NACA 1957 *Inspection*

LEWIS FLIGHT
PROPULSION LABORATORY

Welcome....................

The National Advisory Committee for Aeronautics welcomes you to the Triennial Inspection of the Lewis Flight Propulsion Laboratory.

It is fitting that this Inspection is taking place so close to the tenth anniversary of the first supersonic flight in manned aircraft. On October 14, 1947, the rocket-propelled Bell X-1 research airplane was flown faster than sound. In the decade since, both speed and altitude limits of our aircraft have been pushed very far. Today, the demands for greater performance are even more urgent than in 1947.

We know that our attainment of these new goals will depend upon our learning how to exploit more fully the potentialities of the engines we can use. The turbojet engine already has been improved enormously, far beyond what we believed to be possible ten years ago, but further improvement can be expected. Although systematic research and development already have assured use of ramjet and rocket engines, realization of their ultimate capabilities is still to be achieved. Beyond lie the problems, and the possibilities, of exploiting nuclear energy and new propulsive devices to power our airplanes and missiles.

We of the NACA are happy to see both old friends and new. We hope that you enjoy your brief stay at the Lewis Laboratory and that you will come back to see us at the next inspection.

J. H. Doolittle

Chairman
National Advisory Committee for Aeronautics

Propulsion Science Looks Ahead

Annually the NACA invites inspection of the facilities of one of its three major laboratories and presents a brief review of current aeronautical research.

These inspections afford the NACA its best opportunity to report directly to the people. They affirm the need for a fully informed public urgently aware that America must maintain air supremacy for survival. The bits and pieces of research facilities and programs that are shown reveal the foundations on which future air supremacy will be built - first in the research laboratory, then in flight.

The incremental gains in aeronautical science revealed annually at inspection may one by one not appear noteworthy. Added together the progress created has been truly encouraging. Remember that fifteen years ago this month the Bell P-59 made America's first flight of a turbojet-powered aircraft. Ten years ago this month the X-1 research airplane powered by a rocket became the world's first manned aircraft to fly faster than the speed of sound. Since then, turbojet-powered fighter airplanes with capabilities of flight at speeds over twice the speed of sound have become available to our military services, and a bomber competitive in speed with the advanced fighters has been flown. Progress has been made with rocket-powered missiles capable of spanning continents in flights outside the earth's atmosphere. Flight in space is planned with an instrumented satellite in the program of the International Geophysical Year.

Unquestionably, aeronautics has progressed rapidly, but what now and what of the future? What role will the air-breathing turbojet and ramjet engines play in propelling advanced aircraft? Will high-energy fuels supplant conventional fuels for turbine and rocket engines? How will nuclear power be applied in flight? Will the extreme temperatures encountered on the surfaces of the engine and aircraft at hypersonic speeds establish a limiting speed for manned aircraft flight through the atmosphere? And also, what are the problems of flight outside the lower atmosphere where the heating problem is alleviated?

Our national security requires that America be first to find answers to these questions. They will come from the research laboratories through theoretical studies and experimental research with advanced facilities.

The Lewis Flight Propulsion Laboratory is directing the efforts of the entire staff at these questions and others of equal complexity with a view toward reaching solutions applicable in flight. Brief resumes of some of the studies are given in the text that follows.

Test Model Readied in Supersonic Tunnel

Mach 4 Turbojet Possible

During the fifteen years since the turbojet engine was first flown in the United States, significant progress has been made in its development. Its maximum speed capabilities first were predicted at some value below the speed of sound. Then, a Mach number of 1.5 was thought possible; then 2.5. Now a Mach 4 turbojet appears possible.

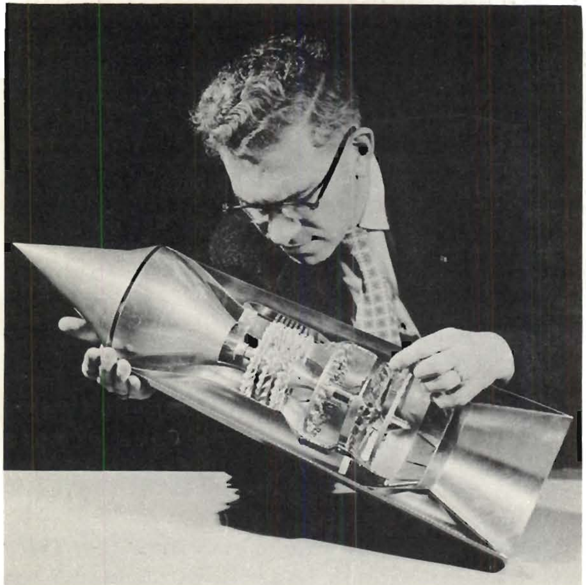
If such an engine is to be developed, great care must be exercised in designing its inlet and exhaust systems. Since an inlet designed for Mach 4 flight speeds will be as large in diameter as the engine, or larger, inlet drag considerations will be more important than ever before. Similarly, the exhaust nozzle will be relatively large and equally influential in affecting drag. Of even greater significance than the size and associated external drag is the internal efficiency of the inlet and exhaust nozzle.

Unfortunately, a fixed-geometry inlet and exhaust nozzle will not maintain satisfactory efficiency over the wide range of altitudes and speeds a Mach 4 airplane will encounter before reaching its design flight conditions. Therefore, provisions must be made for varying the size and shape of these components.

