A E R O N A U T I C S

I N N A C A A N D N A S A

These years of U.S. aeronautical research have resulted in spectacular progress that will be difficult to match, particularly since the rate of advancement typically slows as a science matures. However, today's researchers do have some significant advantages. We have seen that coordinated public, private, and university research can accomplish remarkable advances, and that American industry has the capability to apply the results in the manufacture of superior aeronautical products. The national importance of commercial and military aviation is evident, and we presently have far more information, and far more advanced tools, with which to identify and address technology needs and opportunities. There is a good basis for optimism that, building on the NACA/NASA historical base and using advanced facilities and computers, the new generations of personnel and leadership will successfully meet the greater challenges of the twenty-first century and be at least as productive as their twentieth century predecessors.

AERONAUTICS

IN NACA AND NASA

LANGLEY RESEARCH CENTER
AMES RESEARCH CENTER
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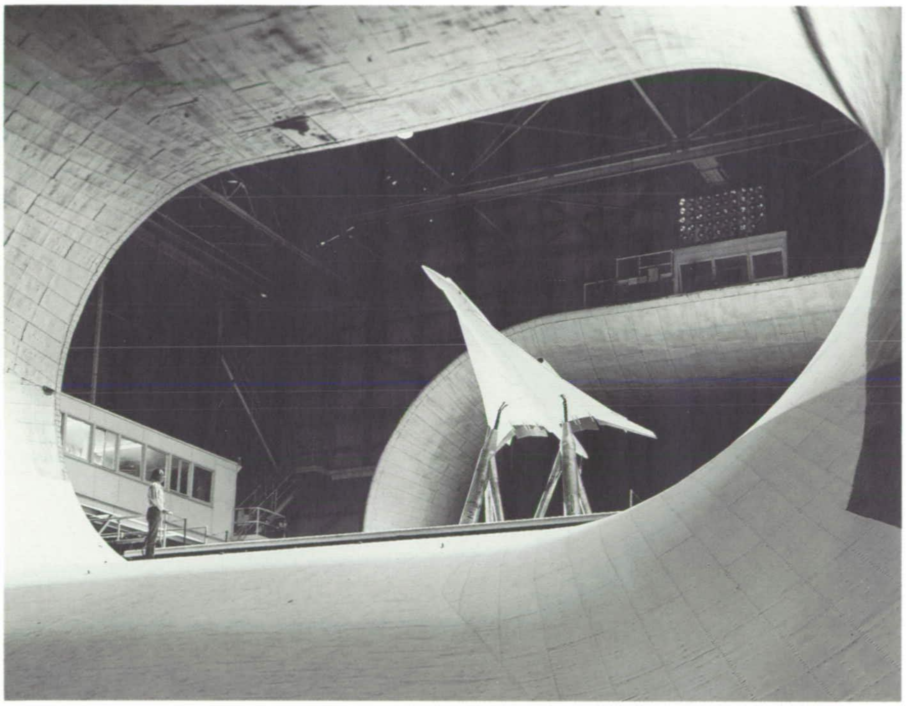


Contents

Dedication

This brief overview of our aeronautical research spans more than three-quarters of a century. Over the years, the National Advisory Committee for Aeronautics and the National Aeronautics and Space Administration have been proud of the recognition and honors the world has given to outstanding researchers and their contributions. Aeronautical research, of course, is a team effort. Success requires both the creativity and leadership of key people and the dedicated, competent, and often brilliant efforts of numerous scientists, engineers, technicians, and administrative personnel. A large number have devoted their entire careers to NACA/NASA Aeronautics.

This book is respectfully dedicated to all of those individuals who have contributed to NACA's and NASA's success in aeronautical research.

Foreword

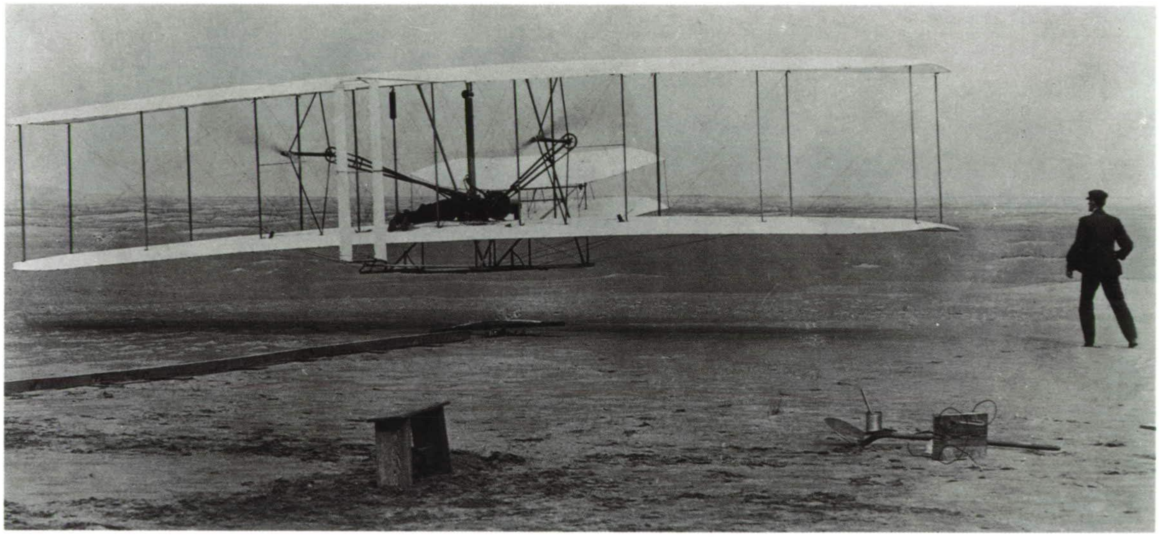
Initiated in 1915, NACA/NASA aeronautical programs have been the keystone of a sustained U.S. Government, industry, and university research effort which has been a primary factor in the development of our remarkable air transportation systems, the country's largest positive trade balance component, and the world's finest military air forces.

The modern airliner can routinely fly several hundred passengers, and substantial cargo, almost halfway around the world. Modern military aircraft have flown at speeds greater than 2000 miles per hour. Both are descended from a vehicle which made the first powered flight in 1903 carrying one man at less than 40 mph for a distance of 120 feet — about half the length of today's airliner. Much of the advancement is a direct result of aeronautical research conducted in government and private facilities throughout the world.

Continued progress and competitive success in aviation's second century will demand technology advances as great as those we have already achieved. Our success in meeting the challenges will depend on how well we apply the knowledge acquired in the past eight decades of aeronautical research and how effectively we maintain the quality of staff and facilities that made earlier achievements possible.

NASA's aeronautical research is now conducted at the Langley Research Center in Virginia, the Lewis Research Center in Ohio, and the Ames Research Center/Ames-Dryden Flight Research Facility in California. The history of the research, including the important contributions of individual researchers and Centers, is well documented in a number of interesting and more detailed publications. Outstanding examples of these publications, which have provided much of the source material for this book, are cited in the bibliography.

This brief overview summarizes the flow of events, and the major trends, that have led from the NACA origins to the present NASA Aeronautics program, and indicates some important directions for the years ahead.



The Formative Years

Aeronautics progressed rapidly in the decade immediately following the first heavier-than-air powered flight in 1903 by the Wright brothers. By 1915, aircraft were far more advanced, in both appearance and capability, than the Wright Flyer. Nevertheless, they were still rather primitive. In the United States there was no widespread appreciation that the airplane would significantly affect the country's economic or military strength. At the start of World War I, although there were several thousand European military aircraft, the United States had only twenty-three.

Fortunately, a small group of scientists and military officers did foresee the importance of aviation. Largely through the efforts of the National Academy of Sciences and the Smithsonian Institution, they were able to convince several influential members of Congress of the need for an aeronautical advisory committee and an aeronautical research laboratory. With little public notice and no debate, the Advisory Committee for Aeronautics was created in a rider to a 1915 Naval Appropriations Act. The Committee itself, at its first meeting, upgraded the stature of the new organization by adding the word "National" to its name.

During the first ten years of its existence, NACA was involved in virtually all aspects of aviation, including resolution of patent and licensing disputes, navigation aids, military procurement problems, airfield location, and air mail

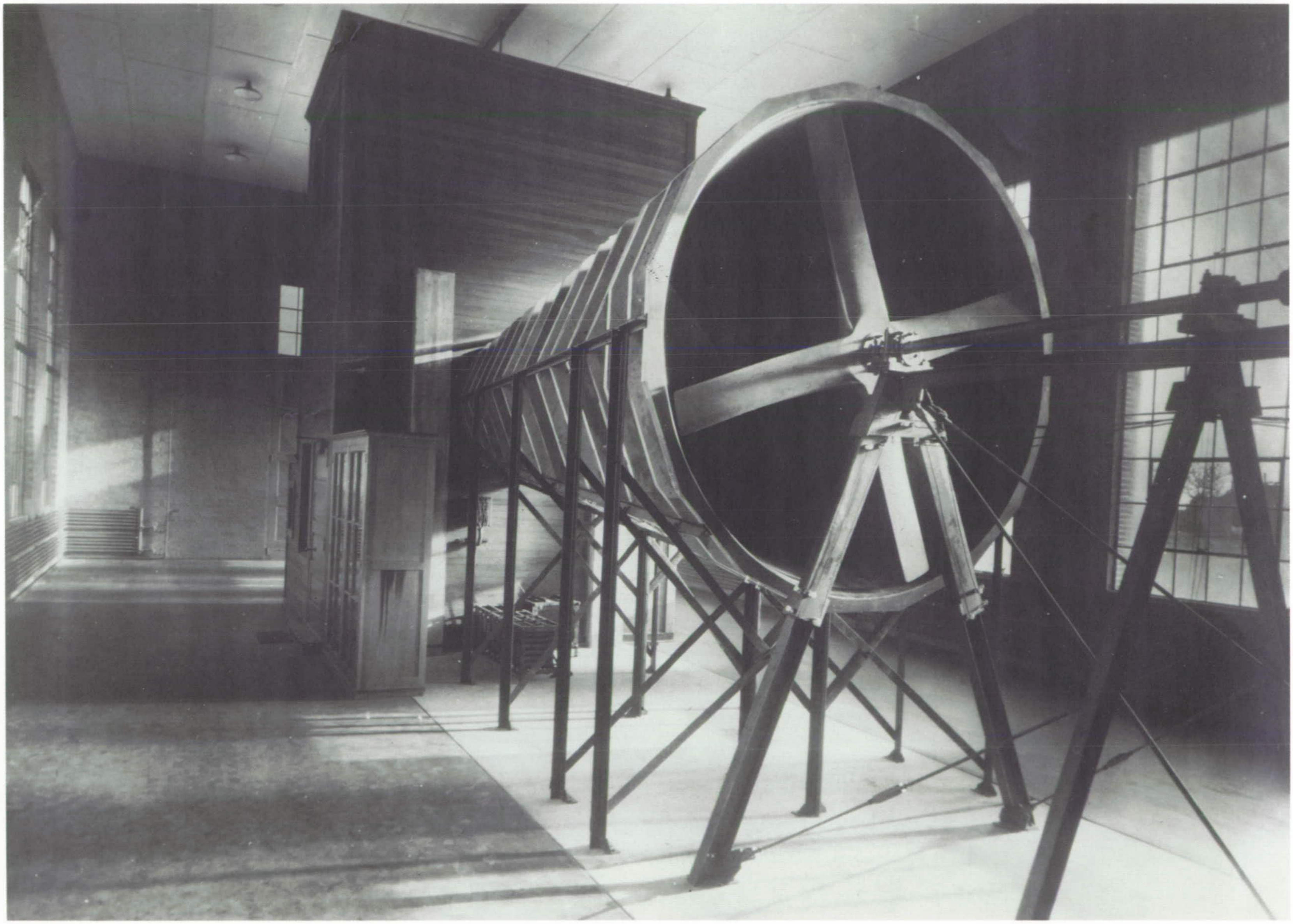
Men first achieved powered flight at Kitty Hawk in 1903. In only a dozen years, the European countries engaged in World War I were flying impressively advanced combat aircraft.

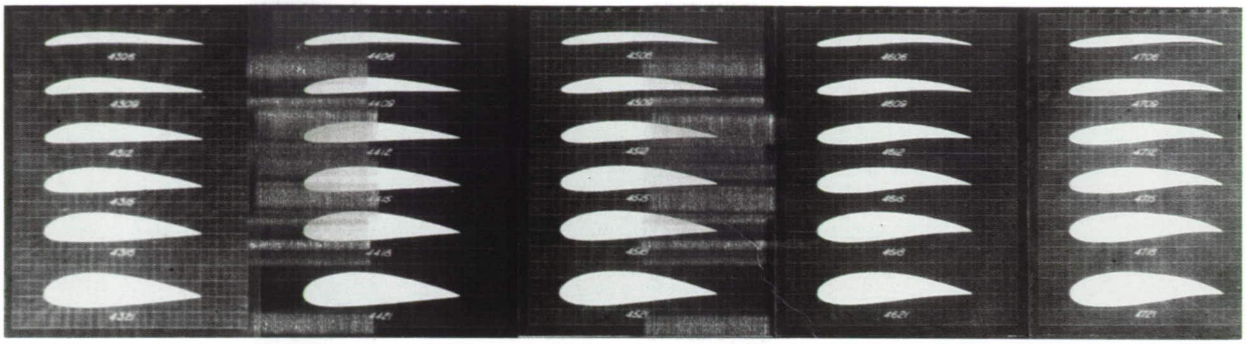
experiments. Committee members were instrumental in securing passage of the Air Commerce Act of 1926, which created the Bureau of Air Commerce and allowed NACA to focus on the primary task of aeronautical research.

Equipping a research laboratory from scratch proved a much more difficult task than changing the committee's name or clarifying its mission. Aerodynamic testing of sorts had been performed by experimenters in the 1700s and even earlier, and mechanisms crudely resembling the modern wind tunnel were in use in the mid-1800s. At the start of the twentieth century, the wind tunnel was still the primary tool for aerodynamics research, but only two such facilities existed in the United States — the Wright brothers' tunnel in Dayton, Ohio, and one built at Catholic University in Washington, D.C. The NACA staff had a lot to learn before they could even start acquiring an experimental capability. They learned quickly, initially benefiting from European experience, and by 1920 the Langley Laboratory had a rudimentary 5-foot-diameter wind tunnel operating.

It was recognized that the use of compressed rather than ambient air in small-scale model testing could provide a more accurate representation of full-scale flow conditions (higher Reynolds number). By 1923 a revolutionary variable-density tunnel (VDT) had been built. Although shut down for over three years because of fire damage in 1927, the VDT by 1933 had made a major research contribution in the form of systematic and comprehensive aerodynamic data on a series of 78 airfoil sections. These data and subsequent similar airfoil research documented the effects of varying parameters such as shape, thickness, and curvature (camber). Designers could now select the airfoils most suitable for specified performance objectives and could determine how best to accommodate structural thickness requirements and other practical design constraints.

NACA's first wind tunnel (1920) was a replica of a ten-year-old British tunnel.





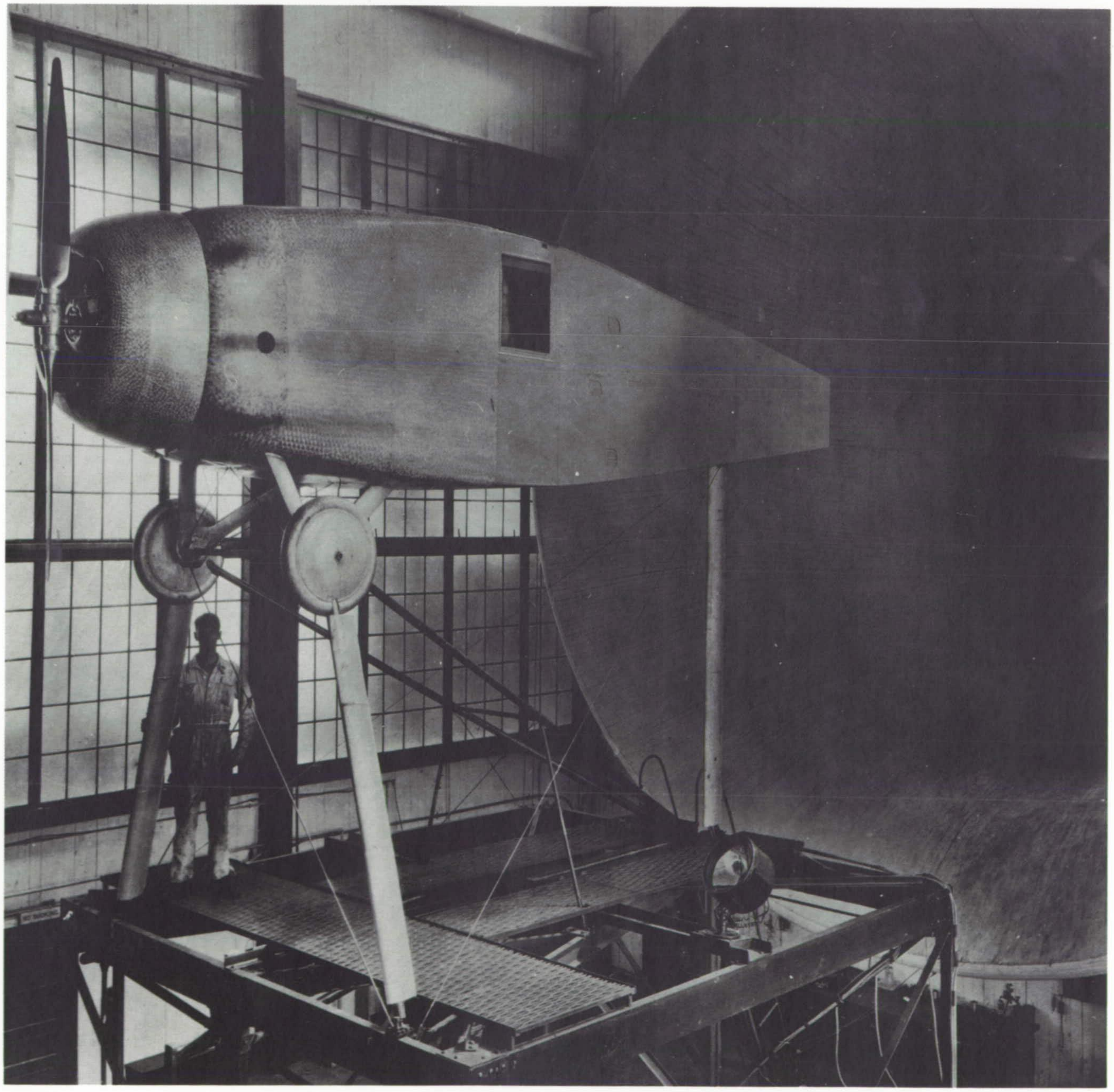
Airfoils developed during the late 1920s in the VDT were categorized in 1933 using a 4-digit code describing airfoil design features. Subsequent research produced more advanced airfoils and more descriptive numbering codes.

