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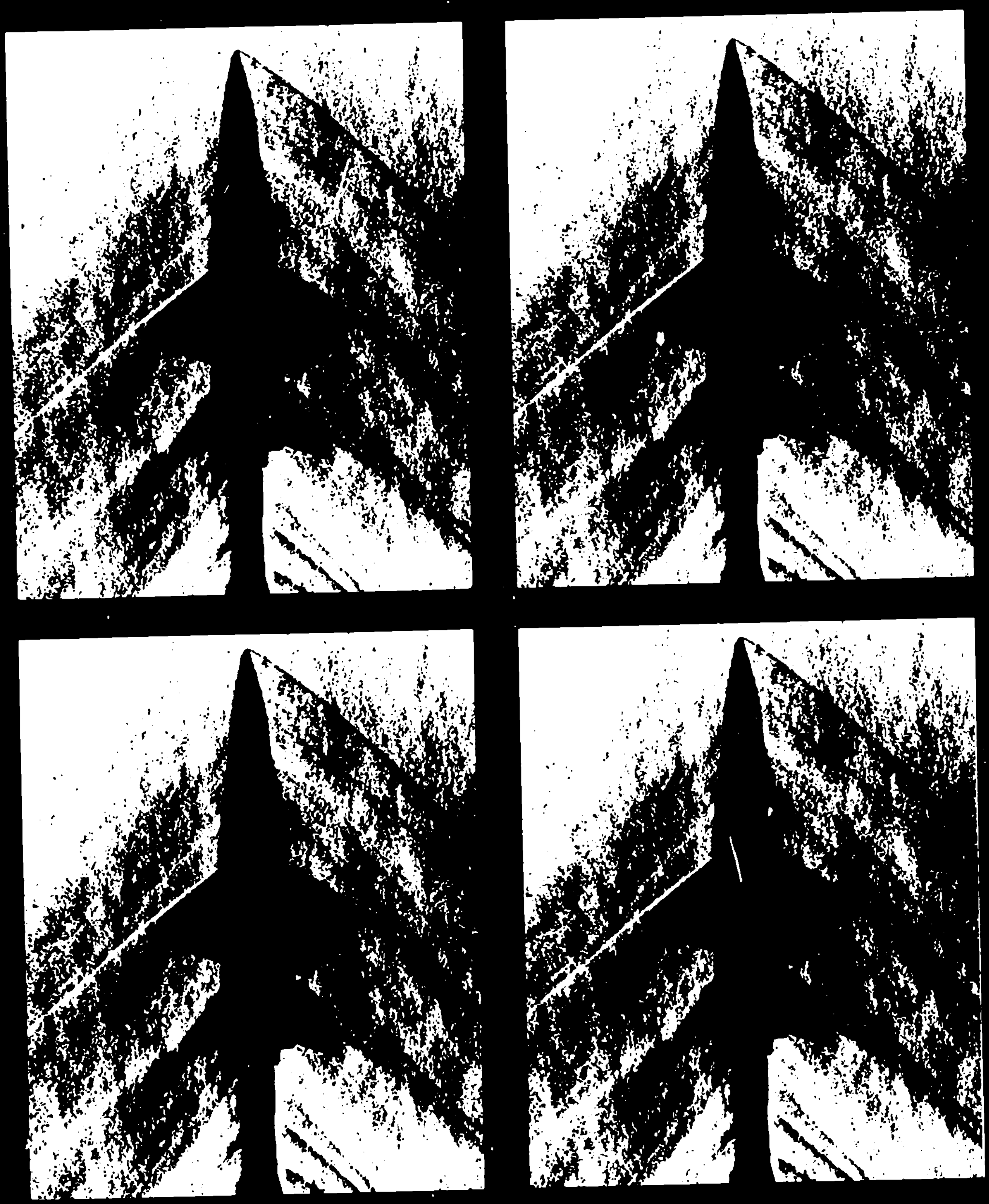
ABSTRACT

The major research and developments in aeronautics during the late 1950's and 1960's are reviewed descriptively with a minimum of technical content. Topics covered include aeronautical research, aeronautics in NASA, The National Advisory Committee for Aeronautics, the X-15 Research Airplane, variable-sweep wing design, the Supersonic Transport (SST), hypersonic flight, today's aircraft, helicopters and V/STOL aircraft, research for spacecraft, air-breathing power plants, and reduction of engine noise. Many photographs and illustrations are utilized. (PR)

AERONAUTICS



National Aeronautics and Space Administration

America In Space: The First Decade

AERONAUTICS

by David A. Anderton

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

Introduction

In 1958 the National Aeronautics and Space Administration was brought into being to explore certain broad areas of research and development which included not only the exploration of space but also the continued responsibility in aeronautics which had been the primary function of its predecessor agency, the National Advisory Committee for Aeronautics. It is seldom recognized by the general public that NASA has a vital and necessary role in the advancement of military and commercial aviation in the United States, and that the level of effort while a small fraction of the agency's total program is very substantial. Roughly 2500 NASA employees supported by funding of about $160,000,000 per year are directly engaged in conducting the research described in "Aeronautics."

The frontiers of flight have not all been explored and the applications of NASA's advanced research in aeronautics will continue to keep the United States in first place in commercial and military aviation in the years ahead until someday we will be able to travel as casually from New York to Australia at 6000 mph as millions do now from New York to Paris at nearly 600 mph.

Neil A. Armstrong
Deputy Associate Administrator/Aeronautics
Office of Advanced Research and Technology

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Aeronautics

Aeronautical Research

Up at the rim of the atmosphere, the rocket-powered X-15 research airplane accelerated to hypersonic speed in one of NASA's aeronautical programs to probe the performance envelopes of tomorrow's air transportation.

At another center, poised a few yards above the concrete apron in front of its hangar, the hovering X 14 measures the stability of vertical takeoff and landing aircraft in a different NASA aeronautical program.

Across the continent, wind-tunnel fans blast air past an intricate model of one of the newest military aircraft to check its predicted performance against actual flight-test data.

In other wind tunnels and test facilities of the National Aeronautics and Space Administration there are other models, ranging from a conceptual design for a hypersonic transport to a light twin-engined airplane flown at hundreds of airports throughout the world by thousands of private pilots.

These aircraft and models span the performance capabilities of modern airplanes from the ground to the edge of space, and from zero speeds to velocities of several thousand miles per hour.

They are some of the tangible signs of the many programs in aeronautics underway at any one time within NASA. But they are more than just evidence of work now being done. They point the way to improved and safer airplanes for tomorrow's private pilot, and to more economical and speedier transports for the air traveler of the 1970s.

1 *Interior of a wind tunnel at the Langley Research Center.*

These aircraft, operating at the extremes of today's flight performance, emphasize the wide range of aeronautics and the depth of the research programs with which they are associated.

And they build on NASA's continuing expertise in aeronautics, that NASA and its predecessor organization, the National Advisory Committee for Aeronautics, have pioneered consistently for more than fifty years.

Aeronautics in NASA

Aeronautics—the scientific and engineering disciplines that deal with the design, construction and operation of aircraft—accounts for a fascinating portion of the current work of the National Aeronautics and Space Administration.

The basic aeronautical research program, carried out on a broad front at NASA research centers, serves two vital functions.

First, it provides the needed technical support for aircraft programs in the national interest through the NASA staff of experienced aeronautical scientists and engineers, and the unequaled test and experimental facilities available to them and to industry.

Second, it encourages the exploration of new concepts and new problem areas, and the development of new facilities to aid that exploration.

The latter function has provided, through the years, the strong foundation of aeronautical technology on which the aerospace industry and the military services have built their requirements.

Hundreds of NASA personnel and about one-quarter of a billion dollars worth of test facilities are grouped in the four centers where aeronautical programs currently are in progress: Langley Research Center, Hampton, Va.; Ames Research Center, Moffett Field, Calif.; Flight Research Center, Edwards, Calif.; and the Lewis Research Center, Cleveland, Ohio.

In addition to its own research projects for these people and facilities, the total NASA aeronautical program includes a large number of contracts placed with industry, research institutions and universities all over this country and in some foreign lands.

An intangible, but important, factor in the aeronautical research program is a continuity of effort that has marked every step of the way from the early days of the National Advisory Committee for Aeronautics and its first methodical approach to the solutions of the problems of strut- and wire-braced biplanes.

Time and time again, the history of a specific research project shows that influence. An older engineer remembers previous work done that can be adapted or extrapolated. An obsolescing wind tunnel is given a new lease on life by a modification to make it serve an entirely new task. A simulator that once produced insight into the behavior of a research aircraft now singles out the problems facing astronauts in future lunar landings.

And beyond these specifics, there is the overall approach to problem-solving that has characterized NASA's aeronautical research. A problem is a problem, whether it was raised in 1918 or 1968. The approach to the solution of that problem does not change with time. First, understand the problem by examining it, defining it, trying to measure it with meaningful parameters. Then go after the solution. That was NACA's earliest approach, and it works today.

The progress of the last ten years in aeronautics has been marked by a series of major developments that serve as milestones along the road of aeronautics. Those milestones have been placed on the solid footings of the aeronautical technology conceived, researched and developed by the National Aeronautics and Space Administration.

To look back at 1958, the calendar year that saw the birth of the National Aeronautics and Space Administration, is to look back at a year when the airlines of the world were plying their routes with aircraft whose lineage traced back to the Second World War. The largest airliners carried about 70 passengers. Their straight wings mounted a quartet of piston engines, driving three- and four-bladed propellers. Compared to today's swift jet transports, they trundled their way along at a speed under 300 mph.

In October 1958, the month of NASA's birth, the first scheduled transatlantic air service flown by jet transports was started, first by British Overseas Airways Corp., and later by Pan American World Airways, Inc. Six years before, BOAC had pioneered jet services on other routes with the first de Havilland Comets, but structural fatigue problems with the airframe forced the withdrawal of that service about two years later.

In the low-speed flight regime, the helicopter was the only vehicle that promised much. Developed too late for extensive use during World War II, it was tempered in the Korean action and showed a performance that its proponents saw as pointing the way toward a future solution of short-haul transportation problems. There were some strange hybrid vehicles, which were supposed to bridge the gap between the helicopter and the fixed-wing airplane by performing the functions of both. These V/STOL aircraft—their designation was shorthand for Vertical or Short Takeoff and Landing—were experimental models, with essentially unproven performance, and uncertain characteristics. They were a long way from being practical.

Supersonic flight was the rare privilege of a few military and civilian test pilots, and the worldwide total was measured more accurately in dimensions of minutes rather than in hours.

But in a single decade all this changed. Today's air traveler rides in a sweptwing jet aircraft that may carry as many as 350 people to the edge of the stratosphere, at a speed that was, in 1958, the exclusive province of the military. He reads about progress on a supersonic transport, an even larger aircraft that will whisk him across continents at more than two and one-half times the speed of sound. He talks with his fellow passengers about the next generation of giant jets that will carry more than 300 passengers or about the huge airbuses that will fly the short runs between such cities as New York and Washington, or Los Angeles and San Francisco.

