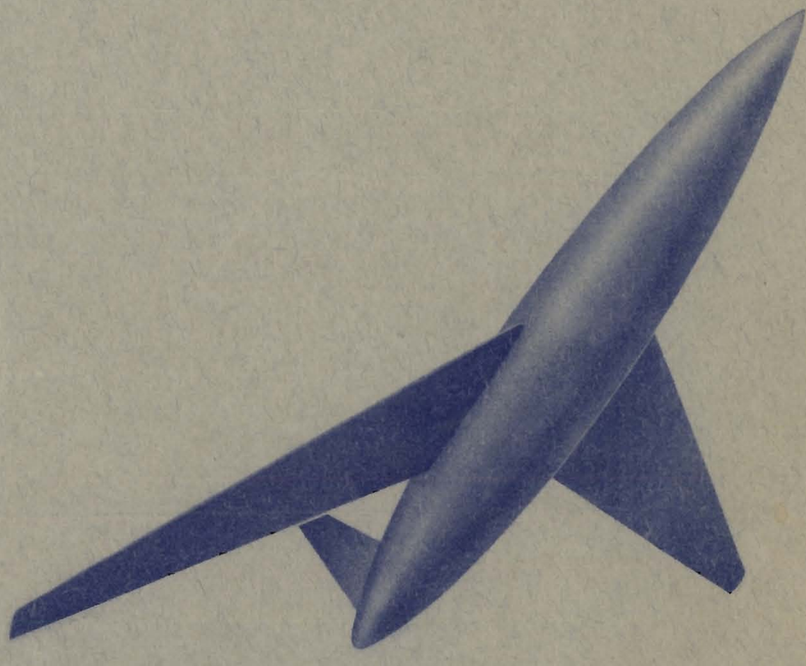
NACA



WASHINGTON, D. C.
LANGLEY FIELD, VA.
MOFFETT FIELD, CALIF.
CLEVELAND, OHIO

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

THE ORGANIZATION - RESEARCH ACTIVITIES AND FACILITIES OF THE NACA.

MARCH, 1948

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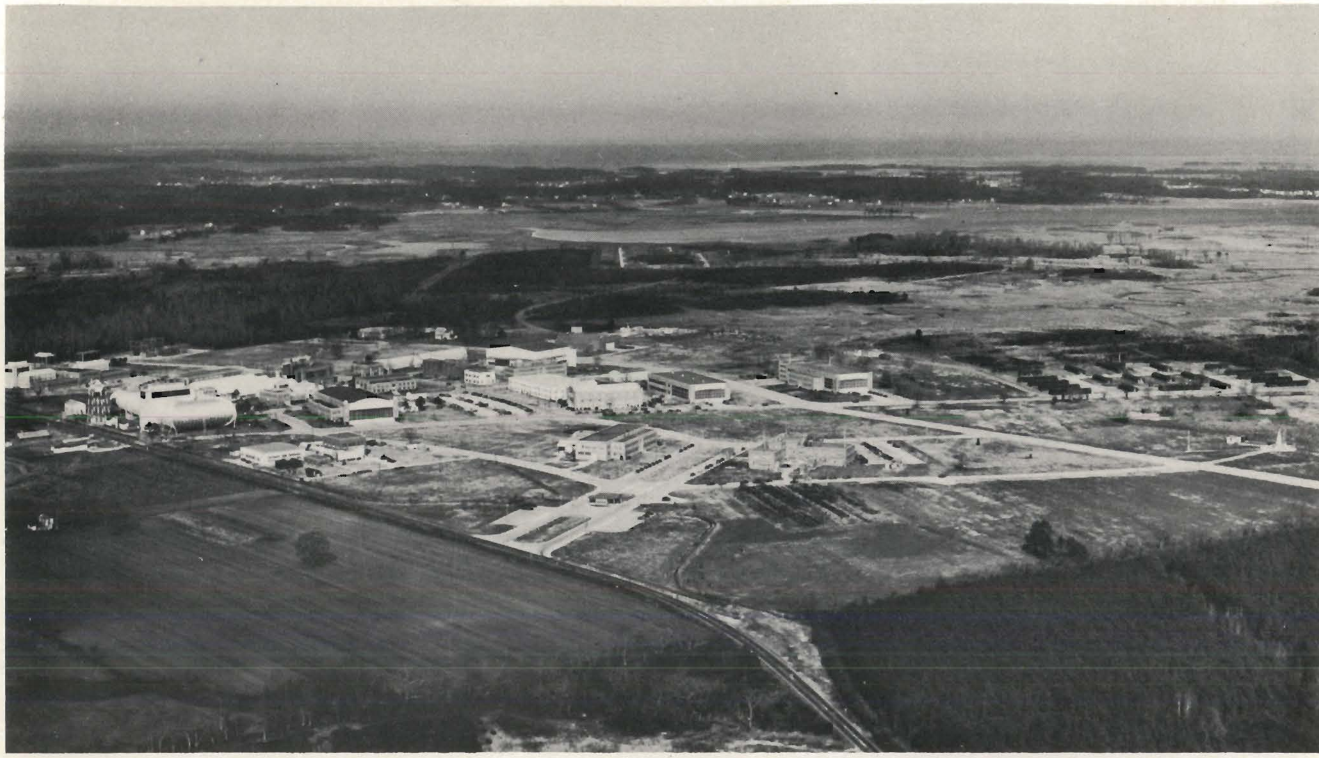
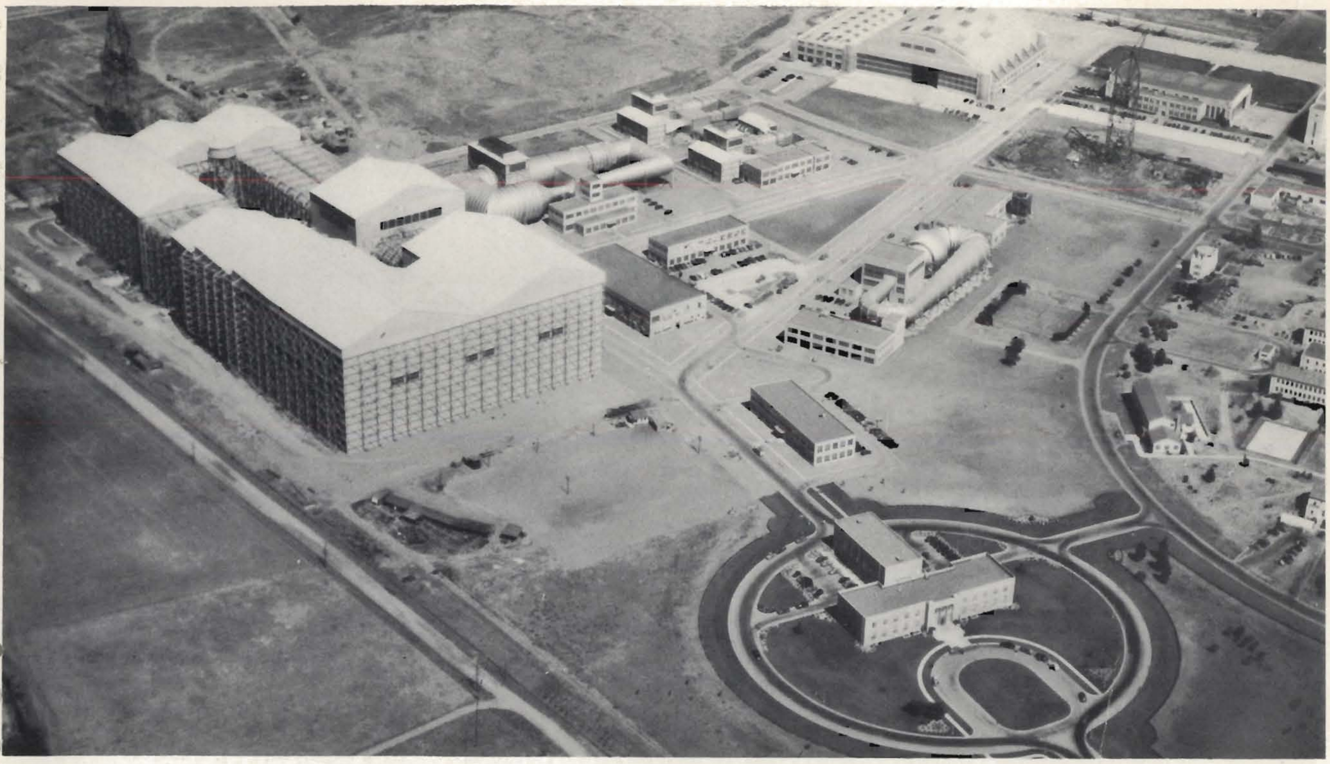


The Langley Memorial Aeronautical Laboratory of the NACA is located in two sections on the USAF's Langley Field, near Newport News, Va. The West section of the laboratory, above, is where most of the facilities built since 1940 are located.

In the East section of Langley Field, Va., the NACA's original laboratory facilities are grouped in with USAF buildings belonging to the Field. Administrative direction of the laboratory is centered here, with many important research facilities.



The Ames Aeronautical Laboratory of the NACA is located on the Navy's Moffett Field, near San Francisco, Calif. The laboratory is chiefly devoted to high speed aerodynamics, and has the largest and some of the fastest wind tunnels in the world.

ORGANIZATION AND FUNCTIONS OF THE NACA

The National Advisory Committee for Aeronautics was established by the Congress in 1915 as the government's aeronautical research agency. The enabling act specifically charges the NACA with "study of the problems of flight with a view to their practical solution." To this end the Committee operates its own research laboratories, coordinates the fundamental research programs of other agencies and encourages and supports research in scientific and educational institutions. Such a scope of activity is made possible by the structure of the NACA.

The main Committee of the NACA consists of 15 members appointed by the President. They include two representatives each of the offices in charge of military and naval aviation, two representatives of the Civil Aeronautics Authority, one representative each of the Smithsonian Institution, the U. S. Weather Bureau, the National Bureau of Standards, together with six additional persons who are "acquainted with the needs of aeronautical science, either civil or military, or skilled in aeronautical engineering or its allied sciences." These latter six serve for terms of five years. The representatives of government agencies serve while in office. All members serve as such without compensation.

The main Committee is supplemented by a system of technical committees and subcommittees to prepare and recommend to the main Committee the programs of research to be conducted in their respective special fields. In addition, these subcommittees assist in coordinating research programs and act as mediums of exchange of ideas and information among all groups concerned with aviation.

The strength of the subcommittee system lies in the fact that its members are selected from every branch of aviation and allied interests. Outstanding technical men from a variety of aviation manufacturing companies; from educational and scientific institutions; from the military establishments, the commercial operators, and other governmental aeronautical agencies, are recruited for subcommittee service.

Administration of Committee research activities is carried out by a Director of Research, who with his immediate staff in Washington controls the operations of the NACA's three principal research laboratories and awards research contracts outside the Committee's own facilities.

Original and largest laboratory is the Langley Memorial Aeronautical Laboratory at Langley Field, near Hampton, Virginia. Research conducted here involves virtually every phase of aerodynamics, hydrodynamics, aircraft structures, and aircraft loads. A flight station for pilotless aircraft at Wallops Island on the Virginia Coast is operated in conjunction with the Langley Laboratory.

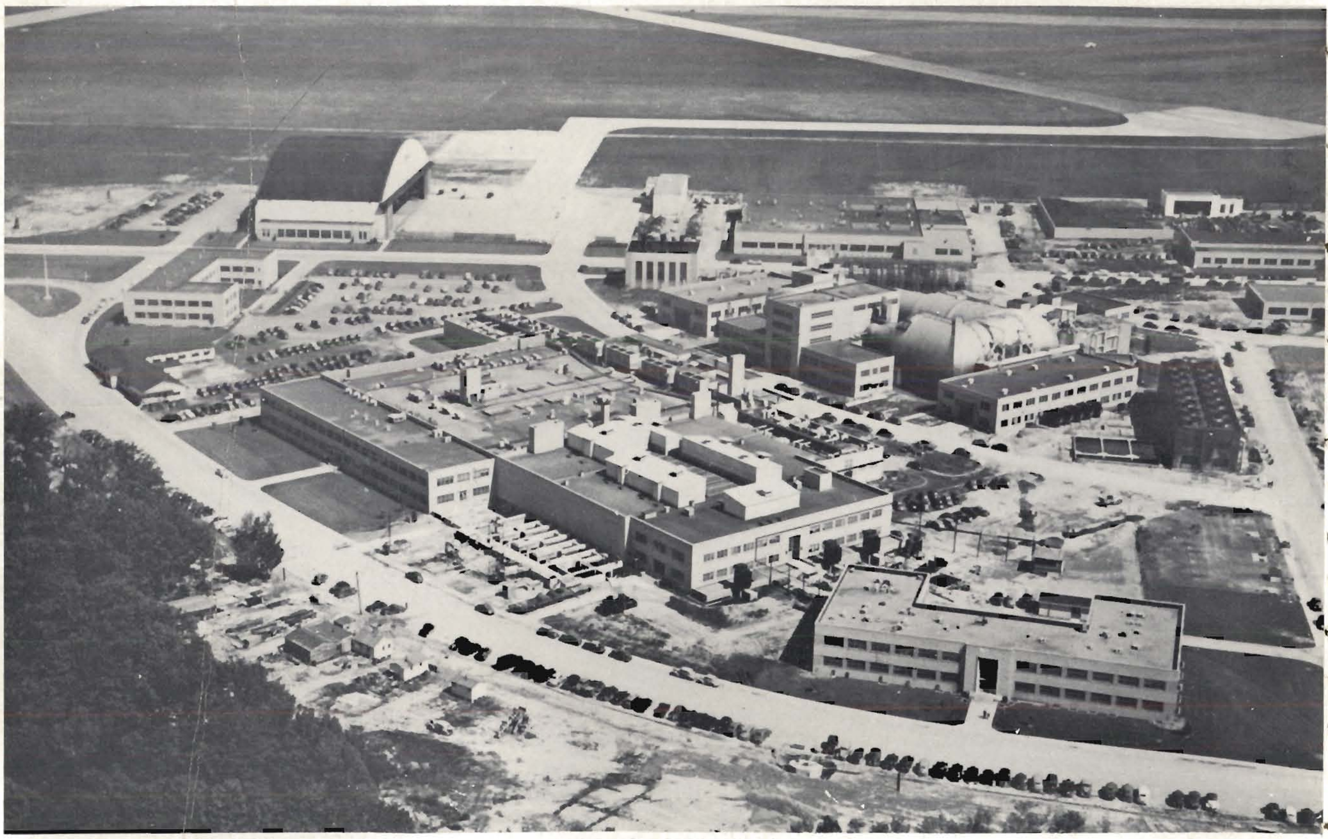
The Ames Aeronautical Laboratory on the Navy's Moffett Field, south of San Francisco, California, is concerned primarily with high-speed aerodynamics and has the largest and some of the fastest wind tunnels in the world.

The Flight Propulsion Research Laboratory is located at Cleveland Airport, Ohio. The work here covers all problems of aircraft propulsion, including the special supersonic aerodynamic problems connected with high-speed propulsion.

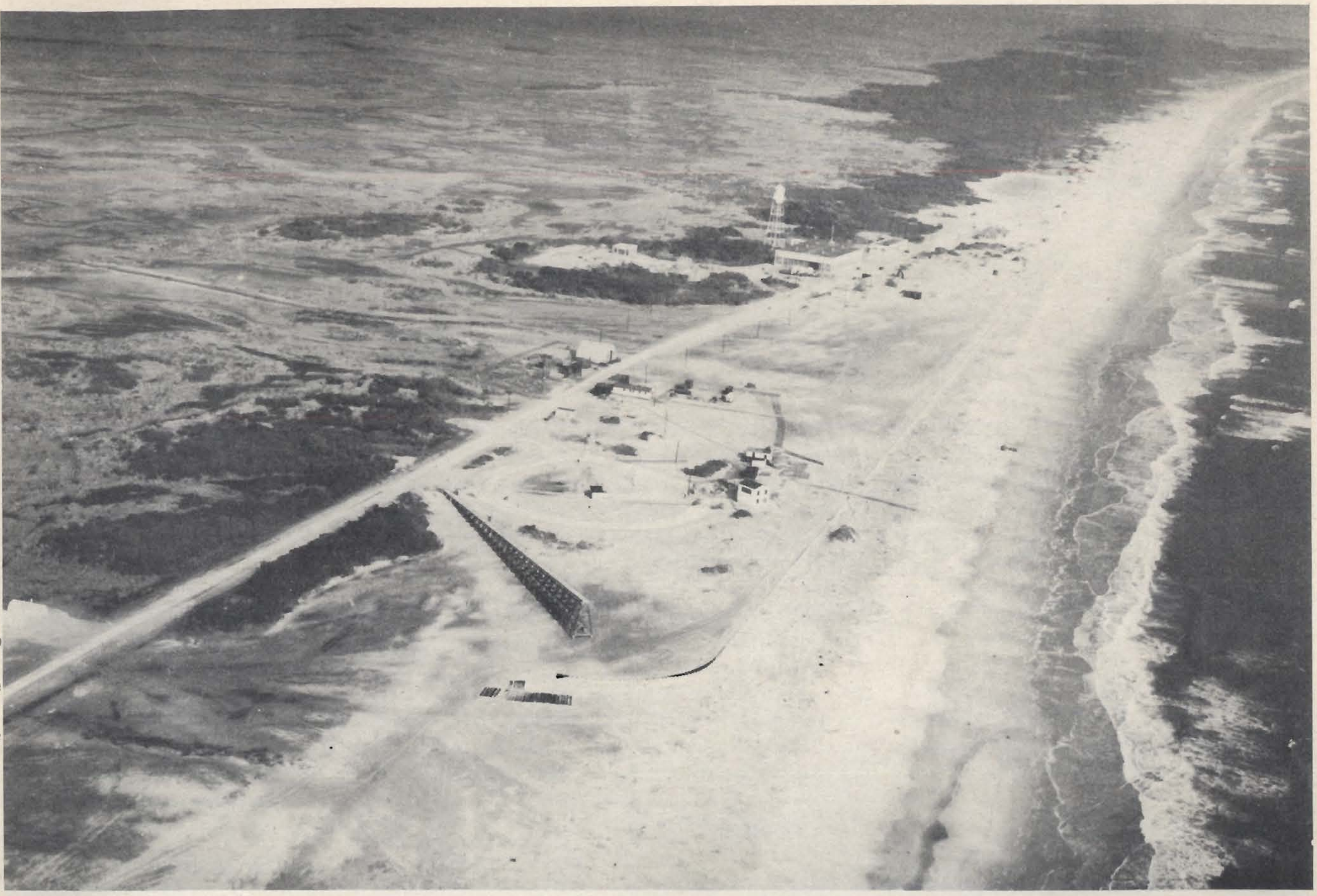
The NACA is constantly expanding its efforts to let research contracts with universities and other organizations having suitable equipment. By so doing, effective use of other research facilities is made, duplication of equipment is avoided, and better utilization of scientific manpower is achieved.

Moreover, by training men in outside groups in the special thinking and technique of advanced research work the depleted reserve of trained personnel is being replenished. This is one of the prime objectives of contract research, for the war did serious damage to advanced training programs. In executing research contracts, universities introduce graduate and undergraduate students to the challenging and exacting requirements of advanced research, giving them opportunity to develop their capabilities in that direction.

The product of research in all these laboratories is an NACA technical report containing detailed and accurate information on the laws and principles governing design, or the use of aircraft, or the behavior of gases and materials under a variety of conditions. They are distributed as a government service to designers, manufacturers and operators of



The Flight Propulsion Research Laboratory of the NACA is situated at the edge of Cleveland Airport, Ohio. Research here is devoted to the problems of all kinds of propulsion systems, and also operating problems such as aircraft and engine icing.



