NASA Facts

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X-31 Enhanced Fighter Maneuverability Demonstrator

X-31 #1 flying over Edwards. Notice the three thrust-vectoring paddles at the rear of the aircraft. (NASA photo EC 93-42152-8)

Two X-31 Enhanced Fighter Maneuverability (EFM) demonstrators flew at the NASA Dryden Flight Research Center, Edwards, CA, and at Palmdale, CA, to obtain data that may apply to the design of highly maneuverable next-generation fighters. The program ended in June 1995.

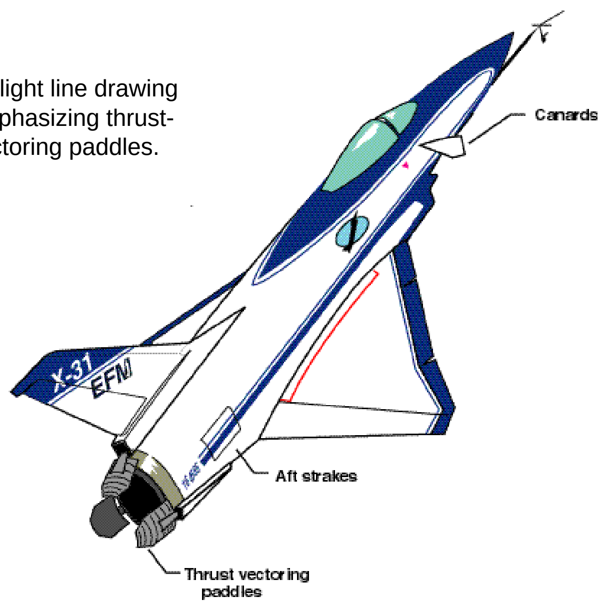
The X-31 program demonstrated the value of thrust vectoring (directing engine exhaust flow) coupled with advanced flight control systems, to provide controlled flight during close-in air combat at very high angles of attack. The result of this increased maneuverability was a significant advantage over most conventional fighters.

Background

“Angle of attack” (AoA or alpha) is an engineering term used to describe the angle of an aircraft’s wings relative to the incoming wind direction. During maneuvers, pilots often fly at extreme angles of attack — with the nose pitched up while the aircraft continues in its original direction. This can lead to loss of control and result in the loss of the aircraft, pilot, or both.

Three thrust vectoring paddles mounted on the X-31's airframe adjacent to the engine nozzle directed the exhaust flow to provide control in pitch (moving the nose up or down) and yaw (moving it right or left) to improve control. Made of graphite epoxy, the paddles could sustain temperatures of up to 1,500 degrees centigrade for extended periods of time. In addition the X-31s were configured with movable forward canards and eventually with fixed aft strakes. The canards were small wing-like structures set on a line between the nose and the leading edge of the wing. The strakes were set on the same line between the trailing edge of the wing and the engine exhaust. Both supplied additional pitch control in tight maneuvering situations.

In-flight line drawing emphasizing thrust-vectoring paddles.



The X-31 operated with a digital fly-by-wire flight control system. It included four digital flight control computers with no analog or mechanical back-up. Three synchronous main computers drove the flight control surfaces. The fourth computer served as a tie-breaker in case the three main computers produced conflicting commands.

The X-31 research program produced technical data at high angles of attack. This information gave engineers and aircraft designers a better understanding of aerodynamics, effectiveness of flight controls and thrust vectoring, and airflow phenomena at high angles of attack. This may lead to design methods providing better maneuverability in future high-performance aircraft and make them safer to fly.

The X-31 program was divided into three phases:

Phase 1

Phase 1 was the conceptual design phase. During this phase, program personnel outlined the payoff expected from the application of EFM concepts in future air battles and defined the technical requirements for a demonstrator aircraft.

Phase 2

Phase 2 carried out the preliminary design of the demonstrator and defined the manufacturing approach. Three governmental design reviews took place during this phase to examine the proposed design. Technical experts from the U.S. Navy, German Federal Ministry of Defense, and NASA contributed to the careful examination of all aspects of the design.

Phase 3

Phase 3 initiated and completed the detailed design and fabrication of two aircraft, which were assembled at the Rockwell International (now Boeing) facility at Air Force Plant 42, Palmdale, CA. This phase required that both aircraft fly a limited flight test program. The first aircraft was rolled out on Mar. 1, 1990, followed by a first flight on Oct. 11, 1990, piloted by Rockwell chief test pilot Ken Dyson. The aircraft reached a speed of 340 mph and an altitude of 10,000 feet during its initial 38-minute flight.