He may have heard some of the ideas for an even faster airliner, the hypersonic transport, that will slice through the thin upper reaches of the atmosphere at speeds seven times that of sound.

But in one respect, there is little change between the air traveler of 1958 and the passenger of 1970: He still has the short-haul transportation problem to face at one or both ends of his journey. The helicopter has not yet been developed to the fine point where it can be operated economically as an inter- or intra-city transport, and the promise of the V/STOL generation remains just a promise.

The National Advisory Committee for Aeronautics

The foundations for today's subsonic jet transport and tomorrow's supersonic transport were laid in large part by NASA and its parent organization, the National Advisory Committee for Aeronautics. Founded by an Act of Congress in 1915, NACA's work for the future was defined by these words from a joint resolution of the Congress:

". . . it shall be the duty of the Advisory Committee for Aeronautics to supervise and direct the scientific study of the problems of flight, with a view to their practical solution, and to determine the problems which should be experimentally attacked, and to discuss their solution and their application to practical questions. In the event of a laboratory or laboratories, either in whole or in part, being placed under the direction of the committee, the committee may direct and conduct research and experiment in aeronautics in such laboratory or laboratories."

As NACA grew through the years after its founding, it contributed to the rapid growth of the art of aeronautics, and was one of the instrumental bodies in transforming that art into science.

Five times the NACA and its scientists and engineers were honored by the award of the Robert J. Collier Trophy, given each year for the greatest achievement in aviation in America, and presented by the President of the United States.

In 1929 NACA won the Collier Trophy for its development of the NACA cowling, a systematically developed housing for radial air-cooled piston engines to minimize their drag and improve the cooling airflow.

In 1946, the Collier Trophy was awarded for NACA's development of a thermal ice-prevention system that led the way to safer flight.

In 1947, NACA shared the award with the United States Air Force and Bell Aircraft Corp. for the successful demonstration of sustained supersonic flight in the rocket-powered Bell X-1 research aircraft.

In 1951, NACA's work on the transonic wind tunnel received another Collier Trophy. That award recognized the theoretical and empirical work that developed a technique of testing models close to, and in the transonic region of flight, that previously mysterious area where conventional testing techniques failed and where theory was still largely unproven by experimental results.

In 1954, the Collier Trophy went again to NACA for the concept and experimental verification of the area rule, an aerodynamic design approach that made it possible for a given airplane to go faster and farther with the same engine thrust.

These awards highlighted the contributions of NACA to aeronautics during the years of its existence. The last three of them further emphasized one of the biggest problem areas that was occupying more and more of the time and energy of the research organization: High-speed flight. The demonstration of the ability to fly safely at supersonic speeds, the development of a testing technique to corroborate flight performance and to predict it for unflown designs, and the application of an advanced aerodynamic technique to the design of a high-speed aircraft, all showed the direction of the future at NACA.

And then came 1958 and the creation of NASA to absorb NACA and other research and developmental agencies into one group, similarly dedicated to advancing the frontiers of flight in and above the Earth's atmosphere and into space.

Quite naturally, NASA inherited the aeronautical problems of NACA; it also acquired a new set of problems as a result of its expanded role in the developing theater of space flight. The experimental techniques that had been painstakingly developed over the years of NACA's life were to be turned to new problems posed by the thrust of aeronautics outward and upward into new areas for exploration.

By the time that NASA was formed, the technology for sustained supersonic flight had been developed to the point where a supersonic transport seemed feasible. A new approach to a tactical fighter configuration had evolved from NACA studies, a concept which depended on changing the shape of the airplane in flight by altering the wing sweepback angle radically.

Wind tunnel and flight tests, by NACA, industry and the military services, had selected and rejected candidate configurations for V/STOL aircraft, and the results of those tests pointed toward the next steps in the development of those specialized aircraft.

Finally, NACA's traditional role in support of a wide range of military aircraft projects was transferred to NASA along with other basic aeronautical research problems and programs.

Over the years, a coordinated approach to problem-solving had evolved. It utilized theory, developed or extrapolated by NACA scientists. To verify theoretical studies, wind-tunnel tests were made in a sophisticated array of specialized facilities. General and specific models, ranging in measurement from fractional inches to the full size of the actual aircraft, were run through extensive tests to verify or expand the theoretical approach.

Carefully instrumented flight tests of the full-size aircraft made valuable contributions to understanding the problem. The flight tests served to give final verification of the other theoretical and experimental approaches and, at the same time, to increase the general understanding of the inherent errors and of the corrections that needed to be applied to theory and scaled-down experiment to produce useful answers.

This three-way approach—theory, model test and full-scale flight test—was a foundation of NACA's technology, and it became a foundation of the work of the National Aeronautics and Space Administration after 1958.

A major contribution to aeronautical research had been made by the joint NACA/USAF/USN series of "X" aircraft, from the X-1's through the X-5, which were designed and flown specifically to advance the technology of piloted aircraft. These aircraft stemmed from the original Bell XS-1, a bullet-shaped, stubby and thin-winged rocket-powered plane that was conceived in 1943 as a vehicle to fly through the "sonic barrier," a theoretically formidable region where the airplane speed was approximately that of the speed of sound, and where aerodynamic disturbances were expected to cause disruption of normal flight parameters.

The XS-1, later designated the X-1, led to a whole series of research aircraft, flown to explore the far reaches of airplane performance by engineering test pilots from NACA, the U.S. Air Force, the Navy and Marine Corps.

The X-15 Research Airplane

The last of the series, North American Aviation's X-15, powered by a 59,000-pound-thrust rocket engine, was first rolled out of the factory two weeks after NASA's first day of business. Less than one year later, it made its first powered flight, and continued to extend the boundaries of manned flight to the edge of space. Five U.S. Air Force pilots have qualified for astronauts' wings as a result of their flights in the X-15 above a 50-mile altitude; three NASA research pilots also have flown the X-15 to altitudes above the 50-mile level. Two X-15 pilots have become NASA astronauts. And one, Neil A. Armstrong, went on to be the first man to land on the Moon.

In 1962, the Collier Trophy was awarded to four X-15 pilots for ". . . invaluable technological contributions to the advancement of flight and for great skill and courage as test pilots of the X-15."

The X-15 program was completed with a final flight on October 24, 1968. In the ten years of its active life, it proved the feasibility of manned space flight, extended the borders of manned flight into the edge of space and the hypersonic speed range, and carried research experiments to sustained heights and speeds that had never before been attained by manned aircraft.

The origins of the X-15 program are obscure. It was conceived after several years of advance thinking about some of the problems of manned flight at very high speeds and altitudes. Industry and the military services, particularly Bell Aircraft Corp. and the Air Force, were influential in establishing the need, the early feasibility and the concept that led to the construction of the X-15.

Its original purpose was twofold. First, it was to verify its theoretical design and its flight envelope, the boundaries of speed and altitude performance established by its own aerodynamic and physical characteristics.

Second, it was to explore methodically the flight envelope, looking at such problems as stability and

2 One of the X-15 aircraft was given a white ablative coating for tests in high-speed and high-temperature flights.

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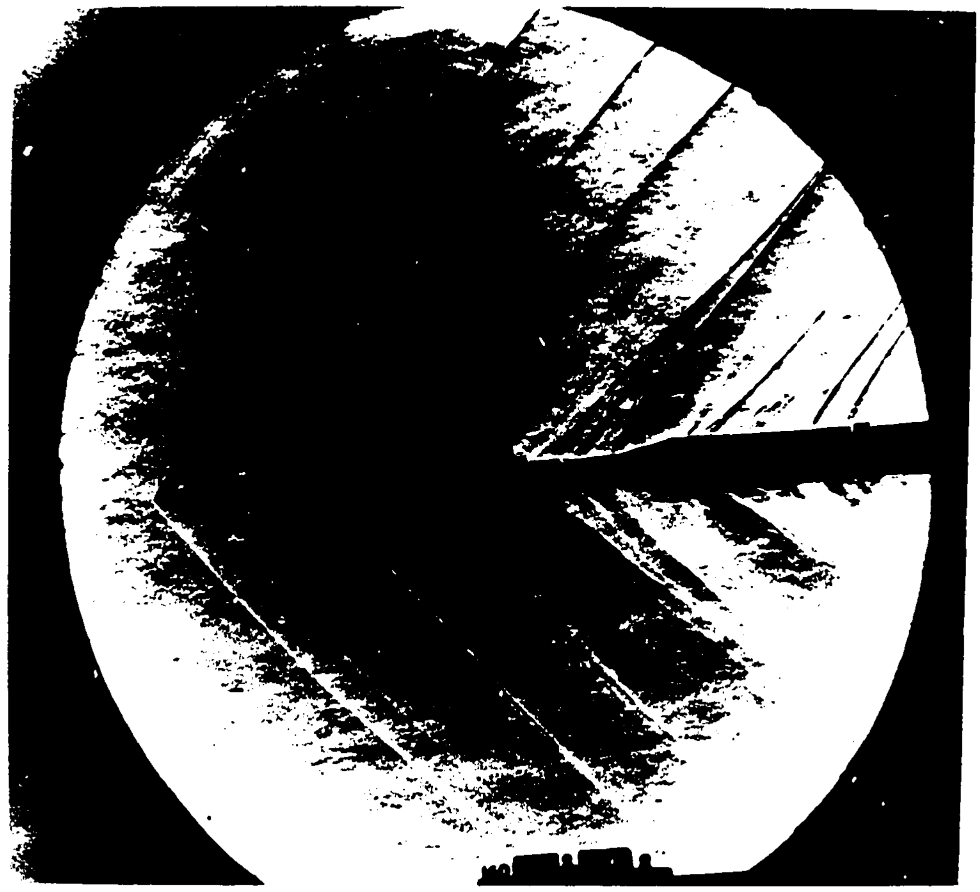

