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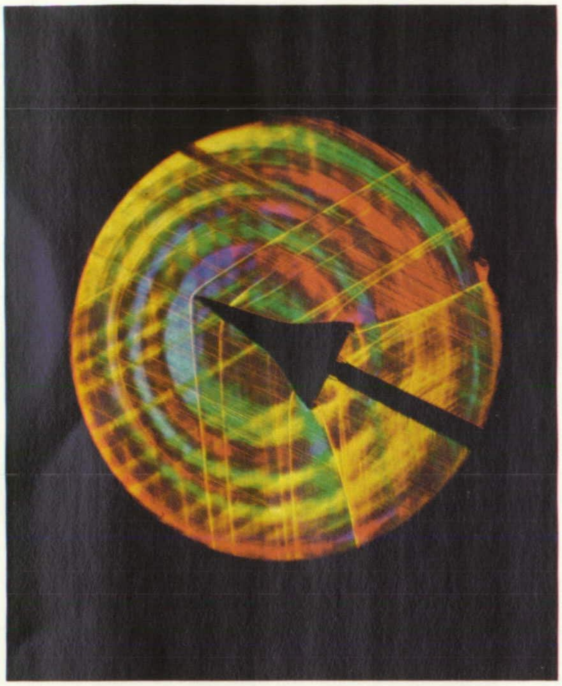
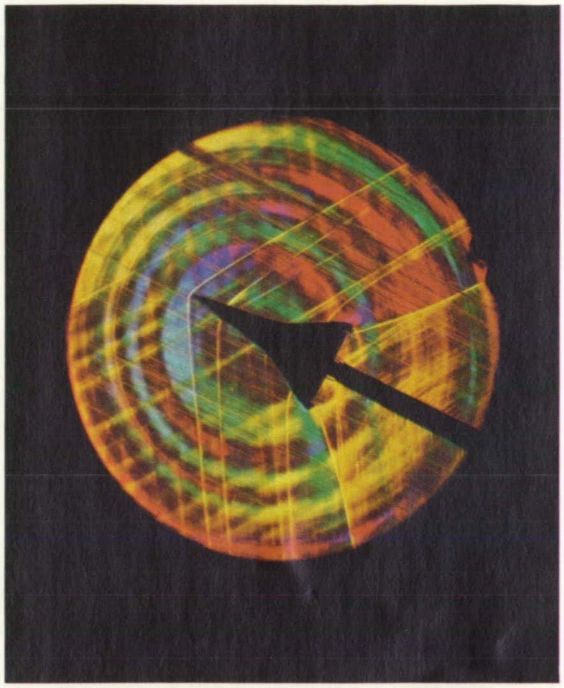
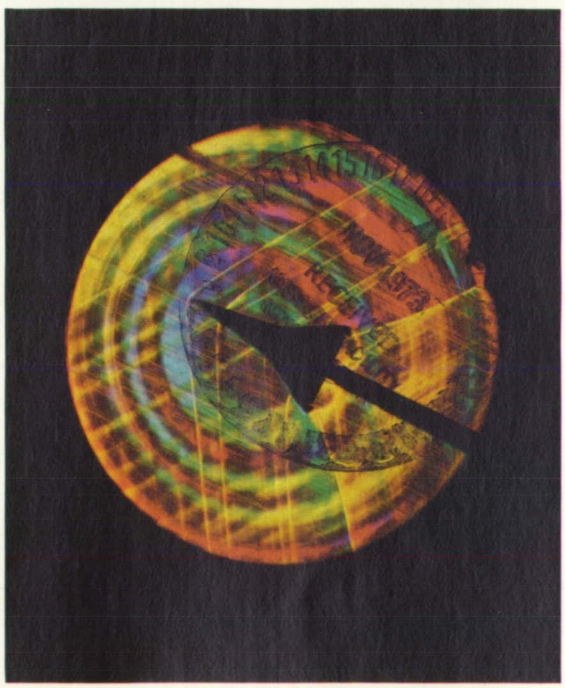
AERONAUTICS

Space in the Seventies







National Aeronautics and Space Administration

SPACE IN THE SEVENTIES

Man has walked on the Moon, made scientific observations there, and brought back to Earth samples of the lunar surface.

Unmanned scientific spacecraft have probed for facts about matter, radiation and magnetism in space, and have collected data relating to the Moon, Venus, Mars, the Sun and some of the stars, and reported their findings to ground stations on Earth.

Spacecraft have been put into orbit around the Earth as weather observation stations, as communications relay stations for a world-wide telephone and television network, and as aids to navigation.

In addition, the space program has accelerated the advance of technology for science and industry, contributing many new ideas, processes and materials.

All this took place in the decade of the Sixties.

What next? What may be expected of space exploration in the Seventies?

NASA has prepared a series of publications and motion pictures to provide a look forward to SPACE IN THE SEVENTIES. The topics covered in this series include: Earth orbital science; planetary exploration; practical applications of satellites; technology benefits; man in space; and aeronautics. SPACE IN THE SEVENTIES presents the planned programs of NASA for the coming decade.

December 1971

COVER:

This photograph, taken in a wind tunnel at NASA's Ames Research Center, illustrates a new color schlieren system. Schlieren photography takes advantage of the fact that light passing through a density gradient in a gas is refracted as if passing through a prism. Thus, the photograph provides a diagram of air flow past the model in the wind tunnel.

AERONAUTICS

By David A. Anderton

National Aeronautics and Space Administration, Washington, D.C. 20546

Temperature patterns on the surface of an HL-10 lifting body reentry vehicle are studied under realistic flight conditions by scientists of the National Aeronautics and Space Administration's Langley Research Center. Information on heating and its distribution is essential to the proper design of thermal protection and structures for reentry spacecraft.

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INTRODUCTION

Orville and Wilbur Wright flew in 1903 because many others had tried to fly before them. The long years of rudimentary research and development in aeronautics culminated in their first flight. They had learned from the experience, and the successes and failures, of others.

And, basically, that is what aeronautical research is all about. It is a scientific, systematic approach to obtain information that will advance aeronautics. It was the only task of the predecessor organization, the National Advisory Committee for Aeronautics, founded in 1915 to conduct aeronautical research in this country. It is one of the major tasks of the National Aeronautics and Space Administration, and has been since the inception of that agency in 1958.

The National Aeronautics and Space Act of 1958, which established NASA, states that the general welfare and security of the United States require that adequate provision be made for aeronautical activities and that these activities be conducted so as to contribute materially to one or more of the following objectives:

- The expansion of knowledge of phenomena in the atmosphere.
- The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical vehicles.
- The preservation of the role of the United States as a leader in aeronautical science and technology.
- The most effective utilization of the scientific and engineering resources of the United States in order to avoid unnecessary duplication of effort, facilities and equipment.

Together with industry, universities and other government agencies and laboratories, NASA research works toward those broad objectives and, specifically, to advance military and civil aeronautics—to point toward new concepts for flight, new approaches to solve the ever-changing problems of transportation, and new ideas to stimulate the designers of tomorrow's aircraft.

This is the story of some of that research.

WHAT IS AERONAUTICAL RESEARCH?

Aeronautical research concerns itself with investigating vehicles and power plants that use the Earth's atmosphere to sustain them in flight. Within the purview of NASA, aeronautical research also applies to space vehicles that depart from, or land on, the Earth.

The primary agency for aeronautical research in the United States is the National Aeronautics and Space Administration. It was chartered by the National Aeronautics and Space Act of 1958, and charged—as one task of several—with the responsibility for advancing the course of aeronautics.

Four NASA centers bear the largest share of aeronautical research: Langley Research Center, Hampton, Virginia; Ames Research Center, Moffett Field, California; Flight Research Center, Edwards, California; and the Lewis Research Center, Cleveland, Ohio.

Supplementing the work done at these centers are additional studies or tasks done at other NASA labs, or at the laboratories and facilities of other government agencies. Private industry, both in self-supported and NASA-funded programs, makes major contributions to aeronautical research. And the universities, with their long tradition of academically oriented research, are partners with NASA and industry.

In planning, NASA works jointly with the Department of Defense and the Department of Transportation to make certain that specific research needs of those departments are considered.

Aeronautical research by NASA helps to assure that this country has aircraft second to none. And the continuing application of advanced technology means that aircraft will be efficiently designed, built and operated.

Air transportation is a key element in America's economy. This country moves much of its commerce, internally and for export, by air. Additionally, the world's airlines buy fleets of American transport aircraft.

The need for aeronautical research to support these portions of productivity is also obvious.

Today, aeronautical research typically is looking ahead, to aircraft types and designs that might be carrying passengers and freight at the next turn of the century. But most of NASA's effort is a continuing, hard look at today's aircraft and at the types planned for the next few years, to make certain that they will be safe, economical and efficient.

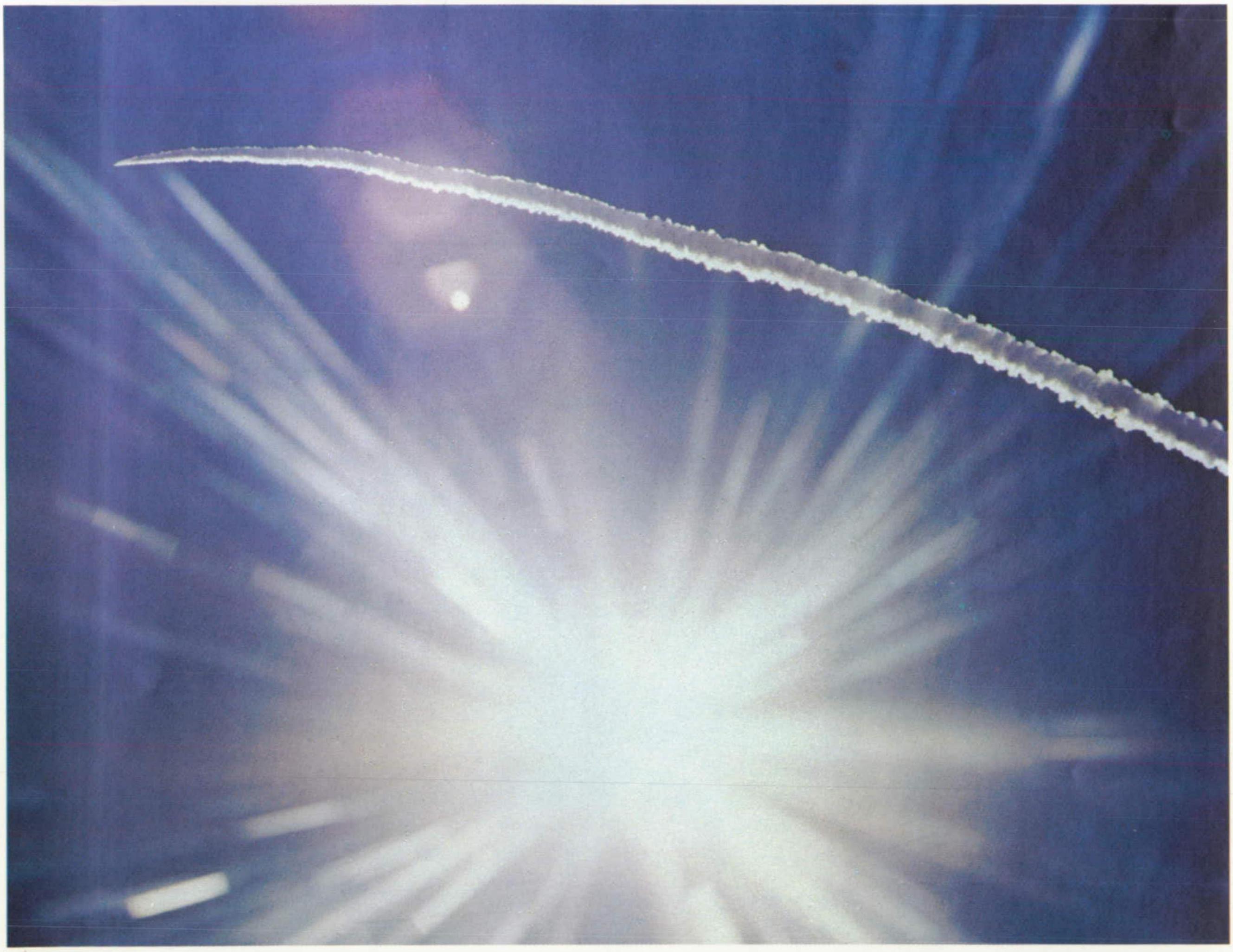
FOUR TYPES OF RESEARCH

NASA aeronautical research can be described as falling into four categories: Proof of concept, extension of the art, future needs, and problem solving.

