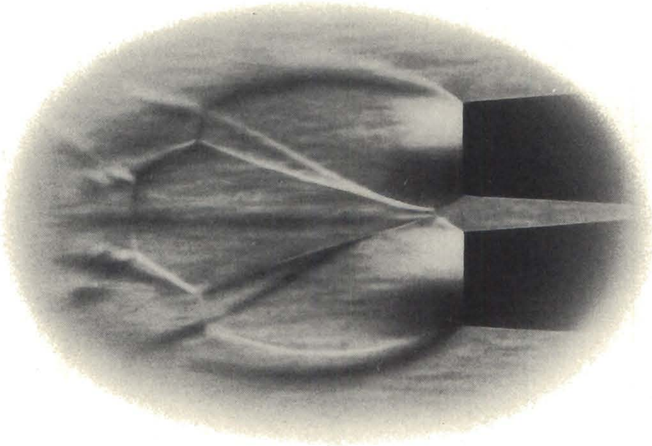

Lewis Flight Propulsion Laboratory

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

1949 INSPECTION

Also
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WELCOME

Welcome to the 1949 Inspection of the Lewis Flight Propulsion Laboratory. On these occasions we look forward to the pleasure of greeting old friends who are familiar with the NACA research centers and their work, and to the making of new friendships with those who visit us for the first time.

Here at the Lewis Laboratory the research program encompasses the broad range of problems associated with the propulsion of aircraft. In attacking these problems, both theory and experiment are employed to accumulate the basic knowledge necessary for the continued development of aircraft engines. The frontiers of such basic aeronautical information are being pushed ever forward. The gains we make often are unspectacular in and of themselves, but this steady enlargement of the area of scientific knowledge, increment by increment, totals a significant annual gain.

These inspections seek to summarize the more noteworthy trends as indicated by research conducted since your last visit with us We are honored by your presence and trust that you will profit, as will we, by this meeting.

J C Hunsaker

Chairman,
National Advisory Committee for Aeronautics

Power . . .
the key to always faster speed

It is hardly ten years since attainment of practicable jet propulsion touched off a revolution in the world of aviation. It is less than eight years since America's first jet-powered airplane took off from the lake bed at Muroc on its maiden flight. The chain-reaction consequences stemming from the first jet flight, August 27, 1939, were of great significance; even so it is difficult to contemplate the further advances which wait only on man's daring and industry for exploitation, except in terms which seem exaggerated.

Man first flew faster than sound October 14, 1947, utilizing the rocket type of jet propulsion in a specially designed research airplane. Subsequently the inevitability of faster-than-sound flight by tactical military aircraft has been underlined by the near-700 mph speeds of production model fighter airplanes, and already bombers are flying so fast, so high, so far that adequate interception has become critically urgent.

So spectacular have been the advances in air speed during the past decade and so obvious the further speed increases yet to be attained that the general public and even those familiar with the problems and workings of aeronautics become impatient unless the gains, each year, when translated into miles per hour, surpass those of the previous year.

The key to this maintenance of always faster speeds is, of course, power . . . power in quantities which even today seem enormous. Elsewhere in this booklet the magnitude of these power requirements is discussed in more detail; for the moment it is necessary only to recognize the problem, solution of which is imperative, first to satisfy military needs and later, for civilian utilization.

Important, therefore, is a better understanding, particularly by those most intimately concerned with the use of aviation for the national welfare, of the pattern which aviation progress is likely to take in the years to come, and of the nature of some of the problems which must be solved. This understanding, inevitably, includes a recognition of the amount of time and effort which must be invested if the attacks on these problems are to succeed. What we did in the past and what we are now doing provide information helpful to this understanding.

Responsible partners in the performance of the mandate to keep America pre-eminent in aviation are the Department of Defense, the nation's aircraft and engine industry, the nation's educational institutions, and the National Advisory Committee for Aeronautics. Each has specific, vital functions to perform; cooperation among the four assures integrated effort.

NACA's mission is the fundamental study of the problems of flight. At the Lewis Flight Propulsion Laboratory, the research program seeks solution of the problems associated with propulsion. This 1949 Inspection is designed to provide the opportunity to note progress made in propulsion research during the past 12 months and, no less, to enable a better understanding of the problems yet to be solved.

