LEWIS FLIGHT PROPULSION LABORATORY

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1948 INSPECTION

WELCOME

It is my privilege to welcome you to the 1948 Inspection of the Flight Propulsion Research Laboratory of the National Advisory Committee for Aeronautics, at Cleveland, Ohio, and to the brief ceremony renaming this laboratory the Lewis Flight Propulsion Laboratory.

When the NACA was created in 1915, the Congress specified that the functions of the Committee are to "supervise and direct the scientific study of the problems of flight with a view to their practical solution" and to "direct and conduct research and experiment in aeronautics." In the execution of these functions the chief official of the Committee was the late Doctor George William Lewis, who served as Director of Aeronautical Research of the NACA from 1919 to 1947. The Committee is happy to recognize the invaluable contributions of Doctor Lewis in the development of its Langley, Ames, and Cleveland laboratories and of a research organization which we trust will continue to justify confidence and support. It is the purpose of the Committee to utilize its research facilities to provide fundamental information which the industry and the armed forces need to assure continued improvement in the performance and efficiency of American military and civil aircraft.

Inspection tours of NACA laboratories are to acquaint our guests with the problems currently under study by the Committee and with some of the more interesting results from our research programs.

The Committee appreciates the honor of your presence and trusts that the information presented will be interesting and helpful to you in the accomplishment of our common task.

J C Hunsaker

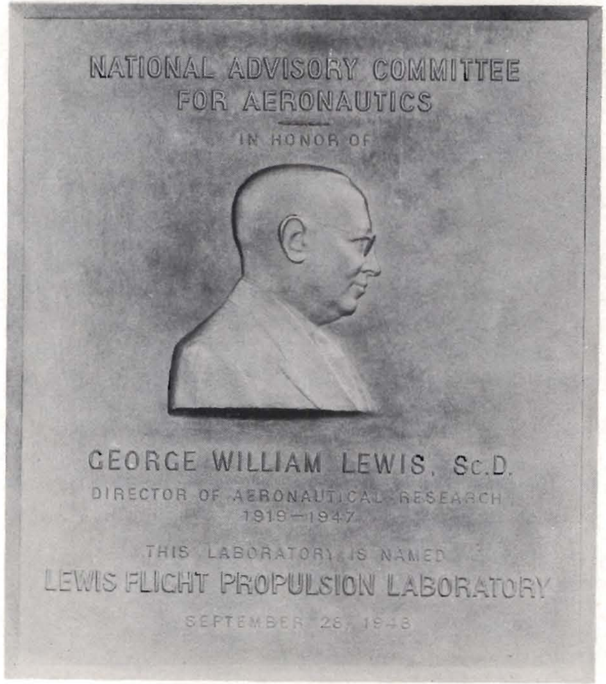
CHAIRMAN,

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

IN MEMORIAM

GEORGE WILLIAM LEWIS, Sc.D.

1882 - 1948


NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
IN HONOR OF
GEORGE WILLIAM LEWIS, Sc.D.
DIRECTOR OF AERONAUTICAL RESEARCH
1919—1947
THIS LABORATORY IS NAMED
LEWIS FLIGHT PROPULSION LABORATORY
SEPTEMBER 28, 1948

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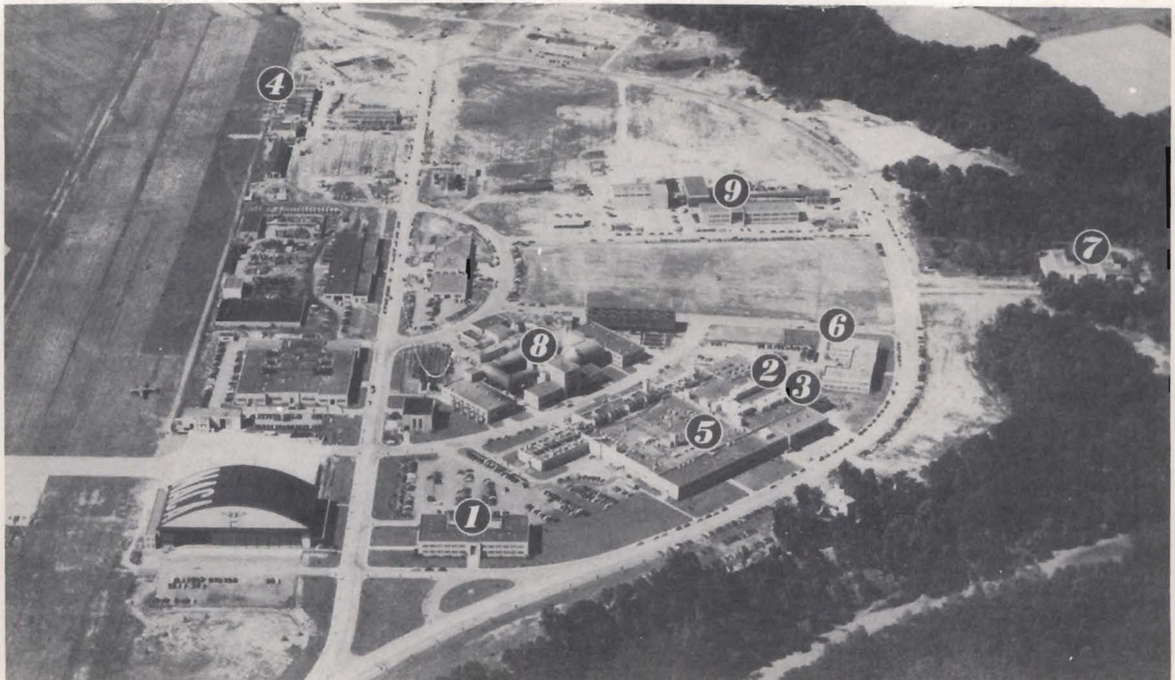
LEWIS FLIGHT PROPULSION LABORATORY



1 INTRODUCTION

The National Advisory Committee for Aeronautics, at its three principal laboratories, is engaged in the fundamental study of the problems of flight. It is the function of the Lewis Flight Propulsion Laboratory to carry out one important phase of this over-all research program, that of solving the problems associated with the propulsion of aircraft. All phases of propulsion are included in this research program.