In the first category, technology is available, but it needs to be proven in an overall concept. This proof of concept approach is best exemplified by

The X-15, in itself a proof-of-concept approach, was used to conduct flight research on a hypersonic ramjet engine.

The X-15 in flight is trailed by its rocket exhaust. The spectacular sunburst was created by a halation of the Sun's image in the camera lens.



the series of specialized flight research aircraft, known as the X Series, that flew mostly in the 1950s. Each was designed, built and flown to prove a general principle of flight, not to serve as a prototype for a specific operational use.

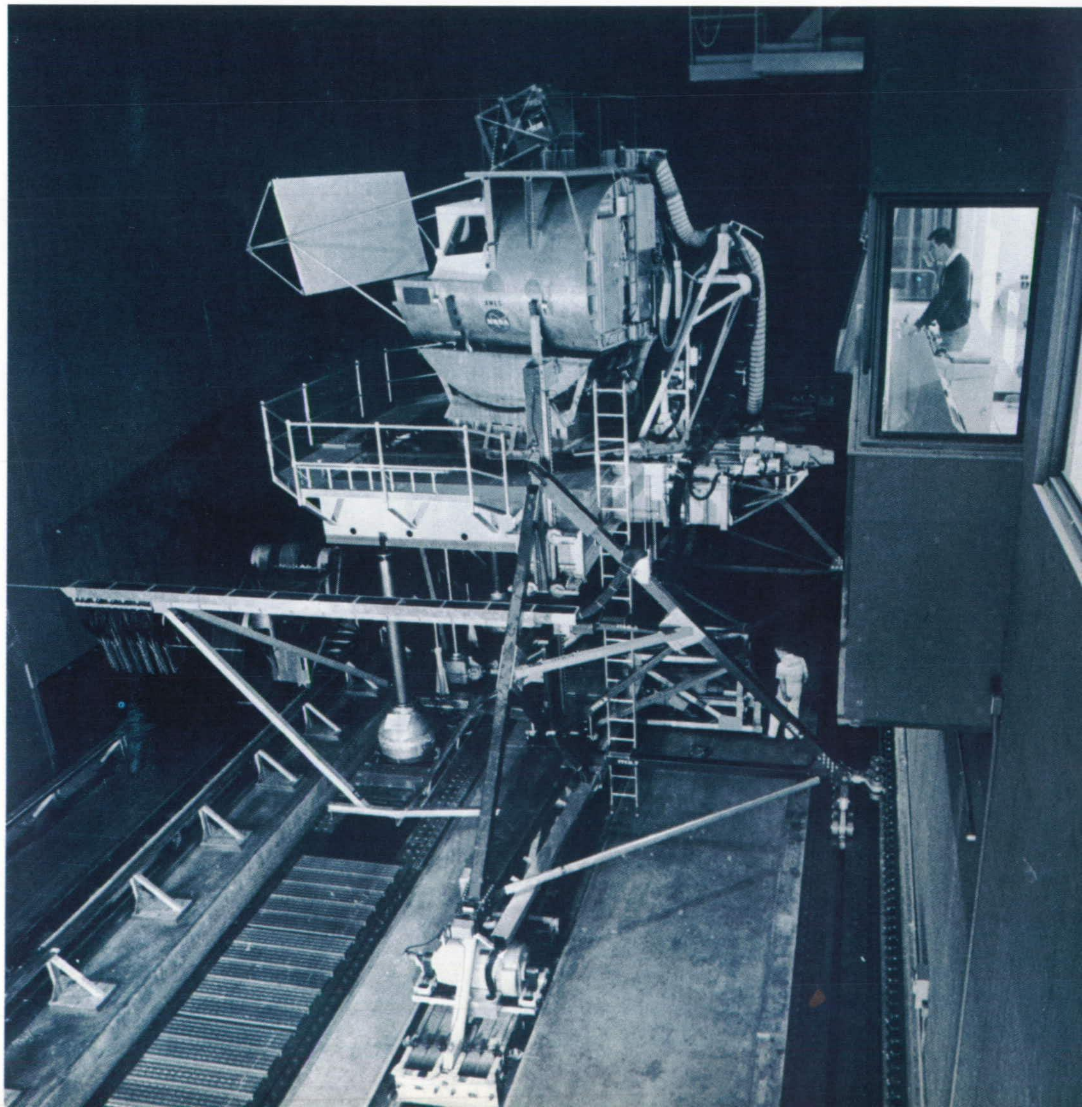
Each airplane in that series of X-aircraft explored, defined and probed a specific regime of flight or flight characteristics. Their legacy has been incalculable. It includes an understanding of the flight, stability, and control problems over the speed range from low subsonic through supersonic to hypersonic.

In the second category of aeronautical research, the so-called "state of the art" has been defined, but needs to be extended. The "state of the art" is a favorite phrase among engineers, who use it to define the status of any technology at any given time. Right now, for example, the state of the art for jet transport is quite well defined for subsonic speeds, somewhat less well defined for supersonic speeds, and almost completely undefined for the transonic region where subsonic and supersonic come together. Future programs are being planned to study the special problems of the transonic region.

The third category is research directed toward future needs. This research is done to build a broad and strong foundation of knowledge, some aimed at specific applications and some directed at the broad foreseeable range of future requirements. Examples are NASA's work on the hypersonic transport, a vehicle intended to travel almost ten times as fast as today's jet transports, and on short-haul mass transportation systems using STOL (short takeoff and landing) aircraft.

If all problems stayed solved, there would be no need for the fourth category of research. But even the most carefully researched designs can—and do—develop quirks after they have been operational for a while. So part of NASA's current work load is tied to solving problems in today's operational and developmental aircraft.

An advanced flight simulator at Ames Research Center is capable of motion about all axes for more realistic simulation. Color television pictures of model terrain are projected on a screen mounted ahead of the windshield.



Finally, NASA also is charged with maintaining an aeronautical research data bank, an intangible repository of technical data that will insure this country's leadership in aeronautics. Much of that documentation is, of course, generated by NASA in its many programs. But some of it comes from outside the agency, often as the result of a NASA-funded program at a university, or with industry.

HOW NASA GOES ABOUT IT

Although many may associate NASA only with wind tunnels, there are other important tools of aeronautical research. NASA's practice has been to approach problems with four basic techniques.

Long before there were wind tunnels, aeronautical scientists used mathematical and physical analyses to determine the probable behavior of a new airfoil—the cross-section shape of the wing—or a body form. Such analyses, now generally computerized for speed and accuracy, are still one of NASA's chief research tools.

Wind tunnels, a mainstay of the NASA laboratories, are a means for testing accurate scale models—and often the real, full-sized aircraft—over the speed range normally encountered by the airplane in flight. These controlled tests—where air is blasted past a model aircraft mounted in the test section of the tunnel—permit prediction of the airplane's characteristics from accurate measurements of the forces and moments acting on the model during the runs.

A third, and increasingly useful, analytical tool is the simulator. This is a way of "flying" an airplane or spacecraft without building it first. Its characteristics, determined from drawings, theoretical analyses, and model tests, are programmed into a computer. The output of that computer can be used in a wide variety of ways to simulate the behavior of an aircraft.

Tied into a full-size, non-flying crew compartment, for example, the computer can drive control systems, produce instrument readings, move the cabin itself, and simulate almost every sensation of actual flight. Filmed or color TV presentations, seen through the windshield and also operated by the computer, heighten the realism. Hardened NASA test pilots sweat out tough flight problems just as if they were airborne, but at considerably less risk.

The simulator also serves in a unique way to predict performance, to refine an airplane design before it has been finally frozen for production, or to study the effect of changes in the aircraft weight, shape or controls.

Finally, the fourth approach is the careful full-scale flight research work on the aircraft itself. NASA research pilots, themselves engineers, work with other engineers and scientists in a meticulous program which gradually probes the flight envelope—the speed, altitude, and load limits—of a new or experimental aircraft. Testing in this way, flight research furnishes real-life answers that may have eluded the theoretical analyses, wind tunnel tests, and simulation.

These are the four major tools of the NASA researcher. They have been used singly, or in combination, to explore problem areas in the safety, efficiency or comfort of aircraft and spacecraft.

TOWARD QUIETER AIRCRAFT

Long before ecology was in the forefront of many minds, and the preservation of life values was the focus of so much attention, NASA was genuinely concerned about aircraft noise. But it was the advent of the supersonic transport program with its passionate proponents and opponents, that did more to focus attention on noise problems than any other single factor.

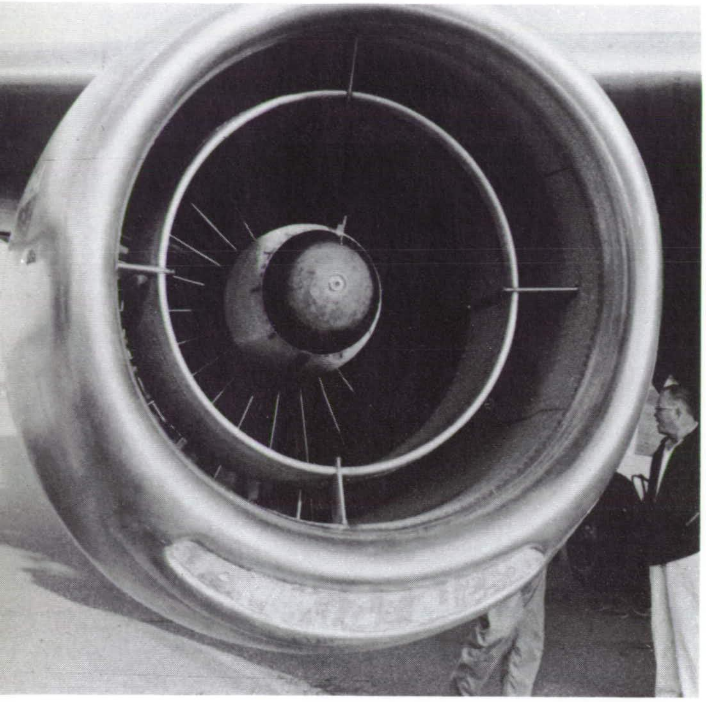
Whatever the impetus, NASA has been working on this problem in a series of programs designed to find out more about noise, its effects and its suppression.