The agency was now developing a solid base of theoretical capability, which both guided and complemented the wind tunnel tests. By the late 1930s, several series of NACA airfoils had been developed, offering significantly increased lift and reduced drag. At the same time, improved theoretical methods had been developed for calculating the airflow and pressure distribution over a given wing and, more importantly, for defining an airfoil shape to produce a desired pressure distribution.

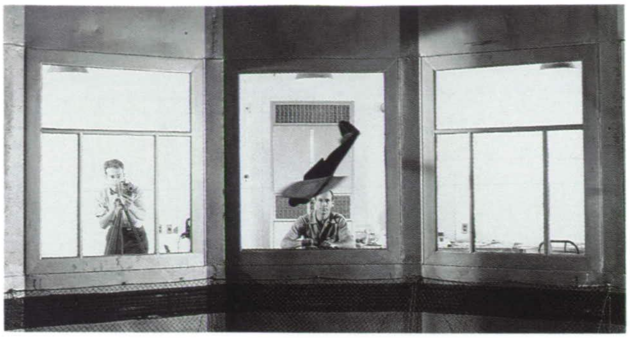
As often happens in research, serendipity played a significant role in several of the early accomplishments. One of the first published NACA reports contained small-scale propeller test results which, when compared with flight data, showed poor correlation. It was decided to construct a special Propeller Research Tunnel (PRT), large enough so that actual propellers could be tested, along with the actual engines and fuselages. The PRT became operational in mid-1927 and produced not only the desired propeller research capability but some unexpected and extremely important bonuses as well.

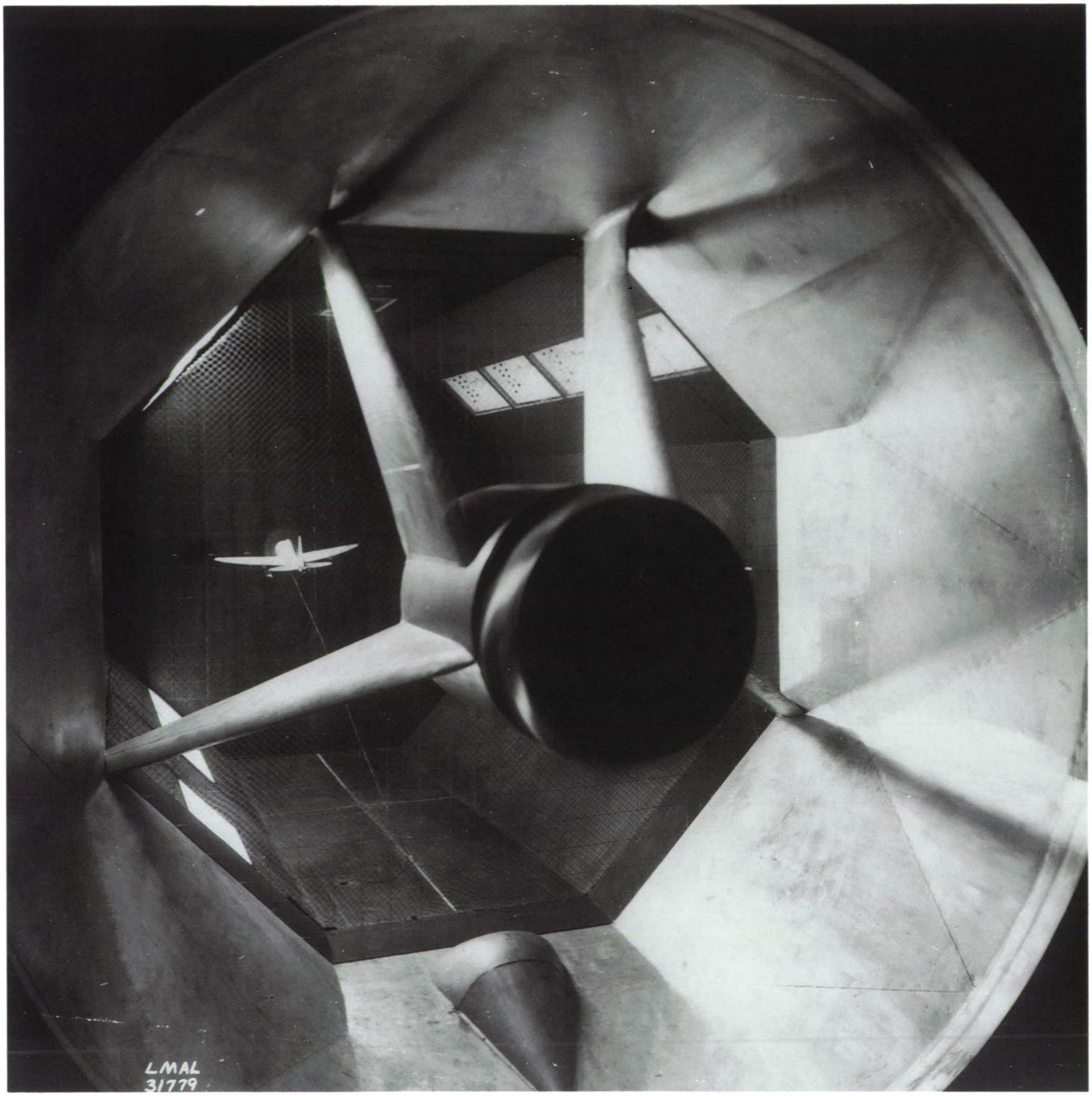
One PRT research discovery was that landing gears accounted for as much as 40 percent of the fuselage drag — a finding that quickly led designers to develop retractable landing gears. Another was that multiengine aircraft performance was improved by placement of the nacelles in the line of the wing chord plane, as was done shortly thereafter in design of the DC-3, B-17, and B-24 aircraft.

The best-remembered achievement in this period, of course, was the discovery that a streamlined cowling covering the air-cooled engine cylinders dramatically reduced the drag of the cylinders and their cooling fins, which previously had contributed almost one-third of the fuselage drag. Moreover, with properly designed internal flow provisions, the engine cooling was actually better with the cowling than with the exposed cylinders. The NACA cowling was first reported in late 1928, less



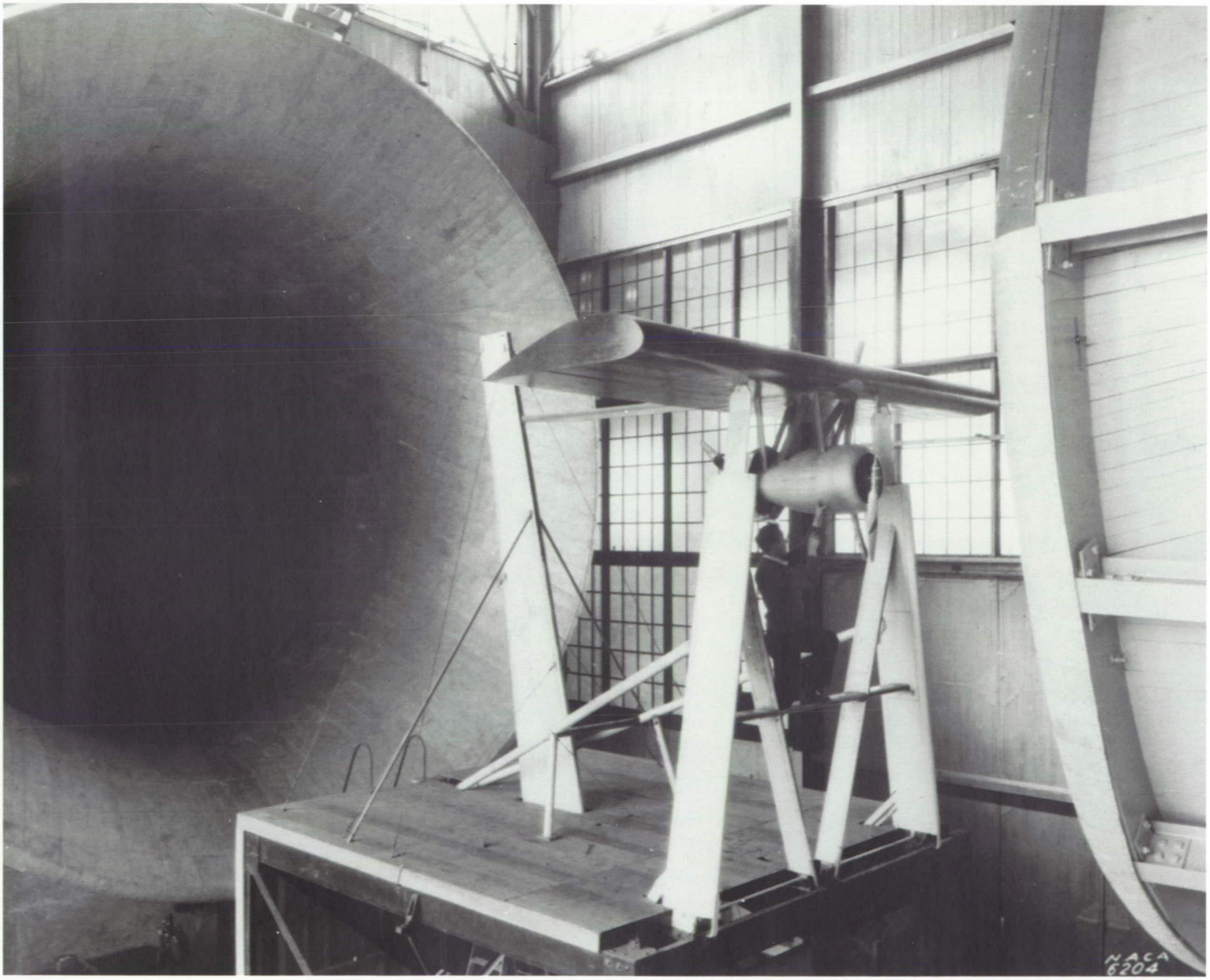
In 1928, NACA cowling showed large drag reduction in PRT model tests and 20-mph speed increase on the Curtiss AT-5A Hawk in flight.

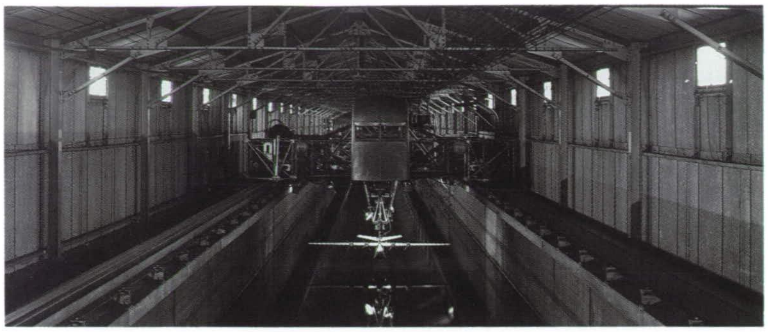


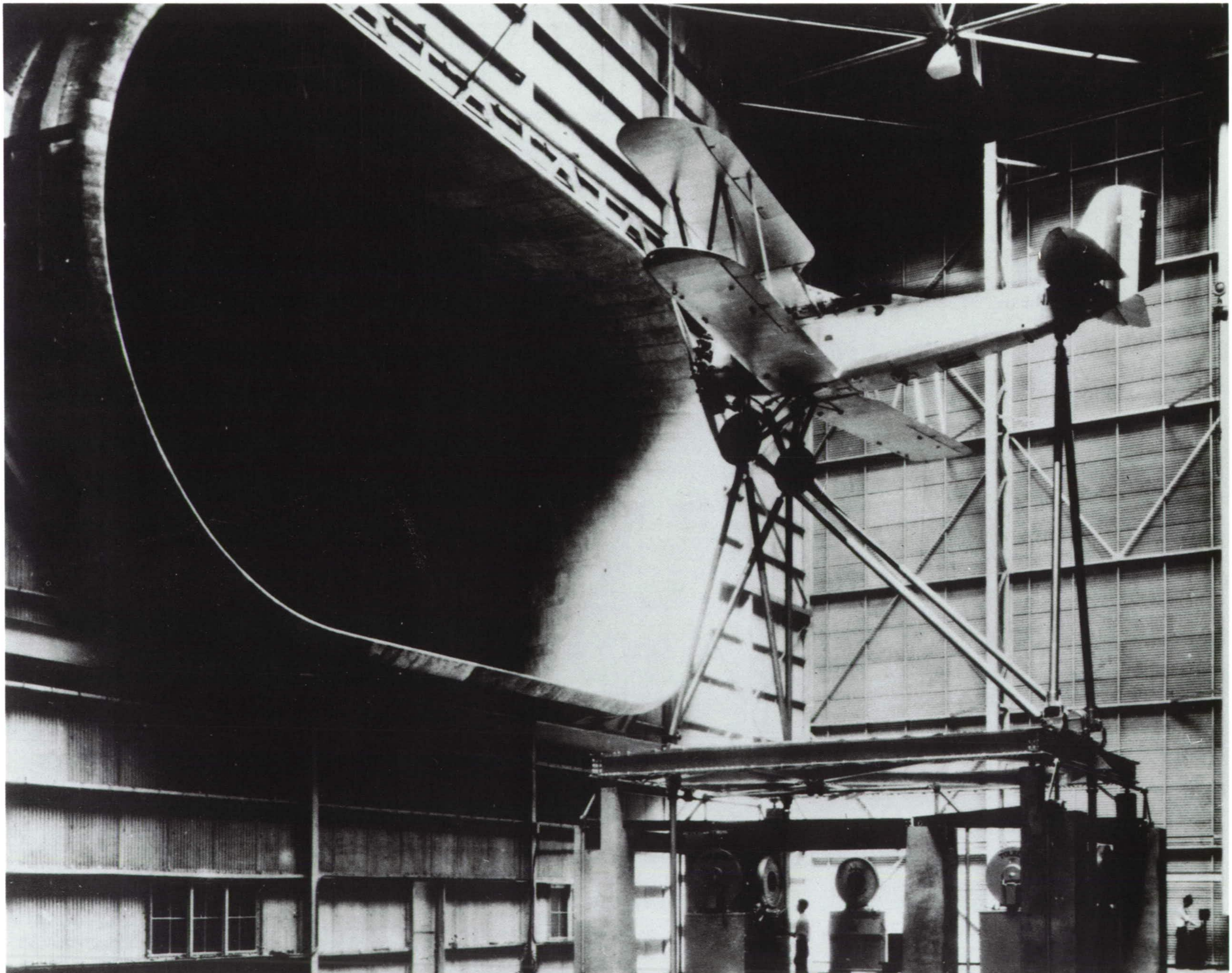


New facilities constructed during the 1930s created novel test capabilities that were used to great advantage during World War II. Shown here are the Spin Tunnel (top left), the Free-Flight Tunnel (bottom left), the Full-Scale (30 X 60) Tunnel (right), and Towing Tank No. 1 (top right) .

Systematic PRT investigation of wing-nacelle combinations (1930) determined drag and performance variations as a function of nacelle location.







than eighteen months after the PRT went into service. It was effective for speeds up to about 350 mph (Mach 0.5) and led to a family of cowlings successfully developed over the next decade for speeds up to Mach 0.84. Although NACA did not pursue jet propulsion research aggressively until after World War II, it used one of these higher-speed cowlings in early ramjet investigations in 1941.

The 7x10-foot Atmospheric Wind Tunnel (AWT) at Langley became operational in 1930. It was large enough for research on high-lift flap devices, and had a unique six-component floating-frame balance that could measure forces and moments about each of the axes. It also had provisions for measurement of local pressures at specific points on the wing and control surfaces. The AWT was the forerunner of other tunnels built at both Langley and Ames. Research performed in these tunnels produced an important knowledge base and essential design data relative not only to basic performance but also to aircraft stability and control, power effects, flying qualities, aerodynamic loads, and high-lift systems.

The early accomplishments demonstrated the value of high-quality versatile test capabilities, and important new facilities were constructed during the 1930s. The 30x60-foot Full-Scale Tunnel became operational in 1931, permitting low-speed testing of actual aircraft. Towing Tank No. 1 (1931) offered the capability for hydrodynamic research on seaplanes and flying boats. The Engine Research Laboratory, placed in operation in 1934, was utilized in research on engine performance, efficiency, cooling, ignition, combustion, and fuel behavior.

Two small tunnels, powered by compressed air exhausted from the VDT, were capable of brief but productive tests on airfoils at near-sonic velocities. The 8-foot High-Speed Tunnel, capable of continuous speeds to Mach 0.75, was completed in 1936. The Spin Tunnel and the Free Flight Tunnel, using dynamically scaled small models, permitted research on spin characteristics, spin recovery, and


ARMY
NINTH ANNUAL AIRCRAFT ENGINEERING RESEARCH CONFERENCE
EXECUTIVES AND ENGINEERS OF AIRCRAFT INDUSTRY AND GOVERNMENT OFFICIALS
FULL SCALE WIND TUNNEL
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
LANGLEY FIELD, VA.
MAY 23, 1934.
VIEW SHOWS ARMY PURSUIT P26A MOUNTED FOR AERODYNAMIC TESTS

Annual conferences, initiated at Langley in 1926 and continued at each of the Research Centers, served as an early mechanism for reporting NACA research progress to the aviation community. Participants included prominent industry, government, and university leaders such as this 1934 group posed under the Boeing P-26A fighter in the 30x60-foot Full Scale Tunnel.

dynamic stability and control. The 19-foot Pressure Tunnel was activated in 1939 to obtain data at full-scale Reynolds number in tests of large models of new or proposed aircraft. And a Structures Research Laboratory was built, highlighting the emergence of structures research as a major element of the research program. The Low Turbulence Pressure Tunnel was activated early in 1941 as a primary facility for airfoil research.