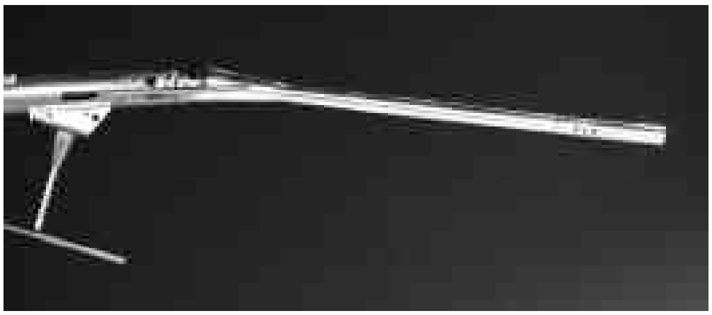
The second aircraft made its first flight on Jan. 19, 1991, with Deutsche Aerospace chief test pilot Dietrich Seeck at the controls. Despite the fact that the number one and two aircraft had identical external dimensions, X-31 number two experienced stronger yaw asymmetries than aircraft number one. For this reason, X-31 team members began to refer to aircraft number two as the "evil twin." The team tested aircraft number two with varying lengths of extended nose strakes and found that it could get the two aircraft to fly identically with 8 1/2 inches of strake length on the second X-31, making it an evil twin no longer.

Flight Summary

During the program's initial phase of operations at Rockwell International's Palmdale facility, pilots flew the aircraft on 108 test missions. They achieved thrust vectoring in flight and expanded the post-stall envelope to 40 degrees angle of attack before flight operations were moved to Dryden in February 1992 at the request of the Defense Advanced Research Projects Agency (DARPA). (Stall is a condition of an airplane or an airfoil in which lift decreases and drag increases due to separation of airflow. Thrust vectoring compensated for the loss of control through normal aerodynamic surfaces that occurred during a stall. Post-stall refers to flying beyond the normal stall angle of attack, which in the X-31 was at 30 degrees angle of attack.)

Because of the basic stability of the aircraft at high angle of attack, it exhibited low tolerance for sideslip. This became a problem at higher angles of attack. Below 30 degrees AoA, the nose boom updated the inertial navigation unit with air data. When the pilots began flying for extended periods above 30 degrees AoA, the inertial navigation unit began calculating large but fictitious values of sideslip as a result of changes in wind direction and magnitude.

To solve this problem, the X-31 team incorporated an unusual noseboom called a Kiel probe instead of the standard NASA pitot tube to calculate air flow. The Kiel probe was bent 10 degrees downward from the standard pitot configuration. The team also had to rotate the sideslip vane down 20 degrees from the noseboom to counter an oscillation that occurred at 62 degrees AoA. With these modifications, the air data to the inertial navigation unit was accurate throughout the AoA envelope, eliminating the problem of false readings of sideslip drift at high AoA.



Side view of the Kiel probe on an X-31 showing the 10-degree bend downward. (NASA photo EC93-42024-1)

At Dryden an international team of pilots and engineers (ITO: International Test Organization) expanded the aircraft's flight envelope, including military utility evaluations that pitted the X-31 against comparable but non-thrust vectored aircraft to evaluate the maneuverability of the X-31 in simulated air combat. The ITO included participation by NASA, the U.S. Navy, the U.S. Air Force, Rockwell Aerospace, the Federal Republic of Germany, and Daimler-Benz (formerly Messerschmitt-Bolkow-Blohm and Deutsche Aerospace).

The first flight from Dryden under the ITO was in April 1992, and by July 1992 the X-31 program was continuing the initial stage of post-stall envelope expansion.

Throughout the process of envelope expansion, the team learned more about the aircraft and had to make many modifications to the control laws (aircraft equations of motion that governed the control of the airplanes through the flight control computers). This was necessary because the actual aerodynamics of the aircraft were slightly different from what the wind tunnels had predicted. The X-31 team was able to make these changes quickly, so they rarely delayed the process of envelope expansion.

When the pilots started flying above 50 degrees AoA, they encountered kicks from the side that they called lurches. The international team added narrow 1/4-inch-wide strips of grit to the aircraft's noseboom and radome to change the vortices flowing from them. The grit strips reduced the randomness of the lurches caused by the vortices, enabling the pilots to finish envelope expansion to the design AoA-limit of 70 degrees at 1 g of acceleration.

As the pilots began flying entries to post-stall angles of attack, they experienced unintentional departures from controlled flight at 58 degrees AoA during maneuvers known as a split-s. Analysis by engineers indicated that the departures were caused by very large asymmetries in yaw (movement of the nose to the right or left)—so large that they overcame the power of the available thrust vector controls.

Previous AoA research and new wind-tunnel testing with an X-31 model led the research team to add strakes to the nose that were 6/10 of an inch wide by 20 inches long. The team also blunted the nose tip slightly (increasing the radius of curvature from essentially zero to 3/4 of an inch). The strakes forced more symmetric transition of forebody vortices and the blunted nose tip reduced yaw asymmetries. Both changes constituted significant improvements to the aircraft's aerodynamics, but the blunting of the nose tip was the more significant of the two.

