

One Hundred Years of Powered Flight

NASA is proud of its achievements, as well as those of its predecessor, the National Advisory Committee for Aeronautics, during the first century of powered flight. This year's "Centennial of Flight" celebration offers a unique opportunity for NASA's 10 field centers to showcase the Agency's historical and ongoing contributions to aeronautics. Through advanced scientific research and technology transfer, NASA continues to impact flight through improved safety, efficiency, and cost effectiveness.

One Hundred Years of Powered Flight

This year, Centennial of Flight celebrations across the United States are marking the tremendous achievement of the Wright brothers' successful, powered, heavier-than-air flight on December 17, 1903. The vision and persistence of these two men pioneered the way for explorers, inventors, and innovators to take aeronautics from the beaches of Kitty Hawk, North Carolina, to the outer reaches of the solar system. Along this 100-year journey, NASA has played a significant role in developing and supporting the technologies that have shaped the aviation industry.

NASA's Origin

NASA's commitment to aeronautics technology stems back to 1915 when Congress established the National Advisory Committee for Aeronautics (NACA) through a rider to the Naval Appropriations Act. Much of what the United States takes for granted in aviation today was pioneered by NACA, which was transformed into NASA under the National Aeronautics and Space Act of 1958. NACA made advancements and contributions to every field associated with aeronautics, including the fledging field of spaceflight.

In the beginning, NACA concentrated on problems related to military aviation, spurred by the onset of World War I. NACA scientists and engineers, charged with the mission "to supervise and direct the scientific study of the problems of flight, with a view to their practical solution," developed a strong technical competence



In this photo taken on March 15, 1929, NACA staff members conduct tests on airfoils in the Variable Density Tunnel. In 1985, the Variable Density Tunnel was declared a National Historic Landmark.

and a commitment to collegial in-house research conducive to engineering innovation. When the war ended, NACA engineers turned their attention to solving a broad range of problems in flight technology. At the first NACA Aircraft Engineering Research Conference in 1925, the U.S. Government promoted the transfer of technology and expertise to industry.

Establishing a Tradition of Excellence

Over the years, NACA expanded to conduct its research at three major research laboratories—the Langley Memorial Aeronautical Laboratory established in 1917, the Ames Aeronautical Laboratory formed in 1940, and the Lewis Flight Propulsion Laboratory founded in 1941. NACA also maintained a small Washington, DC, headquarters and two small test facilities.

One of the earliest landmark events for NACA was the formal dedication of the wind tunnel at NACA Langley, later renamed NASA Langley Research Center. This tunnel was the first of many now-famous NACA/NASA wind tunnels, enabling engineers and scientists to develop advanced wind tunnel concepts to support aircraft design. In 1922, Langley's Variable Density Wind Tunnel (VDT) employed high-pressure air to better simulate flight conditions with scale models. The VDT was the most advanced wind tunnel of its day, helping the United States become a leader in aeronautical research. Over the next 10 years, NACA compiled research from the VDT that culminated into NACA Report 160, which included a groundbreaking systematic study of airfoils and produced the airfoil numbering system of today.



The official seal for National Advisory Committee for Aeronautics depicts the first human-controlled, powered flight made by the Wright brothers in December 1903 at Kitty Hawk, North Carolina.



Langley metal workers fabricated NACA cowlings for early test installations.

NACA continued to expand by starting the Cowling Wind Tunnel research at Langley in 1928. The research paved the way for a series of component drag studies, helping NACA to develop a low-drag cowling for radial air-cooled aircraft engines. This breakthrough technology was adopted by all aircraft manufacturers, as the cowling greatly reduced the drag that an exposed engine generated, resulting in significant cost savings and increased aircraft speeds and range. The National Aeronautic Association awarded NACA the Robert J. Collier Trophy, the most prestigious award for great achievement in aeronautics and astronautics in America, for the low-drag

cowling. This would be the first of 19 Collier Trophies for NACA/NASA leading up to the present day.

Strategic Value in World War II

When NACA Langley's Atmospheric Wind Tunnel became operational in 1930, it produced a knowledge base and essential design data relative not only to basic aircraft performance, but also to aircraft stability and control, power effects, flying qualities, aerodynamic loads, and high-lift systems. While NACA's research had both military and civil applications prior to the outbreak of World War II, its activity became almost exclusively military with stronger industry ties during the war. Dozens of corporate representatives visited Langley during this time to observe and assist in testing, as NACA focused on refining and solving specific problems. One major advance was the development of the laminar-flow airfoil to solve a turbulence problem at the wing trailing edge that was limiting aircraft performance.