If this variable-geometry feature is not incorporated, it is doubtful that the engine can provide sufficient net thrust for the airplane to reach its design speed. Since the inlet and exhaust are complex mechanisms, attention cannot be confined to the aerodynamic characteristics. Such matters as weight, complexity, methods of control, and interaction effects with the rest of the airplane all must be understood before a component design can be made satisfactory.

The engine one might visualize for flight at 2600 miles per hour is more compact and far more efficient than present turbojets.

The use of transonic design principles and lower compression ratios may make possible a compressor with only three stages, whereas twelve to fifteen stages are now required.



Component Research Generated Mach 4 Turbojet

Because of the high ram temperature (about 1200° F at a Mach number of 4), however, the compressor will introduce much more severe material problems than exist in today's engine. If the lowest possible weight is to be achieved, then the combination of high compressor stress and temperature will require the use of the strong high-temperature alloys currently being used for turbines.

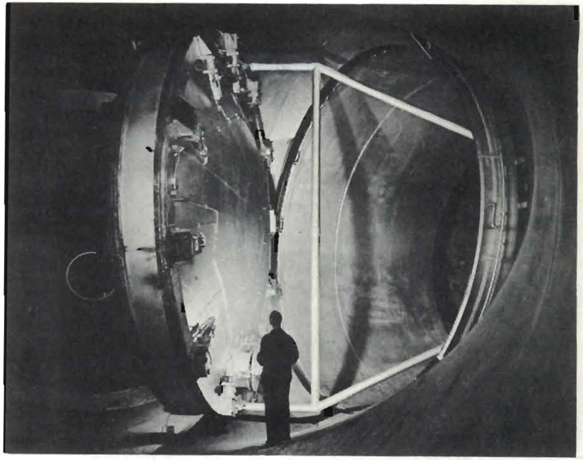
Recent studies of special fuels and increased knowledge of combustion-chamber design indicate that the engine can have shorter and more compact combustion chambers.

Although the fundamental knowledge on which to base the design of such an engine seems well defined, construction will be very difficult, mainly because of the high temperatures at which the engine must operate. Among the many details that must be investigated are high-temperature lubricants, bearings, and seals.

Supersonic Tunnel Aids Engine Research

The facilities used to study turbojet and ramjet engine problems at Lewis are many and varied. They include compressor and turbine rigs, combustor setups, and high-altitude test chambers in which conditions up to 2000 miles per hour and 90,000 feet can be simulated. The newest major facility is the 10- by 10-Foot Supersonic Wind Tunnel. In it are studied the problems of engine inlets and exhaust nozzles, the interactions of engine and airplane configurations, and the performance of full-scale engines at speeds from about 2 to over 3.5 times the speed of sound. This tunnel complements the older 8- by 6-Foot Supersonic Wind Tunnel which has a top speed of twice that of sound. This tunnel has recently been modified to operate subsonically and through the speed of sound.

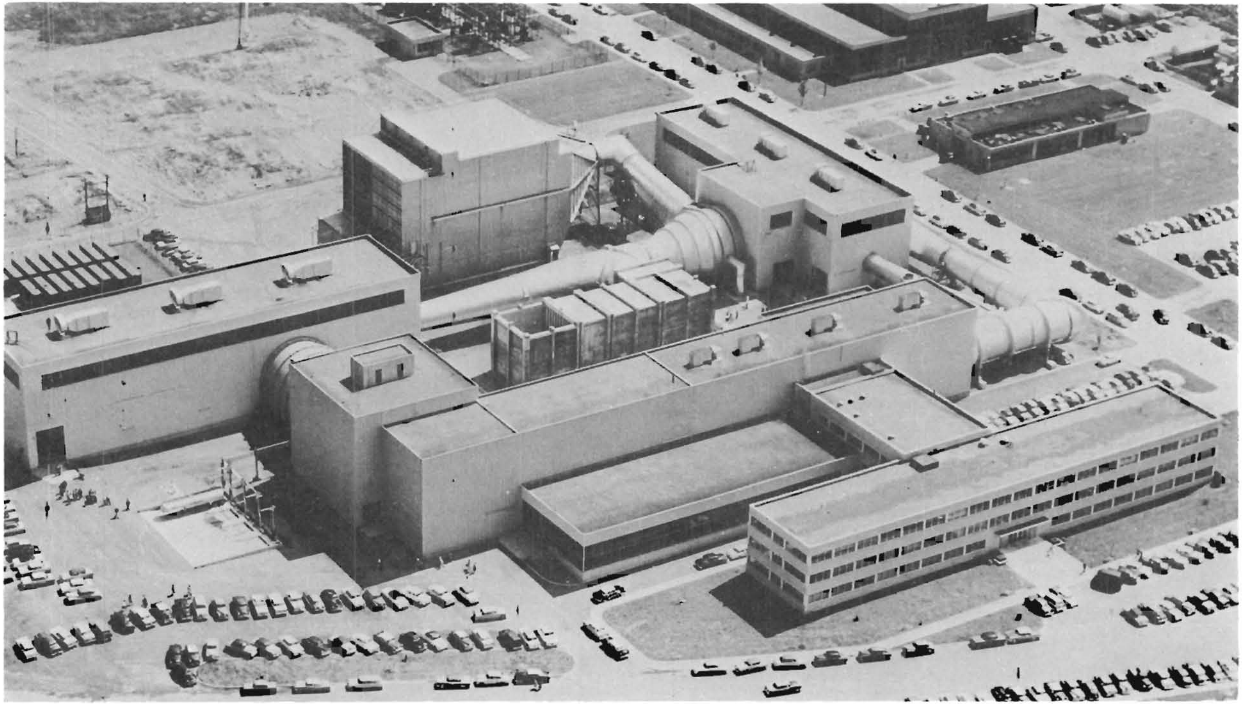
An important feature of the 10- by 10-Foot tunnel is that it can operate on two different cycles. When engine operations are being studied, air is brought from the atmosphere, passed through the tunnel, and discharged