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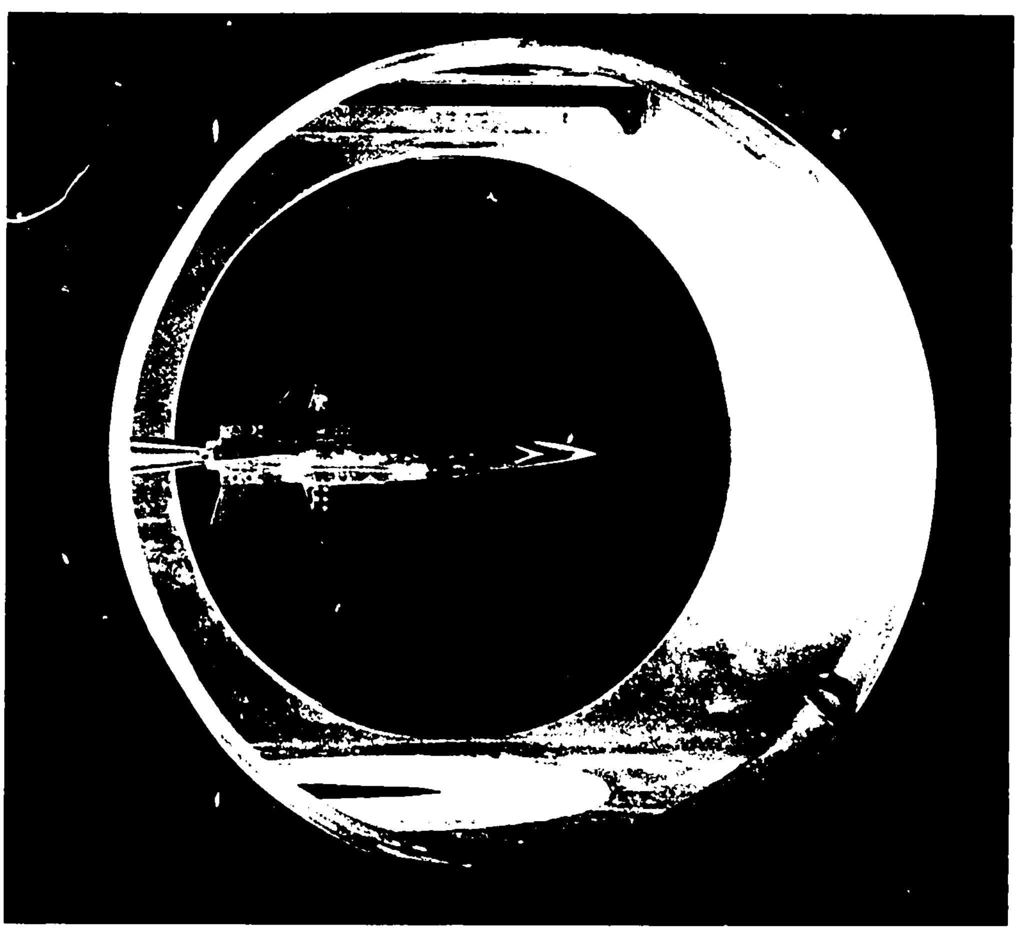


3 *A small scale model of the X-15 in the four by four-foot supersonic pressure tunnel at the Langley Research Center. Lines flowing away from the model are shock waves.*

4 *X-15 model in the supersonic tunnel at Langley.*

control, aerodynamic heating from the rush of air at the high speeds envisioned, and the relationship of man to the machine.

Later, a third purpose was added: it was to serve as a carrier vehicle for tests and experiments at sustained altitudes and speeds that could not be reached with any other type of aircraft or rocket.

Like other research aircraft before it, the X-15 was to bridge the gap between the theory and experiments in the laboratory, and the actual free-flight performance of the aircraft. That gap had been the subject of considerable debate during the early thinking that led to the entire "X" series of aircraft, and it continues to excite interest today.

The original goals of the X-15 program were to reach 6,600 feet per second (more than six times the speed of sound) and an altitude of 250,000 ft. The speed was reached and exceeded; so was the altitude goal. The current altitude mark for the X-15 is 354,200 feet, or 67 miles, and at that level, the X-15 was above 99.999% of the Earth's atmosphere. The X-15 reached 4,520 mph. in its fastest flight, just exceeding its speed goal.

An enormous amount of detailed engineering data has come from the test flights of the X-15. The predicted hypersonic aerodynamic characteristics were verified, proving that the gap between theory and experiment was not so wide as had been feared in this particular case. The heating rates of the structure, caused by its rush through the air during reentry into the bulk of the Earth's atmosphere, also were verified by X-15 flights.

In that environment of high heating and the high loads imposed by reentry and maneuvering flight, the X-15 structure—instrumented to determine its characteristics—produced valuable data about the way to build hypersonic aircraft and spacecraft. There were some superficial failures of structure due to the heating, but no primary structure ever failed, or gave any indication of failing.

Such localized phenomena as skin buckling, although it did not materially affect the X-15 or its performance, did underline the importance to designers of future hypersonic aircraft to investigate the problem carefully. Skin panel flutter, where a section of the aircraft covering would vibrate under aerodynamic loading that triggered a resonant response, was evaluated and cured on the X-15. Windshield crazing or cracking on several flights taught another lesson in the design and construction of transparent surfaces for hypersonic flight.

When the X-15 was flying above most of the atmosphere, there was quite literally not enough air for its conventional airplane-type control surfaces to "bite" into. The X-15 had to be stabilized and controlled during the flight at those extreme altitudes to avoid a reentry at some unusual attitude that could destroy the aircraft. The problems of such stability and control needs were probed and solved by the X-15.

One of the largest contributions made by the X-15 program was in the area of the importance of man to the machine, or the pilot-aircraft relationship. Studied in a simulator, the basic flight profiles of the X-15 produced no extraordinary problems for the chosen pilots. But a flight simulator on the ground is a totally different environment from the real aircraft in the air. There is a new dimension of anxiety added by the real thing which never can be simulated.

Consequently, early flights of the X-15 measured pilot physiological responses, and helped to determine performance and the importance of the man in the airplane.

Other flights proved that the pilot served as an extremely important sensor and recording instrument. There were many occasions when the pilot was the only factor that made completion of the research mission possible. Automatic equipment had failed or was malfunctioning. There were also occasions when the airplane would have been lost had there not been a pilot aboard to analyze the problem, apply judgment, and take action.

Part of the man-machine relationship was the pressure suit developed for the X-15 program specifically. It began as just another component of the overall X-15 system that required development, and evolved through continuous updating. Its design has made contributions to the manned space flight programs, and an adaptation of the pressure suit has become the standard for U.S. Air Force pilots in the Air Defense Command.

As the X-15 went from success to success in its initial research programs, some scientists began considering its use as a vehicle to carry aloft experiments that could not get to high altitudes or speeds by any other available vehicle. As a prelude to the space program, it seemed very desirable to make tests with data-gathering packages that could remain out of the Earth's atmosphere for a fairly lengthy test period, and then be returned intact to the ground for subsequent study and evaluation.

The X-15 offered a method of doing this, and during its test program it carried packages that photographed the Earth, the upper atmosphere and the stars; evaluated structural components and coatings for sustained high-speed and high-temperature flight; measured micro-meteorite density in some regions of the flight envelope; and determined the exhaust characteristics of infrared and ultraviolet radiation in the exhaust plume of its own rocket engine.

In its last test role, covered with a white protective coating, X-15 No. 2 carried out an assault on Mach 8 speeds, using additional fuel in auxiliary drop tanks, in order to evaluate a hydrogen-burning supersonic combustion ramjet engine mounted in place of the aircraft's ventral fin.

The X-15 has made major contributions to the understanding of the problems of manned flight, both in the atmosphere and in space. It has explored the phenomenon of weightlessness, aided the development of protective clothing for the crews of supersonic fighters and manned spacecraft, demonstrated man's ability to control a flight vehicle in the high-speed and high-altitude environment, and pointed the way to efficient structural design of components to withstand the high temperatures of reentry from space. It has been called the most successful of the research aircraft, and there are few who would quarrel with that accolade.

Variable-Sweep Wings

In the excitement following the rollout of the X-15 from North American's factory in 1958, it was easy to overlook another major development in the evolution of manned flight, made in a NASA wind tunnel. Continuing along a line of development they had started at NACA, scientists solved the problems of stability for a wing whose sweepback angle could be changed in flight. In doing so, they opened an entirely new range of aircraft designs.

The concept of changing the wing sweep in flight is not a new one. It had been conceived, tested in model form, tried on a handful of full-sized aircraft and discarded for several reasons long before NASA was born. But in at least one of its applications, to the Bell X-5, one of the research aircraft, it stirred enough interest to stimulate a low level of continuing study within NACA.

The reason for using sweepback is to reduce the drag of the airplane for economical operation at high speed. This is the primary reason that today's military fighters and bombers, and commercial jet transports, mount sweptback wings. But using sweepback does introduce some complications, among them being higher landing and takeoff speeds, and occasional stability and control problems. At some point in time, many engineers must have visualized that the best way to solve those problems was to make the wing sweep variable. Start (and complete) the mission with the wings spread to a nearly straight position, they thought, and take advantage of the simplified characteristics of an essentially straight wing. Then increase the sweep angle to increase the speed of the airplane, and take full advantage of sweepback that way.

The Bell X-5, which first flew in June 1951, was the first full-scale airplane to be developed whose wing sweep angle could be changed in flight. Its test program, conducted at NACA's High-Speed Flight Station at Edwards Air Force Base, California, proved its capabilities in short takeoffs and landings. With its wings fully swept, the Bell X-5 showed an extra flight dividend: It demonstrated that it would respond less to gusts and other turbulence at extremely low altitudes and high speeds than would the more conventional airplanes of the day.

But the X-5 required an intricate and heavy mechanism to move the wing fore and aft along the fuselage as the sweep angle was changed. It had to be done that way to keep the airplane within acceptable limits of stability and controllability.

For various reasons, variable sweep as a design approach lay dormant for several years. But about 1957, military and engineering thinking began to coalesce around the concept of a multi-mission aircraft that could perform more than one job effectively. It had previously been the policy to design interceptors for high-altitude work and ground attack aircraft to work at the lower levels. The performance of each type had suffered when it was pressed, as had happened historically with high frequency, into a role in the environment for which it was not designed.

Interest in variable sweep was revived because it seemed to be an answer to several problems which were being raised. First, it appeared to make possible the design of a multi-mission aircraft that could perform at high or low altitudes and at high or low speeds by reshaping itself in flight to the most efficient aerodynamic form for the mission.

Second, it seemed to offer the possibility of development into a configuration that would include the capability to cruise at supersonic speeds over long ranges instead of over short dashes.

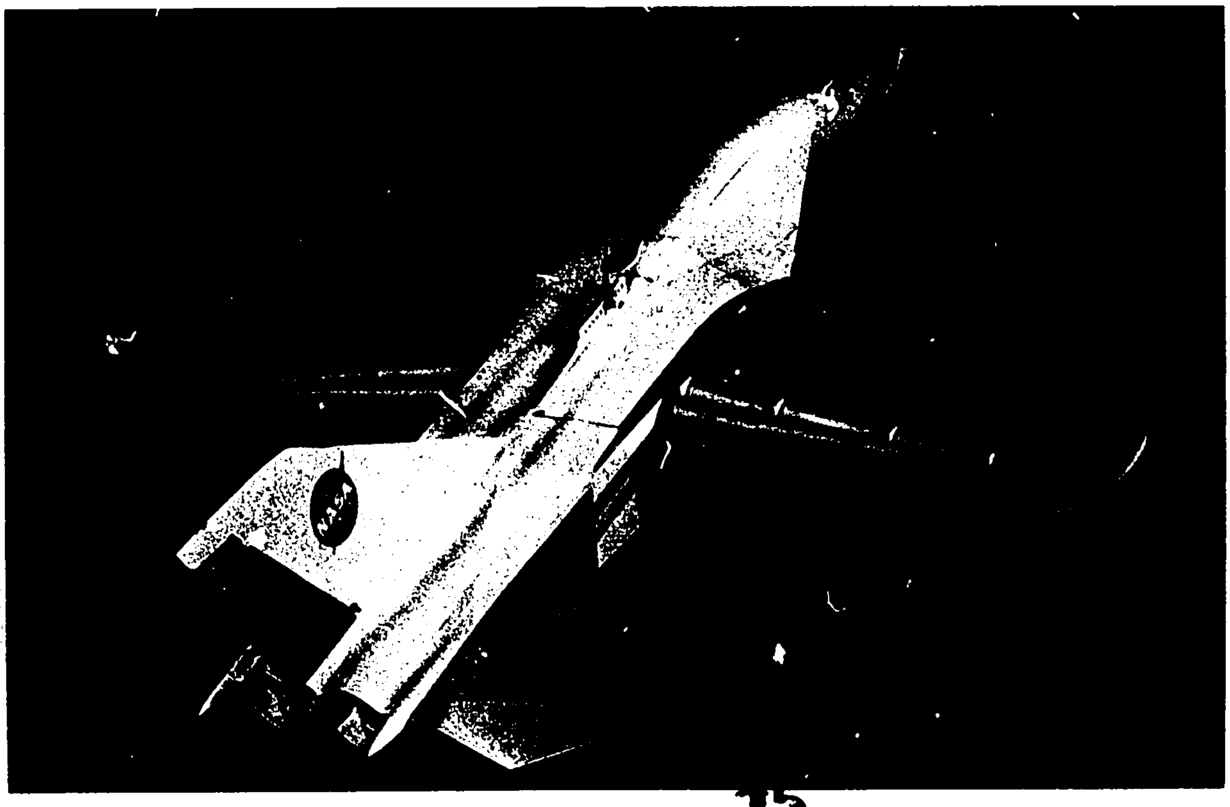
Third, it offered a way to fly very close to the ground at very high speeds to avoid detection by any enemy radar until the last possible seconds before the strike.

