Damping Derivatives

The increasing emphasis placed on studies of the dynamic stability of aircraft has intensified the need for satisfactory methods for predicting the dynamic stability derivatives. In turn, a need has arisen for satisfactory apparatus for measurement of these derivatives to obtain experimental checks on the theoretical methods and to provide sources of information in those areas in which theoretical methods are not yet available The various systems in use to date approach the problem in several different ways, but all have deficiencies of one sort or another. A system in which the model executes forced oscillations with two degrees of freedom has recently been developed by the Ames Laboratory. The details of the design and development are published in Technical Note 3348 to serve as an aid to others desiring to develop such systems. Although the system is characterized by nonlinear equations of motion, linearization of the equations by assuming small perturbations and constant coefficients yields sufficiently accurate results. Results of tests to ascertain the accuracy of the system indicated that the rolling derivatives, the directional stability, and the damping-in-yaw derivatives could be obtained satisfactorily. Results obtained from the data-reduction equations for the rolling moment due to yawing velocity and due to side slip angle were unreliable, however, and prevented the evaluation of these derivatives.

Another wind-tunnel test technique for measuring the rotary damping derivatives and cross derivatives at transonic and supersonic speeds is discussed in Technical Note 3347. This report describes a method in which a model is forced to oscillate in a wind tunnel with varying components of rolling, pitching, and yawing motion, depending on the arrangement of the axis of oscillation. From measurements of the damping and frequency of the oscillations for different positions of the oscillation axis, the damping and stiffness derivatives can be determined. The apparatus can be used with equal facility whether the motions are damped or divergent, an automatic control utilizing a feedback circuit being used to stabilize the frequency and the amplitude of the oscillations. An automatic data-reduction process is employed wherein the output of strain gages responsive to the force required to maintain the model oscillation is introduced into an analog computer whose output is a direct measure of the aerodynamic damping. The method has been applied to measurement of the damping derivatives of several current and projected airplane designs at Mach numbers up to 0.95.

A low-speed, experimental investigation has been conducted in the Langley stability tunnel to determine the effect of the lag of sidewash on the vertical-tail contribution to the oscillatory damping in yaw of two airplane models for which a systematic variation of the sidewash gradient at the vertical tail could be obtained. This was accomplished for one model by mounting auxiliary vertical fins on the fuselage at the center of gravity and for the second model by varying the height of the wing. The results of this investigation, presented in Technical Note 3356, show that the damping in yaw of a model performing oscillations is increased over the damping in yaw associated with steady curved flight by a factor which depends on the lag of the sidewash. The directional stability is influenced by the static sidewash under both steady- and oscillatory-flow conditions but is not affected by the lag of the sidewash.

On the basis of linearized rotational-flow theory, theoretical estimates have been made in the Langley Stability Analysis Section of the lift and pitching moment due to increment in angle of attack, the damping in pitch, and the damping in roll for rectangular wings of infinite aspect ratio at finite angles of attack. The results of this analysis, presented in Technical Note 3421, are valid for a range of Mach number and angle of attack for which the flow behind the shock is supersonic. Approximate estimates of a number of aerodynamic derivatives of rectangular wings at finite angles of attack are also presented.

An Ames Laboratory study has been completed (summarized in Report 1188) in which the concept of indicial aerodynamic functions was applied to the analysis of the short-period pitching mode of aircraft. By the use of simple physical relationships associated with the indicial-function concept, qualitative studies were made of the separate effects on the damping in pitch of changes in Mach number, aspect ratio, plan-form shape, and frequency. The concept is of value in depicting physically the induced effects on a tail surface which follows in the wake of a starting forward surface. Theoretical techniques were developed whereby the transient response in lift at the tail to the wing wake may be estimated and numerical results for several representative cases were presented and analyzed to reassess the importance of the contribution to the rotary damping moment of the interference lift at the tail.

Dynamic Stability

The various techniques developed by the NACA and others for predicting and measuring the dynamic response characteristics of airplanes for use by airplane or automatic-control-system designers have been discussed in past annual reports. However, little has been said about specific flight tests on high-performance airplanes.

In Technical Note 3521, the lateral oscillatory characteristics of a high-speed 35° swept-wing fighter airplane are compared with calculations made considering that the aircraft was rigid and that unsteady-flow effect was negligible. The airplane was found to be laterally stable, statically and dynamically, throughout the range of speeds tested (Mach numbers from 0.35 to 1.04). At altitudes of 10,000 and 35,000 feet the variation with Mach number of the period and the damping of the lateral oscillation was satisfactorily predicted from available and estimated aerodynamic parameters.

In another study of this airplane the longitudinal derivatives were evaluated over a similar Mach number and altitude range. The longitudinal rotary damping derivative was found to be sharply reduced at a Mach number of 0.92; the static longitudinal stability parameter increased rapidly with Mach number above a Mach number range of 0.85 throughout the transonic range.

The effects of structural flexibility mentioned in a previous paragraph as being important for control on thin, swept wings are also of concern with regard to dynamic stability. A theoretical study has been conducted to estimate the effects of wing flexibility on the dynamic longitudinal stability of thin-wing airplane configurations. In order to investigate the effects of various important parameters, the configurations were assumed to vary in wing sweep angle (from 0° to 60°), in center-of-gravity location, and in ratio of wing mass to airplane mass. An analysis of the solutions reported in Technical Note 3251 indicates no dynamic instability due to wing flexibility for configurations having 40° to 60° sweepback. For configurations having no sweepback, the wing was subject to a decrease in oscillatory stability for the large ratio of wing mass to airplane mass accompanied by forward center-of-gravity locations.

The problem of determining the total forces, moments, and stability derivatives for a slender body performing slow maneuvers in a compressible fluid is considered in Technical Note 3283, using slender-body theory. Formulas have been developed in terms of the body shape. Coupling of the longitudinal and lateral motions (which arises from the squared terms in the pressure relation) has been included, and a number of general relationships among the various stability derivatives have been found which are independent of the configuration. The role of the apparent-mass concept in slender-body theory has been clarified by the present analysis, and calculations of the stability derivatives have been carried out for two triangular wings with camber and thickness and for two wing-body combinations, one having a vertical fin.

Another factor which may affect the motion of high-speed airplanes is atmospheric turbulence. Calculations, described in Technical Note 3425, have been made in the Langley stability tunnel of the lateral response to representative time histories of atmospheric turbulence for two airplanes having widely different dynamic properties, and explanations are given for their differences in behavior. The results of the calculations indicate that, under the proper conditions, atmospheric turbulence can initiate and maintain a lateral hunting oscillation of an airplane and that this oscillation can be fairly regular in both amplitude and frequency. This effect is more pronounced for lightly damped airplanes. This phenomena may be the cause for some of the cases of airplane snaking that have not been explained by other considerations.

For some types of vertical-takeoff airplanes, particularly transports, it is desirable to keep the fuselage as nearly horizontal as possible to facilitate loading and handling of passengers. One configuration mentioned in a previous paragraph which has been proposed to accomplish this aim is a reasonably conventional airplane with wing flaps and possibly auxiliary vanes to turn the propeller slipstream downward to provide direct lift for hovering flight. An investigation of the takeoff, landing, and hovering-flight characteristics of an airplane model of this type has been conducted with a remotely controlled free-flight model. The results of this investigation, which are presented in Technical Note 3440, showed that it was possible with some difficulty to fly the model in the hovering condition without the use of any artificial stabilization. The use of artificial damping in pitch was very desirable, however, to alleviate a violently unstable oscillation. Vertical takeoffs and landings could be performed satisfactorily, although, when trimmed for hovering flight well above the ground, the model had a slight tendency to move forward as it took off or neared the ground on landing.

Flying Qualities

Considerable emphasis has been placed in the past year on the new flying-qualities problems introduced by the different dynamic stability characteristics of airplane configurations and wing plan forms suitable for very high speed flight. One of the most effective research tools has been the variable-stability airplanes developed at the Ames Aeronautical Laboratory. The equipment itself and many of its applications were described in a paper presented at the Institute of the Aeronautical Sciences.[1]

The use of this equipment as a basic flying-qualities research tool is shown by a recent study of the lateral oscillatory characteristics required for satisfactory fighter aircraft. An airplane in which the dihedral effect, the static directional stability, and the directional damping could be varied in flight was used to conduct a pilot-opinion survey and establish boundaries which defined satisfactory and tolerable lateral oscillatory characteristics. The boundaries were presented in the form of relations between the cycles to damp to half amplitude and the ratio of the bank angle to the side velocity in the oscillatory mode. Through tests of this type it is hoped to provide suitable numerical criteria against which the measured or predicted stability and control characteristics of piloted airplanes can be graded.

In the design of the pilot's control the amount of displacement of the control stick required to deflect an airplane control surface usually has been based on the desire for the highest possible mechanical advantage compatible with cockpit size and reach of the pilot. Studies of the effects of stick displacement and related force characteristics on the pilot's abilities in performing a specific task have not generally been made. Recently, an investigation has been made at the Langley Aeronautical Laboratory to obtain an indication as to the desired magnitudes of the stick forces and stick displacements in relation to the performance of a tracking task. These tests have been performed on a ground simulator with one degree of freedom (pitch). The stick force and stick displacement per unit response were varied, and the period and damping characteristics were adjusted to be typical of those of current fighters operating at low altitudes and at subsonic speeds. The results of the tests, as reported in Technical Note 3428, show that, for a well-damped airplane, as the required stick displacements and stick forces were reduced, the accuracy in performing the tracking task improved.

In order to shorten the landing runs of high-speed airplanes, it is desirable to approach at as high an angle of attack as possible consistent with the following requirements: satisfactory stability and control characteristics, sufficient speed for satisfactory engine acceleration, and an adequate margin below the stall lift to allow for air turbulence and to provide for flight-path adjustment and flaring. Some work has been done using a stick shaker, actuated at the angle of attack desired, as a stall-warning indicator. Such an arrangement does not appear to be entirely satisfactory, however, because it supplies no indication of the magnitude of variations from the desired flight condition. The question has arisen as to whether a desired lift coefficient or angle of attack could be maintained with sufficient accuracy if the pilot were provided with a continuous angle-of-attack or lift detector which would supply a continuous variation of either stick-shaker frequency or amplitude over the desired range of lift. To study this possibility an exploratory investigation was undertaken at the Langley Aeronautical Laboratory. The study was made with simulator equipment which provided a control-stick shaker with amplitude and frequency of vibration varying with stick displacement. The amplitude ranged from 0.006 to 0.3 inch and the frequency, from 4 to 26 cycles per second. The results, reported in Technical Note 3355, show that the desired lift margin could probably be maintained, provided the allowable variations from the desired angle of attack or lift coefficient produced changes in amplitude of vibration of about 100 percent or changes in frequency of about 40 percent. A brief study was also made which indicated that the subject's sensitivity to amplitude changes increased with increase in amplitude and frequency; sensitivity to frequency did not appear to be materially affected by amplitude.

Automatic Control and Stabilization

The present trend toward automatic control of high-speed aircraft has led to severe requirements for autopilot servo performance. The autopilot is required to develop large forces or moments and still meet strict requirements with regard to size and weight. For this reason hydraulic servos are generally employed. In such servos oil flow to the cylinder is restricted not only by the limits on size and weight but also by structural considerations. This results in a servo with a limited output rate, a significant nonlinearity which often produces oscillatory or unstable airplane responses to large input commands and sluggish responses to small error signals. These undesirable effects can generally be compensated for by introducing other nonlinear elements into the system. In Technical Note 3387 a simple method is developed for designing the appropriate nonlinear functions into a rate-limited system to give large gain levels for small errors and low gains for large errors so that satisfactory responses can be obtained with step inputs of any magnitude. The method requires a knowledge of the transfer function that describes the airplane response but ignores the

[1] See Kauffman and Drinkwater paper listed on p. 59.

dynamics of the servo and requires only simple hand calculations.

The need for devices to limit the maximum maneuvering acceleration of airplanes has been realized for some time. An idealized analysis of the operation of several simple restrictor devices during which the elevator was assumed to move at a constant rate has been made in the past; recently, it was considered desirable to extend this investigation to include a more realistic simulation of the elevator motion. In this study, the simulator consisted of a control stick geared to a magnetic brake unit and an analog computer which simulated the dynamic characteristics of the airplane. The restrictor was so designed that, when the brake control signal (which was a function of various combinations of normal acceleration, pitching acceleration, and pitching velocity) reached a certain preset value, the brake would stop the elevator motion. Tests were made to cover a wide range of airplane flight conditions and various types of brake-operating signals. The results obtained for three of the control signals tested are presented in Technical Note 3319. The first signal was the quantity normal acceleration plus the product of a gain constant and pitching acceleration; the second signal was the quantity normal acceleration, plus the product of a gain constant and pitching acceleration limited to positive values, plus the product of a gain constant and pitching velocity operated on by a canceling network; and the third signal was the same as the second except that the limitation on pitching acceleration was removed. The results show that, with the use of an acceleration restrictor, the response of an airplane to an abrupt elevator deflection can be controlled for a wide range of conditions. Pilots manipulating the control stick of the simulator to approximate a rapid pull-up maneuver objected to the "coarse steps" in elevator motion caused by lag in the operation of the brake unit employed; however, by designing a brake unit with little lag in its operation, the undesirably large steps in elevator motion could be made smaller.

Another acceleration restrictor which limits the elevator motion of the airplane has been analyzed by means of an electronic analog computer. The signal used to control the system was, in one case, proportional to normal and pitching acceleration and, in the other case, a function of normal and pitching acceleration and pitching velocity. The mechanical design of the system has not been considered, but the device used to stop the motion of the elevator has been assumed to have several values of lag. The results, reported in Technical Note 3243, indicated that, when the airplane was controlled by an acceleration restrictor sensitive to a signal proportional to normal and pitching acceleration, the ratio of peak to preset acceleration was about 1.4 when the device used to stop the elevator had approximately zero lag. The ratio was constant for airspeeds ranging from 200 to 1,000 feet per second. Increasing the lag to about 0.02 second caused the ratio of peak to preset acceleration to vary from 1.2 to 1.6 as the airspeed increased from 200 to 1,000 feet per second. When the control signal was a function of normal and pitching acceleration and pitching velocity, the ratio of peak to preset acceleration was 1.1 throughout the speed range for the case of zero lag. Increasing the lag to 0.02 second had little effect on the performance of the system. An acceleration restrictor with a ratio of peak to preset acceleration of 1.1 throughout the speed range would allow the airplane to reach normal accelerations near the limit load factor and still prevent the airplane from ever exceeding this value.

As part of a general research program investigating various means of automatic stabilization, several nonlinear control systems for missiles have been considered by the Langley Pilotless Aircraft Research Division as simple effective ways of obtaining desirable missile response automatically. The results of a theoretical investigation of a proportional-plus-flicker automatic pilot are summarized in Technical Note 3427. The nonlinear principle used requires a more or less conventional proportional autopilot for small errors about the desired reference. For errors greater than a certain magnitude the control surface is made to provide its maximum corrective control, a full deflection or flicker action, until the error is reduced to the maximum allowable for proportional operation. This principle thus insures a fast correction of large errors while maintaining its close control over small errors. A comparison is made of the proportional-plus-flicker system with a proportional system showing the differences in response characteristics, and the important effects of the time lag between flicker and proportional operation are also noted.

High Lift and Stalling

The design of airfoils for high-speed flight often makes impractical the application of conventional devices for obtaining high lift at low speed. Studies have been made to ascertain the effects of various unconventional devices and of airfoil modifications on the areodynamic characteristics of wings at low speeds. These devices and modifications have been designed to maintain, as nearly as possible, the high performance required at high subsonic and supersonic speeds. The results of these studies indicate that it is possible to make compromises in design to obtain improved performance in the low-speed ranges without loss of performance in the high-speed range.

One means of obtaining high maximum lift with thin uncambered wings is the use of leading-edge area suction as a method of controlling the boundary layer. Studies of this means of increasing the maximum lift have previously been conducted primarily in wind tunnels. Recently, however, a leading-edge suction system was installed in an F–86 airplane. The flight tests defined the low-speed lift and handling characteristics of the modified airplane and included checks of the high-speed performance of the airplane. Measurements of maximum lift capabilities and suction power requirements were made for several configurations of porous area. With full-span area suction, a maximum lift coefficient of 1.80 was obtained. In comparison, leading-edge slats provided a maximum lift coefficient of 1.36. Respective stalling speeds were 84 and 97 knots. To obtain the highest lift values, an input to the suction pump of about 135 horsepower was required; however, for maximum-lift values equivalent to those provided by the slats, only 20 horsepower was required. The stalling characteristics were at least marginally satisfactory for all configurations tested. No deleterious effects of the porous-area installation on the high-speed flight characteristics of the airplane were noted. The tests indicated that no discontinuities in the porous area could be tolerated; however, the installation appeared to be relatively insensitive to leading-edge surface condition. No difficulties due to clogging of the porous material were encountered.

Wing trailing-edge area suction has also been found to be an effective means of increasing lift. An investigation was recently conducted in the Ames 7- by 10-foot wind tunnels to determine the effectiveness of trailing-edge suction on a NACA 65_1–012 airfoil modified to incorporate a porous, round trailing edge. A thin, small-chord vane was located on the trailing edge. A section lift coefficient of 1.9 was obtained for a 5-percent-chord vane and, of 2.5, for a 20-percent-chord vane deflected 57° at zero angle of attack for a section flow coefficient of 0.010. With suction off, the respective lift coefficients were 0.7 and 1.5. The results indicate that with suction the vane was effective in controlling the lift without change in the angle of attack. The vane acted to fix the rear stagnation point and hence to control the circulation. These results have been published in Technical Note 3498.

In the course of these investigations of area suction, the flow-resistance characteristics of a number of commercially available permeable materials were studied. In Technical Note 3388, the flow-resistance characteristics of fibrous-glass compacts, consisting of blown-glass fibers with a phenolic resin bonding agent, are presented. The permeability was controlled by the density and thickness of the compact and, for constant-thickness compacts, was varied over the range generally required for applications of area suction for boundary-layer control. It was found that the compact can be molded to any desired shape and thickness. In operation, the fibrous-glass compact can easily be removed and replaced if it becomes partially clogged.

Spinning

The spinning and spin recovery of airplanes are still of concern to manufacturers and pilots. The action and effectiveness of various applied moments in upsetting spin equilibrium and in bringing about satisfactory recovery are not clearly understood. Although tests in free-spinning tunnels have been an expeditious means of determining whether the spin-recovery characteristics of the airplane are satisfactory, it has not been possible to determine from these tests how the various spin parameters change as the models recover. An analytical investigation was therefore undertaken in an attempt to learn more about the factors which make up a spin and the mechanism of spin recovery. Use was made of rotary-balance data and a step-by-step integration process of Euler's equations of motion allowing six degrees of freedom. An analysis was made of an airplane recovery from a right spin where constant applied antispin yawing moments due to application of 800 and 1,600 pounds of force at the left wing tip were considered. The results of the investigation, reported in Technical Note 3321, indicate that the spin recoveries for both applied yawing moments were fairly rapid (1 turn or less), the larger applied yawing moment effecting a somewhat faster recovery than the smaller one. When the smaller yawing moment was applied, oscillations occurred in the angle of attack and sideslip during the recovery and gradually increased until recovery was effected. When the larger yawing moment was applied, the angle of attack went rapidly to an unstalled condition; however, the angle of sideslip oscillated somewhat during the recovery. The recovery motion of the airplane appeared to be affected primarily by the action of the moments rather than the forces.

Research Equipment and Techniques

A simplified method for obtaining free-flight measurements of the zero-lift damping in roll has been developed for use with rocket-powered models by the Pilotless Aircraft Research Division. The basic principle of this method is that the model is forced to roll by a nonaerodynamic rolling moment of known magnitude which is produced by canted-rocket-nozzle assembly, and the damping in roll is computed by balancing the moment acting on the model. For rectangular wings of low aspect ratio and thin sections, damping in roll is maintained through transonic speeds. The damping-in-roll data from this torque-nozzle technique have been compared with similar data of much lower scale from the sting-mounted-model technique using rocket vehicles as described in Technical Note 3314. In the sting-mounted technique the test configuration is attached to the nose of the vehicle by a sting. The entire test vehicle is forced to roll by offset stabilizing fins. The resulting damping moment of the test configuration is measured by a balance in the nose of the rocket vehicle. Good agreement of the damping-in-roll derivative has been obtained between the two techniques for a configuration consisting of a pointed cylindrical body having three rectangular unswept wings.

INTERNAL FLOW

Inlets

A large amount of data is available on the drag of wings and bodies at transonic and supersonic speeds, but data pertaining to the drag associated with air inlets in this speed range have been relatively meager. A series of tests of rocket-propelled models in free flight was therefore undertaken to provide additional information on the transonic characteristics of inlets. In Technical Note 3218, results of such tests to determine the external drag and total-pressure recovery of an NACA 1-series nose inlet are reported. The test vehicle was a fin-stabilized ducted body of revolution having an NACA 1–40–250 nose inlet and equipped with a rotating shutter mechanism which varied the internal flow rate continuously from zero to the maximum possible during flight. Data were obtained over a range of Mach numbers from 0.9 to 1.8. The test results indicate that up to a Mach number of 1.14 the drag at the higher flow rates was lower than the drag of the parent pointed-nose body of revolution which had similar contours behind the inlet-lip station. At higher Mach numbers, the drag of the inlet configuration increased rapidly relative to that of the pointed body. The total-pressure recovery of the inlet configuration exceeded that of an external-compression supersonic inlet up to a Mach number of about 1.3.

Additional research on NACA 1-series open-nose inlets was conducted on three configurations in the Langley 8-foot high-speed tunnel at high subsonic and low supersonic speeds ($M=1.2$) with and without central bodies. Results of the study, reported in Technical Note 3436, show that the external pressure drag decreased regularly with the same increases in effective inlet fineness ratio that brought about increases in critical Mach number at subsonic speeds. The addition of the central bodies had no appreciable effects on the Mach number of the supercritical drag rise and did not decrease the pressure recovery appreciably at the maximum test Mach number of 1.2.

A circular-nose inlet utilizing various shapes of inlet lips has been investigated at low speeds in the Ames 7- by 10-foot wind tunnel to ascertain the total-pressure recovery for various angles of attack. Pressure-recovery data were obtained with inlet flows ranging from low values to choking and at angles of attack from 0° to 25°. A sharp inlet lip having a wedge angle of 7½° was tested in addition to two circular-arc profiles and two elliptical profiles formed within the wedge of the sharp lip by cutting back the leading edge various amounts. It was found that, for a given amount of cutback, the circumferential variation of total pressure at the measuring station was about the same with either an elliptical- or a circular-arc-profile lip; however, the average total-pressure recovery characteristics were better with the elliptical-profile lip. Details of the tests and the results of the investigation have been published in Technical Note 3394.

Inlets located adjacent to the fuselage behind the nose must be specially tailored to handle the fuselage boundary layer and to suit the local flow field outside the boundary layer. The difficulty of this tailoring is governed to a large extent by the location of the inlet on the airplane. An investigation of an air inlet installed in the root of a 45° sweptback wing has been made at low speeds in the Langley two-dimensional low-turbulence tunnel. Step-by-step refinement on the basis of a systematic study of the effects of lip shape, lip thickness, and lower lip stagger resulted in a configuration which gave nearly 100-percent total-pressure recovery up to about 86 percent of the maximum lift coefficient of the wing through a wide range of inlet-velocity ratio. Installation of the inlet was accomplished with no adverse effects on the external drag and lift. This study is reported on in Technical Note 3363.

An exploratory investigation of a conventional air scoop submerged in a dimple in the fuselage surface was made in the $1/15$-scale model of the Langley full-scale tunnel at low speeds. The results, reported in Technical Note 3437, show that boundary-layer suction provided appreciable gains in pressure recovery over a wide range of inlet-velocity ratio. An analysis of the significance of these gains indicated that they would result in important improvements in the net thrust and specific fuel consumption of a typical jet engine. It was found also that the type of flow instability frequently encountered by twin, internally coupled inlets should not occur over a wide range of inlet-velocity ratio.