There are two basic areas where noise from an aircraft is a problem. The first is in the immediate vicinity of airports, in areas which lie under the usual approach and departure paths of jet transports. The second is on the ground anywhere under the flight path of any plane traveling at supersonic speed. These two problems are different, and demand completely different approaches and solutions.

In some ways, aircraft noise is the unwitting creation of the passengers. More people want to travel and—with air traffic as dense as it is—the best solution is to make larger and faster aircraft. Bigger and faster transports demand more power, more installed thrust. More power means more noise, and there hasn't been much of an alternative until recently.

The first attempt to reduce noise on the ground under departure paths was to change the nature of that path. Many air travelers have experienced that change; shortly after takeoff, the pilot reduces power while maintaining a constant-altitude flight over residential areas. Once clear of the urban crush below, he increases the power to climb to an assigned altitude.

Practical treatment to reduce engine noise is typified by this acoustical treatment of a nacelle inlet.



But this is only a temporary solution to take some of the burden off those living next to the runways. A longer-term solution is to make engines quieter.

Studies have shown that the major noise annoyance from jet engines centers on the screaming sound of turbofan engines. The fans which give this class of engine its name also give it a characteristic whine.

NASA decided on a two-step solution to the problem. First, research would be done on current engine installations, changing them to reduce their noise. Second, a new design for a basically quieter engine would be developed.

For work on contemporary engine installations, NASA funded experimental efforts by the Boeing and McDonnell-Douglas companies, the producers of the bulk of today's turbofan-powered transport aircraft. Both companies developed acoustic treatment techniques for production engine nacelles, and the approaches were similar.

Acoustic absorptive materials—metals with high porosity are one example—were installed in the inlet and exhaust areas of the jet engine nacelles. Additional rings of the material were placed in the engine inlets. The results were dramatic. Noise levels were reduced substantially. In some cases, the reduction in a four engine aircraft was greater than that obtained by shutting down three of four untreated engines. But like almost every other modification, it costs money and increases the weight of an airplane to change the nacelles so that the generated noise is reduced. Jet engines with acceptable noise levels can be available technically. It's a matter of economics.

Modification is, at best, a temporary fix, and one that is often limited by pre-existing conditions and designs. The ideal approach is to design a "quiet" engine from the beginning.

DEVELOPING QUIETER ENGINES

NASA and industry have mounted a team effort to design, develop, test and assemble advanced engine components with the aim of developing a "quiet engine," actually a quieter engine.

As one part of this Quiet Engine Program large-scale fans have been built and tested at the Lewis Research Center, to obtain basic noise data. Early test data show that the new fans operate much more quietly than those used today on commercial jet aircraft.

Major work is being done for NASA by the General Electric Company leading to the design, fabrication, and testing of the "quiet engine." This calls for the construction and testing of two complete demonstration engines.

Typical of the developmental work in the first phase is the study of large-scale fans. The turbofan engine gets its name from a driven fan which is mechanically linked to the shaft of a turbojet engine. Crudely stated, the turbofan engine is a very specialized form of the engine-propeller combination.

The fan functions in the same way as does the propeller; it accelerates a large mass of air at a low velocity in a rearward direction to generate thrust. Additionally, the turbojet engine core of the turbofan powerplant also is producing thrust from its highspeed, hot exhaust. The air that passes through the fan only is ducted around the turbojet core engine; it never passes through the injection, combustion and exhaust cycle of that core. However, the power to drive the fan comes from the turbine of the core engine and, as a result of the power removal, the core jet velocity is substantially decreased to a point where it is not a major source of complaints about noise.

The studies being made under NASA's Quiet Engine Program will identify the important parameters that cause the fan noise, and study ways to change them without impairing the efficiency of the engine itself.

Acoustically damped development inlet configuration shows one current approach to reducing jet engine noise.

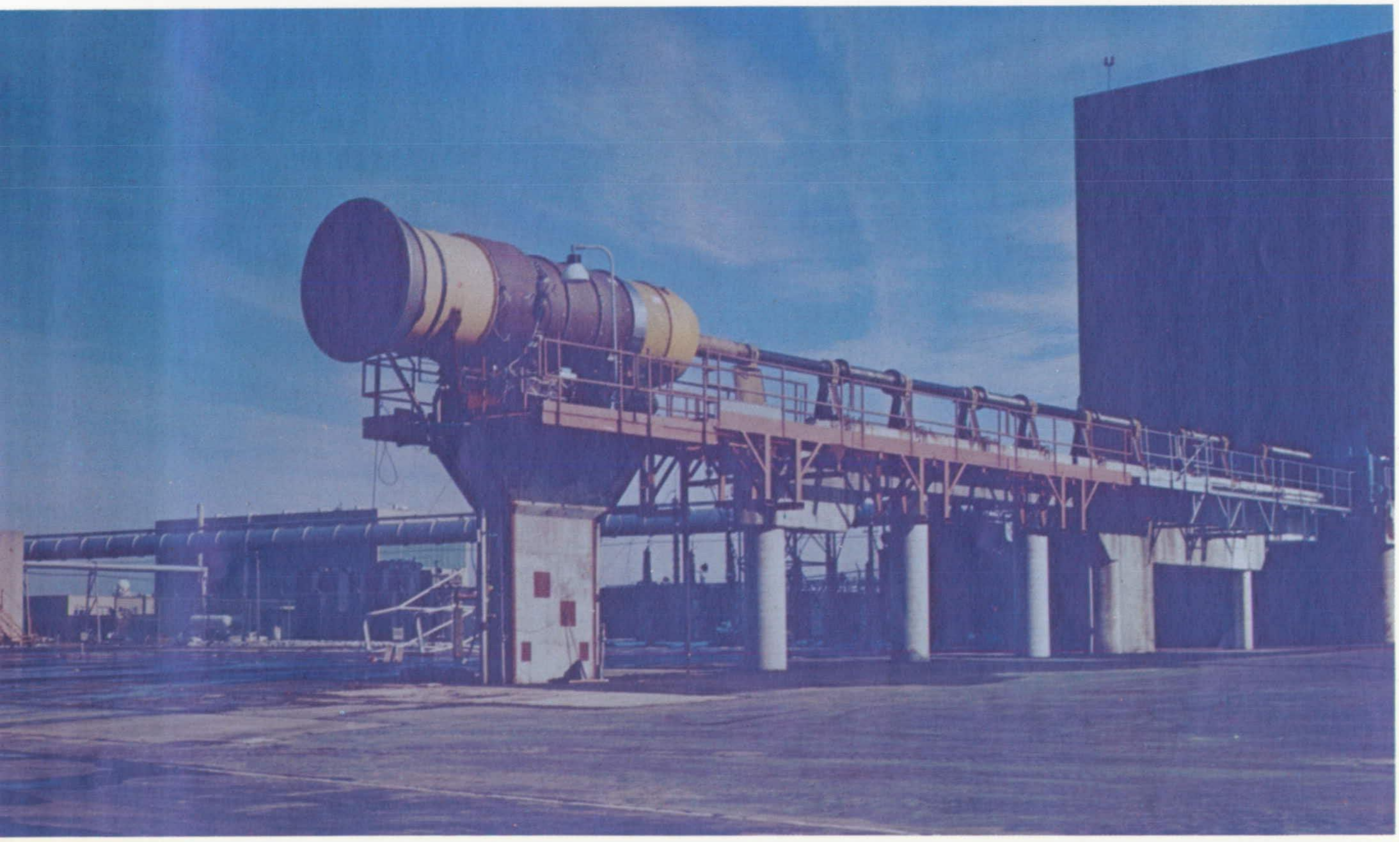
For example, perhaps fewer fan blades could be used, with higher aerodynamic loadings per blade. Perhaps the fans could be redesigned to operate as efficiently at lower speed, and therefore at lower noise levels. Perhaps the inlet and outlet guide vanes could be reduced in number or size, or treated acoustically to reduce their contribution to the engine sound.

Initial tests of some of these strategems have been encouraging.

STEEPER APPROACHES, QUIETER APPROACHES

Coupled with these programs to reduce engine noise at its point of generation is a continuing study to reduce engine noise at its point of observation. For several years, NASA research pilots have been flying a variety of typical transport aircraft on "steep" approaches to an airport. The idea behind this is that, by arriving or departing on steeper flight paths, the noise on the ground underneath these approaches or departures can be significantly reduced.

Fan test stand at Lewis Research Center is used in developmental testing of fan configurations in the noise-reaction program.



Steepness, by the way, is relative. Current approaches to airports are made at an angle of only three degrees above the horizontal. The NASA tests have been made at double that figure, or six degrees, for the outer portion of the approach, with a transition to the standard three degree approach delayed until necessary to conform to instrumentation standards at airports.

The results of those flight experiments proved that ground noise was indeed reduced. The remaining problem now is really implementation.

SONIC BOOM

The shock waves generated by supersonic flight have received much publicity. That "sonic boom" is caused by the character of supersonic flow, and it can no more be eliminated than can gravity.

But, it can be reduced by a number of techniques. For one obvious example, the higher the airplane cruises, the less is the observed intensity of the sonic boom. Heavy cloud between the airplane and the ground also helps to attenuate the sonic boom.

The size, weight, and shape of the airplane change the characteristics of the sonic boom. Turning flight may focus it at one point, causing an abnormally loud or abrupt disturbance on the ground. There are so many factors, and they are so inter-related, that the first NASA task was to try to sort them out.

A flight research program was established by NASA and other concerned agencies to find some means of measuring and—perhaps—defining the sonic boom so that steps could be taken to reduce its intensity. Those flight tests showed that the boom was indeed the product of a large number of factors, and that not too many of them could be controlled.

Paralleling the flight tests were experiments made with tiny wind-tunnel models, the size of a fingernail, tested in supersonic flow to determine the physical characteristics of the sonic boom. Theory was compared to the tests, and modified to take into account the test results.

All these experiments have resulted in better understanding of the sonic boom. The final answers are not yet in, but one fact is clear: The sonic boom cannot be eliminated, but it can be reduced. Until it is possible to reduce the effect of the sonic boom to an acceptable level, FAA regulations or public laws will prohibit commercial supersonic flights over the United States.