Because current aviation problems are primarily concerned with high-speed aircraft, the emphasis in propulsion research is on systems that are capable of producing high power in a compact, lightweight package, such as the turbine-propeller, turbojet, ram-jet, and rocket engines. In these powerful propulsion units, which are continually required to operate at higher temperatures and faster speeds, the problems are many and varied.

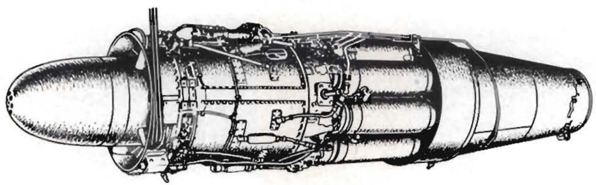
For example, the compressor, the turbine, and the combustor comprise the nucleus of the gas-turbine engine; the success of the over-all power plant is dependent on the proper operation of each of these components. Particular attention is therefore being given to the aerodynamics of flow through compressors and turbines in an effort to improve their performance characteristics. Inasmuch as large gains in power output and fuel economy of gas-turbine engines can be realized by increasing operating temperatures, methods of cooling turbine blades and of obtaining materials that can withstand high temperatures are under investigation. An associated problem is that of designing rotor disks and blades that can withstand high rotating stresses, as well as intense heat.

The continuous generation of enormous quantities of hot gases is the function of gas-turbine and rocket engines; problems of combustion and of combustor design therefore require careful study. It is essential that fuel and propellants be obtained that are well adapted for use in these engines and that deliver large amounts of heat energy.

The use of these various types of engine necessitates the solution of a variety of control and operational problems. The NACA program includes the study of such problems as altitude operational limits, icing, and thrust augmentation. Because supersonic flight gives rise to additional problems unique to this speed regime, the supersonic operation of propulsion systems is also under investigation.

In order to obtain the fundamental data required in this wide field of propulsion research, it is necessary to employ a variety of specialized instruments. The development of this instrumentation required for the successful conduct of the basic propulsion research is therefore an associated research field at the NACA.

The propulsion research conducted at the Lewis laboratory is closely coordinated with the aerodynamic research being conducted at the Langley and Ames laboratories, in order to form an integrated NACA program of aeronautical research. This booklet briefly relates the research trends that are being presented at this 1948 Inspection of the Lewis Flight Propulsion Laboratory.



❷ COMPRESSOR RESEARCH

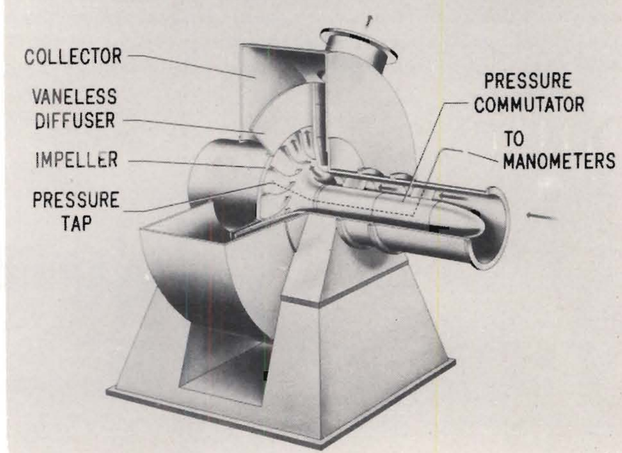
Analysis of gas-turbine power plants has shown that the compressor must take in large quantities of air and efficiently compress it to the required density in order to obtain high engine power and low specific fuel consumption. The compressor must also be reliable, compact, and easily manufactured. For high-speed aircraft, these characteristics must be obtained in a unit having a minimum frontal area.

The two compressor types in general use today are the centrifugal compressor and the axial-flow compressor. The centrifugal type of compressor, in which the air is compressed by centrifugal action, has the advantages of simplicity, reliability, ease of manufacture, and high pressure ratio per stage; the axial-flow compressor has the advantages of small frontal area for a given flow capacity and high efficiency.

The rate of development of the centrifugal compressor has been somewhat handicapped by the lack of adequate theory and of fundamental data on the nature of flow through the complex passages of the impeller. The NACA is currently attempting to supply this information by making measurements of flow within the rotating passages of a 48-inch-diameter centrifugal impeller. In conjunction with this investigation, a theoretical method of determining the flow characteristics in the impeller passages has been developed. The correlation of these

THE 48-INCH CENTRIFUGAL IMPELLER PROVIDES A MEANS OF OBTAINING DETAILED MEASUREMENTS OF FLOW CHARACTERISTICS IN THE ROTATING IMPELLER.

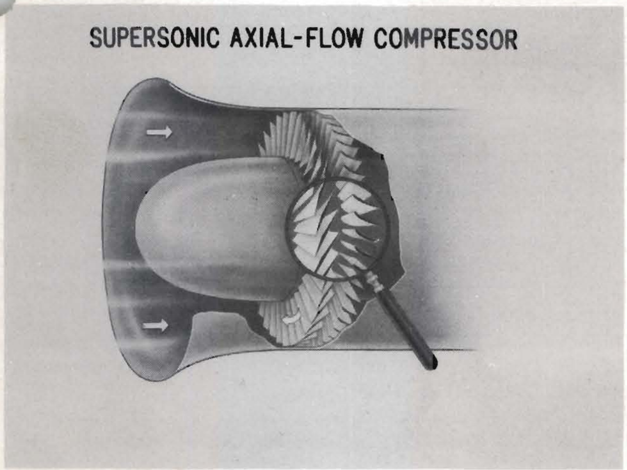
INSTALLATION OF 48 INCH IMPELLER



two studies is expected to point out the source of losses and indicate the design modifications required to improve both the efficiency and the flow capacity of this type of compressor.