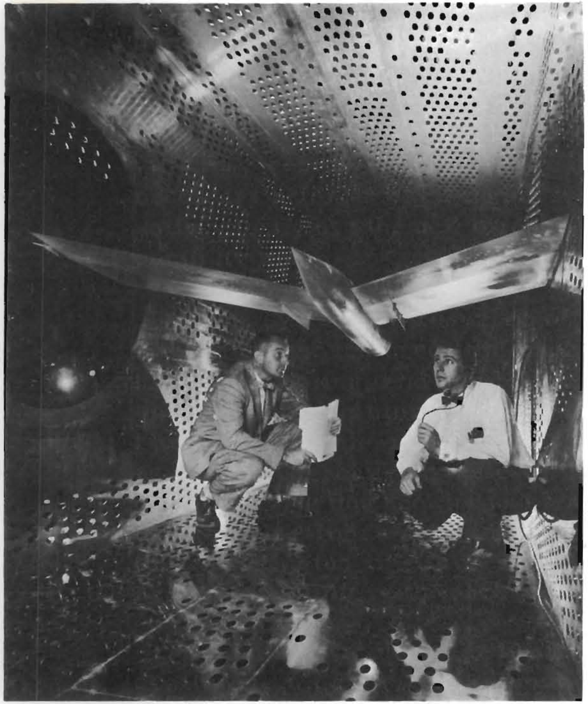
Huge Valve Controls Tunnel Air-flow Cycles

back to the atmosphere through an acoustic muffler. For aerodynamic runs, air passes continuously around the tunnel circuit. The cycle path is controlled by the setting of a 24-foot-diameter, 34-ton valve.

The supersonic speed in the test section is obtained by expanding air through a nozzle. Two axial-flow compressors supply the nec-



Speed Range of Lewis 10x10-Foot Tunnel is Mach 2.0 - 3.5 for Full-Scale Engine Research



Holes Provide Transonic Speed in 8x6 Tunnel

essary pressure differential required for tunnel losses. During tunnel operation, the primary compressor runs all the time and sucks the air through the test section. The secondary compressor operates only at high tunnel speeds and pressurizes the air ahead of the test section. Four electric motors supply a total of 150,000 horsepower to the primary compressor, and three additional motors supply 100,000 horsepower to the secondary compressor.

The temperature of the tunnel cycle is raised considerably by heat of compression as well as by combustion in the research engine. This heat must be removed continuously by coolers located ahead of each compressor. The coolers are supplied with water from cooling towers.

Although the temperature of the air before it enters the nozzle may be 300° F, the expansion process by which supersonic velocities are achieved may reduce the temperature to as low as -230° F in the test section.

Any moisture in the airstream would condense in the nozzle and cause nonuniform flow in the test section. For this reason, before the air enters the tunnel, moisture is removed in an air dryer. The huge dryer contains 1900 tons of activated alumina, which can remove as much as 60 tons of water in a single hour on a hot, humid summer night. After tunnel operation, this water is removed from the dryer by heating the alumina.

The entire tunnel operation is conducted from its control room, which contains instruments for automatically recording temperatures, forces, and other data. The control room is some distance from the test section, and several television screens located around the room permit operators to monitor action in the test section.

Problems of Hypersonic Propulsion

Hypersonic flight speeds are generally assumed to be more than a Mach number of 5, or 3300 miles per hour. The only air-breathing engines that might now be considered for the lower end of this speed range is the ramjet. Lacking both compressor and turbine, and utilizing booster arrangements for takeoff and climb, this engine type is inherently simple in its design and working principles.

The main problems requiring solution before the ramjet or any alternate propulsion system will be satisfactory for hypersonic flight are those of high temperature. For example, at Mach 5 air temperatures reach values of about 2000° F on the engine surfaces; at Mach 7 the air temperatures are about 4000° F. Extensive cooling can be accomplished with minimum losses, however, if fuel can be used as the coolant in the same manner as in the liquid-fuel rocket engine. Much research now is directed towards evaluating various cooling methods.

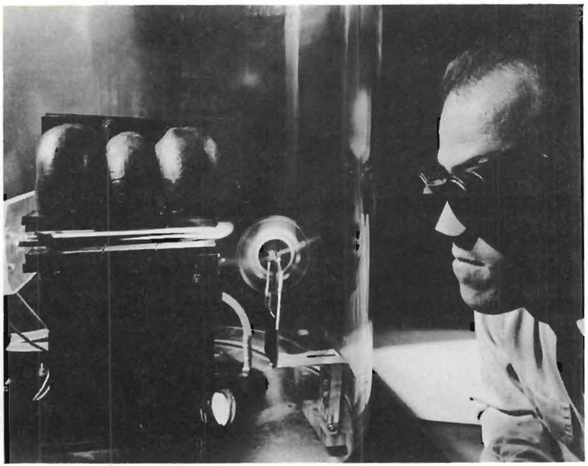
The problem of converting the energy of the fuel being burned into thrust becomes very difficult at hypersonic speeds. The extremely high internal air and combustion temperatures are sufficient to cause the air and products of combustion to break down or dissociate. This process ties up large quantities of energy, which cannot contribute to useful thrust unless the dissociated particles can be recombined within the engine. Research directed towards understanding this problem is under way.