Langley also helped to improve the performance of existing aircraft through tests in its full-scale tunnel and 8-foot, high-speed tunnel. The 8-foot tunnel was unlike any other in the world, giving the United States a strategic advantage in the war. The first tests in the tunnel evaluated the effects of machine gun and cannon fire on the lift and drag properties of wing panels. This led engineers to check the effects of rivet heads, lapped joints, slots, and other irregularities on drag. The tests demonstrated drag penalties as high as 40 percent over aerodynamically smooth wings. As a result, aircraft manufacturers quickly switched to flush rivets and joints.

New high-speed propellers and engine cowlings also emerged from tests in Langley's 8-foot tunnel, but the development of the Lockheed P-38 Lightning dive recovery flap provided tremendous proof of the wind



The 8-foot, high-speed wind tunnel at the NACA Langley Aeronautical Laboratory provided the means for testing large models and some full scale components at a simulated speed of 500 miles per hour.



View of the 16-foot, high-speed wind tunnel at the NACA Ames Aeronautical Laboratory in Moffett Field, California.

tunnel's value. The P-38, a high-speed, twin-boom fighter that helped beat back the threat of Japanese Zero airplanes in the South Pacific, introduced a new dimension to American fighters with its second engine. The multi-engine configuration reduced the P-38 loss-rate to anti-aircraft gunfire during ground attack missions.

When the P-38 was first introduced into squadron service in 1941, pilots were plagued by heavy buffeting during high-speed dives. On several occasions, their dives steepened and they could not pull out. Lockheed's test pilot for the P-38, Ralph Virден, lost his life trying to solve the dive problem. Shortly after Virден's death, the Army asked NACA for help. Crucial tests were conducted using one-sixth scale models in the 8-foot tunnel, indicating that above 475 miles per hour, the P-38's wings lost lift and the tail buffeted, causing a strong, downward pitching motion of the plane. Controls stiffened up, preventing the pilot from pulling the plane out of its dive. In addition, the buffeting could cause structural failure, as it had in Virден's case.

Langley's solution to the P-38 dive problem was the addition of a wedge-shaped dive recovery flap on the lower surface of the wings. Aerodynamic refinement of the dive recovery flap was continued in a coordinated program between Lockheed engineers and NACA's newly founded Ames Aeronautical Laboratory (later renamed NASA Ames Research Center) in Moffett Field, California, in the latter's 16-foot, high-speed tunnel. The dive recovery flaps ultimately were incorporated on the P-47 Thunderbolt, the A-26 Invader, and the P-59 Airacobra, America's first jet aircraft.

Aviation Safety Measures

Right from the start, the aviation community was unanimous in its desire to develop systems and procedures that would make flying safer. While NACA information on airflow over wing surfaces and dive flaps helped pilots retain control over diving airplanes, NACA was also asked to determine how air crews and aircraft could better withstand water impacts. NACA forwarded test results regarding the problem to aircraft manufacturers, resulting in new designs that helped save the lives of countless air crews.

Another concern for aviation safety was ice build-up on aircraft wings and propellers, which reduced lift and increased drag, leading to fatal crashes. From 1936 into the mid-1940s, NACA created Thermal Ice Prevention Systems to investigate effective countermeasures to the problem of ice formation on aircraft. Ames, in particular, began to make strides in icing research. Prototypes of an Ames anti-icing system were evaluated in the B-17 and B-24 heavy bombers during World War II, while a substantive program on the C-46A Commando icing research aircraft led to the definition of icing system design criteria.

Ames' icing work consisted of both research and extensive design of actual hardware installed on airplanes. In 1946, Lewis A. Rodert, a leading icing researcher at Ames, received the Collier Trophy for the development of an efficient wing deicing system, which piped air heated by hot engine exhaust along the leading



The Curtiss C-46A Commando icing research aircraft helped Ames define icing system design criteria.



This mid-1950s photograph shows the Douglas D-558-2 and the North American F-86 Sabre chase aircraft in flight. Both aircraft display early examples of swept wing airfoils.

edge of the wing. The system protected the lives of many pilots flying in dangerous weather conditions.

In addition to icing research, Ames worked on transonic variable stability aircraft and flying qualities, stability and control, and performance evaluations. Flight research at Ames progressed from idea development to stages of wind tunnel and ground-based simulator tests to analyses in its facilities. Collaborative efforts to use a combination of facilities led to more substantive results. The standardized system for rating an aircraft's flying qualities is perhaps the most important contribution of the evaluation programs and experiments conducted on the variable stability aircraft at Ames. George Cooper, Ames' Chief Test Pilot, developed the rating system to quantify the pilot's judgment of an aircraft's handling and apply it to the stability and control design process.