FLYING UP, DOWN AND SIDEWAYS

Is there a commuter who hasn't longed to rise above the traffic jam and to soar to a rooftop heliport on his office building? How long has that been a dream?

Too long, if you judge by the current state of the art of vertical takeoff and landing (VTOL) aircraft. Even their simpler cousins, the short takeoff and landing (STOL) aircraft aren't yet a practical reality in daily transportation.

Today, the helicopter is the only commercially available vehicle that can lift vertically out of a restricted area, fly at reasonable speeds to a short-range destination, and let down vertically to another restricted area. But helicopters are expensive to buy, to maintain, and to operate.

There are possible alternatives. VTOL aircraft definitely are feasible—the helicopter is only one specialized example—but they need much development before they are ready to make money for commercial operators and stockholders.

The advantages of VTOL, STOL or the combined V/STOL aircraft are obvious. They would make it possible to increase traffic at existing airports, by using small landing areas or the short runways for their operations, safely out of the path of the bigger jets. They would also make possible a network of smaller airports, sited and planned to take advantage of the unique characteristics of V/STOL aircraft.

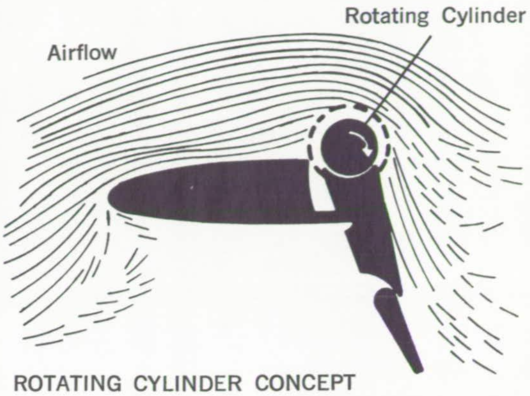
During recent years, NASA has done research on a series of V/STOL models, test vehicles, and prototype aircraft. Wind tunnel tests, theoretical analyses, simulator exercises, and full-scale flight research all have played their parts in extending the field of knowledge about these unusual aircraft and the techniques of operating them.

What has been the basic result of all the testing is a NASA conviction that the ultimate vehicle still eludes the designers, and that new concepts in control, high-lift devices, propulsion and noise reduction must continue to be explored, some to the proof-of-concept stage.

WIND THROUGH THE FLAPS

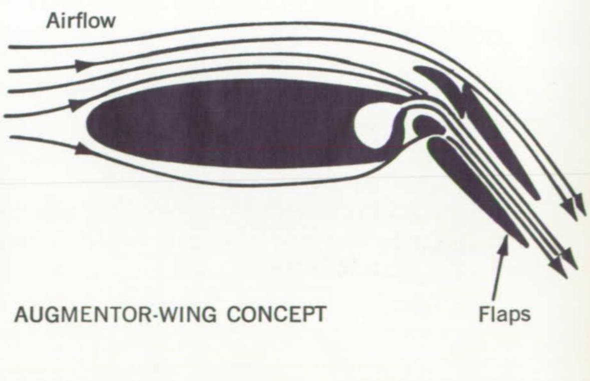
Wing flaps—which are auxiliary airfoil surfaces at the trailing edge of the wing—are used to increase the lift of an airplane for slower and safer takeoffs and landings. Intensive research and development by NASA and industry over many years have produced contemporary flap designs which contribute major increments of lift to the wing.

A rotating-cylinder flap concept was tested in an Ames Research Center wind tunnel both in small scale and in full scale as shown here.



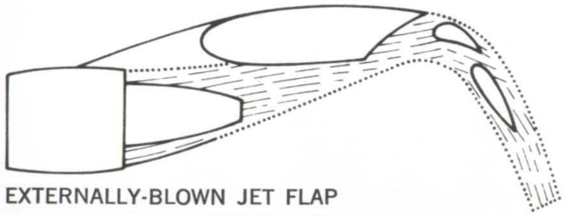
ROTATING CYLINDER CONCEPT

The augmentor wing concept was tested in model form in the full scale tunnel at Ames Research Center.



AUGMENTOR-WING CONCEPT

Generalized model of an externally blown flap is studied in a Lewis Research Center wind tunnel.



EXTERNALLY-BLOWN JET FLAP

Basically, the function of the flap is to direct some of the air downward after it has passed over the main portion of the wing and to accelerate the airflow over the top of the wing. The accelerated curving of that air produces an upward reaction, which translates into extra lift and—when desired—extra drag.

But there is a limit to what a flap can do when the flow over it separates at high lift. If additional energy could be added to the air near the trailing edge of the wing, then the air might cling to a larger area of flap, or at a greater flap deflection, and thus increase the lift increment even further.

One suggested way to do this is to install a rotating cylinder at the leading edge of the flap itself, and to spin it at high speed with the exposed surface rotated in the direction of the airflow. This does two things: It delays the breakaway of the airflow over the wing and flap, and it creates a stronger downward flow of air. The resulting lift increment is about one and one-half times that available with the flap alone.

This concept first was tested on a small scale in wind tunnels, and then a full-scale model of the North American Rockwell OV-10A aircraft was modified and also tested. Those full-scale tests appeared promising, so the Navy loaned NASA an OV-10A aircraft for modification into a flight-research vehicle to test the actual characteristics of the rotating-cylinder flap.

Another way to add energy to the airstream over the flaps is to blast air through slots in the wing ahead of the flap. This is the basis of the augmentor-wing concept, the subject of a development program jointly shared by NASA, the Canadian government, and industry on both sides of the border.

In the augmentor wing, air is bled from the jet engine, piped along the wing interior, and blasted downward into a slot ahead of the wing flap. The highspeed blast of air acts like an air pump, and draws additional air through the slot. The extra air flowing over the flap acts to delay separation of the external airflow over the wing and to augment the lift by directing the flow of air downward.

Work on the augmentor flap system started with small-scale wind-tunnel tests, progressed to a larger model for tests in a full scale wind tunnel, and then reached the point where a de Havilland C-8A Buffalo aircraft, provided to NASA by the U.S. Air Force, was delivered to the Boeing Company for major modification so that the augmentor-wing concept could be tested in flight.

Another type of propulsive lift also shows promise. In some aircraft designs, it would be a mechanically complex problem to pipe the engine bleed air through the wings and into a slot ahead of the flaps. But in many of the large jet transports, the engines are mounted conveniently out on the wing, just ahead of the flap section. The exhaust from those engines can be directed against the flaps to augment their lifting capability. This idea is called the externally blown flap, because the air blast comes from a source external to the wing and does not pass through any ducting to reach the flaps.

There are some obvious problems, such as hot exhaust blasting against the flap surfaces. But most jet transports now use turbofan engines, in which the exhaust is relatively cool, and the flap structure can be made rugged enough to withstand additional loads at higher temperatures for the short times required for landings and takeoffs.

And there are some uncertainties, such as noise. Will this technique produce a noisier aircraft at takeoff? Will the flap immersed in the engine blast act like a vibrating reed and generate additional noise?

And what about acoustic fatigue? Could the noise level at the flap be enough to overload the flap and cause local failures of the skin or structure?

Some of these answers are being obtained from wind-tunnel tests, some from analysis, and some from simulation. More than 6,000 hours of wind-tunnel time and hundreds of hours of piloted simulator work have been done so far on the externally blown flap idea.

But ultimately there is only one way to prove this concept, and that is to build and fly a large test aircraft designed to use the blown flap efficiently.

A large test vehicle can furnish much operational data on control systems and characteristics that would be useful to airlines and other potential users of this advanced technology.

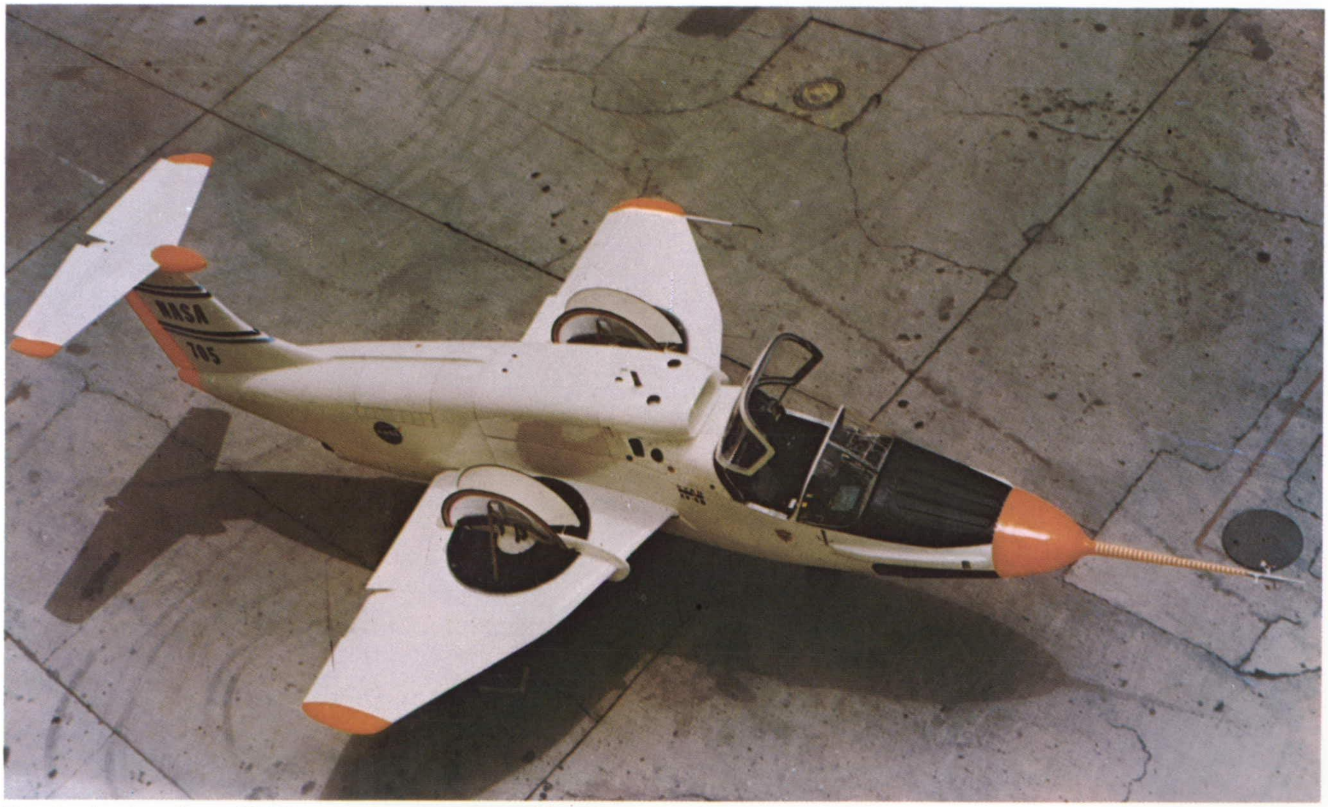
TILTING WINGS AND LIFTING FANS

There are other interesting concepts for vertical or short takeoff aircraft, and they are the subjects of continuing or past research by NASA.