The Langley 8-foot transonic tunnel has also made a study of three annular fuselage inlets with fuselage forebodies shaped so that substream velocities would be maintained everywhere ahead of the entrances up to low supersonic speeds. Results of the tests show that adverse boundary-layer shock-interaction effects on the body nose were avoided at low angles of attack up to the maximum Mach number of 1.19. The maximum impact-pressure recovery was about 0.96 at this Mach number and throughout the subsonic test Mach number range of 0.4 to 0.94. Flow separation and strong shocks were encountered on the outer surface of the lips when the inlets were operated at low inlet-velocity ratios. The use of a high-critical-speed lip shape improved the drag-rise Mach number and reduced the external pressure drag at supersonic speeds.

The air induction system of an aircraft should supply the prescribed air flow to the engine at high pressure recovery with as little external drag as possible. A method of evaluating the ratio of aircraft thrust minus drag to ideal thrust for any inlet pressure recovery is presented in Technical Note 3261. Three types of typical air-breathing engines having equal air-flow capabilities are compared at given operating points.

For a turbopropeller engine equipped with a conventional cowling-spinner combination, the problem of obtaining low losses in intake pressure is complicated by the presence of an initial boundary layer on the spinner ahead of the inlet and by interference effects introduced by the propeller. An investigation at low subsonic speeds was undertaken in the Langley low-turbulence pressure tunnel to study the effects of propeller-shank thickness and propeller-spinner-juncture shape on the aerodynamic characteristics of a cowling-spinner combination equipped with a dual-rotation propeller. The results of this study show that inlet pressure recoveries nearly equal to those measured with the propeller removed could be obtained with a 12-percent-thick propeller shank operating at the design cruise condition. Further increases in propeller-shank thickness, however, caused significant reductions in pressure recovery. An airfoil-type propeller-spinner juncture that permitted blade-angle changes was developed which provided pressure recoveries about equal to the values obtained with the juncture sealed. This study was extended to investigate the effects of compresssibility at Mach numbers up to 0.8 on the internal-flow characteristics of the cowling-spinner-propeller combination. A 24-percent-thick propeller shank was used for these tests. The results obtained indicate no appreciable compressibility effects on the pressure recovery with the propeller operating at the design cruise blade angle. With increases in shank loading, however, shock- and shock-boundary-layer-interaction effects caused a reduction in pressure recovery at a Mach number of 0.8.

Another method of eliminating the losses associated with the propeller is to use an NACA E-type cowl, an annular inlet which extends ahead of the propeller blades and rotates with the propeller. An inlet of this type has been investigated in the Ames 12-foot pressure wind tunnel. The results of this investigation have shown that the efficiency of the internal flow with this inlet are high, the internal losses being less than 2 percent at Mach numbers up to 0.88. The external drag of this inlet was also extremely low up to the highest Mach number at which tests were conducted. A second type of inlet considered for use with the turbopropeller engine is the NACA D-type cowl, an annular inlet located behind the propeller. Results of recent tests of a D-type cowl in the Ames 12-foot pressure wind tunnel have indicated that, in the absence of the propeller, induction efficiencies of the order of 0.98 are available at the higher inlet-velocity ratios at forward Mach numbers up to 0.88. With the propeller operating ahead of the inlet, this efficiency is decreased by 4 percent to 8 percent, depending on the inlet-velocity ratio, the blade angle, and the advance diameter ratio.

Outlets and Ducts

The high auxiliary-air-flow requirements of high-speed aircraft place increased emphasis on the design of efficient outlets through which this air is returned to the outside air stream. The use of small outlets to establish desired pressure fields in certain areas also finds application in boundary-layer control and in aircraft control systems. Technical Note 3442 presents some preliminary design information obtained in recent tests at transonic Mach numbers regarding the effect of geometric configuration and flow rate on the discharge coefficients of typical outlets and on the static-pressure distribution in the vicinity of such outlets. Tuft observations showing vortex formations caused by the outlet discharge from a perpendicular and an inclined outlet are also presented.

Another problem is associated with the design of adequate drains which must be provided in modern aircraft to discharge fuel and other liquids while in flight and to prevent their accumulation in various parts of the aircraft. Technical Note 3359 reports an investigation of the characteristics of various types of drains discharging liquids. The experiments were conducted in a small research apparatus over a range of Mach numbers from 0.5 to 1.3. The boundary-layer thickness in the vicinity of the outlets was approximately one-eighth inch. It was found that the angle of sweep and length of the drain projection into the air stream were the predominant factors in preventing liquids discharged under pressure from flowing back onto the surface. Sweepback of the drain tube reduced the drag of the drain in addition to preventing droplets from impinging on the adjacent surfaces.

In most calculations involving duct air-flow properties, it is not convenient to consider local flow variations within the duct. Therefore, the properties of the flow are treated as though they were uniformly distributed, and one-dimensional equations are applied to this uniform flow. Inasmuch as the real flow seldom approaches uniformity at planes of interest, the equivalent uniform flow must be determined by some method of averaging the properties of the flow. In Technical Note 3400, various weighing methods are applied to typical nonuniform duct flow profiles to determine average flow properties. The analysis covers a range of subsonic duct Mach numbers but is confined to flows having uniform static pressure and total temperature.

When an ideal or frictionless fluid passes through a nozzle, the flow rate is a function only of the pressure drop, fluid properties, and nozzle geometry. For the measurement of the flow rate of an actual fluid, this functional relation must be modified to include the effects of friction. This is usually done by introducing a "discharge coefficient," which is defined as the ratio of the actual mass-flow rate to the ideal rate. A method of determining the discharge coefficients of flow nozzles by analytical means is described in Technical Note 3447. The coefficient was obtained by integration of an approximation for the velocity profile through the cross section of the nozzle. The resulting expression shows the discharge coefficient to be a function of the Reynolds number and the geometry of the nozzle. Good agreement is shown between this expression and published experimental data for Reynolds numbers between 10^4 and 10^6.

PROPELLERS FOR AIRCRAFT

Aerodynamic Problems

Aeroelastic effects on propellers have become increasingly important with reduced blade thickness ratios and increasing flight speeds. Until recent years the accuracy of computational procedures for computing the torsional deflections of propellers had not been verified for high rotational speeds, high forward speeds, and high loads. It has now been determined that the deflections may be computed with good accuracy from a knowledge of the section physical characteristics, the aerodynamic forces acting on the blade, and the propeller operating conditions.

Aeroelastic effects on propeller blades are also becoming very evident in the reduction of the stall-flutter velocity to the point where stall flutter may be experienced in the takeoff range of operating conditions. One method for alleviating this condition without changing the primary aerodynamic characteristics is the use of propeller blades with large torsional structural damping. The torsional damping of a series of models simulating the dimensions of thin propeller blades has been investigated. If the damping gains realized in this investigation could be achieved in practical propeller-blade construction, appreciable increases in the minimum flutter speed of thin propellers would be expected.

In the transonic speed range knowledge is required of the effects of velocity gradient along the propeller blade, the three-dimensional tip effects, and the action of centrifugal force on the boundary layer along the blade. A preliminary investigation was therefore made in the Langley 16-foot high-speed tunnel to determine the propeller section characteristics by measuring the pressure distribution on the airfoil sections of an operating propeller. Although the forward Mach number did not exceed 0.7 in these tests, the combination of rotational and forward speeds produced blade-section Mach numbers as high as 1.2. The results of this preliminary investigation shed considerable light on the operating characteristics of the blade sections at high Mach numbers and led to a more comprehensive program of tests. Five propellers were constructed and instrumented for the measurement of the pressure distribution on any section along the blade radius. The blades had NACA 16-series sections with design lift coefficients of 0, 0.3, or 0.5 and varied in thickness from about 3 to 30 percent. The results of this investigation have been presented in tabular form. In addition, values of the induced angle of attack for all the blade sections have been computed using Theodorsen's method.

Several investigations have been completed in the Langley 8-foot high-speed tunnel to determine some of the effects of compressibility, design camber, and blade sweep on propeller performance at blade angles up to 70° and forward Mach numbers up to 0.925. It was found that the adverse effects of compressibility were delayed to a Mach number of 0.71 for a blade angle of 65°, for which conditions the efficiency was 88 percent. At high supercritical Mach numbers, operation at reduced advance ratios gave improved efficiency, but moderate changes in camber did not produce appreciable changes in maximum efficiency. Large amounts of blade sweep did not result in significant delays of the adverse compressibility effects but did result in efficiencies nearly 10 percent more than those for similar straight propellers at a Mach number of 0.85.

An investigation of the operating characteristics of an eight-bladed dual-rotating propeller, which included both wake-survey and force measurements, has also been conducted in this facility. The tests were carried out over a blade-angle range from 55° to 80° at forward Mach numbers up to 0.925. The results indicated that good efficiencies can be obtained at high subsonic Mach numbers if high blade angles are used. Large decreases in thrust loading at high subsonic speeds were the result of changes in the angle of zero lift and increases in the drag coefficients of the local blade sections. The changes in thrust loading with Mach number were less pronounced at the tip than at the root sections.

Structural Problems

An important consideration in the design of propellers is that which deals with vibratory stresses which occur with a frequency of 1 cycle per revolution—commonly referred to as 1–P. These stresses are due to 1–P oscillating aerodynamic thrust loads imposed on propeller blades as a result of thrust-axis inclination and asymmetries of the flow fields in which the propeller operates. Recently completed studies have resulted in a method which will enable the designer to predict these stresses from the original design without recourse to additional measurement. These studies, reported in Technical Note 3395, have also provided a concept of the mechanics of air flow which causes the 1–P loads.

This concept may be used by the designer to effect possible rearrangement of the aircraft components which would materially reduce the 1–P loads.

HELICOPTERS

Loads and Flutter

The periodic nature of the loads imposed on the helicopter rotor system requires that the designer be supplied with means for calculating the bending frequencies and mode shapes of the lifting rotor blades. Simplified procedures and charts for the rapid estimation of bending frequencies of rotating beams are presented in Technical Note 3459. A Rayleigh energy approach utilizing the bending mode of the nonrotating beam in the determination of the bending frequency of the rotating beam was evaluated and was found to give good practical results for helicopter blades. Charts are presented for the rapid estimation of the first three bending frequencies for rotating and nonrotating cantilever and hinged beams with variable mass and stiffness distributions, as well as with root offsets from the axis of rotation. Some attention is also given to the case of rotating beams with a tip mass. A more exact mode-expansion method used in evaluating the Rayleigh approach is also described. Numerous mode shapes and derivatives obtained in conjunction with the frequency calculations are presented in tabular form.

In the course of flight testing an experimental two-bladed jet-driven helicopter, the main rotor blades were found to be subject to a condition of near resonance between the frequencies of the first elastic bending mode of the blades and the third harmonic component of the aerodynamic loading which results in high bending strains during the normal flight conditions. An experimental investigation, reported in Technical Note 3367, has been made on a 1/10-scale dynamic model of this helicopter to determine the effect of various changes in the design configuration on the blade bending strains. These changes included the addition of different amounts of concentrated weight to the blades at various radial and chordwise locations and variations in the design counterweight locations, as well as changes in blade pitch-control stiffness and blade bending stiffness. Tests were made under both hovering and forward-flight conditions up to a tip-speed ratio of approximately 0.18. The results of the tests show that the maximum bending strains occurred at tip-speed ratios in the vicinity of 0.10 and that the strains could be reduced materially by attaching to the blades, at proper radial stations, concentrated weights that would minimize the condition of resonance. Further reductions in bending strains could be obtained by the proper location of the weight along the chord. A concentrated weight equal to 5 percent of the blade weight appeared to be about two-thirds as effective as a weight equal to 10 percent of the blade weight.

One of the most important aspects of the helicopter loads problem is that of fatigue, including any contributions that might arise from gust loads. Although military and civil rotary-wing design specifications require that load factors due to an arbitrary gust be considered, the response of a lifting rotor to gusts is difficult to predict analytically because of the transient nature of the disturbance. A comparison is made in Technical Note 3354 of the effects of gusts on a single-rotor helicopter and an airplane flown in formation. The results indicate a somewhat greater gust alleviation for the helicopter than for the airplane over the speed range investigated, and a substantial effect of speed on the normal accelerations due to gusts was observed. The need for a rigorous analytical approach, compared with the simplifying assumption of only a rotor angle-of-attack change, is also discussed.

In addition to a knowledge of the overall response of a helicopter to gust loads, information is also needed which provides some insight into operating gust and maneuver loads and corresponding flight conditions, the maximum loads likely to be encountered, and the percentage of time spent in various flight conditions by helicopters in various fields of application. Such information is of interest as an aid in establishing a more rational basis for helicopter design and in more realistically estimating the service life of certain critical helicopter components. Technical Note 3434 presents an analysis of the normal accelerations and operating conditions encountered by two different airmail helicopters and a military pilot-training helicopter. Tables and graphs are used to illustrate the effect of operating conditions on acceleration levels. The results based on 4,325 flights indicate that maneuvers are usually responsible for the large accelerations encountered, whereas gusts contribute primarily to the large number of smaller accelerations.

In order to determine the stress response of a rotor to a gust of known velocity, preliminary investigations have been made in the Langley gust tunnel to determine the effects of a sharp-edge vertical gust on the blade flapwise vibratory bending moments of small model rotors having either fixed-at-root or teetering blades. Both rotor configurations were tested up to a tip-speed ratio of about 0.35. The results, reported in Technical Note 3470, for simulated forward flight (which include the effects of the change in rotor angle of attack due to the gust) indicate that the effect of the gust on the maximum vibratory bending moment is of less importance for the teetering rotor than for the fixed-at-root rotor. Increasing the rotor speed decreases the magnitude of the vibratory bending moments resulting from a given gust. At a given rotor speed, the magnitude of the vibratory components due to the gust increases with increasing tip-speed ratio. Increasing the rotor speed at a constant forward velocity decreases the maximum vibratory bending moments for all conditions tested. The rate of increase of the vibratory bending moments with tip-speed ratio is approximately twice as great for the fixed-at-root rotor as for the teetering rotor.

In general, helicopter designers are not greatly disturbed by the phenomenon of flutter, primarily because rotor blades are generally massbalanced throughout their length in consideration of other more imminent problems, such as undesirable control forces. These favorable conditions may not exist indefinitely, however; for example, the introduction of irreversible controls may lead the designer to select blades which are not completely massbalanced in order to obtain the desired strength with minimum weight. The use of such design features in conjunction with higher tip speeds may cause flutter to become a problem. Some experimental studies have therefore been conducted to determine the general characteristics of rotor-blade flutter under hovering and simulated forward-flight conditions by means of flutter tests of the rotor system of a one-tenth-scale dynamic model of a two-bladed jet-driven helicopter. Tests were made of several configurations to evaluate the effect of variations in the blade pitch-control stiffness and forward speed on the flutter speed. The results of the investigation, reported in Technical Note 3376, show that the flutter speed of the model blades was increased as the blade pitch-control stiffness was increased and indicated that the structural blade modes of primary significance with respect to flutter were the first torsion mode and the flapping mode. The results also show that the rotor speed at flutter was reduced slightly as the tip-speed ratio was increased from a hovering condition and that the nature of the flutter motion was changed from a sinusoidal oscillation having a distinct frequency to a more random type of oscillation of comparable amplitude but without a well-defined frequency.

Performance

Current design trends require methods for estimating the effects of changes in design variables and flight condition on the performance of helicopters operating at high forward speeds and at high rates of climb. Basic equations for calculating such effects are already available. However, because of the length and complexity of these equations, their application is considerably simplified by presenting them in the form of charts from which helicopter performance can be quickly estimated. Technical Note 3323 presents theoretically derived charts for use in predicting profile-drag thrust ratios of rotors having hinged blades with −8° twist. The charts are considered applicable to rotor operating conditions in which high tip-speed ratios or large rotor angles of attack are encountered; however, they do not include the effects of compressibility. Limit lines showing the conditions of onset of stall are included in the charts, and the effects of blade twist on the stall limits are discussed.

Although the effect of blade twist on the rotor profile-drag power is not very significant at certain flight conditions, differences in profile-drag power between blades of different twist can become appreciable at other flight conditions, particularly at high tip-speed ratios. Charts published in Technical Note 3323 for estimating the performance of high-performance helicopters are applicable to rotors having hinged rectangular blades with a linear twist of −8°. Supplementary charts covering twists of 0° and −16° are presented in Technical Note 3482.

As helicopter forward speeds increase, the flapping behavior of the main rotor blades becomes more critical, both from the standpoint of the stability of the motion and also in regard to the blade-fuselage clearance problem. Although the flapping motion of helicopter blades has shown itself to be very stable for conventional tip-speed ratios (below about 0.5), some doubt exists as to the stability of the motion at tip-speed ratios equal to or greater than 1.0. Technical Note 3366 presents a method for studying the transient behavior of the flapping motion, as well as for calculating the steady-state flapping amplitudes, of free-to-cone and seesaw rotors operating at extreme flight conditions. The method is general and can be applied to blades of any airfoil section, mass distribution, twist, plan-form taper, root cutout, and flapping hinge geometry. Stall and compressibility effects can also be accounted for. Applications of the method to the calculation of the stability of the flapping motion of unloaded rotors and to the transient blade motion resulting from arbitrary control inputs under conditions of extreme stall are included.

In the performance analyses of rotating-wing aircraft under extreme operating conditions, very-high-angle-of-attack airfoil data are needed for the inboard locations of the retreating rotor blades. In order to supply some of this high-angle-of-attack information, the two-dimensional aerodynamic characteristics of the NACA 0012 airfoil section have been obtained in the Langley low-turbulence pressure tunnel at low speeds at angles of attack from 0° to 180°. The results, presented in Technical Note 3361, show that the application of surface roughness or a reduction of Reynolds number had only small effects on the lift coefficients obtained at angles of attack between 25° and 125°. The drag coefficient at an angle of attack of 180° was about twice that for an angle of attack of 0°. The drag coefficient at an angle of attack of 90° was closely comparable with the drag coefficient of a flat plate of infinite aspect ratio inclined normal to the flow.

Rotor Inflow

Continued progress in all phases of rotor aerodynamics requires increasing experimental and theoretical knowlege of rotor flow fields. To help fill this need, wind-tunnel flow surveys have been conducted in the vicinity of single and tandem helicopter rotors in the Langley full-scale tunnel. Preliminary results, published in Technical Note 3242, indicate that the average induced velocity across the span of a rotor may be calculated to an acceptable degree of accuracy by existing theory. The surveys also show many points of similarity between the flow behind a rotor at cruising speeds and the flow behind a wing. These measurements were used to calculate the approximate magnitude of the induced power requirements for a tandem-rotor system.

Stability and Control

Information obtained during NACA flying-qualities studies of a tandem helicopter indicated that the tandem-rotor configuration was susceptible to instability with speed in forward flight. An undesirable instability, evidenced by rearward stick motion with increasing forward speed at constant power, was indicated to be caused by variations with speed of the front rotor downwash at the rear rotor. An analytical expression for predicting changes in speed stability caused by changes in rotor geometry has been derived, and constants for use with the analytical expression have been presented in chart form to facilitate design efforts toward reduction of this instability.

In connection with the current interest in small, one-man helicopters, a series of flight tests has been conducted by the Langley Pilotless Aircraft Research Division to determine the flying qualities of a platform powered by a teetering rotor and supporting a pilot. The rotor investigated was 7 feet in diameter and was driven by air jets at the rotor tips fed through hollow blades by air hoses connected to an external air supply. The machine was tested indoors in hovering and in limited translational flight and outdoors in light and strong gusty winds at elevations of from 1 to 7 feet. The stability and controllability of the machine and flyer combination were found to be satisfactory.

SEAPLANES

Hydrodynamic Elements

Recent developments in water-based aircraft have resulted in configurations utilizing planing surfaces operating in ranges of trim, length-beam ratio, and Froude number beyond those for which most of the available planing theories were correlated with experimental data. The existing theories for a rectangular flat plate in pure planing have therefore been correlated with existing data, including recent unpublished data. These results, published in Technical Note 3233, indicate the need for a rational theory that will agree with data in the recently extended ranges. A theory based on the consideration of linear lifting-line theory, the suction component of lift, and crossflow effects is presented. The agreement between the proposed theory and experimental data was found to be satisfactory for engineering calculations of pure-planing rectangular-flat-plate lift and center of pressure.

As a continuing part of the NACA research program to provide data needed for the application of hydro-skis to water-based aircraft, the force characteristics of an aspect-ratio-0.125 flat plate operating submerged beneath the water surface at several depths have been determined. These data are reported in Technical Note 3249 where they are compared with similar data from flat plates having aspect ratios of 1.00 and 0.25 and also with various aerodynamic theories. The comparisons indicate that decreasing either the aspect ratio or the depth of submersion decreased the lift coefficient, drag coefficient, and lift-drag ratio. The center of pressure moved rearward with decreasing aspect ratio. Cavitation at the leading edge caused a gradual decrease in lift coefficient and a gradual increase in drag coefficient. The planing-bubble type of high-angle separation caused sharp decreases in lift, drag, and moment coefficients. The ventilation boundaries defining the start of the high-angle separation moved to higher speeds and higher angles as the aspect ratio was decreased. A theory obtained by modifying Falkner's vortex-lattice theory, which had shown good agreement at all angles for aspect ratios of 1.00 and 0.25, also agreed with the data for the aspect-ratio-0.125 plate except at angles above 16° where the predicted lift proved too high.

The data for the three submerged rectangular flat plates having aspect ratios of 1.00, 0.25, and 0.125 were obtained with the plates mounted on a single strut. The mutual interference effects of the flat plates and the strut and the strut tares have been evaluated experimentally and the results are given in Technical Note 3420. The interference effects of the strut on the lifting surface proved negligible at all depths of submergence for drag and at all but the very shallow depths for lift and pitching moment. At the very shallow depths the interference effects caused slight increases in both lift and pitching moment. Strut-tare effects on lift and pitching moment were negligible at all depths, although strut-tare effects on drag were not. Comparisons of the strut drag with wind-tunnel drag data for the same airfoil section indicate that wind-tunnel data at the proper Reynolds number can be used to estimate section drag of a strut operating in the water at subcavitation speeds. The water-surface-intersection drag coefficients for the strut were approximately constant for Froude numbers above the critical wave speed. Below

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this critical value, a sharp increase in the coefficient occurred and the value obtained agreed fairly well with the predictions of wave-drag theory.

Research Equipment and Techniques

Waves are of importance to seaplanes because even relatively mild sea conditions can induce critical loads and uncontrollable motions. The characteristics of seaplanes in rough water are investigated in the Langley tanks by means of self-propelled dynamically similar models having freedom in the vertical plane. The methods used in these investigations are described in Technical Note 3419. The maximum trim, rise, vertical acceleration, and angular acceleration during a number of landings are used as criteria for comparisons. For landings in waves of a given height, the criteria are primarily dependent on wave length and usually peak at a critical wave length. Significant reductions in the motions and accelerations have been obtained by practical increases in hull length-beam ratio, afterbody length, angle of dead rise, and suitable combinations of these features. Vertical loads calculated from experimental contact parameters were found to be in reasonable agreement with the vertical accelerometer data. The mean resistance to motion through waves was found to be higher than the resistance in smooth water.

POWER PLANTS FOR AIRCRAFT

In order to maintain aerial supremacy it is necessary to have tactical aircraft that have ever-increasing capability in range, flight speed and altitude. These requirements give rise to a number of complex power plant problems. The research of the NACA in the propulsion field has continued toward solving the problems pertinent to high-thrust engines of light weight with high efficiency in order to meet the increasing range, speed and altitude requirements.

Efficient diffusers at high Mach number, greater airflow handling ability of compressors, increased combustion efficiencies, at high altitudes without combustion blowout or instability, increased turbine-inlet gas temperatures, increased energy content of fuels, and engine control and component matching are problems which require extensive power plant research. Power plants, such as the turbojet, the turbopropeller, the ram jet, the rocket, and combinations of these engines utilizing chemical and nuclear fuels are currently under investigation. As a result of this research, continued improvement in the range, speed and altitude characteristics of the interceptor, long-range bomber, and the guided missile can be expected.

The following paragraphs briefly describe some of the unclassified research conducted by the NACA during the past year in the field of aircraft propulsion.

AIRCRAFT FUELS

During 1955, the search for fuels to give more power per pound of engine, per unit volume of engine, per pound of fuel, and per unit volume of fuel was continued. The greater emphasis was directed toward fuels such as alkylsilanes, aluminum metal, and alkyldiphenylmethanes.

