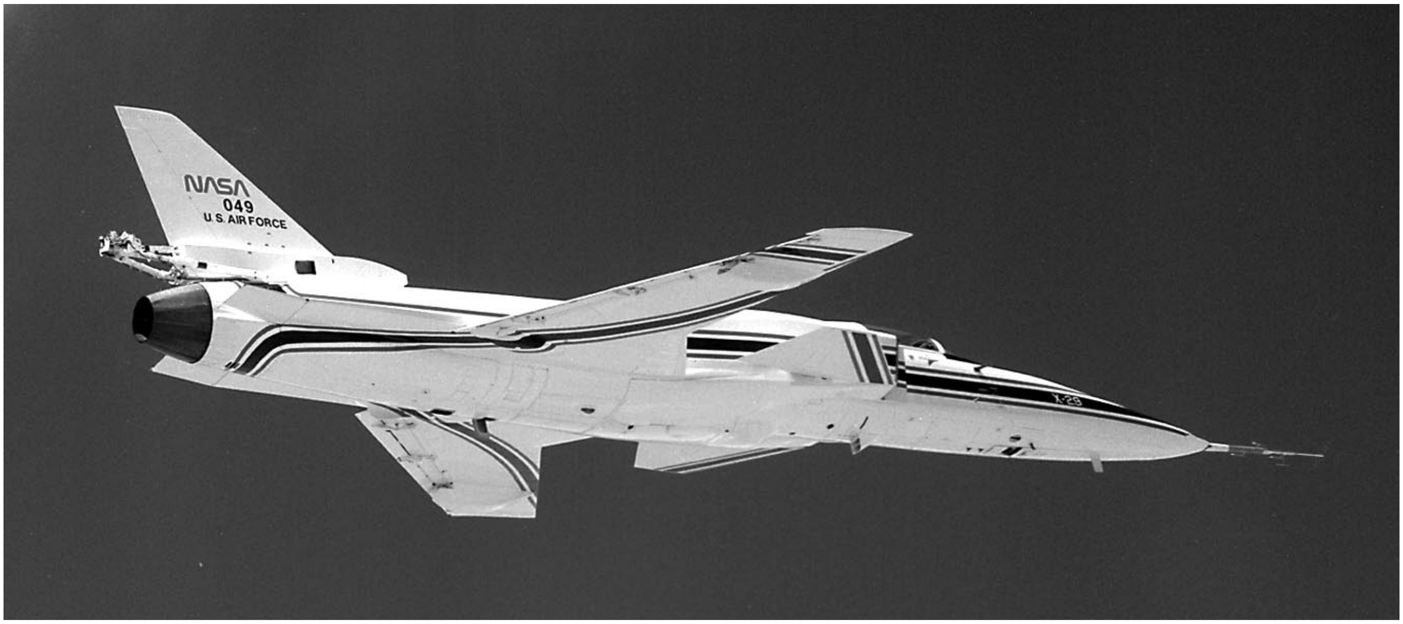
NASA Facts

National Aeronautics and
Space Administration

Dryden Flight Research Center
P.O. Box 273
Edwards, California 93523
Phone 805-258-3449
FAX 805-258-3566

FS-DFRC-95(09)-008



EC 89-0127-04

The X-29

Two X-29 aircraft, featuring one of the most unusual designs in aviation history, were flown at the NASA Dryden Flight Research Center, Edwards, CA, as technology demonstrators to investigate a host of advanced concepts and technologies. The multi-phased program, conducted from 1984 to 1992, provided an engineering data base that is available in the design and development of future aircraft.

The concepts and technologies the fighter-size X-29 explored were the use of advanced composites in aircraft construction; variable camber wing surfaces; the unique forward-swept-wing and its thin supercritical airfoil; strake flaps; and a computerized fly-by-wire flight control system that overcame the aircraft's instability.

Research results showed that the configuration of forward swept wings, coupled with movable canards, reduced aerodynamic drag by up to 20 percent at transonic speeds, and gave pilots excellent control response at up to 45 degrees angle of attack.