The axial-flow compressor is essentially a series of rotating airfoils. When high over-all pressure ratios are desired, a large number of stages are required. Research on this type of compressor is therefore directed at increasing the pressure ratio per stage and thus obtaining a more compact and less-expensive compressor of high air-flow capacity and high efficiency. Theoretical studies of airfoil blade sections capable of producing higher pressure ratios are being made. Experimental studies have indicated that a pressure rise per stage of the order of two to three times that of conventional designs is possible.

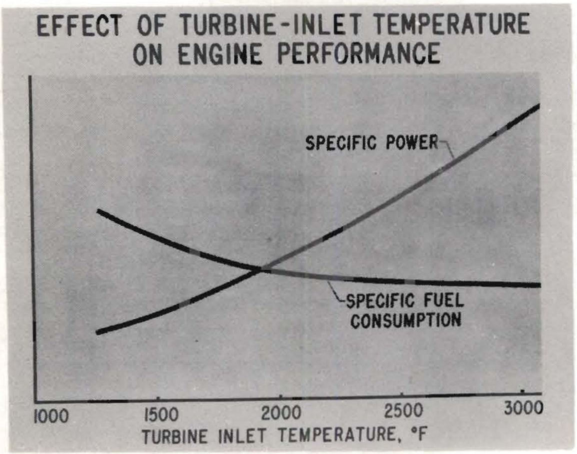
Further gains in pressure ratio per stage are offered by the supersonic-type axial-flow compressor, in which shock waves are utilized to compress the air. As a result, the velocity of sound does not provide a limitation and extremely high pressure ratios may be realized. The successful development of efficient high pressure ratio stages will mean that current multistage axial-flow compressors may be replaced by more compact and relatively less costly compressors. The supersonic compressor is now being investigated by the NACA, but much more information is necessary before the principle of supersonic compression can be generally applied.



THE SUPERSONIC TYPE OF AXIAL-FLOW COMPRESSOR UTILIZES THE SHOCK PHENOMENON TO OBTAIN COMPRESSION OF THE AIR.

TURBINE RESEARCH

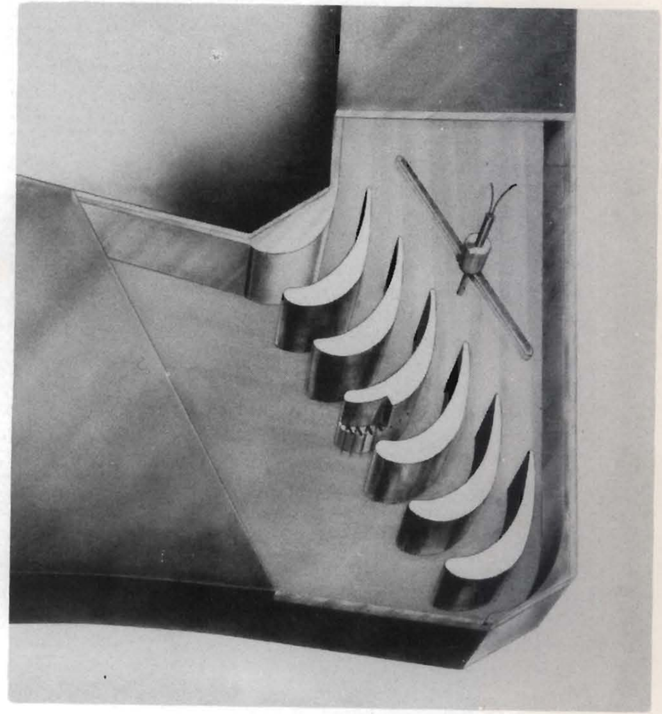
In current gas-turbine engines, the temperature limitations imposed by turbine blades and turbine parts requires that two-thirds of the air that passes through the engine be used to cool the hot gases. Analysis of the effects of various parameters on the power output of the turbine-propeller-type engine has shown that large gains in power and fuel economy can be obtained by increasing the turbine-inlet temperature and at the same time appropriately increasing the pressure ratio of the unit. Because the maximum temperature obtainable in gas turbines using hydrocarbon fuels is of the order of 3500° F, methods of constructing turbines that can withstand these temperatures are at present an urgent objective of NACA study. Considerable effort, therefore, has been expended to develop methods of turbine cooling. Much valuable information has been obtained from an analytical study of various methods of air or liquid cooling. Experimental results obtained on liquid-cooled turbines at this laboratory indicate that cooling of turbines also offers promise for using nonstrategic materials for turbines.



In applying turbine cooling to blades, it may be necessary to use shapes different from those now in use, so that cooling passages can be accommodated. In order to utilize high gas temperatures efficiently, it will also be necessary to increase the pressure ratio. These modifications must be realized, however, without impairing the efficiency and the flow capacity of turbines. The NACA is conducting extensive research on the nature of flow around turbine blades. One of the research methods utilizes cold-air turbines for the investigation of various turbine-design parameters. A two-dimensional cascade tunnel provides a further facility for obtaining fundamental data on the flow around turbine blades.

INCREASING THE TURBINE-INLET TEMPERATURE AND UTILIZING A PRESSURE RATIO CORRESPONDING TO MAXIMUM POWER RESULTS IN A SUBSTANTIAL INCREASE IN POWER OUTPUT AND FUEL ECONOMY OF THE TURBINE-PROPELLER ENGINE.

A TWO-DIMENSIONAL CASCADE TUNNEL IS USED TO INVESTIGATE THE FLOW AROUND TURBINE BLADES.