The breakthrough occurred in November 1958. Scientists working in the NASA wind tunnels on developments of variable-sweep concepts discovered a way to beat the old tendency toward instability and uncontrollability. By moving the pivot points outboard on the wings, so that there remained a fixed center section and only the outboard panels swung in the fore-and-aft direction, the configuration remained stable at both extremes of the sweep position. It varied only slightly from the extremes during the swing cycle.

This development was the real beginning of the variable-sweep aircraft configuration that later developed into the Boeing 2707 and the General Dynamics F-111 in this country.

Within a year, the Air Force and Navy had studied the idea and asked NASA for further information and studies of the application of variable sweep to multi-mission military aircraft.

5 A wind tunnel model of the F-111 variable-sweep fighter.



The Navy first considered the idea, applying it to an airplane being developed for combat air patrol, to make the plane theoretically able to perform high-altitude attack and low-level strike missions equally well. It was a "paper" airplane, based on limited data and a "paper" engine, but it showed so much potential that it completely outclassed any weapon system then in the conceptual stages.

The military requirements, the work done by NASA, and the paralleling studies conducted by industry, and military research and development agencies finally were merged in February 1961. Secretary of Defense Robert S. McNamara ordered that the several requirements of the military be combined into a single fighter under the project designation of TFX.

The TFX design competition was won by General Dynamics Corp., and work began on the F-111 series of aircraft, tactical fighters planned around the variable-sweep concept and intended to serve the Air Force and Navy in a number of roles.

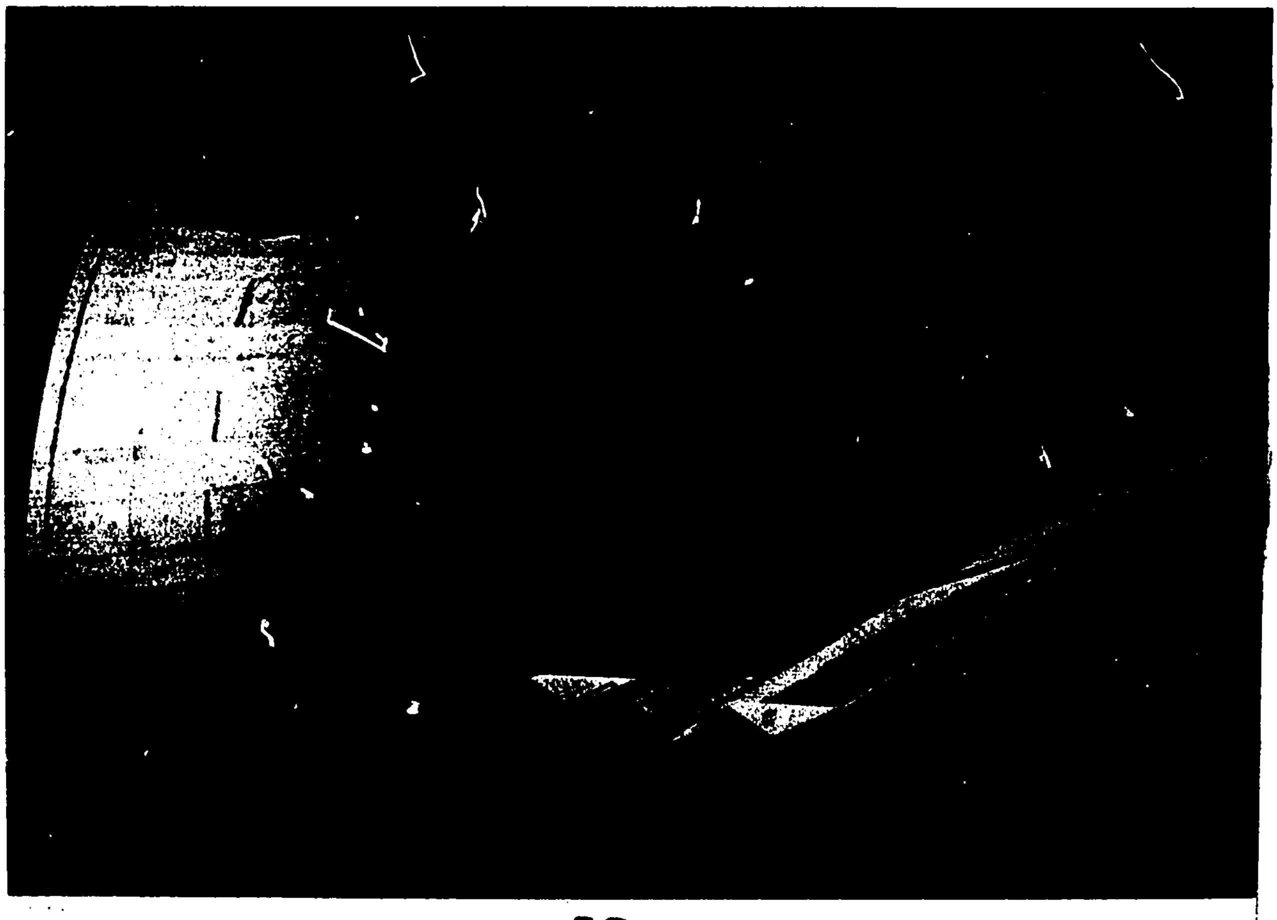
With the competition settled, NASA's role in the F-111 program reverted to its traditional one of post-research support. Refined design data and evaluations of proposed changes were areas where NASA lent a helping hand. Specific problems were subjected to theoretical analysis and wind-tunnel experiments to produce solutions, even after the prototype aircraft had been built and were flying. The NASA work in support of the F-111 program was accomplished by analysis, experiment and flight-test work on an F-111 assigned to NASA.

The Supersonic Transport (SST)

There was a parallel between the military requirements for a multi-mission fighter and the commercial requirements for a supersonic jet transport. No commercial SST would be bought by the airlines of the world unless it were to prove capable of cruising efficiently—and therefore economically—at supersonic speeds over intercontinental distances. No supersonic transport would be acceptable to any airline unless its stability and control at the low-speed end of the scale guaranteed safe operations during takeoffs, approaches and landings.

Commercial jet service around the world started in 1959. By the end of that year, NASA scientists were ready to present their case for a supersonic transport

6 A NASA test of a supersonic configuration at Langley Research Center wind tunnel.



that would be efficient and economical. They had just finished a round of briefings to the military and industry on the advantages of variable-sweep for the multi-mission fighter and were, in effect, looking toward a new technical world to conquer.

Sustained supersonic cruise was to be demonstrated by the flight performance of the North American XB-70, an aircraft in which NASA-developed technology played an important part. But the XB-70, which first flew in September 1964, was a military aircraft and could tolerate something well outside the economic guidelines that airlines had established for transport operations. Further, there was less concern for the low-speed end of the XB-70 performance because of the higher landing and takeoff speeds acceptable by the exigencies of military operations.

NASA proposed that the variable-sweep concept be applied to the design of a supersonic transport, in combination with a new and advanced propulsion system. This combination, NASA reasoned, would solve the problems associated with the required wide performance range of a commercially effective SST. And, said NASA in 1959, "The present research position is that no fundamental problem appears with regard to these off-design conditions that cannot be solved by concentrated research effort."

NASA made its formal presentation to the Administrator of the Federal Aviation Agency, then Lt. Gen. E. R. Quesada. Published later as a Technical Note, the NASA briefing discussed performance, noise, structures and materials, loads, flying qualities, runway and braking requirements, traffic control and operations, variable-geometry design concepts and possible areas for performance improvements.

That briefing was the beginning of serious effort on the commercial SST program. Within weeks, a joint NASA-FAA program was well along.

NASA work on the SST program centered on the development of basic configurations that would meet the requirements of airline customers. In spite of its early espousal of the variable-sweep concept, NASA prepared to make configuration studies on a variety of aircraft layouts. Called by the acronym of SCAT, for Supersonic Commercial Air Transport, a series of configuration studies was started in 1962. The overriding general requirement, of course, was to make a commercially feasible aircraft configuration. Some of the specific points were to better the XB-70's lift-drag ratio in cruise, and to make possible aerodynamically efficient flight at the off-design points in the aircraft's mission.