NACA's first quarter-century produced numerous important contributions to the advancement of aviation, and saw construction of a variety of unique, world-class research facilities, many of which remain in productive use today. In addition, the early NACA researchers developed a balanced effort including both fundamental and applied research, and they cultivated close working relationships with the evolving manufacturing and operating communities and with the universities and other research organizations. These patterns of operation laid the framework for coordinated and highly successful national progress in aeronautics. The principles of balanced effort and close coordination with the external aviation community have characterized the NACA and NASA programs ever since. ■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World War II

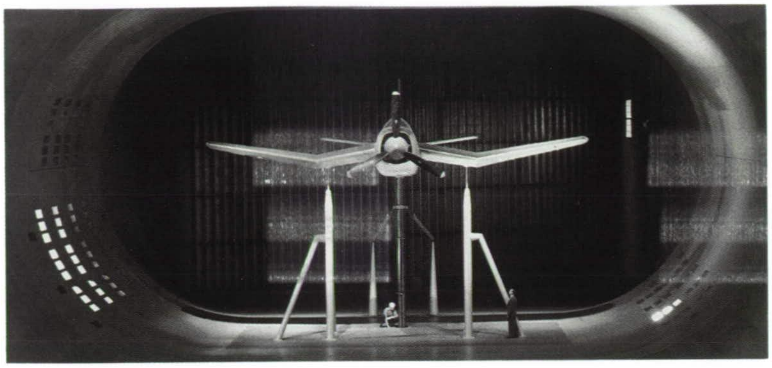
Despite its impressive start and the activation of high-quality facilities, NACA was still a small organization with very limited resources at the start of World War II in 1939. The total research staff complement was under 300, supported by approximately 250 administrative and service personnel. With the occasional exception of university projects, the research was conducted entirely at Langley Field in Virginia. The threat of war brought about an increase in funding to expand the efforts in aerodynamics, propulsion, and structures.

Most significantly, the additional funding was to start construction of a second aeronautical research laboratory (now Ames Research Center) at Moffett Field in California in 1940 and a dedicated engine research laboratory at Cleveland, Ohio, in 1941 (now Lewis Research Center). Two 7x10-foot tunnels and a 16-foot high-speed tunnel were built and became operational at Ames in time to see active and important wartime service, as did the Altitude Wind Tunnel for engine testing completed at Cleveland early in 1944. These initial wind tunnels at the two new laboratories marked the beginning of a long-term growth period which resulted in the impressive array of unique facilities now seen at each of the three Research Centers.

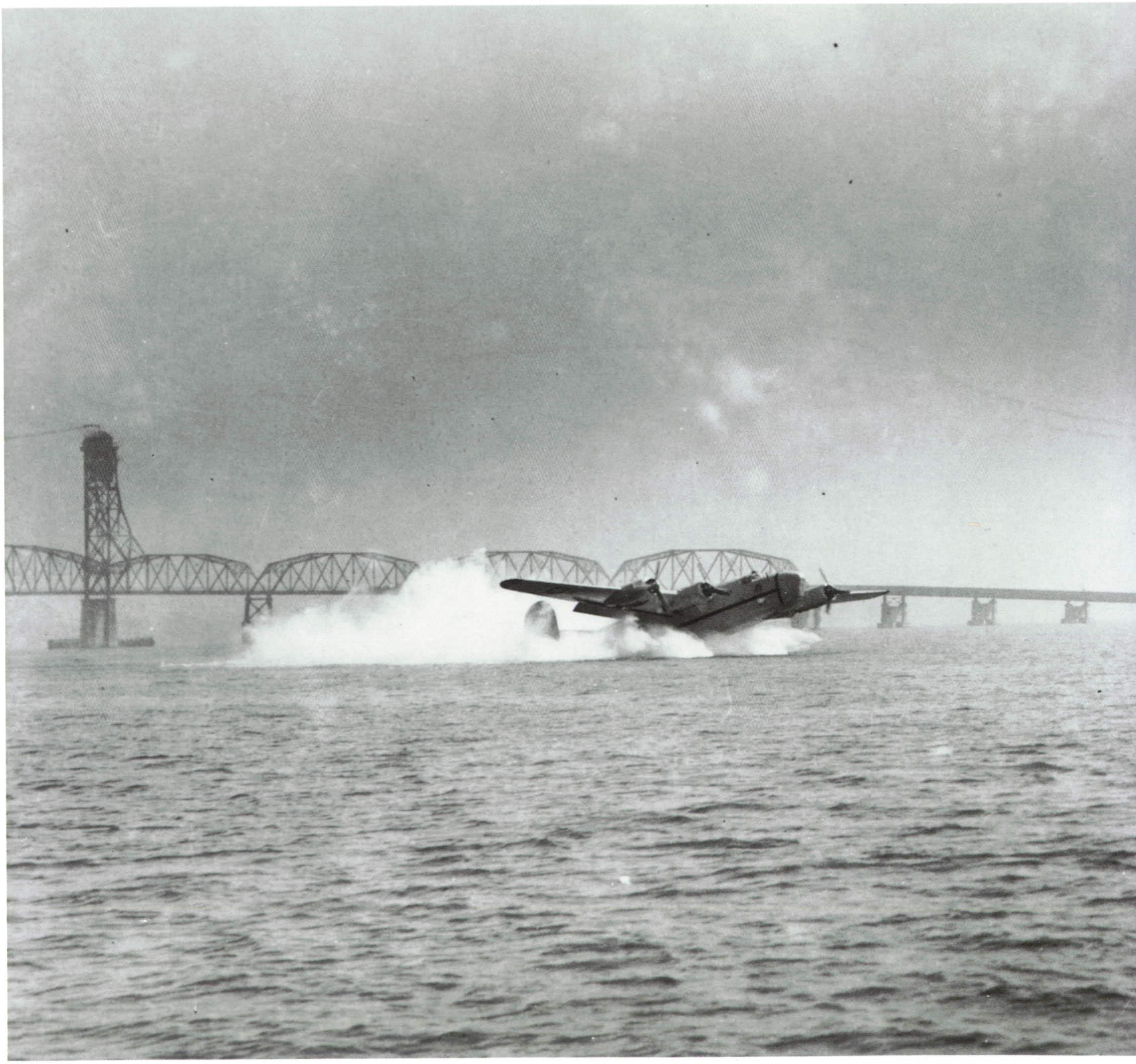
Wartime pressures led to more than a fivefold increase in the research staff. The research was directed almost exclusively at the support of military aircraft development and improvement and at the solution of operational problems. With all three laboratories making invaluable contributions, the results bore out the wisdom and foresight of the 1915 legislative action.

Research facilities were devoted totally to the war effort. A North American P-51 fighter is shown in the 30x 60-foot Full Scale Tunnel.

All of the primary U.S. World War II combat aircraft had been designed using NACA low-drag airfoils, cooling and exhaust methods, and high-lift devices. The designs had also benefited greatly from lessons learned in an extensive series of "drag cleanup" tunnel tests on full-scale aircraft in which the drag effects of surface roughness, wrinkles, air scoops, antennas, external struts, exposed rivet



The Douglas BTD-1 torpedo bomber (top), was the first development aircraft tested in the new Ames 40x80-foot wind tunnel. The James River served as a research facility for a ditching experiment on a Convair B-24 land-based bomber (bottom).



heads, lapped joints, surface gaps and air leaks, and a variety of other design and manufacturing details, were isolated and reduced. NACA research was credited with having made possible the Navy's development of the first aircraft capable of vertical dive bombing.

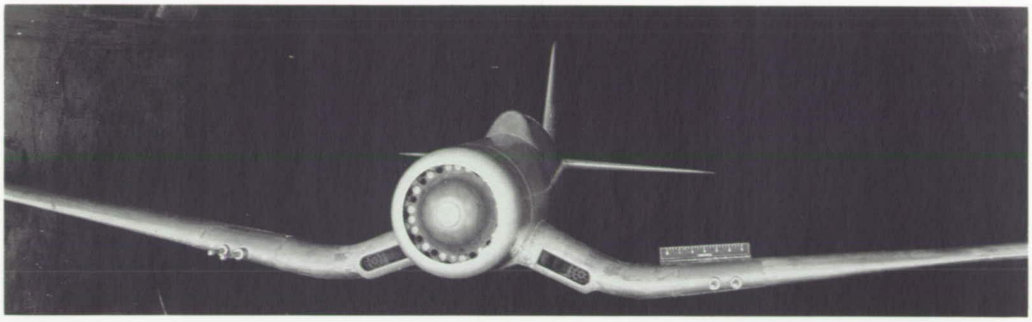
Throughout the war, military designs were constantly brought to the laboratories for test and evaluation and for resolution of technical problems encountered in development or service. Between 1941 and 1945, NACA wind-tunnel, towing-tank, and flight tests were conducted on more than 100 military aircraft. Many of the findings were reflected almost immediately in design changes; others provided a basis for improvement in subsequent versions.

Examples of NACA/industry wartime R&D accomplishments include:

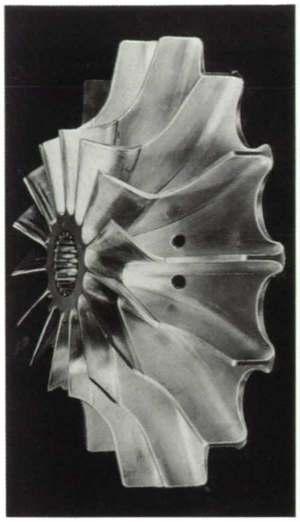
- Important improvements in combat aircraft lateral control were made by reduction of aileron control forces on the P-47, P-51, P-63, and A-26 airplanes through application of differential linkages, control balance devices, and servotabs. Similar balance devices were also used to reduce bomber longitudinal control forces.

- A kit to correct P-51 high-speed directional control deficiencies by field installation of a dorsal fin and improved rudder tab linkage was developed and was delivered in time for installation prior to the Normandy invasion.

- Vertical tail redesign cured directional instability on the BT2D-1 torpedo bomber, and wing planform modifications eliminated serious lateral stability and control deficiencies on the XBT2C-1 torpedo bomber.



A Vought F4U-1 fighter model is shown (top) in a wind tunnel test with a high-speed version of the NACA cowling. A Lockheed P-38 twin-fuselage fighter is shown (bottom), under test in th 30x60 foot Full-Scale Tunnel.



Research on centrifugal superchargers provided important increases in efficiency, leading to improved altitude performance and survivability of World War II bombers.

- PB2Y flying boat hull redesign produced improvements in hydrodynamic performance, stability, and spray suppression and resulted in a fourfold increase in payload for long-range missions. Similar improvements made possible a 50-percent increase in maximum takeoff weight capability for the PBM-3 Mariner.

- Research on emergency water landings of land-based combat aircraft resulted in increased crew survivability through development of optimum ditching techniques for a variety of aircraft and a structural reinforcement kit for the B-24 Liberator.

- Development of dive recovery flaps for the P-38, P-47, and A-26 (and later the experimental P-59 jet aircraft) provided a necessary interim fix for the newly encountered compressibility induced problems of control loss and tail failures in high-speed dives.

- Redesign of the P-51B Mustang belly scoop cured high-speed flow instability which was so serious that production had been halted. Modifications to the P-63 Kingcobra scoop resulted in significant improvement in high-speed performance.

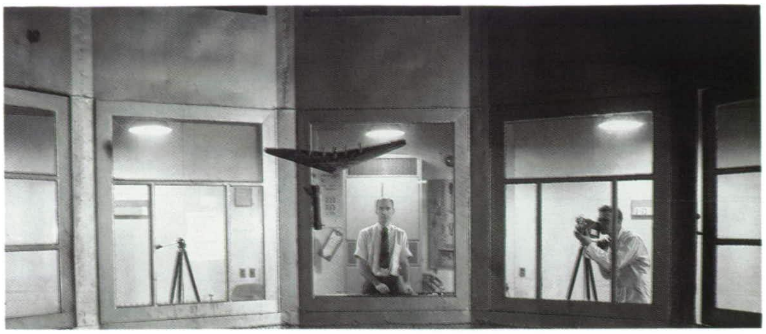
- Extensive research on the Allison 1710-45 engine used on the P-38, P-39, P-40, and P-63 aircraft led to modifications that effectively increased power by more than 35 percent.

- Improvements in turbo-supercharging, carburetion, and cooling for the B-29 Superfortress powered by Wright R-3350 engines resulted in important and timely increases in B-29 altitude and payload performance.

- Research identified the causes of high-altitude observable vapor trails and provided the basis for improved bomber survivability through changes in flight procedures which greatly reduced the condensation.

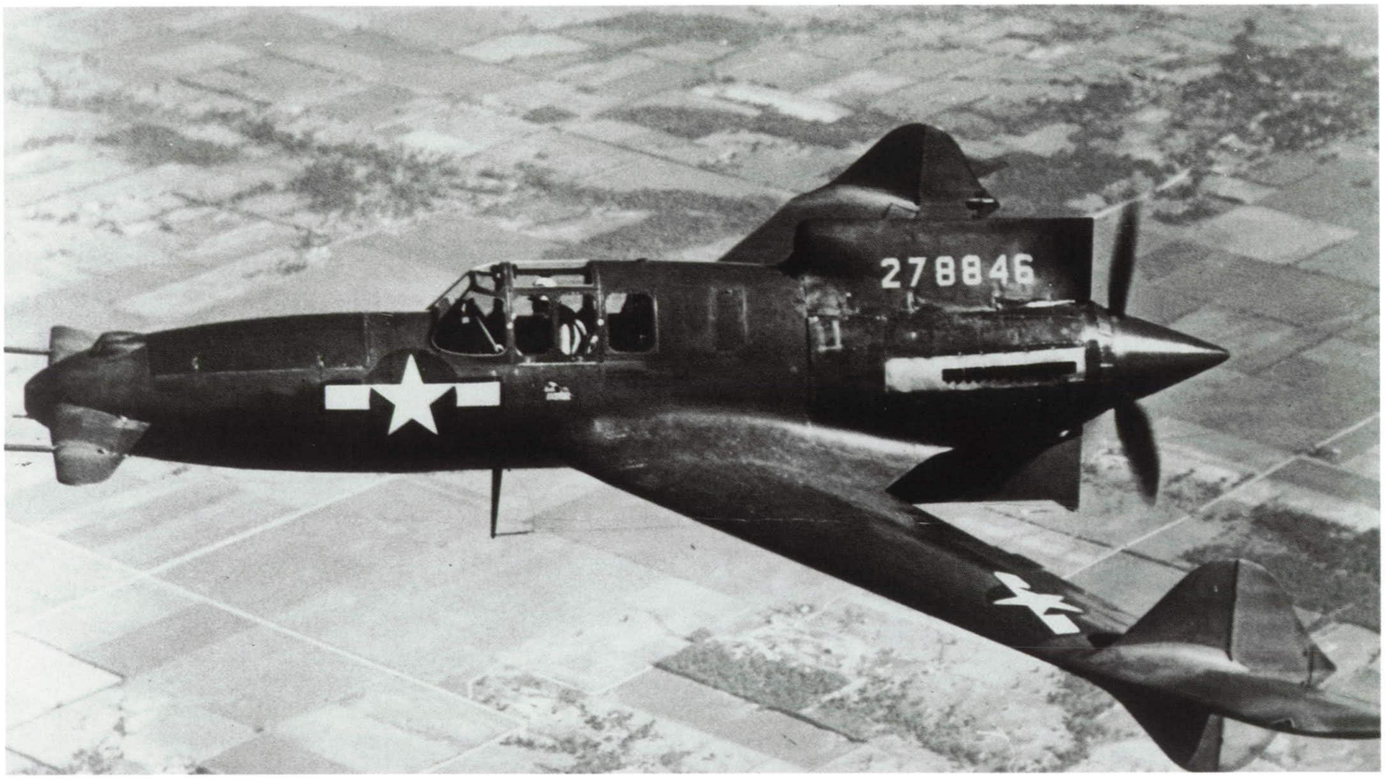
- An improved method of flush riveting was developed, enabling the manufacture of the low-drag wings needed for the high-performance aircraft produced in the latter years of the war.

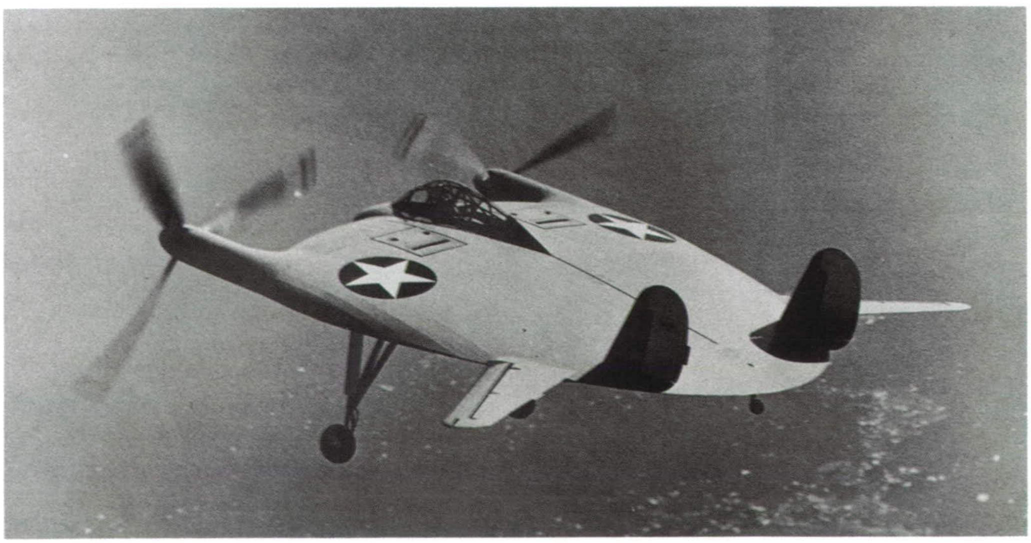
Apart from the numerous specific accomplishments, the World War II experience provided an important and far-reaching additional benefit in that it strengthened the working relationships between the NACA research staffs and the industry design teams. The researchers had acquired increased understanding of design, production, and operational problems, and the industry engineers had found the research expertise and facilities a valuable asset. The wartime experience augmented the technology foundation for continuing aeronautical progress in the subsequent peacetime years.