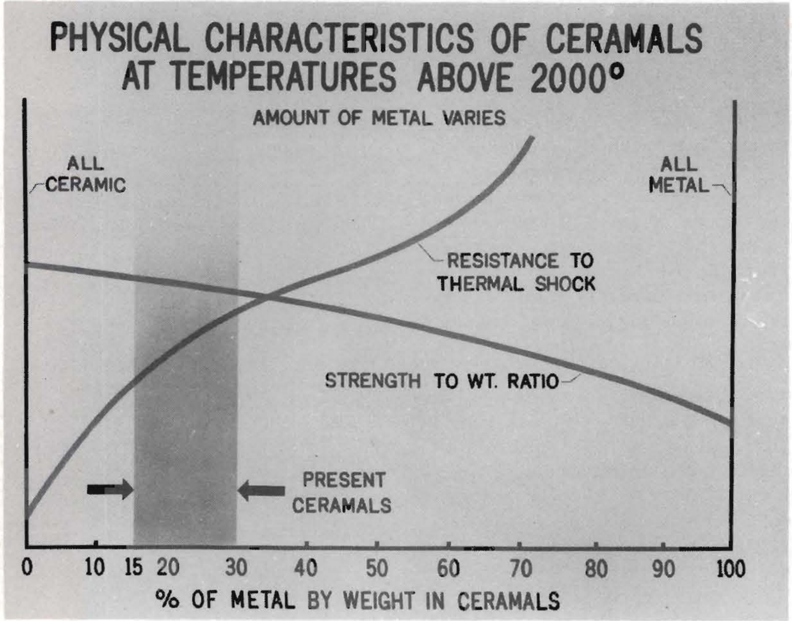


4 HIGH-TEMPERATURE MATERIALS

Substantial increases in operating temperatures, which are required for improving the power output and decreasing the specific weight of gas turbines, can be achieved by obtaining materials that can operate successfully at these high temperatures. Research effort to raise the temperature limits imposed by present materials is being applied to all the important phases of the field of high-temperature materials. Studies are being made to determine which properties of materials require improvement to permit operation at higher temperatures, and which properties can be sacrificed. A corollary investigation is under way to determine which laboratory-determined properties of a material can be used to predict accurately the performance of a material when used as an engine part. Studies of new alloy systems, of the role of temperature-phase relations, of composite metal construction, and of pressure-phase relations are under way. Studies are being made of the physics of solids in order to extend the existing knowledge of the forces that bind solid materials. Much of the fundamental work in progress has as its ultimate objection the attainment of knowledge that will permit the production of materials superior to those in current use from elements that are more plentiful and less expensive than those currently used.

One phase of this research effort is the study of materials of very high melting points, including refractory metals, ceramics, and ceramic-metal combinations (ceramals). Preliminary results indicate that ceramals offer great promise of providing a material that can operate at temperatures 800° F above that of present metal alloys. A promising ceramal investigated at this laboratory showed a strength-to-weight ratio at 1800° F that was 1.5 times as high as that of a high-temperature alloy of metal in wide current use. A ceramal has the further advantage that the raw materials are domestically plentiful and low in cost in contrast to the strategically critical, high-cost metal alloys.

In starting the gas-turbine engine, the engine parts are subjected to extreme and rapid temperature changes, momentarily creating severe stresses. This stress condition is defined as thermal shock. The addition of metal to ceramic materials has been found to increase greatly the resistance to thermal shock. Ceramals have been investigated that have good oxidation resistance up to 2400° F. Such resistance is important because the high-temperature parts of a gas-turbine engine are always surrounded by gas containing a great deal of oxygen. Oxidation of the turbine-blade material may produce changes in shape or result in a new material of inferior properties. The solution to this oxidation problem, therefore, requires the choice of materials that either resist oxidation or that protect themselves by confining the oxidation to the surface. The problem remains, however, of finding ceramal compositions that combine good oxidation resistance with high strength-to-weight ratio and good thermal shock resistance.



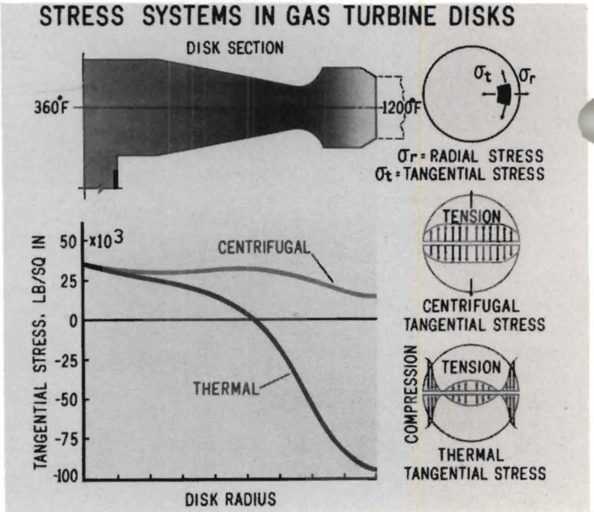
THE RESISTANCE TO THERMAL SHOCK AND THE STRENGTH-TO-WEIGHT RATIO OF CERAMALS, WHICH ARE MAJOR FACTORS IN TURBINE OPERATION, ARE DEPENDENT UPON THE AMOUNT OF METAL PRESENT IN THE CERAMAL.

4 STRESSES RESEARCH

At its rated take-off speed, the wheel of a typical aircraft turbine possesses more kinetic energy than an average automobile at a speed of 100 miles per hour. Fragments of such a wheel burst in a spin pit at about twice rated speed have been known to penetrate more than 8 inches of steel. Because of the obvious danger to pilot and aircraft, insurance against failure of the wheel in flight is a prime objection in turbine design.

The design of a gas-turbine disk poses unique problems because of the temperature difference between the hot rim and the cool hub that are characteristic of such a disk. This temperature gradient introduces thermal stresses that combine with the centrifugal stresses of rotation to produce a complex total stress system. This stress system is further complicated by plastic flow of the disk material at regions of high stress. Before optimum design can be achieved, a number of basic questions must be answered.