To solve problems of hypersonic propulsion systems, research facilities are required in which air can be heated to correspond to the temperatures of the test speeds and then be expanded through a nozzle to the desired test speed. Both rocket-tunnel and pebble-bed air-heater research facilities provide these conditions.

The rocket tunnel employs a rocket chamber to provide a high-pressure and high-temperature supersonic gas stream. Using ammonia and liquid oxygen as propellants, with an excess of oxygen in the chamber, it is possible to obtain the same percentage of oxygen in the rocket exhaust gas as normally is present in the air, although very large amounts of water vapor are also present. The gases are expanded through a rocket nozzle into a test section in which the model is placed. Such an installation is comparatively inexpensive.

The pebble-bed air heater stores heat in a reservoir of material capable of withstanding extremely high temperatures. The ceramic pebbles are contained in an insulated tank. The pebble material is first heated to working temperature by passing the combustion products of a gas flame through the bed. High-pressure air then passes through the bed from bottom to top, is heated by the pebbles, and expands through a nozzle to provide a hypersonic stream of air in which test models can be placed.

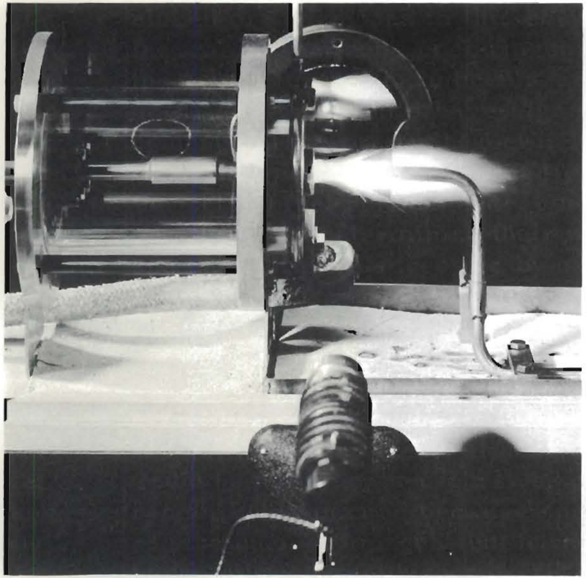
Before flight into outer space can become reality, we must study propulsion systems under conditions likely to be found beyond the earth's atmosphere. At extreme altitudes, air-breathing engines will not operate; therefore, space engines must be capable of operating in a vacuum. In re-entering the atmosphere, future aircraft will be exposed to temperatures as high as 30,000° F, where the behavior of matter changes. To simulate these conditions, new high-temperature facilities are being developed.



Model Demonstrates Usable Ion Thrust

One such facility is the electric-arc tunnel, in which a high-current discharge occurs in an arc chamber. When a working fluid is injected into the chamber, it is heated by the arc. This fluid is then expanded through a nozzle to produce a high-speed stream at temperatures of 10,000° to 20,000° F, in which re-entry problems are studied. This device has a distinct advantage in that it can be operated for sufficiently long periods of time at high speeds and temperatures.

The arc tunnel also suggests an attractive propulsion device for outer-space flight. If a stream of ions, as in an arc jet, can be accelerated to high velocities by use of electric or magnetic fields, a small amount



Arc Chamber Produces Extremely Hot Jet

of thrust will be produced. The ions are tiny bits of matter, carrying electrical charges. They are formed when an electron is added or removed from an electrically neutral atom or molecule. They constitute most of the weight of the atom; and if they can be accelerated to high velocities, their energy can give useful thrust for gradual acceleration and control of the orbit of a satellite vehicle. Development and improved efficiency of such a propulsion device may lead to its application in flight beyond the atmosphere.

Heat-Resistant Materials Needed

Advanced materials are required to withstand the very high rates of aerodynamic heating that will be most serious in the nose cones and propulsion systems of advanced aircraft and missiles. Within the next few years it is urgently desired to raise the material temperatures from their present level of about 1650° F in the turbojet engine to over 2000° F and from about 2500° to 3100° F in the ramjet. For the nuclear rocket, material temperatures as high as 5000° F are being considered. The difficulty of attaining these goals is apparent when these objectives are compared with the slow progress of the past ten years. In that period, the temperature capabilities of jet-engine turbine blades were raised only 300° F.

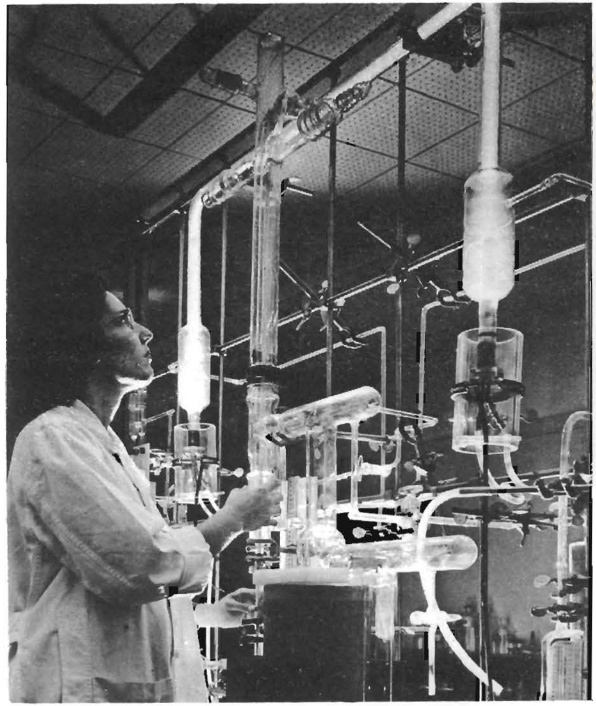
One proven way of increasing the maximum useful temperature of materials is to disperse stable, heat-resistant particles in the alloy (precipitation hardening). These particles lock the atomic structure in place and prevent the material from deforming. As long as these particles remain, materials hold their strength. At the very high temperatures desired for advanced aircraft and missiles, the particles used in conventional high-temperature alloys dissolve in the alloy and lose their effectiveness in stiffening the material against deformation. Fortunately, there are a number of materials available that possess the heat resistance and chemical inertness necessary to be useful.