Cooper's approach forced a specific definition of the pilot's task and performance standards. Further, it accounted for the demands the aircraft placed on the pilot in accomplishing a given task to some specified

degree of precision. The Cooper Pilot Opinion Rating Scale was initially published in 1957. After gaining several years of experience through applying the scale to many flight and simulator experiments and through its use by the military services and aircraft industry, Cooper modified it in collaboration with Robert Harper of the Cornell Aeronautical Laboratory in 1969. The Cooper-Harper Handling Qualities Rating Scale is one of the enduring contributions of Ames' flying qualities research, as the scale remains the standard for measuring flying qualities to this day.

Picking up Speed

In 1944, Ames' 40- by 80-foot full-scale wind tunnel became operational, allowing whole aircraft to be wind tunnel tested, as compared to models at low-flight speeds. As World War II ended in 1945, NACA aerodynamicist Robert T. Jones developed the Swept Wing Concept, which identified the importance of swept-back wings in efficiently achieving and maintaining high-speed flight. Jones verified the concept, designed to overcome shockwave effects at critical Mach numbers, in wind-tunnel experiments. To this day, Jones' swept-back wings are used on almost all commercial jet airliners and military craft.

High-speed flight research was often a collaboration between NACA and U.S. Army Air Forces. In the late 1940s and throughout the 1950s, a succession of experimental aircraft was flown at Muroc Army Airfield (now Edward's Air Force Base) through NACA's Muroc Flight Test Unit, which would later become NASA's Dryden Flight Research Center. On November 14, 1947, the air-launched, rocket-powered X-1 aircraft broke the sound barrier. Chuck Yeager piloted the X-1 during this monumental flight, ushering in the era of supersonic flight. Record flights by the military and NACA's rocket planes probed the characteristics of high-speed aerodynamics and stresses on aircraft structures. NACA's John Stack led the development of a supersonic wind tunnel,



The X-1 was the first piloted supersonic aircraft to break the sound barrier.



Glenn Research Center's Icing Research Tunnel was established in 1944. The Altitude Tunnel is in the center background, the Propeller Motor Drive Housing is in the right background, and the Air Dryer and Cooling Tower is in the left background.

speeding the advent of operational supersonic aircraft. He shared the Collier Trophy in 1947 with Yeager and Lawrence Bell for research determining the physical laws affecting supersonic flight.

Meanwhile, NACA's newly founded Aircraft Engine Research Laboratory in Cleveland, Ohio—today's NASA Glenn Research Center—was steadily translating German documents on jet propulsion tests that quickly became basic references in the new field of gas turbine research. Italian and German professionals joined their American colleagues at Glenn to work on this new aspect of flight research. To cope with continuing problems of how to cool turbine blades in the new turbojets, Glenn's Ernst Eckert laid the basic foundation for heat transfer research as the laboratory examined this issue.

In 1944, Glenn also began testing ice protection systems with the completion of its Icing Research Tunnel. Most ice protection technologies in use today were largely developed at this facility. In 1987, the American Society of Mechanical Engineers designated Glenn's tunnel an International Historic Mechanical Engineering Landmark for its leading role in making aviation safer for everyone.

Between 1950 and 1960, Glenn engineers pursued the development of an axial flow compressor for jet engines that improved efficiency by an order of magnitude. This research became the basis of the modern high-bypass jet turbofan. The engineers also developed new ways to solve complex combustion, heat exchange, and supercharger problems. While engine research did not receive much public attention at this time, Glenn's work on Army aircraft contributed to one of the mili-

tary's most successful airplanes—the Army's Boeing B-17 Flying Fortress, a high-altitude, high-speed bomber.

In 1951, Langley's Richard T. Whitcomb determined the transonic "Area Rule," which explains the physical rationale for transonic flow over an aircraft. This concept allows modern supersonic aircraft to penetrate the sound barrier with greatly reduced power, and is now used in all transonic and supersonic aircraft designs. Twenty years later, Whitcomb went on to develop the supercritical wing, which yields improved cruise economy of approximately 18 percent by delaying the drag increase at transonic speeds, delaying buffet onset, and increasing lift.

Whitcomb's concept is widely used on commercial and military aircraft today.

Another step in laying the groundwork for modern aviation was NACA Report R1135, "Equations, Tables, and Charts for Compressible Flow." Published in 1953, the report became a "bible" for compressible flow aerodynamics. Also that year, the D-558-2 aircraft, flown by Dryden's Scott Crossfield, was the first aircraft to break Mach 2, or twice the speed of sound. The achievement culminated a joint Navy/NACA high-speed flight research program.