From its earliest days, NACA has studied propulsion problems. In 1923, an NACA report by Edgar Buckingham of the Bureau of Standards considered the future of jet propulsion, a future which at that time looked dim because speeds faster than 250 mph were hard to envision. In the years which followed, propulsion research was continued, centering on the problems, which in retrospect seem relatively simple, involved in further perfection of the reciprocating engine.

Wartime requirements demanded immediate

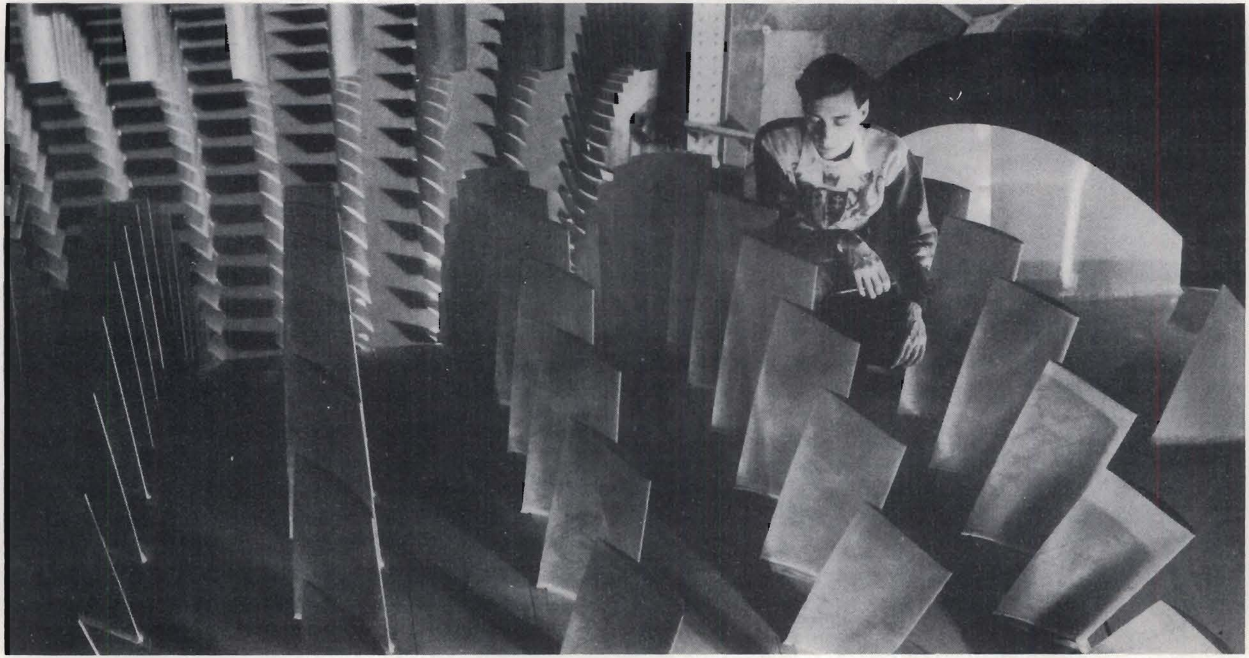
extension of the power potential of the reciprocating engine, which industry was equipped to build in the needed numbers, and during its early years the Lewis Laboratory devoted much of its energy to this work. Nonetheless, the Laboratory from the very first conducted research on problems created by the revolution in propulsion technology which created the jet engine, and to an ever greater degree the research emphasis was shifted, until finally, virtually all research effort was concentrated on the new problems.

The new power plant, with its compressor, turbine and burner cans, burned different fuels from those perfected over the years for the reciprocating engines. New research techniques and the new research tools had to be devised, and the Laboratory underwent a complete physical transformation.

It became necessary to provide altitude wind tunnels and tanks in which the internal characteristics of full-scale engines could be investigated under conditions simulating those to be found at altitudes as high as 80,000 feet. With the possibility of supersonic speeds, supersonic tunnels were designed and built to permit simultaneous study of the internal and external characteristics of the engine. Tunnels operating at a Mach number of 1.9; at 4, and only this summer, at a Mach number of 6. Largest and most immediately needed was the 8- by 6-Foot Supersonic Wind Tunnel, capable of speeds from a Mach number of 1.4 to 2, which this year was placed in operation. All these supersonic tunnels, and there are others, are of the nonreturn-passage type, so that fuel and air can be burned in the engines under actual operating conditions.