During its flight history, the X-29s were flown on 422 research missions - 242 by aircraft No. 1 in the Phase 1 portion of the program; 120 flights by aircraft No. 2 in Phase 2; and 60 flights in a follow-on phase. An additional 12 non-research flights with X-29 No. 1 raised the total number of flights with the two aircraft to 434.

Program History

The first attempt to design an aircraft with a forward swept wing was made by Germany during World War II. The concept, however, was not successful because the technology and materials did not exist then to construct the wing rigid enough to overcome bending and twisting forces without making the aircraft too heavy.

The introduction of composite materials in the 1970s opened a new field of aircraft construction, making it possible to design rugged airframes and structures stronger than those made of conventional materials, yet lightweight and able to withstand tremendous aerodynamic forces.

Construction of the X-29's thin supercritical wing was made possible because of its composite construction. State-of-the-art composites permit aeroelastic tailoring which allows the wing some bending, but limits twisting and eliminates damage caused by divergence.

In 1977, the Defense Advanced Research Projects Agency (DARPA) and the Air Force Flight Dynamics Laboratory (now the Wright Laboratory), Wright-Patterson AFB, Ohio, issued proposals for a research aircraft designed to explore the forward swept wing concept and validate studies that said it should provide better control and lift qualities in extreme maneuvers, reduce aerodynamic drag, and fly more efficiently at cruise speeds.

From several proposals, Grumman Aircraft Corporation was chosen in December 1981 to receive an $87 million contract to build two X-29 aircraft. They were to become the first new X-series aircraft in more than a decade. First flight of the No. 1 X-29 was Dec. 14, 1984, while the No. 2 aircraft first flew on May 23, 1989. Both first flights were from the NASA Dryden Flight Research Center.

Flight Control System

The flight control surfaces on the X-29 are the forward-mounted canards, which share the lifting load with the wings and provide primary pitch control; the wing flaperons (combination flaps and ailerons) used to change wing camber and function as ailerons for roll control when used asymmetrically; and the strake flaps on each side of the rudder that augment the canards with pitch control at low speeds such as on takeoff or during steep, slow maneuvering.

The control surfaces are linked electronically to a triple-redundant digital fly-by-wire flight control system that provides an artificial stability.

The forward swept wing, close-coupled canard design is inherently unstable. The X-29's flight control system compensates for this instability by sensing flight conditions such as attitude and speed, and through computer processing, continually adjusts the control surfaces with up to 40 commands each second.

Each of the three digital flight control computers has an analog backup. If one of the digital computers fails, the remaining two take over. If two of the digital computers fail, the flight control system switches to the analog mode. If one of the analog computers fails, the two remaining analog computers take over. The risk of total systems failure is less in the X-29 than the risk of mechanical failure in a conventional system.

Phase 1 Flights

The No. 1 aircraft validated earlier predictions about performance. Results of Phase 1, which concluded after 242 research flights, showed that the X-29's forward swept wing reduces drag by up to 20 percent in the transonic maneuvering range.

Because the air moving over the forward swept wing flows inward, rather than outward as it does on a rearward swept wing, the wing tips remain unstalled at high angles of attack (also called high alpha).

The aircraft's supercritical wing airfoil also enhances maneuvering and cruise capabilities in the transonic regime. Developed by NASA and originally tested on an F-8 at Dryden in the 1970s, supercritical airfoils -- flatter on the upper wing surface than conventional airfoils -- delay and soften the onset of shock waves on the upper wing surface, reducing drag.

Phase 2 Flights

The No. 2 X-29 investigated the aircraft's high angle of attack characteristics and the military utility of its forward swept wing/canard configuration during Phase 2 of the program, with 120 research flights logged.

In Phase 2, flying at up to 67 degrees angle of attack, the aircraft demonstrated much better control and maneuvering qualities than computational methods and simulation models had predicated. The No. 1 X-29 was limited to 21 degrees angle of attack maneuvering during Phase 1 flights.