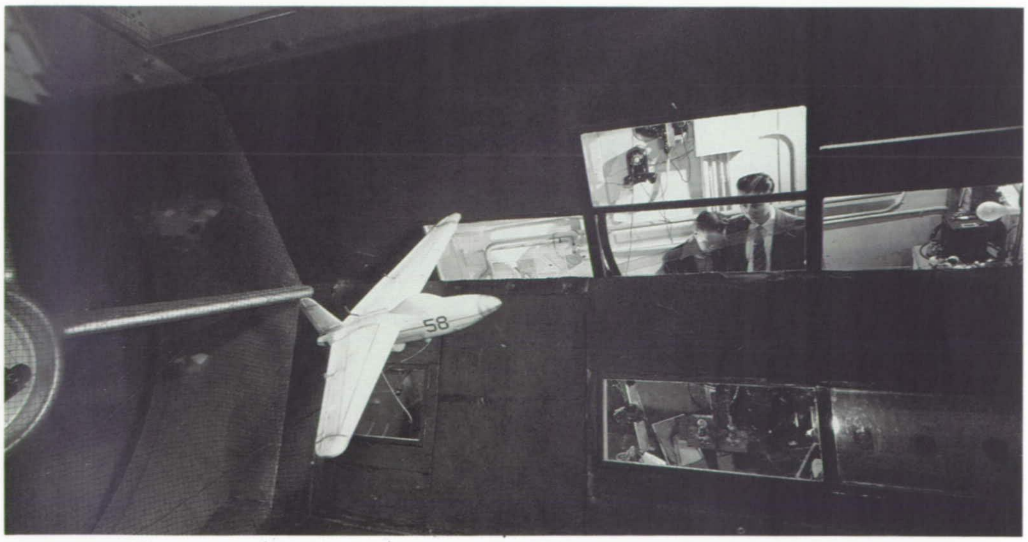
Not all of the aircraft designs studied during the World War II years became operational, but some design features presaged subsequent developments. Unusual designs tested included:

A flying-wing bomber–(Northrop XB-35) (top), a canard fighter–(Curtiss-Wright XP-55 "Ascender") (middle), and a low-aspect-ratio prototype (V-173) (bottom) of the experimental Vought-Sikorsky XF5U-1 development.





A tailless fighter (Northrop XP-56) (top) and a conceptual forward-swept-wing fighter (bottom).



The Post-War Years

The end of the war, and the results of the accelerated wartime research, provided an impetus for further advances in aeronautical technology and for renewed attention to civil air transportation. The benefits of continuing increases in performance, safety, and efficiency were clear, and the researchers were eager to apply their talents to a number of promising new areas, such as jet propulsion, supersonic aerodynamics, and helicopters, in which considerable progress had already been made in Europe.

Despite NACA's impressive early achievements, the pre-war staff and facilities had been limited, and the wartime growth had necessarily been applied almost entirely to development and near-term improvements. As a result, the agency was once again in a "catch-up" mode with respect to some of the new research challenges. And, once again, it moved quickly and effectively.

A major new goal was practical supersonic flight. Supersonic and transonic theoretical approaches were being pursued, but researchers were still highly dependent on experiment. Improved high-speed wind tunnel facilities, although being considered, were not yet available. Nevertheless, the interest in high-speed research inspired a number of ingenious alternative approaches to transonic and supersonic testing. Instrumented free-falling bodies were dropped from high-altitude aircraft; small models were mounted in areas of localized high-speed flow–that is, on the upper surface of an airplane wing or on "speed bumps" in a wind tunnel; and rocket-propelled models were fired out to sea from a coastal launching station. The wing-mounted model concept provided NACA's first experimental data relative to the emerging swept-wing theories for high-speed flight developed independently at NACA and in Europe.

Intensified high-speed aerodynamics research was made possible by modification of existing wind tunnels for transonic testing, followed by construction of new supersonic and hypersonic facilities at all three Research Centers.

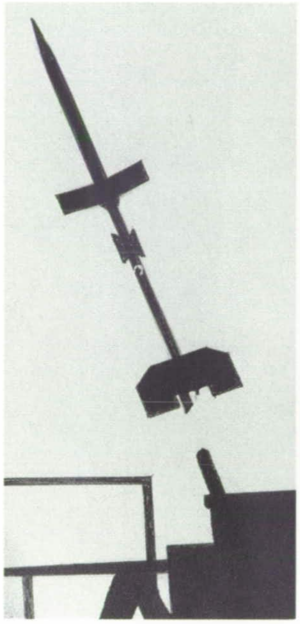
The rocket-propelled model approach was found sufficiently promising to warrant establishment in 1945 of a Pilotless Aircraft Research Station at

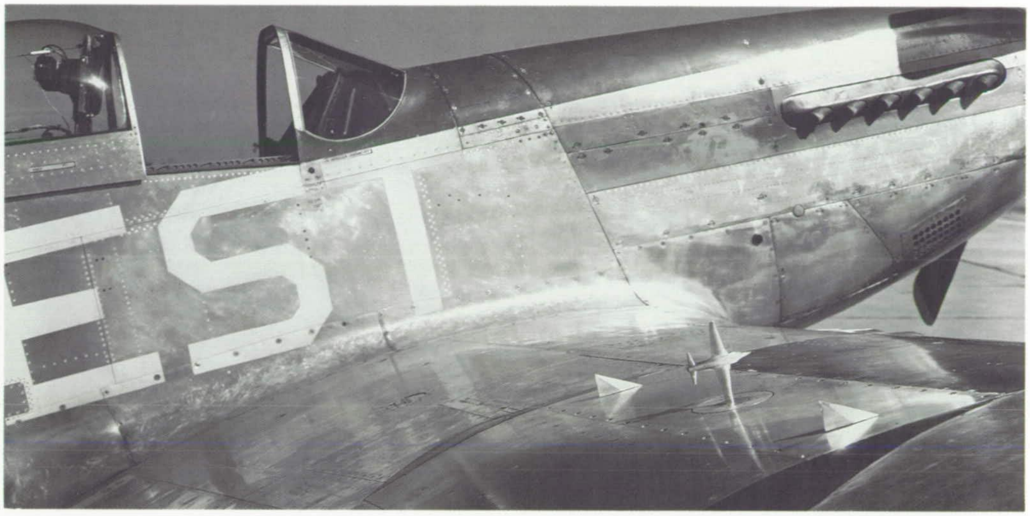
Interim transonic test techniques included (left) models dropped from high altitudes, (opposite page, left) free-flight rocket-launched models and (opposite page, right) models mounted on aircraft wings in flight or on speed bumps in wind tunnels.

Wallops Island off the Virginia coast. The rocket-model research provided limited but otherwise unobtainable high-speed aerodynamic data. Perhaps more importantly, the efforts devoted to test vehicle and launch vehicle development, launch operations, guidance and control, and telemetry provided valuable precursor experience for later missile and space activities.

The intense interest in high-speed flight phenomena also led to the well-known "X-airplane" programs, in which experimental aircraft were designed and built specifically for transonic and supersonic flight research. With strong support from the military, and effective industry participation, these programs were highly successful. They accomplished the desired research, further verified the swept-wing and delta-wing concepts, and made it possible not only to "break the sound barrier" but also subsequently to develop entirely new families of military and civil aircraft. Moreover, they demonstrated the value of piloted flight research in the exploration of new flight regimes, concepts, and environments.

Flight testing was, and remains, an integral element of the

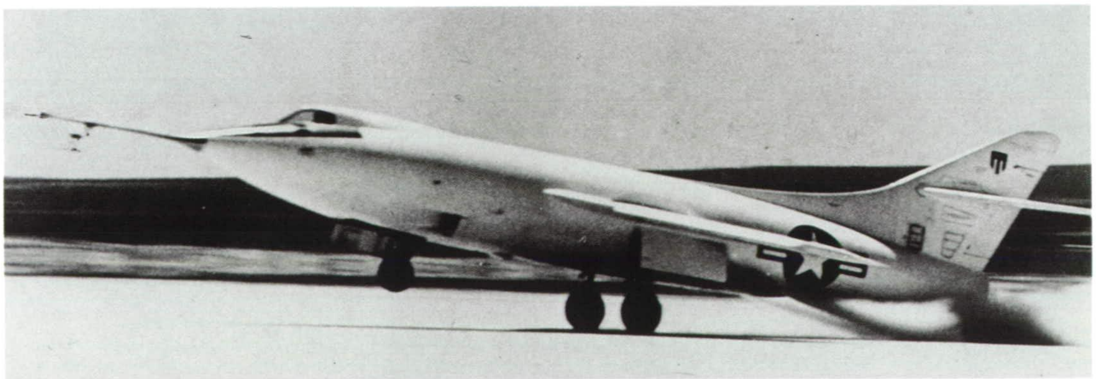


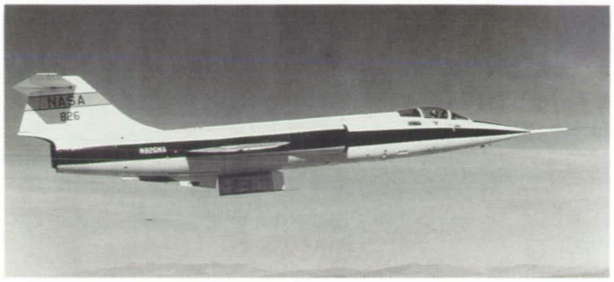


research at each of the Centers. The new high-speed flight testing, however, required additional, unique aerospace and test range faculties. The Dryden Flight Research Facility, established for this purpose, soon became a renowned flight research facility. The X-airplane programs established a pattern for subsequent NASA exploratory flight research programs, generally conducted jointly with the Department of Defense (DoD). The early successes inspired subsequent exploratory flight research vehicle programs, such as the supersonic/hypersonic X-15, the XV-15 tiltrotor, and the X-29 forward-swept-wing aircraft, as well as the X-30 research vehicle currently under study as a major focus of the National Aero-Space Plane hypersonic/transatmospheric program.

The X-aircraft programs and the flight research on high-performance operational aircraft fostered considerable advancement in flight test facilities and capabilities. The Dryden Flight Research Facility became a world-renowned flight research facility, while specialized flight test capabilities were maintained at each of the Research Centers.

The first of the X-aircraft series of research vehicles, the NACA/Air Force X-1 (originally XS-1) (top), performed pioneering supersonic flights to Mach 1.5 in late 1947 and early 1948. NACA Navy D-558-2 (bottom), became the first airplane to fly at twice the speed of sound, reaching Mach 2 in November 1953.

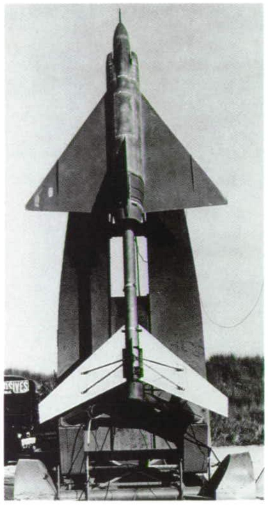




Shortly after the war, construction of large supersonic wind tunnels was begun at all three Research Centers. Modifications to several of the existing high-speed tunnels were also made to permit research at transonic speeds. The "slotted throat" test section, which eliminated the choking effect of the tunnel walls at speeds near Mach 1, was a major research accomplishment. The modifications were followed by construction of new transonic tunnels with slotted or porous test sections and several supersonic tunnels. Under the National Unitary Wind Tunnel Plan Act of 1949, large supersonic tunnels were constructed at the three Research Centers, with priority utilization reserved for industry testing. The country's first hypersonic tunnel, an 11-inch Mach 7 facility built as a pilot model for a larger tunnel, went into operation in 1947 and was used as a research facility for twenty-five years. A variety of hypersonic test facilities — impulse tunnels, expansion tubes, helium tunnels, blowdown tunnels, and others — were activated during the 1950s and 1960s and were used extensively in space vehicle atmospheric testing.

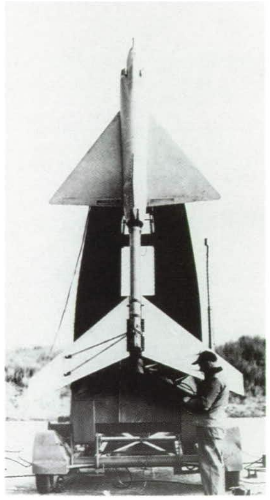
During the 1950s, NACA flight research on century series fighters such as the Lockheed YF-104 (top) and North American F-100A (bottom) complemented the X-aircraft research. Although these aircraft have been retired from operational service for many years, a later F-104 production vehicle still serves as a test bed for supersonic aerodynamics experiments.

The new test facilities proved their worth almost immediately, much as the PRT had a quarter-century earlier. The "Area Rule" concept of transonic drag reduction was discovered and verified and quickly applied in design of the F11F-1, F-102A, and F-106 fighters and the Convair 990 jet transport. Research on transonic compressors and related components led to the high-pressure-ratio com-



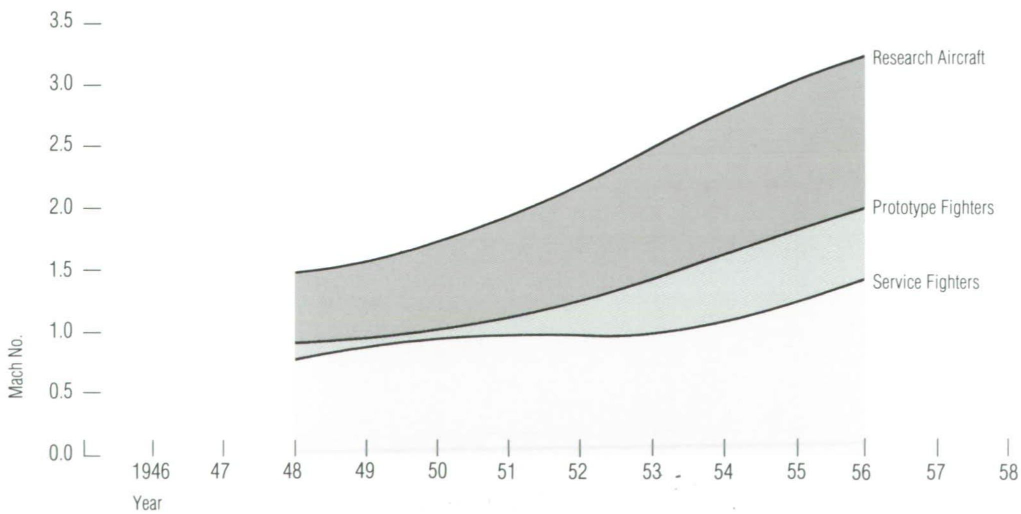
pressors and high-bypass fans used in today's commercial turbofan engines. And high-speed research on ballistic missile re-entry problems produced the blunt-body concept, which later became the basis for design of the Mercury, Gemini, and Apollo entry vehicles.

Although high-speed flight was a primary interest following World War II, it was by no means the sole focus of NACA aeronautical research. At the low end of the speed spectrum, a strong helicopter research capability was developed, resulting in significant advances in helicopter performance, stability, control, and structural dynamics. Earlier research devoted to aircraft flying qualities criteria was resumed, and provided a data base for design and a technical foundation for both military specifications and civil certification standards. The flying qualities research was expanded to incorporate helicopters and vertical or short takeoff and landing vehicles (V/STOL). A variety of new VTOL and STOL concepts were explored, providing a basis for the development of experimental and operational V/STOL vehicles several decades later.



Application of the NACA "Area Rule" to the YF-102A (model on left) resulted in a 25-35 percent increase in top speed relative to the original YF-102 (model on right) and enabled the "A" version to achieve supersonic flight.

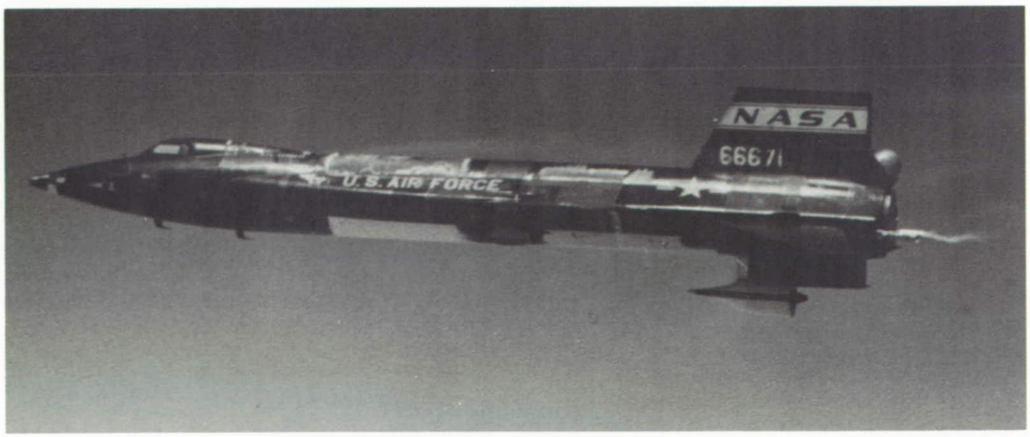
Early supersonic flight research preceded operational military vehicles by five to ten years.