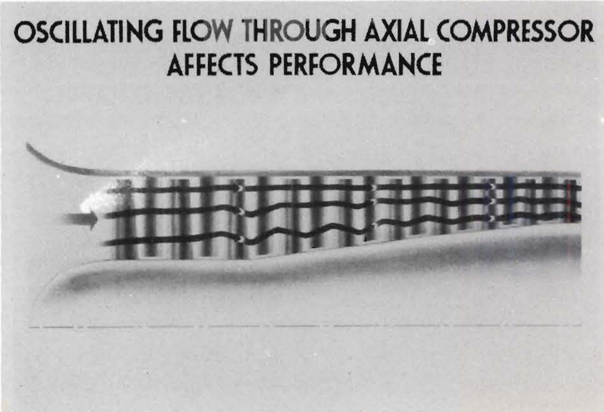
Solution of one problem gives rise to others, more fundamental, which in turn must be explained if the primary answers are to be found to the continuing question - how to design more and yet more powerful engines. These solu-

COMPRESSOR BLADES OF NEW SUPERSONIC TUNNEL



tions, these research gains, are not easily won. Sometimes it is necessary to buttress partially formulated theory with experiment, thus to achieve tentative answers which must suffice until the ultimate theory can be developed.

The increment gains, in this enlargement of the area of knowledge about propulsion, often in and of themselves are unspectacular, especially when charted against time, but in the sum represent steady progress. The pages which follow outline in briefest form significant forward steps which have been taken since the Lewis Laboratory's last inspection.



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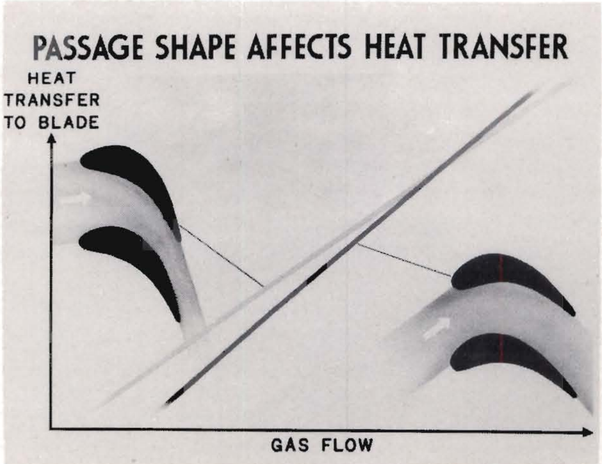
Higher pressures, cooler turbines

Among prime research goals of the Lewis Laboratory are obtaining data which will enable design improvement of compressors and turbines, thus to produce engines having higher power, lower weight, lower specific fuel consumption, lower manufacturing costs and lower operating costs. Progress toward this overall goal was reported at the last Inspection, and it is now more evident the principal improvements in gas-turbine engine performance will come from increasing the engine pressure ratio, and by turbine cooling which permits increasing the maximum cycle temperatures.

There is an increasing awareness that peak-engine performance requires designing the engine for a particular application rather than seeking to use a single engine for a wide range of service requirements. Sufficient fundamental knowledge of the flow conditions in compressors and turbines is needed to enable the design of engines for particular use, i.e., in small fighters or large, long-range bombers, greatly reducing the expensive, time-consuming program of development.



Beginning with theoretical work, problems are divided into their basic elements and the characteristics of each studied. At those points where present theories reach their limits, fundamental experimental research is carried on in cascades (small wind tunnels especially adapted for study of blades) where flow details can be readily and economically investigated. Research then moves to single-stage and finally to full-scale investigations. In addition to supplying data for aerodynamic design, this coordinated research provides a better knowledge of the flow conditions necessary for improved turbine cooling.

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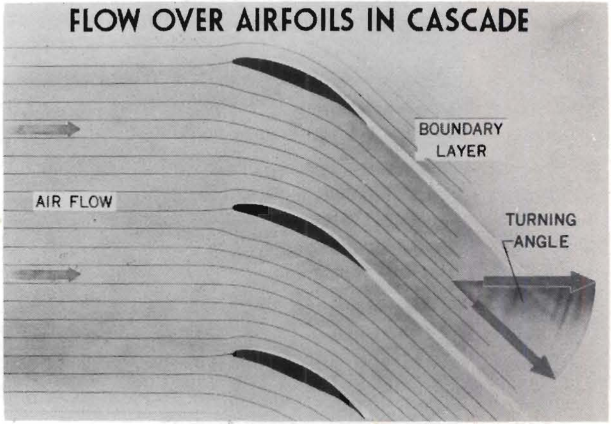