Studies of applying this strengthening method to high-temperature alloys were made by mixing small quantities of finely divided aluminum oxide with nickel. The resulting alloy retains its strength at temperatures where the conventional strengthening particles used in nickel-base alloys will dissolve and be ineffective. By this technique it is hoped that the maximum useful temperature of nickel-base alloys can be significantly increased without producing undue brittleness.

Another approach is to start with base materials having much higher melting points. Among those being considered as base metals for future alloys are columbium and tungsten. As might be expected from its very high melting point (in excess of 6000° F), tungsten retains considerable strength at temperatures as high as 3500° F. It has, however, an oxidation problem. Unfortunately, this lack of oxidation resistance is characteristic of most high-melting metals, including columbium. Attention is being directed toward improving the oxidation resistance of columbium. Considerable progress has been made in reducing the rate of oxidation and in altering the type of oxide that is formed, but it is still too early to say whether this approach will prove to be the most fruitful.

A third method to provide materials for very high temperatures is through the use of refractory ceramics. While many ceramics have the necessary oxidation and heat resistance, they are extremely brittle and cannot withstand the thermal and mechanical shocks that are expected in missile re-entry and propulsion-system applications. The reason for the brittleness of ceramics is not completely understood.

Recent studies indicate that some ceramics may actually be inherently ductile, but that surface imperfections which tend to make them brittle have masked this



Material Tested under Barrage of Atoms

possibility. Studies are being made of the role of surface imperfections. In a limited way, it has been shown that surface treatment can remove these imperfections and that, with single crystals of sodium chloride and magnesium oxide, ductility can be maintained. While this is encouraging, much additional research will be required before ceramics can be considered practical high-temperature materials for use in aircraft and missile engines.

High-Energy Fuels Boost Performance

Petroleum fuels burned in jet aircraft are relatively cheap, plentiful, and safe. The energy content of these hydrocarbon compounds is however limited to about 18,500 Btu per pound. This figure is too low to satisfy the maximum range requirements of the military services for high-speed missiles and airplanes.

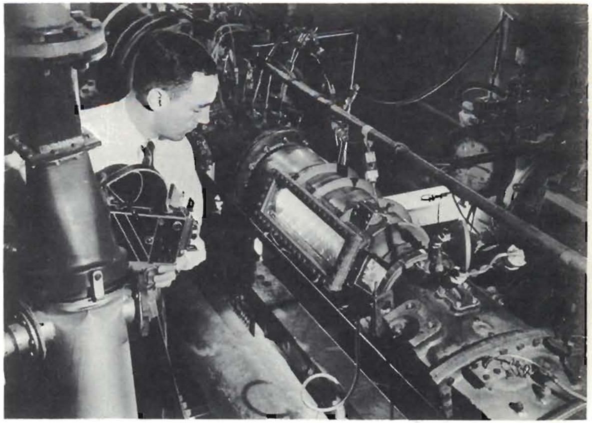
Since the end of World War II, at least eleven organizations in this country, with increasingly strong encouragement from the armed forces, have been searching for new fuels that would have higher energy contents. The work by the Lewis laboratory over this period has included predicting theoretical fuel performance, compounding new fuels and determining their properties and those of fuels suggested by others, and studying the use of the potential new fuels in engines.

The approaches to the problem have been many-sided. Work has included investigation of light metals as fuels, although the gains would be in higher thrust instead of greater range. This occurs because such metals as aluminum and magnesium burn to higher temperatures and at higher over-all fuel-air ratios than hydrocarbons, but do not contain as much heat energy per pound. Studies were made of the burning characteristics of the light metals as solids and as finely suspended particles in hydrocarbon slurries.

Much of the research interest has been centered upon boron and its compounds. In addition to its high-temperature burning, boron has a high energy content per pound and thus is attractive as a means of extending range as well as increasing thrust. In a theoretical study of a ramjet missile flying at an initial altitude of 60,000 feet and a speed of 2100 miles per hour, it was calculated that use of boron could extend range 40 percent over that calculated for JP-4 jet fuel.

Early in the NACA investigation of boron fuels, slurries of metallic boron and jet fuel were studied with disappointing results. A practical solution to the problem of obtaining high combustion efficiency under the difficult conditions of high altitude could not be achieved.

The energy content of boron-hydrogen compounds, the boron hydrides or boranes, is considerably higher than that of boron



High-Energy Fuel Combustion Test Apparatus

itself. Further, many of these compounds can be prepared in liquid form, and thus are more conveniently handled in aircraft tanks and fuel systems.

Only small amounts of boron have been produced in the past, but large quantities of boron-containing salts are available, notably in California. Because of the elaborate and difficult chemical processes in their manufacture, liquid boron hydrides have been priced in the hundreds of dollars per pound in the quantities produced to date.