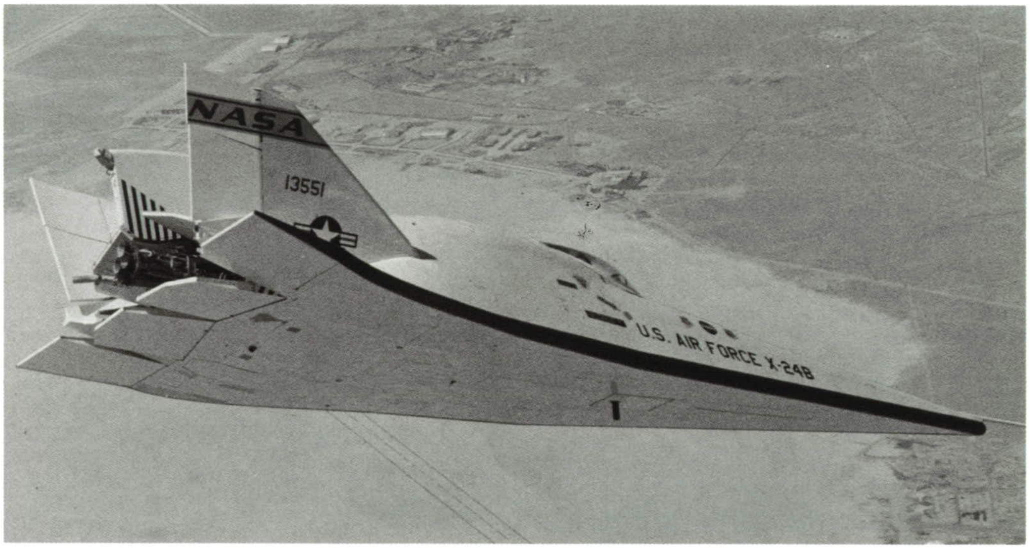
Significant advances were made in thermal ice protection, gust research, and landing loads analysis and testing. Flight simulation was further developed as a research tool, and serious research on automatic stabilization as a primary design feature was begun. With the emergence of operational high-speed aircraft, new emphasis was placed on low-speed flight characteristics of high-speed configurations (including development of the outboard-single-pivot variable-sweep concept employed in the F-111, F-14, and B-1 designs).

Research in structures and materials provided improved understanding of aeroelasticity, which led to improvements in flutter prediction and suppression and, subsequently, to development of computational codes now used broadly throughout industry for aeroelastic analysis. Conversion of the 19-foot Pressure Tunnel to a Transonic Dynamics Tunnel provided an important complementary capability for flutter and dynamics testing now conducted routinely on new aircraft designs. This capability immeasurably increased confidence to proceed with high-performance aircraft development and flight testing. The aerostructures research also developed techniques for structural shell analysis and methodologies for metallic structure fatigue and fracture analysis, crack growth prediction, and life prediction.

History making X-15 flight research at low hypersonic speed also provided data and experience vital to manned space flight programs.



Lifting body flight research included testing of the X-24 B configuration, with improved lift-to-drag ratio. The X-24 B flights demonstrated the feasibility of pin-point unpowered landing on conventional runways.



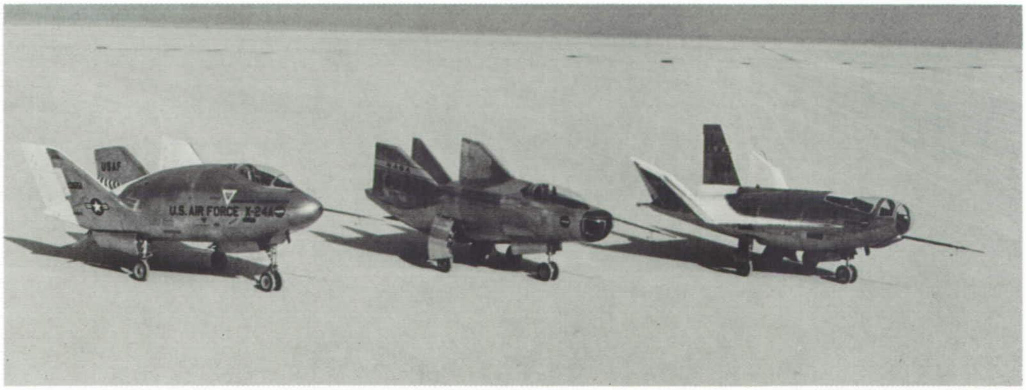
Researchers were only beginning to solve the problems of supersonic flight. At the same time, however, because of the growing importance of ballistic missiles and the possibilities of space flight, it became necessary to enlarge the research envelope even further and investigate the hypersonic-speed regime. Existing facilities were inadequate for hypersonic testing, particularly with respect to aerodynamic heating. After considerable study and discussion, it was agreed in late 1954 to use the exploratory flight research approach successfully employed in the X-aircraft programs.

The X-15 hypersonic research aircraft program, initiated in 1955 as a joint effort with the Air Force and the Navy, was a dominant element of NACA's activity in the years immediately preceding the establishment of NASA. When the first flight was made in 1959 NACA no longer existed, but the program was even more timely in view of NASA's much broader charter and responsibilities. The X-15 flew successfully to speeds of slightly under Mach 7, at attitudes as high as 67 miles. It conducted the deserved aerodynamic, thermal, and structures research, and in addition, it was an important precursor to the manned space flight programs. The present Shuttle's high angle-of-attack entry, transition from space reaction controls to atmospheric aerodynamic controls, artificial damping, and automatic stability and control devices are, to a significant degree, all derived from X-15 concepts and experience. The hypersonic flights also provided important relevant information on aerothermodynamics and structural heat protection.

In the X-15 flight research, rocket propulsion was used for acceleration to the hypersonic speeds. At the same time, the Agency initiated research on advanced propulsion concepts for sustained hypersonic flight. It also demonstrated in flight the feasibility of flying conventional jet engines on liquid hydrogen fuel — an accomplishment which now, more than thirty years later, may take on considerably increased significance.

During this period, extensive research was conducted on lifting-body entry vehicles. Wind tunnel testing in all atmospheric flight regimes was followed by piloted flight tests in the critical range from low supersonic speed to unpowered landing. The flight research provided information–and confidence–essential to later design of the Shuttle orbiter.

Flight research on the X-24, M2-F2, and HL-10 lifting-body vehicles, including unpowered landing, helped pave the way for the Space Shuttle design.

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Aeronautics in the Space Era

The aeronautical research staff and facilities had provided much of the foundation and impetus for the Nation's space programs. Many elements of discipline research support both aeronautics and space needs, particularly with respect to manned flight. However, with the establishment of NASA and authorization of ambitious and exciting new space projects, there was an unavoidable emphasis shift with personnel, facilities, and resources applied to the urgent needs of the evolving space program. A reasonably effective level of effort was maintained in most of the more critical aeronautical disciplines, and the aeronautics momentum was essentially regained during the late 1960s — but the aeronautical research program was undoubtedly slowed for the better part of a decade.

In retrospect, the temporary setback can be seen to have had some beneficial effects. Since each element of the "comeback" had to be argued on its merits, the reconstituted program was stronger in many respects. Moreover, the increases approved were in most instances carefully selected applied research efforts required to achieve specific significant benefits. The successful rebuilding effort thus helped in the evolution of an "investment strategy" approach, which proved valuable in subsequent research planning.

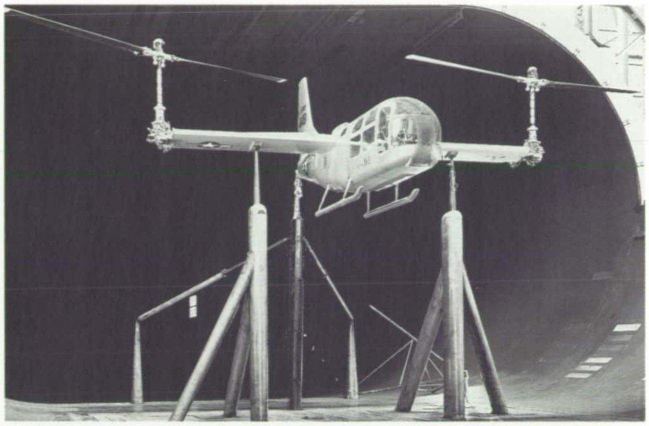
Starting in 1969, NASA conducted supersonic flight research on YF-12 aircraft, prototypes of the Mach 3 SR-71 reconnaissance aircraft.

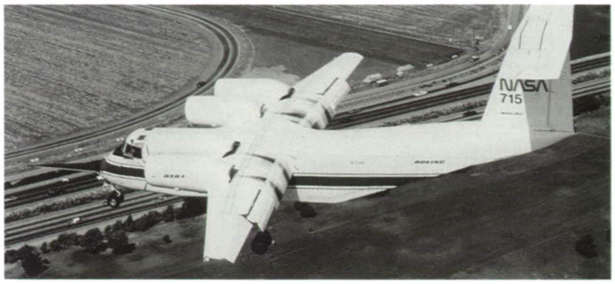
During this period, NASA also took even stronger steps to increase and solidify its relationships with industry, DoD, and the academic community. NASA research via contracts or grants to industry, private laboratories, and universities increased rapidly and now constitutes a significant component of the total program. In addition, the Agency pursued increased opportunities for mutually beneficial cooperative programs. One particularly fruitful joint venture was the establishment, beginning in 1970, of co-located U.S. Army research organizations at the NASA Research Centers. Originally focused on rotorcraft structures and aeromechanics research, this partnership has flourished and expanded; it continues to

provide technology for civil and military applications, as well as economies in national research.

The birth of the space age essentially coincided with the birth of the modern jet age in civil aviation. The rapid growth in domestic and intercontinental air travel provided ample need and opportunity for advanced technology, and a substantial portion of the NASA research program was devoted to air transportation improvement. The supercritical airfoil technology generated during this period led to early speculation about a "Mach 1 transport" but instead sparked development of far more efficient high-speed subsonic transports. Technology for low-noise fan design and nacelle noise suppression, together with an extensive noise prediction data base, provided a basis for establishment of, and compliance with, considerably more stringent noise regulations. Pioneering propulsive-lift and tiltrotor research provided foundations for future advances in short-haul civil transportation, congestion relief, and military logistic transport systems, and numerous contributions were made to safety in air transportation and general aviation.

Joint NASA/Army research activities have included cooperative rotary-wing flight research and extensive development of tilt-rotor concepts. Shown are the Rotor Systems Research Aircraft (left), the XV-15 tiltrotor research vehicle (right), and its predecessor the XV-3 (bottom).



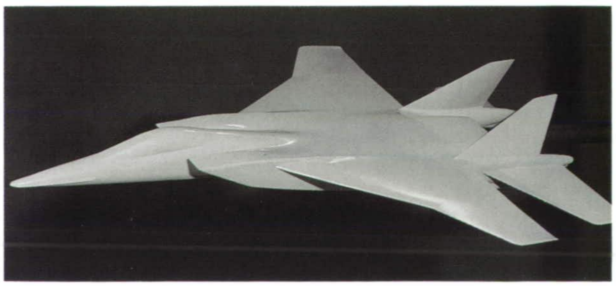


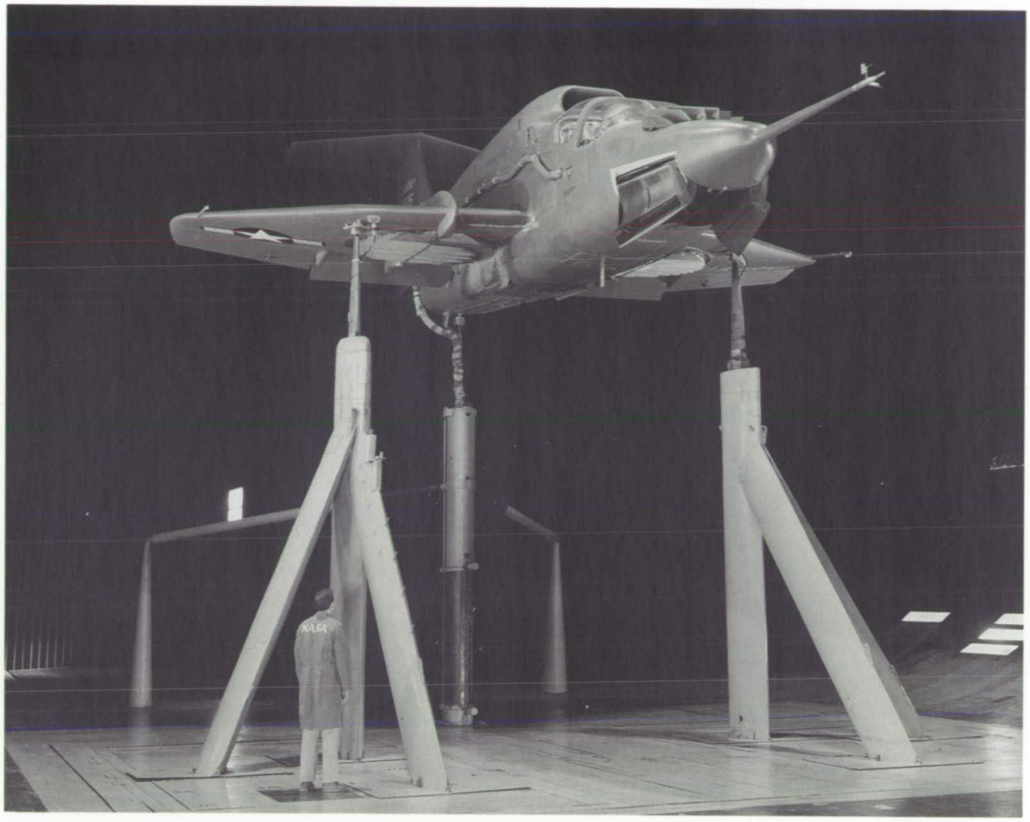
NASA supersonic transport research led to the U.S. SST prototype program now, along with European and Russian efforts, generally viewed as having been premature. That attempt, however, resulted in improved understanding of problems such as environmental compatibility, sonic boom, community noise, and performance economics, and helped define requirements for additional research on those and similar issues. One valuable by-product of the SST research was the development and demonstration of advanced flight simulation capabilities as a primary tool in the establishment of large transport aircraft handling qualities certification criteria.

The strong emphasis on transport-related technology during the early NASA years did not diminish the Agency's contributions to military aeronautics. A series of design studies resulted in the definition of variable-sweep and fixed-sweep advanced fighter concepts embodying features later incorporated in the F-14 and F-15 aircraft. Both programs benefited also from data bases and design improvements developed in extensive NASA testing. Research conducted in cooperation with the military explored several VTOL concepts for potential military mission applications.

The start of the space programs had been made possible by an initial base of technology, data, analytical techniques, test capabilities, and expertise derived largely from aeronautical research. Conversely, the quality and scope of

NASA propulsive-lift short-takeoff-and landinig (STOL) research, including flight tests on Quiet Short-Haul Research Aircraft (QSRA) (top), provided a technology foundation for STOL transport development. NASA studies and wind tunnel tests on advanced high-perfomance aircraft concepts facilitated subsequent F-14 and F-15 development (bottom).





The XV-5A fan-in-wing vehicle was one of several VTOL concepts investigated for potential subsonic military applications.

aeronautical research today owe quite a bit to the stimulation provided by the space programs. This trend has been particularly evident with respect to flight systems and materials.

With the advent of guided missiles and high-performance aircraft requiring enhanced stability and control, aeronautical researchers had adopted analytical techniques employed by electrical engineers and servomechanism designers. These techniques, and simulation capabilities made possible by development of the analog computer, were effectively used by NACA in the X-15 program and provided a basis for subsequent spacecraft stability and control analyses and simulation. The challenging guidance and control problems associated with the Apollo program, however, necessitated even more advanced and sophisticated solutions. The capabilities and hardware developed to meet the needs of the manned lunar flight programs greatly enhanced NASA's ability to pursue aeronautical control system advances and, in fact, led directly to the initial NASA F-8 digital fly-by-wire aircraft flight control

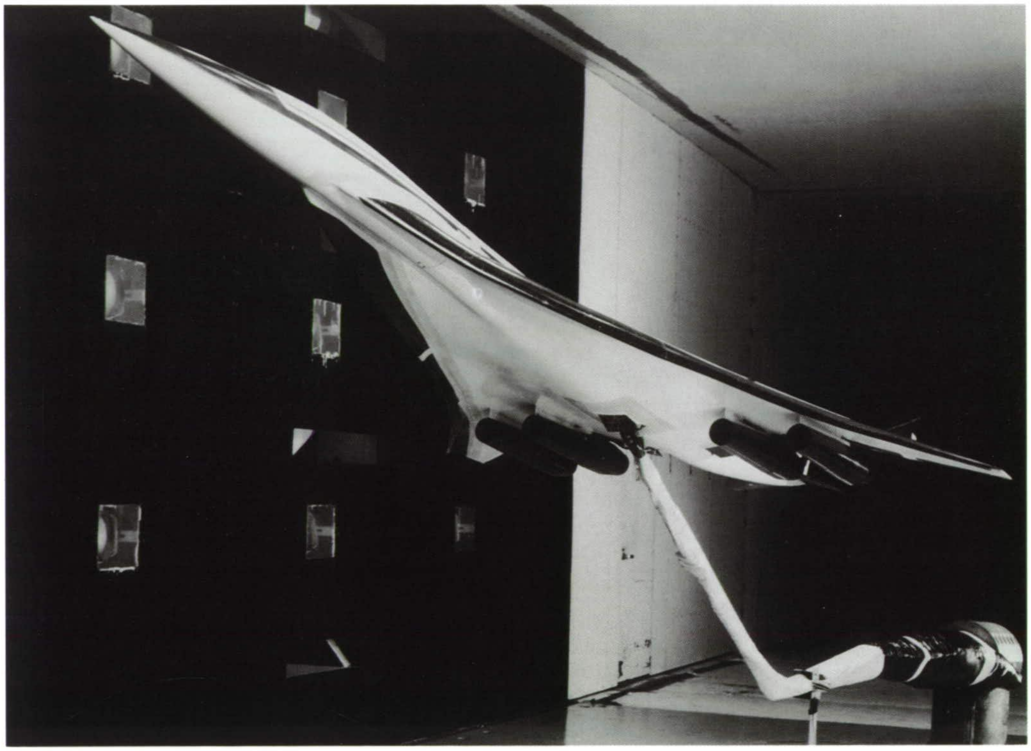
Flight simulation proved particularly valuable in study characteristics of unconventional new aircraft such as VTOL and propulsive-lift STOL, as well as subsonic and supersonic transports. It subsequently became an important tool in Space Shuttle development and astronaut training.

system, the first such system flown without mechanical control backup.