One such concept is the tilt-wing design, an aircraft in which the entire wing—plus its wing-mounted powerplants and propellers or rotors—

In this wind tunnel test of a short takeoff and landing (STOL) model, an externally blown flap is being studied. The wing and engines are so located that the jet exhaust is directed against a deflected flap, thus converting part of the engine thrust to lift.

The XC-142A tilt-wing vertical/short takeoff and landing (V/STOL) aircraft taking off for a test flight at Langley Research Center.



The fan-in-wing Ryan XV-5B is designed to take off vertically, cruise at subsonic speed, and land in an area no larger than a tennis court.

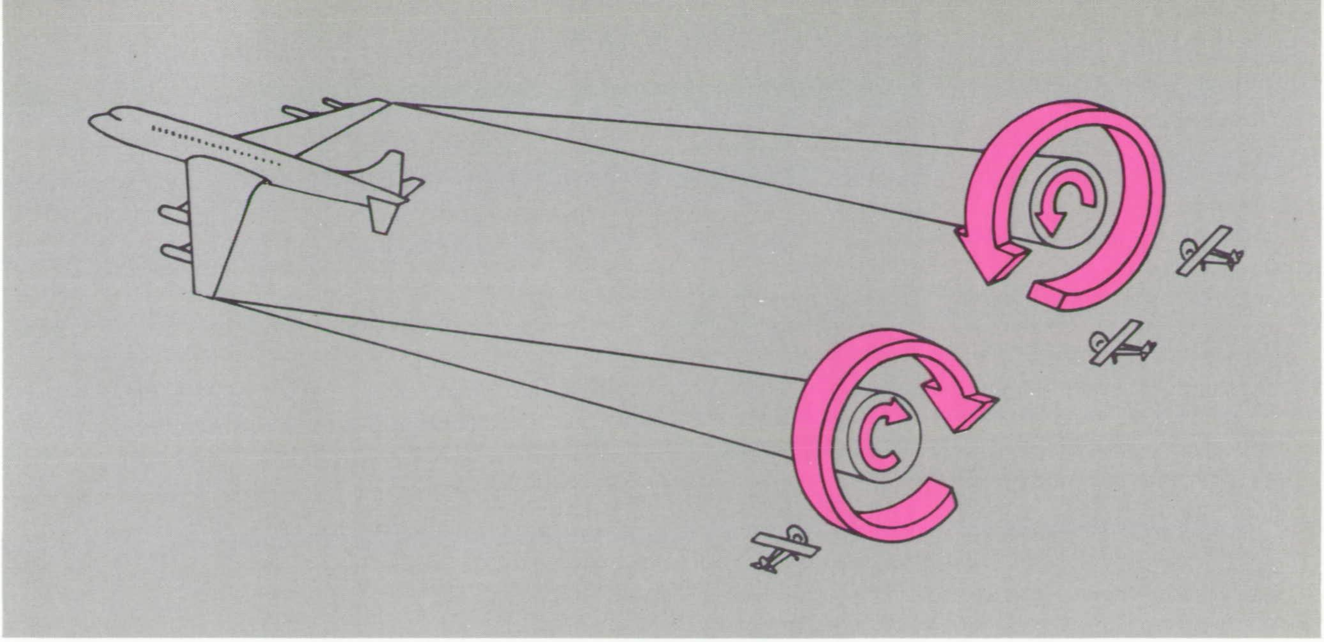


Diagram of trailing vortex wake and types of possible encounters with other aircraft. The vortices move downward at a steady rate and drift with the wind.

turns from the horizontal to the vertical position and back again, to make the transition between the level and vertical phases of flight.

Early NASA studies proved the feasibility of this layout, and later test vehicles, like the Vertol Model 76 and the Vought-Hiller-Ryan XC-142A, extended that proof of concept into piloted flight research. Both these aircraft, now retired from active status, contributed to an understanding of how to design future carriers of this type.

NASA, with the Army and Air Force, also works on the tilt-rotor concept in which the wing does not rotate. These aircraft have a rotor on a pylon on each wing tip. After vertical takeoff, the rotor tilts forward for cruise flight.

The lift-fan, or fan-in-wing, system is another potential type for V/STOL aircraft. In this layout, packaged powerplants driving lifting fans are integrated into the wings or special horizontal surfaces of the aircraft. The powerplants in one concept are modified turbojet engines which are valved to drive these fans, or to blast through tailpipes for forward propulsion, or to do a bit of both.

The basic advantage of the system is that the fan layout can be submerged in a relatively thin wing, and the resulting aircraft can show a good turn of high-speed performance, not limited by the more conventional rotor systems.

NASA has been evaluating the 500-mile-per-hour GE-Ryan XV-5B, a lift-fan vehicle developed by industry as the XV-5A for the U.S. Army. The VTOL aircraft, modified and instrumented for research purposes, was flown at NASA Ames to explore more fully terminal area operations of the fan-in-wing concept and other control and operational aspects.

One of the more useful tools for future NASA research is a special V/STOL wind tunnel. This new research device will enable NASA engineers to get more accurate test data on these unusual aircraft whose characteristics have taxed the capabilities of the conventional wind tunnel.

One feature of the V/STOL tunnel is a moving-belt floor in the test section. It can be driven to simulate the approach and landing speeds typical of V/STOL aircraft, so that the interplay between the aircraft and the ground in this critical phase of operations can be carefully studied.

STALKING THE TRAILING VORTEX

A vortex is the swirling pattern you see in a tub drain. It occurs in nature as whirlpools, water spouts, dust devils, and hurricanes and it also occurs in trails behind a body moving through any fluid, such as a wing moving through air.

Scientists observed this years ago—Lanchester, in 1897, for one—and began to study the vortex on the sole ground that it might contribute something to the understanding of why a wing creates lift. For more than 70 years, research has been done on vortex flows, and a substantial body of data has accumulated. Its contribution to wing lift is now generally understood.

But recently, as larger aircraft have entered commercial and military service, the vortex has threatened to be a villain like its natural counterpart, the tornado. A heavy airplane, such as a big jet transport or cargo craft, trails vortices from its wingtips which are large and powerful, and which can remain, whirling unseen in the air, for several

In this test, the trailing vortex is made visible by smoke injection, providing an indication of the scope of this "horizontal whirlwind."

miles and several minutes after the big airplane has passed. A light airplane flying through the vortex could be upset, and even dashed into the ground at low altitudes.

To solve this problem, NASA and other agencies began an intensive study program, using flight research and analytical methods. One cornerstone of the program is the body of theoretical knowledge amassed over the years on vortex flow. This work had been done originally with no specific intention of contributing to the solution of an operational problem in the 1970's but with hope that it would contribute to the advance of aeronautics.

This, incidentally, points out the value of every bit of research, regardless of how esoteric or broad-based it may have seemed originally.

The problem of the trailing vortex can be solved by avoiding it. Time intervals between scheduled takeoffs and landings are increased to allow time for the vortex strength to dissipate. But obviously, increasing the time intervals between takeoffs and landings means actually limiting—or even reducing—the capacity of an existing airport and runway system.

Where parallel runways exist, simultaneous arrivals and departures can help. But the invisible vortices still can be hazardous under certain conditions, and the physical separation of flights to parallel runways may not offer much improvement.

Flight research programs conducted at the Langley Research Center and the Flight Research Center are trying to understand the vortex problem by measurements, to get quantitative data on vortices generated by different airplanes under different conditions, and on the effects these vortices have on other aircraft.

At Ames Research Center, scientists are searching for an approach to wing design to reduce the intensity of the trailing vortex at its source. They also are looking at possible ways to break up a generated vortex by some means such as blowing air or exhaust into it.

The work at the Marshall Space Flight Center of NASA is looking at laser Doppler technology, an offshoot of spaceflight instrumentation, to develop new instruments for detecting and monitoring trailing vortices in airport areas.

This is typical of a serious and current operational problem that is demanding concentrated effort by several NASA centers.

WET RUNWAYS AND AUTOMOBILE SAFETY

NASA research into operational problems produced the first knowledge of "hydroplaning," that dangerous characteristic shared by airplanes and automotive vehicles moving on wet runways or pavements.

Hydroplaning requires some standing water on the runway or road, unfortunately a typical rather than a rare condition. At certain combinations of speed and tire pressures, any vehicle—sports car, motorcycle, tractor-trailer, or aircraft—will hydroplane, sliding along on the surface of the water just as if it were a speedboat. That kind of a skid is uncontrollable and unstoppable. And every vehicle has a critical speed, above which it can hydroplane out of control.

NASA research on a special track at Langley Research Center uncovered the problem, defined it, and determined a criterion for hydroplaning. Extensive publicizing of the results helped to caution motorists about the hazard.

It was relatively easy to solve the problems on airport runways. A series of transverse grooves, shallow enough to eliminate roughness, but deep enough to carry off the standing water, were cut in a few test runways. Hydroplaning stopped. The technique is available for the price of cutting the grooves, and is being used on highways in several places in the nation, often with dramatic reductions in accident rates.

Transverse grooves on the airport runway provide a solution to "hydroplaning." In this test, the grooves were one-quarter of an inch deep and spaced about an inch apart.

HOW DOES IT FEEL TO FLY?

Flying qualities of aircraft are major subjects of NASA research into operational problems. The reason is that piloting an aircraft still remains a subjective experience to a great degree. A pilot who has logged many hours in a single type of airplane knows its idiosyncracies. But a pilot new to a type has to learn, and unfortunately too many pilots have learned the hard way.

Most airplanes being flown now have a direct link between the pilot and the control surfaces. The pilot supplies the muscle and the airplane turns. He can feel the resistance of the air on the control surface through the cables and rods that connect it to his hands.

But jet aircraft, generally, are different. Because of their speed range, the forces on their controls are beyond the capabilities of humans. Flying would be at best fatiguing and at worst impossible unless the pilot had some additional power available to him, like the power-steering system on today's automobiles.

But like power steering, powered flight controls eliminate the pilot's feel for the control loads. If the control system has enough power, the pilot can literally tear the tail off the airplane just as easily as he changes its flight path by a few degrees.

The answer is to give the pilot some artificial feel, proportioned to the loads on the controls, so that he has some indication of what the controls are experiencing.

And at this point, it becomes necessary to determine some measurable system to judge the way an airplane handles.

Without powered controls, no airplane ever feels the same way to two different pilots. A muscular type might be able to perform acrobatics easily, where a weaker pilot would have trouble flying a steady path.

During World War II, NACA developed a judgment scale after lots of airplanes had been evaluated, and established a basic criterion to define the flying qualities of future aircraft. That early work is continuing, and still is part of every flight research program NASA undertakes on a new airplane.

The airplane first is flown for familiarization, and then is extended through its flight regime. During these flights, experienced NASA research pilots learn the way the airplane feels and, more importantly, can spot its feel on a rating chart which can serve as a guide for other pilots.