Throughout the study of pressure ratios, weight flow and work output of compressors and turbines, it is necessary to determine exactly the paths of flow and the velocities of the fluid (air) at every point in the machine. Known mathematical methods will not permit solution of the problem, and so simplifying assumptions must be used. Progress is being made; for example, within recent months, a method has been developed for computing the thickness of the boundary layer at any point along the blade when the perfect-fluid velocity is known. Study is also being made of flow velocities which are greater than sound, and of the shock waves and their interactions which result.

Encouraging performance on a service-type centrifugal compressor, using information from this program, has resulted, and in the work with supersonic axial-flow compressors, practical units have been developed, utilizing blades thicker and more sturdy than the finely machined, razor-like blades of earlier such machines. This 16-inch supersonic compressor, in addition to being more practical in construction, gives improved performance.

Advantages looked for in turbine cooling include increased power, economy and reliability

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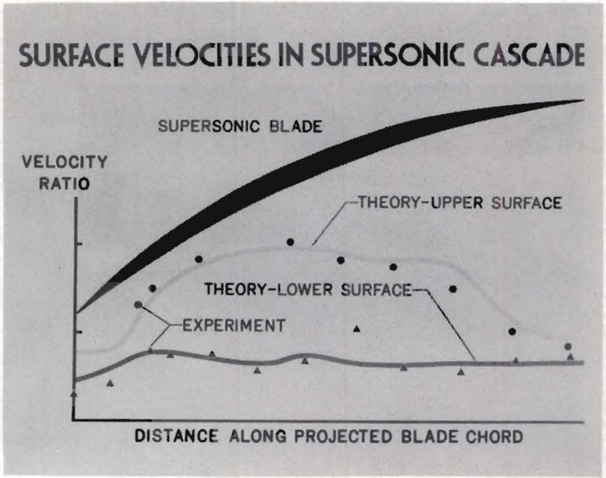
of operation, and conservation of strategic materials now used in turbine manufacture. If operating temperatures are increased from 1500° F to 3000° F power can be more than doubled. Today, even with the use of heat-resisting alloys having up to 96% content of scarce elements, operating temperatures are generally limited to about 1500° F because of stress limitations.

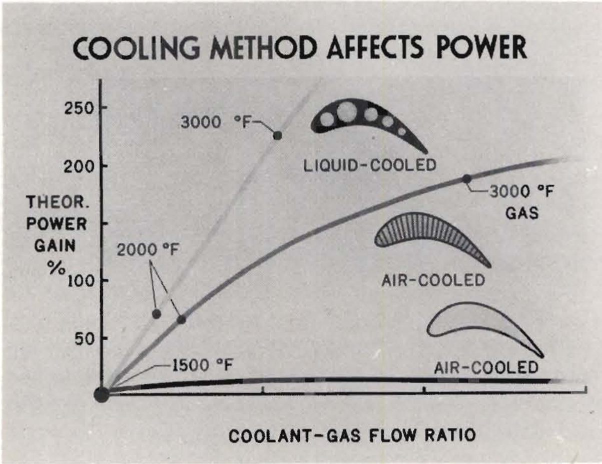
Possibilities include use of hollow blades and internally-finned hollow blades, and additional cooling by use of air or water. Even allowing for the power drop because of cooling losses, cooling with either water or air results in substantial net power gains as operating temperatures are raised to 3000° F. When cooled blades, containing only 2% strategic materials, are used, it is still possible to operate with gas temperatures of over 2000° F.

Continuing work is planned, both experimental and theoretical, including investigations of air cooling, liquid cooling, blade configurations, use of ceramic coatings and blade materials, as well as determination of the characteristics of the boundary layer around the blade which controls heat transfer.



Wanted:- Non-critical materials

Aside from continuing research to enable further improvements in powerplants, the possibility of an emergency calling for manufacture of jet engines at the rate, say, of 100,000 a year (in one year of the last war, 257,000 reciprocating engines were built) requires review of the metallic elements used in the manufacture of these engines. If these elements be critical in supply - and columbium, tungsten, cobalt, chromium, and nickel are high on such a list - then other approaches to the problem of fabricating certain engine parts must be made.