The Dawn of NASA

NACA began researching flight beyond Earth's atmosphere in the early 1950s. Laboratories studied the possible problems of space flight, while engineers discussed aircraft that could reenter the atmosphere at a high rate of speed, producing a great amount of heat. Ames' H. Julian Allen developed the "blunt nose principle," suggesting that a blunt shape would absorb only a very small fraction of the heat generated by an object's reentry into the atmosphere. The principle was later significant to NASA's Mercury capsule development.

NACA's work also led to the creation of the rocket-propelled X-15 research airplanes, which helped verify theories and wind tunnel predictions to take piloted flight to the edge of space. Over the course of a decade, the X-15 program embarked on a new frontier, exploring the possibilities of a piloted, rocket-powered, air-launched aircraft capable of speeds around five times that of sound. The remarkable X-15—half plane, half rocket—bridged the gap between air and space flight, putting Dryden Flight Research Center on the map. Dryden's testing of the program's 199 flights produced invaluable data on aerodynamic heating, high-temperature materials, reaction controls, and space suits.

In 1957, when the Soviet Union launched Sputnik, the first man-made object to orbit the Earth, the United



In the 8-foot, high-speed wind tunnel in April 1955, Richard Whitcomb examines a model designed in accordance with his transonic Area Rule.

States' efforts to reach space intensified. On January 31, 1958, a U.S. Army rocket team at the Redstone Arsenal in Huntsville, Alabama, led by Army Ballistic Missile Agency Technical Director Dr. Wernher von Braun, launched a four-stage Jupiter-C rocket from a Florida launch site. The rocket carried Explorer I, the Nation's

first Earth-orbiting satellite, and marked the United States' initial entry in the space race.

Following Explorer I, American leadership questioned whether the emerging U.S. Space Program should be administered by a military or civilian agency. The debate resulted in the creation of the National Aeronautics and Space Administration (NASA), a civilian organization, on October 1, 1958. When President Dwight D. Eisenhower signed the National Aeronautics and Space Act of 1958, all NACA activities and facilities were folded into the newly formed NASA. NACA and other organizations from the Army and Navy became the nucleus of the new agency, which was tasked with both aeronautics and astronautics responsibilities. While NASA's major focus would be space research, aeronautics remains the first "A" in its name.

Emerging NASA Centers Shoot for the Moon

President Eisenhower signed an executive order indicating that personnel from the Development Operations Division of the Army Ballistic Missile Agency in Huntsville should transfer to NASA. Soon after, in 1960, the Marshall Space Flight Center was founded to provide launch vehicles for NASA's exploration of outer space. Dr. von Braun became director of the new center in Huntsville, as he and his rocket team expanded the Jupiter C's payload lifting capabilities, creating the Juno II space vehicle to launch various Earth satellites and space probes.

During its first 5 years, NASA continued to expand its facilities. In 1959, Goddard Space Flight Center in Greenbelt, Maryland, was established as NASA's first



As crew members secure the X-15 rocket-powered aircraft after a research flight, the B-52 mothership used for launching this unique aircraft does a low fly-by overhead. Information gained from the highly successful X-15 program contributed to the development of the Mercury, Gemini, and Apollo piloted spaceflight programs, and also the Space Shuttle Program.



The swing arms move away and a plume of smoke signals the liftoff of the Apollo 11 Saturn V Space vehicle and astronauts Neil A. Armstrong, Michael Collins, and Edwin E. Aldrin, Jr. from Kennedy Space Center Launch Complex 39A.

space flight center. Under Goddard project management, the Explorer VI provided the world with its first image of Earth from space. In 1961, Houston, Texas, became the site of NASA's Manned Spacecraft Center, which was renamed Johnson Space Center in 1973 to honor the late President and Texas native, Lyndon B. Johnson.

NASA also announced its decision to build a national rocket test site in 1961, establishing the John C. Stennis Space Center in Hancock County, Mississippi, 3 years later to test the first and second stages of the powerful Saturn V rocket that Marshall developed for the Apollo and Skylab Programs. On July 1, 1962, the Marshall Launch Operations

The F-8C Digital Fly-By-Wire Control System was first tested in 1972. The use of electrical and mechanical systems to replace hydraulic systems for aircraft control surface actuation was flight-tested. Today widely used by commercial airliners, the system allows for better maneuver control, smoother rides, and for military aircraft, a higher combat survivability.