The NACA Pilotless Aircraft Research station is located on the Virginia seacoast. It was established to study problems of aerodynamics and control at very high speeds in free flight, and is operated in conjunction with the Langley Laboratory.

aircraft, and to technical and scientific libraries throughout the country.

In choosing an airfoil, for example, a designer can consult the compiled characteristics of airfoils and select the type best suited to his purpose. From the accumulated research reports on stability and control, he can design stability and good handling qualities into an airplane. The same is true of power plants, structures, propellers, and all aircraft components. Information provided extends to problems of operation, such as icing in flight, loads sustained in flight, and landing, and even to emergency ditching of landplanes at sea.

The NACA is an important integral part of the air-power structure of the United States. Closely allied with the manufacturing, civil operations, and military function, its contribution of fundamental research is practically unique. Such research is essentially a function of the Government, because of its relatively low cost when the results are available to all for application to design and operation of aircraft, Moreover, fundamental scientific research is dependent on an atmosphere of freedom from immediate specific goals and time tables, freedom to discuss and exchange ideas, and freedom from controls and restrictions. The laws of physics are discovered more readily by area exploration rather than by pursuit of specific objectives leading to immediate profit. The discovery of new knowledge, which is the prime objective of NACA research, flourishes only in an atmosphere of greatest freedom and signals each important advance in the aeronautical art.

As aeronautical science advances to new fields of higher speeds and higher altitudes, its problems become more and more interwoven with the other sciences, until propulsion involves nuclear physics and aerodynamics is concerned with the laws of thermodynamics. In this expanding and deeply probing field, opportunity is afforded for wide ranging studies that have become a challenge accepted by some of the best minds in the country.

The laboratories of the NACA provide the scientists who have chosen to work there with the finest equipment in the world for the solution of their problems. In many fields of study, individual equipment is planned and devised by the engineers themselves, and ample latitude is afforded for creative ingenuity. Even the larger items of equipment, such as the wind tunnels, have been evolved in this way through NACA experience with research needs. The laboratories are maintained to provide dependable knowledge unavailable from other sources.

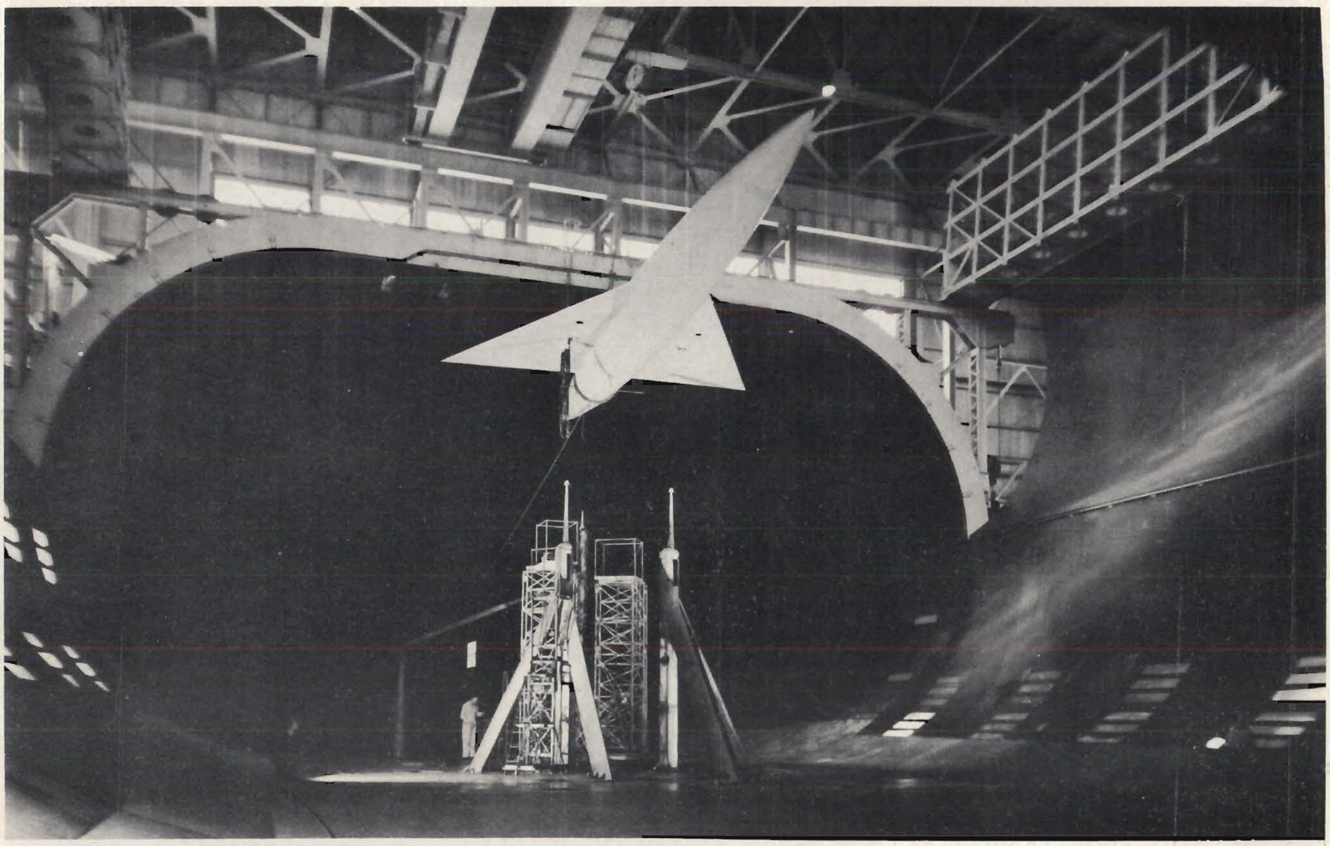
PROBLEMS AND TOOLS OF RESEARCH

Basic research in a broad dynamic field such as aeronautics is an ever-expanding activity. The function of the NACA is to probe areas of the unknown for new knowledge of the phenomena of flight. Upon establishment of each new bridgehead, the organization must exploit and develop knowledge to the point of practical application by the industry, the military, and civil operating groups. Frequently, the development of new knowledge resulting in new aviation performance exposes a new unknown area which must be explored.

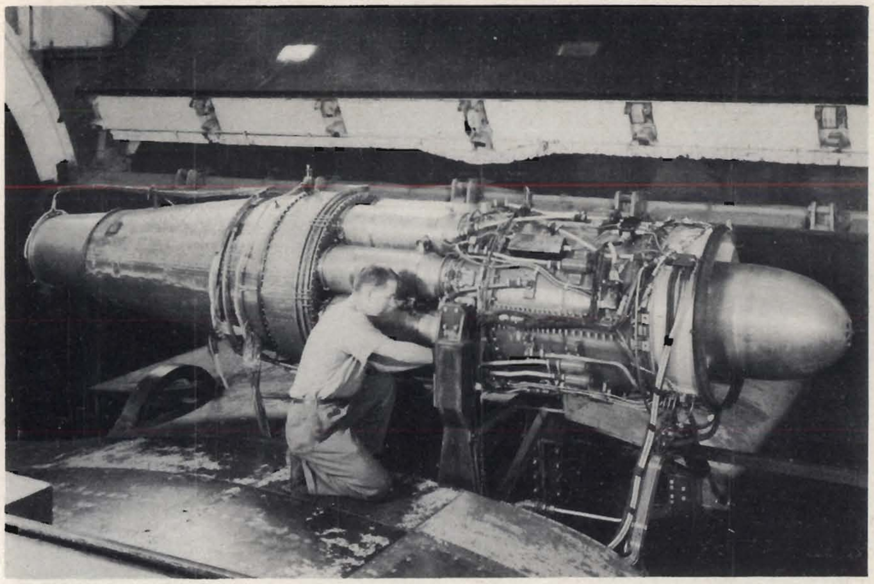
Many research problems have been with us for a long time and require unrelenting effort for continued progress. Solution of some lead to new ones such as the difficulties involved in transonic and supersonic flight, which are as strange and meaningful as those attendant upon the first flight of man.

NACA research facilities have grown apace with the new and expanding areas of research. Because of the time differential between basic research and ultimate successful development, the newer research equipment reflects the shape of things to come. And yet, the older equipment rarely becomes obsolete because so long as aircraft must start from rest and return safely to rest; so long as the need exists for better small personal aircraft, for large transport aircraft and for supersonic machines, research equipment spanning the entire range of performance and size is required to operate at full capacity.

In the following pages are briefly described the areas of research engaged in by the NACA, and the



equipment of exploration. Impressive as the array of physical research equipment may be, the primary tool of any research organization is brain power. From the creative thinking of the curious mind evolves the incisive recognition of the research problem and the design of exploratory equipment. The NACA has succeeded in attracting to its employ many of the finest scientific and mechanical minds in the world. By virtue of the various committees there has been marshaled the outstanding talent of aeronautical America. The following pages describe the problems against which this talent is deployed and the tools for the task.



An axial-flow turbo-jet engine is prepared for investigation under accurately simulated operating conditions in the Altitude Wind Tunnel of the NACA at Cleveland

For convenience of description, the areas of NACA research are roughly divided as follows:

- Aerodynamics
- Hydrodynamics
- Propulsion
- Aircraft Loads
- Airframe Construction and Materials
- Operating Problems
- Physical Research
- Flight and Pilotless Aircraft

Aerodynamics

The rapidly increasing speed of military aircraft and the prospective use of high-speed flying missiles have placed great emphasis on solution of the problems of high-speed flight. Wartime development resulted in military aircraft capable of level flight at speeds exceeding 550 mph. At such speeds, certain aerodynamic phenomena associated with compression shock and the attendant airflow separation appeared to impose serious limitations to any further performance improvement. New aerodynamic techniques for delaying the flight speed at which shock occurs, and for minimizing the adverse effects of shock when it does occur, together with new and more powerful types of propulsion systems now available, will permit substantial increases of speed. The high-speed airplanes of the near future will fly faster than the speed of sound.

A dynamically scaled airplane model being launched at the NACA's Pilotless Aircraft Research Station. Information is obtained through telemetering and tracking.

Extensive investigations of wings and other airplane components are being conducted in wind tunnels and in flight to perfect known methods, such as planform variations and boundary-layer control, for alleviating shock losses. Better understanding of the mechanics of shock waves must be obtained through fundamental and theoretical studies. Inasmuch as flight at very high speed appears to demand radically different configurations from those used for slow speed flight, means of satisfactorily flying such configurations at the low speeds required for landing and take-off are being studied.

In the lower speed region of flight in which commercial transport and cargo airplanes now operate, further increases in speed and range and further reduction in operating costs may be expected through aerodynamic refinement. Systematic investigation of the complete range of airfoils permitting extensive laminar flow is being conducted in low-turbulence wind tunnels and in flight to correlate and evaluate the various airfoil characteristics.

Keystone of research is men and their ideas. Through cooperative effort and exchange of ideas, they determine how to get the information desired on any problem.

The possibilities of large gains from the use of boundary-layer control for reducing drag and increasing maximum lift have been merely touched upon, and must be completely investigated theoretically and experimentally, in wind tunnels and in flight. Further fundamental theoretical and experimental studies of boundary layer are in process because the mechanics of transition from laminar to turbulent flow are not known, and the mechanics of separation of turbulent flows are not understood.

Propulsion

There has been a greater change in the character of propulsion research in recent years than in any branch of aeronautics. Successful new types of power plants have opened the way to new combinations of ideas. These new possibilities, while greatly advancing our abilities, bring with them new and difficult problems.

Combustion in the continuous, open cycle of jet engines presents new phenomena to be investigated. The combustion process is complicated by the presence of high-speed airstreams capable of hindering combustion and reducing efficiency unless means are found to speed up the burning process. Corollary to combustion research is the study of new fuels to meet the new requirements. High speeds demand fuels of greater energy content. With both jet engines and rockets, range is limited because of high fuel consumption in relation to thrust received. Thermodynamic study is necessary to provide the values required to evaluate the heat processes in new propulsion systems and for calculation of performance.

The greatly-increased demands on compressors to furnish air at higher pressures and larger volumes entails energetic research to achieve best performance in the most compact units. Turbines to drive large compressors and propellers involve stringent requirements of blade efficiency, strength and resistance to high temperature. Search for new materials with increased resistance to high temperatures and stresses is demanded for nearly every component of new propulsion systems.

The presence of large compressors and turbines revolving at high speeds emphasizes the need for better understanding of friction, and for knowledge that will lead to more efficient bearing surfaces and materials.

The value and importance of theoretical research in aeronautics cannot be over-emphasized. Healthy growth of any science depends on experiment and theory keeping pace with each other. The science of aeronautics is becoming increasingly complex and theory must be encouraged to keep pace with and to guide experiment. Every branch of theoretical physics may be involved to some degree in any program of theoretical research in aeronautics. As a general rule, every fundamental experimental project is associated with a theoretical project. In view of the considerable extension of experimental facilities, an expansion of theoretical work is in prospect.

NACA scientists devised an efficient, five-blade geared propeller and an engine muffler for this L-5 to demonstrate the possibilities of effective noise reduction.

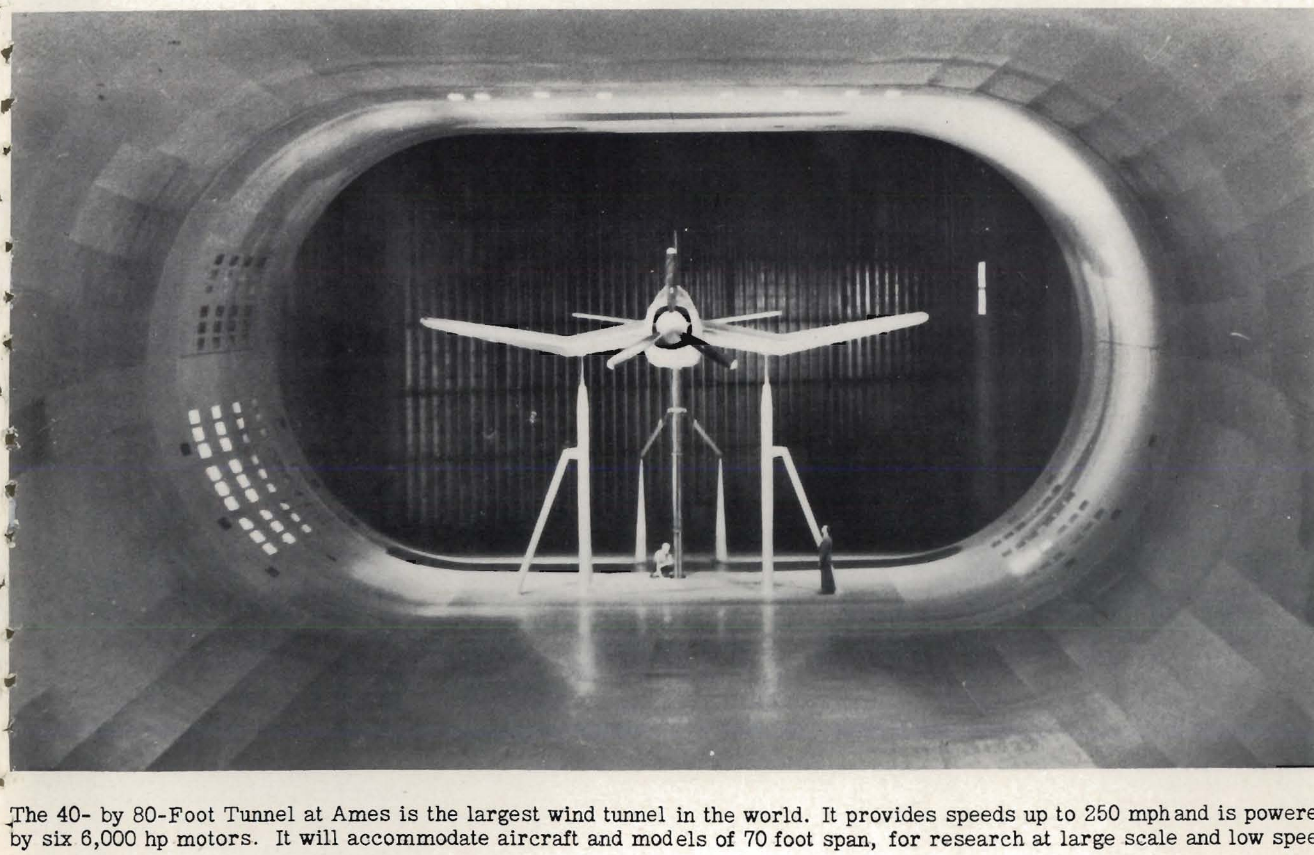
AERODYNAMICS

SUBSONIC AERODYNAMICS

Subsonic aerodynamics is basic and is an essential field of research for man-carrying aircraft throughout the entire speed range. Such study includes investigation of all kinds of airfoils and aerodynamic shapes. In a systematic program, the work involves development of theory, progresses to experimental verification and development in specialized wind tunnels and is then extended to larger scale in full-scale and pressure tunnels. Also included in this work is study pertaining to drag, boundary-layer control and interference of airplane components in combination.

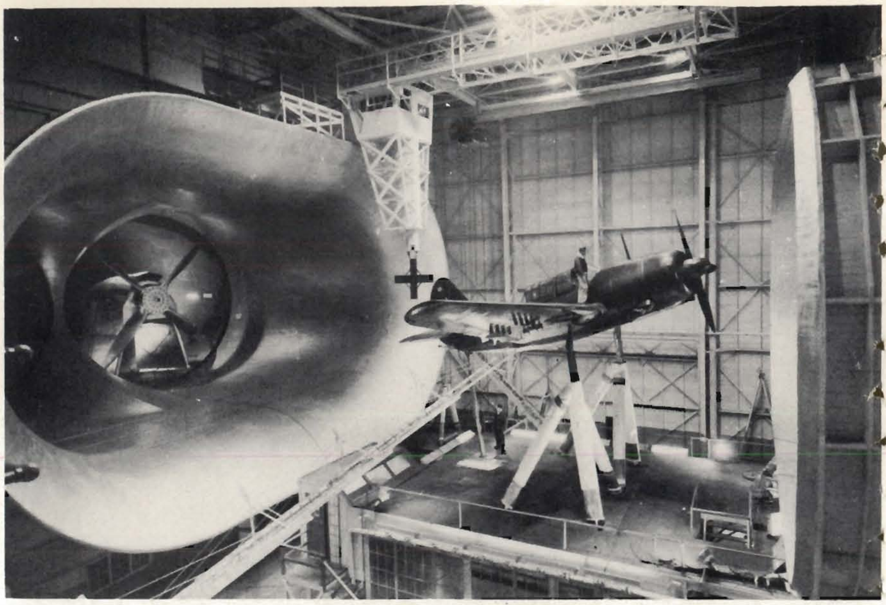
In presenting aerodynamic research methods, it should be stated that flight research is one of the most important. This applies to every branch of the subject, but especially to high-speed study of complete aircraft combinations. For this reason, flight research and its special branches are treated in a separate section entitled "Flight and Pilotless Aircraft" (p. 34), rather than repeated everywhere it applies.

The NACA has pioneered the design and use of full-scale tunnels. The 30- by 60-Foot Tunnel was the largest ever planned when it was completed in 1931. It has been exceeded in size only by the 40- by 80-Foot Tunnel at the Ames Laboratory. The two tunnels are used for large-scale drag investigations, boundary-layer control studies, and are particularly valuable for investigating stability and control, in the landing speed range, of large-scale wings and shapes designed for high-speed and supersonic flight. In these tunnels full-sized airplanes can be studied with engines operating, whether powered by reciprocating engine and propeller or gas turbine installations.



The 40- by 80-Foot Tunnel at Ames is the largest wind tunnel in the world. It provides speeds up to 250 mph and is powered by six 6,000 hp motors. It will accommodate aircraft and models of 70 foot span, for research at large scale and low speed.