Synthesis and Analysis

The synthesis, purification, and properties of several diphenylmethane and dicyclohexymethane derivatives were reported by Lamneck and Wise.[2] Each of the 13 hydrocarbons was prepared in a state of purity of at least 99 mole percent. The physical properties included melting point, boiling point, refractive index, density, heat of fusion, net heat of combustion, and kinematic viscosities. Two general methods of synthesis were used for the alkyldiphenylmethanes. The first (used for 4-isoprophyl-, 2-s-butyl-, 4-s-butyl-, 2-, and 4-ethyl-diphenylmethanes) was the hydrogenolysis of the corresponding alkylbenzhydrol, which was prepared by treating the appropriate Grignard reagent with benzaldehyde. The second method (used for 4-propyl-, 2-butyl-, and 4-butyl-diphenylmethane) was direct synthesis of the hydrocarbons by the reaction of benzyl chloride with the appropriate Grignard reagent. The alkyldicyclohexylmethanes was prepared by the complete hydrogenation of the corresponding purified diphenylmethanes.

Recently, considerable interest has been shown in the dielectric properties of suspensions and mixtures of solids. The relation between the dielectric constants of the suspensions and the shapes of the dispersed particles are of considerable interest and importance. Although theoretical formulas have been derived relating the dielectric constants of suspensions to the properties of their components for spherical and ellipsoidal particles, no theoretical formulas exist which are satisfactory for arbitrary shapes of particles. In a paper by Altshuller,[3] the mathematical relation connecting the dielectric constants of dilute suspensions with the dielectric constants and volume fractions of the components and with the shapes of the suspended particles are discussed in some detail for particles distributed at random and oriented with respect to the electric field.

Although the dielectric constants of several alkene-1 compounds have been determined, the results obtained have been scattered and somewhat contradictory. Therefore, it was useful to determine the dielectric constants of highly purified samples of pentene-1, hexene-1, heptene-1, and octene-1 as representatives of

[2] See papers by Lamneck and Wise listed on p. 59.

[3] See paper by Altshuller listed on p. 58.

the class $H_2C=CHR$. The dielectric constant of 2-methylbutene-1 was determined as a representative of compounds of the $H_2C=CR_2$ type.[4] The dielectric constants of cyclohexene and transhexene-3 were also measured. The dipole moments of the polar alkenes have been calculated by means of the Onsager equation and are compared with the available dipole moments in the gaseous state. The relation between the observed dipole moments and the bond moments in the alkenes is very briefly discussed.

Very few measurements of dipole moments of alkylsilanes and only one measurement of the dielectric constant of the pure liquids have been made. The paper by Altshuller and Rosenblum reported the determination of the dielectric constants and refractive indices at three wave lengths for *n*-butyl-, isobutyl-, diethyl-, triethyl-, tetraethyl-, tetramethyl-, and dimethyldipropylsilane at 20° C. The atomic polarizations of these alkylsilanes have been calculated. The dipole moments of diethyl-, *n*-butyl-, isobutyl-, and triethylsilane were calculated by use of the Onsager and Kirkwood equations. The Si-H, Si-R, and Si-C bond moments were evaluated.

The value 0.7 has generally been accepted as the contribution of the cyclopropyl ring to the molar refraction of cyclopropane derivatives. However, a recent procedure for the determination of the contribution of the cyclopropyl ring has been developed. From data obtained principally with alkyl cyclopropane, mono-, and dicarboxylates, the value 0.614 was assigned to the ring contribution. In previous investigations, the number of derivative types was limited; consequently, it was uncertain (1) whether any one value adequately expresses for all cyclopropane derivatives the contribution of the ring to the molar refraction and (2) which of the methods proposed for determining the ring contribution is most likely to give such a "constant" value. The physical properties of 30 cyclopropane derivatives were available from previous work at the Lewis Laboratory. These data were used in a paper by Slabey in the present effort to answer these questions.[5]

In the course of investigating the synthesis of cyclopropane derivatives, a method of establishing the presence of the cyclopropyl ring in the synthesis products was desired. The detection of the cyclopropyl ring by chemical means is difficult, and of the physical methods infrared spectroscopy appeared to be the most promising. While the investigation was in progress, three papers were published in which the respective authors suggested three different regions of the spectrum between 2 and 16 as being useful for determining the presence of the cyclopropyl ring. These three regions are discussed in a paper by Slabey based on the infrared spectra obtained of 34 cyclopropane derivatives.[6]

Fuels Performance Evaluation

A considerable amount of research is now being conducted in this country and abroad in an effort to learn something about the mechanisms that control the combustion process in continuous-flow engines such as the gas turbine. A paper by Gibbons, Barnett, and Gerstein reviews briefly available information on the effect of fuel molecular structure on some combustion properties including critical ignition energy, spontaneous ignition temperature, ignition delay, flammability limits, quenching distance, flame velocity, and smoke formation.[7] In addition, the qualitative relations between fundamental combustion properties and performance in a gas-turbine combustor are shown for five hydrocarbons.

The use of turbojet engines over wide ranges of operating conditions involves not only problems of combustor stability and efficiency but also problems of fuel ignition. Ignition may be required either at sea level over a wide range of climatic conditions or during flight over a wide range of altitude and flight-speed conditions. A study conducted to determine the ignition characteristics of three turbojet-engine fuels (AN–F–32, grade JP–1, and two blends of AN–F–58A, grade JP–3) in a single can-type combustor has recently been reported.

The potential availability of AN–F–32, grade JP–1, fuel for jet-propulsion engines was critical because of limitations in boiling temperatures and composition. In order to increase the potential supply of fuel for these engines, AN–F–58, grade JP–3 (present designation, MIL–F–5624), which had wider specification limits, was proposed. Three fuel blends conforming to AN–F–58 specifications were prepared in order to determine the influence of fuel boiling temperatures and aromatic content on combustion efficiencies and altitude operational limits. The investigation was conducted in a single combustor from a British Rolls-Royce Nene turbojet engine and two single J33 combustors. The performance of the three fuel blends was compared in a range of altitudes from sea level to 65,000 feet and at various rated engine and flight speeds.

The present turbine-engine fuel specification, MIL–F–5624, was formulated to permit maximum variations in fuel properties that would result in satisfactory turbojet-engine operation and performance. In order to supply a MIL–F–5624 type fuel for engine development purposes, fuel specification MIL–F–5161 has been issued. This specification provides for a "minimum quality" fuel with more rigid control of the fuel prop-

[4] See paper by Altshuller listed on p. 58.

[5] See paper by Slabey listed on p. 60.

[6] See paper by Slabey listed on p. 60.

[7] See paper by Gibbons, Barnett, and Gerstein listed on p. 59.

erties influencing engine performance. Operation with MIL–F–5161 fuel, together with particular batches of MIL–F–5624 fuel, has been reported to result in excessive carbon deposition accompanied by warping and cracking of liners in both annular and tubular combustion chambers of full-scale turbojet engines. The investigations that were conducted to determine the carbon-forming characteristics of MIL–F–5624 and MIL–F–5161 type fuels in a single combustor from a J33 turbojet engine and of a MIL–F–5161 fuel in a J35 full-scale engine are presented in a recent publication from the Lewis Laboratory.

A critical problem encountered in the operation of turbojet engines with current wide-boiling-range hydrocarbon fuels is combustion-chamber carbon deposition. Methods for predicting the carbon-forming tendency of turbojet-engine fuels from results of simple laboratory tests of the fuels are discussed in a recent report. The accuracy and reliability of the methods and the simplicity of the laboratory tests required are considered with a view toward the application of such methods to the control of jet-fuel quality.

Work has been done at the Lewis Laboratory to determine the feasibility of utilizing liquid fuels having higher volumetric energy content than present jet-engine fuels for application to high-speed, volume-limited aircraft. The combustion efficiency and the altitude operational limits of three liquid-hydrocarbon fuels having high volumetric energy content (decalin, tetralin, and monomethylnaphthalene) were compared with an AN–F–58 fuel in a single tubular combustor from a J33 turbojet engine. The independent effects of combustor-inlet-air temperature, pressure, and mass air flow on the combustion efficiency of the four fuels were determined around a standard combustor-inlet condition.

The interest in metals as fuels arises from the need to extend range, thrust, and operating limits of supersonic aircraft. From the results of an initial study, aluminum was chosen as one of the metals on which combustion experiments will be concentrated. The aluminum fuel was injected in both powder and wire form into 2-inch-diameter ram-jet-type combustors.

COMBUSTION

Fundamentals of Combustion

One of the major problems of high-speed, flight-propulsion research involves the behavior of the fuel-air mixture during the combustion process. Among the properties investigated to gain a better understanding of this phenomenon have been the rates of flame propagation of various gaseous hydrocarbon in air and the relation of these rates to the molecular structures of the fuels. Previously published results include laminar burning velocities determined by both the tube and the Bunsen burner method and consideration of these data in terms of existing theories of flame propagation. Burning velocities in air of 29 pure hydrocarbons, 2 deuterated hydrocarbons, 6 oxygenated hydrocarbons, acrylonitrile, and isopropylamine are presented and the semitheoretical calculations are extended to include the majority of these latter data in a paper by Wagner and Dugger.[8] Burning-velocity measurements were made in either a horizontal tube or a Bunsen burner type of apparatus.

The relation between molecular structure and combustion behavior has been under investigation at the Lewis Laboratory. One phase of this general program has been concerned with the influence of molecular structure on the burning velocities of hydrocarbon-air mixtures. A paper by Wagner on the acetylene derivatives should allow further insight into these phenomena.[9] Burning velocities were measured in an open-burner-type apparatus at a pressure of 1 atmosphere. Burning velocity of isopropenyl acetylene was measured at an initial mixture temperature of 298° K. The high boiling point of di-isopropenyl acetylene required that the burning-velocity determinations be made at elevated initial mixture temperatures.

The flame velocity of a combustible mixture can be increased by preheating the mixture. However, as the preheating is carried to higher temperatures and longer contact times between hot fuel and hot air, there is an increasing amount of preflame reaction, which, in turn, alters the flame velocity. A paper by Dugger, Weast, and Heimel describes studies in which propane and air were passed through a constant-temperature coil for 0.5 to 15 seconds before being burned in a Bunsen flame.[10]

The determination and interpretation of the stability limits of open Bunsen type flames of preheated homogeneous mixtures of propane and air is reported in a paper by Dugger.[11] In this paper, the preheat temperature is referred to as the initial temperature. It represents both the temperature of the unburned gas leaving the burner port and the temperature of the burner wall or port because the burner was operated isothermally.

Much of the theoretical and experimental work on hydrocarbon flames has revolved around the concept of a fundamental burning velocity. This burning velocity or "flame speed" is defined as the rate of advance of a reaction zone into a nonturbulent gas stream. In most practical combustion systems such as furnaces, combustion chambers, and aircraft power plants, however, the burning gases are highly turbulent. The need thus arises for a study of the burning velocities of flames in turbulent gas mixtures. Radiation measurements have been made on open propane-air flames to determine the

[8] See paper by Wagner and Dugger listed on p. 60.
[9] See paper by Wagner listed on p. 60.
[10] See paper by Dugger, Weast, and Heimel listed on p. 58.
[11] See paper by Dugger listed on p. 58.

extent to which radiant flux intensity can be used to measure the surface area of such flames.

The process of flame quenching is of interest, since it is a measure of flame reactivity which may be related to other combustion phenomena of engineering importance, such as flame stabilization, flammability limits, and the general behavior of flames near cold walls. Flame-quenching processes become especially important in turbojet combustion systems when operation at low pressure is considered. Flame quenching is usually studied experimentally in terms of the quenching distance, which is defined as the minimum channel size that will allow a given flame to propagate. A rigorous theoretical treatment of the quenching process appears to be a most difficult task. Consequently, present theoretical treatments of quenching are necessarily approximate and seek primarily to correlate the quenching process with the variables that affect it, such as pressure, temperature, fuel type and concentration, inert-gas concentration, and quenching-surface geometry. Flame-quenching distances for a variable-width water-cooled rectangular-channel burner as a function of pressure for various propane-oxygen-nitrogen mixtures are presented and correlated in a paper by Berlad.[12]

The study reported in Technical Note 3398 contains the derivation of a thermal quenching equation whose general form is independent of the rate-controlling reaction. Two possible rate-controlling reactions are postulated, and the resulting two quenching equations are tested using published quenching data. It is shown that, if the oxygen-fuel reaction is assumed to be rate controlling, quenching data are satisfactorily correlated for both rich and lean propane-oxygen-nitrogen flames. The pressure dependence of the quenching distance and the relation of quenching distances to burning velocity are also discussed.

In a turbojet engine, additional thrust may be obtained by injecting a suitable coolant into the compressor; ammonia and water have been employed for this purpose. Since ammonia is itself a fuel, it is desirable to determine how its presence will affect combustion. Some insight may be gained by studying the fundamental combustion properties of the ammonia when used alone and when combined with a typical fuel. In Technical Note 3446 pressure limits were reported at reduced pressures (up to 400 mm Hg) for isooctane, ammonia, and mixtures of the two in air at several temperatures in the range of 60° to 400° C. The work was performed in a Pyrex glass tube of standard dimensions (2-in. inside diameter and 4 ft long) closed at both ends. A hot wire was used as the ignition source and propagation was upward. Gaseous ammonia with ammonia-air ratios of 0.020 and 0.039 by weight was added to the isooctane-air mixtures. Data showing the amount of ammonia consumed after passage of flame through rich and lean mixtures containing isooctane and ammonia are presented.

In order to provide information for the design and operation of jet-engine combustors, research is being conducted at the Lewis Laboratory to study the fundamental variables affecting the ignition and combustion of fuel-air mixtures. As part of this research, the parameters that may influence the energy required for a spark to ignite homogeneous fuel-air mixtures are being investigated. A theory of spark ignition in nonturbulent- and turbulent-flowing homogeneous gases using long-duration discharges has been reported. The theory is based on the concept that only a portion of the discharge length, a line source of ignition, is important in the ignition process. The theory developed assumes that only a portion of the total energy supplied to the discharge is available for the ignition process.

In any combustion process where self-ignition can occur, the time lapse before the flame appears is an important factor. As the time delay of ignition may be an inverse measure of the rate at which the preflame reactions proceed, a study of the factors influencing the delays may provide information on the kinetics and mechanism that prevail in the ignition process. A paper by Jackson, Brokaw, Weast, and Gerstein describes an apparatus that may be used to study ignition lags of hydrocarbon vapors at elevated temperatures.[13] Preliminary data on ignition delays of propane-air mixtures are also presented.

Combustion properties of hydrocarbon fuels such as flame speed, flammability limit, ignition energy, and quenching distance have been investigated at the Lewis Laboratory. For certain combustion processes, it is desirable to employ fuels that have more favorable combustion characteristics than the hydrocarbons but that possess similar physical properties. A class of compounds which might meet these requirements is the alkylsilanes. Technical Note 3405 describes a study directed toward establishing the conditions of temperature and concentration in dry air that will permit safe handling of this class of fuels. The spontaneous explosion limits of nine alkylsilanes were determined as a function of temperature and fuel-air composition at a pressure of 1 atmosphere.

Explosions in a given system may lead to the following two different combustion processes: Under some conditions, the explosion results in a flame or combustion wave which may travel at a rate of only a few feet per second; under other conditions, a detonation wave may result which travels at several thousand feet per second. Higher pressures and greater destructiveness are associated with the detonation wave. Although

[12] See paper by Berlad listed on p. 58.

[13] See paper by Jackson, Brokaw, Gerstein, and Weast listed on p. 59.

many systems that may contain unburned combustible mixtures (that is, exhaust ducts and mixture feed pipes) are designed to withstand the slower and lower pressure rise of a combustion wave, these systems are often not designed to withstand the greater pressures and destructiveness of a detonation wave. The results of an investigation at the Lewis Laboratory to determine whether a stoichiometric natural gas-air mixture at pressures from 0.4 to 0.2 atmosphere may give rise to explosions with velocities and pressures characteristic of detonations are presented in a paper by Gerstein, Carlson, and Hill.[14]

In spite of expanded efforts on combustion research in recent years, the burning of metallic solids has not received much attention. While solid carbon has been the subject of extensive investigations, which clearly indicate the significance of surface reaction in the utilization of nonvolatile carbon, there is relatively little information available on the detailed mechanism of the combustion of metals. A possible reason for this lack of information is that previous investigators may have generally assumed that the burning of metal solids resembles that of liquid hydrocarbons. The purpose of an investigation, reported in Technical Note 3332, was to study the gross physical mechanism of the combustion of magnesium metal in order to learn whether a vapor or surface reaction is involved and, further, to examine the effect of the composition of the oxidizing atmosphere, both as a matter of general interest and in the hope that such studies might be informative as to the details of the physical and chemical processes involved. In particular, magnesium ribbon was burned in 17- to 100-percent oxygen mixtures with argon, nitrogen, helium, and argon-water vapor as diluents. The experimental data are compared with average burning times calculated from hypotheses involving diffusion and heat-transfer relations.

Operational experience with turbojet and ram-jet engines has shown that combustion efficiency is adversely affected by increase in flight altitude. The establishment of design criteria to improve combustion efficiency at altitude is one of the most important problems confronting the combustion-chamber designer. Burning rates were recently presented for single isooctane drops suspended in various quiescent oxygen-nitrogen atmospheres at room temperature and pressure. The burning rates were compared with those predicted by a previously developed theory based on a heat-mass-transfer mechanism and with values predicted by a modification to this theory. The drop-burning-rate data were applied to equations for a burning fuel spray in order to calculate the predicted change in burning rate of a fuel spray with variation in oxygen concentration.

[14] See paper by Gerstein, Carlton, and Hill listed on p. 59.

Combustion-Chamber Research

When a liquid fuel is injected into the fuel-preparation zone of a ram-jet or a turbojet engine, or into an afterburner, the liquid is broken up into a cloud of droplets which are then accelerated to stream velocity. While accelerating, they evaporate at a rate determined by (1) the air-stream velocity, temperature, and static pressure, (2) the droplet velocity, temperature, and diameter, and (3) the physical properties of the liquid and vapor. Thus, the vaporization rate of sprays in air streams of known temperature, pressure, and velocity may be determined by use of heat-transfer equations when data on drop-size distribution, drop acceleration, and drop-surface temperature are available. A droplet camera developed at the Lewis Laboratory was used to obtain drop-size-distribution and drop-velocity data for isooctane injected from a simple orifice directly into a turbulent air stream. From these data and wet-bulb-temperature data, vaporization rates and drag coefficients were calculated for isooctane drops accelerating and evaporating in streams having velocities of 140 and 180 feet per second. These data are reported in Technical Note 3265.

The high volumetric heat-release rate required in present-day and future jet-engine combustors has placed an ever-growing emphasis on turbulent combustion research. The theory of turbulent flame propagation is as yet in a formative stage, partly because of the lack of reliable experimental methods for determining the effect of turbulence on the rate of flame propagation. The purpose of the investigation reported in Technical Note 3456 was to explore a new experimental method believed to approximate more nearly a theoretical, or ideal, flame model than previous methods. Effective flame speeds of free turbulent flames were measured by photographic, ionization-gap, and photomultiplier-tube methods and were found to have a statistical distribution attributed to the nature of the turbulent field. The effective turbulent flame speeds for the free flame were less than those previously measured for flames stabilized on nozzle burners, Bunsen burners, and bluff bodies. Hot-wire-anemometer measurements of the longitudinal velocity fluctuation intensity and longitudinal correlation coefficient were made and were employed in the comparison of data and in the theoretical calculation of turbulent flame speed.

An analysis has been made of the effect of turbulence on flame speed and noise generation. The results of this analysis are reported in Technical Note 3407.

The flow in the combusition chambers of jet engines is frequently subect to resonant oscillation. A study of this phenomena is reported in Technical Note 3152.

Research Equipment and Techniques

A concentric-cylinder rotational viscometer has been designed that is capable of recording meaningful flow curves of rate of shear against shearing stress for most non-Newtonian materials. This instrument is described in Technical Note 3510.

A method for determining pressure losses due to the flow of non-Newtonian materials in pipelines by using basic flow data obtained from measurements of flow curves, which are curves of rate of shear against shearing stress, is described in Technical Note 3397.

LUBRICATION AND WEAR

Fundamentals of Friction and Wear

The broad and extremely high range of temperatures occurring in turbine engines is being extended continually by new designs for high-speed flight. Present synthetic lubricants have higher temperature limitations than petroleum oils of suitable viscosity. With maximum bearing temperatures from 500 to 1,000° F, however, liquids may be inadequate and nonconventional means of lubrication must be considered. New bearing materials are also required for the high temperatures. Fundamental friction and wear properties of bearing materials, liquid lubricants, solid lubricants, and gaseous lubricants have been investigated for possible use at temperatures up to 1,000° F.

Silicones have the best viscosity-temperature relation of any known class of fluids and some of the silicones have a high-temperature chemical stability that is at least as good as that of any synthetic lubricant now being considered for use in aircraft turbine engines. They are, however, extremely poor boundary lubricants for ferrous surfaces. It has been hypothesized that silicones do not maintain oxide or other reactive coatings on metal surfaces. Conventional chemically active additives and other, more active, compounds, such as peroxides, were investigated (Technical Note 3257) to obtain a better understanding of the mechanisms of lubrication by silicones and to find ways of improving lubrication. Conventional additives were not effective, but the more active materials, such as peroxides, did give effective lubrication. However, all the chemically active types of additives were inferior to solvent-type additions such as diesters.

Solid lubricants have become important in current lubrication research because they have much better chemical stability at high temperatures than liquids. A number of possible solid lubricants with various crystal structures were studied in a low-speed, high-load friction apparatus under conditions of continuous sliding. This study is reported in Technical Note 3334. Some solids with layer-lattice crystal structure provided effective lubrication. Those materials, which include CdI_2, $CdCl_2$, PbI_2, $CoCl_2$, $AgSO_4$, CoS_2, $CuBr_2$, and WS_2, were at least as effective as zinc stearate and graphite in these tests. Not all solids with these structures were good lubricants. The criterion for good lubrication over extended periods seemed to be the formation of adherent films on both mating specimens. Some low-shear-strength materials that did not have a layer-lattice structure afforded effective surface protection.

Halogen-substituted methane and ethane gases can have excellent chemical stability at temperatures of interest in turbine lubrication. A series of such materials has been studied as possible boundary lubricants for steel surfaces. This study is reported in Technical Note 3402. Several compounds containing flourine and two or more chlorine atoms per molecule functioned as boundary lubricants of steel-on-steel to reduce friction and to prevent surface welding and metal transfer; stable fluorine compounds containing no chlorine did not prevent surface failure and therefore were not effective lubricants. Proper run-in was necessary to prevent initial surface failure with chlorine-substituted gases. Difluorodichloromethane and other similar gases lubricated almost as well as conventional liquid lubricants at room temperature, and the gas was effective in runs at 480° F. The method and conditions of application are very critical in lubrication by gaseous materials.

Wear or surface-failure tendencies of materials for cages or retainers of rolling contact bearings have continued to be problems in the development of new engines. Materials with high-temperature strength, oxidation resistance, dimensional stability, and hardness properties better than those of currently used metals were included in a series of wear and friction experiments. Runs were made with surface speeds to 18,000 feet per minute and with ambient temperatures as high as 1,000° F.[15] Both sliding velocity and temperature had considerable effect on wear of various unlubricated metals sliding against hardened steel. The effects, however, were markedly different for the different metals.

As predicted by friction theory, several series of experiments showed that friction and surface damage of metals can be reduced by solid surface films. This study is reported in Technical Note 3444. Of importance to lubrication are (1) naturally formed films such as oxides on metals, (2) chemical-reaction films such as those formed by the use of sulfur or chlorine compounds as lubricant additives, and (3) surface films of solid lubricants. Some surface films, such as Fe_2O_3, can be harmful to friction and wear when they are abrasive. Desirable films from a friction standpoint have low shear strength.

In fluid-film or hydrodynamic lubrication the viscosity is an important physical property of the lubricant. An investigation was recently completed at Harvard University under NACA sponsorship to determine the effect of temperature and high shear rates

[15] See Johnson, Swikert, and Bisson paper listed on p. 59.

on the viscosity of lubricants. This study is reported in Technical Note 3382.