The NACA's contributions to the problem take the form of a three-pronged attack. One is research leading to the development of non-strategic materials suitable for jet engines. Another is establishment of design methods resulting in a reduction in use of critical materials. A third, discussed in the description of compressor and turbine research, is development of cooling methods making possible the use of lower-temperature alloys of ready availability.

A complete turbine wheel accounts for 30%

24947

of the critical elements used in the fabrication of a typical jet engine, and is therefore a focal point in the search for means to reduce the use of materials in short supply. During the past year the systematic study of possible combinations of non-strategic materials has continued and a number of reports have been issued.

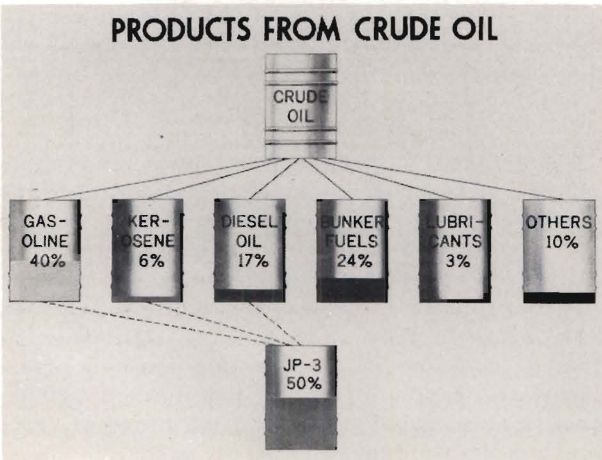
In these systematic studies materials have been combined and classified according to their strength at high temperatures, resistance to thermal shock, oxidation resistance, ductility, and other characteristics essential to use in turbines. Samples of the most promising have been fabricated for experimental study in rotating machinery and under the numerous conditions peculiar to turbine operation. Such research may not yield early and direct results but much knowledge has been derived from which new, non-strategic materials will undoubtedly be developed for turbine use.

An example of another attack being made on the critical materials problem is to be seen in the substantial progress made by manufacturers in reducing the total amount of material used in making turbine disks. This has been made possible by the growing knowledge of stresses and how to design them. One of the important research tasks of the Lewis Laboratory is to contribute to stress knowledge so that further reductions in use of critical material can be made.

Considerable progress has been made during the past year in the development of a design method for insuring that turbine disks are stressed to the level of their maximum capabilities. Whether such ideal design procedures can be applied in practice can be ascertained only after further research and experimentation to be sure that no unexpected new problems are encountered. If the method proves practicable, substantial savings in use of critical materials appear to be assured.

More fuel for more jet engines

Development of a specification for the most suitable turbojet engine fuel involves many considerations. Foremost among these is the requirement that it must be readily available in time of emergency.



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Present model turbojets burn either a kerosene-type fuel (JP-1) or, because of greater availability, gasoline. From a barrel of crude, only 6 percent kerosene is obtained, not enough to supply the large numbers of aircraft operating in time of emergency. Nor is it desirable, if another suitable fuel can be developed, to burn large quantities of highly refined aviation gasoline even though this is potentially available as 40 percent of the barrel of crude.

A maximum availability equaling 50 percent of the products refined from a barrel of crude was suggested for the new jet fuel blend (JP-3). This meant utilizing all the kerosene, all the gasoline, and about one-fourth the Diesel and heating oils (17 percent of the crude).

The NACA determined the suitability of the JP-3 fuel blend for practical jet operations. Among the factors studied were boiling point temperature range, aromatic content as it affects carbon deposition, altitude starting and altitude operational limits, combustion efficiency, heat energy release per gallon, and vapor loss. Used in these studies were four types of modern turbojet engines with both can-type and annular-type burners. Test operations were conducted in altitude tanks, the altitude wind tunnel, and in flight at the NACA's Lewis Laboratory. These investigations showed that the JP-3 fuels measured up substantially equal to or slightly better than JP-1 fuel with respect to all specification characteristics.