The 40- by 80-Foot Tunnel is the largest in the world and has been used to study airplanes and wing panels up to 70 feet in span. The entire structure covers an area of eight acres. The largest part of the air passage, ahead of the test section, measures 132 feet high by 172 feet wide. In completing a circuit of the tunnel, the air -- 24,000,000 cubic feet, weighing about 900 tons -- travels nearly half a mile. All the tunnel controls, as well as those for the airplane engines, are installed in the balance house directly under the test section.



Second largest wind tunnel is this 30- by 60-Foot Tunnel at the Langley Laboratory. It permits study of large-scale wing forms and aircraft at speeds up to 120 mph.

Two-Dimensional Low-Turbulence Pressure Tunnel

The NACA has developed many specialized wind tunnels for particular purposes. Some of these are pressure tunnels, in which the effective scale of models can be increased by the amount that the air density is increased above normal pressure. Others are two-dimensional tunnels of very low turbulence, close to that of free air, and a combination of the two in a pressurized, two-dimensional, low-turbulence tunnel.

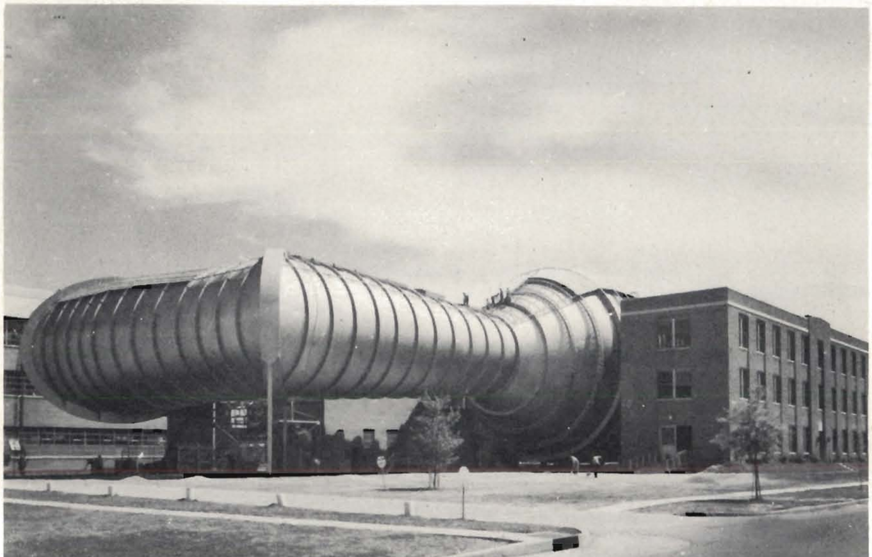
Full-Scale Tunnels

The 40- by 80-Foot Tunnel - Ames

Test Section	40 x 80 ft., oval, closed
Speed	250 mph
Power	36,000 hp
Pressure	Atmospheric

The 30- by 60-Foot Tunnel - Langley

Test Section	30 x 60 ft., oval, open
Speed	120 mph
Power	8,000 hp
Pressure	Atmospheric



The 19-Foot Pressure Tunnel at Langley provides speeds up to 260 mph and pressures up to 2-1/3 atmospheres. It is used for study of airfoils and complete models.

The two-dimensional low-turbulence tunnels of the NACA at Langley Field are of particular importance, since they made possible the experimental and practical development of the NACA series of laminar flow, low-drag airfoils. Practical application of such airfoils to aircraft was the result of continued work in these tunnels to evaluate conditions such as surface roughness and deformation that would be present in any manufactured wing.

The unpressurized low-turbulence tunnel was completed in 1938, and the Low-Turbulence Pressure Tunnel in 1941. They are used primarily for airfoil research and study of high lift devices and control surfaces under finely-controlled conditions.

The 19-Foot Pressure Tunnel and the 12-Foot Low-Turbulence Pressure Tunnel are used to extend research on airfoils to the study of complete wings at high Reynolds numbers. They are well adapted for study and improvement of complete wing characteristics, the development of high lift and lateral control devices, and evaluation of improvement of stability, control, and performance characteristics of airplanes in the design stage.

A unique feature of the 12-Foot Tunnel at Ames is that by partially evacuating the tunnel, investigations can be taken up to high subsonic Mach numbers.

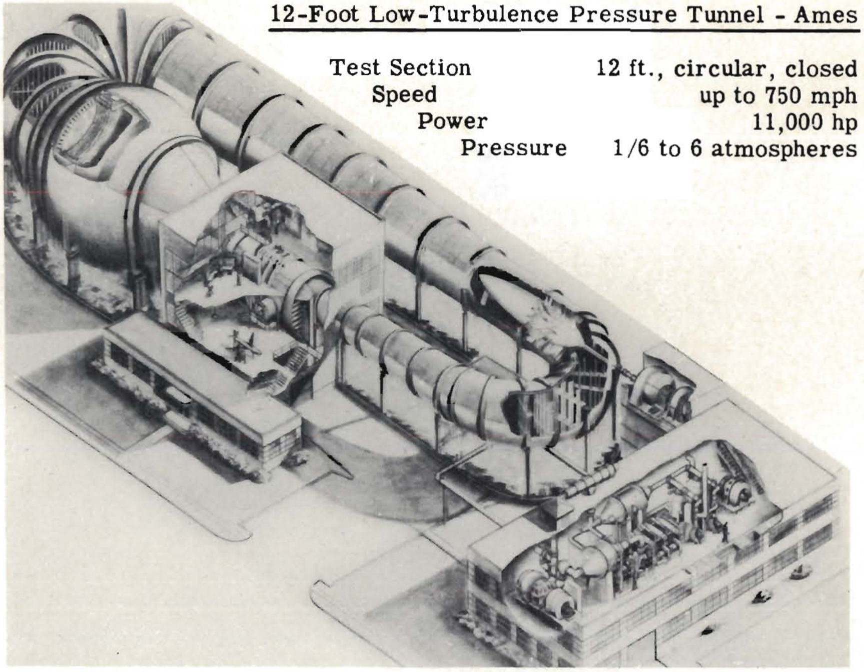
7- by 10-Foot Tunnels

The size and speed of these tunnels makes them well suited to a wide variety of general aerodynamic and control studies. The corrections for data from these tunnels have been so well established that excellent agreement is obtained between tunnel and flight results. Accurate predictions of handling qualities of a design can be made. In addition, they are well suited for fundamental research on such problems as high-lift devices, control surface hinge moments, and the boundary layer.

Model of XS-1 ready for control investigation in Langley 7- by 10-Foot Tunnel.

12-Foot Low-Turbulence Pressure Tunnel - Ames

Test Section	12 ft., circular, closed
Speed	up to 750 mph
Power	11,000 hp
Pressure	1/6 to 6 atmospheres



The 19-Foot Pressure Tunnel - Langley

Test Section	19 ft., circular, closed
Speed	50 to 260 mph
Power	8,000 hp
Pressure	1 to 2 1/3 atmospheres

Two-Dimensional Low-Turbulence Pressure Tunnel

Test Section	3 x 7 1/2 ft., rectangular, closed
Speed	0 to 350 mph
Power	2,000 hp
Pressure	1 to 10 atmospheres

Two-Dimensional Low-Turbulence Tunnel

Test Section	3 x 7 1/2 ft., rectangular, closed
Speed	0 to 159 mph
Power	195 hp

7- by 10-Foot Tunnels

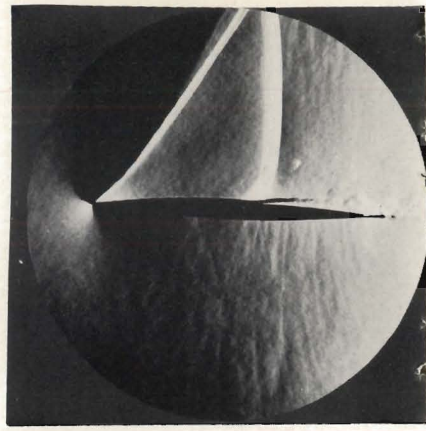
Langley No. 1 and Ames Nos. 1 and 2

Test Section	7 x 10 ft., rectangular, closed
Speed	300 mph
Power	1,600 hp

Langley No. 2

Test Section	Nominal 7 x 10 ft., rectangular, closed
Speed	500 to 700 mph
Power	10,000 hp

TRANSONIC AERODYNAMICS



Some of the NACA's outstanding work has been in attacking the special problems of aerodynamics near the speed of sound. Transonic problems arose many years ago in connection with the high tip speeds of propellers. Later, aircraft speeds entered the transonic speed region, and the NACA concentrated on the attendant problems. Now, with supersonic flight in the offing, exploration of the transonic aerodynamics field ranks high among the NACA's research projects.

Unique research methods have been developed by the NACA in the transonic field. The wing-flow investigations and use of rocket powered and freely-falling bodies with telemetering are outstanding examples, and are described more fully under the Flight and Pilotless Aircraft sections of this book.

Wind tunnels of unparalleled accuracy and efficiency have been designed by the NACA for its high-speed research. At this time, it is possible to span the transonic speed region by the wind-tunnel method, and the data have proved to be reliable. Following are the NACA tunnels used in high-speed research.

A wide variety of research is conducted in these tunnels on the high-speed characteristics of airfoils, propellers, air inlets, internal flow arrangements for jet-propulsion systems and other airplane components.

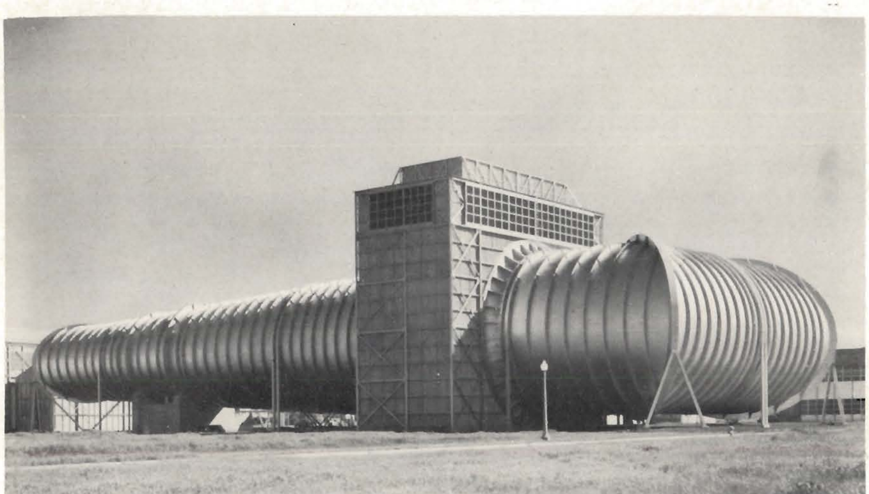
Plans are under way to increase the power of the Langley 16-Foot Tunnel from 16,000 to 40,000 horsepower and provide for speeds greater than the speed of sound.

In the smaller tunnels investigations are conducted on the fundamental nature of compressible flows.

The 8-Foot Tunnel at Langley was the first large tunnel to enter the transonic range. It has provided reliable data up to nearly the speed of sound and is responsible for much of the design information used in the transonic research airplanes now flying.

Transonic aerodynamics is a complex field and the need for theory is great. Most of our knowledge at present is purely the result of experiment. We do not yet know all that happens nor why. There is challenging opportunity in this field for developing the mathematics and theory necessary to explain the phenomena encountered and to guide future experiment.

A new piece of equipment used in this field is a Bell electric computer to provide fast, accurate answers in the numerical solution of complex problems.



Typical of the larger high-speed tunnels is this 16-Foot Tunnel at the Ames Laboratory. It is powered by a 27,000 hp motor and provides speeds up to 680 mph.

One of the most valuable transonic tunnels is the 8-Foot Tunnel at Langley.

High-Speed Tunnels

8-Foot High-Speed Tunnel - Langley

Test Section	8 ft., circular, closed
Speed	750 mph (to M 0.97 and 1.0)
Power	16,000 hp
Pressure	Atmospheric

12-Foot Low-Turbulence Pressure Tunnel - Ames

(Described in Subsonic Aerodynamics section, p. 11)

16-Foot High Speed Tunnels

Langley

Test Section	16 ft., circular, closed
Speed	525 mph (M 0.7)
Power	16,000 hp
Pressure	Atmospheric

Ames

Test Section	16 ft., circular, closed
Speed	680 mph (M 0.9)
Power	27,000 hp
Pressure	Atmospheric

1- by 3 1/2-Foot Tunnel - Ames

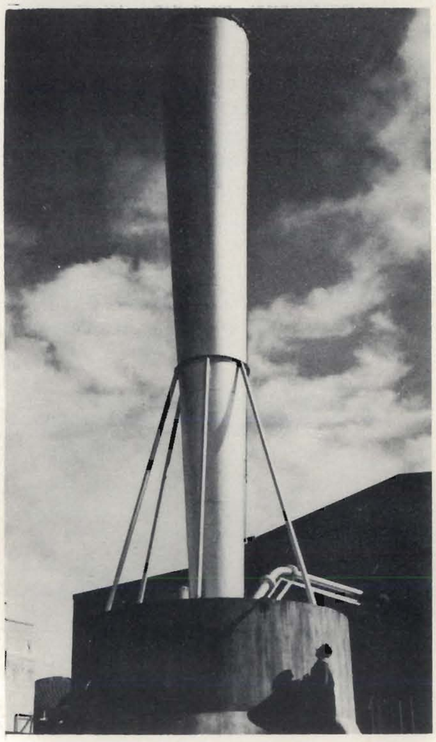
Test Section	1 x 3 1/2 ft., rectangular, closed
Speed	730 mph and up (M 1.2)
Power	2,000 hp
Pressure	Atmospheric

Rectangular High-Speed Tunnel - Langley

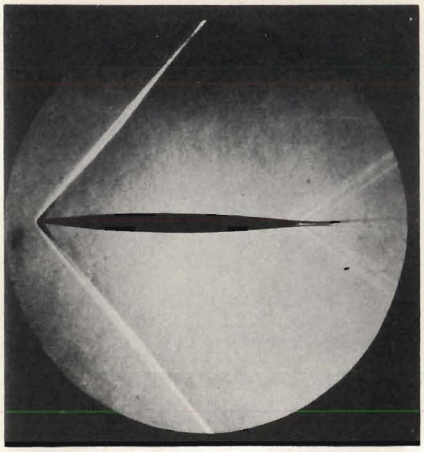
Test Section	4 x 18 in., Variable
Speed	155 to 915 mph (M 0.2 to 1.4)
Power	Induction air jet
Pressure	Atmospheric

24-Inch High-Speed Tunnel - Langley

Test Section	24 in., Variable
Speed	155 to 695 mph and up (M 0.2 to 1.4)
Power	Induction air jet
Pressure	Atmospheric



The 24-Inch Tunnel at Langley provides high subsonic and supersonic speeds.



SUPERSONIC AERODYNAMICS

Analyses based on information now available indicate that man-carrying supersonic flight is possible with propulsion units of the gas turbine and ram-jet types at their present stage of development. This possibility has opened up a great new field of aerodynamics. Rather than simplifying or eliminating old problems, it has added a host of new ones. To the old problems of low-speed stability and control there are added the transonic and supersonic problems, entailing whole new areas of research on airfoils, wing and body forms and propulsion.

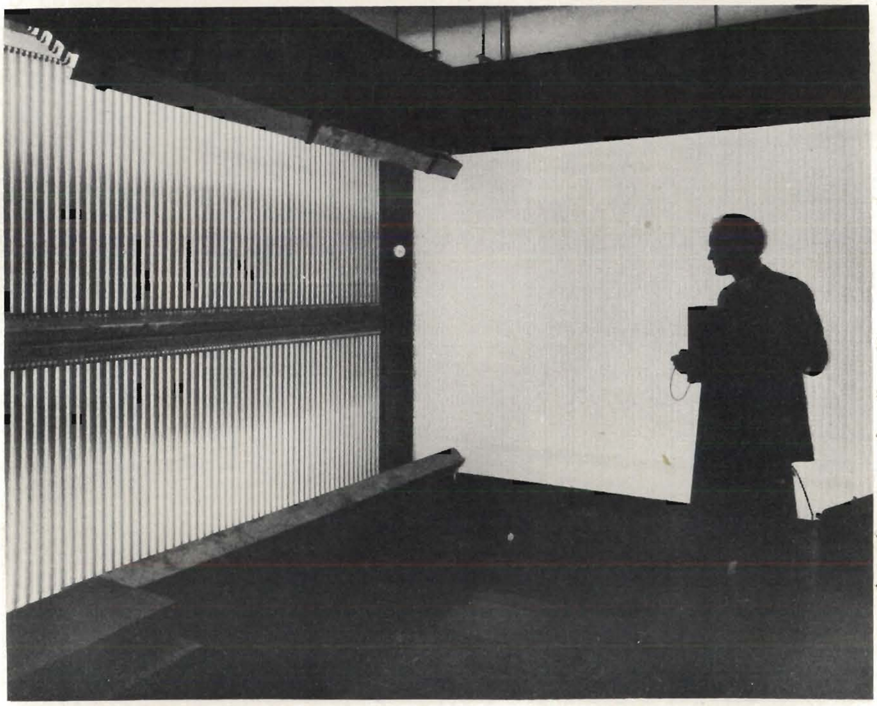
Although present theories of supersonic flows are fairly well established, a great deal of experiment remains to be done to confirm the theory. Added knowledge is necessary on conditions of large disturbances, where present theory does not apply. Extension and confirmation of the theory is needed for the design of any type of supersonic aircraft.

Other problems not susceptible to theoretical treatment are boundary layers and their interaction with shock wave formation in supersonic flows; effects of scale or Reynolds number; flow of rarefied gases in relation to aerodynamics at extremely high altitudes, dealing with particle mechanics as contrasted with more normal fluid flows.

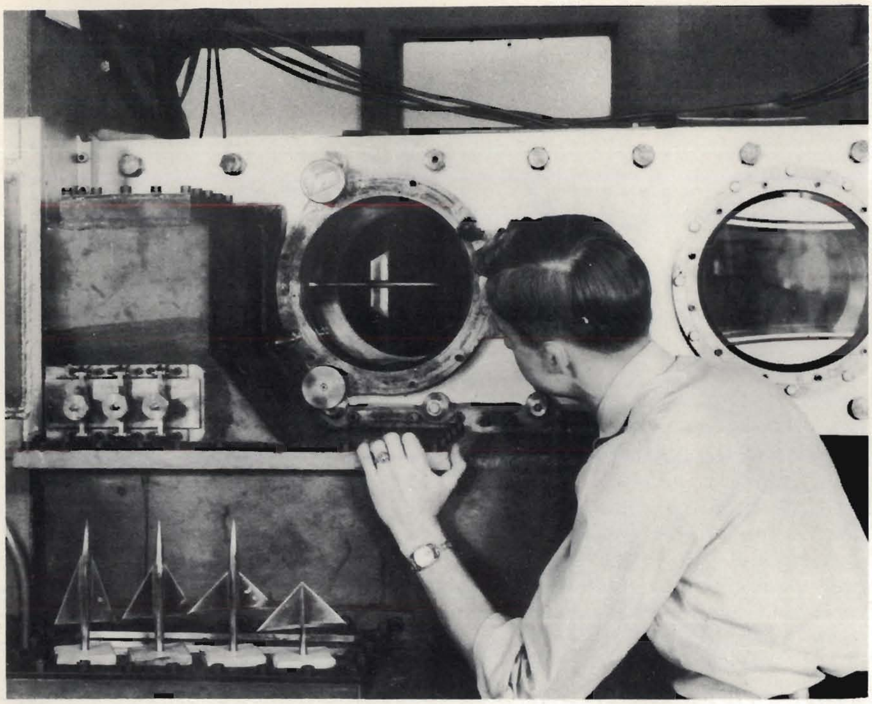
The problem of aerodynamic heating, in relation to the pilot and the airplane structure is important, but this can be treated theoretically to some extent.