The increasing use of simulation in aeronautical research and the departure from simple mechanical controls required additional expertise in related areas such as displays, electronics, and human performance. Research in controls and guidance, flight systems, and human factors has grown considerably and is now a major component of the aeronautics program. NASA was a major contributor to development and adoption of the Microwave Landing System (MLS). Flight simulation and flight testing validated curved approach feasibility and provided a basis for system specifications, design criteria, and international agreement on the U.S. MLS approach as the world standard.

The space programs can also be credited with accelerating the pace of advances in computer development. Now, increasingly powerful computers and supercomputers, and the analysts who employ them, have become an indispensable component of our aeronautical research capability. Computational fluid dynamics, internal fluid mechanics, and structural mechanics are major elements of the program which not only complement but, in many instances, guide the experimental efforts. Computational codes derived from research conducted or supported by NASA are used commonly throughout the industry for flow field analysis, design optimization, and finite-element analysis of stress, vibration, and heat-transfer characteristics.

The Numerical Aerodynamic Simulation (NAS) program was initiated to provide cutting-edge supercomputing capability for continued leadership in computational aeronautics and related fields. The program vision is to provide, by the year 2000, an operational computing system and associated software capable of simulating an entire aerospace vehicle system within several hours. The NAS facility at Ames Research Center — which has become the centerpiece of the aeronautics computational capability — contains supercomputers that have data links to other NASA Centers and aerospace companies and are used extensively in the space programs, as well as in pioneering aeronautical research. In addition, through interconnection with various national networks, they currently support approximately 1400 researchers throughout the country. ■



Focused Technology Programs

Two activities undertaken during the 1970s were significant departures from NASA's normal research approach. The two efforts emphasized close relationships with industry in cooperative, jointly funded applied research. In different ways, they both promoted technology advancement in specific target areas, through programs highly focused on potential applications. The Supersonic Cruise Research (SCR) program was initiated shortly after the U.S. SST prototype program was canceled in 1971. The SST effort had uncovered technical problems that available technology could not adequately overcome, but supersonic transportation was still viewed as a desirable goal. The SCR objective was therefore to develop improved technology upon which successful future developments could be based. Cooperative NASA/industry design and systems studies were conducted throughout the program as a guide for the research and a mechanism for evaluating the resulting technology advances.

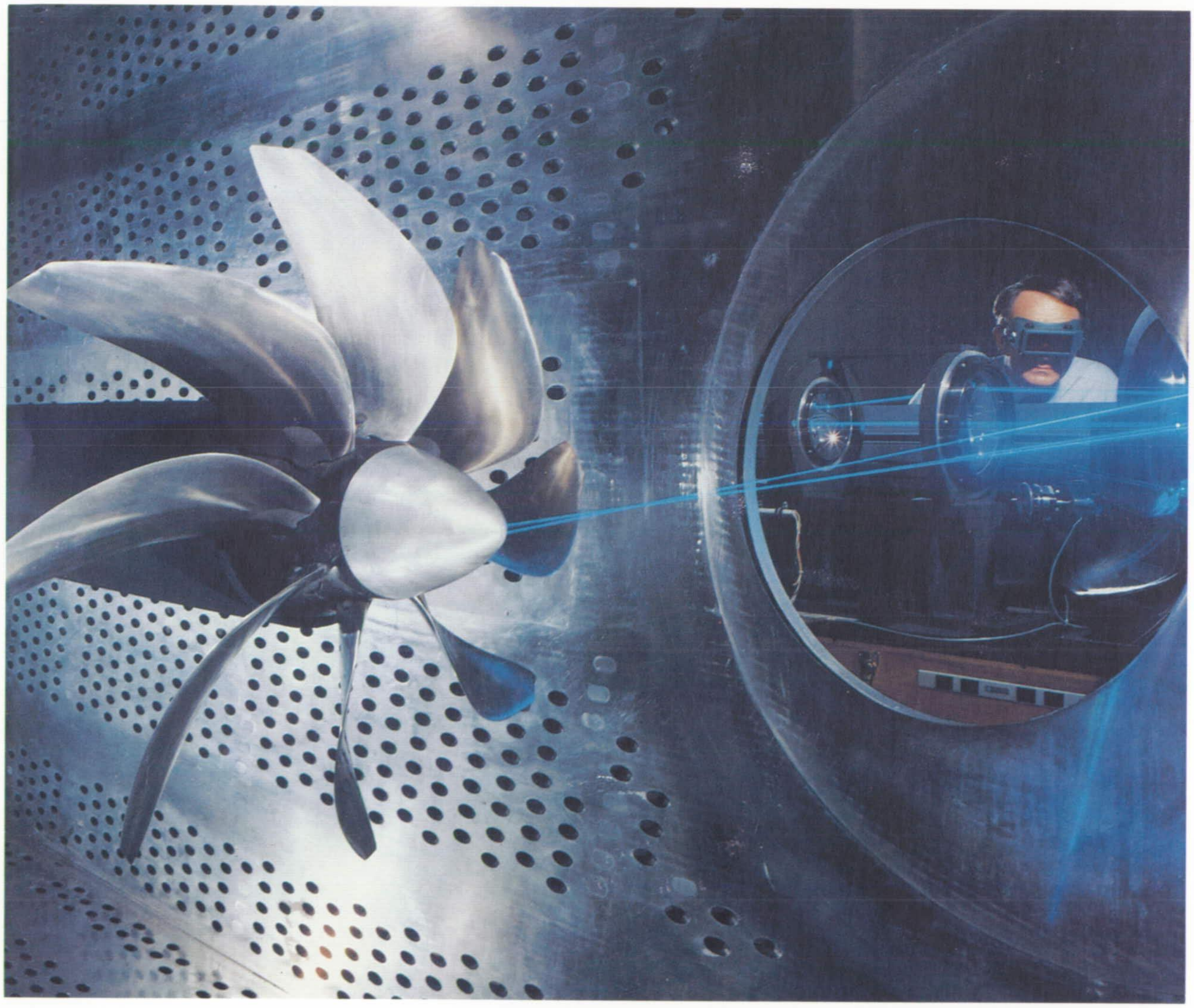
During the SCR program, a 25- to 30-percent increase in supersonic lift-to-drag ratio was realized in a structurally realistic blended-wing-body configuration. Large weight savings were achieved through application of superplastically formed, diffusion-bonded sandwich structure technology, with fiber reinforcement providing an eightfold increase in stiffness. Variable-cycle engine technology and engine weight reductions resulted in a considerable increase in attainable thrust-to-weight ratio, and significant improvements were made in noise suppression technology. However, serious interest in near-term commercial supersonic transport development did not materialize. In the face of more compelling resource requirements, the supersonic effort was reduced to a lower level of continuing research.

Following the 1971 cancellation of the U.S. SST prototype program, additional supersonic cruise research produced significant technology advances, which will serve as an improved point of departure for future high-speed transport efforts.

The Aircraft Energy Efficiency (ACEE) program was another focused NASA/industry effort, directed at six specific subsonic technologies. Initiated in FY 1976 following the OPEC oil embargo, the activity was originally motivated by fuel conservation concerns. It soon became apparent that, in addition to the fuel savings, technology for aircraft and engine efficiency improvement could be of great importance in worldwide competition for multibillion dollar air transport markets. The ACEE contract costs were shared with industry. In addition, recoupment agreements were included in contracts for the Engine Component Improvement (ECI) element of the program because of the near-term product improvement potential. In view of the projected longer-term commercial benefits, the NASA effort also triggered large additional industry research investments, which in some instances greatly exceeded the NASA funding.

As anticipated, the ECI program produced engine component technology for significantly improved performance and performance retention in engine retrofits and new production. Subjects included fan blade improvement, turbine aerodynamics, blade cooling seals, and active clearance. Applications appeared as early as 1978 and are now evident in all modern transport engines. The longer-term Energy Efficiency Engine (EEE) effort, completed in 1983, made possible a much greater reduction in cruise fuel consumption and accelerated technology readiness for incorporation in a new generation of fuel-efficient engines. EEC technologies included compressor, fan, and turbine gas-path improvements, improved blading and clearance control, and structural advances, and made possible a 15-percent reduction in cruise-specific fuel consumption.

The Advanced Turboprop Program (ATP) was directed at still greater efficiency improvement for future turboprop-powered aircraft cruising at or near jet transport speed. It culminated in successful testing of thin, swept-tip, multibladed, high-speed single-rotation, as well as dual-rotation geared and ungeared versions. The advanced turboprop, or unducted fan, technology represents a potentially important option for medium-range transports with fuel savings of 25 percent or

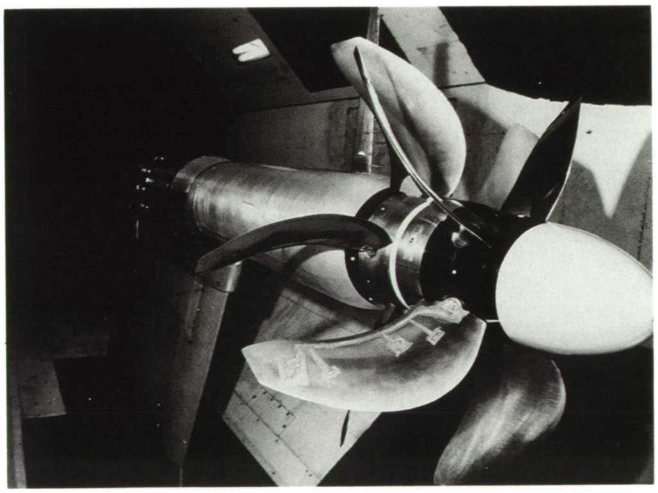


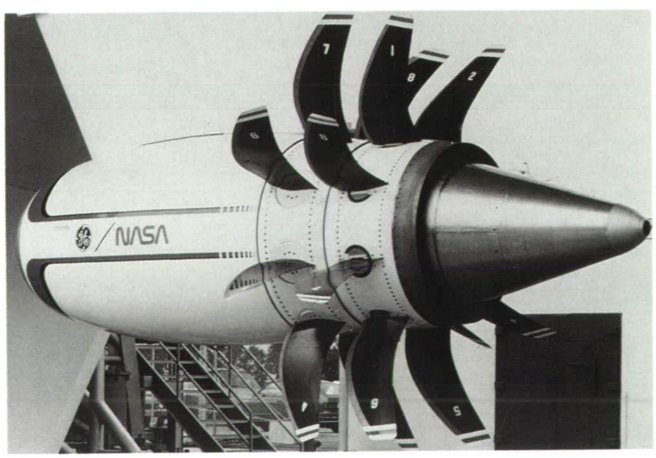
Advanced turboprop (shown with laser-velocimeter flow instrumentation in transonic wind tunnel) offers a potential 30- to 50-percent fuel savings over equivalent technology turbofans at competitive speeds and altitudes.

more relative to equally advanced turbofan engines. To date, however, the technology has not been incorporated in actual transport development. Research is continuing, with additional emphasis on ultra-high-bypass ducted fans suitable for wing pylon mounting on large, long-range aircraft.

The Energy Efficient Transport (EET) program focused on aerodynamic and control concepts such as high-aspect-ratio, low-sweep supercritical wing technology; new high-lift devices; propulsion/airframe integration; digital avion-

Hamilton Standard and General Electric counterrotating turboprop concepts were included in the ATP research.





Winglets, one of the more visible results of the Aircraft Energy Efficiency (ACEE) program, have improved performance of both new and derivative transport designs.

ics, and active controls. It led to the application of winglets, which have now appeared on the Boeing 747-400, McDonnel Douglas MD-11, and other aircraft, and the wing load alleviation system developed for the Lockheed L-1011-500. The Composite Primary Aircraft Structures (CPAS) program built upon previous NASA composites research and cooperative efforts with industry in development and flight service validation of secondary structural components. This program involved the fabrication and successful flight testing of primary composite empennage structures, but did not progress as originally planned to the validation of large wing and fuselage structures, nor did it resolve manufacturing technology or cost problems. Subsequent NASA and industry research has addressed the broader use of composites in large primary structures for civil transports.

Laminar Flow Control (LFC) was recognized early in the program as a high-risk, long-term endeavor. The ACEE effort furthered considerably the LFC active suction research and provided the basis for development of a more practical and economical "hybrid" approach combining active control with natural laminar flow. The hybrid approach has been successfully tested recently in flights of an experimental installation on a B-757 transport.

In all, these focused efforts demonstrate the benefits of NASA/industry cooperation in developing and validating advanced technology for use in civil applications. They also demonstrate that such undertakings involve critical selection and timing considerations, as well as high cost and economic as well as technical risk, and must be reserved for situations of major national importance. The DoD/NASA National Aero-Space Plane (NASP) effort is the most prominent example of a major focused program undertaken in recent years.

Recent Advances

Despite the reduced emphasis on focused technology development efforts, the overall aeronautics program remained strong during the 1980s, and in fact, was demonstrably productive in critical areas:

- Research on advanced drag reduction concepts including natural laminar flow, hybrid laminar flow control, and turbulent drag reduction devices progressed into large-scale ground testing and preliminary flight experimentation, with very promising results.

- Advanced turboprop analytical and model-test results were verified in large-scale flight testing.

- Considerable progress was made in the development of high-temperature engine materials, digital electronic engine controls, and airframe/engine controls integration.

- Mathematical models and software algorithms for optimized fuel-economical flight trajectories were developed and validated and are currently in use by commercial airlines.

- Improved air transport flight management system and display concepts were developed incorporating flight path optimization and time-based flight management consistent with air traffic control constraints.

Commuter transport engine inlet/nacelle under test in the Icing Research Tunnel (IRT) at Lewis Research Center to determine icing sensitivity and ice protection performance. Ice-sensitive components of most civil and military aircraft are tested in the IRT.

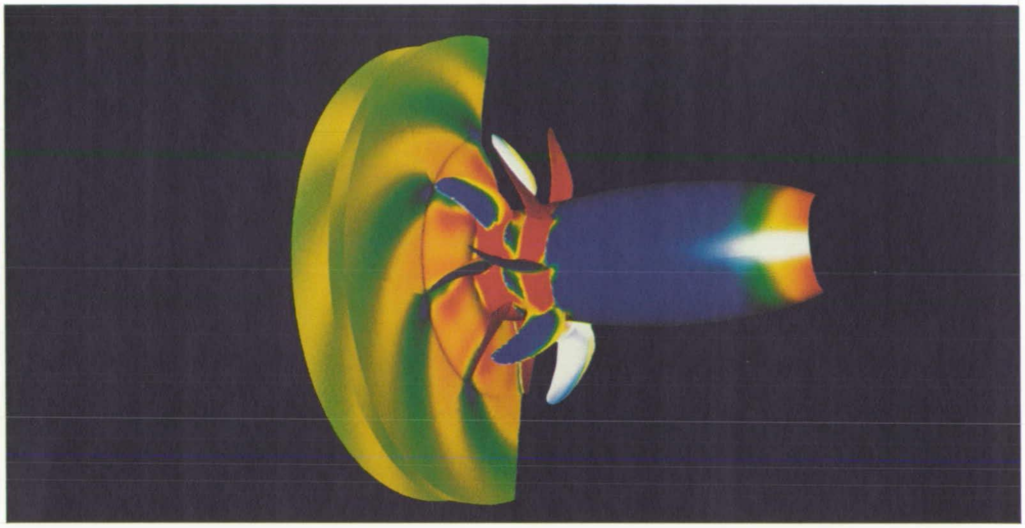
F-18 free-flying model with coupled propulsive flight control demonstrates stable, controllable flight at 80-degree angle of attack in 30x60-foot wind tunnel during "supermaneuverability" research.

- Cockpit system and display research included improvements to Traffic Alert and Collision Avoidance Systems (TCAS) and wind shear detection capability. (One recent outgrowth of the research is a flat electroluminescent display panel now used in U.S. Army tanks.)

- Laboratory and flight research on the effects of lightning strikes resulted in improved understanding of lightning encounters and avoidance, and the development of new international "electromagnetic threat" standards for use in the design of aircraft digital components and subsystems.

- New ice protection concepts compatible with advanced transport propulsion systems and structural materials were developed and tested.

- Impressive progress has been made in computational fluid dynamics. CFD has become an invaluable tool in the research programs. With various simplifying



Flow field and interactions are computed for advanced counter-rotating propeller blades. The color coding depicts pressure distribution (red=high pressure, blue=low).

assumptions compatible with the capabilities of available computers, CFD is also used routinely in practical design. The CFD research is developing more accurate and efficient prediction methods by which, as continuing supercomputer advances materialize, the complete, unsimplified equations of fluid motion can eventually be solved in suitably economical, practical, design applications.

- Further advances were made in rotorcraft aeroacoustics and vibration reduction and in tiltrotor technology.

- Research on supersonic short-takeoff/vertical-landing technology was initiated.

- Sustained commitment to fundamental hypersonic research, even through periods of severely constrained budgets, made possible the initiation of the

National Aero-Space Plane (NASP) program. Since then, support to NASP has reinvigorated the hypersonic research activity, with several inactive facilities restored to service and improvements being made to others. Various hypersonic engine models have been investigated, and major advances have been made in scramjet mixing and fuel injection techniques. Significant advances have also been made in high-temperature materials and structural concepts.

- The National Transonic Facility was built to permit experimentation at full-scale flight Reynolds number by testing in a super-cold (cryogenic) environment.