Directorate came to Florida to initiate NASA's Launch Operations Center, later renamed the John F. Kennedy Space Center. The Jet Propulsion Laboratory, managed by the California Institute of Technology, was also founded during the 1960s, leading NASA's robotic exploration of the universe.

On July 20, 1969, U.S. astronauts walked on the Moon for the first time after the Apollo 11 crew was launched from Kennedy and safely transported by Marshall-developed rocket boosters that were tested and proven flight worthy at Stennis. Mission Commander Neil Armstrong sent the message back to Johnson, "Houston, Tranquility Base here. The Eagle has landed!" With the completion of the Apollo Program in December 1972, NASA journeyed forward to build new aeronautic achievements upon its groundbreaking accomplishment.

Advancing Towards Modern Aviation

With the new frontier of space within its grasp, NASA continued to improve aviation for Earth-bound purposes. Initiated in 1972, NASA's Digital Fly-By-Wire (DFBW) flight research project, a joint effort between Dryden and Langley, validated the principal concepts of all-electronic flight control systems. On May 25, 1972, Dryden's highly-modified F-8C DFBW research aircraft, with pilot Gary Krier at the controls, became the world's first aircraft to fly completely dependent upon an electronic flight control system. Soon after, electronic fly-by-wire systems replaced older hydraulic control systems, freeing designers to create safer, more maneuverable, and more efficient aircraft.

NASA's DFBW system is the forerunner of current fly-by-wire systems used on the Space Shuttles and on military and civil aircraft such as F/A-18 fighters and the Boeing 777. Modern digital flight control systems make flying safer for both civil and military aircraft. Multiple computers "vote" instantaneously to choose the correct control input for maneuvers requested by the



The Boeing Quiet Short-Haul Research Aircraft.

pilot, who uses the traditional stick and rudder controls in the cockpit. Digital systems make aircraft more maneuverable because computers command more frequent adjustments than human pilots. For airliners, computerized flight controls ensure a smoother ride than a pilot alone could provide with stick and rudder controls. The DFBW research program, which spanned 13 years, is considered one of the most significant and most successful NASA aeronautical programs since the inception of the Agency.

Beginning in 1974, NASA Langley's 737 research aircraft flight-tested a variety of large transport aircraft technologies, such as "glass cockpits," airborne wind shear detection, microwave landing systems, and head-up displays. After Langley pioneered the glass cockpit concept in ground simulators and demonstration flights, Boeing developed the first glass cockpits for production airliners. The success of the NASA-led glass cockpit work is reflected in the total acceptance of the electronic flight displays that began with the introduction of the Boeing 767 in 1982. Both airlines and their passengers benefited. Flight safety and efficiency were increased with improved pilot understanding of the airplane's situation relative to its environment.

Ames also led several innovative programs during the 1970s. The Center's Quiet Short-Haul Research Aircraft program developed and demonstrated technologies necessary to support short-takeoff and high-lift cargo aircraft. The aircraft documented stable flight at lift levels three times those generated on conventional aircraft and operated aboard an aircraft carrier without the need for launch catapults or landing arresting gear.

Its technologies were employed on the Air Force's C-17 Globemaster II.

NASA's XV-15 tiltrotor research aircraft was the first proof-of-concept vehicle built entirely to Ames' specifications. In 1976, the aircraft hovered for the first time. Two years later, it demonstrated conversion and forward flight as the first tilting rotor vehicle to solve the problems of "prop whirl." Its success directly led to the Marines' V-22 Osprey development, as well as current development of the Bell 609 civil tiltrotor.

In 1979, wing tip "winglets," an invention by Langley's Richard Whitcomb, were introduced to improve vehicle aerodynamics and improve fuel efficiency. Applied at the tips of an aircraft's main wing, winglets

are seen on many of today's advanced aircraft, as the technology is now universally accepted. In 1997, The Gulfstream V aircraft incorporated Whitcomb's supercritical wing characteristics and winglets to set 46 world and national performance records. Other aircraft that incorporate these innovations are the Boeing 777 and the C-17.

Remotely Piloted Vehicles

The concept of using remotely piloted vehicles for aeronautical testing and research was first introduced by NASA at the Dryden Flight Research Center in 1969 as a way of eliminating the need for a pilot on a high-risk flight project. Today, remotely piloted aircraft are important engineering tools for aeronautical researchers. Known as remotely piloted research vehicles (RPRVs), these aircraft help NASA improve flight safety, lower flight test and development costs, and improve aircraft construction, materials, and systems.