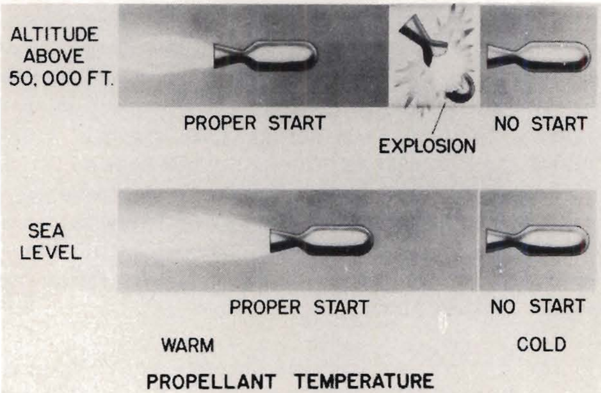
During the last war, less than a third of the gasoline available was used for aviation, and the amount of JP-1 required was small because jet aircraft were a late development. In time of future emergency, of course, aviation will be but one of several heavy users of both gasoline and kerosene. Because of the likelihood of tight supply, studies are being continued at NACA to determine the minimum requirements for satisfactory jet fuels with regard for supply availability.

Rocket engines pose problems, too

Unsurpassed as a heat engine wherever high thrust is required for short periods of time, the rocket develops the greatest thrust per unit of engine weight with the smallest frontal area per pound of thrust of all engines used in aircraft propulsion. It is the only power plant whose performance does not decrease with higher altitudes because it carries its own oxidant and does not depend upon the earth's atmosphere. Its specific fuel consumption, however, is much greater than that of any of the other engines used.

Its ability to provide super-performance, although for only short periods, has caused it to be used as a primary powerplant for military missiles and upper-atmosphere research vehicles. It has been used as an auxiliary powerplant for launching missiles, especially those powered by a ram-jet because the ram-jet is incapable of delivering appreciable thrust except at high speeds. The rocket has been used for assisting take-off of aircraft, and for thrust augmentation of aircraft for high climb rates or high speeds. The rocket permits long ranges for vehicles that are brought to high speed and then allowed to coast, following a trajectory path like a projectile.

ALTITUDE STARTING OF ROCKETS



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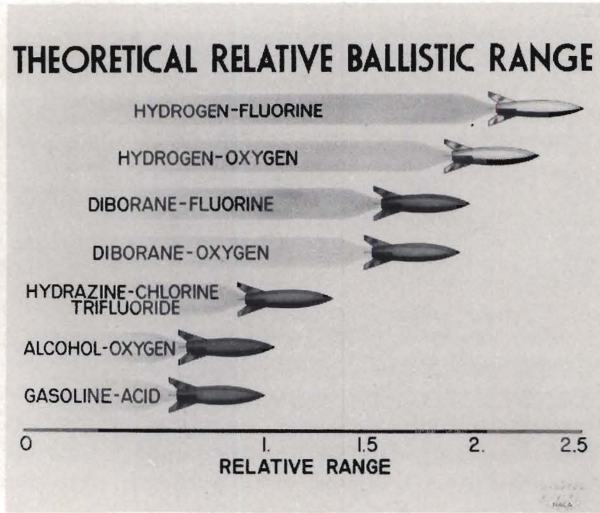
A major problem in rocket engines is to secure the highest possible thrust from a unit of propellant. Investigating this problem, Lewis Laboratory researchers have, both on paper and experimentally in the laboratory and with engines, determined the extent to which improved propellants will exceed specific impulse given by the gasoline-nitric acid propellant which is rated as 1. (Alcohol-oxygen is rated at 1.08.) This program now is being extended to include propellants with still higher energy potentials, and consideration is being given to such properties as ignitability, density, boiling and freezing points, stability, toxicity, and availability.

The heat release of a rocket engine producing 1,000 pounds of thrust can be 520 million Btu/hr/cu ft, compared to 25 million for a turbojet engine. Temperatures to 6,000° F are produced. Cooling must therefore be provided to keep the rocket chamber walls from melting.

One method of providing this cooling is to circulate the propellants over the engine surfaces prior to injection and combustion, but often this is not sufficient, or the high-energy propellants are not suitable for such circulation.

Another method maintains a film of coolant along the inner surface of the rocket chamber in direct contact with the hot gases. NACA is studying the characteristics of internal film cooling to provide the engine designer with generalized data which he can apply to his specific problems. As a first step this study was made at gas temperatures up to 1800° F with the investigation to be carried into the higher temperature range.



Broadening usage of rocket power plants at high altitudes and low temperatures has resulted in research being focused on starting the rocket engine under these conditions. Propellants, which at low altitudes and moderate temperatures ignite spontaneously and rapidly upon contact, may at high altitudes refuse to ignite or ignite in explosive fashion destroying the rocket engine. Two solutions are being worked on at the Lewis Laboratory: (1) Keeping the engine and propellants sufficiently warm to insure prompt, safe starting, and (2) use of additives to the fuel to shorten the ignition lag.