The No. 2 X-31 achieved controlled flight at 70 degrees angle of attack at Dryden on Nov. 6, 1992. On that same day, it performed a controlled roll around the aircraft's velocity vector at 70 degrees angle of attack.

On April 29, 1993, the No. 2 X-31 successfully executed a minimum radius, 180-degree turn using a post-stall maneuver, flying well beyond the aerodynamic limits of any conventional aircraft. The revolutionary maneuver has been dubbed the "Herbst Maneuver," after Wolfgang Herbst, a German proponent of using post-stall flight in air-to-air combat. The maneuver has also been described as a "J" turn when flown to an arbitrary heading change.

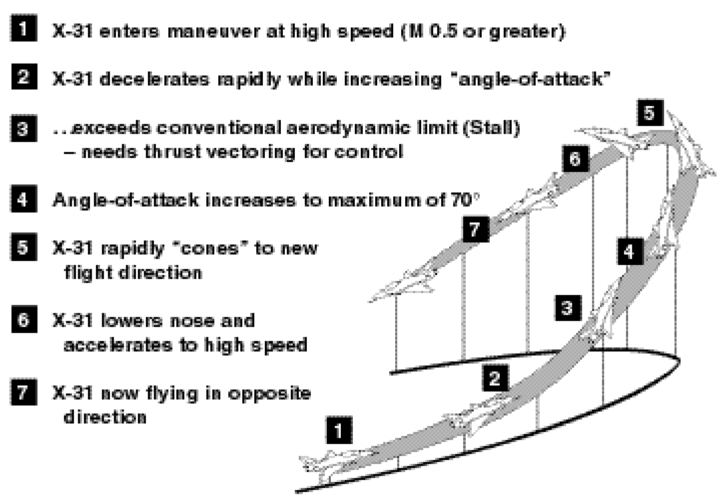


Diagram illustrating Herbst maneuver.

X-31 at high angle of attack—Herbst maneuver. (NASA photo EC94-42478-4)

During the final phase of evaluation, with the X-31's engaged in simulated air combat scenarios against adversaries flying F/A-18's and some other tactical aircraft, the X-31's were able to outperform other aircraft without thrust vectoring through use of post-stall maneuvers.

The X-31 constituted a revolution in air combat in the post-stall region. The pilots in the program did not support trading off other important fighter characteristics just to acquire the EFM capabilities the X-31 possessed. But they did conclude that the improved pitch pointing and velocity-vector maneuvering permitted by thrust vector control did provide new options for the pilot to use in close-in combat. Post-stall maneuvering allowed the pilots to rotate and point the nose of the vehicle at the adversary aircraft in such a way that the adversary pilot could not counter the maneuver. But this was true only when used selectively and rapidly. The X-31 also greatly improved flight safety since it was fully controllable and flyable in the post-stall region, unlike other fighter aircraft without thrust vectoring.

Despite this greater safety, the No. 1 X-31 aircraft was lost in an accident Jan. 19, 1995. The pilot, Karl Heinz-Lang, of the Federal Republic of Germany, ejected safely before the aircraft crashed in an unpopulated desert area just north of Edwards. The crash resulted from an unexpected single-point failure in the noseboom airspeed system.

The X-31 program logged an X-plane record of 580 flights during the program, 559 research missions and 21 in Europe for the 1995 Paris Air Show. A total of 14 pilots representing all agencies of the ITO flew the aircraft.

Quasi-Tailless Demonstration

In 1994, software was installed in the X-31 to simulate the feasibility of stabilizing a tailless aircraft at supersonic speed using thrust vectoring. Tests also included subsonic speeds. During the flights the pilot destabilized the aircraft with the rudder to stability levels that would be encountered if the aircraft had a reduced-size vertical tail. The X-31 quasi-tailless flight test experiment demonstrated the feasibility of tailless and reduced-tail fighters. Had the capability been part of the airplane's design from the beginning, the benefits had the potential to outweigh the complexity the concept entailed.

1995 Paris Air Show

The X-31's enhanced maneuvering capabilities were demonstrated to the international aerospace industry during daily flights at the 1995 Paris Air Show. These flights featured post-stall maneuvers at low altitudes. The aircraft flew to Europe aboard a U.S. military C-5 transport. A small team of NASA and industry personnel supported it there.

Program Management

An international test organization of about 110 people, managed by the Defense Advanced Research Projects Agency (DARPA—redesignated ARPA from March 1993 to 1996), conducted the flight tests at Dryden and Palmdale. NASA was responsible for flight test operations, aircraft maintenance, and research engineering after the project moved to Dryden. As the research flight program matured, the test organization declined in size to approximately 60 persons.