Bearing Research

Operating temperatures of high-speed rolling contact bearings are at present limited mainly by the lubricants and, to a lesser extent, by the bearing materials and designs. The temperature limitations of various lubricants were studied for small ball bearings operating in air. This study is reported in Technical Note 3337. In these experiments, solid lubricants were more effective than liquid lubricants at the higher temperatures. Graphite provided effective lubrication to 1,000° F with bearings equipped with either a beryllium copper or a cast Inconel cage; MoS_2 was effective to 850° F with a bearing equipped with a cast Inconel cage. A silicone-diester blend was the best high-temperature liquid lubricant in this investigation. The blend provided effective lubrication to 700° F and allowed operation of the bearing at 850° F, although bearing operation was rough and friction torque was high.

An experimental investigation was conducted at Cornell University under NACA sponsorship to study the behavior of full journal bearings under steady load when acted upon by a steady misalining couple. This study is reported in Technical Note 3352.

COMPRESSORS AND TURBINES

Compressor Research

The complex nature of flow within centrifugal compressors makes exact design of compressor components difficult. To provide fundamental information about the internal flow of centrifugal compressors, two- and three-dimensional potential-flow solutions involving relaxation methods have been developed. However, these solutions yield no information concerning the flow behavior ahead of and at the entrance to blades of finite thickness or blades that are not alined with the inlet air stream.

A rapid approximate method has been developed that will predict the blade surface velocities in centrifugal impellers. However, there has been no verification of this method for the inlet region because of the lack of an exact solution.

In order to provide fundamental information on the internal flow in centrifugal impellers, a matrix method has recently been developed for the solution of flow in the blade-to-blade or circumferential plane. This method has been applied to the study of a radial-inlet-type impeller at both design and off-design conditions. The results obtained with this accurate method have been used to verify and evaluate the rapid approximate method which was developed previously. It was found that the approximate method was not applicable in the region of the blade leading edge and did not give accurate results in the region of the impeller tip. Over the major portion of the range, however, the approximate method was found to be adequate (Technical Note 3448).

The flow behavior in the region of the leading edge of centrifugal impeller blading is critical in that the rapidly decelerating flow may cause boundary-layer separation. A detailed analysis was made of the flow around the blade nose of a radial-inlet impeller using relaxation techniques. As a result of this study, it was found that the stagnation point shifts from the driving to the trailing face of the blade as the weight airflow increases. On the basis of minimizing the velocity gradients around the nose of the blade, a small positive local angle of attack was indicated as desirable (Technical Note 3449).

A rapid approximate method for the design of centrifugal compressors of given blade shape with compressible nonviscous flow characteristics has been developed using techniques based upon stream-filament theory. Axial symmetry is assumed, but meridional-plane forces derived from tangential pressure gradients are included. The method was applied to the design of an impeller in order to determine the approximate maximum meridional streamline spacing that could be used. Three numerical solutions for different streamline spacings were made using the same hub profile, blade shape, and prescribed velocity distribution along the hub. The shroud profiles obtained from the three solutions, which utilized three, five, and nine streamtubes, were negligibly different (Technical Note 3399).

When a fluid enters a compressor or turbine cascade of sharp-nosed blades at an angle different from that of the blade camber line at the nose, potential-flow solutions indicate an acceleration to an infinite velocity by the fluid as it moves from the stagnation point around the sharp nose. Real fluids cannot overcome the resultant steep pressure gradients and therefore the flow separates off the suction surface of the blade at the sharp nose.

A method of computing the losses in total pressure caused by a nonzero angle of attack at the inlet to a row of sharp-nosed blades is developed for both incompressible and subsonic compressible flow in Technical Note 3149. The results of the analysis indicate that for the range of variables considered increases in upstream flow angle cause sharp rises in total-pressure-loss coefficient and corresponding drops in static-pressure coefficients for negative angles of attack, but for positive angles of attack and upstream flow angles less than 60° there is little variation in total-pressure-loss coefficient with upstream flow angle.

In compressor design, allowances must usually be made for the various types of unavoidable losses in order to obtain optimum matching of the components. Consideration in this work will be given only to the losses arising from rapid adjustments in the flow which may be required at the cascade inlet.

An approximate analysis of cascade induction loss variations with incidence angle, Mach number, and leading-edge thickness is presented along with computational results in the form of curves in Technical Note 3327. Results are based on the solution of the energy, continuity, and integrated momentum equations under the assumption that the blade leading-edge pressure approaches zero at appreciable incidence angles. Results indicate that relatively small blade leading-edge radii (of the order of 2 percent of blade gap) lead to good inlet characteristics for the average conditions generally encountered in compressors.

In studying the flow of air through a compressor, it is desirable to have a description of the internal velocity field. Several two- and three-dimensional methods of obtaining potential flow are available, but present two-dimensional methods are frequently inadequate, while three-dimensional methods are impractical with standard computing techniques.

In Technical Note 3329 a method is presented for calculating supersonic potential flows in annular cascades of blades by the method of characteristics. It is found that helical flows may be adjoined by helical shocks of uniform strength; these constitute a considerable addition to the class of simple flows available for designing cascades of lifting blades. It was also found that, by selection of the proper variables, the derivatives of the velocity components, which occur in the characteristic equations, could be combined into an exact differential. This form of the equation facilitated computations. A flow and several cascade designs were computed.

Blade Vibration and Flutter

The widespread use of compressors and turbines in current aircraft power plants has greatly increased the interest in the flutter of airfoils in cascade. Compressor blades in particular are susceptible to vibrations, and some of these vibrations have been attributed to flutter.

An analysis was therefore made in which the exact equations for oscillatory aerodynamic forces acting in an unstaggered infinite cascade of airfoils in potential flow were derived. Aerodynamic coefficients similar to those of the isolated airfoil were obtained as functions of the cascade geometry and the phasing between successive blades; the phasings considered were 0°, 90°, and 180°. The coefficients were plotted for the case when all the blades were vibrating in bending in phase. It was shown that for this case the effect of cascading is to reduce greatly the aerodynamic damping (Technical Note 3263).

Turbine Aerodynamics

When fluid in an annular cascade is turned, the resulting mainstream pressure gradients are imposed on the boundary layers of low-momentum fluid on the walls and the blades, so that more than free-stream turning of the low-momentum boundary-layer fluid results. These deviations of flow direction in boundary layers and wakes, referred to as secondary flows, were experimentally investigated to clarify the nature and causes of such flows and to present information that permits an estimate of the extent of their influence on cascade and turbine performance. Still and motion pictures were made of boundary-layer and wake secondary-flow phenomena visualized by smoke. Two annular cascades of turbine nozzles were used, both designed for constant discharge angle but differing in blade shape and suction-surface velocity distribution. Flows were similar to those obtained with pressure and angle measurements at near-sonic airspeeds. Boundary-layer cross-channel and trailing-edge radial flows caused vortices and an accumulation of low-momentum air at the hub, which may affect flow in following blade rows. Motion of a downstream rotor blade row produced pulsations in trailing-edge radial flow (Technical Note 3260).

Turbine Cooling

Transpiration cooling is receiving increased consideration as a means of reducing the temperature of walls exposed to hot gas streams to values the wall material can safely withstand. With this method, the air or coolant builds a cool film along the surface that protects the wall from the influence of the hot gases. The coolant also cools the wall by convection as it passes through the material. In some applications, the surface roughness inherently connected with a porous material may exceed the limit for which such a surface is considered as hydraulically smooth. In order to obtain information on friction and flow characteristics of rough surfaces under the condition of fluid injection, an investigation with turbulent air flow was made in a rectangular channel. Provisions were made so that porous samples with varying degrees of roughness could be installed in the lower wall.

Velocity profiles and friction factors for these surfaces are presented for ratios of air-injection velocity to mainstream velocity ranging from zero to approximately 0.017. For zero injection velocity, the friction data compared favorably with available data on impermeable rough surfaces. The shape of the velocity profile was decidedly influenced by the fluid injection (Technical Note 3339).

A method is presented in Technical Note 3408 by which either the local permeability necessary for a prescribed distribution of the coolant flow or the coolant-flow distribution resulting from a prescribed local permeability can be predicted. The method is based on a one-dimensional treatment of the gas flow through a rotating channel with varying cross section and partially porous walls. Sample calculations are presented for two blind radial passages of a rotating transpiration-cooled turbine blade. The effects of passage-area variation, passage-inlet pressures, and passage-inlet Mach number are investigated.

A knowledge of the behavior of the boundary layer adhering to cooled or heated bodies immersed in a moving fluid is essential for accurate prediction of heat transfer or skin friction. The simultaneous effects of a variable temperature and a permeable wall on heat transfer of wedge-shaped bodies are analyzed (Technical Note 3151) by the solution of the laminar-boundary-layer equations with constant-property values.

Solutions were computed for a Prandtl number of 0.7 and a range of cooling-air flows and pressure and wall temperature gradients. For each case, boundary-layer thickness and heat-transfer and friction coefficients were also computed and tabulated. Steeper temperature profiles for a given coolant flow were obtained by increased wall temperature gradients. Wall temperature gradients for zero boundary-layer temperature gradients at the wall were increased by increased pressure gradient and decreased by increased coolant flow.

Procedures available for accurate cycle calculations to determine engine performance depend on the use of tables or charts of the thermodynamic properties of air and combustion gases. Calculations made in this manner are usually cumbersome and time-consuming. In order to simplify and accelerate calculation procedures, a series of curves was prepared and a calculation procedure devised to provide a quick and accurate method of determining component or engine performance for gas-turbine power plants (Technical Note 3335).

Curves based on the thermodynamic properties of air and combustion gases for a hydrogen-carbon ratio of 0.167 were presented to relate parameters affecting each engine component. The curves cover a range of flight Mach numbers from 0 to 3.0, compressor pressure ratios from 1 to 30, turbine-inlet temperatures from 1,500° to 3,000° R, and afterburner temperatures from 2,800° to 3,500° R. Except for extreme cases, the curves are accurate to at least 3° R in temperature and 1 percent in pressure ratio, fuel-air ratio, and specific thrust. Procedures required for performance evaluation are explained for both uncooled engines with no compressor bleed and for engines utilizing both compressor bleed and turbine cooling.

Heat Transfer

The prediction of heat-transfer and friction coefficients for flow in passages is necessary for the design of present and future aircraft, especially those employing nuclear propulsion. Both experimental and theoretical research must be conducted for flow of various fluids in passages having both circular and noncircular cross sections.

An experimental investigation was made to determine heat-transfer and friction coefficients for air flowing through stacks of parallel flat plates. The plates were electrically heated and had short length-to-effective-diameter ratios. Two stacks of plates were alined in series in the direction of air flow, with a one-fourth-inch spacing between plates in each stack. The Reynolds number varied from 15,000 to 80,000. Data were obtained for various gap spacings, for various degrees of plate misalinement between stacks, and also with the upstream stack removed from the tunnel. The average and the local heat-transfer coefficients obtained for the downstream stack with the two stacks alined were slightly higher than the values for round tubes for the same length-diameter ratios. The effects of changes in plate misalinement and gap spacing between plates were found to be negligible.

An analysis was also made of the laminar forced-convection heat transfer in the entrance region of flat rectangular ducts (Technical Note 3331). The simultaneous development of temperature and velocity profiles was studied by using the Kármán-Pohlhausen method. In previous analyses the velocity profile was assumed fully developed. When the development of the velocity profile was considered, a separate curve was obtained for each Prandtl number when Nusselt number was plotted against Graetz number. In contrast, the Nusselt numbers for the case of a parabolic velocity profile throughout can be plotted against Graetz number as a single curve, which is applicable for all Prandtl numbers.

An analysis for turbulent heat transfer and flow in tubes was generalized and applied to an annulus with various eccentricities (Technical Note 3451). Expressions for eddy diffusity, which were verified for flow and heat transfer in tubes, were assumed to apply, in general, along lines normal to a wall. Velocity distribution, wall shear-stress distributions, and friction factors, as well as wall heat-transfer distributions, wall temperature distributions, and average heat-transfer coefficients, were calculated for an annulus having a radius ratio of 3.5 at various eccentricities. For the concentric annulus, the Nusselt numbers and friction factors based on hydraulic diameter agreed closely with those for a circular tube. As the annulus became eccentric, the Nusselt numbers and friction factors decreased.

The results of various investigators of liquid-metal heat transfer were examined and found to be not always directly comparable because of differences in experimental apparatus or in methods of calculation. The experimental data were therefore reevaluated using similar assumptions and methods and then compared with theoretical results (Technical Note 3336). The reevaluated data were found still to have considerable spread, with the bulk of the data being lower than predicted by the well-known Martinelli analysis.

A theoretical and experimental investigation was made of fully developed heat transfer by laminar natural convection between parallel plates (Technical Note 3328). The plates were oriented in the direction of the body force with one wall heated uniformly and the other cooled uniformly. For the experimental investigation, parallel walls were simulated by using an annulus with a ratio of inner to outer diameter near 1. The experimental results were compared with the theory on the basis of the ratio of the actual temperature drop to the temperature drop for pure conduction. Good agreement was obtained between theory and experiment.

In another analytical study of free convection, the effect of nonuniform wall boundary condition on the heat transfer was investigated (Technical Note 3508). Laminar free convection on a vertical plate with prescribed nonuniform wall heat flux or prescribed nonuniform wall temperature was analyzed. The flow was taken to be of the boundary-layer type, and the problem was formulated by the Kármán-Pohlhausen method. The solution of the resulting equations was achieved by a series expansion. For the situation where the wall heat-flux variation is prescribed, graphs were presented from which the resulting wall-temperature variation may be obtained. For the situation where the wall-temperature variation is prescribed, graphs were presented from which the overall rate of heat transfer from any length of plate may be obtained.

Some measurements of boiling burnout heat flux were made for water flowing upward through an electrically heated tube. The burnout heat flux is the heat flux at which the boiling changes from nucleate to film. Its accurate prediction is important for nuclear-power applications where the heat is removed from the reactor by a boiling liquid. The range of variables investigated included pressures from atmospheric to 2,000 pounds per square inch and length-diameter ratios from 25 to 50.

As a part of an investigation of the effective thermal conductivities of powders, a study was undertaken to determine the effective conductivity of uranium oxide powder at temperatures up to 1,500° F. Helium, argon, and nitrogen gases and mixtures of helium-argon and xenon-krypton gases were introduced into the powder void, and the experimental effective thermal conductivities of the gas-powder mixtures were determined. All tests were performed at a gas pressure above the breakaway pressure where the thermal conductivity is independent of pressure. For temperatures above 500° F, the effective thermal conductivity of the uranium oxide powder was independent of temperature. By assuming that the ratio of effective conductivity to gas conductivity is a function of the ratio of the solid to the gas conductivity for a given void fraction, all the data for the uranium oxide powder in various gases were correlated on a single curve.

ENGINE PERFORMANCE AND OPERATION

Effect of Heavy Rainfall on Turbojet Aircraft Operation

The effect of operating turbojet-engine-powered aircraft in heavy rainfall conditions was analyzed by considering experimental data obtained on four production engines and several single combustors under simulated flight conditions.[16] These data indicate that combustion stability would not be seriously impaired by ingestion of water-air ratios up to 0.015 such as would be encountered during a maximum rainfall condition (12.4 in./hr). No adverse operational effects were encountered with any of the engines considered during operation under conditions simulating maximum possible precipitation. However, rain taken into bearing cooling and accessory gear systems will tend to corrode the metal parts unless precautions are taken to remove it within a short time.

Turbine Engines for Transport Airplanes

Three different turbine engines, the turboprop, the the turbojet, and the turbofan, are suited to transport use. The final choice of engine depends on the judgment exercised in evaluating the technical characteristics of the engine and the many vital engineering, operational, and economic problems of the engine-airplane configuration. As an aid in this engineering evaluation, the design and off-design characteristics of three engines are analyzed.[17] Possible future gains in airplane performance resulting from improved engine characteristics are briefly indicated. At present transport-airplane speeds, the turboprop is in direct competition with the reciprocating engine and is obviously an engine of great interest. Exploitation of the tremendous market open to the cargo-carrying airplane may depend heavily upon its continued development. At flight speeds approaching and somewhat above the speed of sound, it is almost equally clear that the turbojet engine occupies a strong competitive position. The hybrid turbofan, or bypass engine, realizes its best performance at flight speeds somewhere between the best speeds for the turboprop and the turbojet engines. All three types of engines have good performance over wide values of flight speed both higher and lower than those required for best performance.

POWER PLANT CONTROLS

Experimental research on automatic control of gas-turbine engines requires methods of control of engine

[16] See paper by Useller, Lewis, and Zettle listed on p. 60.
[17] See paper by Silverstein and Lundin listed on p. 60.

fuel flow that provide essentially linear response to input signals over a frequency band extending from zero to approximately 50 cycles per second. Three valve-controlled systems that may be utilized for this purpose are (1) a throttle (valve) with a regulated (constant) upstream pressure, (2) a throttle with a regulated (constant) pressure differential (bypass-type regulator), and (3) a throttle with a regulated pressure differential (reducing-valve regulator). These three systems of flow control are widely known and have long been applied in other fields. However, in the application to gas-turbine engines, the requirement of an adequate flow response at a 50-cycle-per-second input signal makes it necessary to consider dynamic effects not often encountered in previous applications. An analysis was therefore made of the factors affecting the response to the three systems at such relatively high input-signal frequencies. Measurements of the output-flow impedance and of the transient and frequency response of the three systems are presented along with the analytically determined frequency responses in Technical Note 3445.

POWER PLANT MATERIALS

High-Temperature Materials

Research to improve the performance of turbojet engines by improving existing high-temperature alloys or developing or studying new materials is continuing.

The turbojet blade is subjected not only to high centrifugal stresses and to elevated temperatures but to thermal stresses, vibratory stresses, and corrosive attack by combustion products. Cast alloys of very high strength have been developed for turbine-blade use, but as in the case of currently used cast alloys the newer materials are subject to inherent casting imperfections and metallurgical variables. As a result, cast blades have been observed to exhibit large scatter, or variability, of performance in turbojet-engine studies. To obtain a better understanding of the metallurgical variables resulting from casting methods, blades were obtained from two different manufacturers for evaluation in turbojet engines. Groups of blades from each source were given several heat treatments, and the performance of as-cast and heat-treated groups were compared in a controlled engine test. In general, solution treatments damaged blades by causing varying degrees of eutectic melting of interdendritic segregates. The effects of heat treatment on blade performance could be either beneficial or harmful, depending upon the initial structure of the castings, which in turn depends on the casting size and manufacturing variables (Technical Note 3512).

Nickel-base alloys with small quantities of aluminum have been used as high-temperature alloys for years. Recently, newer nickel-base alloys have been developed with considerably improved properties. Improvements have been made largely by increased additions of aluminum and titanium. One of the principal hardening agents in these alloys is the phase Ni_3Al, which may contain varying quantities of titanium, molybdenum, and chromium replacing some of the aluminum. Thus, this intermetallic compound is interesting in itself because of its prevalence in such vital alloys. This type of compound is usually brittle and, in fact, has been found by others to have almost no ductility. The NiAl alloys have been found to have appreciable strength at 1,800° and 2,000° F, temperatures well advanced above normal alloy use temperatures. An investigation of nickel-aluminum alloys ranging in aluminum content from 14 to 34 percent by weight was conducted (Technical Note 3259). This composition range includes the phases Ni_3Al and NiAl and mixtures of the two phases. Alloys containing two phases (Ni_3Al and NiAl) were almost twice as strong as either compound alone. The two-phase alloys showed promise for high-temperature work in that they were rollable, had ductility in tension, and exhibited a martensitic type of transformation upon heat treatment.

In another program, a newly developed iron-aluminum alloy Thermenol was found to have stress-rupture properties at temperatures of 1,100° and 1,200° F roughly equivalent to those of the stainless steels AISI 310 and 321. Both tensile and bend ductilities of the alloy were low. The alloy has been of interest because of its low-strategic-element content.

Cooling of the hottest portions of engines may prove to be very desirable, in that the engine operating temperatures may be increased and, as a result, thrust and speed of the aircraft increased. Cooled turbine blades have been designed with hollow channels and airfoils which require fabrication by brazing or welding. An investigation was conducted on brazing of complicated engine components (Technical Note 3450). Two brazing techniques were studied, vacuum and salt-bath brazing. Both vacuum- and salt-bath-brazing methods produced adequate shear strengths, although vacuum-brazed strengths were superior to salt-bath-brazed strengths. In the salt-bath process, the shear strengths of the brazed specimens increased as brazing temperatures increased. In the vacuum process both temperature and time at temperature were shown to be important, and an optimum time and temperature for brazed specimens were ascertainable from the data.

The use of molten sodium hydroxide as a high-temperature heat-transfer fluid offers many advantages in some types of propulsion systems. The main difficulty with its use is that it is highly corrosive and leads to mass transfer in most container materials. An extensive effort is being made to find suitable conditions under which the corrosive attack might be reduced or eliminated. Experiments were conducted to determine the effect of temperature, temperature gradient, test duration, and flow velocity on corrosion and mass transfer in nickel. Free convection and forced circulation at the rate of 15 feet per second were studied at temperatures to 1,500° F. The use of additives that might repress the rate of attack on nickel was also studied. The additive studies gave positive indication that mass transfer can be repressed.

Many of the modern heat-resistant alloys which have been developed for the severe temperature conditions encountered in the aircraft gas turbine are extremely complex. Consisting of from 6 to 12 alloy elements, the alloys depend on the various microstructures which can be produced through heat treatment and fabrication procedures for their strength. In order to produce the best microstructure, it is necessary to be able to identify the chemical composition and structures present. Currently used identification techniques such as chemical analysis and X-ray diffraction are not sufficiently sensitive. The use of radioactive isotopes in other fields for identification purposes prompted a similar study for use in alloys (Technical Note 3209). A technique was proved to the point where it was demonstrated that autoradiographs could be produced which would resolve radioactive areas separated by less than 10 microns. The autoradiograph is viewed without removing it from the surface under investigation so that the microstructure and the autoradiograph can be seen simultaneously under the microscope. Recommended procedures are given for the preparation of the metallographic mount, addition of the thin plastic protective layer, and photographic emulsion processing.

The complexity of the modern high-temperature alloys mentioned above has made it extremely difficult to understand the principles which govern the load-carrying ability at the temperatures and conditions where joint creep and fatigue can occur simultaneously. A special panel appointed by the NACA Subcommittee on Heat-Resisting Materials undertook to relate the fatigue and static properties of wrought N–155 alloy over a wide range of temperatures (Technical Note 3216). The results showed that, in general, a superimposed dynamic stress on a steady load had a decreasingly smaller effect on the rupture time as the steady stress was reduced. In addition, limited data indicated that, under combined stresses up to 67 percent of the steady load at 1,350° and 1,500° F, the fatigue stress did not appreciably alter the creep characteristics through the second stage of creep.

There has been considerable interest in the use of ceramic coatings to protect metals from corrosive attack. Among the various factors that contribute to the degree of protection achieved is that of the adherence of the ceramic to the base metal. It has been postulated that the amount of oxygen present in the furnace atmosphere used in applying ceramic coatings should have an effect on adherence. A study of this effect was undertaken (Technical Note 3297). The results showed that a decrease in the amount of oxygen in the furnace atmosphere necessitated an increase in the amount of cobalt oxide in the enamel if optimum adherence was to be secured. To a lesser extent the reverse effect was true. Metallographic examinations of the interface between the ceramic and metal showed a qualitative correlation between adherence and surface roughness regardless of the oxygen content of the furnace atmosphere.

Stresses Research

Many high-temperature alloys exhibit high notch sensitivity when tested in stress rupture in certain ranges of time and temperature. This notch weakening appears to be associated with precipitation effects during creep. It is greatly increased in some low-alloy steels by the heating cycle used for brazing of air-cooled turbine blades and by the presence of the braze material. An investigation of the influence of normalizing and tempering procedures was undertaken for a typical Cr-Mo-V low-alloy steel with the object of developing a heat-treatment procedure to reduce the notch sensitivity and to overcome the damage of brazing.[18] The results show that the large decrease in ductility and increase in notch sensitivity associated with normalizing at high temperatures (in the order of the brazing temperature) can be completely overcome by re-heat-treating. In addition, it is shown that the notch strength at 1,000° F can be considerably increased with only a small sacrifice in smooth strength by tempering at relatively high temperatures for short periods of time. This procedure, in combination with re-heat-treating, greatly improves the operating lives of brazed air-cooled turbine blades of Cr-Mo-V steel.