Still another problem is the phenomenon of combustion vibration or "chugging" whereby violent oscillations are set up in the combustion chamber and feed systems. This chugging has been analyzed theoretically and the approximate range of conditions determined over which chugging can occur.

Experiments are being conducted to learn how chugging is affected by variations in such factors as chamber and injection pressures, and combustion volume. From this knowledge, it is hoped that chugging can be eliminated

For sustained supersonic flight

With accomplishment of short duration supersonic flight speeds by full-scale research aircraft and with the imminence of sustained supersonic flight speeds, research effort is being intensified to solve the basic supersonic propulsion problem: - How to obtain engine types capable of developing the extremely large powers required.

A subsonic airplane of about 50,000 pounds capable of flight at 400 mph at 30,000 feet requires engines developing 3,000 hp. An airplane of this same weight reaching a speed approximately 1.5 times that of sound at 50,000 feet would require an engine providing 15,000 hp, while an airplane of this weight reaching speeds 2.5 times that of sound at 70,000 feet would need about 45,000 hp.

Because of their ability to handle large quantities of air relative to their size, and because their power increases with flight speed, turbo-ram and ram-jet engines are suitable for supersonic flight. Problems of these engines are the subject of intensive investigations at the Lewis Laboratory.

Problems common to supersonic engines are efficient compression of the air, combustion of the fuel, aerodynamic efficiency of the engine, and inter-related effects between engine and airplane. Efficient conversion of the heat energy of the fuel to useful propulsive energy requires that the process occur with the highest possible compression of the combustion air. In the ram-jet engine compression is obtained by slowing the air from flight velocity at the inlet to a low speed in the combustion chamber. In slowing down, the air converts its velocity energy to pressure energy. This ram compression increases with flight speed. Special inlet designs are necessary to obtain

MODEL IN NEW SUPERSONIC TUNNEL

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efficient compression at supersonic speeds by reducing shock losses at the inlet.

NACA's three Laboratories are investigating the compression problem at supersonic speeds, and although considerable improvement at all speeds has been achieved, research is continuing to bring actual compressions even closer to the theoretical maximum compressions.

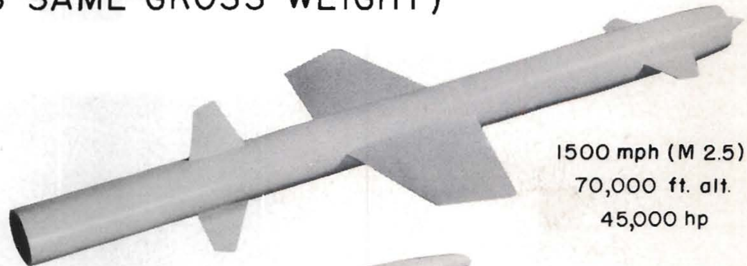
The problem is made more difficult by the great sensitivity of inlets at supersonic speeds to operation at altitudes and speeds other than those for which the engine is designed (off-design point). This sensitivity is largely expressed as compression loss and increased engine drag. Research is directed to evaluating the off-design characteristics of different supersonic inlets to determine how they influence the utility of engines of fixed design.

Previous investigations showed that pressure pulses associated with combustion may seriously reduce ram compression. Indications are that engine design and operating conditions influence this pulsing problem. Research is now under way to learn how the pulsations occur and whether the problem is an inlet or combustion phenomenon. Determining the quantitative effects of pulsations on compression over a range of operating conditions is another research task.

Because air in a ram-jet engine passes through the combustion chamber at high velocity, there is a tendency for the flame to blow out. Operating the engines at high altitudes with resulting low pressures also makes combustion difficult. Since 1945, the velocities at which good combustion efficiencies can be maintained have been increased almost threefold and further progress is expected. Similarly, progress has been made increasing the altitude limits for satisfactory combustion, a result of intensive research on flame-holding