Between 1979 and 1983, two RPRVs were flown in one of Dryden's most successful research projects. The vehicles, called Highly Maneuverable Aircraft Technology (HiMAT), were utilized to explore and develop high-performance design and structural technologies that could be applied to future aircraft. The rear-mounted swept wings, digital flight control systems, and forward controllable canards gave the vehicles a turn radius twice as tight as conventional fighter aircraft. The RPRV concept was chosen for the program because the experimental technologies and high-risk maneuverability tests would have endangered pilots.

About 30 percent of the aircraft's construction materials were experimental composites such as fiberglass and graphite-epoxy, which allowed them to withstand high-force-of-gravity conditions. Knowledge gained from the HiMAT program strongly influenced other

advanced research, and these types of structural materials are now commonly incorporated on commercial and military aircraft. The program produced considerable data on integrated, computerized controls; design features such as aeroelastic tailoring, close-coupled canards, and winglets; the application of new composite materials for internal and external construction; a digital integrated propulsion control system; and the interaction of these then-new technologies upon one another.

The Next Mode of Space Transportation

A new chapter in NASA's history started on January 5, 1972, when President Richard Nixon endorsed plans for the Agency to build a new space vehicle. NASA's Space Shuttle, unlike earlier expendable rockets, was designed to be launched multiple times, serving to ferry payloads and personnel to and from space. As the Space Shuttle concept was being developed, NASA assigned areas of program responsibility to its centers. Kennedy assumed design for ground support facilities and systems for the Shuttle. Johnson led the Shuttle Program and was responsible for the design and procurement of the orbiter. Marshall was tasked with the design and procurement of the external propellant tank, the three main engines of the orbiter, and the solid rocket boosters.



A close-up view of a Space Shuttle Main Engine during a test at Stennis Space Center shows how the engine is rotated to evaluate the performance of its components under simulated flight conditions.



The Highly Maneuverable Aircraft Technology subscale research vehicle, seen here during a research flight, was flown by Dryden Flight Research Center from 1979 to 1983. The aircraft demonstrated advanced fighter technologies that have been used in the development of many modern high performance military aircraft.

In May 1975, the first Space Shuttle Main Engine was tested at Stennis. The main engines that boost the Space Shuttle into low-Earth orbit were flight certified at Stennis on the same test stands used during the Apollo Program. Columbia, the first orbiter scheduled for space flight, was delivered to Kennedy in March 1979, where it began flight processing for its first launch on April 12, 1981. The partially reusable space vehicle was the first flown aerodynamic, winged vehicle to reenter Earth's atmosphere from space, employing technologies developed over 30 years. By the end of 1985, three more orbiters arrived at Kennedy: Challenger, Discovery, and Atlantis.

Aviation Advances in the 1980s

NASA continued to make its mark on civilian flight after the first Space Shuttle mission. When Ames demonstrated a head-up guidance display in a Boeing 727-100 transport airline in the early 1980s, the aviation industry subsequently adapted the technology and certified it for civil transport operations. Riblets, another NASA development, also impacted commercial aviation during this time. Invented by Langley, riblets are small, barely visible grooves that are placed on the surface of airplanes. The V-shaped grooves reduce aerodynamic drag, translating into fuel reductions and significant savings for U.S. commercial airlines.

The Laminar Flow Control project that took place at Dryden between 1986 and 1994 sought to provide similar benefits. By developing active flow control over all speed regimes, the project produced laminar flow over 65 percent of the wing of an aircraft, reducing drag and promoting better fuel efficiency. NASA's research to

improve laminar flow dates back to 1930 when NACA photographed airflow turbulence in Langley's Variable Density Tunnel.

From January 1981 through January 1988, nearly 400 commercial airline traction-related accidents occurred as aircraft ran off the ends of runways or veered off shoulders. The resulting crew and passenger fatalities motivated the Landing and Impact Dynamics Branch at NASA Langley to define runway surface maintenance requirements and minimum friction level limits in adverse conditions. Its Safety Grooving research program worked to reduce aircraft tire hydroplaning, the primary cause of uncontrolled skidding during wet weather conditions. The researchers proved that cutting thin grooves across concrete runways to create channels for draining excess water reduces the risk of hydroplaning. As a result, hundreds of commercial airport runways around the world have been safety-grooved. The NASA program improved aircraft tire friction performance in wet conditions by 200 to 300 percent, and countless lives have been saved as a result.

The airborne wind shear detection system that was developed and refined at Langley is another NASA technology that contributes to aircraft landing safety. Wind shear occurs when invisible bodies of air are traveling in different directions of each other at different speeds. Pilots experience severe difficulty in correcting changes in flight path during a wind shear disturbance, particularly while attempting to land. This invisible aviation



Langley Research Center's Boeing 737 research aircraft is fitted with a Doppler radar wind shear detection system that sends a beam well ahead of the airplane to detect microbursts.

hazard is so dangerously unpredictable that about 26 aircraft crashed, resulting in over 500 fatalities between 1964 and 1985.