To aid in the quest for knowledge about supersonic flight, the NACA has designed and built a number of supersonic wind tunnels -- about 14 -- ranging in size from a few inches to the 6- by 8-foot giant at the Cleveland Laboratory. In conjunction with the rocket, free-falling body and wing-flow techniques for spanning the transonic zone, NACA facilities now cover the entire speed range from low subsonic speeds up to 4.5 times the speed of sound.

In view of the importance of scale effects at supersonic speeds, supersonic tunnels even larger than the 6- by 8-Foot will be needed to accommodate sufficiently large models without tunnel choking and shock wave reflection. More complete knowledge of the basic nature of supersonic flows is required for adequate detail design of a very large supersonic wind tunnel. More basic research will be needed for the continued improvement of supersonic wind tunnel design.



This battery of manometers registers the pressures over airfoil and model surfaces in one of the supersonic tunnels at the Flight Propulsion Research Laboratory.



A supersonic wing model ready for study in the Langley 9-Inch Supersonic Tunnel with other wing and body forms below. The tunnel provides Mach numbers up to 2.4.

1-by 3 1/2-Foot High-Speed - Ames

(Described in Transonic section, p. 13).
Speed - M 1.2

8- by 8-Inch - Ames

Test Section - - - 8 x 8 in., closed
Speed - - - - - - - - - - - M 2.3

9-Inch - Langley

Test Section - - 9 x 7 1/2, closed
Speed - - - - - - - - M 1.2 and 2.5
Power - - - - - - - - - 1,000 hp

Intermittent Supersonic Tunnels

1- by 3-Foot No. 2 - Ames

Test Section - - - 1 x 3 ft., closed
Speed - - - - - - - - - - - M 3.4
Pressure - - - - - - - - Variable

24-Inch High-Speed - Langley

(Described in Transonic section, p. 13)

Rectangular High-Speed - Langley

(Described in Transonic section, p. 13).

Continuous Supersonic Tunnels

6- by 8-Foot - Cleveland

Test Section - - - 6 x 8 ft., closed
Speed - - - - - - - - - - - M 1.8

6- by 6-Foot - Ames

Test Section - - - 6 x 6 ft., closed
Speed - - - - - - - - - - - M 1.6

4- by 4-Foot - Langley

Test Section - - - 4 x 4 ft., closed
Speed - - - - - - - - - - - M 2.2

2- by 2-Foot - Cleveland

Test Section - - - 2 x 2 ft., closed
Speed - - - - - - - - - - - M 4.5

1- by 3-Foot No. 1 - Ames

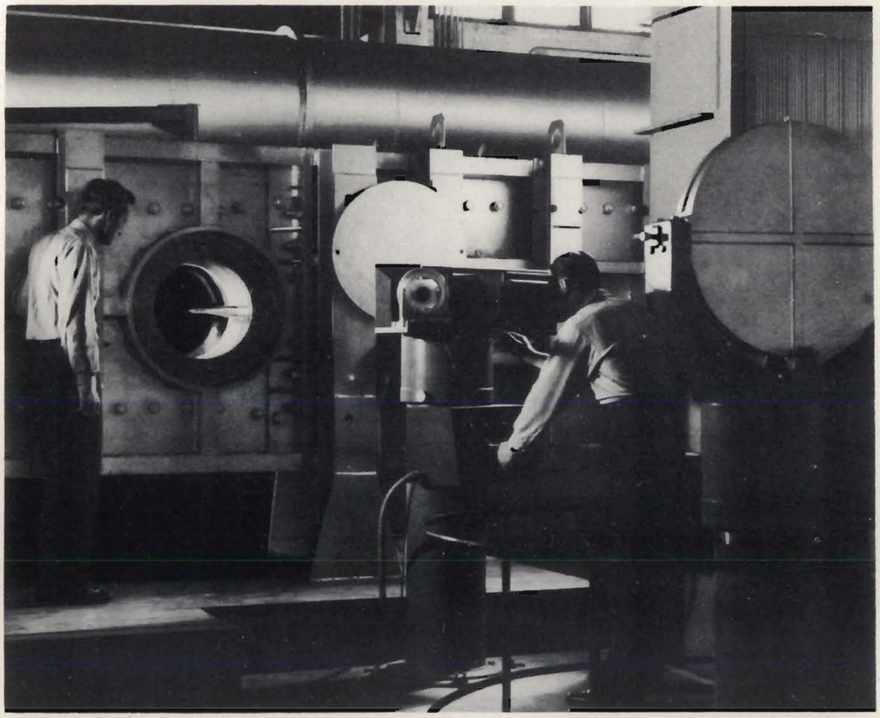
Test Section - - - 1 x 3 ft., closed
Speed - - - - - - - - - - - M 2.2
Power - - - - - - - - - 10,000 hp
Pressure - - - - - - - - Variable

20-Inch - Cleveland

Test Section - - - 20 in., circular
Speed - - - - - - - - - - - M 2.0

18- by 18-Inch - Cleveland

Test Section - - 18 x 18 in., closed
Speed - - - - - - - - - - - M 2.2



The 1- by 3-Foot Supersonic Tunnels at Ames Laboratory provide Mach numbers up to 3.4. Schlieren photos of the flow field are made through the glass side plates.

STABILITY AND CONTROL

In the field of airplane stability and control, the rapid increase in airplane size, speed and power has necessitated an increasingly delicate adjustment of all the factors affecting the flying qualities of aircraft in order that the work of controlling the airplane does not exceed the pilot's capabilities. Control forces, for example, increase approximately as the square of the speed and as the cube of the size. For geometrically similar airplanes, doubling both the size and speed would increase the control forces by a factor of about 32. A greater proportion of the forces must consequently be balanced either aerodynamically or by means of auxiliary power systems. With very large or very fast aircraft, such a large proportion of the forces must be balanced that relatively small changes in the air forces, resulting from little-understood effects of Mach number, Reynolds number, and surface covering deflection and roughness may change the net force the pilot must handle by several hundred per cent. As a result, independent and systematic fundamental investigations are being conducted, utilizing the most suitable wind tunnels and covering necessary ranges of Mach number, Reynolds number, and airfoil, control, and balance shape. These data are being coordinated and verified by flight tests.

A large part of the laboratory investigations of stability and control is conducted in facilities also used in general aerodynamics. In addition there are several facilities particularly designed for this work.

Special new branches of stability and control study are included in transonic and supersonic aerodynamics. In addition to these, conducted in the high-speed and supersonic tunnels, there is the new field of automatic stability and control, investigated by means of rocket test vehicles. This work is described under Pilotless Aircraft, p. 34.

The Langley Free-Flight Tunnel permits safe study of new designs in flight.

7- by 10-Foot Tunnels

(Described in Subsonic Aerodynamics section, p. 11)

Full-Scale Tunnels

(Described in Subsonic Aerodynamics section, p. 10)

20-Foot Spin Tunnel - Langley

Test Section	12-sided polygon, 20 ft. across
Speed	0 to 60 mph, vertical
Power	400 hp
Purpose	Spin studies on dynamic models

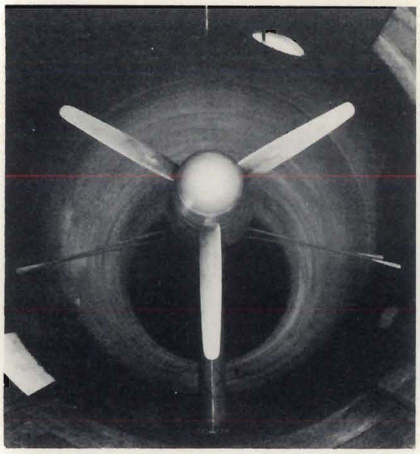
Free-Flight Tunnel - Langley

Test Section	12-sided polygon, 12 ft., across
Speed	0 to 60 mph
Power	280 hp
Purpose	Studies on remotely-controlled dynamic models in free flight

Stability Tunnel - Langley

Test Section	Approximately 6 ft. square, circular and rectangular. Sides adjustable for curving flow; vanes in circular section for rotating flow
Speed	0 to 220 to 360 mph, according to section size
Power	600 hp
Purpose	Study of stability and control of two- and three-dimensional models in curved and rotating flow simulating maneuvers

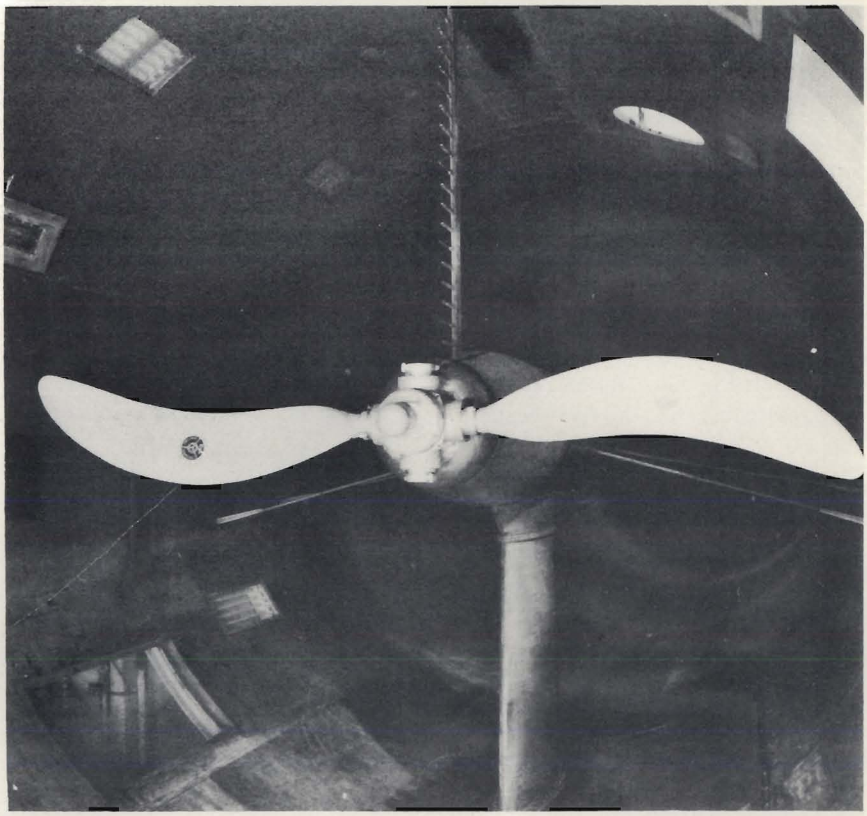
PROPELLERS



At speeds up to at least 500 mph, the screw propeller is the most efficient known propulsive device for aircraft. High efficiencies can be maintained for all the important airplane operating conditions, including take-off, climb, cruising, and high-speed flight. In the laboratory, propellers have been designed, built, and operated that have yielded efficiencies scarcely less than the theoretical maximum attainable. Subsonic propeller theory is regarded as adequate and means exist for applying the theory in practice. The only barriers to realization of the high theoretical propeller efficiencies in commercial applications are the difficult mechanical problems involved in obtaining a completely clean juncture between a wide airfoil propeller shank and the spinner. This problem lies in the realm of commercial development rather than in the field of research. A number of special propeller research projects related to vibration, icing, trailing edge extensions, tip shape, and so forth, remain to be worked on, and other similar problems will arise. The most important basic propeller research at present is that which will extend the efficient operating range of propellers into the supercritical high-speed region. Propeller research in this direction is proceeding along three lines; one is an attempt to increase the critical tip Mach number by sweeping back the propeller blade; the second is to apply the principle of low aspect ratio; the third is research on propellers for completely supersonic operation.

Propeller research properly begins with airfoil research in facilities already described, such as the two-dimensional and small high-speed tunnels. Blades and complete propellers are studied in the larger high-speed tunnels, such as the 8-Foot High-Speed Tunnel at Langley and the 16-Foot Tunnels. Complete engine installations are investigated in the 16-Foot and Full-Scale Tunnels. These studies cover the combined effects of the whole engine installation, including interference effects on the propeller.

In addition, there are some special facilities that permit propellers and blade sections to reach tip speeds above the speed of sound.



A swept-blade propeller on a dynamometer mounting in the Langley 16-Foot Tunnel. The wake-survey rake to the rear provides information on blade efficiency.

ROTATING WING AIRCRAFT

The helicopter, still in an early stage of development, has proved of great value because of its unique ability to fly slowly or to hover in the air and to take off and land in a limited space. These characteristics have made it the ideal aircraft for many commercial applications and its usefulness may be expected to increase steadily as its present limitations are removed. However, development of the helicopter has been handicapped by the lack of fundamental understanding of the aerodynamic and structural problems peculiar to rotating-wing aircraft. Development of the helicopter into a practical machine with desirable features of performance, reliability, and utility critically depends upon the success in solution of the many technical problems.

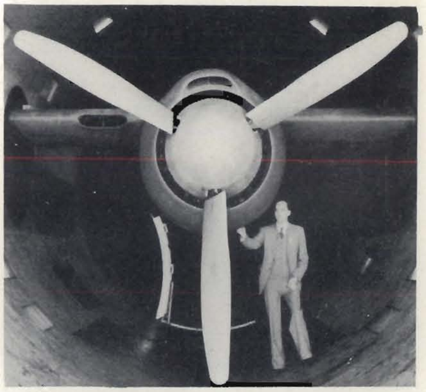
Results of wartime specific research have been used, as far as possible, to provide basic information applicable to all types of helicopters. However, the need for a systematic survey of all phases of helicopter flight is being attacked so that rational design criteria can be established for improvement of future designs.

An analytic and experimental investigation is required to determine the effects of rotor blade planforms, twist, airfoil section, and surface condition on hovering, cruising, high speed, and auto-rotative performance. The factors underlying rotor vibration and flutter need to be thoroughly understood. As usefulness of the helicopter increases, means should be found to reduce the degree of skill required to fly it. Increasing importance will therefore be attached to fundamental knowledge of stability and to the methods of improving and simplifying helicopter control systems. In order to insure smooth and efficient operation and to decrease maintenance costs, development of rotor blades of improved surface design and uniformity of mass and aerodynamic characteristics must be carried out. Paralleling development of fixed wing aircraft, the ability to fly at greater speeds will be demanded of the helicopter as soon as satisfactory performance and handling qualities are achieved in the low speed range. With this in mind, the blade stalling, vibration, and compressibility problems of high-speed helicopter flight are undergoing thorough study both in flight and in the laboratory.

The helicopter test tower is a special piece of equipment for investigating rotors. It is a steel cone 40 feet high, with a rotor mounting head and provision for all controls. A 1,500 horsepower motor furnishes power for rotors of up to 10,000 pounds of thrust through a speed range of 80 to 400 rpm of the rotor. Anemometer installations to either side give accurate records of wind conditions. The tower is sufficiently high to elevate the rotor above the level of ground effect, and duplicates conditions of hovering.

In addition to research in full-scale tunnels and with the Helicopter Tower, helicopters are studied in flight to provide data on control, performance and vibration.

AERODYNAMICS OF ENGINE INSTALLATION



The greatly-increased diversity of aircraft power plants and the immediate importance of flight at transonic and supersonic speeds have multiplied the related aerodynamic problems in urgent need of solution. Internal flow velocities in aircraft ducting underwent a large upward revision with the advent of turbine propeller and turbo-jet engines. As sonic flight speeds are approached and exceeded, the familiar patterns of external and internal flow are drastically altered. Ram-jets have shown great potentialities as a propulsive means for flight at supersonic speeds, and the development of this type of power plant has created a need for aerodynamic knowledge in previously unexplored fields.

These developments have greatly emphasized the urgent need for immediate extensions of fundamental internal and external flow research in order to make adequate progress in the design of aircraft power plant installations. In addition, aerodynamic refinement of air intakes, ducts, outlets, turbines, combustion chambers, compressors, and nozzles must be accomplished if the goals of high-speed and supersonic flight are to be realized. The need for fundamental research in the field of external flow about bodies suitable for housing power plants for high-speed and supersonic aircraft is as critical as the need for extensive internal-flow research.

Research in the field of internal air handling is so much involved with propulsion that the research in the two fields is almost inseparable. This is particularly true at supersonic speeds, where such propulsion systems as the ram-jet are basically flying ducts. Consequently this subject is attacked both in aerodynamics and propulsion research. Supersonic tunnels are extensively used in the study of ducted body shapes. The laws governing efficient combination of duct entries and airplane body shape need to be well established to make supersonic flight a useful reality.

Early research in internal aerodynamics led to the development of the radial engine cowling. That work has progressed through the years from the simple ring cowl, sufficient for low speeds, to the series of refined, high-speed cowlings that provide for speeds in excess of those presently attained by propellered aircraft. It now extends to supersonic airflows and the study of inlets and diffusers in supersonic wind tunnels.

In addition to supersonic tunnels at all its laboratories, the NACA maintains a complete induction aerodynamics laboratory, with facilities that provide large volume airflows over a range of pressures and velocities, at its Langley Laboratory. In conjunction with propulsion research facilities at the Cleveland Laboratory, increasing opportunity presents itself in this vital and expanding field.

Duct and inlet test setups in the Induction Aerodynamics Laboratory at Langley. Progress to higher flight speeds involves major problems of internal air handling.

HYDRODYNAMICS

Use of the seaplane in the war demonstrated that its speed and range must be increased, not only by reduction of aerodynamic drag of the hulls or floats, but also by development of improved over-all configurations, and by incorporation of all the technological advancements available. In addition, the flying boat should be able to operate in the roughest seas likely to be encountered in service without being unduly penalized by excess weight of structure. Provision of fundamental data from the wind tunnel and towing tank, the associated theoretical studies used as a guide for the experimental work, and the necessary correlations with actual seaplane operation to attain these objectives form the basis of the hydrodynamic research program.

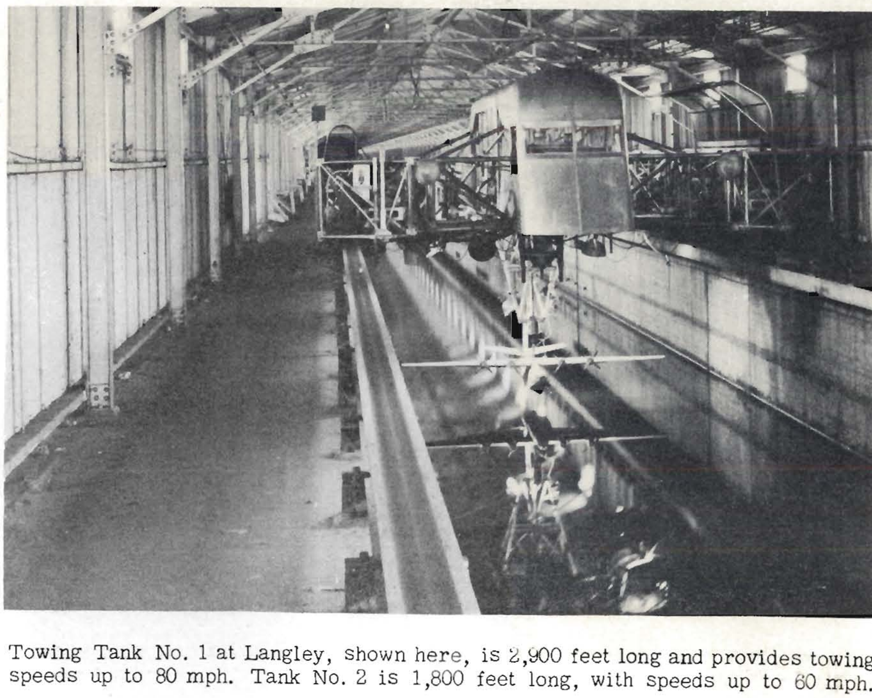
In order to achieve the best compromises in design aerodynamic and hydrodynamic research must go hand in hand on such items as the rounding of chines, fairing of steps, changes in proportions and variations in shape. Novel forms of hulls and floats as well as airplane configurations are being evaluated in terms of spray, stability, controllability and water resistance. In the tank the influence of design parameters on the dynamic behavior and accelerations in waves are determined in order that the requirements of operation in rough water may be taken into account by development engineers.