First, the relative importance of the various material properties must be evaluated. The roles of ductility, of



TURBINE DISKS ARE SUBJECTED TO CENTRIFUGAL STRESSES OF ROTATION AND TO THERMAL STRESSES RESULTING FROM TEMPERATURE GRADIENTS, RESULTING IN A COMPLEX TOTAL-STRESS SYSTEM.

creep strength, and of other high-temperature properties must be studied. The theory of thermal stresses in rotating disks must be enlarged to include effects of plastic flow.

Considerable experimentation has already been conducted to evaluate ductility and tensile strength. A large spin pit has been built in which disks can be rotated at any desired speed while heated to produce any desired temperature gradient. In this manner centrifugal and thermal stresses can independently be adjusted to arbitrary values and their relative importance in causing bursting can be determined.

Current research is also aimed at establishing a sound basis for the design of compressor and turbine blades. Blades of gas-turbine engines are subjected to high centrifugal stresses and are further stressed by vibrations induced by variations in pressure and velocity of the gas stream. If the frequency of the gas-stream pulsations becomes resonant with the natural frequency of a blade, blade vibrations of large amplitude can result. A second type of vibration, flutter, can be induced by a steady flow of gases.

The amplitudes and the frequencies of vibrations in compressor and turbine blades of current engines is being determined under operating conditions. Experimental rigs have been built to investigate on single blades wide ranges of operating conditions and possible methods for reducing vibration. The results of such investigations, translated into new designs, will increase the operating life of turbine and compressor blades.

RESULTS OF BURSTING A TURBINE DISK IN THE SPIN PIT.

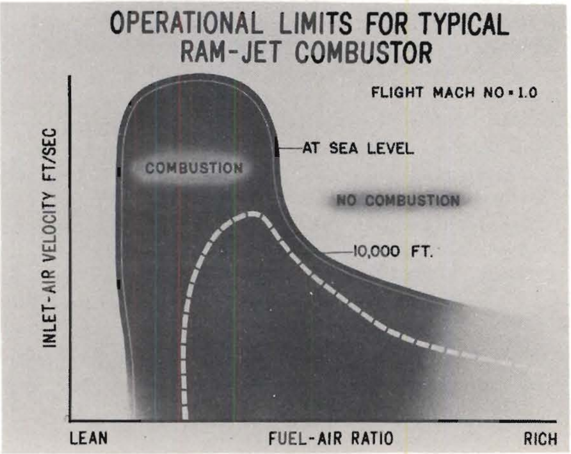
5 COMBUSTION RESEARCH

The major problem of engine combustion is to release efficiently heat energy from the fuel at a high rate per unit volume. Important attendant problems are: low pressure loss, light weight, and durable combustion equipment; flexibility of operation (especially at other than design points); and proper distribution of temperature across the combustor-outlet area to avoid harmful hot zones.

Research on the ram jet at conditions simulating different flight speeds and altitudes has shown that, in the present state of development, any one ram-jet combustor must be carefully designed for the desired range of operation. In order to widen this range of ram-jet-combustor operation, current research is aimed at learning basic design principles for flame holders and fuel injectors.

The combustion problem for the gas-turbine engine differs from that for the ram jet in that not only must fuel be burned efficiently in a fast-flowing air stream and with low pressure loss, but combustor-outlet temperatures in the turbine engine must not exceed values harmful to the turbine.

Early investigations by the NACA on the operating characteristics of a number of turbojet combustors disclosed that combustion efficiency decreased with altitude, and that turbojets had a combustion-imposed altitude operational limit. Research revealed the causes of these phenomena and further systematic research effected satisfactory improvements. But raising the ceiling imposed by combustion aggravated another pro lem, that of combustor-outlet temperature distributio

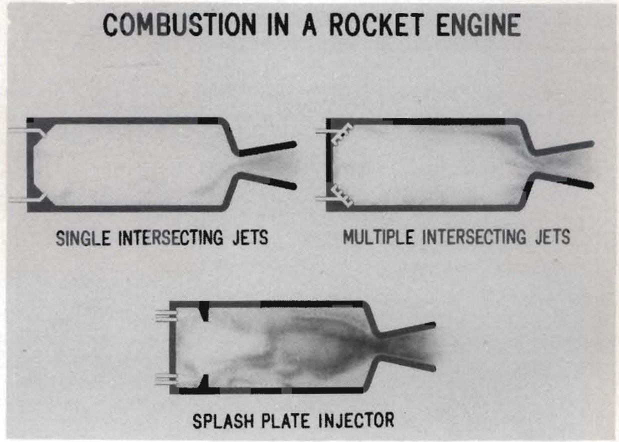


IN THE RAM-JET COMBUSTOR, A RANGE OF FUEL-AIR RATIOS AND INLET-AIR VELOCITIES EXISTS WHERE THE COMBUSTOR WILL OPERATE; OUTSIDE OF THIS RANGE, NO OPERATION IS POSSIBLE.

It is essential to the life of the turbine blading that hot spots on the blading not be caused by faulty distribution of temperature from the combustor. Currently, research is being directed at ways and means of achieving preferred temperature profiles from gas-turbine combustors.

The rocket engine operates on fuel and oxidant that are carried in tanks and thus requires no outside air. The fuel and oxidant react so vigorously upon mixing in the combustion space that no flame-retaining devices are required. The major problems for the rocket engine are to select fuel and oxidant combinations that give large thrust per unit weight flow and volume flow and still have properties that permit their handling and use, to prevent failure of the engine from the thousands of degrees of temperature attained by the reaction products, and to achieve efficient combustion in the smallest possible unit.