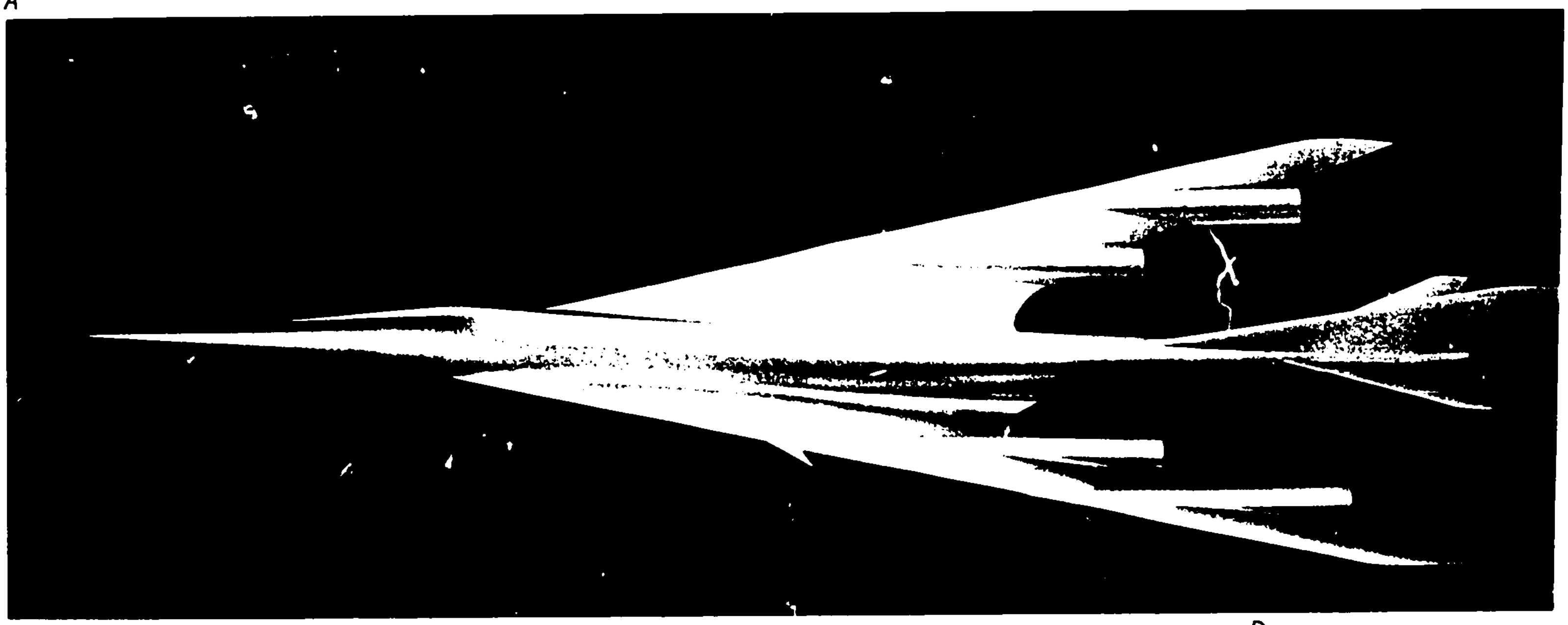
Less than one year later, the NASA approach had selected four candidate configurations for the SST: SCATS 4, 15, 16 and 17. SCAT 4 was a fixed-wing airplane that carefully integrated wings, fuselage, tail surfaces and powerplants into a highly swept, twisted and cambered configuration. SCAT 15 and 16 were based on variable-sweep wings, using two different approaches. SCAT 17 had a fixed delta-winged planform with forward canard control surfaces, similar to the basic concept of the XB-70.

At this point, NASA went to industry and invited evaluation of the four concepts. Two were chosen, the SCAT 16, eventually to be a foundation for the Boeing 2707, and the SCAT 17, to lead toward the competing SST configuration developed by Lockheed Aircraft Corp.

The enormous and detailed amount of theoretical and experimental work that accompanied the SST program and the development of the SCAT configurations paid a handsome dividend. As test results led toward modification of theories, so did the theories become that much more able to predict the real conditions. This narrowing of the gap between theory and practice led to the ability to predict, by computer techniques, the aerodynamic characteristics of aircraft. The principal characteristics that determined airplane performance could be spotted within 3 percent of actual test data, time after time. This meant that an airplane could be designed or changed on paper, transformed into a computer program, and analyzed for performance within a matter of hours, instead of the weeks it formerly took to complete the design and analysis cycle.

7 Four candidate configurations of supersonic transports were developed at Langley: (A) SCAT 4; (B) SCAT 15; (C) SCAT 16; (D) SCAT 17.

A



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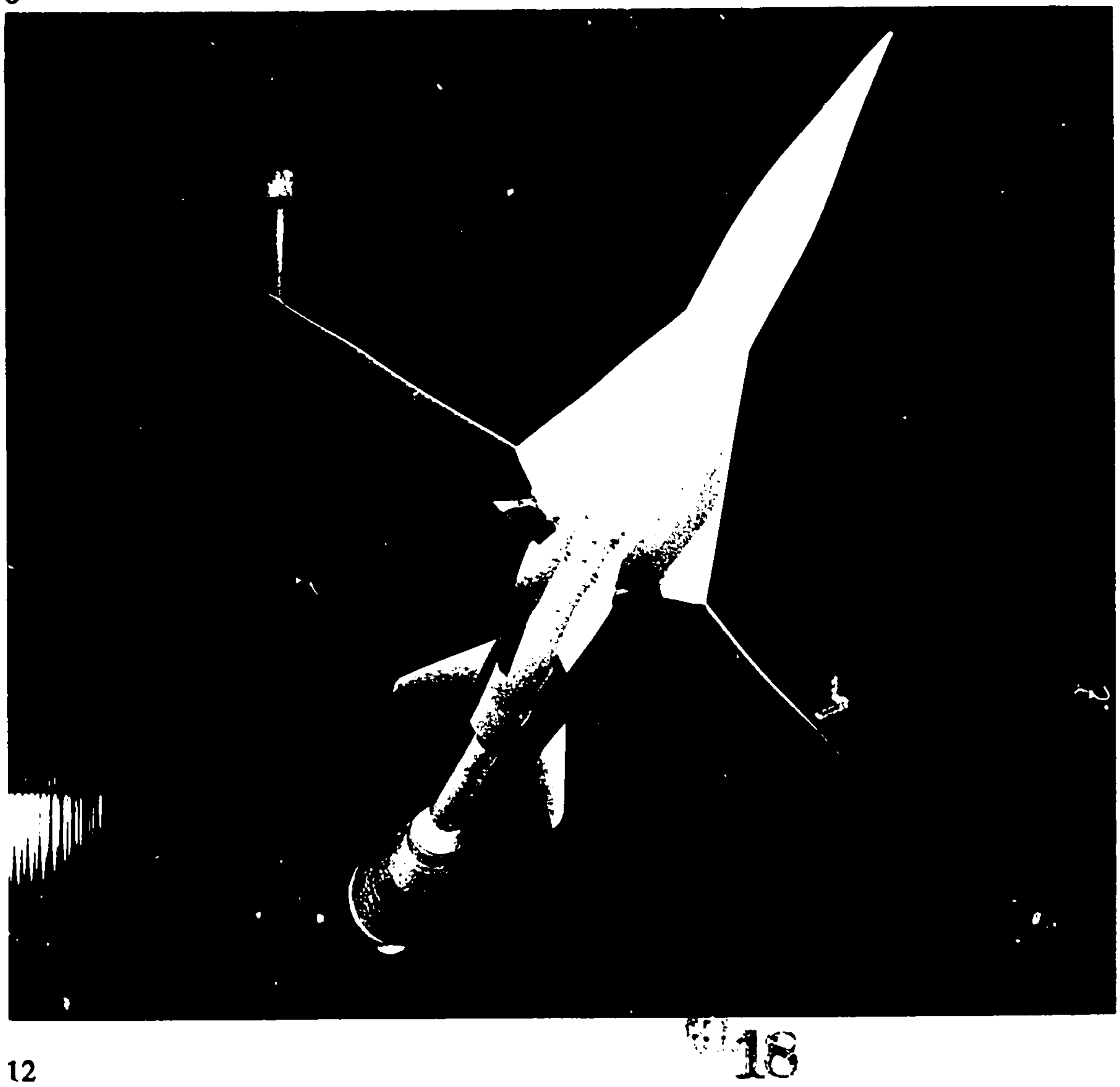

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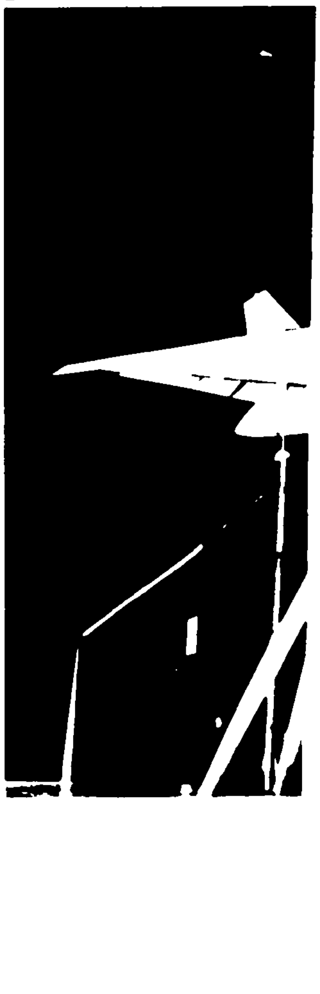

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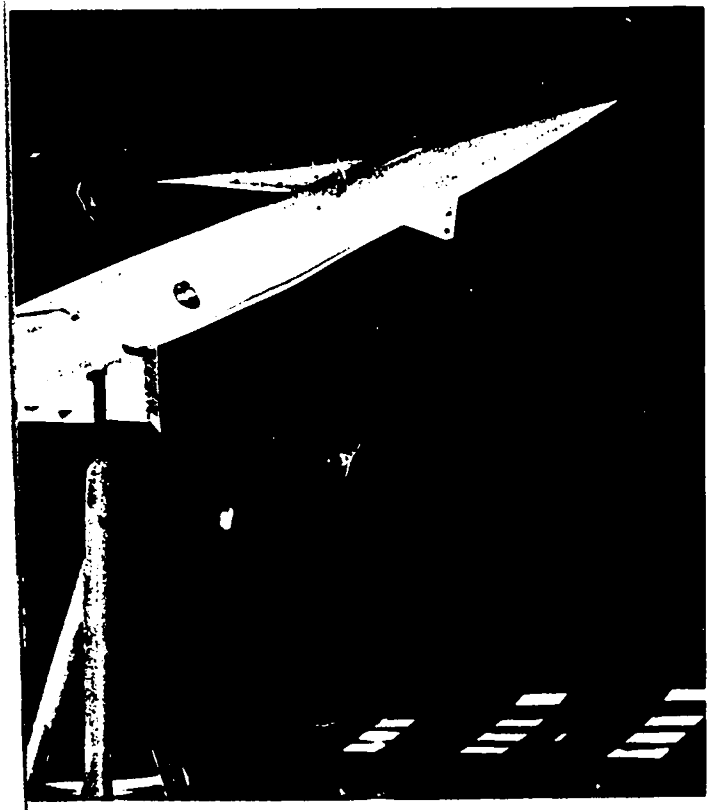

NASA has extended that technique into two other areas. One of them is the prediction of the performance of an airplane under severe structural loads which cause it to become deformed from its ideal configuration. Since the loads and response of an aircraft during maneuvering are of great importance to both military and commercial operators, this step forward in analysis will prove very valuable.

In the other approach, the computer program which described the airplane's aerodynamic characteristics can be modified to produce the airplane's geometric characteristics as well. The geometric output of the computer can be fed through a numerical tape control into a machine tool to produce a wind tunnel model of the design within a matter of hours.

The supersonic transport as an operational airplane has accounted for several major programs of research by NASA. In one of them, tiny models of the proposed SST were tested in supersonic wind tunnels to determine the characteristics of the sonic boom, that natural phenomenon that threatens widespread commercial employment of the SST. Paralleling the tests were extensive theoretical investigations and flight tests made with available supersonic aircraft, to

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try to determine the magnitude of the sonic boom problem and to isolate, define and perhaps modify some of its parameters.