Development of new forms of propulsion will have a profound influence on the commercial and military seaplane of the future. The intensive effort toward very high-speed airplanes in the subsonic and supersonic ranges opens up vast possibilities for the use of water as a medium for take-offs and landings Such possibilities make further hydrodynamic research on a large scale imperative if the best solutions are to be found. The hydrodynamic characteristics of configurations incorporating the new prime movers must be observed and methods for investigating them at high take-off and landing speeds need to be evolved. Fundamental research on the properties of planing surfaces at high Froude numbers and hydrofoils at low cavitation numbers is included in the program to provide data for estimation of the forces acting at speeds well above those for which data are available. The effect of sweep and dihedral on the performance of hydrofoils is being investigated as well as use of planing surfaces or hydrofoils to localize the heavy water loads incident to high landing speeds Configurations of these lifting elements that will be dynamically stable, controllable, and free from mutual interference should be developed by systematic testing at and beyond the highest speeds available in the tanks.

The NACA has evolved unique facilities for hydrodynamic research. There are two towing tanks of a design pioneered by the NACA, providing towing speeds of 60 and 80 mph. In addition there is an impact basin that accurately reproduces rough water landings under known and controlled conditions.

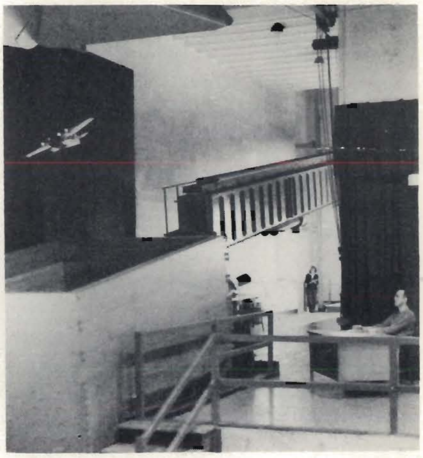
Another overlapping branch of study is investigation of ditching characteristics of landplanes, which combines hydrodynamic study with aircraft structural loads and operating problems.

All hydrodynamic facilities of the NACA are located at Langley Field, Virginia.



Towing Tank No. 1 at Langley, shown here, is 2,900 feet long and provides towing speeds up to 80 mph. Tank No. 2 is 1,800 feet long, with speeds up to 60 mph.

AIRCRAFT LOADS

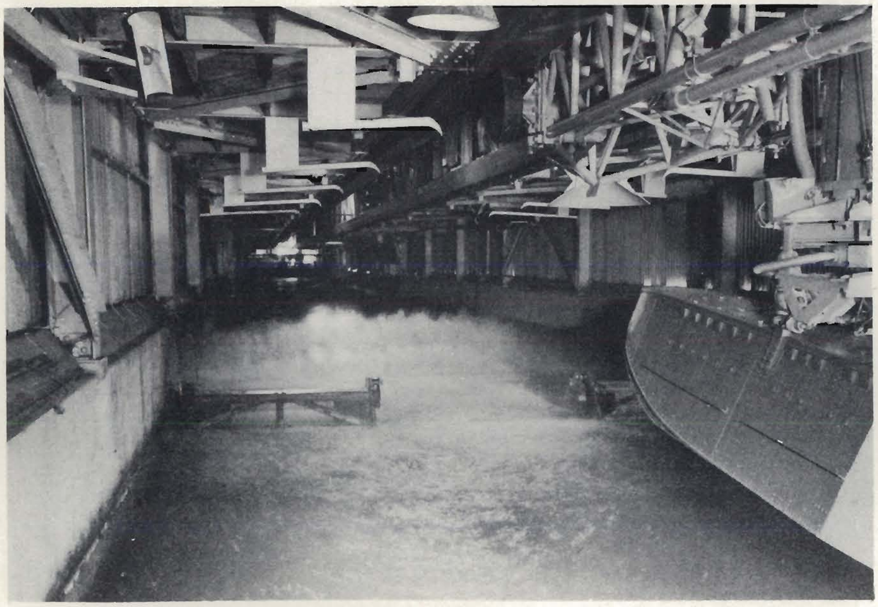


Applied loads are the forces imposed on aircraft structures in flight operations including landing and take-off. These forces have to be known quantitatively to a high degree of accuracy to insure against structural failure under normal demands and at the same time avoid excess weight. Structural failures of fighter airplanes that occurred during the war as a result of high flight speeds and failures of larger types of airplanes as a result of dynamic loads either in the air or during landing have emphasized the need for more intensive research on applied loads. New airplane configurations designed for supersonic flight have introduced new problems in evaluation of the magnitude and distribution of applied loads, both in gusty air and in maneuvers, that must be solved if these new designs are to be capable of actual flight without disastrous consequences. In the commercial field, the trend toward very large sized airplanes has resulted in heavy investments per airplane and a consequent need for high utilization. This trend, in combination with use of high strength alloys of relatively poor fatigue properties as a weight-saving measure, has pointed up the need for investigation of repeated loads and other factors that govern the fatigue life.

Facilities for research on aircraft loads are also located at the Langley Laboratory. Implementing the mathematical and theoretical approach, there are three important experimental facilities:

Gust Tunnel

The Gust Tunnel is a unique wind tunnel operating in a vertical plane, designed to reproduce controlled and measured up and down drafts. Dynamically weighted and scaled models up to 6 feet in span are catapulted through these gusts at speeds up to 100 mph. The gusts can be "shaped", as they are in the atmosphere, by controlled variation of the velocity gradient.



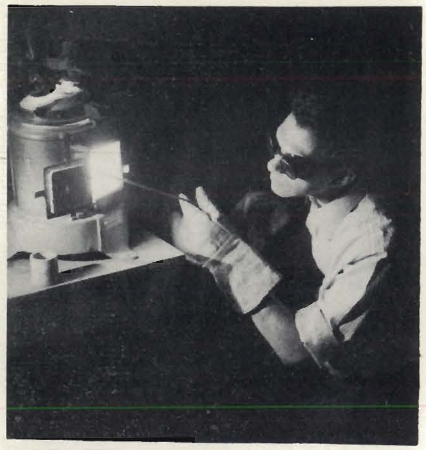
The Impact Basin at Langley is designed to simulate conditions of rough water landings for investigation of stresses and pressures on seaplane floats and hulls.

Aircraft Loads Calibration Laboratory

The Aircraft Loads Calibration Section is equipped to apply loads to complete airplanes, including the largest bombers, to determine characteristics of actual aircraft structures under applied loads. This work is closely connected with flight loads research. Aircraft instrumented for flight loads research are subjected to measured loads in the laboratory. These are then correlated with the readings given by the instruments. In this way the loads measured in flight can be known exactly. Information brought back from flight tests is interpreted in the loads laboratory in relation to the known characteristics.

Impact Basin

Water landing impact loads can be reproduced with accuracy and control in the Impact Basin. It is equipped with a wavemaker that can produce waves of any size up to over 3 feet in height and 60 feet from crest to crest. Landing of a model or float from the catapult can be timed so that the landing will take place at any point in relation to the wave. The basin is 360 feet long, 24 feet wide, and models or floats up to 2,400 pounds can be landed at speeds up to 70 mph with controlled vertical speeds and simulated wing lift. It is used for accurate measurement of landing forces and pressures, on float and hull bottoms, and has greatly aided in hull stress analysis.



CONSTRUCTION AND MATERIALS

The ultimate aim of aircraft structural research is twofold; to decrease the weight and to increase reliability of the structure. Decrease in weight must be carried much farther than in other branches of engineering, because the cost of air transportation is critically dependent on a high ratio of payload to dead weight of structure. Reliability is imperative because even minor structural failures may be fatal to the airplane and all its passengers.

The first step in strength analysis of any structure is calculation of the internal stresses caused by applied loads. Existing methods for calculating the stress distribution apply only to simple types of structures. The shell type of structure used for aircraft consists of an intricate assembly of skin, longitudinal stringers and transverse ribs. The external shape of the structure is dictated by aerodynamic considerations and does not follow simple mathematical laws. Although considerable progress has been made in the last five years in developing methods for finding the stress distribution in shells, much additional work remains to be done to achieve the degree of accuracy necessary for aircraft work.

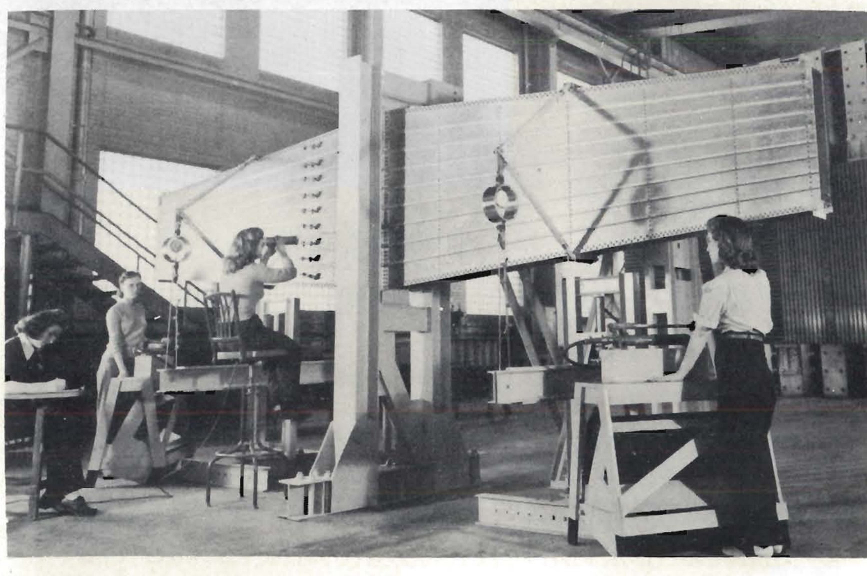
Experimental and theoretical work on structures is carried on at the Langley Laboratory. Testing equipment includes four machines capable of exerting the great stretching or compressive forces required for structural testing at large scale. The largest machine has a capacity of more than 600 tons. There are also wide varieties of special jigs and instruments developed by men of the NACA to adapt standard machines to special research needs.

One specialized NACA apparatus is a combined load testing machine capable of applying a twisting force with either tension or compression.

In order to conduct experimental research on structures in an efficient and scientific manner, a considerable amount of supporting work is in progress on the properties of materials actually used in these investigations. The immediate purpose of this work is to furnish detailed data for the proper evaluation of experimental data on assembled structures; the general purpose is to improve understanding of the fundamental relations between properties of materials and behavior of structures, so that the behavior of a structure may ultimately be predicted from a general theory of structures and a knowledge of the material properties.

Research on structures materials is a specialized adjunct of aeronautical research and one for which many organizations in the country are already well equipped. For this reason most of this work is accomplished through research contracts with properly qualified groups. Much university research falls in this class.

The most urgent problems in materials are met in the propulsion field, particularly in relation to high temperature. The research conducted by the NACA on this subject is treated under Propulsion, Materials and Stresses, which will be found on page 30.



The Structures Research Laboratory at Langley is equipped for study and analysis of structural stresses to provide more complete design knowledge for aircraft.

PROPULSION

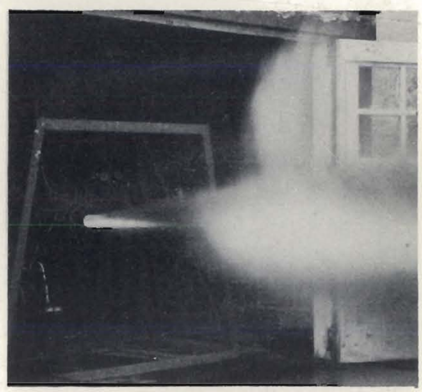
Intensive research activity in the past few years has resulted in a more rapid advancement of propulsion systems that at any previous period in aeronautical history. A transition from investigations for peak development of the reciprocating engine to fundamental research work on new high-speed propulsion methods has been in progress. The period has been marked by the development of reciprocating engines of high power and efficiency and by the birth and development of gas turbines, ram-jets, and rocket engines. Many of these achievements can be traced directly to the expansion of research effort in this country in the field of propulsion.

The NACA operates a complete propulsion research laboratory in Cleveland, Ohio. With exception of fundamental investigation of combustion and detonation, propulsion research is now entirely devoted to new types of jet-propulsion systems, including rockets and turbine systems. Facilities are provided to reproduce every kind of operating condition of temperature and altitude.

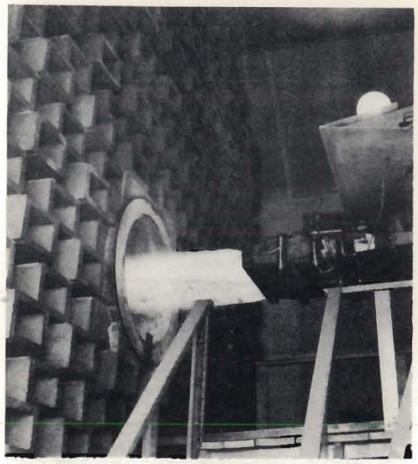
A majority of the propulsion research at Cleveland is conducted in the huge Engine Research Building, which contains nearly a hundred different research laboratories devoted to the study of all elements of aircraft power plants. To mention a few, there are numerous engine, compressor and gas turbine dynamometer laboratories, jet propulsion burner laboratories and altitude chambers for investigating engine accessories at low temperatures or air pressures. There are laboratories for research on gear and piston mechanisms, fuel and ignition systems, engine controls, and bearings of all kinds. Still other laboratories are devoted to fundamental and objective research on problems of heat transfer, metallurgy, lubrication, combustion, waste heat recovery, vibration and stress of engine parts and ice formation in engine-induction systems.

The nerve center of this vast operation is a main control room in the mezzanine basement of the building. From this small room, one man can dispatch power, cooling air, cooling water, and provide reduced air pressures and temperatures which makes it possible to run tests on engines and components under simulated altitude conditions.

Other facilities include the Fuels and Lubricants Building, Altitude and Icing Tunnel group, Jet Propulsion Static Test Stands and the High Pressure Combustion Laboratory for rocket study.



A research rocket being tested at the Flight Propulsion Research Laboratory.



COMBUSTION

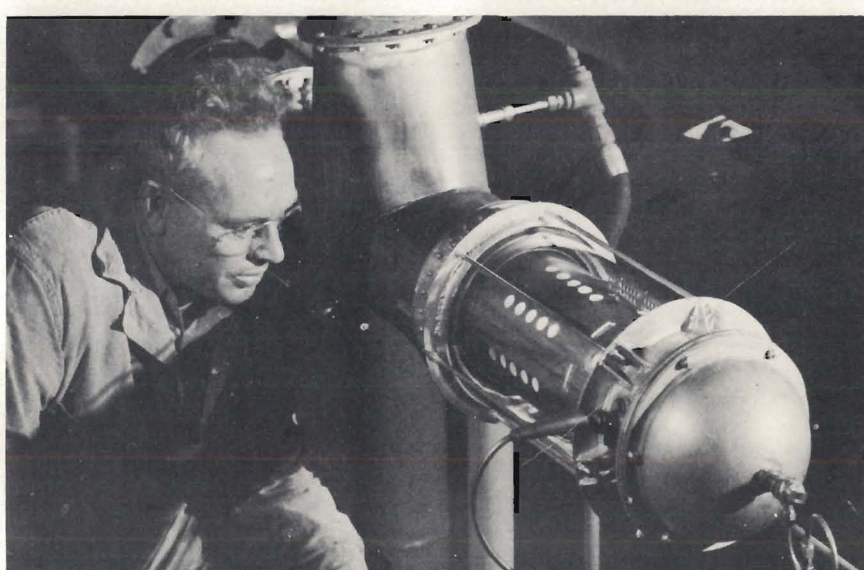
The combustion research program at the Cleveland Laboratory is directed mainly toward fundamental combustion problems of jet-propulsion engines. The research program is based on two broad overall objectives: One, to obtain generalized results and conclusions about combustion that will be applicable to design, operation, and related problems currently encountered in aircraft engines. Work of this sort might be considered short range, although it will continue with constant modification as it keeps pace with the continually developing status of aircraft engines; two, to secure step-by-step information on the eventual physical-chemical explanation of combustion, irrespective of any immediate practical application of the information to engine design. This research is long range. The intent is to find the new knowledge and the new theories that permit application to new developments. It is recognized that these two objectives are not mutually exclusive; a project aimed at one will generally contribute something to the other.

Much of the combustion research pertinent to specific applications is conducted with specific burner units. This work is of fundamental value because there are problems pertinent to the aircraft engine that can only be solved in the actual combustion chamber. Also, the work with these chambers provides a valuable background of information from which to proceed with more basic studies.

Facilities for combustion research are located in the Engine Research Building at the Cleveland Laboratory. This building is equipped with a wide variety of test cells. An extensive air supply system provides large volumes of air over a range of pressures and temperatures. These conditions of altitude can be separately controlled and varied, permitting isolation of different factors that influence combustion. Investigations made possible by these facilities have provided the first definition of the limitations imposed by altitude on combustion. From this it is now possible to explain the behavior of turbo-jet engines at altitude and to improve their capabilities.

Another important tool of combustion research is the NACA high-speed camera. This instrument can record combustion processes at the rate of 400,000 frames per second. It has been used in study of detonation, and is being applied to study of continuous cycle combustion.

A new high-pressure combustion laboratory devoted to rocket combustion problems is well established, and is being expanded to help encompass the pressing new problems of rocket propulsion.



Study of combustion in turbo-jet engine combustion chambers provides basic data on combustion characteristics of fuels and burner units under varied conditions.

FUELS

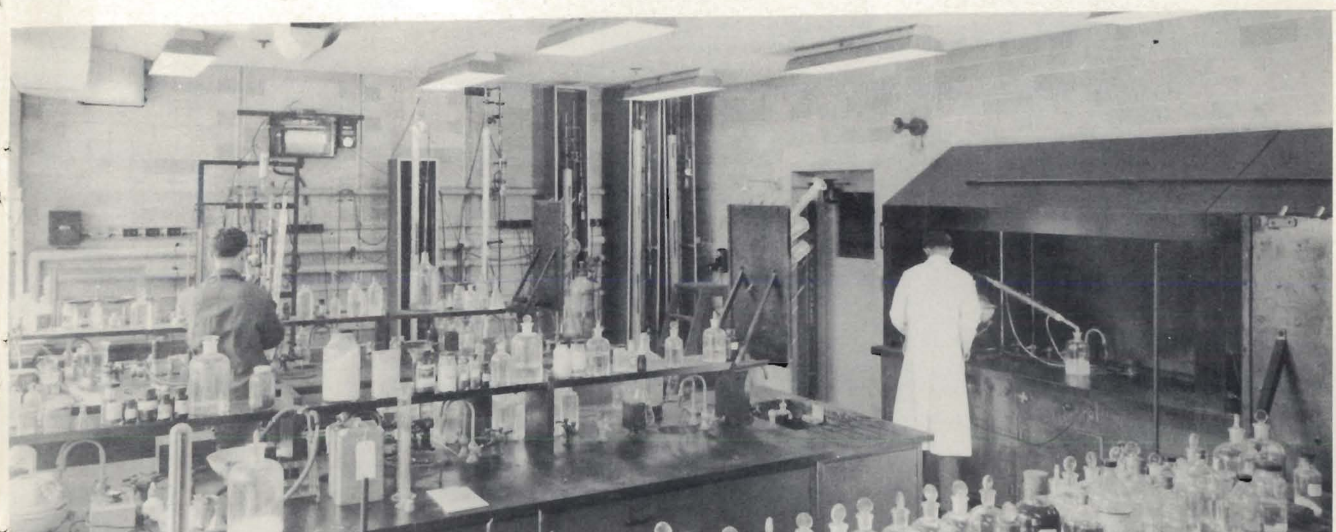
Turbo-jet, turbo-propeller, and ram-jet engines have similar fuel requirements, for in each type of engine the fuel is sprayed into a rapidly moving air stream and the combustion takes place continuously at a relatively low pressure. During the early stages of development of these engines, little attempt was made to improve the characteristics of the fuel Now, however, the special requirements are fully recognized.