After a Delta Airlines jetliner was brought down by wind shear near Dallas, Texas, in August 1985, it was evident that something had to be done to provide pilots with greater advance warning of wind shear situations. The Federal Aviation Administration (FAA) and NASA Langley combined forces from 1986 to 1993 to develop better wind shear detection capabilities for the airlines and the military. The first challenge was to learn how to model and predict the phenomenon. Langley developed



Wind shear occurs when invisible bodies of air travel in different directions of each other at different speeds. During wind shear disturbances, pilots experience severe difficulty maintaining their flight path, particularly while attempting to land.

the F-factor metric that is now the standard for determining if the airflow ahead of an aircraft is dangerous wind shear.

The next step was to determine what sort of sensor would be the most effective in detecting the wind shear 10 seconds to 1 minute ahead of a flying aircraft. Langley's 737 flying laboratory, NASA 515, flew over 130 missions into severe weather situations, learning how to hunt the invisible hazards 2 to 3 miles ahead of the aircraft. The resulting technological advances have enabled aircraft to read the speed and direction of invisible particles of water vapor or dust in the wind and provide pilots the necessary advance warning of wind shear conditions.

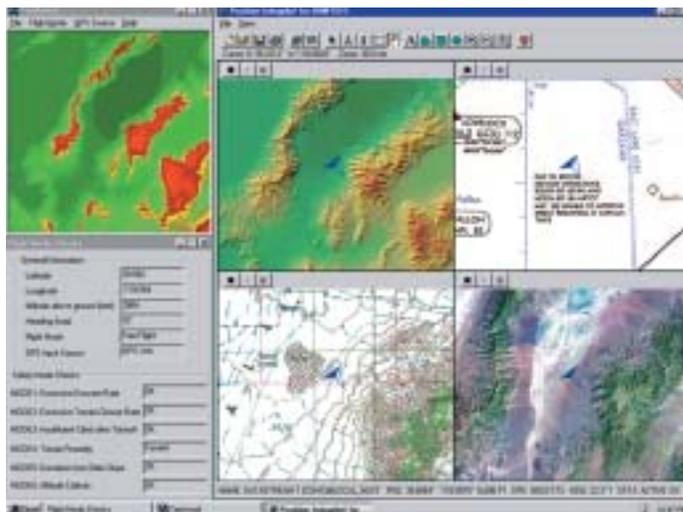
Doppler radar-based systems were developed based on the Langley research and were commercially certified by several companies. The system had its maiden flight on Continental Airlines less than 2 years after the Langley Wind Shear Program declared "mission accomplished" and concluded testing.

Safety Strategies in the 1990s

Flying a small plane lost and surrounded by unknown terrain can be a pilot's greatest fear. Through a licensing agreement between JPL and private industry, JPL successfully applied synthetic aperture radar for terrain mapping and Global Positioning Satellite (GPS) data to provide pilots with accurate location and local terrain information in any weather.

In 1994, the Technology Affiliates Program introduced the start-up company of Dubbs & Severino, Inc., to JPL's Dr. Nevin Bryant. Dubbs & Severino had an idea for mapping software to help private airplane pilots, inspired in part by the fatal crash of a pilot friend. The package needed to be completely software-driven, instead of requiring expensive hardware, as was the norm up to that time. Bryant's Cartographic Applications Group at JPL had developed GeoTIFF, an architecture standard providing geolocation tools for mapping applications. GeoTIFF proved to be the crucial key that Dubbs & Severino needed to bring the idea to fruition. With JPL's assistance, the company developed two low-cost software packages that enable pilots to use laptops to detect and avoid hazardous terrain and find their location on maps.

In 1997, NASA created the Aviation Safety Program in response to a report from the White House Commission on Aviation Safety and Security. Forming a partnership, NASA, the FAA, the aviation industry, and the Department of Defense set the program's goal to develop and demonstrate technologies that will contribute to a reduction in the aviation fatal accident rate by a factor of



Dubbs & Severino, Inc., creators of the low-cost software packages TerrAvoid and Position Integrity, have designed six warning modes to reflect the FAA categories of concern about safe flight. This image demonstrates how the software packages work together to provide pilots with enhanced situational awareness through the use of six mutually supporting graphic windows.