The solution of practical problems encountered in the application of the combustion process to aircraft engines requires the results and conclusions from basic and fundamental studies. The NACA is conducting research on the physical chemistry of combustion in an effort to evaluate the factors that control the combustion rate. The dynamics of fuel-droplet evaporation is under intensive investigation, because research has shown that the fuel spray is a significant factor in combustion-chamber performance. Additional research is directed at determining how aerodynamic factors, such as turbulence and gas-stream mixing, influence flame propagation.



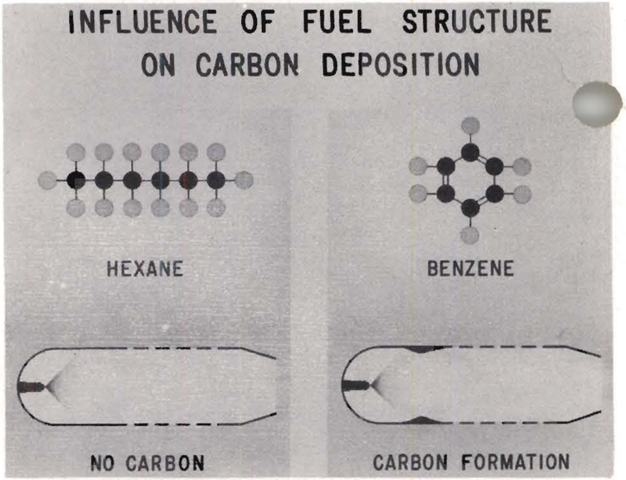
HIGH-SPEED PHOTOGRAPHS OF THE ROCKET-COMBUSTION PROCESS, TAKEN THROUGH A TRANSPARENT-WALLED ENGINE, REVEAL CONSIDERABLE INFORMATION ABOUT THE COMBUSTION PROCESS IN THE ROCKET.

6 FUELS RESEARCH

The projected use of turbojet, turbine-propeller, and ram-jet aircraft in large numbers for both military and commercial applications has indicated the need for a jet fuel that will be available in large quantities. Representatives of the petroleum industry have indicated the types of fuel that can be made available in maximum quantity. These fuel types must be evaluated in terms of over-all engine performance.

The NACA's part in the project consists in evaluating the fuels on the basis of altitude operational limits, carbon deposits, combustion efficiency at altitude, starting at both sea level and altitude, and other operating characteristics. When the project is completed, it will be possible to establish what types of fuel can be used in current engines and to estimate what quantities of fuel will be available. It will also be possible to determine what changes have to be made in current engines in order that the fuels available in the greatest quantity can be used.

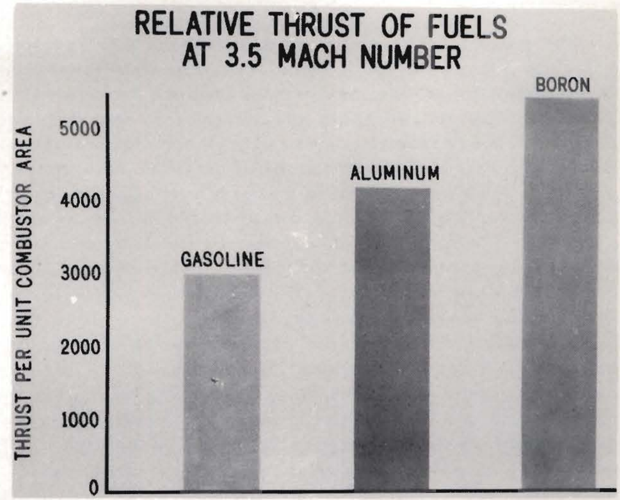
A second aspect of the problem is to determine which components of hydrocarbon fuels give the best performance in jet engines. It is a well-known fact that fuels



THE MOLECULAR STRUCTURE OF FUELS INFLUENCES THE QUANTITY OF CARBON DEPOSITED IN JET ENGINES.

derived from petroleum contain hundreds of individual hydrocarbons. It is important to know the performance of the individual components in jet engines. In reciprocating engines, the individual hydrocarbons vary widely in their knock-limited performance and research to date indicates that marked differences also exist in their performance in jet engines.

A third problem that is receiving continued research emphasis at the NACA is the matter of fuels to extend the flight range of jet aircraft. Such airplanes are streamlined for high-speed operation and the space for fuel storage is very limited. It is therefore important to use fuels that will deliver the maximum heat energy per unit volume. The NACA is investigating hydrocarbon fuels that will deliver 30 percent more energy per unit volume than current aviation gasoline. Investigations are also under way to utilize solid metals as aircraft fuels. If aluminum metal could be utilized as an aircraft fuel, it would deliver over two and one-half times as much heat energy per unit volume as aviation gasoline and other metals could deliver almost four times as much gasoline.



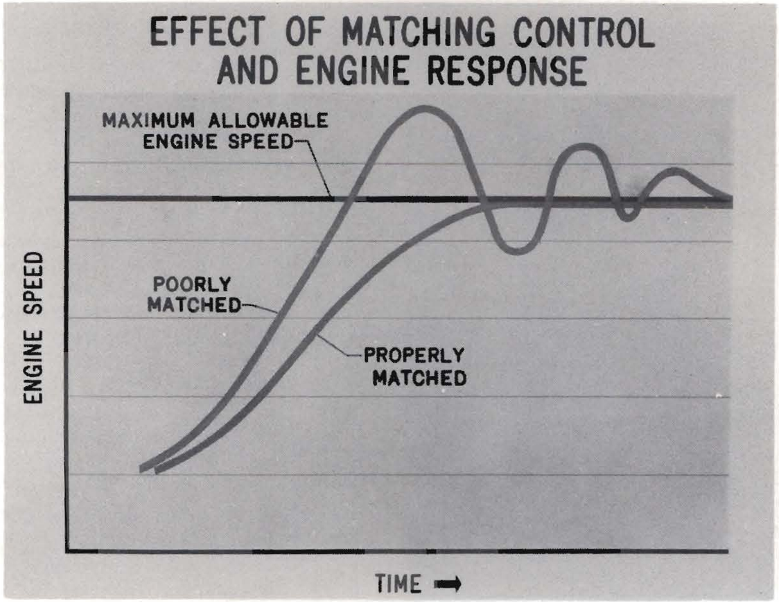
THE USE OF SOLID METALS FOR AIRCRAFT FUELS WILL RESULT IN AN APPRECIABLE INCREASE IN THRUST PER UNIT CROSS-SECTIONAL COMBUSTOR AREA OVER THAT AVAILABLE FROM AVIATION GASOLINE.