Research at the Lewis laboratory has been aimed at evaluating the effectiveness of borane compounds over a wide range of conditions, including, recently, limited use in full-scale ramjet and turbojet engines. There are difficult problems remaining. Boron compounds can be quite toxic, and the products of combustion can produce deposits within the engine which depreciate performance. It may be necessary to modify the borane fuel by chemical means to minimize these characteristics.

It is one thing to accomplish satisfactory use of a radically new fuel type under the precisely controlled conditions of the laboratory, and something perhaps entirely different, and much more difficult to achieve similarly happy results in actual flight use. The latter step has already been taken in a small way; speeds greater than a Mach number of 3 were recorded in free flight by an experimental full-scale ramjet test missile burning a boron-compound fuel. Not until the multimillion dollar plants now under construction can produce relatively large amounts of the new high-energy fuels will it be possible to complete the large-scale research that remains to be accomplished before these fuels can be effectively applied to aircraft propulsion.

More Energy to Propel Rockets

For rocket engines, the heat content or specific impulse of the fuel-oxidant combination is of even greater importance for aircraft or missile range than it is for air-breathing engines. The improvement in rocket performance possible through use of some of the combinations suggested as high-energy propellants is so large that a major portion of the NACA's rocket research effort has been concentrated on this problem.

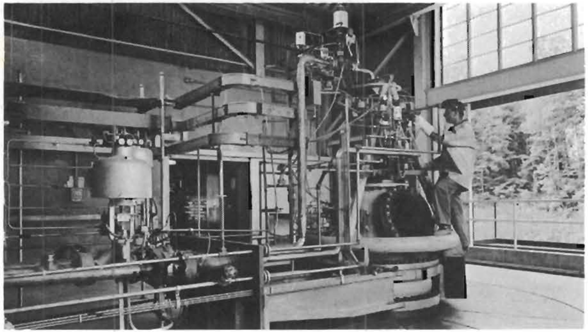
The fuel-oxidant combination most commonly used in rocketry today is modified jet fuel and liquid oxygen. Red fuming nitric acid and dimethylhydrazine are also being used extensively. Some of the combinations that offer substantially higher specific impulse are fluorine-ammonia, fluorine-hydrazine, oxygen-hydrogen, fluorine-hydrogen, and ozone-hydrogen.

Many problems must be solved before the high-energy combinations can be put into operational use. Hydrogen has a high heat content but its density is so low that it requires very large tank space. Further, hydrogen is very difficult to maintain in liquid state.

Most of the problems, however, arise from the need to use oxidizers that will be highly effective. Ozone, theoretically one of the best oxidizers, is extremely unstable. If it is jarred or heated, or contacts the wrong material, a violent detonation is likely to occur.

In many ways, fluorine is the most desirable of all the oxidizers. At the same time it is among the most difficult to handle, and it is so reactive that it is difficult to contain in storage and flow systems. Many of the common materials used in the fabrication of fuel systems decompose, or burst into flame, in the presence of fluorine. Considerable work has been necessary to learn how to use new materials for the special needs of fluorine in fuel lines and storage tanks.

Fluorine's reactivity with fuels is so strong and the resulting combustion temperatures are so high that extraordinary difficulties must be overcome to accomplish successful injection of the fluorine and fuel into the burner chamber. Fluorine-supported flames may be 2000° to 3000° F hotter than oxygen - jet-fuel flames, which reach 5000° F. Better ways must be learned to cool rocket chambers when fluorine-fuel combinations are burned.



New Facility for Rocket Propellant Studies

The realization of smooth and efficient combustion in the rocket engine is critically dependent upon the propellant injector system. The injector must be tailored specifically for each of the different propellant combinations and for different sized rockets. Considerable research and development effort on injectors is expected before fluorine will be an effective rocket oxidizer. Design of gas generators, turbines, pumps, exhaust nozzles, and controls capable of efficient operation in the presence of violently reactive oxidizers, will also be necessary before rocket-engine systems can satisfactorily use the new oxidant-propellant combinations.

In the systematic research of the Lewis Laboratory, much useful information about handling, cooling, and combustion of high-energy-fuel combinations can be derived from small-scale experiments. However, scale effects greatly complicate the process of transferring this knowledge - transferring, for example, from a small, simple burner to the complicated injection and combustion system of a full-scale rocket engine.

Recently completed at the Lewis Laboratory is a new rocket-engine research facility, equipped to accommodate substantially larger rockets than heretofore in use at this laboratory. The facility consists of four main elements, thrust stand, exhaust system, propellant storage, and water treatment plant. The thrust stand, capacle of testing a 20,000-pound vertically fired rocket, is housed in a building remote from the control center located in the main laboratory area. Elaborate instrumentation enables scientists to gather large amounts of information during a single rocket firing, and closed-circuit television cameras monitor each firing. All rocket exhaust products are carefully controlled. Water from a 400,000-gallon storage tank is sprayed into the exhaust duct during firing to scrub out all toxic gases. The water then is collected and decontaminated before disposal.

Heat, Radiation, Problems of Nuclear Power

Two characteristics make nuclear energy attractive for flight propulsion. They are the tremendous energies available per pound of fuel and the very high temperatures that can theoretically be obtained from nuclear fission. Several disadvantages accompany these desirable characteristics. First, shielding must be provided to protect the crew from radiation. Since the shielding is made in part from heavy elements such as lead, considerable weight is involved. Second, radiation has an adverse effect on many of the materials used in an airplane. The presence of a strong radiation field often will induce additional radioactivity in areas far removed from the reactor. This factor further complicates the shielding problem.