Many brittle materials possess good high-temperature strength and corrosion-resistant properties that make them attractive for high-temperature power-plant use. However, these materials often are comparatively weak in thermal-shock strength. Theories of thermal-shock resistance have been developed in an attempt to understand and improve this property. Present theories predicting the resistance of brittle materials to thermal shock are based on the premise that failure occurs upon the attainment of a definite critical stress. However, the failure of many of these materials has been shown to depend on stress distribution within the body rather than on the maximum-stress criteria. Weibull's statistical theory of strength which accounts for this behavior has been adopted to predict the strength of circular disks subjected to peripheral thermal shock. The analysis shows, for those materials in which tensile strength differs appreciably from the bending strength, that considerable error can be introduced by the use of the conventional maximum-stress

[18] See paper by Jones, Newman, Sachs, and Brown listed on p. 59.

theory of fracture when predicting thermal-shock resistance over a wide range of quenching severities.[19]

Physics of Solids

In order to gain a better insight into the behavior of materials under conditions of stress, low temperature, and radiation, fundamental studies of materials were continued. An investigation of the extent of work-hardening taking place during fatigue was made. The order-disorder transformation occurring in a binary alloy was used to indicate the strain-hardening by severe fatigue. This study was based on the fact that the resistivity of a disordered alloy is very much greater than that exhibited by the alloy when ordered. While it is known, in a general way at least, that the changes associated with cold-work are due to the multiplication and trapping of dislocations, the nature of the fatigue process is still undetermined. The most generally accepted theory is that there are produced in a fatigued metal a large number of rather small local regions of severely strain-worked material. If this fatiguing were done on an ordered alloy, these regions would become disordered and the resistance would increase correspondingly. A change of the resistivity of ordered AuCu of approximately 1 to 2 percent at the temperature of liquid nitrogen was found to occur as a consequence of severe fatigue.[20]

The idea for using the order-disorder transformation in AuCu as a tool in the investigation of the mechanism of fatigue stemmed from a separate series of experiments conducted to determine the variation of the room-temperature resistivity and the magnetoresistivity of AuCu as a function of the degree of order. Measurements were made first of all on samples quenched to room temperature after reaching equilibrium at temperatures below the Curie point. Measurements were also made on samples that were first disordered by quenching from a temperature above the Curie point, then annealed for various lengths of time at 265° C, and finally quenched to room temperature. The equilibrium curve for the magnetoresistivity shows a minimum and a pronounced maximum which are close to the transition temperature for the phase change of AuCu I to AuCu II. No such extremes in the value of the coefficient of magnetoresistivity occur during the annealing of a thermally disordered sample.[21]

The occurrence and properties of the superconducting state in metals have been studied. A number of attempts had been made by other investigations to relate on an empirical basis the ability of a metal to become superconducting with other more fundamental properties. It is now accepted that the occurrence of superconductivity is due to the interaction of the conduction electrons with the lattice vibrations. A new criterion for the occurrence of superconductivity based on the (average) freedom number of the free electrons in the metal has been proposed and applied to 9 superconductors and 12 nonsuperconductors for which the necessary information is available. This test fails for only one of the 21 metals. A simplified criterion for which less information is necessary is applied to a still larger number of elements, which, while somewhat less successful than the former criterion, is still better than any previously suggested in the literature.[22] An experimental investigation of thermoluminescence in sodium chloride resulted in the proposal of a specific model to explain the results obtained. The emission spectrum at 500° K of synthetic NaCl crystals that had been irradiated with X-rays at room temperature was determined. Also the intensity of light was determined when emitted by NaCl crystals irradiated with X-rays and ultraviolet light and then heated as a function of the temperature. Eight bursts of light were found. It was suggested that these results indicate that the thermoluminescence takes place by means of a two-stage process of the following sort. The first stage which is the same for all the bursts and is thermally activated with the measured activation energy takes place when trapped electrons are raised from F-centers into the conduction band. In the second stage, electrons in the conduction band fall into different empty energy levels, there being one type of level for each burst. The large observed differences between the peak temperatures of the different bursts are then due to large variations in the probabilities of this second process for different levels.[23]

Further studies on the scattering of neutrons and X-particles in matter were performed as part of the program on radiation damage. A theoretical investigation of the slowing-down length of neutrons in water was conducted to attempt to resolve the discrepancy of about 20 percent that existed between the theoretical value and the experimentally determined value. An expression was derived that took account of the deviation from spherical symmetry of the elastic scattering by nonhydrogen nuclei. The correction to the previous theoretical value that was obtained lies in the right direction but is only 3 percent in magnitude. Hence, the effect of asymmetry can account for only a small part of the 20-percent discrepancy between the experimental and calculated values.[24] The range and straggling of low-energy alpha-particles were also measured in a cloud.[25] Earlier experiments on slow alpha-particles were meager because of the very short range of alpho-particles and the difficulty of introducing mono-

[19] See paper by Manson and Smith listed on p. 59.
[20] See paper by Webeler listed on p. 60.
[21] See paper by Wiener, Schwed, and Groetzinger listed on p. 60.
[22] See paper by Groetzinger, Kahn, and Schwed listed on p. 59.
[23] See paper by Hill and Schwed listed on p. 59.
[24] See paper by Volkin listed on p. 60.
[25] See paper by Barile, Webeler, and Allen listed on p. 58.

energetic low-energy alpha-particles into a cloud chamber. These difficulties were solved by using a low pressure in the chamber and passing the alpha-particles through a thin nylon window into the chamber, thereby allowing accurate measurements of the ranges of low-energy alpha-particles.

The diffusion process is responsible for changes in the properties of alloys while in use and also is a process that controls the methods by which alloys can be prepared. In order to gain a better understanding of the diffusion process in a pure metal, self-diffusion in silver was studied by the use of an autoradiographic technique. A radioactive isotope of silver was plated on the end of a silver bar. The progress of the radioactive atoms through the bar at high temperature was followed by taking radioautographs of the bar at various time intervals. The results obtained by this new technique compared favorably with previous results by other methods and indicated that the technique would be useful for other systems.[26]

A large group of equations (matrix) involved in the search for an answer to certain physics problems has no known solution. However, a satisfactorily accurate solution can be obtained by a trial and error calculation routine. For very large problems this routine becomes extremely tedious and time-consuming, even when handled by rapid punch-card equipment. Two new formulas were developed and incorporated into the calculation routine. Results show that by reducing the number of trials solution time is considerably reduced. An application of this method to a very cumbersome nuclear physics problem concerning neutron diffusion is presented in Technical Note 3511.

The distance traveled by fast neutrons in a chain-reacting system during moderation is important to reactor criticality evaluation. In the design of reactors, iron may be used in considerable quantities; and its effect on criticality is very important, since iron alters the neutron slowing-down process. Measurement of the mean-square slowing down distance of neutrons to the indium resonance energy for water-iron mixtures provides qualitative and quantitative indications of the moderating properties of these mixtures. The values of the mean-square slowing-down distance to the indium resonance energy for water-iron volume ratios of 1, 2, and 3 and for water were 347, 336, 314, and 291 centimeters squared, respectively.

[26] See paper by Krueger and Hersh listed on p. 59.

ROCKET ENGINES

Propellants

Nickel, Monel, and aluminum are resistant to attack by gaseous fluorine up to 450° C, while the resistance of stainless steels is unsatisfactory above 200° to 250° C. No information is available in the literature, however, on the corrosion of metals by liquid fluorine at −196° C or by alternate exposure to liquid and gaseous fluorine. The corrosion of 3003–0 and 5052–0 aluminum, AISI 347 and 321 stainless steels, "A" nickel, and low-leaded brass has been determined from the weight change of specimens exposed alternately to liquid and gaseous fluorine. Experiments were continued for a total exposure time of up to 3½ months. Corrosion was negligible under the conditions of the experiments. No visual differences were observed between those surfaces exposed to the gaseous phase only and those exposed to both the liquid and the gaseous phases. These data are reported in Technical Note 3333.

Low-Pressure Exhaust Ducts for Rocket-Propelled Models

An investigation of the aerodynamic losses involved in the use of low-pressure tailpipe exhaust ducts for rocket-propelled pilotless aircraft models was conducted. In order to achieve stability in rocket-propelled aircraft, it is necessary to locate the center of gravity of the propellant at the center of gravity of the aircraft and convey the jet exhaust to the rear of the aircraft through exhaust ducting. The reduction in impulse caused by aerodynamic losses in low-pressure tailpipe ducts was determined experimentally for several tailpipe length-diameter ratios and was found to be within practical limits insofar as the overall propulsion requirements for pilotless aircraft models are concerned.

AIRCRAFT CONSTRUCTION

The need continues for increased research in the field of aircraft construction. The major advances which have been made in the fields of aerodynamics and propulsion with their attendant increase in aircraft performance have caused problems related to the aircraft structural safety, such as aeroelastic deformation, flutter, air loads, and choice of structural materials to assume paramount importance. Furthermore, these problems are being complicated by aerodynamic heating effects as aircraft speeds increase into the supersonic realm. This is requiring research in new fields, although the need continues for research on other problems of long standing nature such as structural design methods, fatigue, gust loads, buffeting, and landing loads.

In order to promote the early use of research results in the design and development of airplanes and missiles, the practice of holding technical conferences with representatives of the military services and the aircraft industry was continued during the past year. A technical conference on structures, loads, and flutter problems was held at the Langley Laboratory in March 1955.

As in the past, research performed at the NACA laboratories is supplemented by research performed under contract at universities and other nonprofit organizations. A description of the Committee's recent unclassified research in the field of aircraft construction is given in the following pages and is divided into four sections: (1) Aircraft Structures, (2) Aircraft Loads, (3) Vibration and Flutter, and (4) Aircraft Structural Materials.

AIRCRAFT STRUCTURES

Static Properties

The stresses near a cutout in a fuselage shell can be much higher than the stresses some distance away from the cutout and may lead to catastrophic static and fatigue failures unless properly accounted for in design. An investigation aimed at the development of a satisfactory method of stress analysis for circular semimonocoque cylinders with cutouts has produced fruitful results. In Technical Note 3199, stress distributions produced by various types of basic loadings on circular semimonocoque cylinders with flexible rings have been derived analytically. These stress distributions form the foundation for the method of cutout stress analysis contained in Technical Note 3200. Extensive tables of coefficients for use in the application of this stress-analysis method have been calculated and are given in Technical Note 3460. With the procedures and data contained in Technical Notes 3200 and 3460, the stress analyst can calculate cutout stresses due to a variety of external loadings for cylinders both with and without local reinforcements about the cutout.

Part of the effectiveness of integrally stiffened plates is due to the fact that stresses in the skin of a plate are transmitted directly into the integral stiffeners. This fact, however, makes difficult the calculation of the elastic stiffness parameters of this type of construction. The shearing stiffness of integrally stiffened plates has been evaluated by means of an electrical analog computer, and the numerical results obtained are presented in Technical Note 3443 for a variety of proportions of rectangular stiffeners with circular fillets.

An extensive study has been made of the effect of rivet pitch, diameter, and location on the strength of short compression panels. It is shown in Technical Note 3431 that panel strength is highly influenced by variations in these rivet parameters. The method of analysis that incorporates the effects of riveting on panel strength is presented and is shown to furnish results which compare favorably with data from tests of a large number of panels.

In order to simplify the construction of thin multiweb wings, consideration has been given to the replacement of alternate webs by open construction such as posts, trusses, and longitudinal stringers. In order to determine whether such methods of interior construction could be used to strengthen and stabilize adequately the cover skin of multiweb wings without weight penalty, an exploratory experimental investigation of the buckling and ultimate strength of several two-cell box beams incorporating various forms of internal construction was performed. The results of this investigation are contained in Technical Note 3231 and indicate that such open construction can perform the function of a solid web with no increase in weight.

The calculation of stresses and deflections of wings of low aspect ratio and high sweep requires extensive theoretical analysis and the use of large computing machines. An alternative method of analysis is based on the test of scale models made of plastic materials. A distinct advantage of the plastic-model approach is that models may be constructed very similar to the actual prototype; whereas, in most theoretical analyses, idealized and substitute structures must be assumed in order to simplify the mathematics. On the other hand, certain peculiar properties of thermal-plastic materials must be taken into consideration in the execution and interpretation of plastic-model tests. An experimental study of a plastic model of a delta wing indicates that, with reasonable care, valuable information can be obtained from plastic-model tests.

Plate elements of aircraft structures can support loads after they have been buckled, but their post-buckling behavior is very difficult to analyze since it involves both large deformations and plastic flow. Technical Note 3368 presents an analysis of the behavior of simply supported flat plates loaded beyond the buckling load into the plastic range; this analysis is based on large-deflection theories and plasticity theory in conjunction with computations carried out on a high-speed calculating machine. The numerical results are given for several plate configurations and for one material stress-strain curve. The results indicate that the rigorous enforcement of restrained conditions along the edges of the plate may be an important influence on the plate strength.

Because structural analyses of shells are often complex, electrical analogies have been found to be quite useful. The California Institue of Technology has developed an analog for a circular shell with a straight axis and variable radius. This analog has been extended to represent more complicated shapes and example problems have been solved. The results of this study are presented in Technical Note 3280.

A shallow spherical dome subjected to lateral pressure is one for which the buckling process is characterized by a rapid decrease in the strength once the buckling loading has been surpassed. The California Institute of Technology has investigated the buckling of such structures and has developed a nonlinear theory for calculating their characteristics. The results of this theoretical and experimental investigation are presented in Technical Note 3212 and indicate that the classical criterion of buckling is applicable to very shallow spherical domes but that energy solutions more closely represent the characteristics of higher domes.

Fatigue Properties

A problem of great practical interest is the prediction of static strength of aircraft components containing small fatigue cracks; failures of aircraft in service indicate that very serious losses of static strength may be produced by such cracks. A systematic study of loss of static strength due to fatigue cracks in simple tensile specimens has been undertaken and some results have been reported. It was found that in simple tensile specimens losses of static strength about one-third greater than those due to a simple reduction of area are encountered in both 7075 and 2024 aluminum alloys, the 7075 alloy strength being slightly more sensitive to fatigue cracks than the 2024 alloy.

Failures of pressurized fuselages initiated by fatigue cracks have varied in character from rather minor rupture to catastrophic explosion. An experimental study has been undertaken to determine whether the character of the failure can be controlled by selection of material or structural proportions. Tests on eight cylinders, all of 2024 aluminum alloy but with various types of stiffening, showed both gradual and explosive types of failure, and it appeared that an important factor in the determination of the type of failure was the ratio of ring reinforcement area to the associated skin area of the cylinder.

Thermal Properties

Although extensive investigations have been made of the static strength of multiweb box beams at room temperature, little is known about the behavior of such box beams at elevated temperatures. Not only is static strength at elevated temperatures important, but, in addition, creep of multiweb box beams under constant load and, ultimately, creep rupture become major considerations at elevated temperature. An initial experimental investigation of the static strength and creep behavior of seven aluminum-alloy multiweb box beams at various elevated temperatures is reported in Technical Note 3310. It was found that room-temperature techniques for the prediction of static strengths were generally successful in the prediction of the ultimate strength of the box beams at elevated temperature. In addition, tensile creep failure of the box beams was satisfactorily correlated with tensile creep data on simple specimens. It was found, on the other hand, that serious gaps exist in available theory for predicting satisfactorily creep deflections and creep buckling failure in the box beams.

Since plates constitute some of the most important load-carrying elements in the structure of an aircraft, knowledge of their strength and creep behavior at elevated temperature is of major importance. A basic experimental investigation of the compressive strength and creep lifetime of 2024–T3 aluminum-alloy plates at elevated temperature supported in V-groove fixtures has been conducted. The results of the investigation show that, when creep effects are negligible, elevated-temperature plate strengths can be predicted satisfactorily on the basis of a relationship previously developed for the strength of plates at room temperature; the effect of elevated temperature enters into the relationship only through the properties of uniaxial stress-strain relations at elevated temperatures. The results of creep-lifetime tests for the plates were found to be reducible to generalized creep-lifetime curves through the use of a time-temperature parameter that has previously been found suitable for summarizing tensile creep rupture data.

In order to determine the creep characteristics of joints, tests have been conducted by the National Bureau of Standards on riveted lap joints fabricated from 7075–T6 and 2024–T3 aluminum-alloy sheet under temperatures of 300°, 400°, and 500° F. The test results, which are presented in Technical Note 3412, show that the creep of riveted joints is considerably greater than the creep of unriveted sheet. The shape of the creep curves, however, suggests that a correlation between the creep of a riveted joint and the creep of its component materials in tension, bearing, and shear may be possible. A number of spot-welded joints employing 301 stainless steel were also tested at 800° F and the creep was found to be negligible.

Research by Syracuse University aimed at studying the heat flow through joints has been reported previously. This work has now been extended to include the effects of pressure on thermal conductance of joints. The results are presented in Technical Note 3295 and indicate that pressure is an important variable in thermal conductance of contact joints.

AIRCRAFT LOADS

Basic Load Distribution

As part of an investigation of the loads on leading-edge slats when used on sweptback wings, the pressure distribution around the leading edge of a 40° swept-back wing has been measured at Mach numbers up to 0.9. These data, obtained through the expected operating range of angle of attack, may be used to predict the normal and chord forces on retracted leading-edge slats of various sizes up to 25 percent of the wing chord.

Reported in Technical Note 3245 are the results of a continuing effort to provide information which will permit a reduction of wind-tunnel and flight-testing times as well as of the work required by the design engineer. The spanwise distribution of load at subsonic speeds and the resulting stability derivatives have been calculated for a systematic series of vertical- and horizontal-tail combinations in sideslip and in steady roll for a wide range of probable tail configurations. Calculations were made by application of the discrete-horseshoe-vortex method to the problem of estimating loads on intersecting surfaces and included variations in vertical-tail aspect ratio, the ratio of horizontal-tail aspect ratio to vertical-tail aspect ratio, the effects of horizontal-tail dihedral angle (for the sideslip case), and the effects of vertical position of the horizontal tail. The angle of sweep of the quarter-chord line of the surfaces varied from 0° to 45°. The results of the investigation are presented in charts from which span loads for the various conditions can be obtained. The resulting stability derivatives are presented as vertical- and horizontal-tail contributions to the stability derivatives as well as total-tail-assembly derivatives. An extensive table of values of sidewash due to a rectangular vortex is also presented.

Gust Loads

The results of an analysis of approximately 100,000 hours of V–G data obtained from one type of four-engine civil transport airplane including the derived magnitude and frequency of occurrence of gusts and gust loads are reported in Technical Note 3358. The data were obtained during routine operations from 1947 to 1954 on five different airline routes. The analysis shows that for each of the five operations normal acceleration increments may equal or exceed the value corresponding to the limit gust-load-factor increment, on the average, twice (once positive and once negative) within the range of 1.9×10^6 to 5.0×10^6 flight miles. A derived gust velocity of 50 feet per second may be equaled or exceeded twice within the range of 0.6×10^6 to 1.9×10^6 flight miles. Seasonal effects or differences in operational utilization had only a small effect on the results.

In Technical Note 3365, VGH time-history-type data obtained from one type of four-engine civil transport airplane during operations on three routes are analyzed to determine the magnitude and frequency of occurrence of gust velocities, gust and maneuver accelerations, and the associated airspeeds. Variations of the gusts and gust accelerations with route and flight conditions are indicated. Estimates of the overall gust and gust-load histories for extended operations on one route are obtained by supplementing the VGH data with available V–G data. Other VGH data have been obtained from one type of twin-engine transport airplane during operations from 1950 to 1952 on a transcontinental route and are analyzed in Technical Note 3371 in order to determine the magnitude and frequency of occurrence of gust accelerations, gust velocities, and the associated airspeeds and altitudes. The results obtained compare favorably with results previously obtained for a similar type of twin-engine airplane during other operations.

Estimates of the probability distribution of the root-mean-square gust velocity of atmospheric turbulence from operational gust-load data by the random-process theory are given in Technical Note 3362. Under the assumption that the operational gust or gust-load history of an airplane is a Gaussian random process with a single parameter, the root-mean-square value, relations are derived between the probability distribution of the root-mean-square acceleration and the associated number of peak accelerations above given values. These relations are then used in the analysis of operational gust-load data available in the form of peak counts to derive estimates of the probability distributions of root-mean-square acceleration. These probability distributions are then transformed on the basis of airplane-gust-response theory so as to derive the associated probability distribution of root-mean-square gust velocity. The application of these results to the calculation of load histories is also considered briefly.

Landing Loads

Flight tests have been conduced with a large bomber-type airplane to determine the ground reactions imposed on multiple-wheel landing-gear trucks under actual landing conditions. The program covered landings made at vertical velocities up to 8.5 feet per second and forward speeds at contact from 95 to 120 miles per hour. Landings were made on both wet and dry concrete runways. The results of the tests indicated that the relationship between the maximum vertical reaction on a landing-gear truck and the truck vertical velocity was apparently unaffected by whether the truck was the first or second truck to make contact with the runway. This relationship also was apparently unaffected by the lower coefficient of friction present in the landings on wet concrete. Calculations of the maximum vertical reaction agreed well with the experimental results, particularly in the variation of the maximum vertical reaction with vertical velocity. The coefficient of friction between the tire and the runway was found to increase during wheel spin-up for the dry-surface condition from an average value at full sliding of 0.43 to an average value at incipient skidding of 0.76. For the wet-surface condition, the average value increased from 0.15 at nearly full sliding to 0.38 at incipient skidding.

An experimental investigation of the effect of wheel prerotation on landing-gear drag loads is reported in Technical Note 3250. A laboratory setup in which landings were simulated with various amounts of prerotation was made with a dropping weight of 2,500 pounds and a forward speed of 85 feet per second at a strut angle of 15°. The results were compared with data from previous tests made at various forward speeds with no prerotation. The effect of prerotation on the maximum drag load was the same as the effect of reducing the horizontal velocity. At low horizontal velocities any amount of prerotation reduced the drag load. The reduction became greater as the vertical velocity was increased. Reductions in drag load resulting from prerotation were accompanied by reductions in vertical load. At high forward speeds somewhat beyond the range where prerotation was tested, however, consideration of existing data indicated that large amounts of prerotation would have to be used in order to assure a reduction in drag load. In this higher speed region, insufficient prerotation could actually increase the drag load. The wheel spin-up process appeared to be a small factor in tire wear and prerotation therefore should not materially increase tire life.

Measurements of shock-strut internal pressures, telescoping velocity, and strut stroke made during drop tests of a small oleo-pneumatic landing gear to determine the characteristics of the orifice and to show the relationships between internal strut pressures and the overall loads developed by the strut are reported in Technical Note 3426. The shock-strut telescoping velocity ranged from 1 to 7 feet per second and corresponded to a Reynolds number range of 9,500 to 66,500. The strut stroke varied from 1 to 7 inches and corresponded to approach-chamber lengths from 6.58 inches to 0.58 inch. Analysis of the data shows that variations in telescoping velocity and strut stroke result in relatively small changes in the orifice coefficient. Comparisons between strut forces determined from internal-pressure measurements and forces measured by an external dynamometer indicate that the strut forces can be accurately determined from the product of the internal pressure and appropriate area. Comparison of time histories of strut force derived from internal-pressure measurements and from measurements of the telescoping velocity and strut stroke indicates that a close approximation of the strut forces during impact can be obtained when the orifice coefficient is assumed to be constant and the air-compression process to be isothermal.

Technical Note 3235 presents the results of an investigation of low-speed (up to 4 miles per hour) cornering characteristics of two 56 × 16, type VII, extra-high-pressure, 24-ply-rating tires for a range of vertical loadings, yaw angles, and tire inflation pressures. Locked-wheel drag tests were also made for one vertical-load condition. The quantities measured included cornering force, drag force, self-alining torque, pneumatic caster, vertical tire deflection, rolling radius, and relaxation length. Some supplementary tests were made which included measurements of tire footprint area, vertical-load-deflection characteristics, and the variation of tire radius and width with inflation pressure. Results indicated that the normal force reached a maximum at between 14° and 18° yaw. The self-alining torque increased with yaw angle up to between 5° and 8° yaw, but increasing the yaw angle beyond this point tended to decrease the self-alining torque considerably. The pneumatic caster was a maximum at small yaw angles and tended to decrease in value with increasing yaw angle. The yawed-rolling and sliding drag coefficients of friction both tended to decrease in magnitude with increase in average bearing pressure. In general, the relaxation length decreases with increase in vertical tire deflection and increase in inflation pressure.