Angle of attack is an engineering term that describes the angle of an aircraft's body and wings relative to its actual flight path. At extreme angles of attack, the airflow around an aircraft tends to separate, creating drag and loss of control surface effectiveness. Most wings start aerodynamic separation at about 15 degrees angle of attack.

During Phase 2 flights, NASA, Air Force and Grumman project pilots reported the X-29 aircraft had excellent control response at up to 45 degrees angle of attack and still had limited controllability at 66 degrees angle of attack. This controllability at high angles of attack can be attributed to the aircraft's unique forward swept wing-canard design. The NASA/Air Force-designed high gain flight control system also contributed to the good flying qualities.

Flight control law concepts used in the current program were developed from radio-controlled flight tests of a 22-percent X-29 drop model at NASA's Langley Research Center, Hampton, VA. The detail design was performed by engineers at Dryden and the Air Force Flight Test Center at Edwards.

The X-29 achieves its high alpha controllability without leading edge flaps on the wings for additional lift, and without moveable vanes on its engine to change or "vector" the direction of thrust.

Flight test data from the high angle of attack/military utility phase of the X-29 program satisfied the end objective of the X-29 program -- evaluate the ability of X-29 technologies to improve future fighter aircraft mission performance.

Vortex Flow Control

In 1992 a program was initiated by the U.S. Air Force to study the use of vortex flow control as a means of providing increased aircraft control at high angles of attack when the normal flight control systems are ineffective.

The No. 2 aircraft was modified with the installation of two high pressure nitrogen tanks and control valves with two small nozzle jets located on the forward upper portion of the nose. The purpose of the modifications was to inject air into the vortices that flow off the nose of the aircraft at high angles of attack.

Wind tunnel tests showed that injection of air into the vortices would change the direction of vortex flow and create corresponding forces on the nose of the aircraft and change or control the nose heading.

During a three-month period 60 flights were flown and successfully demonstrated vortex flow control.

The Aircraft

The X-29 is a single-engine aircraft 48.1 feet long. Its forward swept wing is 27.2 feet wide.

Each X-29 was powered by a General Electric F404-GE-400 engine producing 16,000 pounds of thrust.

Empty weight was 13,600 pounds, while takeoff weight was 17,600 pounds.

The aircraft had a maximum operating altitude of 50,000 feet, a maximum speed of Mach 1.6, and a flight endurance time of about one hour.

The only significant difference between the two aircraft is an emergency spin chute deployment system mounted at the base of the rudder on aircraft No. 2.

External wing structure is primarily composite materials incorporated into precise patters to develop strength and avoid structural divergence (bending and twisting). The wing substructure and the basic airframe itself is aluminum and titanium.

Wing trailing edge actuators controlling camber are mounted externally in streamlined fairings because of the thinness of the supercritical airfoil.

Dayton and EAA Exhibitions

During the summer of 1990, X-29 No. 1 was flown to the Dayton (Ohio) International Air Show, and to the Experimental Aircraft Association's (EAA) International Convention and Sport Aviation Exhibition at Oshkosh, Wisc. It was the only time the X-29 was flown at a location other than Edwards.

At each location, the X-29 was the centerpiece of the NASA aeronautics exhibit and was viewed by several million people.

NASA, Air Force and Grumman project pilots ferried the aircraft on the cross-country roundtrip, which included two refueling stops on both the east- and west-bound legs.

The 12 flights to ferry the aircraft between Dryden, the exposition sites, and return, added 12 missions to the total log of 254 flights for aircraft No. 1 and raises to 434 the total missions flown by the two X-29s.

Program Management

The X-29 program was funded initially by the Department of Defense Advanced Research Projects Agency. The program was managed by the Air Force's Wright Laboratory, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson AFB, Ohio.

The flight research program was conducted by the Dryden Flight Research Center, and included the Air Force Flight Test Center and the Grumman Corporation as participating organizations.

-nasa-

August 1995