Most jet engines are installed in high-speed aircraft which have very small fuselages and thin wings, greatly restricting the space available for fuel tanks. An investigation is under way to find liquid fuels which will occupy less space for a given energy content than do conventional fuels. Such fuels would result in greater range for existing jet-engined aircraft, or greater speed for new designs. In the case of ram-jet engines designed to propel aircraft at supersonic speeds, attainment of long-range flight will depend on development of fuels giving energy releases in excess of those possible with fuels derived from petroleum. Here investigations must be conducted on metallic and other non-hydrocarbon fuels.

With increasing prospects for the use of rocket power, intensive research is in progress on rocket fuels that will provide greater thrust and greater endurance for increased range. Rocket fuel research facilities are being constantly expanded and have already made possible advances in this new field.

Research on other engine fuels is conducted in the Fuels and Lubricants Building, where chemical analysis and synthesis of new fuels is performed in correlation with combustion research. The objective is to gain basic knowledge of fuel structure and characteristics.

Research on fuels makes extensive use of the sciences of chemistry and physics. The Fuels and Lubricants Building contains well equipped chemistry and physics laboratories where fundamental research is conducted on aircraft fuels and lubricants. Rare fuels, unobtainable commercially, are synthetically produced in glass-lined reactors and purified in three-story-high distillation columns. The laboratories are equipped with the latest in spectographic apparatus, an electron microscope capable of 30,000 diameter magnification, special equipment for studying combustion and other advanced research tools.



Chemical synthesis and analysis of special research fuels is conducted in well equipped chemistry laboratories. Other equipment includes spectroscopes and electron microscopes, used in correlation of fuel composition with performance.

THERMODYNAMICS

The thermodynamic research conducted by the NACA in relation to propulsion systems may be classified under three headings:

Properties of Gases, concerned with basic study of thermodynamic properties of the working fluids in aircraft engines.

Heat Transfer, concerned with all cooling and heating problems.

Cycle Analyses, concerned with evaluation of performance and capabilities of engine types and components.

Properties of Gases

The design of efficient aircraft engines that involve the use of a gas turbine as the principal source of power or as an auxiliary, and analysis of the performance of such engines, depend on a knowledge of the thermodynamic properties of the working fluids. Much of the work concerns calculation of the thermodynamic quantities involved in the steady flow processes of jet engines.

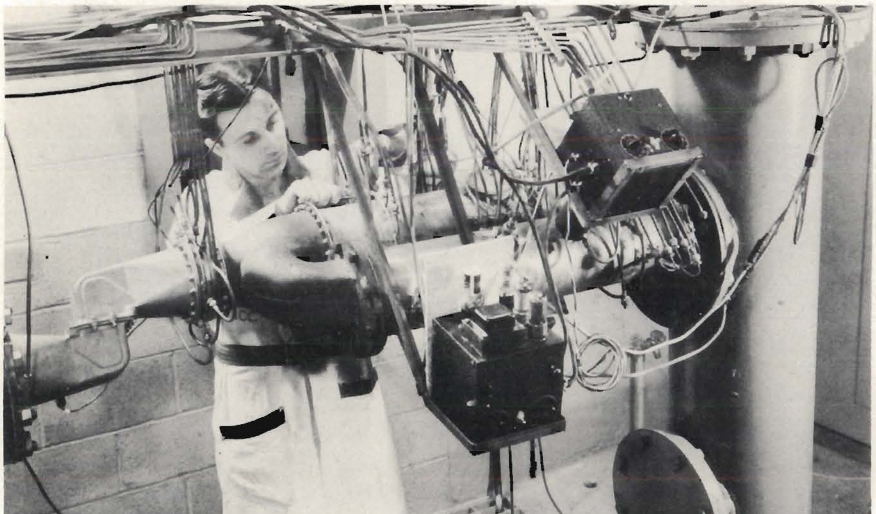
Heat Transfer

All problems of exchange of heat between gases and materials come under the heading of heat transfer. Some of the most important research conducted by the NACA has been in the field of engine cooling. Basic information has been established on the heat transfer rates of various fluids. Important new branches of cooling research are turbine cooling and rocket cooling. The immediate gains possible through increasing operating temperatures in these engines are so large that this phase of cooling research, combined with research on materials, is of great importance.

Thermal ice protection of all aircraft engine and components depends on knowledge of heat transfer rates and efficient heat exchangers. Design knowledge of compact, large capacity heat exchangers was a necessary prerequisite to the development of thermal ice prevention systems now coming into use. Continued thermal ice prevention research is being carried on in relation to jet engine induction icing.

Cycle Analyses

Profitable expenditure of research effort on new engine types and engine components must be planned in relation to probable immediate and long-range gains. Analyses of various engine cycles aid in defining necessary fields of research. Cycle analyses also map the probable range of application of engine types on the basis of performance, weight, size, and operating characteristics. Careful evaluation of all engine processes is needed to determine the compromises necessary in engine components in relation to weight, size, speed, and efficiency. Promise of advances in performance and fuel economy lie in new combinations of heat regeneration and reheat between turbine stages.



Thermodynamic research involves accurate measurements of heat processes in engines and components. Here an engineer adjusts combustion chamber thermocouples.

COMPRESSORS

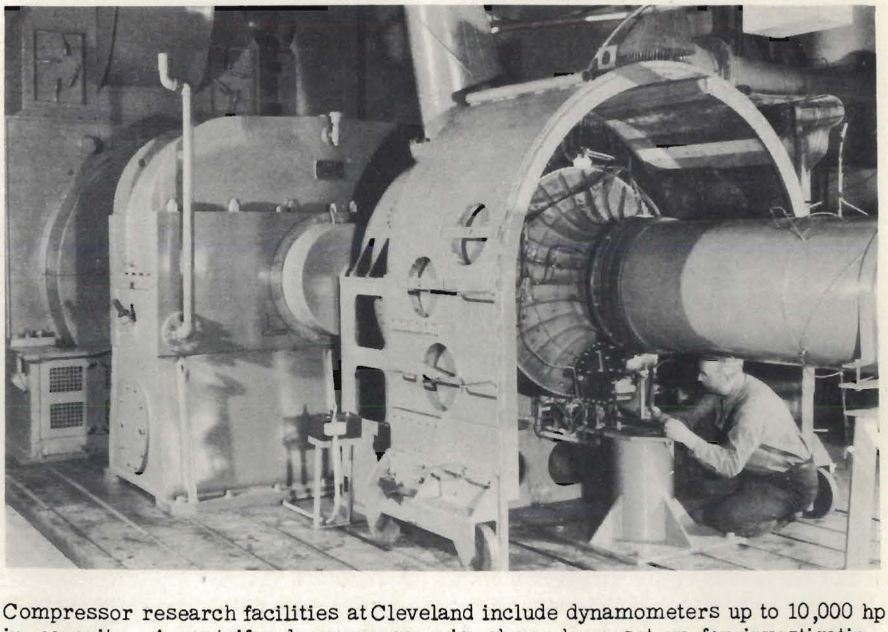
Because of the increased importance of compressor-turbine engines in the field of aircraft propulsion systems, an urgent need exists for fundamental research on all phases of compressor development. While maintaining its conventional role with regard to reciprocating engines, the compressor stands not as an accessory but as a major integral part of either the turbo-jet or turbo-propeller engine. In such installations the compressor serves the vital function of taking in a very large quantity of air, compressing it efficiently, and delivering it at high pressure to the combustion chamber and so to the turbine. A compressor-turbine has therefore greatly increased the demands made upon the compressor. Increases must be effected in capacity, pressure ratio, efficiency and reliability. The developments of the past several years alone have led from the reciprocating engine compressor, which was of the order of 500 horsepower, to present compressors for turbo-jet or turbo-propeller engines which absorb up to 10,000 horsepower. Very recent developments have resulted in compressors of nearly 15,000 horsepower, with future expectations far surpassing this value. Each of the three types of commonly-used compressors (axial flow, mixed flow, and centrifugal flow) have certain inherent advantages that may be exploited in specific installations. The NACA is conducting research along all three lines, as well as on some radically new ideas.

The fundamental problems of compressor design are primarily aerodynamic in character and are quite complicated because of the involved nature of the flow paths, the effect of non-steady flow, viscosity, and compressibility. Because of these inherent difficulties, present theory is inadequate, and it becomes necessary to look for new data and new theories that will be capable of application to compressor design.

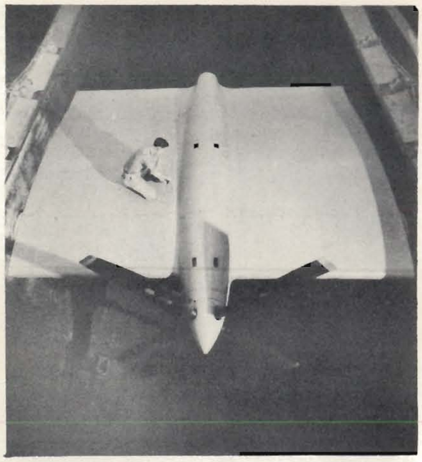
Intensive research on all the interrelated phases of compressor design and performance promises notable improvements in the performance of future propulsion units and the airplanes in which they will be used.

Compressor research is also conducted in the Engine Research Building, where study is aided by exceptionally well-equipped test cells, and the large air supply that also serves combustion research units.

Facilities for compressor research are located in the Engine Research Building at the Cleveland Laboratory. The central air supply and refrigeration systems that serve the combustion and altitude research facilities are also available for compressor research. Test cells are provided with dynamometers up to 10,000 horsepower in capacity for driving research compressors. Inlet air temperatures and pressures can be controlled and varied to duplicate the desired conditions of operation. Specially built research compressors have been devised to permit isolation and study of design variables, such as blade angles.



Compressor research facilities at Cleveland include dynamometers up to 10,000 hp in capacity. A centrifugal compressor is shown here set up for investigation.



TURBINES

In its position as one of the major elements of the compressor-turbine engine, the gas turbine represents an unusually great research challenge and involves problems the solution of which are vitally important to further development.

The demands made upon the gas turbine are greatest in its role as a component of the turbo-propeller engine. In the turbo-jet engine, the turbine need extract only enough energy from the gas to drive the compressor. The turbine installed in the turbo-propeller engine, however, is called on to drive not only the compressor but the propeller as well. The magnitude of these requirements may be illustrated by considering the turbine that would be needed in a 5,000 horsepower turbo-propeller engine. In addition to the 5,000 horsepower delivered to the propeller, about 15,000 horsepower would be needed to drive the compressor and account for losses. The turbine would therefore have to develop about 20,000 horsepower. Such installations represent great strides from the 500 horsepower turbine of the typical turbosupercharger on the reciprocating engine.

Foremost among turbine problems is that of increasing its efficiency, an improvement which affords a nearly directly proportional increase in engine efficiency. The most promising areas for research leading to future increases in turbine efficiency are in aerodynamic and thermodynamic improvements. A more detailed knowledge of the actual flow conditions through the turbine, an aerodynamic problem, is necessary to establish improved design methods. In addition, it is necessary that design principles and theory be developed to the point where the turbines will perform according to the design predictions. Theoretical and experimental studies are therefore in progress whose objective is to obtain basic aerodynamic information on the flow through turbine blades. Aside from the study directed toward the flow through a single stage, considerable effort is being expended on the equally important problem of determining the interaction of successive stages.

The net output and efficiency of a turbine is increased appreciably by an increase in the gas temperature at the turbine inlet, when accompanied by a corresponding change in pressure ratio. Two methods are available for increasing the allowable gas temperature: Development of materials which will withstand operation at increased temperatures; and providing means for cooling the turbine blades, thereby maintaining present blade materials within allowable limits while using hotter gases. Ceramic materials, which are known for their ability to withstand high temperatures, are among the logical materials for use at high turbine temperatures, and their application to turbine blades is being investigated.

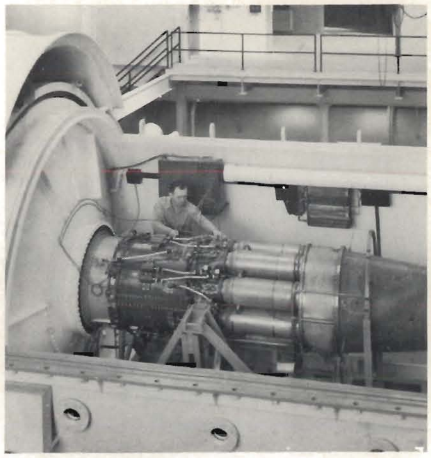
Various methods of cooling are also under intensive study. Experimental test units are being used to investigate the cooling methods that have been favorably indicated by analysis. Heat transfer effects, direct blade-cooling methods, determination of optimum blade shapes for internal cooling, use of cooling fins, and evaluation of the merits of various cooling fluids are being investigated.

In addition to the fundamental problems involved in the performance of the turbine itself, there are many factors which arise when a turbine is combined with the other components of the compressor-turbine engine. The turbine research program includes investigation of over-all performance of the turbine itself and the performance when combined with any of its various components.

Turbine research facilities are also located in the Engine Research Building, where large refrigeration machines, air pumps, exhaust gas coolers and evacuators make it possible to duplicate any condition likely to be encountered in flight.

Turbines are studied to improve heat resistance, strength and performance.

PERFORMANCE OF COMPLETE SYSTEMS

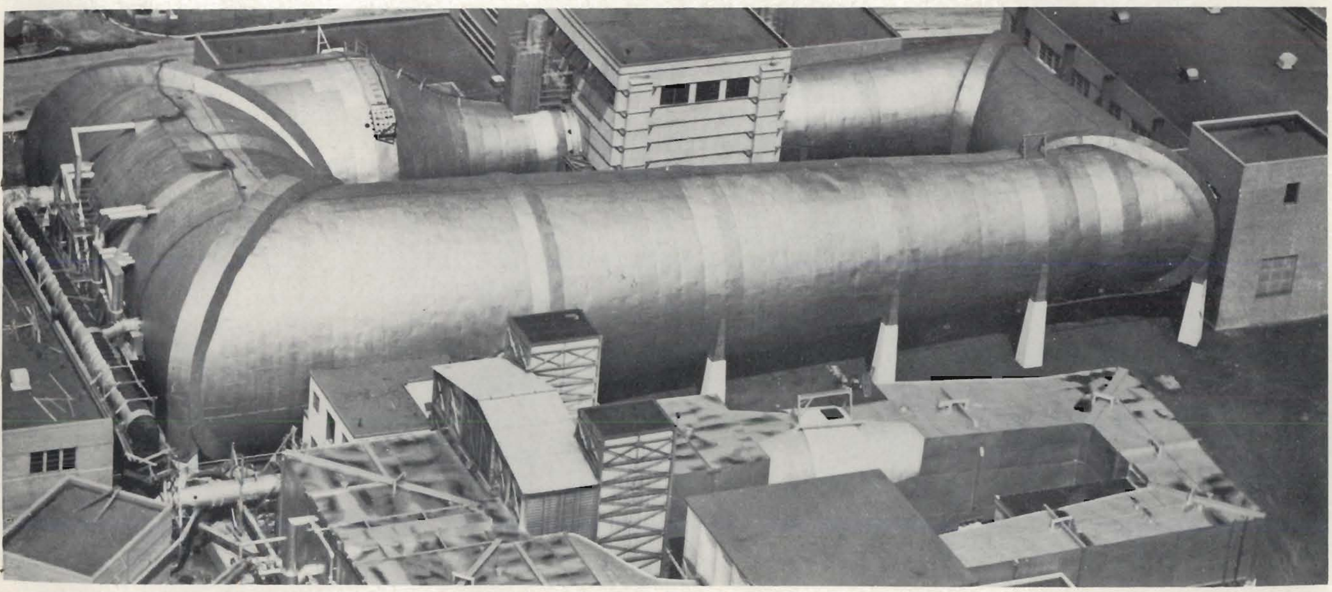


Evaluation and test of complete propulsive systems is necessary both to find out what a given engine will do under various conditions and to assess and integrate the basic work on the various components that has preceded. Facilities for handling all types of engines are available. The Engine Research Building houses numerous test cells for complete engines. The Jet Propulsion Static Test Unit is equipped to study turbo-jet engines. There are also engine-propeller test houses for both reciprocating and turbo-propeller systems, as well as rocket pits for investigation of rocket combustion and performance.

An important facility is the Altitude Wind Tunnel, in which jet and turbo-propeller engine installations can be studied in operation under simulated altitude conditions. The tunnel provides pressure altitudes up to 50,000 feet, temperatures down to minus 48 degrees Fahrenheit and speeds up to 500 mph. By use of special ducting, jet units can be investigated at supersonic speeds, enabling study of large ram-jet engine types.

Additional altitude chambers are available that are capable of reproducing approximately the same conditions of altitude as the Altitude Tunnel. The air supply system can provide ram-air pressures equivalent to high flight speeds. These facilities amplify the laboratory's capacity for research under simulated altitude conditions.

One of the many important developments from NACA engine performance study is thrust augmentation, by any of several means. These have achieved thrust increases up to 40 and 50 per cent of the original engine thrust. In combination with improved duct design, thrust augmentation made possible the high speed of the P-80-R which first broke the British speed record.

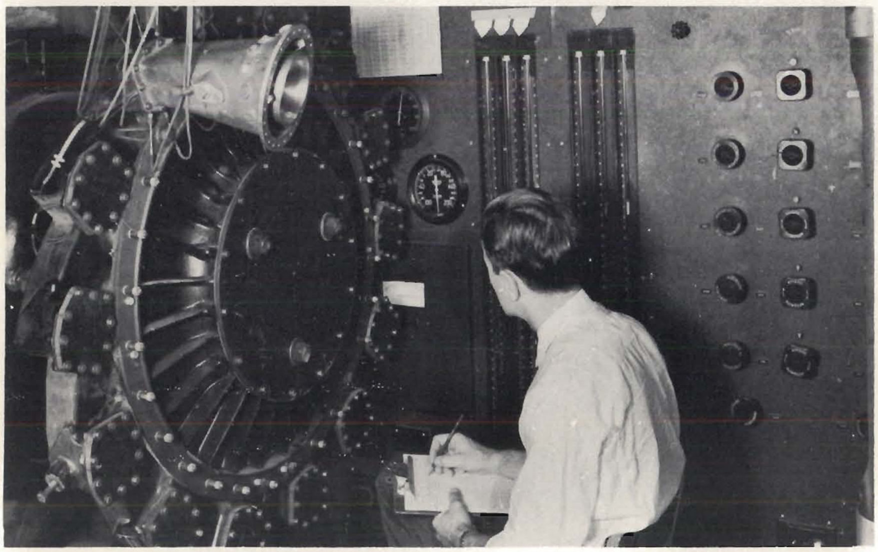


The Altitude Tunnel (background) at Cleveland enables investigation of complete propulsion systems in operation under altitude conditions. The Icing Research Tunnel (foreground), provides icing conditions for aircraft components and engines.

MATERIALS AND STRESSES

All aircraft engine designs could be greatly improved if the designer had a wider range of materials from which to choose, a more definite knowledge of the properties of materials, and how these materials will behave under any given set of conditions. For example, an increase in the operating temperatures of aircraft engines would increase the over-all power output from the unit and thus require less fuel for a given performance specification; the advent of new high-temperature materials would place this goal within the designer's grasp. Again, if operating stresses in various engine components were accurately known, it might be possible to reduce appreciably the mass of these parts and effect a saving in power absorbed in driving the engine; this would also be reflected in greater fuel economies, as well as in increased performance.