On the flight testing side, a special modification was made to Boeing's original prototype jet transport, the 707-80, so that it would simulate the handling characteristics of the SST in flight. NASA test pilots flew the 707-80 through a series of approaches and landings, in carefully instrumented tests, to simulate the behavior of the SST in this critical flight regime.

Other simulation of the SST's operations, this time in the approach area to the John F. Kennedy International Airport, was the subject of a joint program with NASA and the FAA. Two simulators—one of the SST itself at Langley Research Center, and the other of the air traffic control situation, operated by the FAA at the National Aviation Facility Experimental Center, Atlantic City, N.J.—were integrated to study the problem of handling the SST in the existing patterns of arrivals and departures of other aircraft. Experienced, professional airline pilot crews from United Air Lines and Trans World Airlines flew the simulated flights, and defined, early in the game, some of the immediate and long-term problems that would be faced with the entry of an SST into commercial flight operations.

The structure of the SST was influenced by early studies made by NASA on concepts, and by a screening process to find suitable materials for the structure. Fatigue of the metals and changes in their physical properties, as they were run through heating cycles for durations up to 30,000 hours, were evaluated in NASA tests.

Hypersonic Flight

The research on supersonic transports, bombers and tactical fighters that has occupied a major share of NASA's aeronautical work during its life has led to serious looks at studies of hypersonic flight, the next stage in the evolution of aircraft. The X-15 research aircraft has demonstrated hypersonic flight, even though it was only able to sustain such flight over relatively short periods of time.

A now cancelled program, the Dyna-Soar, which was conducted by the Air Force with NASA support, was aimed at extending the flight range from the hypersonic speeds of the X-15 right up to the orbital speeds of Earth satellites. Dyna-Soar was basically a space glider, to be launched by a multi-stage rocket booster vehicle and to reenter the Earth's atmosphere using the flight principle of dynamic soaring—from which term came the name Dyna-Soar.

Before the program was cancelled, Dyna-Soar had provided a lot of the basic insights and some of the fundamental data that directed NASA thinking toward sustained hypersonic flight. At the operational speeds of Mach 7 now under consideration, a typical hypersonic aircraft would develop temperatures above 2,000°F on its nose and above 1,600°F on the leading edge of the wing.

The configuration of such an aircraft has been under study in NASA wind tunnels for several years. A series of proposed shapes has been developed and tested, using such ingenious techniques as building tiny models out of quartz to enable them to withstand the heat of the tunnel test.

That heat on the full-scale counterpart imposes the major restraints on the design of a hypersonic aircraft. Completely new approaches to structural design have been investigated by NASA, using such ideas as the thermos bottle, where an outer shell takes the heat, houses the insulation and holds an inner shell which houses fuel and passengers. Other structural ideas, developed as part of the Dyna-Soar program by NASA and industry, have been evaluated.

Selection of materials for the structure reaches into the superalloy field, and NASA is studying and screening, much as it did for the supersonic transport, the range of candidate materials for hypersonic aircraft.

A few years ago a new NASA wind tunnel became available at the Langley Research Center, adding a unique capability to the agency's testing facilities. The only one of its kind in the world, the new tunnel has an eight-foot diameter test section which can be run at sustained high temperatures characteristic of hypersonic flight. The size of the test section, and the performance capability of the tunnel, make it possible to study large models, and in some cases, full-size components, of proposed hypersonic craft under simulated flight conditions, including full temperature simulation.

Today's Aircraft

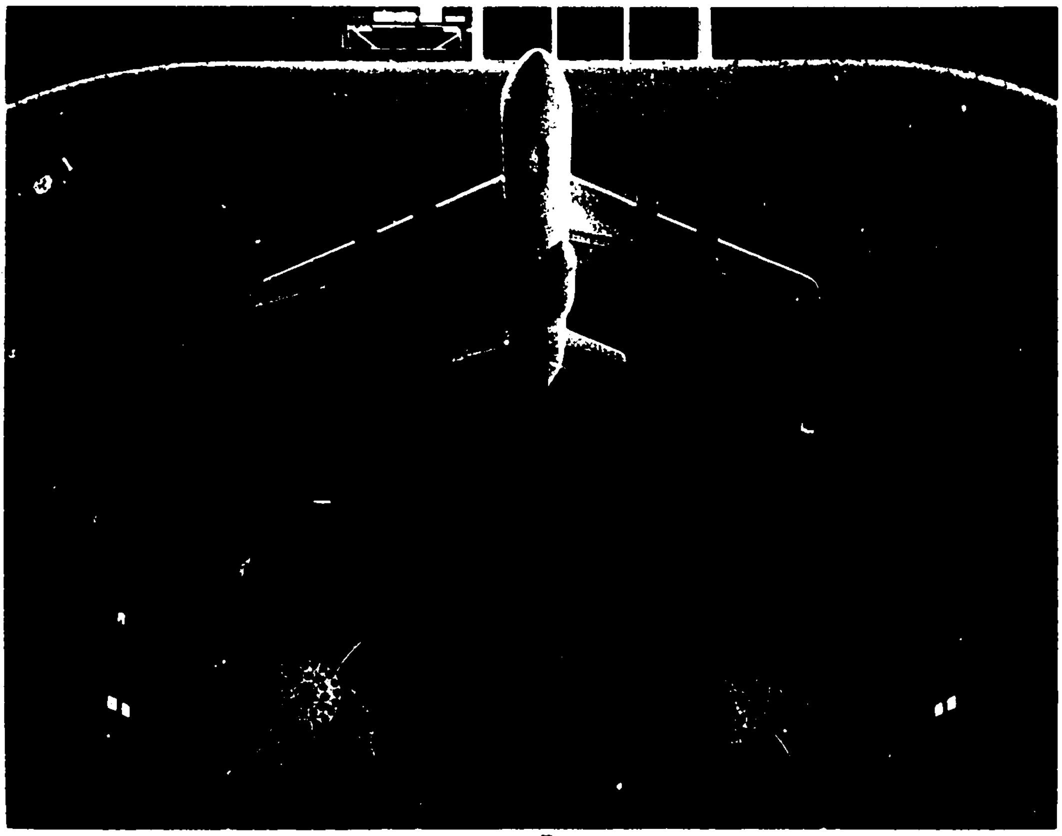
But these are tomorrow's aircraft. There are still today's aircraft that have problems, or that show some potential for further improvement. NASA studies are aimed at these types, also.

The current subsonic jet transport, for example, is one of these. Its basic design dates back to the technology available in the early 1950 time period. Now, nearly 20 years later, those basic designs have been honed and polished, but basically they haven't changed much.

Today's jet transports, for example, cruise at subsonic Mach numbers, generally somewhere between 0.72 and 0.80. These speeds cover the normal long-range and high-speed cruise conditions. If those cruise speeds could be raised, the working potential of each transport could be increased. By getting from point to point in less time, it could make more round trips in a given period of time, thus increasing its productivity.

The NASA Supercritical Wing holds a promise for that kind of a cruising speed. It uses a trailing-edge slot to mix high energy air from the under surface of the wing with the lower energy air off the top surface and keep the boundary layer attached to the wing. This results in decreased drag, and a higher cruise speed. It is theoretically possible, NASA studies show, to reach cruise speeds above Mach 0.90 with the NASA Supercritical Wing.

8 *Model test for the heavy logistic transport C-5A.*



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Air transports could also be made to fly more slowly, NASA believes. Takeoff, approach and landing speeds could be reduced substantially by resorting to a form of boundary layer control, such as the blown flap systems installed on the Boeing 707-80 or the Lockheed BLC-130. NASA pilots evaluated both aircraft to determine what the handling qualities of such an airplane, so equipped, would be.

The comfort of air travel is related to the aircraft's response to air turbulence. More than 20 years ago, NACA scientists were investigating a method of gust alleviation, in which the airplane is instrumented to sense oncoming turbulence and to anticipate and correct for it by appropriate control motion. The controls are applied automatically to compensate for the turbulence, and the result is a smoother ride, or one which stresses the airplane less.

Recently, the basic principle of gust alleviation was built into a test Boeing B-52 airframe under a program funded by the Air Force, and the data from those flight tests provided valuable insight into prolonging the life of large, flexible aircraft, and easing the ride for its passengers.

Operations of today's aircraft have occupied a large share of program time at the various NASA research centers. The dangerous phenomenon of tire hydroplaning, in which the airplane—or automobile—tire rides clear of the ground on a slick wave of water, was first analyzed and evaluated by NASA. The inherent dangers of hydroplaning, which has been responsible for several known aircraft accidents and probably for countless automobile accidents, were first described to the aircraft and automobile industry by NASA.

Related to hydroplaning is the problem caused by slush on the runway. One-half inch of slush is the current limit for permissible legal aircraft operations, and it was NASA studies of the problem and their systematic tests that established that particular criterion.

Helicopters and V/STOL Aircraft

Far down in the low-speed flight regime are the helicopters and V/STOL aircraft that the military services and NASA have sparked and tested during recent years. Here again the work has followed the traditional patterns of problem-solving, integrating theory and experiment in test facilities with flight tests of full-scale aircraft. And beyond problem-solving there has been the conceptual development of a class of VTOL aircraft that now appears to offer efficient short-haul transportation.

In this latter category is the tilt-wing configuration, which evolved from wind tunnel and dynamic model flight tests by NASA scientists through concepts,

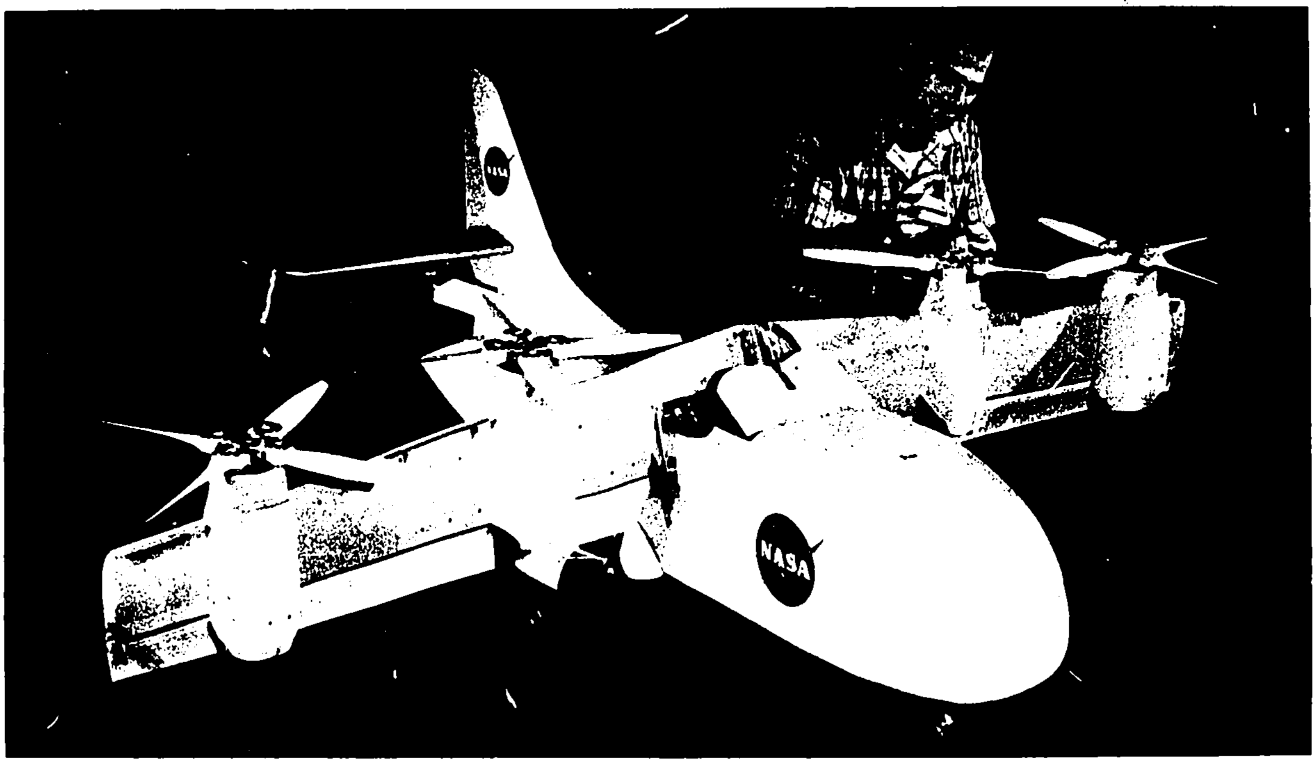
9 The Lockheed XH-51A in studies of hingeless rotor helicopters.