Transports, general aviation aircraft, fighters and other types of aircraft are flown routinely at Ames, Langley and Flight Research Centers, in calibrated studies of their flying qualities and performance. From these studies, and from individual pilot analyses of the flying qualities of each airplane, will come useful design data for tomorrow.

GENERAL AVIATION AIRCRAFT

Improving the safety and utility of general aviation aircraft is a special concern of NASA.

Getting results can take a long time. The NACA, as far back as 1922, called for the development of a simple autopilot system that would relieve some of the workload and worry inherent in flying.

Those simple light aircraft autopilots finally have been developed, although it took the better part of a half-century. Even now they are options at extra cost, and—to the novice pilot who has gone into debt to buy his first airplane—they too often are placed in the category of unnecessary options.

NASA has a number of research programs underway, in cooperation with industry, to investigate and further advance the light aircraft of today's generation. Some of the goals of those programs are familiar ones.

High on the list is the development of a simple autopilot, or a stability augmentation system, to relieve the pilot of a major portion of his workload. Collision-avoidance systems, or pilot-warning systems, are another top-priority item. Cost reductions in powerplants and electronics also are on the list.

The development of these ideas or systems is properly the province of industry. But NASA is in the business of investigating the need for those systems, and providing the technological base for their development.

Part of NASA's work on general aviation aircraft has involved the wind-tunnel and flight testing of a series of representative types. For wind-tunnel tests, production aircraft are acquired, less engines and instruments. The engines are replaced by controllable electric motors whose outputs can be carefully metered.

Airplanes for flight research are, of course, bought or leased complete from dealers, including engines and instruments.

In either case, the first step is to make the fundamental measurements. Aircraft lift and drag are measured carefully, in the tunnel and in flight, with the airplane in a variety of configurations and attitudes. Control forces are noted during steady maneuvers in flight, or at preset angles of attitude in the wind tunnel.

Correlation between wind-tunnel and flight tests gives important insight into the prediction of performance of future designs. And flight research further adds the important measurements of handling characteristics.

The aim of the NASA flight research program in general aviation is to find out first, what these airplanes actually do in flight; second, to define whether such behavior is bad or good; and third, to suggest some improvements where needed.

These programs add to the basic store of aeronautical knowledge. The designers and manufacturers of light aircraft will have a better bank of data regarding existing aircraft and a basic body of technology on which to build and from which to extrapolate future designs.

NEW TRANSPORTATION CONCEPTS

Today's subsonic jet transports are marvels of reliability and safety in terms of performance, but they could be even more efficient.

Safety and quieting programs have been described earlier. NASA has concrete programs in those areas and has other aeronautical research programs which examine the possibilities of extending the performance capabilities of current aircraft, and aim at developing a new generation of aircraft with greatly improved potential and efficiency.

There is, therefore, a new shape that took form originally in the wind tunnels at the Langley Research Center, and it is sparking lively interest in a possible new generation of jet transports.

This exciting new concept—called the NASA supercritical wing—is designed to permit commercial airplanes to fly very near to the speed of sound, something they cannot do today.

Today, jet transports cruise typically around the 500 mile-per-hour mark, or between 70 percent and 85 percent of the speed of sound. The speed of sound, which divides subsonic from supersonic flight, is a reference speed which has long been used in physics, ballistics, and aerodynamics. Its importance as a parameter was first recognized by Ernst Mach, an Austrian physicist, and his name survives in the term, "Mach number," which defines the ratio of the speed of a projectile or aircraft to the speed of sound. So those typical jet transports are cruising between 0.7 and 0.8 Mach number.

But the NASA supercritical wing looks as if it will permit flight at Mach 0.99, a major increase in commercial aircraft performance. The flight that now takes four hours could be accomplished in three; the trans-Atlantic crossing that now takes

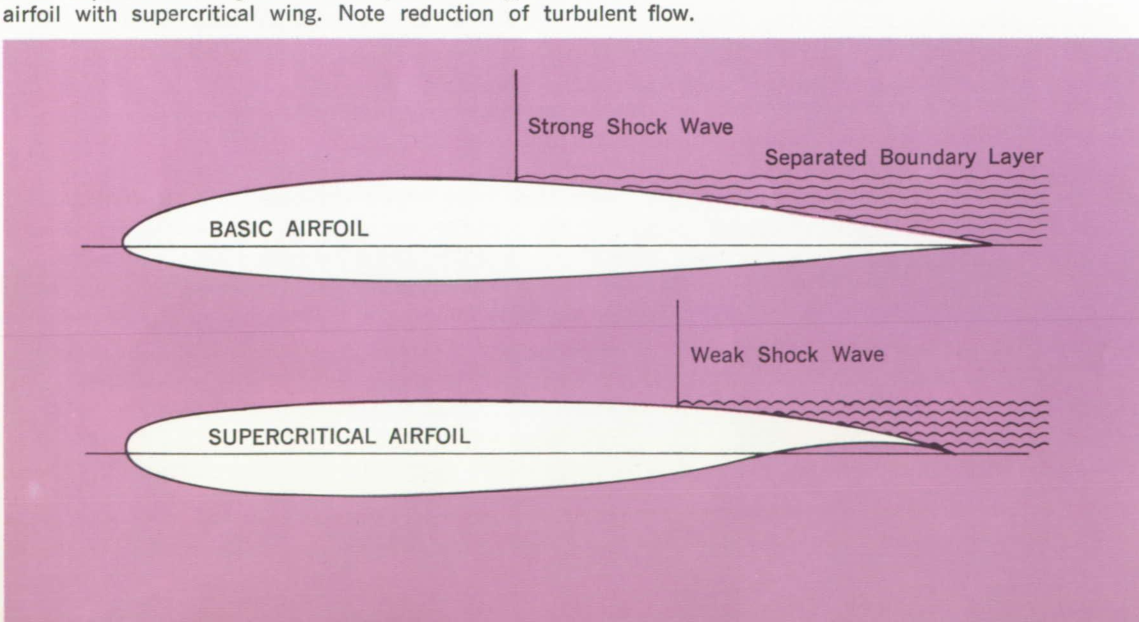
Light twin-engine general aviation aircraft are evaluated in flight at the Flight Research Center in a program aimed at improving operational efficiency. In the test flight illustrated here tufts of fiber have been affixed along the sides of the fuselage to provide measurements of air flow across the surface.

eight hours could take six instead. Aircraft productivity, one major criterion of airline economics, could be increased.

One enemy of high-speed flight has long been known. It occurs in the boundary layer, a thin sheet of air moving next to the wing surface. At low speeds, the sheet is laminar—flat, smooth, undisturbed. But in certain flow situations, the boundary layer breaks abruptly into turbulent disorder. The drag increases markedly.

One of the situations that triggers the change from laminar to turbulent boundary layer flow is the approach to the speed of sound. At high speeds, a shock wave—proof of the establishment of localized sonic speed—will form on the upper surface of the wing, the cockpit canopy, or other regions of the airplane where, due to the curvature, the air velocity is actually higher than the flight speed of the airplane. Behind the shock which forms at that critical speed is turbulence, and that turbulence causes a sudden drag rise which limits the speed of the airplane.

NASA supercritical wing section. Comparison of typical basic airfoil with supercritical wing. Note reduction of turbulent flow.



The NASA supercritical wing is being flight tested by NASA's Flight Research Center aboard an extensively modified TF-8A jet trainer.

The NASA supercritical wing moves the point at which the localized shocks appear much farther back on the wing, keeping the flow ahead of the shock laminar and the drag low. By careful shaping, it has been possible to delay the drag rise so that it does not occur until the aircraft is nearly at the speed of sound, instead of at a substantially lower Mach number.

Meticulous attention to the entire flow pattern over wing, fuselage, tail and nacelles produces further refinement, and delays the total drag rise to very near the speed of sound. The resulting blend of wing and body has been developed into a typical transport configuration for testing in NASA wind tunnels. Industry also is looking hard at the idea.

One version of the NASA supercritical wing has been built for flight research on a converted Navy Vought (TF-8A). The tests are expected to produce more knowledge about the behavior of the commercial-type supercritical wing than has ever before been obtained on any wing. The instrumentation will be detailed and copious. Pitot rakes—assemblies of tubes to measure static and dynamic pressures—will be mounted behind the wing. Orifices in the wing will measure local static pressures, which can be translated into lifting performance. Strain gages and accelerometers will assess overall performance under the loads of normal and maneuvering flight.

There is another possibility for the NASA supercritical wing which exploits its performance in a thick section, generally associated with heavier and slower aircraft. On an airplane with a moderate cruise speed, such as Mach 0.75, the wing thickness could be increased from 12 percent of the chord (the distance from leading edge to trailing edge) to 17 percent of the chord without a corresponding increase in drag, or any performance penalty.

This would give a much larger volume of wing structure in which to store fuel, weapons, or other mechanical or electronic equipment.

A model of this adaptation has been tested at Langley Research Center, and a Navy-loaned T-2C trainer has been modified and flight-tested in a joint Navy-NASA flight research program to assess the performance of the thick supercritical wing. The flight tests have confirmed there was no increase in drag.

One model of a transport configuration built around the supercritical wing has a hemispherical nose, and large blunted wing leading edges. To anyone familiar with the shapes of contemporary jet transports, this looks like a step backwards. And yet the blunted shapes offer advantages for near-sonic flight. The fuselage nose is actually less blunt than today's transports, even though the particular geometry chosen makes it appear otherwise. And the blunt wing leading edges offer excellent low-speed flight characteristics.

It will be some time before all the results are in on this particular development. But there is a very strong possibility that—before too many years have passed—the NASA supercritical wing will be on production airplanes flying the airlines of the world.

BEYOND THE SPEED OF SOUND

Beyond Mach 1 lies the supersonic speed range, the flight regime pioneered by the X-1 rocket research airplane in 1947. The X-1 and its descendants, part of the fleet of NACA/NASA research aircraft, blazed the trail and then widened it into an aerial highway for generations of military and civilian airplanes to follow.