In order to improve current engines, an extensive program of evaluation of present high-temperature materials is being conducted. Fundamental research is under way on the basic reasons for the relative performance of heat-resisting materials in general, the mechanism of failure, the roles played by precipitated particles and mechanical and thermal treatments of materials, and the effect of protective coatings on turbine components. The laboratory is conducting a program aimed to extract basic experimental data such as the effects of elevated temperature on pure materials, and equilibrium data on alloy systems suitable for high-temperature use. Other research is under way for study of conservation of critical alloying elements in high-temperature materials.



Materials which go into turbines, compressors and other critical parts of new engines are studied for development of superior resistance to stresses and heat.

The general aim of the program on engine stresses is to obtain a more complete knowledge of permissible operating stresses and actual operating stresses of present designs of aircraft engine components. Studies have been undertaken on centrifugal and thermal stresses in turbine discs, and thermal and centrifugal vibratory stresses in turbine and compressor blades, with the aim of improving design of parts or substituting materials of equivalent thermal strength and superior mechanical properties. The main problem in this field is to evolve methods of measuring and recording operating or residual stresses in engine parts to confirm speculations. Projected research will involve engine balance and critical speeds, ducting, bearing, gear and valve vibration surveys, and investigation of the mechanism of failure of materials.

Facilities are provided in the Engine Research Building for investigation of vibration, effects of high temperatures, and study of material structure through use of electron microscopes.

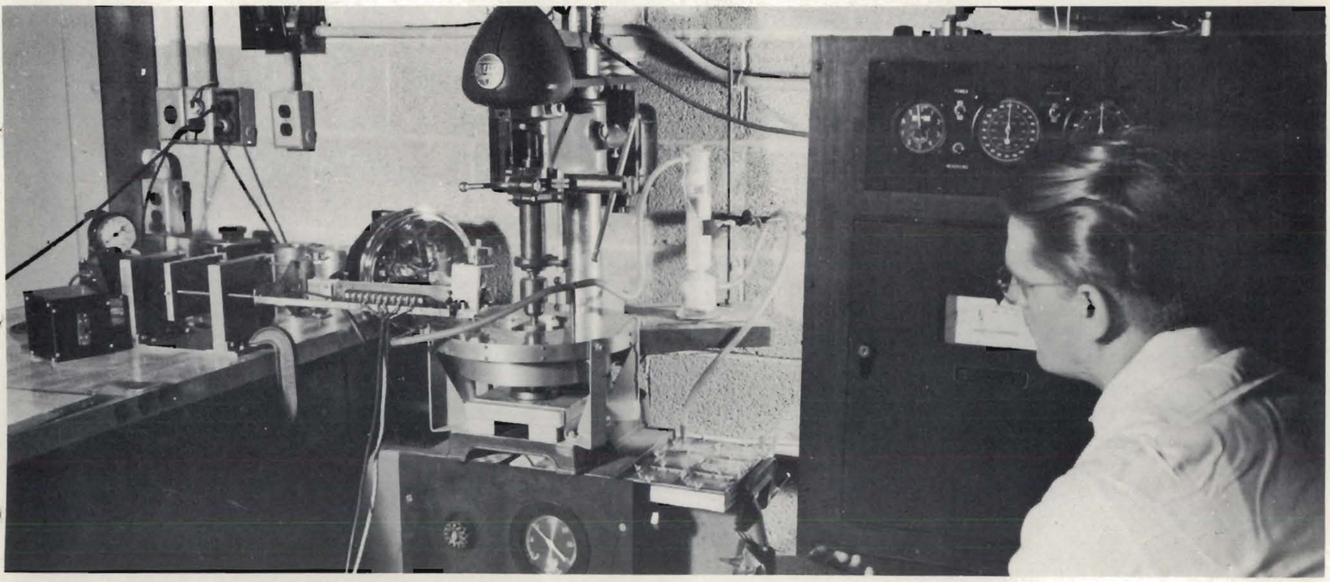
LUBRICATION, FRICTION AND WEAR

Previous research in the field of lubrication and friction has resulted in much useful information. However, much of this data is of an empirical nature, and truly fundamental information is required to help in extending the present data into the range of higher speeds and greater loads. The problem of high-speed bearings is an example of a field in which more research data of a fundamental nature are needed to extend present low-speed data into the speed range of 10,000 to 50,000 rpm. The problem of sliding and rolling friction also illustrates this point; there is a definite lack of information on the exact nature or mechanism of failures occurring in surfaces subjected to rolling and sliding. The complex behavior of plastic materials under the repeated surface stresses set up by rolling and sliding friction is, at present, far from being understood; consequently, a study of the fundamentals involved is needed in order to shed light on possible basic methods for alleviation of failures.

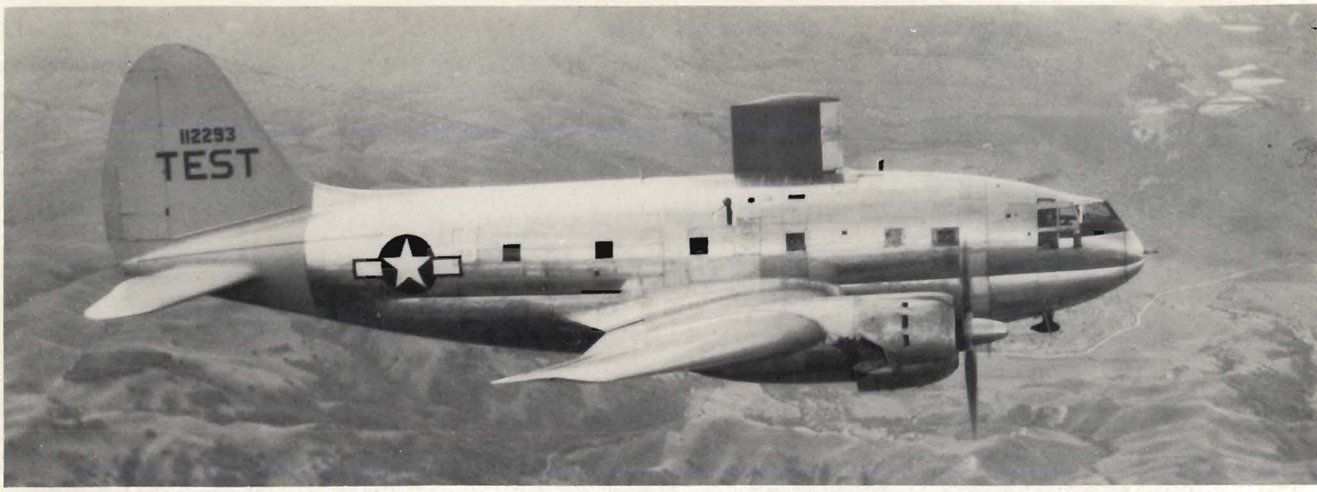
Problems met in connection with compressor and turbine bearings illustrate how new engine types can complicate an old problem. The compressor-turbine unit is heavy, imposing high loads over large bearing areas at high rotative speeds. The bearing thrust loads imposed by reaction forces are large and are further complicated by inertia loads caused by rapid accelerations and by gyroscopic forces.

Other typical problems are "run-in" of surfaces and the characteristics of various lubricants.

Research on basic friction and wear problems is carried on in the Engine Research Building. General and special devices are evolved as the need arises to meet any particular question. Backed by extensive service and the finest of machine shop facilities, scientists of the laboratory are ready to solve any problem incident to the research.



The basic problem of what happens to surfaces subjected to different types of friction is investigated in many ways to obtain knowledge on how to improve bearings and reduce wear. Test setups are improvised to provide the desired conditions.



An NACA icing research airplane, flown in investigation of thermal ice prevention on wings, tail surfaces and propellers.

OPERATING PROBLEMS

Important problems of aircraft operation during recent years have been icing, gust loads produced by atmospheric turbulence and landing loads. The latter includes both normal landing loads and emergency water landings of landplanes, popularly known as ditching.

The NACA thermal ice-prevention system provides a means for virtual elimination of icing hazards to aircraft powered by reciprocating engines and propellers. Research over a period of years, culminating in more than two years of safe flight research through icing conditions has proved the system and provided enough information to protect any properly equipped airplane from danger of icing. Recognition of this achievement was highlighted by award of the Collier Trophy for 1946 to Mr. Rodert, NACA engineer who headed the research program. Most new airplanes of the transport type incorporate thermal ice-prevention systems.

Icing problems of jet engines, however, remain to be thoroughly solved. Axial flow units are particularly vulnerable, and means of protection for these and other types is a subject of continued research at the Cleveland Laboratory.

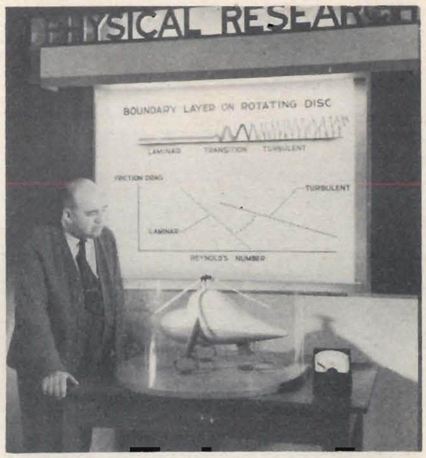
In addition to flight research facilities, the NACA has designed and built an icing research wind tunnel capable of furnishing 1,500 tons of simulated rain per 24 hours, refrigerated to provide almost any freezing condition at airspeeds up to 435 mph. This tunnel is used to study icing on aircraft components such as air ducts and inlets, radio antennae and pitot tubes. Downstream from the test section a complete airplane, without outer wing panels, can be mounted and studied under icing conditions with engine and propeller operating.

NACA research on turbulence and gusts has resulted in a large amount of data on gust structure and occurrence. The NACA began research in thunderstorms in the early 1930's. Records of gust loads from air routes all over the world have been made by means of the NACA V-G recorder, which records maximum accelerations as a function of the airspeed. The problem of gust loads increases in importance with increase in airplane speeds, and much knowledge remains to be gained about gusts and how to alleviate the loads.

Ditching investigations, started on military and transport landplanes during the war, continue on new military types and transports in order to establish operating procedure, to develop safety devices and modifications and to make recommendations on the structure where necessary.

Research on cabin heating and cooling and ventilation becomes of added importance as airplane speeds increase. Even high subsonic speeds bring the need for cockpit cooling. Looking ahead to supersonic flight, many problems of cooling and heat radiation come into play, not only in relation to pilot and passengers but to protect the airplane structure itself. The temperature rise accompanying supersonic speeds may well be the first limiting factor to high-speed flight. The questions of balance of friction heating and heat radiation must be answered before cooling requirements can be determined. This is one of many new problems posed by high-speed flight that calls for new approaches and vigorous, inventive thought.

PHYSICAL RESEARCH



Much of the study of fundamental physical phenomena involves purely theoretical analysis. Theoretical study is often sufficient to provide adequate design criteria, but in many cases it serves rather as a guide for experimental investigations.

Because of the abstract nature of some basic physical problems, and the importance of securing generally applicable knowledge about them, the NACA has established a Physical Research Section at the Langley Laboratory to conduct a large amount of the fundamental theoretical work involved in other branches of research. Typical problems attacked in this section are high-speed flutter, propeller flow theory, compressible flow theory, boundary layer mechanics, and helicopter vibration.

In the course of study of basic physics, many original devices and processes have been created. One of these was the first use of Freon 12 in aerodynamic study. The speed of sound in Freon is about half of what it is in air, therefore Mach numbers of 1 and higher can be provided with less power and at lower stream speeds than with air.

The division has facilities to provide experimental data on certain basic subjects, including a Flutter Wind Tunnel for investigation of aerodynamic flutter at high speeds and a free-flight apparatus for study of reactions of various bodies traveling freely at high speeds.

Free-Flight Apparatus

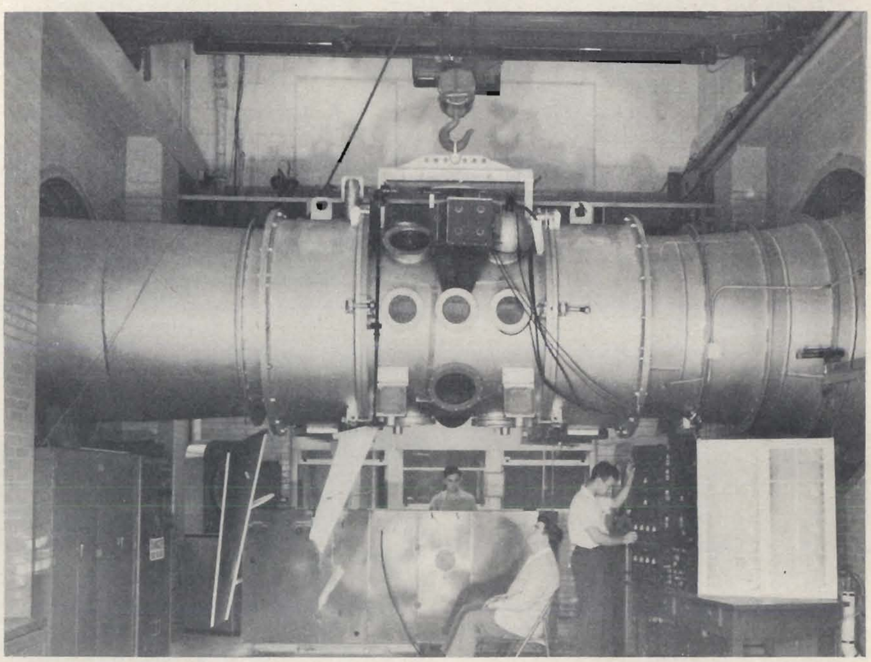
Tank 100 feet long, 8 foot diameter

Provides information on lift, drag, and stability of bodies propelled from compressed gas gun at velocities between 500 and 1,000 miles per hour

Test Medium: Air, Freon, or mixtures

Flutter Tunnel

Test Section	4 1/2 ft., circular, closed
Speed	M 0 to 0.90
Power	1,000 hp
Pressure	0 to 1.8 atmospheres
Test Medium	Air, Freon, or mixtures



The Flutter Tunnel is one of several pieces of special equipment used for study of basic physical phenomena such as high-speed vibration and flutter of wings.

FLIGHT AND PILOTLESS AIRCRAFT

Pilotless aircraft research by means of rockets has grown into a special, important branch of flight research. Through the use of many kinds of rockets, vital information has been obtained all through the speed range up to Mach numbers of 2 or more. In addition to basic wing and body studies, investigations are carried out on automatic stability and control of guided missiles and on high-speed flutter. Dynamically scaled models of actual aircraft are also studied in free flight for characteristics at high speeds in anticipation of piloted flight. This branch of research is one of our most valuable assets in reaching out ahead of man's present abilities, to find out what problems we shall run into and how to solve them.

The NACA Pilotless Aircraft Research Station, located on the seacoast of Virginia, is equipped with a variety of rocket launching, handling, and controlling equipment. Rocket vehicles and models are built in the shops at Langley Field, and transportation by air and boat links the rocket station with the laboratory.

Actual flight research is indispensable on general aerodynamics, stability and control and performance under conditions of speed, power, altitude, and accelerations not capable of simultaneous duplication in existing wind tunnels. Flight research provides the final check on any theoretical or wind tunnel findings, and extends the usefulness of wind-tunnel research by serving as a measure of verification or correction for wind-tunnel data. Conversely, wind-tunnel research provides a valuable guide in planning and interpreting flight tests.

During the war, a large amount of data had been obtained from the 16-Foot Tunnel at Ames on specific airplanes. At that time, the models were tested under power-off conditions without the effects of a propeller and application of the data to full scale, powered airplanes was under question. To furnish a direct comparison between tests on a detailed scale model of the P-51 and the actual airplane, the propeller was removed from a P-51 and the airplane was then towed aloft behind a P-63. At sufficient altitude the P-51 was released, and dive tests were made in a clean, propeller-less, power-off condition duplicating as nearly as possible the conditions simulated in the tunnel. The model had purposely been made to include the slight irregularities that are found in any service airplane. The results from these tests were in excellent agreement and established the reliability of the tunnel information. This is one of many unusual projects undertaken in flight research.

With the day of transonic flight at hand, flight research becomes even more important. Although wind tunnel speeds reach closer and closer on either side of the speed of sound, complete investigations at the speed of sound are still not feasible.

The D558-II is one of several research airplanes built for the NACA under contract to the Armed Services, for transonic flight research with piloted aircraft.

Such vital problems of scale, controls, and acceleration loads cannot yet be simultaneously studied on the ground. The answer to this situation was foreseen by the NACA in 1944. In March of that year the NACA proposed the plan that has resulted in practical transonic research airplanes like the XS-1 and the two phases of the D558, all built for and flown in NACA flight research.

Flight research projects include propeller surveys, helicopter flight, handling qualities, and a wide variety of airfoil and control research work at full scale.

Special methods in the high-speed field are NACA wing-flow tests and free-fall body tests. By the NACA wing-flow technique models are mounted in the region of high-speed airflow on a high-speed airplane wing, with recording instruments underneath. Aerodynamic measurements can then be made from low speeds continuously through the speed of sound up to a Mach number of 1.2 or more. Use of free-fall bodies, dropped from high altitudes, with data recorded by radar and telemeter, provides another source of continuous transonic information, in undisturbed air, up to Mach numbers of about 1.5. These bodies are used to obtain basic drag information on various wings and airfoils, flutter investigations and body shape studies.

Launching of a Tiamat, an NACA research rocket designed to fly a predetermined course. Such rockets provide valuable data on automatic stability and control.

To carry out this broad program of flight research, the NACA maintains a flight section at each of its laboratories. NACA research pilots have to be engineers as well as highly skilled in flying, for the work involved has to be thoroughly understood and carried out with precision. The planning and preparation for flights is so careful that although many of the projects involve unusual flight procedures, virtually every flight brings back the sought-for data.

The airplanes used, generally loaned by the Air Forces or Navy, may start out as conventional aircraft, but they soon take on a new, strange look of their own. Models appear on wings; long booms with special airspeed and yaw heads grow out of wings and noses. The C-46 used in thermal ice-prevention research had a large low-drag airfoil mounted on top of the fuselage, while the B-24 used on the same project had a rebuilt nose carrying a variety of windshields to study their icing characteristics.

NACA flights have taken their research pilots into strange worlds. In the first studies of thunderstorm turbulence, the airplane was deliberately flown through thunderheads, and on one occasion was whirled up several thousand feet, to above its service ceiling, in a matter of seconds. Ever since the beginning of NACA flight research, NACA pilots have made a practice of exploring unknown regions of flight to bring back new information for increasing the performance, safety, and utility of aircraft.

Highlight of NACA flight research is the transonic flight research program, using specially designed aircraft built through contract with the Armed Services for the NACA. Using the now-national flight test center at Muroc Dry Lake, California, NACA pilots are exploring a new flight range that represents man's first steps toward flight above the speed of sound.

NACA research airplanes and pilots carry out projects in all phases of aeronautical research. Here, combustion in an experimental ram-jet is studied in flight.

PERSONNEL INFORMATION

Variety and Scope of Research

The NACA is engaged in numerous research projects designed to improve the performance, efficiency, and safety of aircraft. Unusual opportunities exist for research on new and challenging problems in all phases of aeronautics. The scope of the Committee's research program is so broad that it is not limited by conventional bounds, but encompasses all of the physical sciences.

Chemists, Metallurgists, Physicists, and Mathematicians are being employed in increasing numbers to investigate problems encountered in the realm of transonic and supersonic flight.