detailed designs and analysis, and tests of advanced configurations in model form. One of the results of that program was the tri-service XC-142A, a four-engine, four-propeller, tilt-wing cargo transport developed for the military by a group of companies including Ling-Temco-Vought, Ryan and Hiller.

Early NASA tests of the tilt-wing concept demonstrated that it could hover, and could make the difficult transition in flight between vertical hovering and horizontal flight. Subsequent tests extended the transitions from hovering to forward flight in the wind tunnel. The results predicted the characteristics of the real aircraft when it entered flight testing at a later date. Still later, an XC-142A was assigned to Langley Research Center for flight research.

Other concepts have been evaluated by NASA. One of the first VTOL vehicles available anywhere, the Bell deflected-jet X-14, has been extensively flown by

10 *Tri-service V/STOL transport, the XC-142A, was tested with dynamic models.*



configuration studies through the use of small wind tunnel models and evaluated the final choice of design with a large-scale model of the XC-142A in the full-scale tunnel at the Ames Research Center.

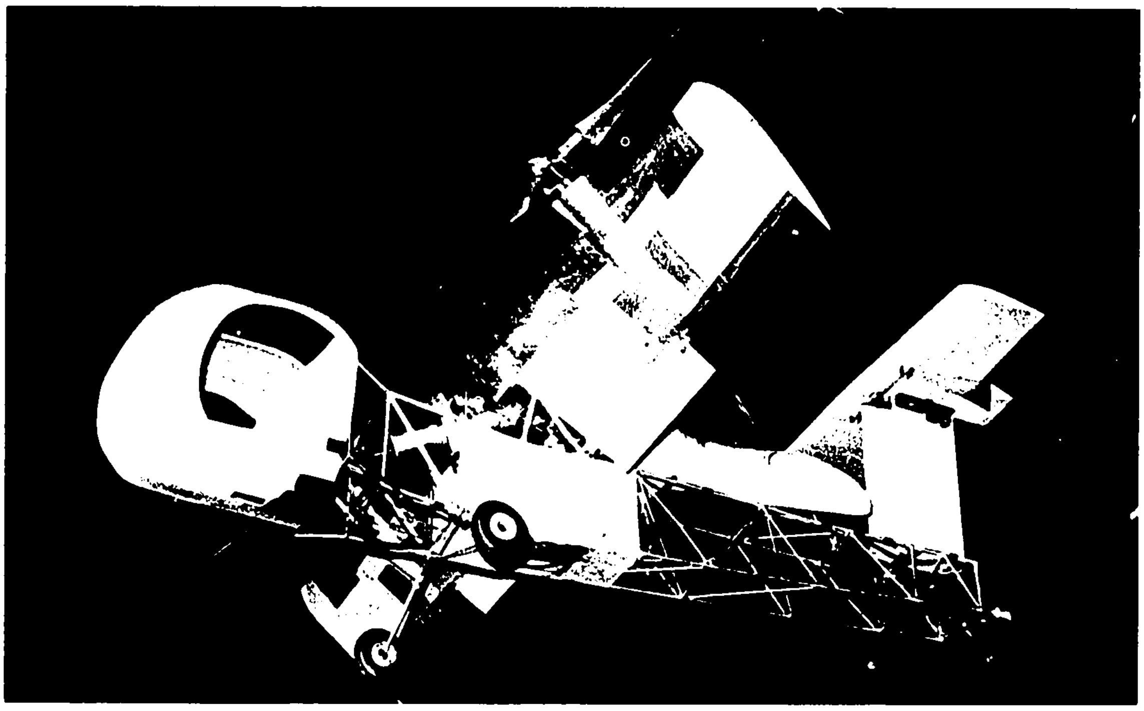
A similar type of aircraft, the Vertol 76, was used as a flying test bed by NASA to evaluate many of the flying quality parameters that were later applied to the design of the XC-142A. Specifically, the approach and hover phases of flight received detailed scrutiny by NASA test pilots.

After the XC-142A became a tri-service military transport, NASA continued to back up the program with research. A remarkable one-ninth scale model was built to exacting detail and flown under conditions dynamically similar to those of full-scale flight in the full-scale wind tunnel at Langley. The model and the test technique used permitted making complete NASA pilots, and has been used to develop generalized data as well as to train pilots to fly on other later VTOL craft.

The tilt-duct idea, first seen on the Doak VZ-4 and later on the Bell X-22A, was tested in its early stages at NASA facilities. The fan-in-wing types of VTOL craft, typified by the General Electric-Ryan XV-5A, were evaluated in model and full-scale form by NASA. So was Britain's Hawker P.1127, a fighter prototype that used deflected thrust from the swiveling nozzles of its jet engine to provide the vertical lifting thrust. In model form, the Hawker P.1127 was extensively tested by NASA in one of the most detailed VTOL test programs ever conducted.

These were largely experimental or research vehicles. But production helicopters also have been evaluated by NASA test pilots. One of them, a Vertol YHC-1A, 11 *The Vertol 76 tilt-wing VTOL aircraft was evaluated at Langley using (A) a free-flight model and (B) the actual airplane.*

A



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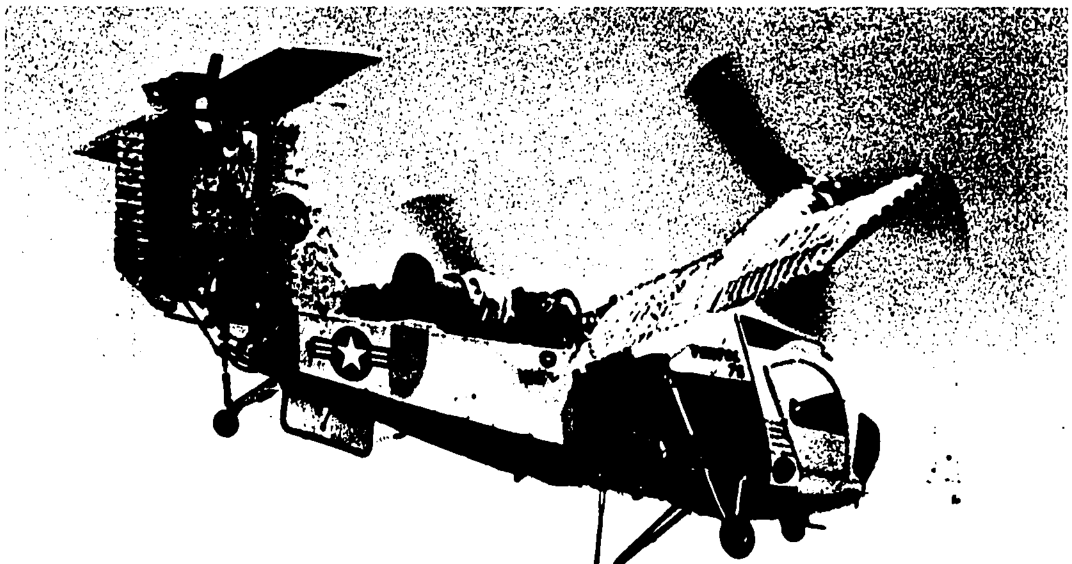


has been modified to serve as a variable-stability helicopter. It can simulate the flying qualities of a wide range of helicopters and VTOL aircraft, and is one of the most useful research tools in the flight testing work.

Somewhere beyond both the rotary wing of the helicopter and the fixed wing of the airplane is the flexible wing, a new concept pioneered at NASA and NACA. The name describes it; it is made from cloth and generally has no rigid structure to hold its shape into a wing form. Instead, a combination of aerodynamic forces on the wing and reactions from the load suspension system serve to shape and maintain the form of the flexible wing.

Some stiffening has been used to match required characteristics in specific applications, but the most interesting variations are those which have no stiffening and therefore can be packed like parachutes.

12 *British Hawker P.1127 V/STOL tactical fighter development aircraft, was flown in free-flight tunnel in model form and in tests.*

More than 20 years of NACA/NASA testing have evolved a spectrum of flexible wing configurations. At one end are the completely unstiffened cloth surfaces, which can be used—and have been tested—for precision aerial delivery of cargo or personnel. Proposals have been made and studied to use this type of stowable wing for landing spacecraft or recovering launch vehicles.

At the other end of the spectrum are stiffened wings for towed or powered aircraft, where it is important to obtain higher speed performance at the expense of stowability.

Research for Spacecraft

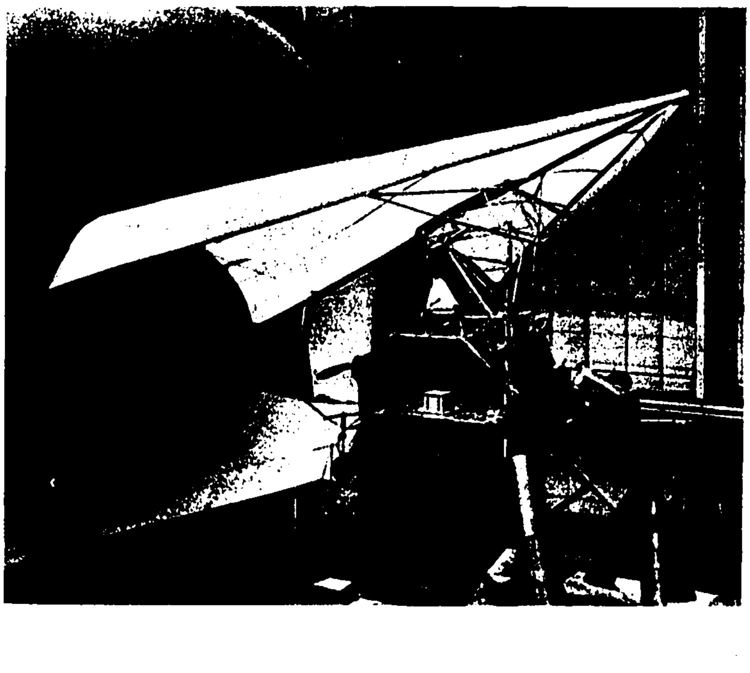
When President Dwight D. Eisenhower signed the National Aeronautics and Space Act July 29, 1958, his statement on the signing said, in part: "The present National Advisory Committee for Aeronautics (NACA) with its large and competent staff and well-equipped laboratories will provide the nucleus for NASA. . . . The coordination of space exploration responsibilities with NACA's traditional aeronautical research functions is a natural evolution . . ."