The X-31 was the first international experimental aircraft development program administered by a U.S government agency and was a key effort of the NATO Cooperative Research and Development Program.

The ITO director and NASA's X-31 project manager at Dryden was Gary Trippensee.

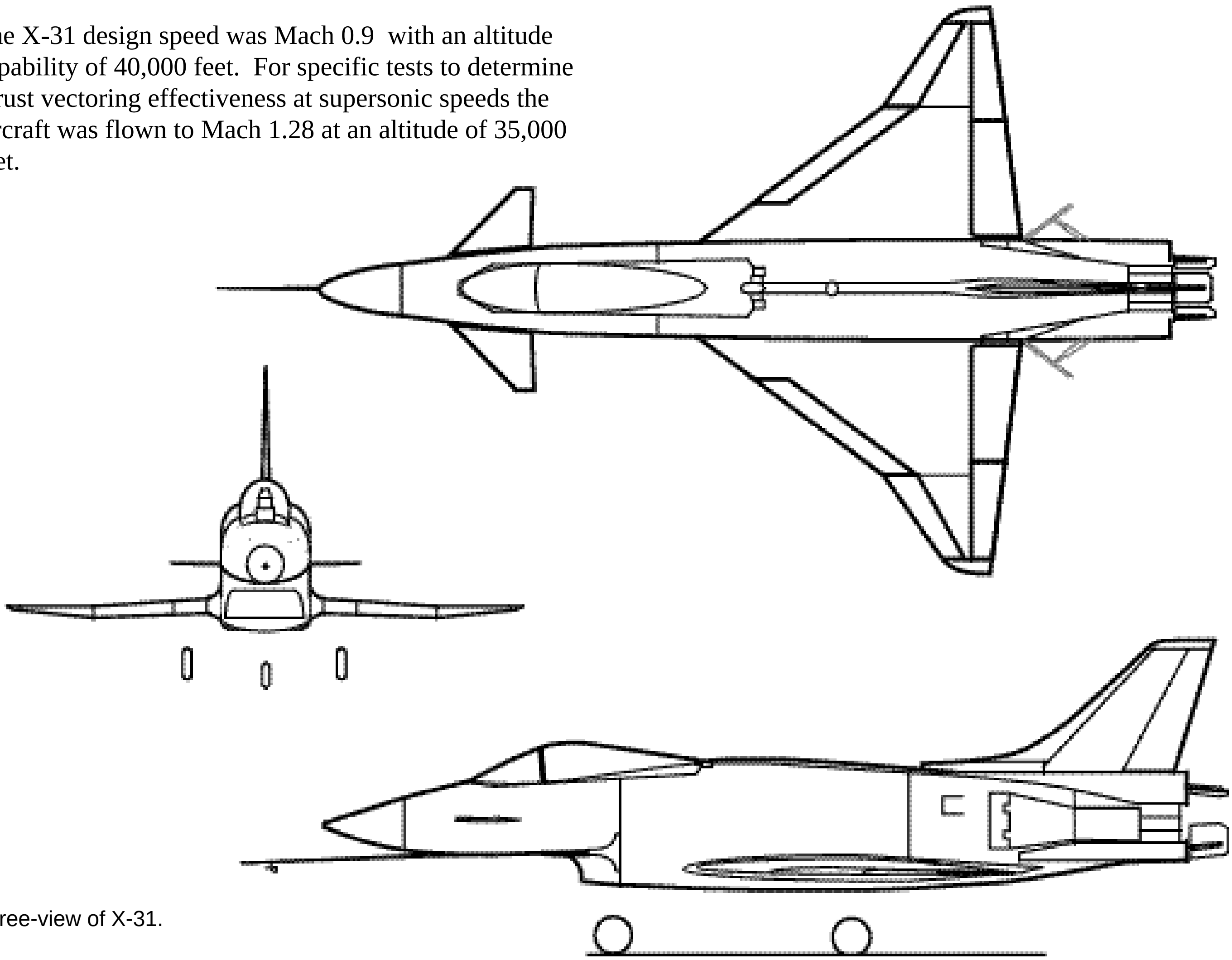
Aircraft Specifications

Designed and constructed as a demonstrator aircraft by Rockwell International Corporation's North American Aircraft and Deutsche Aerospace, the X-31 had a wing span of 23.83 feet. The fuselage length was 43.33 feet.

The X-31 was powered by a single General Electric F404-GE-400 turbofan engine, producing 16,000 pounds of thrust in afterburner.

Typical takeoff weight of the X-31 was 16,100 pounds including 4,100 pounds of fuel.

The X-31 design speed was Mach 0.9 with an altitude capability of 40,000 feet. For specific tests to determine thrust vectoring effectiveness at supersonic speeds the aircraft was flown to Mach 1.28 at an altitude of 35,000 feet.



Three-view of X-31.

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