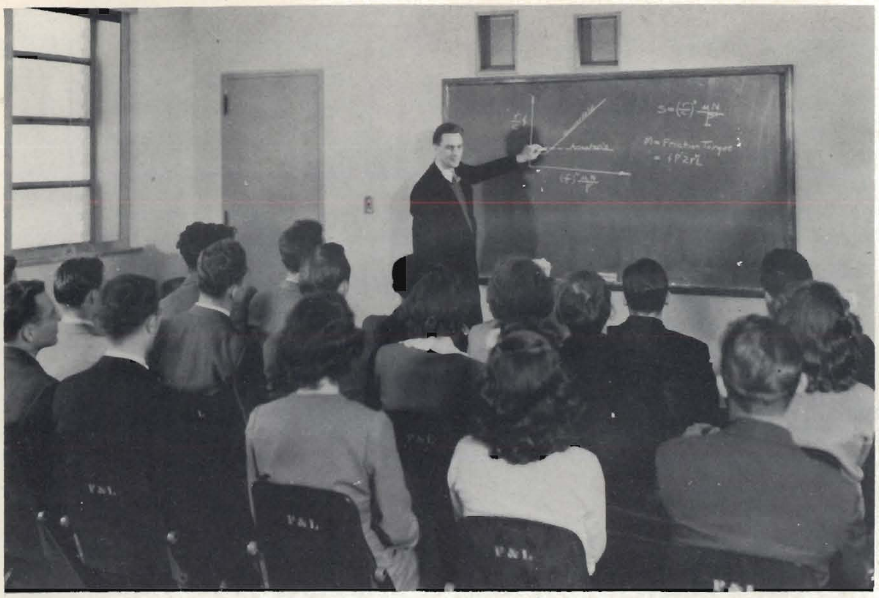
Facilities and Equipment

In forecasting the trend of aeronautical development, the NACA designs and constructs its own facilities and equipment to investigate anticipated research problems. Its laboratories, therefore, are among the most modern and well-equipped in the world, and contain many facilities that are unique in the scientific field. In addition to its laboratories, the Committee has highly developed service organizations which provide mechanical, administrative, and technical assistance to facilitate progress of the research program. Competent and well-trained craftsmen work in large modern shops with the finest machine tool equipment. Some of the equipment, such as the airfoil machine, is unique in the field. Skilled machine shop personnel, instrument makers, aircraft metalsmiths, model makers, and many other specialized craftsmen make possible unusually complete and advanced research services.

Research scientists are served by staffs of trained computers who carry the burden of mathematical load, and editorial staffs who handle the mechanics of editing research reports. Also assisting these scientists are engineering and drafting services, photographic services, illustrators, and all other technical services which to to complete the operating team of a research organization.

Placement and Promotion

The NACA has actively participated in the movement to obtain proper appreciation of the problems and requirements of scientific work and personnel in the Federal service, and to offer adequate recognition and reward for successful scientific endeavor. In addition to its efforts to promote the welfare of scientific personnel in general, the Committee constantly endeavors to make the best possible use of its own employees, through placement in the most suitable capacity.



Additional training and advancement are encouraged at the NACA, through lectures and instruction within the organization as well as outside courses with universities.

Since its inception in 1915, the NACA has increased in size from an organization of about 15 employees to one employing over 6000 personnel. Current expansion in major phases of the Committee's research program has created openings for well-qualified applicants. Scientific personnel are assigned to specialized research projects as soon as they report for duty, and are given ample opportunity to develop within their chosen field. Individuals will find no "blind alley" positions in the NACA: On the contrary, the policy of the Committee is to assure all possible recognition and advancement to those employees who merit them. In other words, promotions within the NACA may be quite rapid, depending upon the demonstrated ability and fitness of an employee to fill a higher level position.

Education and Training

The NACA encourages the educational and professional development of its employees by providing lectures and seminars to keep personnel advised of the latest developments in their own and related fields of specialization. In addition, arrangements have been made with local educational institutions to make available to NACA employees special after-hours courses offered by the engineering and scientific departments of these universities.

Professional Societies

Employees are encouraged to attend meetings of professional and scientific societies, and to take active part both in the presentation of papers and in the official conduct of society business. Where the activities at a meeting will contribute directly to the Committee s research program, selected members of the staff may attend the meeting at Government expense.

Scientific Prestige

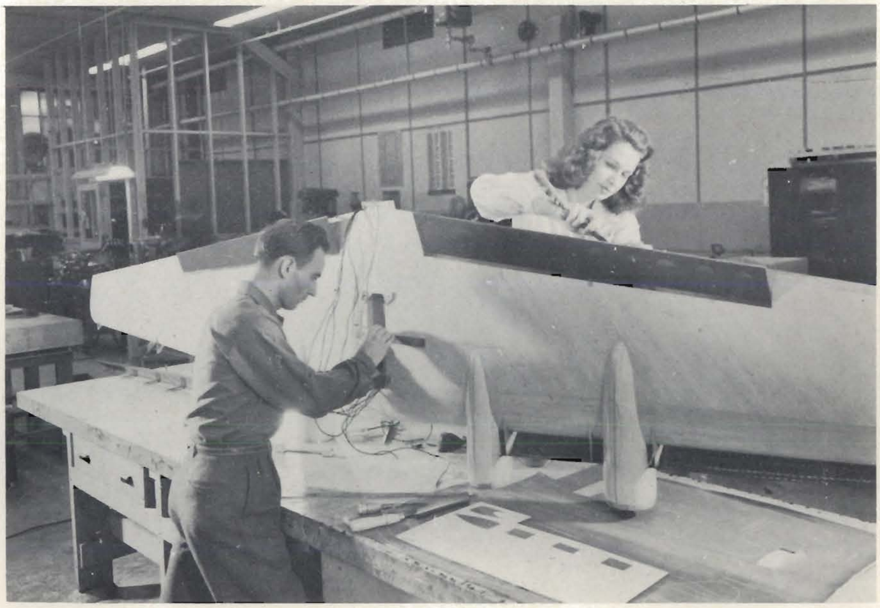
Opportunity is offered for professional association with some of the nation's leading scientists who are directing research projects for the NACA.

Technical Publications

Information obtained as a result of investigations conducted by the NACA is prepared in report form, and disseminated to the military and naval services, the aircraft industry, and others concerned. These reports are prepared by the scientific and technical personnel working on the particular research projects; therefore, ample opportunity is offered for the preparation and authorship of technical NACA reports. In addition, the Committee actively encourages and sponsors the publication in scientific and technical journals of articles based on work performed in the Committee, or on other special interests of its personnel. Such articles are, of course, subject to security clearance.

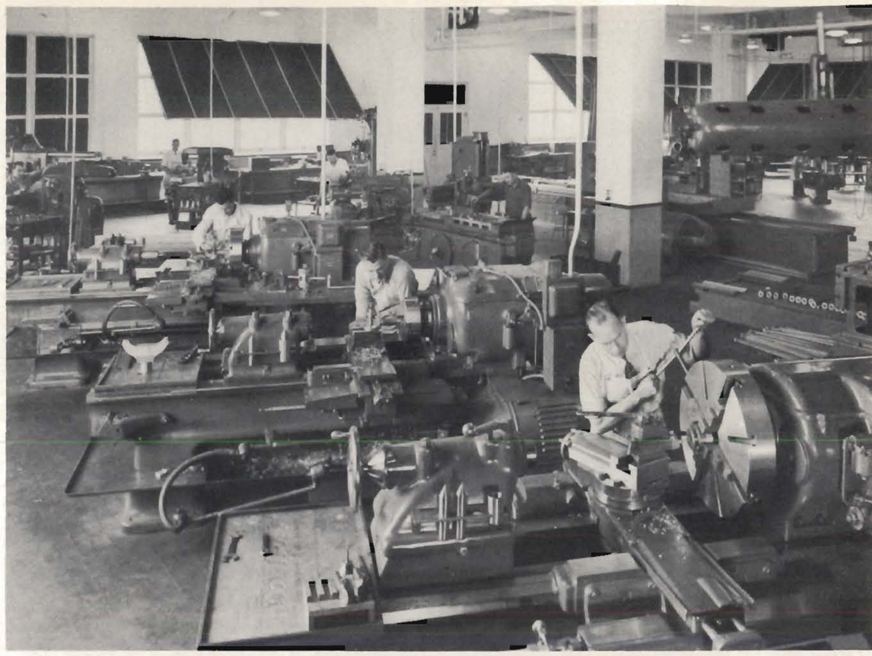
Patent Policy

The patent policy of the NACA is designed to protect the employee's rights, as well as those of the Government. Patents on inventions related to the Committee's work programs will be secured without ex-



Construction of research models requires fine craftsmanship. The model shops are well equipped and maintain a high level of workmanship among skilled employees.

pense to the inventor. The only instance in which the Government assumes full title to an invention is when the idea is integrally connected with the specific work assignment of the employee. In all other cases, the employee retains the commercial rights, or all rights, of the patent depending upon the nature of the invention.



Supporting technical services are a vital part of successful research. Modern machine shops, metal and woodworking shops are operated to meet research demands.

Recreational Facilities

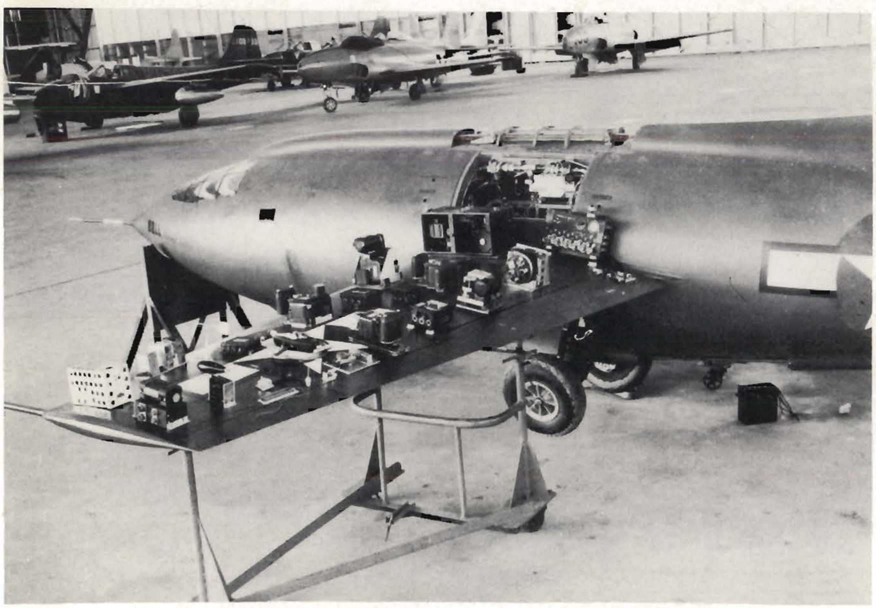
It is the policy of the NACA to encourage and support any organized activity on the part of employees which will help to maintain a high working morale Employees have formed social clubs, sports groups, musical organizations, hobby clubs and theatre groups which have a semi-official standing, and whose activities are reported in a weekly newspaper. Excellent social and recreational facilities are also offered in the communities in which NACA offices are located.

Salary Range

Entrance salaries, which are based on position duties, are determined in large measure by the qualifications of the appointee. Periodic increases are provided for employees whose performance meets prescribed standards of efficiency. Salaries are also adjusted from time to time to meet changing conditions.

Eligibility Requirements

Applicants with a bachelor's degree and one year of research experience are not required to take a written examination, but may qualify on the basis of their education and experience. Advanced scientific degrees may be substituted for the minimum experience requirements.



The reliability of NACA information has been due in large measure to the fineness of its instrumentation. Shown are NACA flight research instruments for the XS-1.

Leave of Absence

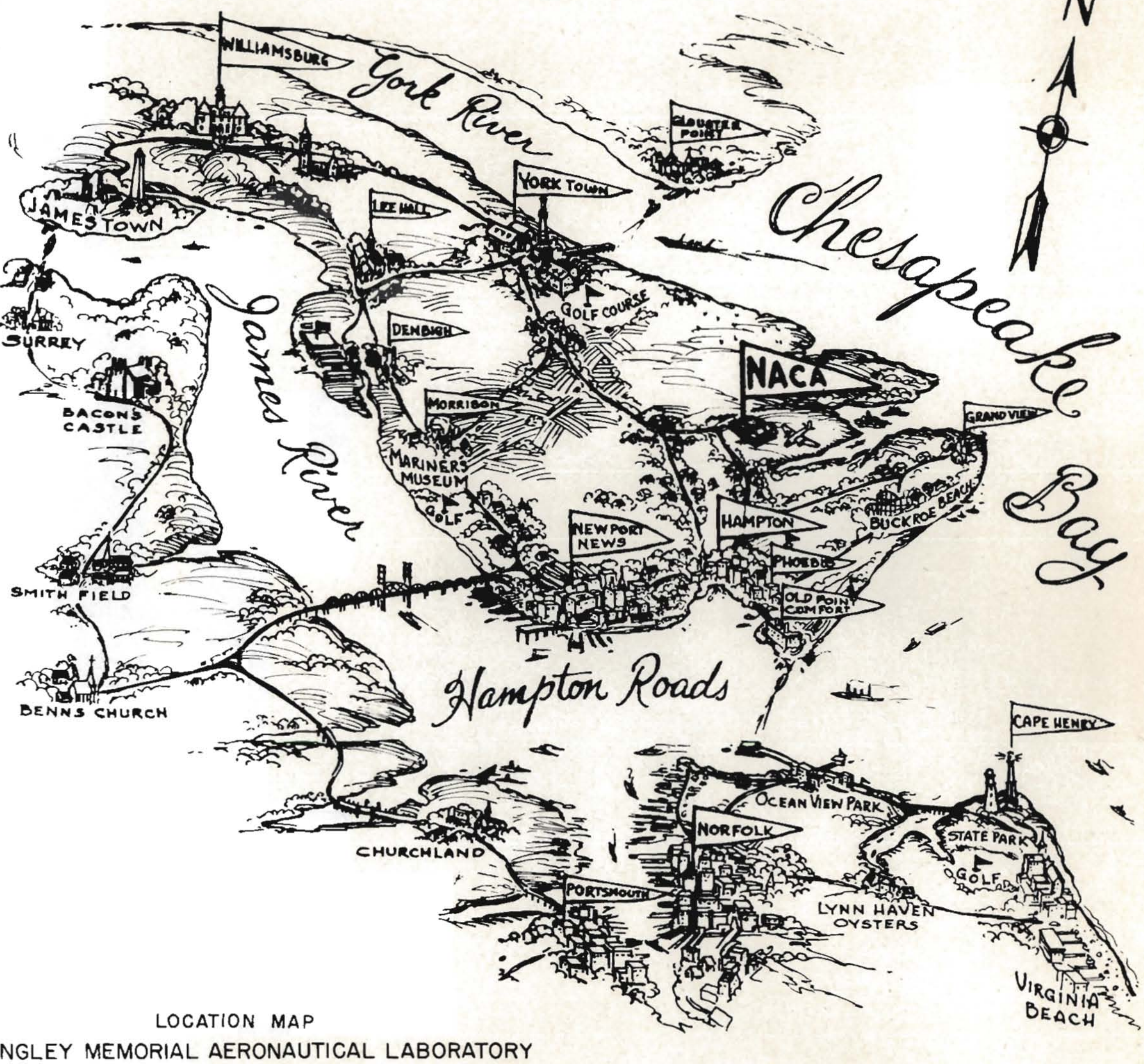
26 days vacation (or annual) leave, and 15 days sick leave, are earned each year. Leave is charged only for absence on regular work days, which does not include holidays or non-work days (usually Saturdays and Sundays). Vacation leave with pay, therefore, amounts to approximately 5 weeks each year. Legal holidays generally are observed as non-work days in the Federal service.

Work-Week

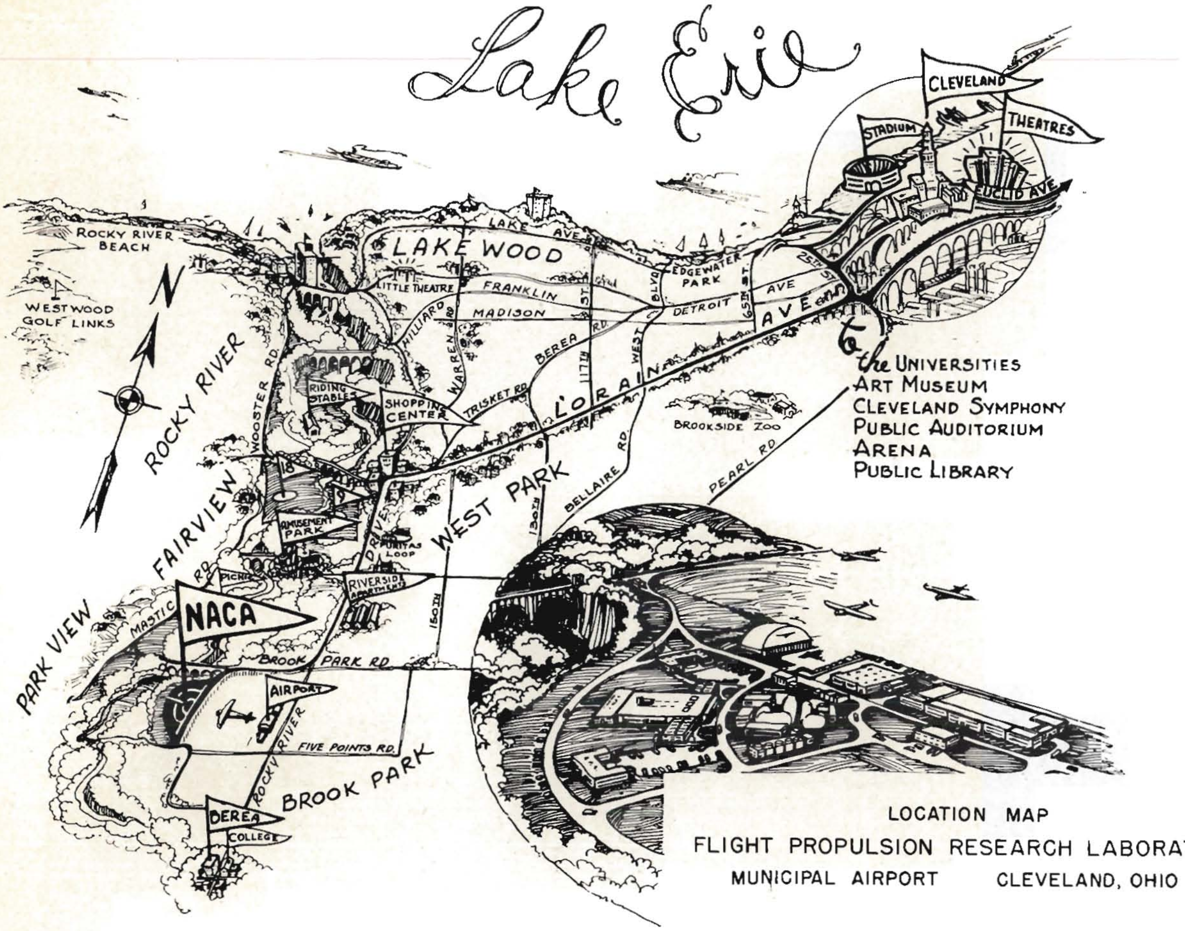
The normal work-week in NACA offices is forty hours (8 hours a day - 5 days a week). Overtime is compensated either by cash, or by equivalent time off from duty.

Retirement

A liberal retirement program permits many employees to retire with substantial annuities, at age 60 (or even 55) if they have the requisite amount of service. A small percentage of the base pay is deducted from an employee's salary for this purpose. The minimum annuity for an employee retiring at age 60, with 35 years of service, is one-half his highest average salary for five consecutive years.



LOCATION MAP
LANGLEY MEMORIAL AERONAUTICAL LABORATORY
LANGLEY FIELD, VIRGINIA



LOCATION MAP
FLIGHT PROPULSION RESEARCH LABORATORY
MUNICIPAL AIRPORT CLEVELAND, OHIO

LOCATION MAP
AMES AERONAUTICAL LABORATORY
MOFFETT FIELD, CALIFORNIA

NACA