The effects of structural interaction, between a landing gear and a flexible airplane structure, on the behavior of the landing gear and the loads in the structure are presented in Technical Note 3467 by treating the equations of motion of the airplane and the landing gear as a coupled system. The landing gear is considered to have nonlinear characteristics typical of conventional gears, namely, velocity-squared damping, polytropic air-compression springing, and exponential tire force-deflection characteristics. It was found that the effects of interaction can result in appreciable reductions in the magnitude of the landing-gear force, particularly when the flexibility of the airplane structure is large and the natural frequency is small. Thus, neglect of interaction effects, that is, the use of the landing-gear forcing function for a rigid airplane, in a dynamic analysis of a flexible airplane can lead to the calculation of erroneous loads in the airplane structure.

A statistical study of the values of wing lift factor at the instant of ground contact for four transport airplanes is presented in Technical Note 3435. The basic data were obtained from acceleration measurements on VGH records of 2,049 landings of four commercial-airline transport airplanes during routine operations. Frequency-distribution curves and probability curves were fitted to the samples of data obtained from each airplane. The results indicate that the mean value of the wing lift factor at ground contact is very nearly 1, the value in the steady-state airborne condition. The deviation of wing lift factor from the mean value is such that, in 95 percent of the landings for all airplanes considered, the lift factor does not differ from 1 by more than ±0.1. The probability of obtaining a value as low as 0.8 or as high as 1.2 is approximately 1 in 10,000.

The frequency of occurrence of large load applications in routine ground airplane operations has caused a growing concern about the roughness of landing and taxiing surfaces. As one of the initial steps in this study, measurements were made of two runways at Langley Field, Va. The two runways selected were known to be of very different degrees of roughness; one runway was considered relatively smooth, whereas the other was considered rather rough—possibly rough enough to preclude active use. Measurements of actual runway roughness obtained by a profile-survey method (engineer's level) and the calculated power spectra are presented in Technical Note 3305. The results presented in this report are reviewed and the application of the techniques of generalized harmonic analysis to the airplane taxiing problem, using results obtained from taxiing tests of a large airplane, are presented in Technical Note 3484. It is indicated that an extrapolation by elementary means of results from low taxiing velocities to higher taxiing velocities would lead to conservative results. Oleo-strut friction is shown to be a very important factor in the taxiing problem. With regard to the load-prediction phase of taxiing loads using spectral techniques, much additional work is required, especially with respect to the treatment of the transfer functions.

In Technical Note 3247 an accelerometer method for obtaining landing-gear drag loads was evaluated for a series of tests with a small landing gear. The drag loads were obtained from time histories of angular acceleration of the wheel, the moment of inertia, and the deflected tire radius. The method involved the use of an angular accelerometer, a torsional pendulum for determining moment of inertia, and linear accelerometers to measure the vertical forces (from which were obtained the force-deflection characteristics of the tire). The results obtained with this method were in good agreement with the results obtained simultaneously from specially constructed dynamometers. This agreement indicated that, under the conditions of this investigation, the applied drag loads can be obtained accurately by use of this accelerometer method and that the deflected tire radius can be obtained from the static-force-deflection curve of the tire up to and including the time of maximum drag.

VIBRATION AND FLUTTER

Flutter

The problem of flutter is assuming an increased importance with the use of thinner wings and stabilizers and the advent of higher airplane speeds. Because of the complexity of the problem and the numerous factors involved, both structural and aerodynamic, a heavy reliance must be placed upon experimental approaches. Thus, numbers of flutter models are being studied in various wind tunnels and in rocket-powered flight with the twofold objective of determining the fundamental effects of various parameters using models of simple construction and of verifying freedom from flutter of particular airplanes using complex dynamically scaled models.

A check of the accuracy of several methods of calculating wing flutter in supersonic flow is presented in Technical Note 3301. A general Rayleigh analysis is used as a basis for developing four methods of flutter analysis that are applied to 12 low-aspect-ratio wings. The four methods of flutter analysis used are: section coefficients for harmonically pitching and translating rectangular wings in a Rayleigh type of analysis, two-dimensional coefficients in a Rayleigh type of analysis, total coefficients for harmonically pitching and translating rectangular wings in a representative-section analysis, and two-dimensional coefficients in a representative-section analysis. Each of the four methods involves two degrees of freedom, namely, first bending and first torsion of a cantilever wing. The comparison of the analytical results with the experimental results indicates that the use of section aerodynamic coefficients derived on the basis of three-dimensional flow leads to a significant improvement in the correlation of theory and experiment.

A theoretical investigation of flutter of two-dimensional flat panels with one surface exposed to supersonic potential flow is described in Technical Note 3465. A Rayleigh type of analysis involving chosen modes of the panel as degrees of freedom is used to treat the flutter of a two-dimensional flat panel supported at its leading and trailing edges and subjected to a middle-plane tensile force. The panel has a supersonic air stream passing over its upper surface and still air below. The aerodynamic forces due to the supersonic air stream were obtained from the theory for linearized two-dimensional unsteady flow and the forces due to the still air were obtained from acoustical theory. Stability boundaries were obtained which can be used to determine the panel thickness required to prevent flutter for any panel material and air density. In contrast with some previous panel-flutter investigations, the results of the present analysis show that sufficiently thick panels are flutter free for the Mach numbers treated and suggest that this is true throughout the supersonic speed range.

Technical Note 3539 presents the results of a preliminary investigation of the effect of nonlinear structural terms on the flutter of a two-degree-of-freedom system. The three types of nonlinear stiffness studied on an analog computer were a flat spot, hysteresis, and a cubic spring. For one case, the flat spot, an experimental investigation of the effect of free play was also made and good correlation with theory was found. In general, it was found that the flutter speed was not changed for small disturbance angles; however, for larger disturbance or input angles, the flutter speed usually decreased. One exception was the cubic hard spring, for which a limited-amplitude flutter was found to exist at a much higher speed.

For airplanes in which the mass of fuel carried in either internal or external wing tanks is a large proportion of the total mass of the wing, the complicated motion of the fuel within the tanks may cause important dynamic effects that are of concern in flutter and in airplane stability. In a flutter analysis, for example, it is generally recognized that there may be a large error in the predicted flutter speed if a large quantity of fuel in the tank is assumed to behave as a solid mass. Fluid-dynamics studies were made (Technical Note 3353) of simplified model fuel tanks mounted on a mechanism that simulated a wing undergoing torsional oscillations of a few degrees. The effective moment of inertia of the fluid was determined experimentally for the various tank configurations over a tank-fullness range from empty to full and some comparisons with theoretical solutions are given.

Along with the studies of the moment of inertia of fluid in tanks, there have been investigations of the effects on wing flutter of fluid in pylon-mounted tanks. Fluid-dynamics studies were made of a tank of fineness ratio 7.0 which was pylon mounted on a simplified two-dimensional flutter model in order to determine the effects of the fluid on flutter. The results of two methods of fuel representation were compared with the actual-fluid case, and it was concluded that, in flutter analyses and tests, the fuel in wing tanks should be represented by a mass having an effective-moment-of-inertia value equivalent to that of the fuel. The damping action of the fluid was also studied, and it was found that sufficient damping was present to limit the amplitude of the flutter and that, at a frequency ratio near 1.0, the fluid damping may produce an increase in the flutter speed.

The aeroelastic instability of rigid open and closed bodies of revolution mounted on thin, flexible struts was investigated experimentally at low speeds. Three types of instability were observed—coupled flutter, divergence, and an uncoupled oscillatory instability which consisted in continuous or intermittent small-amplitude yawing oscillations. An attempt was made to calculate the airspeeds and, in the case of the oscillatory phenomena, the frequencies at which these types of instability occur by using slender-body theory for the aerodynamic forces on the bodies. This study was reported in Technical Note 3308.

One of the problems in experimental investigations of aeroelastic effects is the control of the bending and torsional stiffness distributions of model wings. The built-up-construction technique, wherein interior members are used to furnish most of the stiffness and an outer covering is used to furnish the exterior form, is difficult to apply in building small models. Another approach for small models is to use solid-construction wings, stiffer than required, and to alter the stiffness locally by perforating the plan form. The holes are then filled with a material that does not contribute appreciably to the stiffness. This technique has been investigated by experiments on perforated flat plates and reported in Technical Note 3423. In this report, the important parameters controlling the stiffness are discussed and data are given that may be used in designing a model wing.

Aerodynamics of Flutter

In conjunction with the studies of flutter itself, fundamental investigations are being carried out on the aerodynamic forces and moments which combined with the structural and inertial forces produce flutter.

In Technical Note 3433 expressions based on linearized supersonic potential theory are given for the total lift and moment coefficients of thin arrowhead wings oscillating in pitch and vertical translation. The arrowhead plan forms treated included all pointed-tip wings, the delta plan form with an unswept trailing edge being a special case. A restriction was that the components of flow normal to the trailing edge must be supersonic or sonic. The total coefficients have been obtained by integration of the section coefficients given in Report 1099 (reported in the Thirty-ninth Annual Report, 1953) for the subsonic-leading-edge wing and in Technical Note 2494 (reported in the Thirty-eighth Annual Report, 1952) for the supersonic-leading-edge wing. The accuracy of these expressions at high frequencies is sufficient to make them potentially useful in flutter applications. A correlation of coefficient notation is given for the present flutter coefficients, for dynamic stability coefficients, and for the exact flutter coefficients developed by Miles for the supersonic-leading-edge delta plan form. For the supersonic-leading-edge delta wing, curves are given to show the comparison of these three types of coefficients.

Technical Note 3438 treats the kernel function of the integral equation that relates a known or prescribed downwash distribution to an unknown lift distribution for harmonically oscillating wings in supersonic flow. The function is expected to be useful for development of lifting-surface methods for calculating flutter derivatives. The treatment is essentially an extension to supersonic flow of that given in Technical Note 3131 (reported in the Fortieth Annual Report, 1954) for subsonic flow. The kernel functions are reduced to forms that can be accurately evaluated by considering the functions in two parts, a part in which the singularities are isolated and analytically expressed and a nonsingular part which can be tabulated. It is shown that treatment of the kernel function for particular cases such as the two-dimensional case leads to known lift distributions for both steady and oscillating wings. The downwash functions associated with "horseshoe" vortices in supersonic flow are also discussed and expressions are derived.

In the evaluation of results obtained by measurement of the air forces on a wing in a wind tunnel, the question of the effect of the tunnel walls arises. In the case of steady flow the problem has been extensively investigated and, in general, relatively simple factors have been determined which can be used to modify measurements of the forces on a wing in a tunnel to correspond to free-air conditions. However, the corresponding problem of the effect of walls on an oscillating airfoil has received relatively little attention, particularly in the case of compressible flow. A theoretical and experimental investigation of the effect of wind-tunnel walls on the air forces on an oscillating wing in two-dimensional subsonic compressible flow is reported in Technical Note 3416. A resonance condition, which was predicted by theory in Report 1150 (reported in the Fortieth Annual Report, 1954), is shown experimentally to exist. In addition, application of the analysis is made to a number of examples in order to illustrate the influence of walls due to variations in frequency of oscillation, Mach number, and ratio of tunnel height to wing semichord.

Buffeting

The rocket-propelled-model technique has been applied to the investigation of low-lift buffeting. Results of preliminary tests show that severe buffeting, wing dropping, and normal-force changes occur almost simultaneously near zero lift in the transonic speed range on unswept wings 12 percent thick. On unswept wings 7 percent thick only mild wing dropping and normal-force changes were experienced and buffeting did not occur. Wind dropping and changes in trim normal force are two different effects of a change in lift on a wing panel and may be influenced by interference effects. Buffeting at near zero lift may be expected to accompany these changes on unswept wings over 7 percent thick.

AIRCRAFT STRUCTURAL MATERIALS

Structural Materials at Elevated Temperatures

Elevated-temperature problems associated with aerodynamic heating continue to be important and so in order to provide information which would be suitable as a basis for making structural efficiency comparisons with other materials, such as titanium and aluminum alloys, tensile and compressive stress-strain data were obtained at both normal and elevated temperatures on SAE 4340, Hy-Tuf, Stainless W, and Inconel X sheet materials which were heat treated to provide ultimate tensile strength in the vicinity of 200,000 p s i. The results of these tests are given in Technical Note 3315.

Because of aerodynamic heating, aircraft and missile structural materials may be subjected to simultaneous loading and rapid heating. Inasmuch as the rates at which the material is heated may vary widely, an evaluation of the properties of materials under such conditions is required. Data are presented in Technical Note 3462 on the tensile properties of 7075–T6 and 2024–T3 aluminum-alloy sheet heated at temperature rates from 0.2° F to 100° F per second under constant load conditions. Comparisons are made with the tensile stress-strain properties for one-half hour exposure to elevated temperature. Master yield and rupture curves, based upon the use of a temperature-rate parameter, are given with which yield and rupture stresses and temperatures may be predicted for these materials over the range of temperature rates employed.

Some preliminary data on the tensile properties of Inconel and RS–120 titanium alloy have also been obtained under rapid heating conditions. As in the case of the aluminum alloys, yield and rupture temperatures for these materials were found to increase approximately in proportion to the logarithm of the temperature rate except in certain limited regions.

In addition to the need for data of direct use to the designer, there exists a need for a better understanding of materials properties at elevated temperatures. An investigation conducted at the Battelle Memorial Institute and reported in Technical Note 3351 describes some research on the plastic deformation of aluminum single crystals at elevated temperatures. Single crystals of high-purity aluminum were studied under tension at temperatures from 82° to 1,100° F. Light microscopy, electron microscopy, and X-ray techniques were used to examine the deformation of the crystals under both constant-stress and constant-load creep conditions. From these observations it has been concluded that plastic deformation takes place predominantly by slip which is accompanied by the mechanisms of kinking and polygonization.

Fatigue

In addition to the research conducted on the fatigue of structures, problems relating to the fatigue of aircraft materials continue to be investigated. The effects of microstructure and anisotropy on the fatigue of 2014–T4 aluminum alloy were investigated at the Carnegie Institute of Technology. Previously developed statistical methods were used to study the effects of variation in microstructure on the fatigue properties of notched specimens of this aluminum alloy in both the longitudinal and transverse directions. The results show a definite anisotropy in the fatigue strength of this alloy for the material in an extruded condition. When the material was extruded and recrystallized, there was no significant anisotropy. Correlation tests with unnotched extruded longitudinal specimens showed that there is more scatter in unnotched than in notched specimens; within the range of stresses tested, the fatigue-strength reduction factor K_f increases with increasing stress. Observations of the microstructure of the fatigue fractures in this investigation were studied, but no significant conclusions were reached.

This investigation is reported in Technical Note 3380.

Despite some concern as to proper allowance for the effect of size on the fatigue behavior of materials, little definite information along this line is available for the aluminum alloys of major interest in aircraft design. Therefore, an investigation was conducted at Battelle Memorial Institute and reported in Technical Note 3291 on the effects of notch size on rotating-beam fatigue behavior of 7075–T6 aluminum alloy. Unnotched and notched specimens with minimum section diameters of ⅛ inch, ¼ inch, ½ inch, 1 inch, and 1¾ inches were tested and a notch consisting of a semicircular groove with a theoretical stress-concentration factor of 2 was used for each size specimen. In the largest diameter specimen, a 60° V-notch with a theoretical stress-concentration factor of 19 was also tested. Within the large (but not exceptional) scatter of fatigue strengths observed, no general size effect could be found for either unnotched or notched specimens. One exception was the fact that the 60° V-notch in the large-diameter specimen did not reduce fatigue strength so much as might have been predicted in view of its high theoretical stress-concentration factor.

Stress Corrosion

The susceptibility of high-strength aluminum alloys to stress corrosion has been a constant problem and the need for a better fundamental understanding of the stress-corrosion process is apparent. A study aimed at improving this understanding was conducted at Columbia University where the intergranular corrosion of high-purity aluminum in hydrochloric acid was studied as a function of iron content, heat treatment, and acid composition. The behavior of specimens quenched to retain a single-phase structure indicated that the rate of attack on the high-angle grain boundaries was influenced by the segregation in these boundaries of iron and possibly other impurity atoms. Segregation of iron alone cannot account for the results and it is expected that copper is also involved. It is believed that metals and alloys generally contain an alloying element or impurity the atoms of which have a considerable tendency to concentrate in the boundaries but that the effect on the properties of the boundaries will be apparent only under special conditions. Under the conditions studied, this segregation reduced the rate of attack and led to the conclusion that the boundaries were inherently anodic. When the heat treatment was such that precipitation of a second phase could have occurred, the corrosion behavior could not be correlated with the small amount of second phase actually observed upon microscopic examination. Intergranular attack is rapid when there is a continual evolution of hydrogen gas from the intergranular crevice. Rapid attack can be obtained at low acid strengths by increasing the copper or iron content of the acid. This favors the strong attack on the low-angle grain and subgrain boundaries observed after certain heat treatments. Metallic impurities in the acid can also be responsible for preferential corrosion of the grain bodies observed in portions of some specimens with relatively inactive boundaries. When both the strength and the metallic-impurity content of the acid are low, a protective film forms over the surface and intergranular attack is very slow. The results of this investigation are reported in Technical Notes 3281 and 3282.

As a part of a broad study of the stress-corrosion cracking of aircraft alloys at Armour Research Foundation, attention has been given to the mechanism involved in the failure of 2024 aluminum alloy. Technical Note 3292 presents the results of a study of the area effect which is of considerable importance in arriving at a satisfactory general explanation for the stress-corrosion phenomena. The area effect is a phenomenon whereby small exposed areas do not suffer stress-corrosion failure in nearly so short a time as do large areas. The effects of stress level, degree of sensitivity of the alloy, and hydrogen peroxide concentration in the corrosion medium were all studied. The results show that stress levels above 60 percent of the yield strength of the alloy are uniformally effective in producing stress-corrosion failure. The area effect seemed most pronounced with specimens having maximum sensitivity to stress corrosion. The stress corrosion of 2024 was found to be very sensitive to hydrogen peroxide concentration in the range 1.5 to 3.5 grams per liter. Oxygen was ineffective in promoting stress-corrosion cracking when substituted for peroxide.

Anisotropy of Materials in the Plastic Range

Although metals and alloys are usually fairly isotropic in the elastic range, considerable anisotropy may be present when the material becomes plastic. In order to study the nature of the anisotropy found in sheet materials, an experimental and theoretical investigation was made of the anisotropy of 3003 aluminum alloy in the plastic range and is reported in Technical Note 3248. Data were obtained in tension and compression and included Poisson's ratio measurements in the plane of the sheet and in the thickness direction. Crystallographic anisotropy was found to be responsible for the variation in Poisson's ratio for the various angles with respect to the rolling direction. A theoretical analysis was made to account for the observed anisotropy based on the behavior of single crystals and on the texture of the sheet.

An investigation was made of the behavior of metals which results in the formation of ears in deep drawing operations. A method for predicting earing behavior, based upon the plastic properties of single crystals, is presented in Technical Note 3439. The results obtained by this method are in satisfactory agreement with reported experimental results.

Mechanical Properties of Cermets

Some of the carbide materials have unusual mechanical properties. Although the carbides are inherently more suitable for elevated-temperature applications, their unusual properties suggest their use at normal temperatures also. One of these, a tungsten carbide cermet with cobalt binder, has a Young's modulus of the order of 95×10^6 p s i and a compressive strength of about 550,000 p. s. i. The results of an investigation of the mechanical properties of four cermets of this material are given in Technical Note 3309 which includes stress-strain data for compression, tension, and torsion; values of the moduli of elasticity and rigidity; Poisson's ratio; ultimate strength; density; and hardness.

OPERATING PROBLEMS

Today modern aircraft fly at higher speeds and higher altitudes than ever before. This increase in performance is due to significant accomplishments achieved through research in the fields of aerodynamics, power plants, and structures. However, these research advances, when applied and developed into the newer aircraft, do not necessarily eliminate the problems associated with the operation of these aircraft under all-weather conditions throughout the world. In fact, many of these problems become more important than ever before; some few become less important. Most of these operating problems fall into several categories: Flight Safety, which includes flight instrumentation, aircraft fires, ditching, and aircraft crash research; Aeronautical Meteorology, which pertains to atmospheric turbulence and icing meteorology; Aircraft Icing, which includes supercooled droplet impingement, ice formation, and ice prevention and removal; and Aircraft Noise, which includes noise-level measurements, noise generation, and noise reduction and attenuation. This section of the report will discuss the unclassified results of NACA research which has been conducted during the past year to provide advance information about those problems for use on the Nation's military and civil aircraft.

As part of the policy to summarize, present, and discuss recent NACA research results with representatives of the aircraft industry and military services, a technical conference on Some Problems of Aircraft Operation was held at the Lewis Flight Propulsion Laboratory. Technical representatives participating in this conference were given a series of technical papers which outlined and defined some of the operating problems being studied. Results of these studies with a view toward practical solutions were presented. Industry comments on this conference were gratifying and the discussions following each paper indicated that the data presented were timely, useful, and well received.

Most of the research conducted by the NACA is indirectly related to aircraft safety. However, many of the specific problems associated with aircraft operations are directly related to the safety of flight. The Executive Committee of the NACA therefore established the Subcommittee on Aircraft Safety to supervise the study of those problems directly related to safety which are encountered or may be envisioned. This subcommittee operates under the parent Committee on Operating Problems and recommends research investigations on safety problems. In conjunction with the establishment of this new subcommittee, the Subcommittee on Aircraft Fire Prevention was dissolved with high commendation and praise for its excellent work in guiding to a successful conclusion the NACA studies of means of eliminating aircraft fires resulting from crashes for both reciprocating- and turbojet-type aircraft. Remaining problems associated with aircraft fire prevention will come under the cognizance of the Subcommittee on Aircraft Safety. In another action, because of the seriousness and complexity of the problem of aircraft noise, the special Subcommittee on Aircraft Noise has been given the status of a permanent subcommittee. In addition to these subcommittees, the Subcommittee on Icing Problems and the Subcommittee on Meteorological Problems also continue to advise the NACA on research in the field of operating problems to be conducted in its laboratories or under contract with nonprofit research organizations.

A summary of results of most of the unclassified investigations on operating problems not previously reported is presented in the following paragraphs.

FLIGHT SAFETY

Aircraft Propeller Thrust Indicator

Inadvertent thrust reversal of an aircraft propeller in flight can result in immediate deterioration of aircraft performance. It is important, therefore, to provide the pilot with means of detecting this reversal or loss in power as soon as it occurs. A simple thrust indicator has been proposed and flight research conducted to fulfill this obective (Technical Note 2979).

Flight tests on a twin-engine transport airplane have been made to determine the effects of fuselage-nacelle interference on the circumferential distribution of the rise in total pressure at one radial station behind the propellers. The effects of this flow interference on the operation of a propeller thrust indicator, which samples the total-pressure rise at two diametrically opposed points in the slipstream (to counteract the effects of variations in angle of pitch and yaw), have been investigated and reported in Technical Note 3432. Fuselage-nacelle interference is shown to be the cause of apparent differences in indicated thrust between power plants operating under presumably similar conditions. Proper placement of the thrust-indicator total-pressure sensing elements eliminates the discrepancies for any preferred flight condition, with only small residual effects remaining at other flight conditions. Thrust indicators installed for comparison purposes in the cruise condition may, for example, be useful as a sensitive means of controlling engine output and airplane trim while still serving as a reliable safety device in all other flight conditions.

Trailing Vortices

The disturbance created by the trailing vortices of an airplane can have a detrimental effect on the flight of another airplane passing through the wake. An attempt has been made, therefore, to measure the velocity distribution and persistence of the trailing vortices of a propeller-driven fighter-type airplane. This airplane was equipped with a smoke-generating device to mark the vortices in the atmosphere. A jet airplane having a high-frequency angle-of-attack vane and a sensitive total-pressure instrument was used to fly through the vortices. The results reported in Technical Note 3377 showed that, in general, the vortex strength did not decrease appreciably up to 35 seconds after the vortices had been shed. After 35 seconds and up to 60 seconds (the largest time interval measured), the vortices gradually deteriorated, but the velocity distribution indicated that a large amount of circulation still remained in the vortex pair. The velocity distributions showed no indications of a disturbance other than that produced by the trailing vortices. Photographs of the trailing-vortex filaments indicated that they did not remain straight but became irregular as a result of atmospheric turbulence. In an attempt to fly in the trailing wake of another airplane, the pilot found that it was very difficult to maintain a precise course and that the disturbance was similar to severe turbulence.