At first glance, it seems a far cry from the technology of a fixed-wing airplane to the engineering design of a manned spacecraft that will never fly in an atmosphere where wings or control surfaces would be of any use. But there are many similarities and analogies, and the comforting thought is that a problem is a problem, and subject to standard methods of problem-solving.

Theodore von Karman, the late elder statesman of aeronautical engineering, put it this way: ". . . those who say that all that men teach and all that men investigate, under the name aeronautical engineering, is obsolete, seem to assume that by some miracle the designers of space vehicles will not encounter problems involving such classical sciences as fluid mechanics, structures, materials and vibrations. I am sure that this will not be the case."

He was right; it was not the case. Those problems were encountered, and they were solved, in many cases by the applications of aeronautical technology developed over the years. This is not to say that there were no new approaches to the problems. The environment of a spacecraft launch, for example, superimposes so many new problems that it is impossible to treat them in any classical manner. The strange new shapes of launch vehicles plus spacecraft, with weight and inertia characteristics different from those of any airplane ever built, pose a different kind of problem. The classical disciplines can be adapted to the solution, but not in the classical way.

13 *Full-scale prototype of XV-8A "Fleep," a Flex-wing aircraft built by Ryan, was "flown" in a full-scale NASA wind tunnel.*



There are a few areas where the problems are about the same, and are being solved in the same way. One of these is in the concept of a lifting body glider or powered vehicle, for returning astronauts from space.

The basic idea of the lifting body is to give the astronaut crew the flexibility to select a landing site, and to maneuver to it, instead of being committed to a limited oceanic recovery area, and being further constrained by the necessity to make a parachute deceleration and letdown into that area.

The lifting body flies on the aerodynamic force generated by the shape of its body. It has no wings, but it does have control surfaces and fins to provide stability and control.

One of the earliest of the NASA programs was the development of two different types of lifting-body configurations, tested earlier by NACA in wind-tunnel evaluations. Development continued to the point where the logical next step was to build and fly some kind of a test vehicle. This was done by constructing a simple and inexpensive test glider, designated the M2-F1, from plywood and tubular steel in a reversion to the aircraft construction techniques of the 1920's and 1930's.

The success of the first tests with the lightweight M2-F1 encouraged NASA to advance the program. Two heavier lifting bodies were designed, and built, differing in detail geometry and in the system of control.

The M2-F2 was designed with a flattened upper surface, a rounded belly, two vertical fins, and a bubble canopy projecting outside the lines of the body shape.

The HL-10 in contrast was rounded on top, had a flat belly, three fins, and a canopy constructed within the profile of the body shape.

Both of these aircraft were built for NASA by Northrop's Norair division, and both made gliding flights after being carried to altitude under the wing of a Boeing B-52 mother ship. The M2-F2 was severely damaged in a landing accident after 15 missions and was taken out of flight status.

An X-24 was built for the Air Force and incorporated into the NASA-managed flight program. It was of a different design from the M2-F2 and HL-10, with more sophisticated controls.

Air-breathing Powerplants

The lifting-body concepts represent one of the farther-out applications of aeronautical technology. Another area, that of air-breathing power plants, also seems far removed from aeronautical technology, but is currently considered as part of the NASA program in aeronautics.

One of the reasons for this is that air-breathing engines have increasingly become creatures of aerodynamic complexity. As the early turbojet designs evolved into engines with higher and higher performance, they demanded more and more refinements in compressor and turbine blade aerodynamic design, inlets, diffuser section geometry and fan blade designs. And as the engines got more powerful, they also got bigger and noisier. To tackle the noise problem requires a knowledge of the behavior of the hot exhaust gases, which again drew on the background of aeronautical knowledge developed by NASA, and before it, by the NACA.

NACA's work with aircraft engines began shortly after the formation of NACA in 1915. There was a war on, and there was obviously a significant military advantage to be gained by having an aircraft engine that would perform well at high altitudes.

At that time, there were no test stands which could be used to simulate altitude operation. The only way was to truck the engine up to the top of a convenient mountain, and run it in the rarefied air at the peak. NACA had commissioned the Bureau of Standards to develop and build a high-altitude test stand, and it operated for the first time late in 1917. But the test stand didn't have all the bugs worked out. At the end of 1917, an NACA technical staff member was sent to supervise altitude tests of a Liberty engine, conducted at the top of Pike's Peak, Colorado.

Systematic propulsion research started at an engine laboratory built in 1920 at the Langley laboratory of the NACA. Propulsion research programs later were transferred to what is now the Lewis Research Center, in Cleveland, Ohio. Lewis was opened in 1941, using a nucleus of personnel drawn from Langley, but adding and expanding both staff and facilities.

Current programs in aircraft engines include NASA work on the development of advanced air-breathing engines. The turbojet and turbofan engines which power today's jet transports are highly developed as a class of power plants. But there is room for improvement: Fuel consumption might be reduced; thrust might be increased without increasing engine weight or volume; noise might be lessened.

Such broad problem areas are under study by NASA scientists, as are such specific problem areas as the efficient operation of an engine air inlet.

Because an engine needs different amounts of air to breathe in order to generate different thrust levels, the most efficient kind of an inlet is one whose area can be changed to match the requirements. The engine itself has a fixed inlet area, determined by the dimensions of the engine and its rigid construction. The only area that can vary is upstream of the engine inlet face, at the entrance to the engine air intake ducting.

To change this area is relatively simple, mechanically; but the problem is complicated because a change at the inlet changes everything downstream, including the exhaust area. So NASA investigated the effects of inlet and exhaust nozzle areas on the performance characteristics of air-breathing engines to evaluate the parameters of the problem, and to discover ways of controlling the matching of those areas for optimum performance of the engine.

Another work area was in weight reduction of turbojet engines. Most of the weight of a turbojet is concentrated in the rotating compressor. The compressor is made of several compressor stages, which are necessary to get the overall compression needed to make the engine efficient.

If each stage could be designed to do more work than it currently does, then the total number of stages would be reduced, and the total engine weight would drop. To get more work out of a stage, the blades must be curved more; the greater the curvature, the more work done by each blade, up to the point at which the airflow breaks away from the blade and the work output drops drastically.

Detailed study of blade shapes and ways to get more work out of a single stage of compression have been a continuing program at Lewis for some years. Other Lewis work has studied increased turbine operating temperatures, because with higher turbine temperatures go higher thrusts.

Two approaches have been pursued. The first has been the development and evaluation of new materials with increased resistance to heat, and greater strength at the higher temperatures. The second has been the development of cooled blades, generally using air led from a cooler location in the engine, and fed into the base of the turbine blade. Centrifugal force pushes the air through the blade and out through a series of tiny holes, slots or even pores in certain materials. The circulation of the air cools the blade and allows it to operate at a higher than usual temperature.

Similar work continues to be done by industry, and experimental—and production—engines have been run with cooled turbine blades.

Reduction of Engine Noise

As engines produce more thrust, they almost invariably produce more noise. Bigger engines and more of them, as air traffic increases, have aggravated the noise problem until it looms as a major obstacle to the further expansion of air transportation.

NASA, and others, are trying to reduce engine noise. With so many noisy engines in service, the obvious first thing is to develop a temporary fix to reduce noise levels as much as possible consistent with safety and economy of operation. The use of sound-absorbing materials in engine inlets has proven effective, for example, and is expected to become a widespread solution for the near-term problem.

On a long-term basis, the second obvious thing is to design an engine which is inherently quieter than current types.

NASA has combined both these approaches into a three-step assault on the noisy engine. The first step is an expanded basic research program on the mechanisms of noise generation. The second step consists of studies and the development of means of reducing the radiation of fan-compressor noise from nacelles by means of acoustic treatment of inlet and discharge ducts. The third is development of quiet engine technology to minimize the noise produced by the rotating machinery and the jet exhaust.

NASA is working on component studies and tests, and has placed contracts with engine and aircraft manufacturers for additional work on the quiet engine, and on quiet installations.

Problem Solving

With an increasing amount of technology available on such possible major improvements as the quiet engine and the super critical airfoil, one can visualize another generation of jet transports, or military aircraft, utilizing some of the unique solutions explored in the research centers of NASA. But in addition to these major areas, there are other important subjects directly related to aeronautical progress under study at NASA.

In aircraft operations, study and experiments have advanced the knowledge of how to fly more safely. Periodic conferences on the problems of aircraft operations, attended by industry, airline and military representatives, have provided invaluable exchanges of ideas, and suggestions for new experimental programs. Aircraft instruments and standards of measurement have been criticized, studied, evaluated and improved as another result of these conferences. New piloting techniques have been tried, new types of presentations of data to the pilot have evolved, and so have new ideas to lessen the pilot's workload during the more-severe demands on his abilities caused by bad weather or aircraft malfunctions.

These are natural tasks for NASA, growing out of its years of experience in contributing to the solution of the problems of flight. But there is a difference. In earlier days, much of the NACA work was confined to defining problems, and later, to solving problems.

The wartime years were almost entirely spent in devising "quick fixes" to solve an urgent problem in military aircraft performance. Postwar, the work of the NACA took on renewed strength in the direction of aircraft research.

In the early years of national reaction to the Russian Sputnik, and the subsequent formation of NASA, basic aeronautical technology seemed almost to have been ignored in favor of the quick and necessary development of some capability in space. But the forced transition of NACA into NASA, a space-oriented group, provided benefits, as well as some possible drawbacks, aeronautically speaking.

In NASA there has been more emphasis on systems work, the study of all the factors which bear on the problem. This was caused partly by evolution, because airplanes, missiles and spacecraft were getting more complex and demanded a systems approach as the only adequate road to accurate and informed analysis.

But there was also some revolution, as the people and facilities which had been developed to solve aeronautical problems were put to work on the different problems of space flight. The nature of the people and facilities changed under this exposure to new disciplines, and NASA itself changed.

Today, NASA's aeronautical efforts are geared to the needs of complete aircraft systems, including powerplants, instrumentation, navigation and communications aids, pilot's comfort and capabilities, structures, and operations.

NASA has built on more than fifty years of aeronautical technology that started with fragile biplanes built of wood, covered with linen and braced with wire. Today's progress traces its roots back to that first systematic approach to the problems of aeronautics. Tomorrow's progress will be based on the work being done today at the research centers of 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.

Information concerning other educational publications of the National Aeronautics and Space Administration may be obtained from the Educational Programs Division, Code FE, Office of Public Affairs, NASA, Washington, D. C. 20546

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