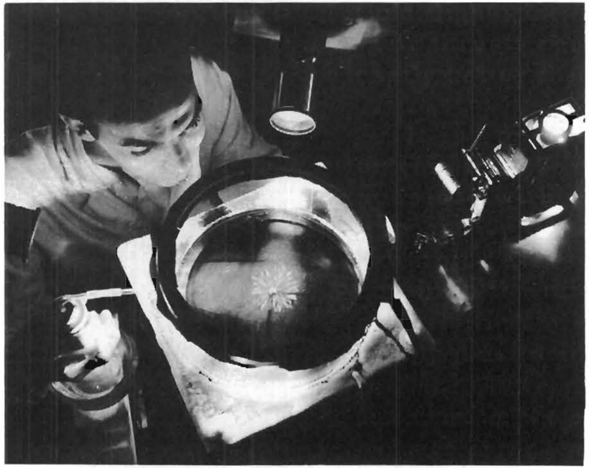
Theoretically, there are a number of ways to harness nuclear energy. All depend on the transfer of the heat produced in a reactor to a working fluid, which in turn is expanded through a nozzle to produce thrust. In air-breathing engines, such as the turbojet and ramjet, air is the working fluid or medium.

In rockets, the working fluid is carried in tanks in the vehicle.

There is little that can be done to alter the properties of air to improve its thrust characteristics when heated. In the rocket, however, since there is a choice of working fluid, light gases would be selected because their thrusts per pound of fuel are significantly better than that of air.

It is apparent that the heat-transfer process must be carried out as efficiently as possible within the temperature limits imposed by the available materials. For example, a reactor fuel element that is hotter in the middle than at either end is not as efficient as one that is operating at nearly maximum temperature over its full length. It is possible to vary the fuel distribution, the coolant flow, or the cooling-passage arrangement so as to obtain a more uniform temperature distribution.

The shielding problem is more difficult. So far as is known, there is no way to eliminate the shield. However, it is possible to concentrate the shielding in those areas where maximum protection is needed (i.e., around the crew) and to lighten the shield where minimum protection is needed.



Radiation Process Studied in Cloud Chamber

Common shield materials are lead for gamma radiation protection and hydrogen-containing materials such as water for neutron protection. Neither lead nor water is necessarily the best shield material. Much research is needed to find and evaluate better shield materials.

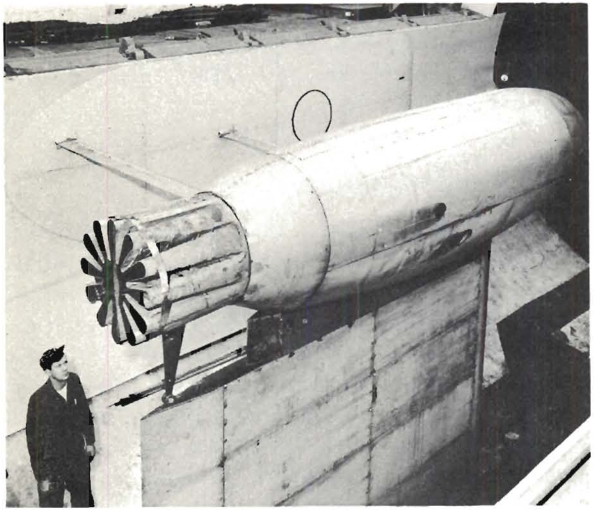
The effect of radiation on materials can be quite marked. Lubricating oils may be turned into a sticky mass; electronic seal and gasket materials may become hard and brittle. On the other hand, some metals show little or no effect, and some materials are actually improved by radiation. The problem then is twofold: the careful selection of materials suitable for the particular radiation environment expected, and the development of radiation-resistant substitutes wherever possible.

To sum up, the application of nuclear energy to aircraft intensifies the high-temperature problems already under study for chemically powered aircraft and brings with it a whole host of new and very difficult problems due to the radiation released by nuclear fission.

The Jet Noise Problem

Within the next year or so, jet airliners will be put into operation in the United States. Because turbojet engines today are substantially noisier than piston engines, commercial use of the jet transports may result in difficulties unless ways are found to reduce the noise produced by their engines. Everyone concerned with air transport is anxious that all practical measures be taken to minimize this problem, and the NACA has been participating in this work.

A basic question is what causes the greater noise of the turbojet engine. It would be reasonable to suspect that the combustion of fuel at tremendous rates, and the whine of the compressor blades



Experimental Nozzle Decreases Jet Noise

might be the principal causes, but actually these noises are not the prime offenders. The "big noise" is created outside the engine by the exhaust jet as it mixes with the atmosphere. The exhaust jet and the air do not mix smoothly; hot gas and air roll up into irregular swirls and eddies, producing fluctuating pressures that are radiated as sound waves.

A simple "cure" for the jet noise problem would be elimination of the turbulent mixing, but fundamentally there is no way to accomplish this. However, it is possible to reduce the strength and size of the turbulent eddies. Intensive research has been conducted on various nozzle shapes, some of which will lessen the noise substantially by reducing the peak sound levels at certain frequencies. Difficulties are encountered in the design of such nozzles in keeping drag, weight, and engine performance penalties at a minimum while at the same time accomplishing the desired noise reduction.