Takeoff Indicator

The operating principles of an instrument, actuated by longitudinal acceleration and impact pressure, for giving an immediate indication of loss in airplane acceleration during takeoff are presented in Technical Note 3252. The results and evaluation of tests of a simple prototype instrument mounted in a tricycle-geared jet trainer are included. The results showed that the instrument performed satisfactorily for the airplane in which it was tested. Response of the instrument to simulated partial power loss was immediate and the indication was consistent up to nose-wheel lift-off for given power settings in different takeoffs. This instrument will be useful to the pilot in indicating whether or not he is developing satisfactory acceleration for takeoff prior to reaching the speed beyond which he can no longer safely stop the takeoff.

Airplane Control in Rough Air

A statistical description of the dynamics of atmospheric turbulence has become important in design considerations of many airplane control problems having a direct bearing on safety of flight in rough air. Some measurements of atmospheric turbulence which were obtained in flight from an airplane equipped with flow-direction vanes mounted on a nose boom are reported in Technical Note 3313. The vanes were used to measure the vertical and horizontal components of gust velocity normal to the flight direction in the relatively high frequency range for which the response of the airplane in this case was negligible. Power spectral densities of the two components of gust velocity were calculated for the range of wavelengths from 200 feet to 10 feet. The power densities of the two components varied directly with the square of the gust wave length and the spectra of the two components were of equal intensity.

Crash-Fire Prevention

As a result of NACA research in eliminating crash fires utilizing the principles of successful inerting with water, a fire-suppression system was designed for a reciprocating-engine aircraft for operational tests. Prior to installation of the system on an operational aircraft, a full-scale crash test was conducted. The system, whose inerting and deenergizing components have been described in published reports, functioned satisfactorily as a complete unit.

The crash-fire work has been extended to the turbine-engine-type aircraft. The results, which have not yet been published, indicate that the NACA crash-fire inerting principles can be successfully applied to this type of aircraft for the different types of engine installations studied.

The fire hazard that arises from the use of inflammable hydraulic fluids is a matter of serious concern to commercial and military airplane operators because of the wide distribution within the airplane of lines carrying the fluid under pressure. In some aircraft, these pressures are as high as 3,000 pounds per square inch. Leakage of the fluid is not uncommon; in addition, a break in the line will permit a stream of fluid or a very inflammable mist to be exposed to a possible ignition source. Attempts have been made by government and private research organizations to produce hydraulic fluids with increased resistance to fire. A survey of the developments in this field has recently been made available in an unclassified report.

Crash Loads and Survival

During the conduct of the full-scale aircraft crash-fire studies, deceleration instrumentation was used to determine the magnitudes of the loads experienced in a crash. Some insight into the problem of survivability was gained and techniques were developed for determining these loads accurately. This preliminary work, previously reported in Technical Note 2996, has been extended to additional crashes of fighter-type and transport-type aircraft. The insight gained in the preliminary studies pointed to methods of improving human survival in crashes by utilizing improved seat design to attenuate the load characteristics found to be present in potentially survivable crashes.

Foreign-Object Damage

Foreign objects thrown from the runway into a jet-engine inlet by the jet discharge or wheels of other aircraft may cause either partial or complete destruction of the engine. Sucking of pebbles from the runway directly into the inlet was also considered a possible source of damage. An investigation of the role that vortices play in the ingestion of foreign objects into jet engines determined that pebbles, typical of objects that damage jet engines, were projected into the air by the vortices and were drawn into the engine by the high-velocity inlet air stream. It was also found that pebbles lodged in surface cracks were more readily picked up than those exposed on a smooth surface. The results of this work have been published in Technical Note 3330.

AIRCRAFT NOISE

The intense noise produced by aircraft engines is one of the serious problems confronting the operators of modern aircraft. Not only is this noise so intense that it disturbs people within a wide radius of an operating engine, but it can be physically damaging to those near the engine and to the associated structure and instruments of an aircraft. Tests made to date indicate that jet noise as produced by turbojet engines and rocket motors can be related to the velocity of the jet stream and the size of the jet; and, as these factors are being increased to provide still more propulsive power, even greater noise levels can be expected. A large part of the NACA's noise research program is aimed at determining just how jet engine noise is produced and at devising methods to reduce the noise output without reducing overall power. High-speed propellers are also still important and produce considerable noise; therefore, research is being continued on the complex noises produced by propellers.

Propeller Noise

Overall sound-level measurements and frequency analysis of tape recordings of the noise emitted from a 10-foot-diameter four-bladed propeller mounted on a turbine-powered vehicle have been made under static conditions. Results of this investigation along with theoretical calculation of the sound-pressure levels by the method of Technical Note 2968 (previously reported) are reported in Technical Note 3422. The overall propeller-noise pattern was unsymmetrical about the fuselage center line, the maximum sound-pressure level being located in the right-rear quadrant. The frequency analysis shows that this unsymmetrical distribution consists primarily of the two lowest propeller harmonics. In the plane of and ahead of the propeller, harmonics as high as the eleventh are important. Theoretical calculations predict accurately the location of and the maximum sound-pressure levels to be expected for the overall noise and the first two propeller harmonics. For higher harmonics this agreement is not evident.

A short series of measurements was made of the oscillating pressures in the vicinity of a propeller at flight Mach numbers up to 0.72. These measurements, reported in Technical Note 3417, were made as part of a brief flight program initiated to check the Garrick-Watkins theory presented in Technical Note 3018 (reported in the Fortieth Annual Report, 1954). The scope of the tests was found to be insufficient to obtain complete verification of the Garrick-Watkins theory for the effect of forward speed on the sound-pressure field around propellers. However, it was possible to substantiate that (1) the oscillating pressures near the tips of a propeller tend to decrease slowly with increase in flight Mach number up to a Mach number of approximately 0.5 and then to increase rather rapidly at higher Mach numbers and (2) the sound-pressure levels of the higher harmonics of the propeller noise increase at a higher rate with increase in flight Mach number than do the lower propeller harmonics.

Jet Noise

As part of the continuing study of jet noise and means for its suppression, an investigation was conducted of the sound-pressure levels, frequency spectrum, and jet velocity profiles of an engine-afterburner combination at various values of afterburner fuel-air ratio. At the high fuel-air ratios, severe low-frequency resonance was encountered, which represented more than half the total energy in the sound spectrum.

Screens placed transversely across the jet as a noise-reduction device were investigated on a full-scale turbojet engine to determine the effect on the sound field of screen mesh, wire diameter, and screen location. The results are reported in Technical Note 3452. The total power level radiated by the engine can be lowered more than 7.5 decibels and is essentially nondirectional. The maximum sound-pressure level for an engine-screen combination can be made about 12 decibels less than that of the engine alone. The screens act to alter the turbulent flow in the jet stream and reduce the jet velocity. While this method is not suitable for use in flight, the screens do offer a practical method of reducing jet noise during ground operation.

As long as the jet flow is entirely subsonic, the noise is a function of the turbulence produced by mixing of the fast-moving jet and the surrounding air. If the velocity of the jet is increased to supersonic conditions, then shock waves are formed and also contribute to the noise. It appears that the interaction of turbulence with shock waves plays a part in generating that noise. An analysis of shock-turbulence interaction as related to noise generation is presented in Technical Note 3255.

At present, rocket noise as related to people is particularly a problem in assisted-takeoff operations of airplanes and in missile-launching operations. There are also problems of structural buffeting and malfunctioning of avionic equipment in proximity to the rocket exhaust. It is desirable, therefore, to provide some information as to the intensity, spectrum, and directivity characteristics of rocket noise. Technical Note 3316 reports results of a systematic investigation of the sound field of a 1,000-pound-thrust solid-fuel rocket and also data on two other rockets, of 900 and 5,500 pounds of thrust, obtained at a few isolated field points. Frequency spectra for the range from 20 c p s to 15,000 c p s indicate that the noise of each rocket is random, with a spectrum envelope which peaks in the lower part of the audible range. Angular distributions of overall sound pressure in the frequency ranges from 0 c p s to 40 c p s and from 20 c p s to 20,000 c p s indicate a similarity to subsonic jet-noise distribution, with the maximum pressures occurring at angles of 30° to 45° off the jet axis downstream of the nozzle.

Besides being a source of annoyance and discomfort, intense noise can cause aircraft structural damage under certain conditions. It is known that jet noise has in many instances caused fatigue failures of airplane-skin panels in proximity to the jet-engine exhaust stream. These failures have been mainly on the fuselage or the wings, depending on the type of engine installation. Some configurations having the engine exits relatively far aft have also experienced damage to panels in the tail assembly. A study of the response of aircraft panels to random acoustic excitation has been made. An application is made of the method of generalized harmonic analysis to the problem of prediction of stresses in airplane-skin panels due to excitation by jet noise. The concepts of the theory are reviewed briefly and some of the significant parameters are evaluated in the tests. Measurements of stresses in some panels due to random acoustic excitation are presented and are found to be in general agreement with calculated results.

Attenuation of Noise

In order to establish a baseline as to the actual noise levels around commercial airports, the firm of Bolt Beranek and Newman, Inc., in cooperation with the University of Chicago and the NACA made surveys of the noise at distances up to 12 miles from the airports in 8 cities in this country. The results have been analyzed to yield a statistical description of the background noise in many different communities and of aircraft noise spectra at various locations with respect to airports and flight paths. This project was reported in Technical Note 3379.

The NACA 8- by 6-foot supersonic wind tunnel at the Lewis Laboratory was constructed as an open-return tunnel for testing various types of jet engines. When the tunnel was operated with an engine operating in the test section, the noise radiated to the surrounding neighborhood was so great that the NACA immediately undertook action to silence the tunnel more effectively. The acoustical firm of Bolt Beranek and Newman, Inc., in conjunction with the NACA staff designed successful mufflers for this tunnel. The research leading to the muffler design as well as details of the design are described in Technical Note 3378.

AERONAUTICAL METEOROLOGY

In anticipation of operating problems associated with the introduction of commercial turbojet aircraft, the meteorological problems and requirements involved in safe, efficient, and economical flight have been analyzed and evaluated. Consideration was given to the principal characteristics of the turbojet transport which are high cruising speed, high cruise level, relatively high fuel consumption, and engine performance sensitive to temperature and air density. The particular problems included in the study concerned temperature, wind, pressure, ceiling, visibility, cloud and clear-air turbulence, icing, and communication of weather information.

The conclusions indicated that no new requirements or problems over and above the present shortcomings are expected even though operating altitudes and speeds are increased and forecast error limitations are more critical, especially in the airport terminal area, for the turbojet as compared with piston-engine aircraft. As at present, the most important meteorological problem is the accurate determination and forecast of airport approach ceiling and visibility. At the higher levels, the measurement and forecast of wind velocity and direction presents a major problem.

ICING PROBLEMS

Measurement of Icing Severity

A flight instrument capable of reliable measurements of icing severity is valuable to pilots, weather forecasters, research meteorologists, and designers of ice-protection equipment. The NACA heated-wire liquid-water-content instrument in modified form has been flight tested in natural icing conditions. Favorable results have been obtained which indicate its suitability for the measurement of liquid-water content (icing severity). Tests substantiated the high values of liquid-water content predicted in a previous statistical analysis, the highest value measured in flight being 3.7 grams per cubic meter.

Trajectory and Impingement Studies

The evaluation of the variation of local liquid-water concentration surrounding an aircraft moving through a cloud has been continued to include an ellipsoid shape of fineness ratio 10. Analysis of the trajectories (Technical Note 3410) utilizing the differential analyzer indicates that local concentrations may be several times the free-stream concentration. The data also indicate that the expected local concentration factors should be considered when choosing the location of devices that protrude into the air stream from aircraft fuselages or missiles or when determining anti-icing heat requirements for the protection of these devices.

The trajectories of droplets in the air flowing past an NACA 65A004 airfoil at an angle of attack of 8° have been determined and reported in Technical Note 3155. The data apply directly to flights in clouds composed of uniform droplets and to nonswept wings of high aspect ratio; the impingement results are considered applicable throughout the subsonic region, because the subsonic compressibility of air does not affect the droplet trajectories appreciably.

In previous determinations of cloud-droplet impingement characteristics of various aircraft components requiring protection, the investigations have been confined generally to analytical solutions. In Technical Note 3338, an experimental method has been developed using a dye-tracer technique whereby the quantity of dye collected on a blotter-wrapped body exposed to an air stream containing a dyed-water spray cloud can be colorimetrically analyzed. The analysis yields the local and total droplet collection efficiencies for the body and the rearward extent of impingement on the body. In addition, the dye-tracer technique can be used to determine the droplet-size distribution and water content of the spray cloud.

Icing Protection

Frictional heating during high-speed flight effectively reduces the susceptibility of aircraft surfaces to icing. An experimental study (Technical Note 3396) of the wet-surface temperature and the air-stream conditions that result in ice-free surfaces for bodies in flight through icing clouds has been made and the results were compared with calculated values for two symmetrical airfoil models. The results for Mach numbers from 0.6 to 1.35 and for altitudes from 25,000 to 40,000 feet showed that experimental values of the wet-surface temperature were consistently 2° to 4° F higher than the calculated values for all but the foremost part of the airfoils. The experiments generally substantiated the analytically determined location of critical regions on the bodies for the initial formation of ice.

Icing Techniques and Research

The status of NACA icing research and techniques was summarized and presented at the AGARD Conference in Ottawa, Canada, June 10–17, 1955. General and specific icing problems were noted along with an indication of the scope of the data available for the design of aircraft icing protection systems. In addition, details were given on NACA icing facilities, specific test equipment, instruments, and techniques used in conducting tests in icing wind tunnels.

RESEARCH PUBLICATIONS

REPORTS

1158. Prediction of Flame Velocities of Hydrocarbon Flames. By Gordon L. Dugger and Dorothy M. Simon.
1159. Impingement of Water Droplets on Wedges and Double Wedge Airfoils at Supersonic Speeds. By John S. Serafini.
1160. The Zero-Lift Drag of a Slender Body of Revolution (NACA RM-10 Research Model) as Determined From Tests in Several Wind Tunnels and in Flight at Supersonic Speeds. By Albert J. Evans.
1161. Average Skin-Friction Drag Coefficients From Tank Tests of a Parabolic Body of Revolution (NACA RM-10). By Elmo J. Mottard and J. Dan Loposer.
1162. Lift Developed on Unrestrained Rectangular Wings Entering Gusts at Subsonic and Supersonic Speeds. By Harvard Lomax.
1163. A Visualization Study of Secondary Flows in Cascades. By Howard Z. Herzig, Arthur G. Hansen, and George R. Costello.
1164. Convection of a Pattern of Vorticity Through a Shock Wave. By H. S. Ribner.
1165. Unsteady Oblique Interaction of a Shock Wave With a Plane Disturbance. By Franklin K. Moore.
1166. Relation Between Roughness of Interface and Adherence of Porcelain Enamel to Steel. By J. C. Richmond, D. G. Moore, H. B. Kirkpatrick, and W. N. Harrison.
1167. Method for Calculating the Rolling and Yawing Moments Due to Rolling for Unswept Wings With or Without Flaps or Ailerons by Use of Nonlinear Section Lift Data. By Albert P. Martina.
1168. Secondary Flows and Boundary-Layer Accumulations in Turbine Nozzles. By Harold E. Rohlik, Milton G. Kofskey, Hubert W. Allen, and Howard Z. Herzig.
1169. Matrix Methods for Determining the Longitudinal-Stability Derivatives of an Airplane From Transient Flight Data. By James J. Donegan.
1170. Behavior of Materials Under Conditions of Thermal Stress. By S. S. Manson.
1171. Effect of Horizontal-Tail Span and Vertical Location on the Aerodynamic Characteristics of an Unswept Tail Assembly in Sideslip. By Donald R. Riley.
1172. A Study of the Application of Power-Spectral Methods of Generalized Harmonic Analysis to Gust Loads on Airplanes. By Harry Press and Bernard Mazelsky.
1173. On Traveling Waves in Beams. By Robert W. Leonard and Bernard Budiansky.
1174. The Structure of Turbulence in Fully Developed Pipe Flow. By John Laufer.
1175. Effect of Variable Viscosity and Thermal Conductivity on High-Speed Slip Flow Between Concentric Cylinders. By T. C. Lin and R. E. Street.
1176. Determination of Mean Camber Surfaces for Wings Having Uniform Chordwise Loading and Arbitrary Spanwise Loading in Subsonic Flow. By S. Katzoff, M. Frances Faison, and Hugh C. DuBose.
1177. Comparison of Performance of Experimental and Conventional Cage Designs and Materials for 75-Millimeter-Bore Cylindrical Roller Bearings at High Speeds. By William J. Anderson, E. Fred Macks, and Zolton N. Nemeth.
1178. Calibration of Strain-Gage Installations in Aircraft Structures for the Measurement of Flight Loads. By T. H. Skopinski, William S. Aiken, Jr., and Wilber B. Huston.
1179. A Note on Secondary Flow in Rotating Radial Channels. By James J. Kramer and John D. Stanitz.
1180. Theoretical Study of the Transonic Lift of a Double-Wedge Profile With Detached Bow Wave. By Walter G. Vincenti and Cleo B. Wagoner.
1181. Structural Response to Discrete and Continuous Gusts of an Airplane Having Wing-Bending Flexibility and a Correlation of Calculated and Flight Results. By John C. Houbolt and Eldon E. Kordes.
1182. Comparison of Effectiveness of Convection-, Transpiration-, and Film-Cooling Methods With Air as Coolant. By E. R. G. Eckert and John N. B. Livingood.
1183. Supersonic Flow Past Oscillating Airfoils Including Nonlinear Thickness Effects. By Milton D. Van Dyke.
1184. The Normal Component of the Induced Velocity in the Vicinity of a Lifting Rotor and Some Examples of Its Application. By Walter Castles, Jr., and Jacob Henri De Leeuw.
1185. The Calculation of Pressure on Slender Airplanes in Subsonic and Supersonic Flow. By Max A. Heaslet and Harvard Lomax.
1186. Formation and Combustion of Smoke in Laminar Flames. By Rose L. Schalla, Thomas P. Clark, and Glen E. McDonald.
1187. Theoretical and Experimental Investigation of Additive Drag. By Merwin Sibulkin.
1188. On the Use of the Indicial Function Concept in the Analysis of Unsteady Motions of Wings and Wing-Tail Combinations. By Murray Tobak.
1189. Theoretical and Experimental Analysis of Low-Drag Supersonic Inlets Having a Circular Cross Section and a Central Body at Mach Numbers of 3.30, 2.75, and 2.45. By Antonio Ferri and Louis M. Nucci.
1190. Axial-Load Fatigue Properties of 24S-T and 75S-T Aluminum Alloy as Determined in Several Laboratories. By H. J. Grover, W. S. Hyler, Paul Kuhn, Charles B. Landers, and F. M. Howell.
1191. On the Development of Turbulent Wakes From Vortex Streets. By Anatol Roshko.
1192. Theoretical and Experimental Investigation of Mufflers With Comments on Engine-Exhaust Muffler Design. By Don D. Davis, Jr., George M. Stokes, Dewey Moore, and George L. Stevens, Jr.
1193. Theoretical Performance Characteristics of Sharp-Lip Inlets at Subsonic Speeds. By Evan A. Fradenburgh and DeMarquis D. Wyatt.
1194. A Study of Hypersonic Small-Disturbance Theory. By Milton D. Van Dyke.
1195. Formulas for the Elastic Constants of Plates With Integral Waffle-Like Stiffening. By Norris F. Dow, Charles Libove, and Ralph E. Hubka.
1196. An Analytical Study of the Effects of Airplane Wake on the Lateral Dispersion of Aerial Sprays. By Wilmer H. Reed III.

1197. A Study of the Characteristics of Human-Pilot Control Response to Simulated Aircraft Lateral Motions. By Donald C. Cheatham.
1198. A Theoretical Study of the Effect of Forward Speed on the Free-Space Sound-Pressure Field Around Propellers. By I. E. Garrick and Charles E. Watkins.
1199. A Study of the Problem of Designing Airplanes With Satisfactory Inherent Damping of the Dutch Roll Oscillation. By John P. Campbell and Marion O. McKinney, Jr.
1200. Method for Studying Helicopter Longitudinal Maneuver Stability. By Kenneth B. Amer.
1201. Performance and Boundary-Layer Data from 12° and 23° Conical Diffusers of Area Ratio 2.0 at Mach Numbers up to Choking and Reynolds Numbers up to 7.5×10^6. By B. H. Little, Jr., and Stafford W. Wilbur.
1202. Charts Relating the Compressive Buckling Stress of Longitudinally Supported Plates to the Effective Deflectional and Rotational Stiffness of the Supports. By Roger A. Anderson and Joseph W. Semonian.
1203. Wind-Tunnel Investigation at Low Speed of the Effects of Chordwise Wing Fences and Horizontal-Tail Position on the Static Longitudinal Stability Characteristics of an Airplane Model With a 35° Sweptback Wing. By M. J. Queijo, Byron M. Jaquet, and Walter D. Wolhart.
1204. Application of Several Methods for Determining Transfer Functions and Frequency Response of Aircraft From Flight Data. By John M. Eggleston and Charles W. Mathews.
1205. A Wind-Tunnel Investigation of the Effects of Thrust-Axis Inclination on Propeller First-Order Vibration. By W. H. Gray, J. M. Hallissy, Jr., and A. R. Heath, Jr.
1206. A Revised Gust-Load Formula and a Re-Evaluation of V-G Data Taken on Civil Transport Airplanes From 1933 to 1950. By Kermit G. Pratt and Walter G. Walker.
1207. Studies of the Lateral-Directional Flying Qualities of a Tandem Helicopter in Forward Flight. By Kenneth B. Amer and Robert J. Tapscott.
1208. A Comparison of the Spanwise Loading Calculated by Various Methods With Experimental Loadings Obtained on a 45° Sweptback Wing of Aspect Ratio 8.02 at a Reynolds Number of 4.0×10^6. By William C. Schneider.
1209. Development of Turbulence-Measuring Equipment. By Leslie S. G. Kovásznay.

TECHNICAL NOTES [1]

3149. Prediction of Losses Induced by Angles of Attack in Cascades of Sharp-Nosed Blades for Incompressible and Subsonic Compressible Flow. By James J. Kramer and John D. Stanitz.
3151. Exact Solutions of Laminar-Boundary-Layer Equations With Constant Property Values for Porous Wall With Variable Temperature. By Patrick L. Donoughe and John N. B. Livingood.
3152. Transverse Oscillations in a Cylindrical Combustion Chamber. By Franklin K. Moore and Stephen H. Maslen.
3155. Impingement of Water Droplets on NACA 65A004 Airfoil at 8° Angle of Attack. By Rinaldo J. Brun, Helen M. Gallagher, and Dorothea E. Vogt.
3163. Use of a Hot-Wire Anemometer in Shock-Tube Investigations. By Darshan Singh Dosanjh.
3168. A New Hodograph for Free-Streamline Theory. By Anatol Roshko.

[1] The missing numbers in the series of Technical Notes were released before or after the period covered by this report.