7 ENGINE-CONTROL RESEARCH

The successful operation of gas-turbine engines, even with the attainment of desired component performance, is dependent on the engine-control system. In general, it is the function of an engine-control system to obtain optimum engine performance and to maintain engine operation within safe and stable operating limits. This general control criterion is difficult to achieve. Complete exploitation of the engine potentialities may be attained only through accurate adherence to definite limits of both engine speed and temperature, and response of the control system must be consistent and reliable for all the varying conditions of operation.

Successful application of controls to the gas-turbine engine requires a thorough knowledge of engine and control-system transient characteristics to enable the designer to match the response of both the engine and the control system. Such matching is essential, as it may determine such important performance characteristics as acceleration and deceleration rates. Maximum stresses in the turbine-propeller reduction gearing, which may ultimately dictate the size and weight of this important component, will result from improper matching of engine and control-system response characteristics. Large torque fluctuations and dangerous overspeeding of the compressor and turbine components may be expected under certain conditions of operation when the engine and the control system are improperly matched.

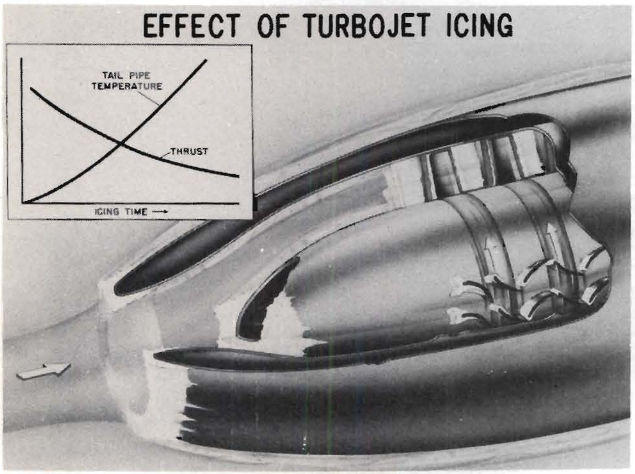
Analytical and experimental control studies are being conducted by the NACA to determine the control-system and necessary response characteristics required for each gas-turbine-engine type. Various stability and response criteria are being studied to enable control designers to match and to evaluate response characteristics of any combination of engine and control system. In order to supplement bench and full-scale-engine test facilities, an electronic engine and control-system simulator will be used to study response characteristics of any combination of engine and control system.



IMPROPER MATCHING OF THE RESPONSE OF THE ENGINE AND THE CONTROL SYSTEMS RESULTS IN UNDESIRABLE OSCILLATIONS AND INSTABILITY OF ENGINE SPEED.

8 TURBOJET RESEARCH

The turbojet engine, in its present stage of development, has several operational characteristics that limit its over-all effectiveness as an aircraft power plant, particularly at high altitude. A study of these altitude operational problems has indicated design trends that would extend the operational limits of turbojet engines. These problems are being investigated in the altitude wind tunnel, in altitude tanks, and in flight.



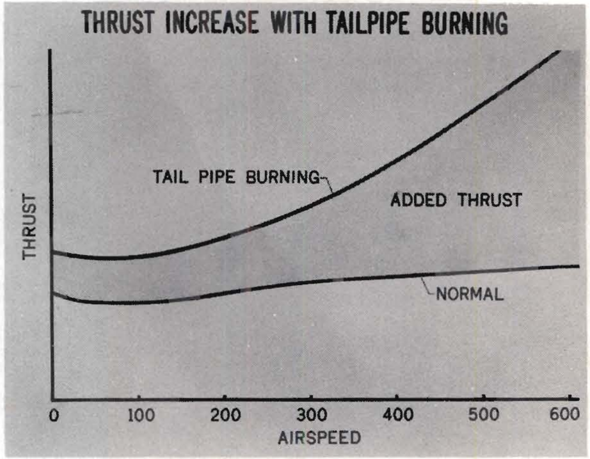
THE ICING OF TURBOJET ENGINES HAS A DELETERIOUS EFFECT ON TAIL-PIPE TEMPERATURE AND AVAILABLE THRUST.

One problem being studied is that of increasing the operable range of engine speed at high altitude. Another problem results from the fact that the inertia of large turbojet engines is so great that the engine cannot quickly respond to throttle changes, particularly at high altitude. Because the ability to accelerate rapidly is essential for military applications, variable-area exhaust nozzles have been developed to provide a means of quickly increasing the engine thrust.

The vulnerability of the turbojet engine to icing conditions is apparent from the rapid increase in tail-pipe temperature, the increase in specific fuel consumption, and the decrease in thrust that occurs when icing is encountered. Laboratory and flight studies of the icing problems have indicated three methods of providing the ice protection that is essential to the safe operation of this type of engine.

The first method provides for surface heating of all inlet components exposed to icing either by electric heaters or by hot gas. The second method involves the bleeding of hot gas from the rear of the engine into the inlet; it is now possible to design a system with good anti-icing characteristics using a minimum of bleedback. The third method removes water droplets from the inlet air by inertia separation; experimental investigations have provided sufficient data for efficient design. The most economical ice-protection system for a specific aircraft installation may well incorporate combinations of these methods.