- An aggressive revitalization program was initiated to update and modernize critical wind tunnel facilities and supporting instrumentation and data systems.

- New instrumentation approaches were developed to improve wind tunnel accuracy by the introduction of nonintrusive sensors based on laser and thin-film technologies and by new techniques for flow field visualization.

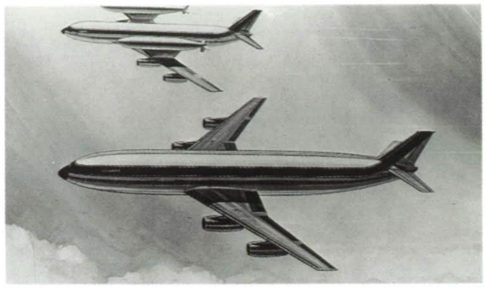
- Innovative techniques such as adaptive walls and magnetic suspension, to eliminate wall effects and model support interference, were developed and successfully tested.

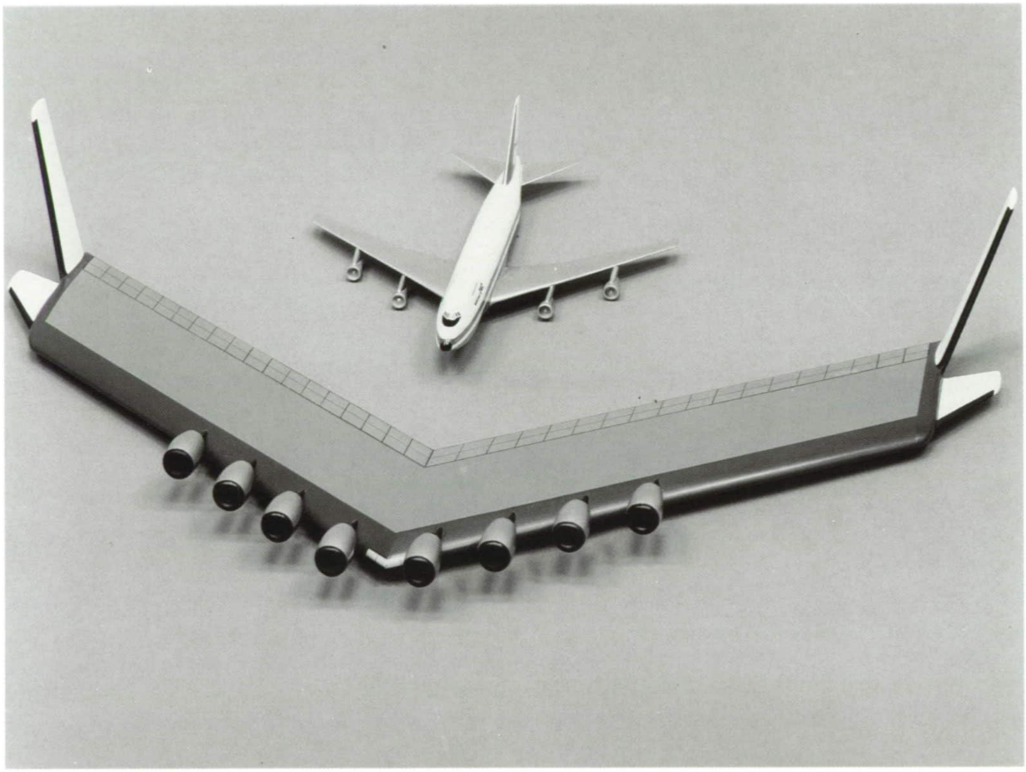
- "Quiet" tunnel concepts for accurate experimentation on supersonic flow transition and turbulence phenomena were developed.

- Flight research produced essential corroborative data and improved understanding relative to variable camber, vortex flaps, integrated engine/airframe control, and high-performance aircraft stability and maneuverability at very high angles of attack.

The X-29 research aircraft flight program verified the performance benefits of the forward-swept-wing concept, and also provided important information on control of an aircraft with a large degree of negative static longitudinal stability, aeroelastic tailoring of composite wings, and integration of multisurface digital fly-by-wire pitch controls. Suitably modified F-11, F-106, F-15, and F-18 aircraft were used as test vehicles.

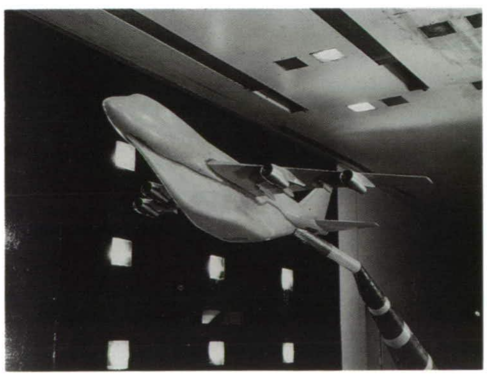
Support to universities was strengthened during this period by increased research grants and inauguration of hypersonic training grants, maintenance of university-staffed Research Institutes at NASA Research Centers, establishment of university-based Centers of Excellence in emerging sciences, and establishment of Joint Institutes — some for NASA/university interchange in selected research areas and some for involvement of undergraduate students and professors in aeronautical design studies. ■

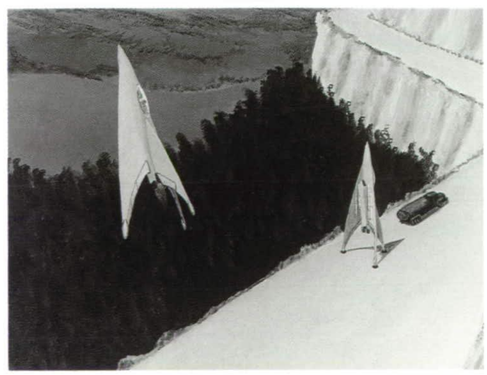




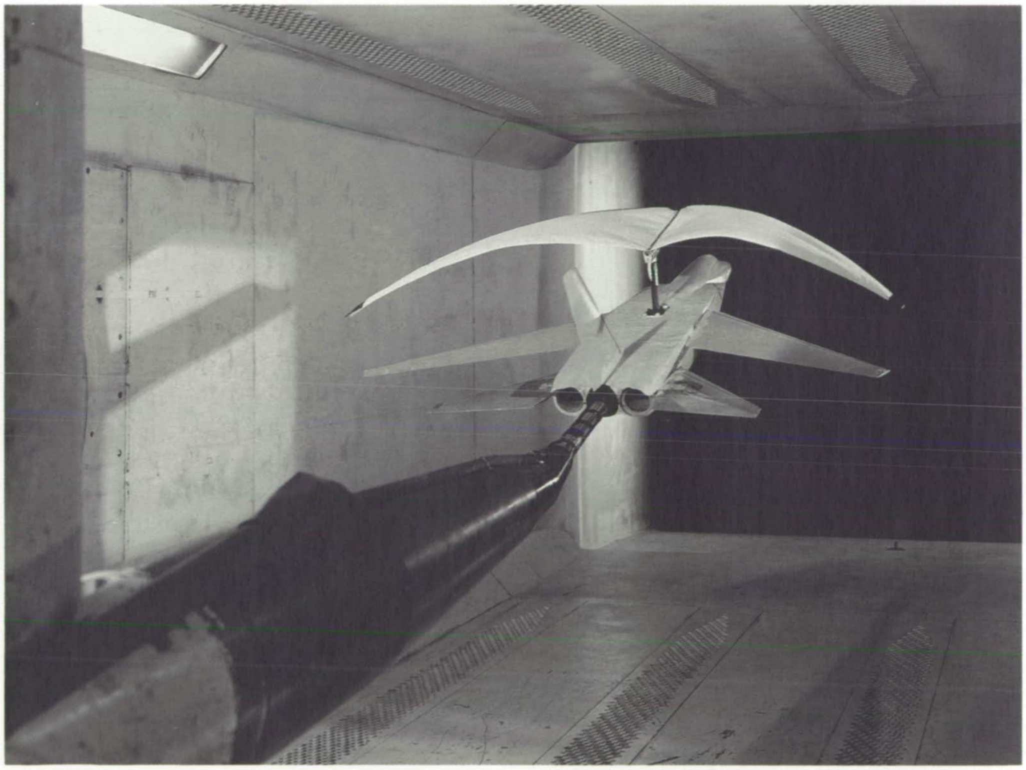
As was true in the early 1940s, research in the 1970s and 1980s included exploratory study of a variety of unconventional concepts. Again, some of these may remain interesting oddities, while some may warrant further consideration in the future.

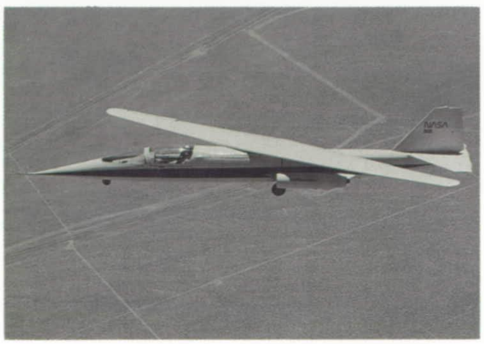
Large transports fueled by liquid hydrogen (top). A giant tailless "spanloader" cargo aircraft dwarfing a B-747 (middle). Jury-rig "piggy-bottom" carriage of ultra-large cargoes (bottom left). "Tail-sitter" VTOL (bottom right).

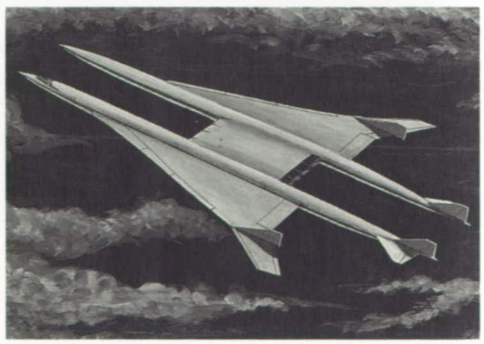




Complete-vehicle emergency parachute recovery (top). Twin-fuselage high-speed transport concept (bottom right). Oblique-wing configuration (bottom left).







Today and Tomorrow

The early NACA research accomplishments, and the pioneer researchers who made them possible, occupy well-earned niches in the annals of aviation history. They are respected and admired by today's researchers — who are nevertheless determined to surpass them. There are, in fact, convincing indications that the present situation reflects considerable improvement over "the good old days."

- Significantly greater national resources are now devoted to aeronautical research.

- The research facilities — laboratories, wind tunnels, test stands, specialized laboratories, flight simulation, numerical simulation, flight testing, instrumentation, data systems — are far more advanced, more capable, and more available to private-sector researchers.

- Government research, once conducted totally in house by NACA, now includes a high percentage of contracted and cooperative efforts in Government/industry partnerships which strengthen the research and increase its relevance to national needs.

- While NASA retains its research and technology focus, the development of high-payoff or critical technologies is carried considerably farther toward validated readiness for application, usually via cooperative or joint projects with industry or DoD.

Focused High-Speed Civil Transport research is directed at establishing the technology for advanced supersonic transports which will meet all applicable environmental standards and compete economically with equally advanced subsonic transports.

- In addition to the discipline-oriented base research, major segments of the programs are directed at clear objectives addressing defined civil and military national needs.

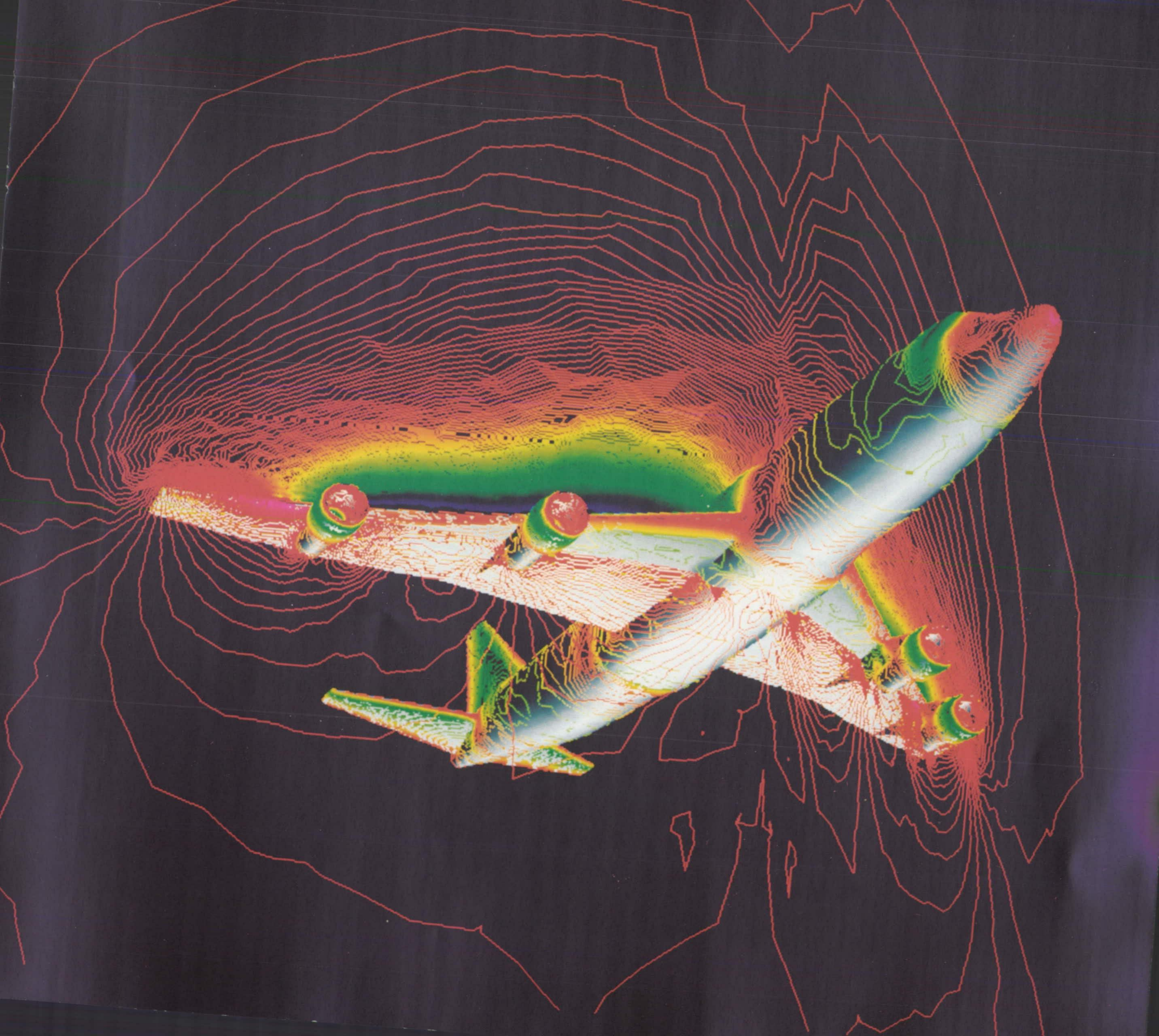
Research on advanced subsonic transport concepts is aided by new computational analysis techniques such as representation of complex configurations by use of unstructured grids–illustrated by the computed pressure field around a complete Boeing 747 flying at Mach .84.

Sparked by great enthusiasm and fascination with the challenge of a new scientific endeavor, the pioneer researchers successfully overcame the disadvantages of small numbers and limited facilities. Because of their successes, aviation today is not only far more advanced, but also considerably more complex.

In a field as dynamic as aeronautics, and with increasingly formidable international competition for huge world aviation markets, leadership cannot be taken for granted. NASA has developed a strategy for aeronautical research and technology during the remainder of this century and into the next which is directed at accomplishing national aeronautical R&D goals defined by the President's Office of Science and Technology Policy (OSTP). Six key thrusts have been identified, four related to future aeronautical development areas critical to national interests, and two to the all-important fundamental research and national research facilities. Relevant programs either are already in progress or are included in future plans.

Subsonic Transportation

The subsonic thrust is to develop selected high-leverage technologies and explore new means to ensure the competitiveness of U.S. subsonic aircraft and to enhance the safety and productivity of the National Aviation System. Objectives to be pursued in cooperation with industry include technology for optimized wing concepts incorporating advanced high-lift systems and drag reduction techniques; highly reliable fly-by-



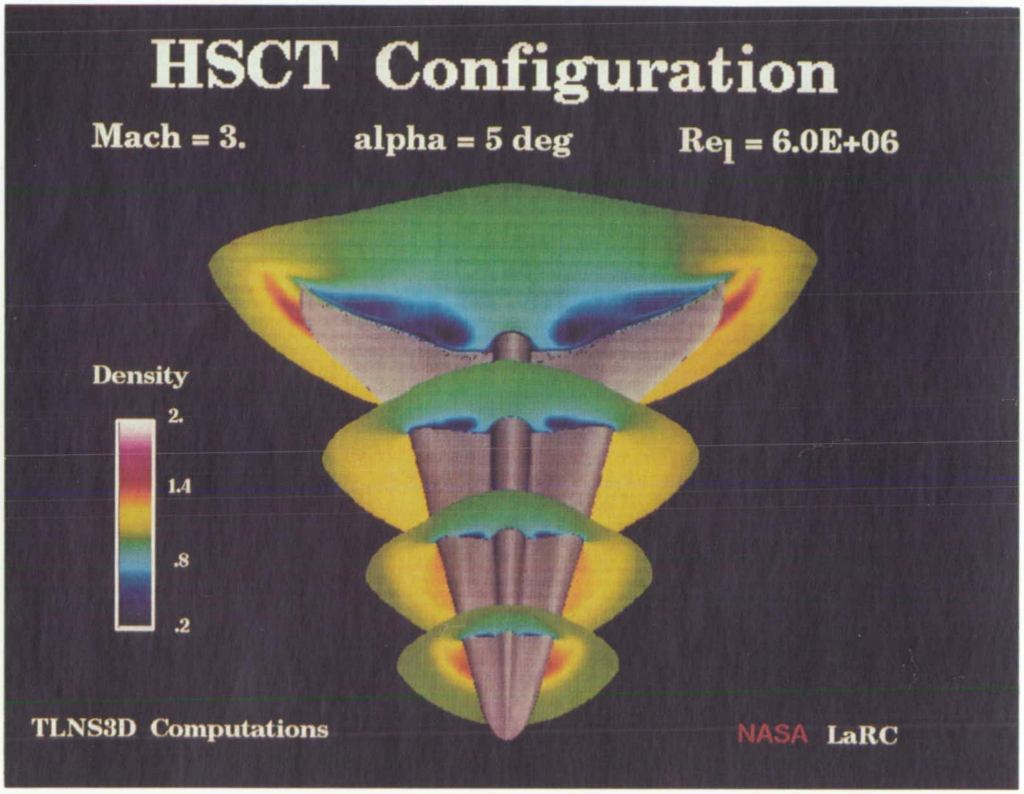
light and power-by-wire flight systems; new cost-effective composite materials and structural concepts; high-temperature materials and components for high-thermal-efficiency core engines; and safe, economical, and environmentally acceptable operation of advanced rotorcraft in the National Aviation System.