3169. On the Drag and Shedding Frequency of Two-Dimensional Bluff Bodies. By Anatol Roshko.
3178. Characteristics of Turbulence in a Boundary Layer With Zero Pressure Gradient. By P. S. Klebanoff.
3199. Stress Distributions Caused by Three Types of Loading on a Circular Semimonocoque Cylinder With Flexible Rings. By Harvey G. McComb, Jr.
3200. Stress Analysis of Circular Semimonocoque Cylinders With Cutouts by a Perturbation Load Technique. By Harvey G. McComb, Jr.
3203. Considerations on a Large Hydraulic Jet Catapult. By Upshur T. Joyner and Walter B. Horne.
3204. An Investigation of the Creep Lifetime of 75S–T6 Aluminum-Alloy Columns. By Eldon E. Mathauser and William A. Brooks, Jr.
3205. Theoretical Investigation at Subsonic Speeds of the Flow Ahead of a Slender Inclined Parabolic-Arc Body of Revolution and Correlation With Experimental Data Obtained at Low Speeds. By William Letko and Edward C. B. Danforth, III.
3206. Torsional Vibrations of Hollow Thin-Walled Cylindrical Beams. By Edwin T. Kruszewski and Eldon E. Kordes.
3208. Heat, Mass, and Momentum Transfer for Flow Over a Flat Plate With Blowing or Suction. By H. S. Mickley, R. C. Ross, A. L. Squyers, and W. E. Stewart.
3209. High-Resolution Autoradiography. By George C. Towe, Henry J. Gomberg, and J. W. Freeman.
3212. Nonlinear Theory of Bending and Buckling of Thin Elastic Shallow Spherical Shells. By A. Kaplan and Y. C. Fung.
3213. Transonic Flow Past Cone Cylinders. By George E. Solomon.
3216. Cooperative Investigation of Relationship Between Static and Fatigue Properties of Wrought N–155 Alloy at Elevated Temperatures. By NACA Subcommittee on Heat-Resisting Materials.
3217. The Influence of Wheel Spin-Up on Landing-Gear Impact. By W. Flügge and C. W. Coale.
3219. Viscosity Corrections to Cone Probes in Rarefied Supersonic Flow at a Nominal Mach Number of 4. By L. Talbot.
3223. An Analysis of Shock-Wave Cancellation and Reflection for Porous Walls Which Obey an Exponential Mass-Flow Pressure-Difference Relation. By Joseph M. Spiegel and Phillips J. Tunnell.
3225. An Experimental Study of the Lift and Pressure Distribution on a Double-Wedge Profile at Mach Numbers Near Shock Attachment. By Walter G. Vincenti, Duane W. Dugan, and E. Ray Phelps.
3231. Bending Tests on Box Beams Having Solid- and Open-Construction Webs. By Aldie E. Johnson, Jr.
3232. An Analysis of the Stability and Ultimate Bending Strength of Multiweb Beams With Formed-Channel Webs. By Joseph W. Semonian and Roger A. Anderson.
3235. Low-Speed Yawed-Rolling and Some Other Elastic Characteristics of Two 56-Inch-Diameter, 24-Ply-Rating Aircraft Tires. By Walter B. Horne, Bertrand H. Stephenson and Robert F. Smiley.
3240. Theoretical Calculations of the Lateral Stability Derivatives for Triangular Vertical Tails With Subsonic Leading Edges Traveling at Supersonic Speeds. By Percy J. Bobbitt.
3242. Preliminary Results From Flow-Field Measurements Around Single and Tandem Rotors in the Langley Full-Scale Tunnel. By Harry H. Heyson.

3243. Theoretical Analysis of an Airplane Acceleration Restrictor Controlled by Normal Acceleration, Pitching Acceleration, and Pitching Velocity. By Christopher C. Kraft, Jr.

3244. Aerodynamic Characteristics of the NACA 64–010 and 0010–1.10 40/1.051 Airfoil Sections at Mach Numbers From 0.30 to 0.85 and Reynolds Numbers From 4.0 x 10^6 to 8.0 x 10^6. By Laurence K. Loftin, Jr.

3245. Calculated Subsonic Span Loads and Resulting Stability Derivatives of Unswept and 45° Sweptback Tail Surfaces in Sideslip and in Steady Roll. By M. J. Queijo and Donald R. Riley.

3247. An Evaluation of an Accelerometer Method for Obtaining Landing-Gear Drag Loads. By Jerome G. Theisen and Philip M. Edge, Jr.

3248. An Experimental and Theoretical Investigation of the Anisotropy of 3C Aluminum-Alloy Sheet in the Plastic Range. By Arthur J. McEvily, Jr. and Philip J. Hughes.

3249. The Hydrodynamic Characteristics of an Aspect-Ratio-0.125 Modified Rectangular Flat Plate Operating Near a Free Water Surface. By John A. Ramsen and Victor L. Vaughan, Jr.

3250. An Experimental Investigation of the Effect of Wheel Prerotation on Landing-Gear Drag Loads. By Dexter M. Potter.

3251. A Theoretical Investigation of the Short-Period Dynamic Longitudinal Stability of Airplane Configurations Having Elastic Wings of 0° to 60° Sweepback. By Milton D. McLaughlin.

3252. Description and Preliminary Flight Investigation of an Instrument for Detecting Subnormal Acceleration During Take-off. By Garland J. Morris and Lindsay J. Lina.

3253. Some Effects of Exposure to Exhaust-Gas Streams on Emittance and Thermoelectric Power of Bare-Wire Platinum Rhodium-Platinum Thermocouples. By George E. Glawe and Charles E. Shepard.

3254. Determination of Flame Temperatures From 2000° to 3000° K by Microwave Absorption. By Perry W. Kuhns.

3255. Shock-Turbulence Interaction and the Generation of Noise. By H. S. Ribner.

3256. Experimental Investigation of Temperature Recovery Factors on a 10° Cone at Angle of Attack at a Mach Number of 3.12. By John R. Jack and Barry Moskowitz.

3257. Effects of Chemically Active Additives on Boundary Lubrication of Steel by Silicones. By S. F. Murray and Robert L. Johnson.

3258. Investigation of Mach Number Changes Obtained by Discharging High-Pressure Pulse Through Wind Tunnel Operating Supersonically. By Rudolph C. Haefeli and Harry Bernstein.

3259. Investigation of Nickel-Aluminum Alloys Containing From 14 to 34 Percent Aluminum. By W. A. Maxwell and E. M. Grala.

3260. Smoke Study of Nozzle Secondary Flows and a Low-Speed Turbine. By Milton G. Kofskey and Hubert W. Allen.

3261. A Method for Evaluating the Effects of Drag and Inlet Pressure Recovery on Propulsion-System Performance. By Emil J. Kremzier.

3262. Starting and Operating Limits of Two Supersonic Wind Tunnels Utilizing Auxiliary Air Injection Downstream of the Test Section. By Henry R. Hunczak and Morris D. Rousso.

3263. Lift and Moment Equations for Oscillating Airfoils in an Infinite Unstaggered Cascade. By Alexander Mendelson and Robert W. Carroll.

3264. Study of the Momentum Distribution of Turbulent Boundary Layers in Adverse Pressure Gradients. By Virgil A. Sandborn and Raymond J. Slogar.

3265. Vaporization Rates and Drag Coefficients for Isooctane Sprays in Turbulent Air Streams. By Robert D. Ingebo.

3266. Experimental Evaluation of Momentum Terms in Turbulent Pipe Flow. By Virgil A. Sandborn.

3267. Boundary-Layer Transition at Mach 3.12 With and Without Single Roughness Elements. By Paul F. Brinich.

3268. Shearing-Stress Measurements by Use of a Heated Element. By H. W. Liepmann and G. T. Skinner.

3269. Additional Static and Fatigue Tests of High-Strength Aluminum-Alloy Bolted Joints. By E. C. Hartmann, Marshall Holt, and I. D. Eaton.

3270. Effect of Dissociation on Thermodynamic Properties of Pure Diatomic Gases. By Harold W. Woolley.

3280. Electrical Analogies for Stiffened Shells With Flexible Rings. By R. H. MacNeal.

3281. Intergranular Corrosion of High-Purity Aluminum in Hydrochloric Acid. I—Effects of Heat Treatment, Iron Content, and Acid Composition. By M. Metzger and J. Intrater.

3282. Intergranular Corrosion of High-Purity Aluminum in Hydrochloric Acid. II—Grain-Boundary Segregation of Impurity Atoms. By M. Metzger and J. Intrater.

3283. Aerodynamic Forces, Moments, and Stability Derivatives for Slender Bodies of General Cross Section. By Alvin H. Sacks.

3285. Section Characteristics of an NACA 0006 Airfoil With Area Suction Near the Leading Edge. By James A. Weiberg and Robert E. Dannenberg.

3286. Generalized Indicial Forces on Deforming Rectangular Wings in Supersonic Flight. By Harvard Lomax, Franklyn B. Fuller, and Loma Sluder.

3288. On the Analysis of Linear and Nonlinear Dynamical Systems From Transient-Response Data. By Marvin Shinbrot.

3291. Experimental Investigation of Notch-Size Effects on Rotating-Beam Fatigue Behavior of 75S–T6 Aluminum Alloy. By W. S. Hyler, R. A. Lewis, and H. J. Grover.

3292. Influence of Exposed Area on Stress-Corrosion Cracking of 24S Aluminum Alloy. By William H. Colner and Howard T. Francis.

3295. Effect of Pressure on Thermal Conductance of Contact Joints. By Martin E. Barzelay, Kin Nee Tong, and George F. Holloway.

3296. Separation, Stability, and Other Properties of Compressible Laminar Boundary Layer With Pressure Gradient and Heat Transfer. By Morris Morduchow and Richard G. Grape.

3297. Effect of Oxygen Content of Furnace Atmosphere on Adherence of Vitreous Coatings to Iron. By A. G. Eubanks and D. G. Moore.

3299. Maximum Theorems and Reflections of Simple Waves. By P. Germain.

3300. Investigation of Lift, Drag, and Pitching Moment of a 60° Delta-Wing-Body Combination (AGARD Calibration Model B) in the Langley 9-Inch Supersonic Tunnel. By August F. Bromm, Jr.

3301. Comparison of Flutter Calculations Using Various Aerodynamic Coefficients With Experimental Results for Some Rectangular Cantilever Wings at Mach Number 1.3. By Herbert C. Nelson and Ruby A. Rainey.

3302. Liquefaction of Air in the Langley 11-Inch Hypersonic Tunnel. By Charles M. McLellan and Thomas W. Williams.

3303. Turbulent-Heat-Transfer Measurements at a Mach Number of 3.03. By Maurice J. Brevoort and Bernard Rashis.
3304. Investigation of the Aerodynamic Characteristics of a Model Wing-Propeller Combination and of the Wing and Propeller Separately at Angles of Attack up to 90°. By John W. Draper and Richard E. Kuhn.
3305. Some Measurements and Power Spectra of Runway Roughness. By James H. Walls, John C. Houbolt, and Harry Press.
3306. An Investigation of a Lifting 10-Percent-Thick Symmetrical Double-Wedge Airfoil at Mach Numbers up to 1. By Milton D. Humphreys.
3307. An Investigation of a Wing-Propeller Configuration Employing Large-Chord Plain Flaps and Large-Diameter Propellers for Low-Speed Flight and Vertical Take-off. By Richard E. Kuhn and John W. Draper.
3308. An Exploratory Investigation of Some Types of Aeroelastic Instability of Open and Closed Bodies of Revolution Mounted on Slender Struts. By S. A. Clevenson, E. Widmayer, Jr., and Franklin W. Diederich.
3309. Mechanical Properties at Room Temperature of Four Cermets of Tungsten Carbide With Cobalt Binder. By Aldie E. Johnson, Jr.
3310. Investigation of Static Strength and Creep Behavior of an Aluminum-Alloy Multiweb Box Beam at Elevated Temperatures. By Eldon E. Mathauser.
3311. Description and Analysis of a Rocket-Vehicle Experiment on Flutter Involving Wing Deformation and Body Motions. By H. J. Cunningham and R. R. Lundstrom.
3312. Initial Experiments on Flutter of Unswept Cantilever Wings at Mach Number 1.3. By W. J. Tuovila, John E. Baker, and Arthur A. Regier.
3313. Some Measurements of Atmospheric Turbulence Obtained From Flow-Direction Vanes Mounted on an Airplane. By Robert G. Chilton.
3314. A Technique Utilizing Rocket-Propelled Test Vehicles for the Measurement of the Damping in Roll of Sting-Mounted Models and Some Initial Results for Delta and Unswept Tapered Wings. By William M. Bland, Jr. and Carl A. Sandahl.
3315. Tensile and Compressive Stress-Strain Properties of Some High-Strength Sheet Alloys at Elevated Temperatures. By Philip J. Hughes, John E. Inge, and Stanley B. Prosser.
3316. Some Measurements of Noise From Three Solid-Fuel Rocket Engines. By Leslie W. Lassiter and Robert H. Heitkotter.
3317. Design Considerations for Wings Having Minimum Drag Due to Lift. By Warren A. Tucker.
3318. On the Small-Disturbance Iteration Method for the Flow of a Compressible Fluid With Application to a Parabolic Cylinder. By Carl Kaplan.
3319. Operating Characteristics of an Acceleration Restrictor as Determined by Means of a Simulator. By Arthur Assadourian.
3320. Flight Measurements of Drag and Base Pressure of a Fin-Stabilized Parabolic Body of Revolution (NACA RM–10) at Different Reynolds Numbers and at Mach Numbers From 0.9 to 3.3. By H. Herbert Jackson, Charles B. Rumsey, and Leo T. Chauvin.
3321. Analytical Determination of the Mechanism of an Airplane Spin Recovery With Different Applied Yawing Moments by Use of Rotary-Balance Data. By Sanger M. Burk, Jr.
3322. An Accurate and Rapid Method for the Design of Supersonic Nozzles. By Ivan E. Beckwith and John A. Moore.
3323. Charts for Estimating Performance of High-Performance Helicopters. By Alfred Gessow and Robert J. Tapscott.
3324. A Note on the Drag Due to Lift of Rectangular Wings of Low Aspect Ratio. By Edward C. Polhamus.
3325. Similar Solutions for the Compressible Laminar Boundary Layer With Heat Transfer and Pressure Gradient. By Clarence B. Cohen and Eli Reshotko.
3326. The Compressible Laminar Boundary Layer With Heat Transfer and Arbitrary Pressure Gradient. By Clarence B. Cohen and Eli Reshotko.
3327. Approximate Effect of Leading-Edge Thickness, Incidence Angle, and Inlet Mach Number on Inlet Losses for High-Solidity Cascades of Low Cambered Blades. By Linwood C. Wright.
3328. Theoretical and Experimental Investigation of Heat Transfer by Laminar Natural Convection Between Parallel Plates. By A. F. Lietzke.
3329. Shocks in Helical Flows Through Annular Cascades of Stator Blades. By Robert Wasserman and Arthur W. Goldstein.
3330. Ingestion of Foreign Objects Into Turbine Engines by Vortices. By Lewis A. Rodert and Floyd B. Garrett.
3331. Analysis of Laminar Forced-Convection Heat Transfer in Entrance Region of Flat Rectangular Ducts. By E. M. Sparrow.
3332. Burning Times of Magnesium Ribbons in Various Atmospheres. By Kenneth P. Coffin.
3333. Corrosion of Metals of Construction by Alternate Exposure to Liquid and Gaseous Fluorine. By Richard M. Gundzik and Charles E. Feiler.
3334. Friction of Possible Solid Lubricants With Various Crystal Structures. By Marshall B. Peterson and Robert L. Johnson.
3335. Methods for Rapid Graphical Evaluation of Cooled or Uncooled Turbojet and Turboprop Engine or Component Performance (Effects of Variable Specific Heat Included). By Jack B. Esgar and Robert R. Ziemer.
3336. Review of Experimental Investigations of Liquid-Metal Heat Transfer. By Bernard Lubarsky and Samuel J. Kaufmann.
3337. Investigation of Temperature Limitation of Various Lubricants for High-Temperature 20-Millimeter-Bore Ball Bearings. By Z. N. Nemeth and W. J. Anderson.
3338. A Dye-Tracer Technique for Experimentally Obtaining Impingement Characteristics of Arbitrary Bodies and a Method for Determining Droplet Size Distribution. By Uwe H. von Glahn, Thomas F. Gelder, and William H. Smyers, Jr.
3339. Experiments on Turbulent Flow Through Channels Having Porous Rough Surfaces With or Without Air Injection. By E. R. G. Eckert, Anthony J. Diaguila and Patrick L. Donoughe.
3340. Generalization of Gas-Flow-Interferometry Theory and Interferogram Evaluation Equations for One-Dimensional Density Fields. By Walton L. Howes and Donald R. Buchele.
3341. An Analytical Estimation of the Effects of Transpiration Cooling on the Heat-Transfer and Skin-Friction Characteristics of a Compressible Turbulent Boundary Layer. By Morris W. Rubesin.
3342. Experimental Determination of Boundary-Layer Transition on a Body of Revolution at M=3.5. By James R. Jedicka, Max E. Wilkins, and Alvin Seiff.

3343. Subsonic Edges in Thin-Wing and Slender-Body Theory. By Milton D. Van Dyke.
3344. Theoretical and Experimental Investigation of Aerodynamic-Heating and Isothermal Heat-Transfer Parameters on a Hemispherical Nose With Laminar Boundary Layer at Supersonic Mach Numbers. By Howard A. Stine and Kent Wanlass.
3345. Arrangement of Fusiform Bodies to Reduce the Wave Drag at Supersonic Speeds. By Morris D. Friedman and Doris Cohen.
3346. Prediction of Downwash Behind Swept-Wing Airplanes at Subsonic Speed. By John DeYoung and Walter H. Barling, Jr.
3347. A Wind-Tunnel Test Technique for Measuring the Dynamic Rotary Stability Derivatives Including the Cross Derivatives at High Mach Numbers. By Benjamin H. Beam.
3348. A System for Measuring the Dynamic Lateral Stability Derivatives in High-Speed Wind Tunnels. By Henry C. Lessing, Thomas B. Fryer, and Merrill H. Mead.
3349. Application of the Generalized Shock-Expansion Method to Inclined Bodies of Revolution Traveling at High Supersonic Airspeeds. By Raymond C. Savin.
3350. The Linearized Equations of Motion Underlying the Dynamic Stability of Aircraft, Spinning Projectiles, and Symmetrical Missiles. By A. C. Charters.
3351. Plastic Deformation of Aluminum Single Crystals at Elevated Temperatures. By R. D. Johnson, A. P. Young, and A. D. Schwope.
3352. Experimental Investigation of Misalining Couples and Eccentricity at Ends of Misalined Plain Bearings. By G. B. DuBois, F. W. Ocvirk, and R. L. Wehe.
3353. Effective Moment of Inertia of Fluid in Offset, Inclined, and Swept-Wing Tanks Undergoing Pitching Oscillations. By James R. Reese and John L. Sewall.
3354. Gust Experience of a Helicopter and an Airplane in Formation Flight. By Almer D. Crim.
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Part II—COMMITTEE ORGANIZATION AND MEMBERSHIP

The National Advisory Committee for Aeronautics was established by act of Congress approved March 3, 1915 (U. S. Code, title 50, sec. 151). The Committee consists of 17 members appointed by the President and includes two representatives each of the Department of the Air Force, the Department of the Navy, and the Civil Aeronautics Authority; one representative each of the Smithsonian Institution, the United States Weather Bureau, and the National Bureau of Standards; and "one Department of Defense representative who is acquainted with the needs of aeronautical research and development." In addition seven members are appointed for 5-year terms from persons "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." The representatives of the Government organizations serve for indefinite periods, and all members serve as such without compensation.

The following changes in membership have taken place during the past year:

On December 16, 1954, the President appointed Dr. Frederick C. Crawford, Chairman of the Board, Thompson Products, Inc., a member of the Committee for a term expiring December 1, 1959. He succeeded Mr. Ronald M. Hazen, at that time Director of Engineering of the Allison Division, General Motors Corp., whose term of membership expired December 1, 1954.

Vice Admiral Thomas S. Combs, USN, Deputy Chief of Naval Operations (Air), was appointed a member of the NACA on April 6, 1955, succeeding Vice Adm. Ralph A. Ofstie, who had just been detached from the same Navy post and assigned to other duty. Admiral Combs had served previously as a member of the Committee in 1952 and 1953 while on duty as Chief of the Bureau of Aeronautics.

On May 13, 1955, the President appointed Hon. Louis S. Rothschild, Under Secretary of Commerce for Transportation, a member of the NACA as successor to Hon. Oswald Ryan, whose membership was terminated December 31, 1954, as a result of the expiration of his term as a member of the Civil Aeronautics Board.

Rear Admiral Carl J. Pfingstag, USN, Assistant Chief for Field Activities, Bureau of Aeronautics, was appointed a member of the Committee effective August 1, 1955, succeeding Rear Adm. Lloyd Harrison upon the latter's retirement from the Navy.

In accordance with the regulations of the Committee as approved by the President, the chairman and vice chairman and the chairman and vice chairman of the Executive Committee are elected annually.

On October 20, 1955, Dr. Jerome C. Hunsaker was reelected chairman of the NACA and of the Executive Committee. Dr. Leonard Carmichael was elected vice chairman of the NACA and Dr. Detlev W. Bronk vice chairman of the Executive Committee.

The Committee membership is as follows:

Jerome C. Hunsaker, Sc. D., Massachusetts Institute of Technology, Chairman.
Leonard Carmichael, Ph. D., Secretary, Smithsonian Institution, Vice Chairman.
Joseph P. Adams, LL. B., Vice Chairman, Civil Aeronautics Board.
Allen V. Astin, Ph. D., Director, National Bureau of Standards.
Preston R. Bassett, M. A., Vice President, Sperry Rand Corp.
Detlev W. Bronk Ph D., President, Rockefeller Institute for Medical Research.
Thomas S. Combs, Vice Admiral, United States Navy, Deputy Chief of Naval Operations (Air).
Frederick C. Crawford, Sc. D., Chairman of the Board, Thompson Products, Inc.
Ralph S. Damon, D. Eng., President, Trans World Airlines, Inc.
James H. Doolittle, Sc. D., Vice President, Shell Oil Co.
Carl J. Pfingstag, Rear Admiral, United States Navy, Assistant Chief for Field Activities, Bureau of Aeronautics.
Donald L. Putt, Lieutenant General, United States Air Force, Deputy Chief of Staff, Development.
Donald A. Quarles, D. Eng., Secretary of the Air Force.
Arthur E. Raymond, Sc. D., Vice President, Engineering, Douglas Aircraft Co., Inc.
Francis W. Reichelderfer, Sc. D., Chief, U. S. Weather Bureau.
Louis S. Rothschild, Ph. B., Under Secretary of Commerce for Transportation.
Nathan F. Twining, General, United States Air Force, Chief of Staff.

Assisting the Committee in its coordination of aeronautical research and the formulation of its research programs are four main technical committees: Aerodynamics, Power Plants for Aircraft, Aircraft Construction, and Operating Problems. Each of these committees is aided by four or more subcommittees. The Committee is advised on matters of policy affecting the aircraft industry by an Industry Consulting Committee.

Membership of the committees and their subcommittees is as follows:

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Col. Daniel D. McKee, USAF, Wright Air Development Center.
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Dean Athelstan F. Spilhaus, University of Minnesota.
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Part III—FINANCIAL REPORT

Funds appropriated for the Committee for the fiscal years 1955 and 1956 and obligations against the fiscal year 1955 appropriations are as follows:

	Fiscal year 1955		Fiscal year 1956
	Allotments	Obligations	Allotments
SALARIES AND EXPENSES APPROPRIATION			
NACA Headquarters	$1, 478, 984	$1, 428, 528	$1, 606, 645
Langley Aeronautical Laboratory	20, 167, 700	20, 062, 354	22, 246, 290
Ames Aeronautical Laboratory	8, 551, 518	8, 482, 111	11, 661, 950
Lewis Flight Propulsion Laboratory	18, 224, 991	18, 189, 861	20, 393, 831
High-Speed Flight Station	1, 722, 856	1, 704, 152	1, 935, 935
Pilotless Aircraft Station	705, 960	687, 858	953, 950
Western Coordination Office	19, 424	19, 236	20, 795
Wright-Patterson Coordination Office	13, 819	13, 505	15, 604
Research contracts with educational institutions	747, 000	742, 183	750, 000
Research contracts with Government agencies	200, 000	200, 000	200, 000
Reserve	407, 748		350, 000
Unobligated balance		710, 212	
Total	[1] 52, 240, 000	52, 240, 000	[2] 60, 135, 000
CONSTRUCTION AND EQUIPMENT APPROPRIATION			
Langley Aeronautical Laboratory	1, 220, 000	477, 918	3, 325, 000
Ames Aeronautical Laboratory	349, 000	219, 091	1, 055, 000
Lewis Flight Propulsion Laboratory	3, 321, 000	636, 217	8, 395, 000
Pilotless Aircraft Station			90, 000
Reserve for transfer to later years	110, 000		
Reserve transferred from prior years	−380, 000	−281, 570	−300, 000
Unobligated balance		[3] 3, 568, 344	
Total	[1] 4, 620, 000	4, 620, 000	[2] 12, 565, 000

[1] Appropriated in the Independent Offices Appropriation Act, 1955, approved June 24, 1954, and the Second Supplemental Appropriation Act, 1955, approved April 22, 1955.

[2] Appropriated in the Independent Offices Appropriation Act, 1956, approved June 30, 1955.

[3] This balance remains available until expended.