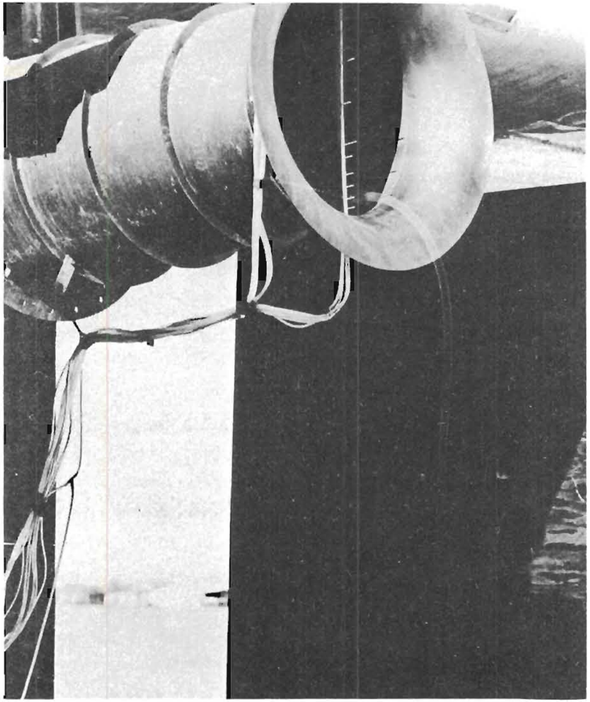
A basically different approach to the problem is to reduce the velocity of the exhaust jet. A small reduction in jet velocity will produce a substantial reduction in noise. Today's engines, designed to provide the maximum performance requirements of the military services, cannot operate efficiently at lower jet velocities. It would be possible to design new engines that would operate efficiently at low jet velocities, and thus with lower noise, but development of such new engines requires additional research and would be costly and time consuming.

There is the further possibility of combining the noise-reduction potential of special nozzle shapes with that of the lower jet velocity. The factors of cost, thrust losses, and weight are of great importance in considering devices that may be used on the commercial jet transports. Much research is still necessary to produce economically practical noise suppression.

Operating Problems Studied

Turbojet engines mix enormous quantities of air with the fuel that is burned in the combustion chamber. Consequently, the airflow through an engine is very high; i.e., in excess of 100 pounds per second for an average engine. When operated on the ground during engine runup, taxi, and takeoff, the inlets tend to act as mammoth vacuum cleaners. Under certain conditions pebbles, small tools, dirt, and debris can be swallowed by the engine with occasional catastrophic results.

Studies of this problem by the Lewis laboratory have shown that vortexes are formed ahead of the inlet. Near the center of the vortex a lifting force results from the suction. The strength of this suction was indicated by measurement of pressure difference across the vortex; this strength was found to be 276 pounds per square foot below atmospheric pressure, quite adequate to lift sizeable objects. The strength and direction of the vortex depend upon a variety of factors. As engine height above

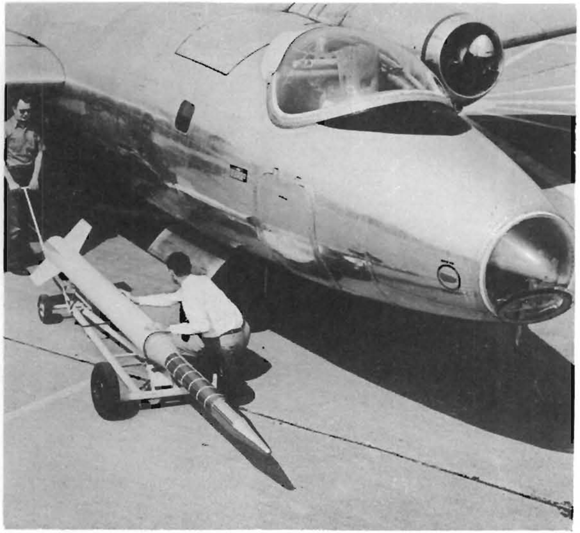


Inlet Vortex Can Lead to Engine Damage

ground is increased, or as engine speed and, therefore, the airflow is lowered, the vortex weakens. When the direction of the wind changes from a head wind to a tail wind, less engine power is required to create a vortex capable of picking up objects.

It was learned that if pebbles are held loosely the vortex base sweeps them away from in front of the engine like a broom, but when they are held as they can be in runway pavement cracks, they are drawn up into the engine. Results prove that care must be used in ground operation of jet aircraft in order to avoid loose objects insofar as possible. One manufacturer, The Douglas Aircraft Co., after studying the program, concluded that the vortex formation could be prevented, and has demonstrated a device for doing this.

Another study in the field of operating problems conducted by the Lewis laboratory centered on the source of ignition in aircraft crash landings. This study revealed that some structural materials are the ignition sources under crash conditions. Friction sparks are created when metals drag on runways or other hard surfaces.



Two-Stage Research Rocket is Hypersonic

These sparks ignite the fuel mist which results from broken fuel tanks and severed fuel lines.

In order to determine which metals produce friction sparks, samples of commonly used aircraft metals were dragged over a runway at various speeds and bearing pressures. Mixtures of fuel and air were then sprayed nearby to simulate crash conditions. In the tests, samples of aluminum, titanium, magnesium, chrome-moly steel, and stainless steel were investigated.

Aluminum proved to be the safest metal tested, failing to ignite mists of gasoline, JP-4 fuel, kerosene, or heated lubricating oil. Titanium produced many sparks and readily ignited the fuel, while magnesium gave off intermittent flashes of burning magnesium powder. The steel samples similarly ignited the fuels, although they neither produced as many sparks nor ignited fires until the metal itself had become heated through friction.

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