Advances to enhance operating safety and productivity, to be developed in cooperation with the FAA and industry, include technologies for airborne wind shear detection systems; minimization of icing and heavy rain effects; advanced structural inspection and life prediction methods; airborne and ground measurements to enhance airport capacity and safety; and reduced airport community noise through source noise reduction, engine/airframe integration, and flight procedures.

High-Speed Research

The high-speed research thrust is to resolve the critical environmental issues and establish a technology foundation for economical high-speed civil transportation. At present, the primary effort is on the three environmental concerns which must be resolved before major high-speed civil transport decisions can be made: atmospheric impact, airport/community noise, and sonic boom. The objective is to establish clearly the environmental effects and the technology needed to ensure environmental compatibility and to identify and verify feasible, economical approaches for satisfying the needs. The primary issues involve reduction of engine emissions to minimize effects satisfactorily on stratospheric ozone and other atmospheric qualities, reduction of noise to ensure compliance with the acoustic standards of today's quietest subsonic

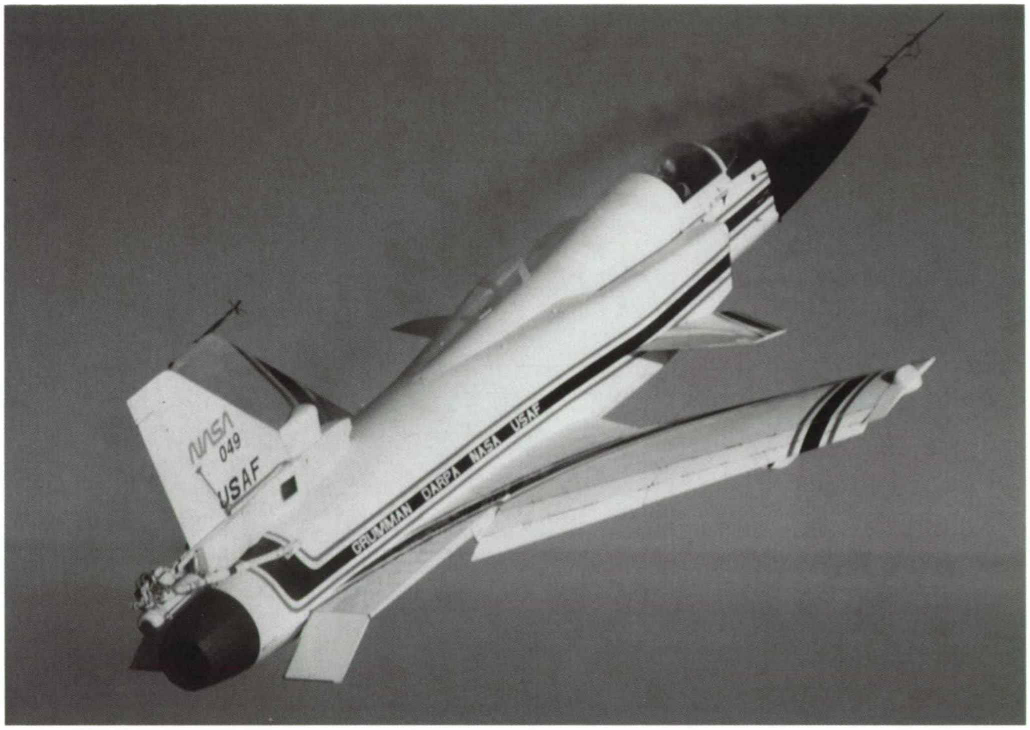
Improved numerical algorithms now permit relatively inexpensive calculation of the flow about conceptual high-speed civil transport designs. Experimental lift and drag measurements for this generic Mach 3 transport correlate well with the computations.

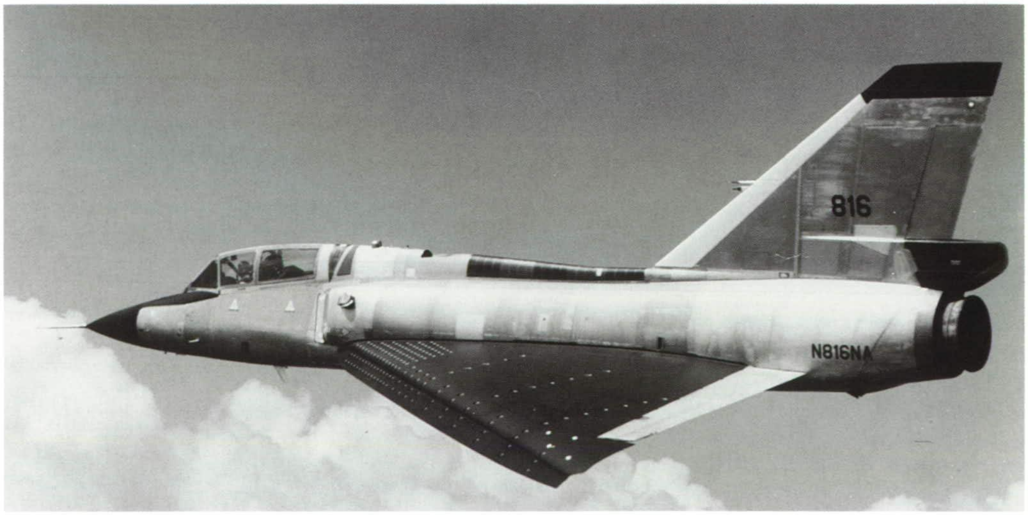


aircraft, and resolution of the sonic boom problems — either by reducing boom sufficiently to permit supersonic flight over land or by increasing subsonic/transonic cruise efficiency for constrained flight segments.

Assuming success in the environmental phase of the research, the next logical step is seen as a focused NASA/industry cooperative program to develop and verify the technology advances essential for viable high-speed transport economics.

The X-29 research aircraft (top) is one of several experimental vehicles being flown in NASA research on control and maneuverability at extremely high angles of attack. Concepts for improved high lift systems for high-speed transports include the vortex flaps shown in flight test on a NASA modified F-106 research vehicle (bottom).





High-Performance Aircraft and Flight Projects

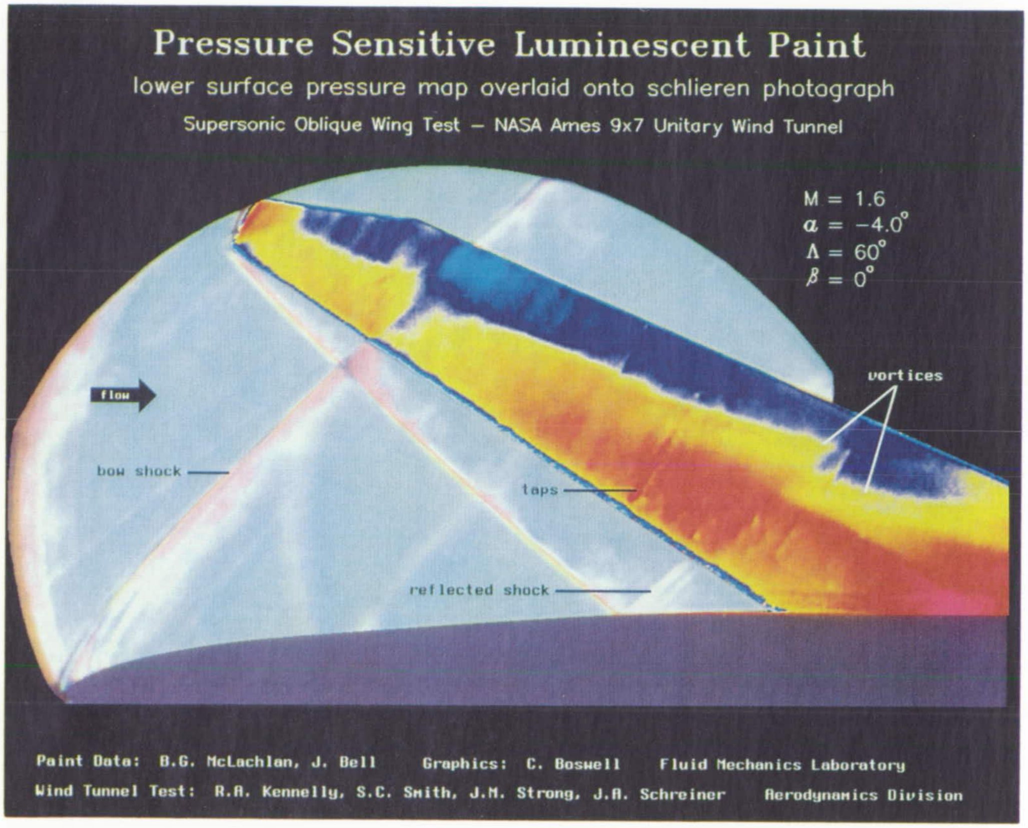
The high-performance military aircraft thrust is intended to provide a proven technology base for revolutionary new capabilities, including unprecedented maneuverability and agility in future fighters, supersonic STOVL capability, and enhanced maneuverability and performance in high-speed rotorcraft. The current high angle-of-attack technology program involves coordinated analysis, computation, wind-tunnel tests, and flight research in the investigation of fixed-wing aircraft flight and control at extremely high angles of attack, using advanced as well as conventional control systems. The rotorcraft effort is directed at development of critical technologies for high-speed cruise, automated low-altitude nap-of-the-earth operation, reduced noise, and very high agility. Future research objectives will include the development of high-leverage technologies for enhanced survivability and for highly integrated control and pilot/vehicle systems in highly agile aircraft.

Hypersonic/Transatmospheric Vehicles

The hypersonic/transatmospheric vehicle thrust is directed at critical technologies required to support ground and flight demonstration of the X-30 NASP program and the development of future hypersonic vehicles. Design, development, and successful flight of the X-30 research vehicle will not represent the conclusion of this activity but rather the beginning of a new era in aeronautics in which the emerging NASP technologies will be extended and applied in a variety of new transatmospheric and hypersonic applications. The current effort includes development and validation of models and methods to describe the physical and chemical phenomena associated with the design of highly integrated propulsion/airframe systems and high-altitude

The NASP program is progressing toward X-30 flight research to complete development of technology for scramjet propulsion at high hypersonic speeds and single-stage flight to orbit.

Research on new aerodynamic wind-tunnel test techniques includes development of pressure-sensitive luminescent paint for measurement of surface pressure and temperatures. Photo shows results of early experiment on oblique wing in supersonic flow.



hypersonic vehicles; provision of an enabling technology base and design methodology for supersonic combustion ramjet systems and other innovative propulsion concepts; and development of high-temperature, high-strength airframe and engine materials, and advanced structural concepts including active cooling. It also includes the development and validation of appropriate guidance, navigation, and control synthesis methodologies and integrated multidisciplinary modeling and analysis methods. Finally, it includes the development and validation of critical hypersonic ground and flight experimental facilities and instrumentation technologies.

Critical Disciplines

Successful pursuit of these directed efforts — or any new aeronautical endeavors that may be undertaken in the future — will be heavily dependent on effective continuing development of fundamental discipline technology, understanding, and methodologies. The critical discipline thrust is intended to pioneer the development of innovative concepts and provide the physical understanding and the theoretical, experimental, and computational tools required for the efficient design and operation of advanced aerospace systems.

Considerable emphasis is being placed on fundamental issues such as boundary layer transition and turbulence, and materials behavior including constitutive laws, failure mechanics, and life prediction. In addition to further development and validation of the individual discipline technologies and analysis methodologies, the research programs include development and evaluation of multidisciplinary methodologies and optimization techniques for design and analysis of complete vehicle systems. They also include the development of ground-based and flight-test techniques and measurement sciences for validation of single-discipline and multidisciplinary predictive capabilities.

National Facilities

The national facilities thrust addresses the development, maintenance, and operation of critical national facilities for aeronautical research and for support of industry, DoD, and other NASA programs. The objectives include:

- Completion of the five-year Wind Tunnel Revitalization program intiated several years ago to upgrade and modernize the major NASA wind tunnels and to institute effective preventive maintenance measures.

- Follow-on activity to further enhance the productivity of selected critical wind tunnels.

- Development of an intergrated national plan for fulfillment of future aeronautical facilities requirements, including essential hypersonic facilities.

- Maintenance of leadership in multidisciplinary numerical simulation of advanced aerospace vehicles and propulsion systems by continued improvements in leading-edge computational facilities and capabilities (including a thousandfold increase in operational capability of the NASA facility by the year 2000).

- Assurance that NASA's national aeronautical experimental, computational, and analytical facilities are appropriately utilized and maintained.

- Strengthening of NASA's Ames-Dryden capabilities as a prime national flight research asset for future U.S. experimental programs. ■

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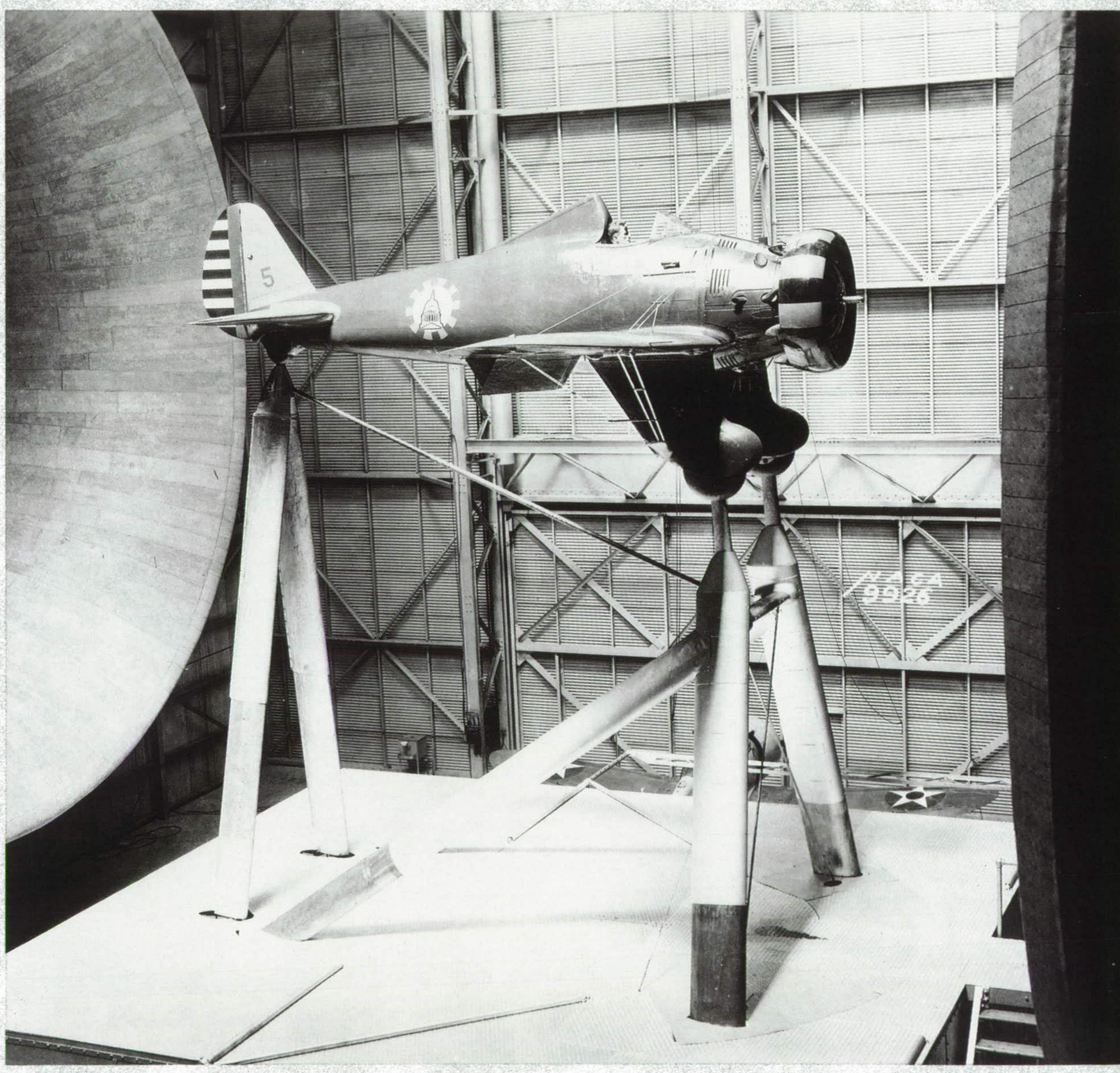
30x60-foot
Full-Scale Tunnel
at Langley Research
Center.



Computed streamlines over F-16 fighter illustrate the first complete solution of viscous 3-D flow aircraft configuration.

FOLDOUT FRAME /.

FOLDOUT FRAME 2

FOLDOUT FRAME 2.

X-29 foward-swept-wing aircraft (left) flying in joint DARPA/NASA-/USAF flight research program. A supersonic short-takeoff/vertical-landing (STOVL) model (right) used in a flow visualization test to study the effects of ground proximity and flow diverters on hot gas ingestion. Supersonic STOVL has been the subject of extensive NASA research in cooperation with the United Kingdom and Canada.