Another significant gas-turbine operational problem is that of increasing engine thrust for take-off and for short bursts of added power at high speed. The injection and burning of additional fuel in the tail pipe of a turbojet engine is one attractive means of obtaining this added thrust. In this process, which is variously called afterburning, tail-pipe burning, or exhaust reheat, the exhaust gases issue from the jet nozzle at higher velocities and higher temperatures than can be tolerated in turbine-limited operation of the conventional engine. Afterburning can increase the engine thrust by as much as 35 percent for take-off and 60 percent at flight speeds of 500 miles per hour. This increased thrust, however, entails a loss in fuel economy. Research is continuing at the NACA to solve the detailed problems of afterburning, including fuel control to maintain safe temperatures and good economy, the determination of optimum tail-pipe size, and the reduction of the losses in power due to the afterburner when it is not in operation.



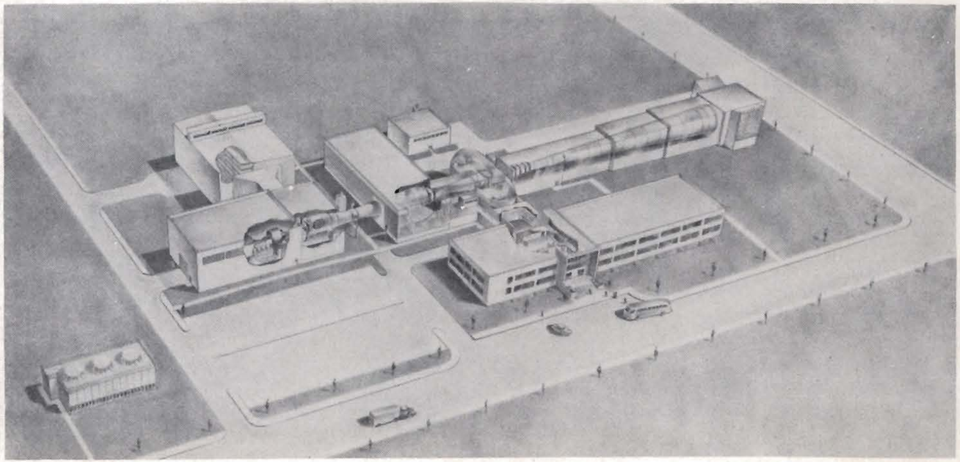
THE USE OF TAIL-PIPE BURNING IMPROVES THE THRUST CHARACTERISTICS OF TURBOJET-POWERED AIRCRAFT.

9 SUPERSONIC RESEARCH

The ram jet possesses operating characteristics that make it ideal for flight at supersonic speeds. Compression of the air is accomplished in the ram jet without any moving parts by simply scooping in the air and utilizing the forward motion to compress the air. Fuel is then injected and burned, and the resulting hot gases are expelled rearward to provide forward thrust.

Shock waves that occur ahead of the inlet of the ram jet cause serious energy losses and reduce engine power. In an attempt to reduce the losses of the ram-jet inlet, various improved designs have been investigated by the NACA. Studies of inlet operation without burning have shown that this energy loss may be minimized by appropriate design and that pressure recoveries within a few percent of the theoretical maximum are possible.

More recent investigations of complete ram j[illegible] operating in wind tunnels at supersonic speeds gave pe[illegible]

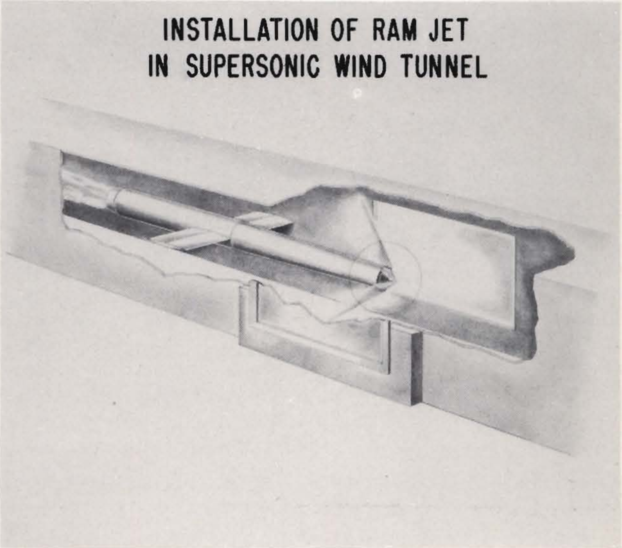


THE 8-BY-6-FOOT SUPERSONIC WIND TUNNEL.

formance considerably below theoretical limits. Measurements have shown that this loss results from interaction of combustion pulsations and diffuser-shock effects. The NACA is continuing the study of the effect of these related problems of acoustics and combustion stability on the flow into inlets of varying geometric proportions on operating ram jets.

Much larger ram jets have been studied at supersonic speeds with a ducted inlet in the altitude wind tunnel and in free flight with a series of ram jets launched from an airplane at high altitude. Results have shown the effect of ram-jet geometry on net thrust as speed is increased. This research on ram jets will be continued, with much of the work to be performed in the new 8-by-6-foot supersonic wind tunnel soon to be placed in operation. This new tunnel marks a major addition to the supersonic research facilities of this country.

The viscosity or friction of air results in the build-up of a thin layer of stagnant air called boundary layer on air-flow surfaces, a factor that complicates the solution of the aerodynamics of supersonic flight. Viscosity affects the separation of air flow from surfaces, the transition from smooth flow to turbulent flow in the boundary layer, the heat transfer at the surface, and the interaction of shock with the boundary layer. The growth of boundary layer on both the wind-tunnel walls and model surfaces complicates the interpretation of experimental data obtained from supersonic investigations. Special research techniques are being employed by the NACA in new facilities designed for the study of boundary-layer and heat-transfer problems as they relate to supersonic-wind-tunnel and propulsion-system design.



THE INSTALLATION OF RAM JETS IN SPECIALLY EQUIPPED SUPERSONIC TUNNELS PERMITS DETAILED STUDY OF OPERATION.

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