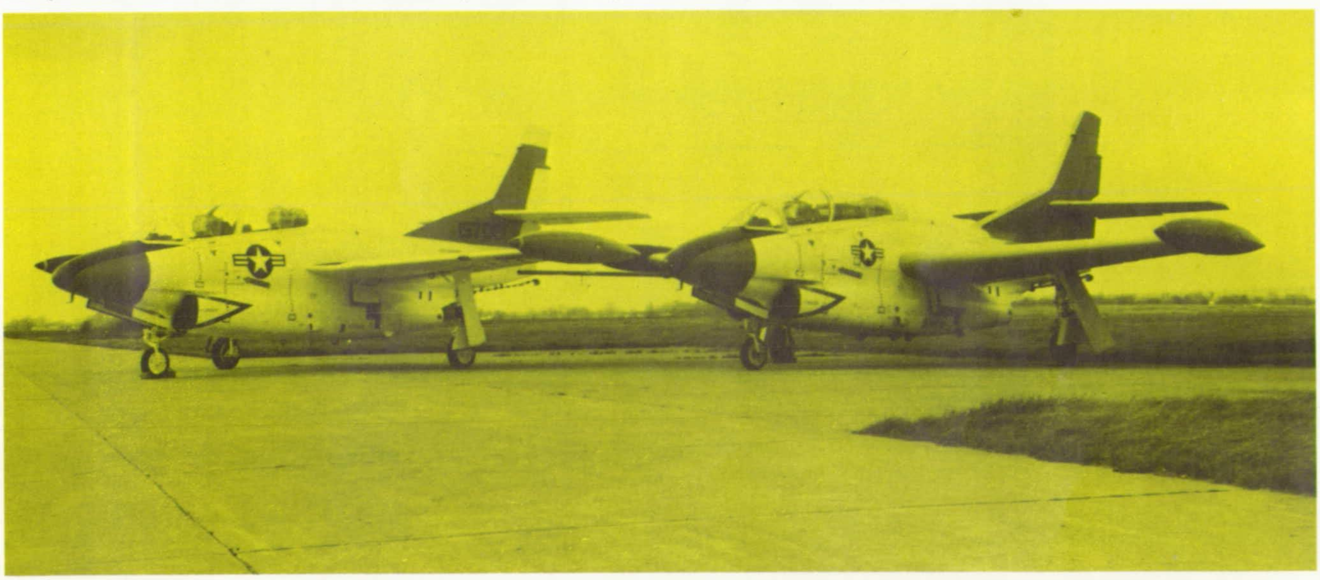
Starting in 1959, NASA did considerable work in the development of basic configurations—aerodynamic shapes—for supersonic commercial air transports.

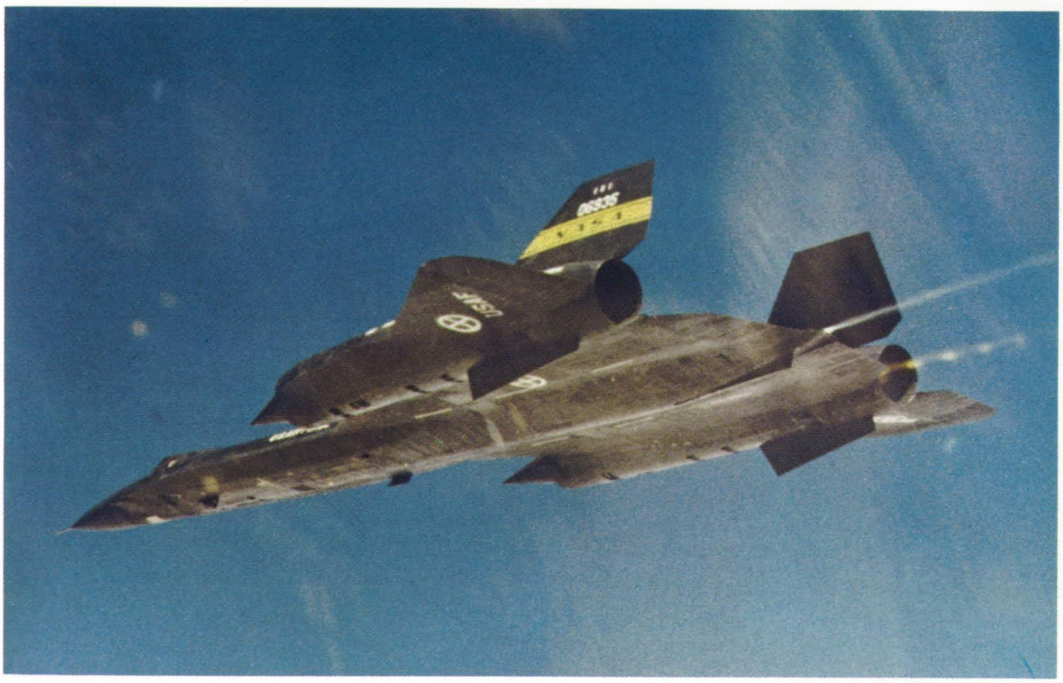
NASA's biggest effort in behalf of the supersonic transport was the evolution of four basic types of layout, foundations for detailed studies by industry. But there were many additional programs, geared to the specific needs of the supersonic transport, which have accounted for real advances in aeronautical technology and which are being applied by NASA, the military, and industry.

One example was the application of computers to predict the aerodynamic characteristics of new designs. Time after time during NASA studies of supersonic aircraft shapes, the computer was able to define the principal performance characteristics within a few percent of the actual test data obtained later in a wind tunnel. This reduced the time cycle between design refinements and performance confirmation to a matter of hours instead of a matter of weeks.

Other advances directly traceable to the supersonic transport program include new approaches to simulation, structural concepts and new materials, emphasizing the point that such programs are producers of technology, not just producers of one specialized aircraft design.

Comparison of standard airfoil with thick supercritical wing on the Navy T-2C trainer.

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Left—A Boeing 707 jet transport was modified to simulate characteristics of the projected supersonic transport for tests of approach and landing maneuvers.

Lower left—The YF-12A aircraft is the vehicle for testing operational problems in supersonic flight; the Air Force has loaned two of the aircraft for use in a program in which NASA and Air Force pilots participate.

AND BEYOND THE SUPERSONIC

Hypersonic flight has been routinely achieved by launch vehicles and test spacecraft, and repeatedly by the NASA X-15 rocket research airplane. Hypersonic speeds—the term is loosely defined as a speed above four or five times that of sound—means that the Atlantic could be crossed in about an hour, and the Pacific in about two.

Mach 7 has been chosen as a typical hypersonic speed for NASA wind-tunnel investigations. At these speeds the air friction is great enough to heat fuselage noses and wing leading edges to the melting point of steel. Artificial cooling of the structure is the only apparent answer, and one that is occupying NASA researchers.

Propulsion is another unknown in hypersonic flight. Rocket engines traditionally have been used, but they would burn prodigious amounts of fuel during a sustained Mach 7 flight in the upper atmosphere. Ramjet engines, which work on the compression of ingested air, and which require no rotating internal components, seem like the best way to propel a hypersonic aircraft.

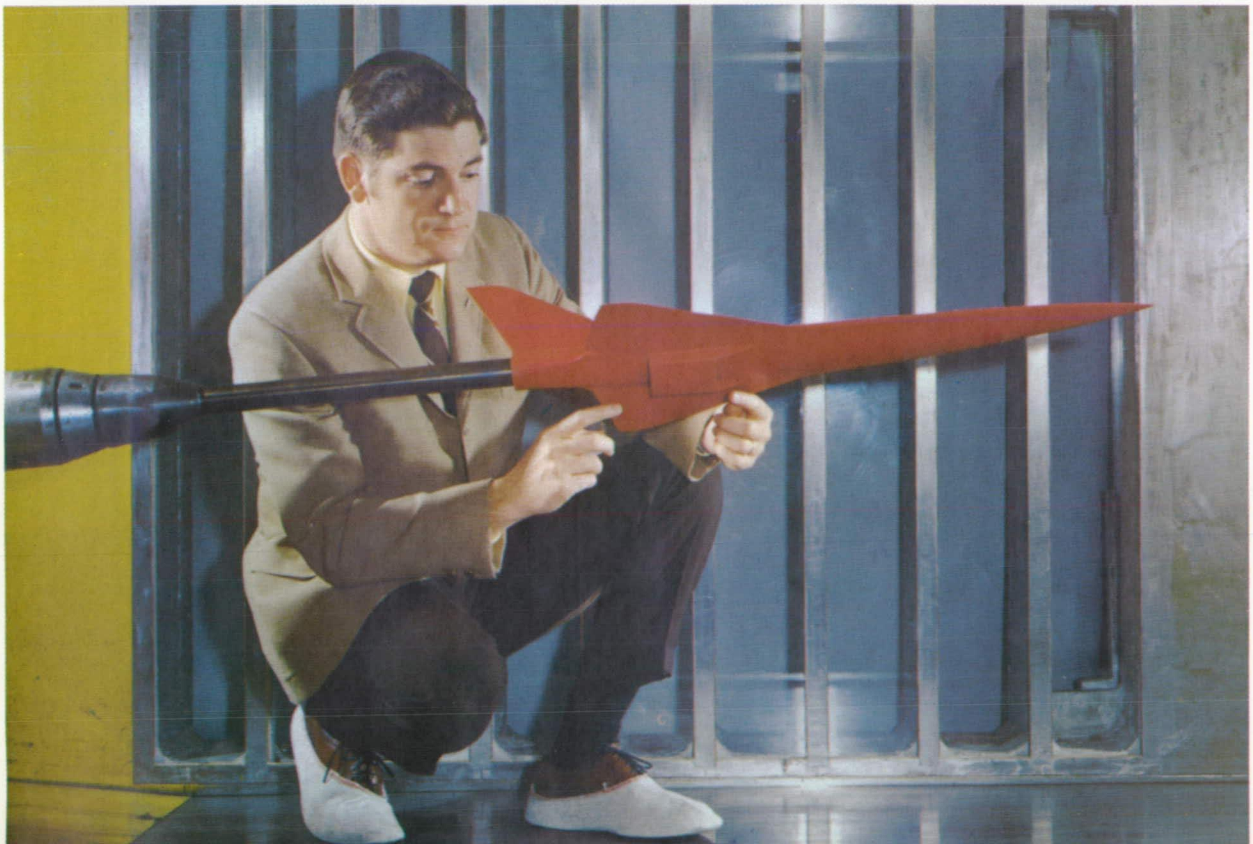
Under NASA contracts with industry, a hypersonic research engine of the ramjet type has been built by the Garrett Corp.'s AiResearch Division, and is being tested to explore some of the problems and possibilities of this type of powerplant.