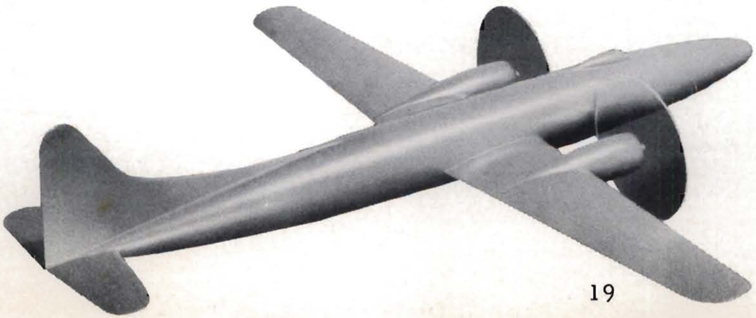
POWER REQUIREMENTS FOR HYPOTHETICAL AIRPLANES

(ALL AIRPLANES SAME GROSS WEIGHT)



1500 mph (M 2.5)
70,000 ft. alt.
45,000 hp

1000 mph (M 1.5)
50,000 ft. alt.
15,000 hp



400 mph (M .63)
30,000 ft. alt.
3000 hp

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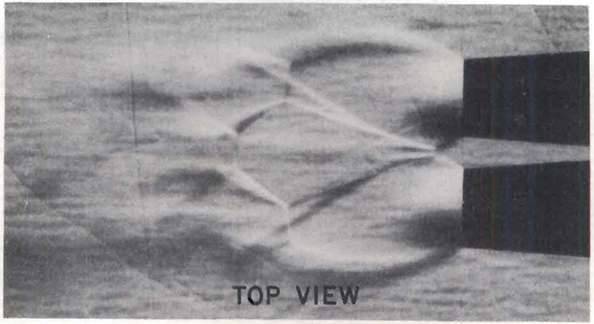
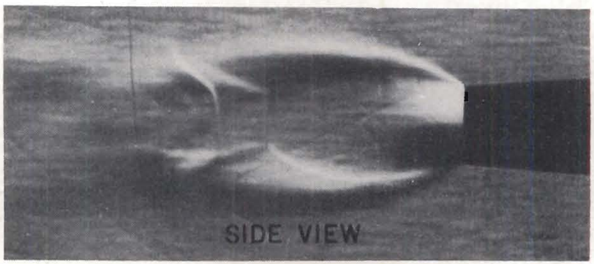
INTERFERENCE BETWEEN TWIN JETS





devices, fuel-injection methods and combustion chamber designs.

At supersonic speeds, the problem of designing engines having the lowest possible drag becomes important, and much research on this subject is required. Air flow disturbances induced by the engine inlet or exhaust jet may seriously alter the effectiveness of the lifting and control surfaces of the airplane, whether the engine be located in a nacelle or totally submerged in the fuselage. Supersonic propulsion systems no longer can be isolated for separate study but must be investigated with the complete aircraft configuration.

To conduct this work the engine nacelle must be completely submerged in a supersonic air stream, and reliable data can only be obtained with large-scale models. The free-flight technique has been valuable in collection of data in the transonic speed range and the new 8- by 6-Foot Supersonic Wind Tunnel will be specially useful in higher speed ranges.

24043

And now, a new research tool

Similar to all the supersonic tunnels at the Lewis Laboratory in that it is of the nonreturn-passage type to permit burning fuel and air in the engine under actual operating conditions, the new 8- by 6-Foot Supersonic Wind Tunnel is the world's largest tunnel operating at faster-than-sound speeds. Under construction for more than a year, it first was placed in operation three months ago, then calibrated, and now is being used to produce useful research data.

Air passing through the tunnel must be extremely dry to prevent condensation and velocity disturbances in the test section. At maximum operating conditions as much as two million cubic feet of air per minute - weighing almost 75 tons - are drawn into the tunnel. Air is dried by passing through beds of activated alumina, which on a hot day remove as much as a ton of water each minute.

Taken from the dryer building, the air moves into the inlet of the compressor, which is powered by three electric motors providing 87,000 hp and connected in tandem. The air leaves the compressor at pressures up to 1.8 atmospheres but at low velocity, and then is expanded to produce the desired speed in the test section. This speed can be varied from 1.4 to 2.0 times that of sound.

Moving into the minimum area of the tunnel throat, the air reaches the speed of sound, and as the tunnel passage is expanded, accelerates until the desired supersonic speed is reached. The amount of area expansion downstream of the minimum section of the nozzle is controlled by flexing two stainless steel side plates, 35 feet long, 8 feet high, and 1 inch thick. To do this flexing work, 14 hydraulically operated screw jacks on each side are employed.

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