5 by the year 2007. Langley leads the program, with critical involvement from Ames, Dryden, Goddard, and Glenn. The program's research and technology objectives address accidents involving hazardous weather, controlled flight into terrain, human error-caused accidents and incidents, and mechanical or software malfunctions.

Working within these objectives, the Icing Branch at Glenn supported the development of a new aircraft ice protection system by providing technical and testing support and **Small Business Innovation Research** program funding to Cox & Company, Inc., in 2001. The company's innovation combines an anti-icing system with a mechanical deicer developed by NASA called the Electro-Mechanical Expulsion Deicing System. Together, the two parts form an ice protection system well suited for airfoil leading edges, where ice contamination can degrade aerodynamic abilities. The system has the distinction of being the first aircraft ice protection system to gain FAA approval for use on a new business jet in 40 years.

NASA and Aviation Today

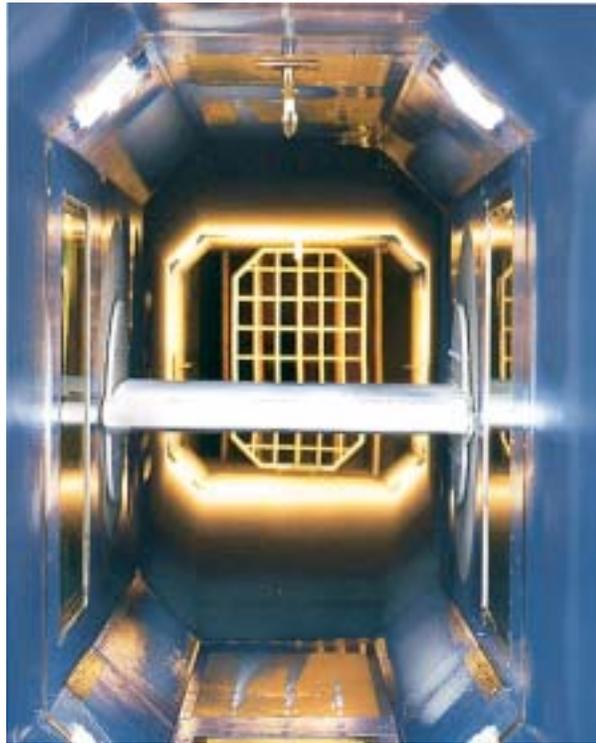
NASA's ongoing research projects contribute to all aspects of aeronautics today. The Agency's emerging technologies have the potential to open a whole new era in aviation, providing advances in air transportation safety and efficiency, national defense, economic growth, and quality of life.

The mission of NASA's Future Flight Central, a fully interactive air traffic control tower simulator located at the Ames Research Center, is to provide a world-class simulation research facility to improve the safety, efficiency, and cost-effectiveness of airport procedures, designs, and technologies. With NASA experts, airport staff can plan new runways, test new ground traffic and tower communications procedures, validate air traffic planning simulations, and perform cost-benefit studies for new airport requirements and designs.

NASA's Intelligent Flight Control, another ongoing research project, developed a neural network technology to help aircraft recover from a loss of control. Current efforts continue to develop neural network technologies that can automatically compensate for damaged or malfunctioning aircraft.

NASA's Environmental Research Aircraft and Sensor Technology (ERAST) project at Dryden serves as a gateway into future aeronautics. Accomplishments such as the solar-powered Unmanned Aerial Vehicle (UAV) Helios prototype, which set an altitude record of 96,863 feet in 2001, are leading the way for future unmanned high-altitude, long-duration, solar-powered aircraft. The ERAST project is also researching a fuel cell-based power system, taking a step toward a UAV that could be sent on missions spanning months at a time.

For over 85 years, the aeronautical contributions of NASA and its predecessor NACA have advanced the safety, efficiency, and cost effectiveness of flight. NASA/NACA technology is on board every U.S. commercial and military aircraft flying today. From wind shear detection and collision avoidance systems to a parachute that lowers an entire aircraft safely to the ground, the aviation benefits derived from the work of



Tests conducted at the Cox & Company Icing Wind Tunnel helped solve the problem of removing ice from airfoils.

NASA/NACA scientists and engineers have impacted the life of every U.S. citizen that has traveled by plane. Through its initiatives and programs, as well as partnerships with the aviation industry, NASA continues to make aeronautics a priority as the United States begins the journey into a second century of flight.



NASA's Future Flight Central, the world's first full-scale virtual airport control tower, opened December 13, 1999 at Ames Research Center in Moffett Field, California. The two-story facility is designed to test ways to solve potential air and ground traffic problems at commercial airports under realistic airport conditions and configurations.