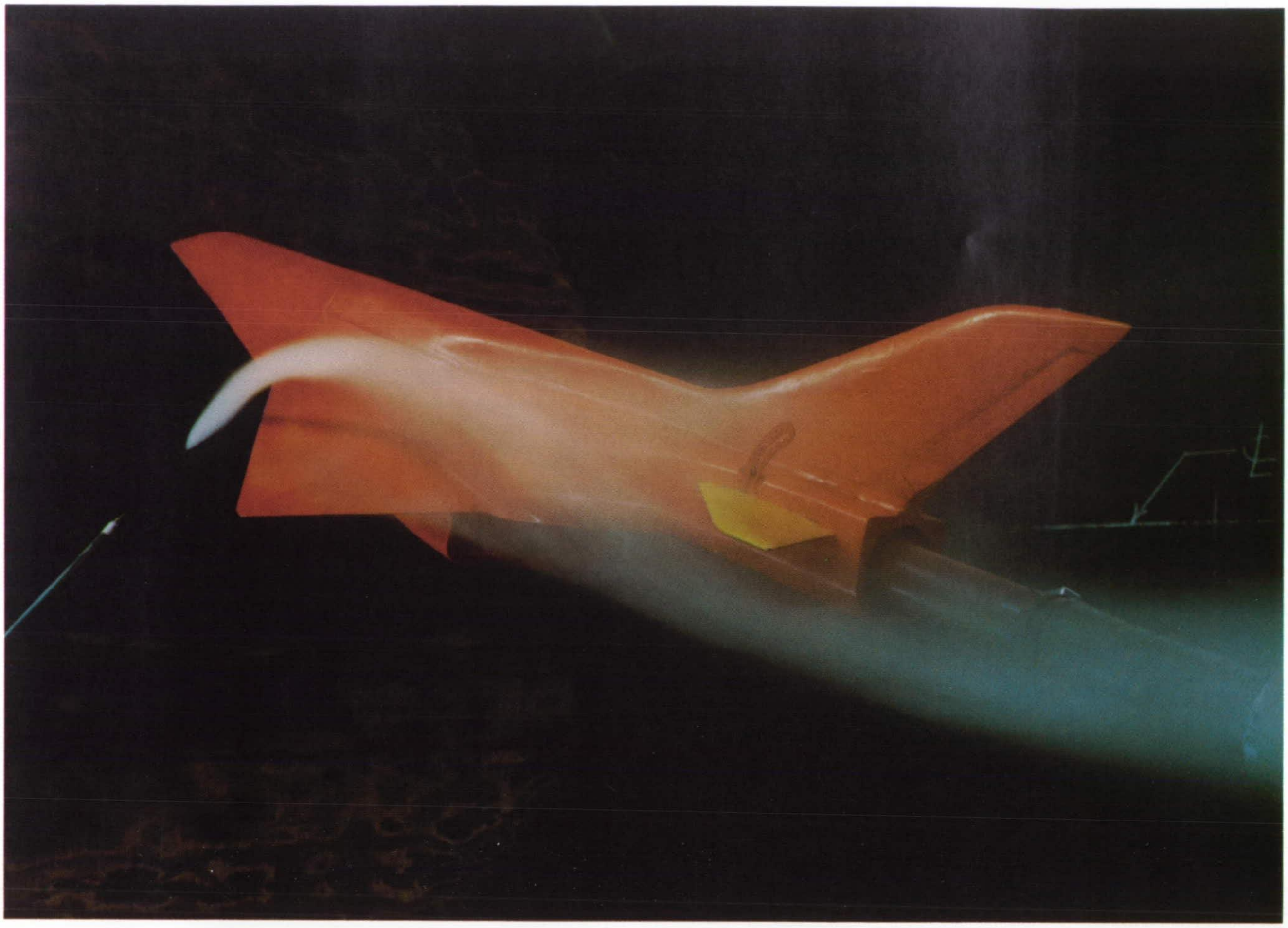
During recent years, new test facilities have become available for hypersonic studies. One of these is a NASA wind tunnel with an eight-foot diameter test section, capable of running at the sustained high temperatures which characterize hypersonic flight. The tunnel size and capability make it possible to test large models, or full-scale components, under simulated flight conditions.

Hypersonic flight as a commercial reality is far off. The problems remaining to be solved are indeed formidable. But then, so were the problems facing the designers of the first jet transport, or the first airplane itself. From this perspective in history, it is possible to look back and see that, in spite of massive difficulties, the pioneers did reach and even exceed the goals they set out to achieve.

This is not to say that the next generation of jet transports will carry you in scenic, four-hour round-the-world tours. But it is to say that progress is a companion of growth and vision. There will,

This hypersonic transport model has been tested in wind tunnels at the Langley Research Center at speeds ranging from Mach 0.36 to 6.0.





Since many of the problems associated with hypersonic aircraft will arise in their operations at low speed (after takeoff and prior to landing), tests have been run with a smoke generator in the 12-foot low speed wind tunnel at Langley Research Center.

some day, be a hypersonic transport, because today there are small models in NASA wind tunnels.

LIFTING BODIES

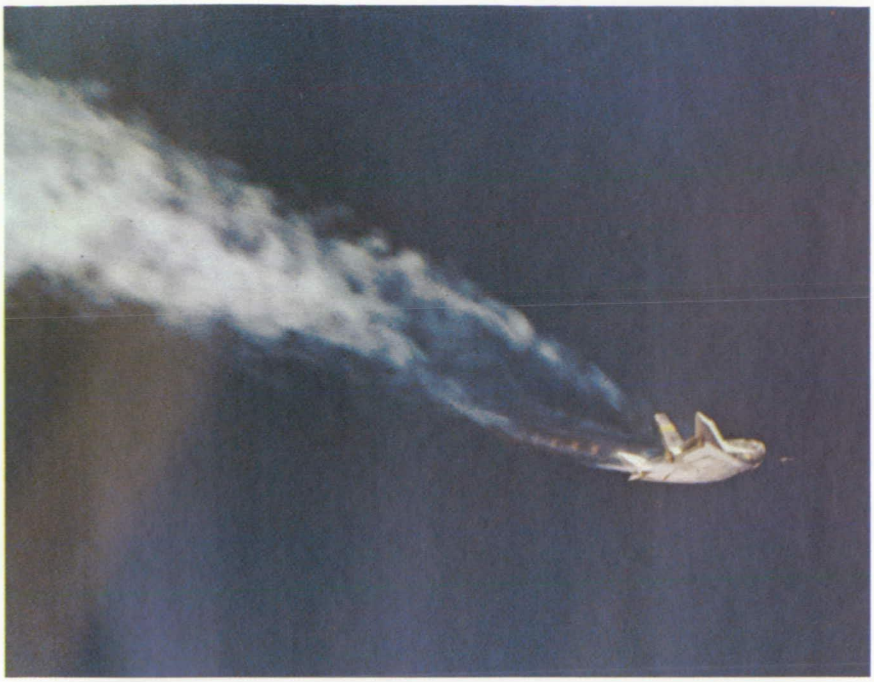
Wingless lifting bodies, which fly in the atmosphere like more conventional aircraft but preserve the essential qualities of re-entry spacecraft, have been under investigation by NASA for several years. Now in an advanced flight-evaluation phase, these aircraft-spacecraft vehicles were derived from extensive wind-tunnel tests and theory.

The experimental lifting bodies attain aerodynamic lift from the rapid flow of air over and around their special airfoil-like shapes. As possible forerunners of returning spacecraft they are especially interesting in view of their capability to be maneuvered within the atmosphere so as to range over a far wider expanse than the Apollo-type blunt re-entry capsules and to make horizontal ground landings like conventional aircraft rather than parachute letdowns over the oceans.

Two differing shapes pioneered the NASA program on lifting bodies. The first, designated the M2, was developed at the Ames Research Center. It features a flat top and a rounded belly. The second, designated HL-10, was developed at Langley. It has a rounded top and a flat belly. Both craft have tail control surfaces.

About 100 flights were made with a lightweight M2-F1 plywood vehicle and then two 2½-ton versions were built and flown—the M2-F2 and the HL-10. The M2-F2 flight version of the Ames M2 body shape was damaged in a landing accident on its 16th flight and was rebuilt under a new designation of M2-F3

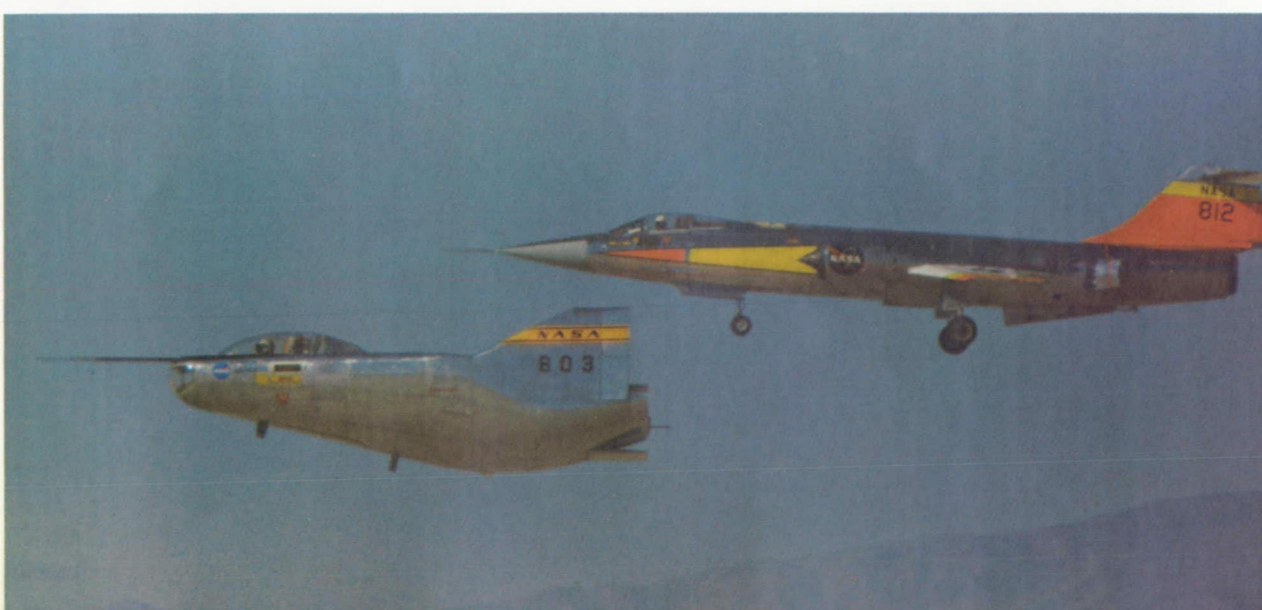
Later, a third type of lifting body, built for the U.S. Air Force by Martin-Marietta under the



Left—The HL-10 lifting body begins to climb, leaving a white exhaust plume from its rocket engine. It is one of three flight research vehicles in the lifting body category.

Center—The three lifting bodies, left to right: X-24A, M2-F3 and HL-10.

Bottom—The X-24A lifting body on approach accompanied by F-104 chase plane.



designation of X-24A, joined the program. This vehicle shows external differences from the others.

The flight research programs for all three vehicles sought to prove the concept, and to evaluate the handling characteristics, flight qualities, and other aspects of the unusual aircraft.

All three vehicles began their flight programs as unpowered gliders, advancing slowly through the flight and performance envelopes as knowledge was acquired. Dropped from a mother B-52 aircraft, they made sustained gliding flights and landings at the Flight Research Center.

Both the HL-10 and the X-24A have completed a substantial number of powered flights, sustained by thrust from an installed rocket motor, although still launched from a mother B-52. These rocket-propelled flights have extended the range of performance and knowledge about these possible aircraft shapes of the future.

AFTERWORD

An ancient prophet wrote it best: "Where there is no vision, the people perish."

NASA's main task now, as in times past, is to create an environment for vision. Past NASA successes show in almost every airplane, every missile, every spacecraft that the United States is flying today, or will fly in the next decade.

NASA's future successes now are taking shape in laboratories, wind tunnels and simulators. Engineers' sketch pads, scientists' blackboards, computers and simulators are defining the paths to the future.

Tomorrow's aeronautical progress is today's workload in the National Aeronautics and Space Administration.

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ADDITIONAL READING

For titles of books and teaching aids related to the subjects discussed in this booklet, see NASA's educational publication EP-48, Aerospace Bibliography, Fifth Edition.

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