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FS-1994-11-023-DFRC

F-16XL Laminar Flow Research Aircraft

Two F-16XL aircraft were used by the Dryden Flight Research Center, Edwards, CA, in a NASA-wide program to improve laminar airflow on aircraft flying at sustained supersonic speeds. It was the first program to look at laminar flow on swept wings at speeds representative of those at which a high speed civil transport might fly.

Technological data from the program will be available for the development of future high-speed aircraft, including commercial transports. As such, it supported the NASA Office of Aero-Space Technology's goal of reducing travel time to Asia and Europe by 50 percent within 20 years.

The initial research phase of the program at Dryden was flown in a single-seat F-16XL-1. This aircraft was later used at Dryden in a sonic boom research project with the SR-71 and in a Cranked-Arrow Wing Aerodynamics Project (CAWAP) to test boundary layer pressures and distribution. In 1997 Dryden replaced the aircraft's analog flight control system with a digital system and planned to use the aircraft as a testbed for autonomous systems to be employed in spacecraft.

The aircraft at Dryden subsequently used for the supersonic laminar flow program was the two-seat F-16XL-2, identical to its sistership except for the cockpit configuration.

NASA's single-seat F-16XL flies over the Sierra Nevada Mountains of CA. NASA photo EC94-42885-1

The two aircraft are the only F-16XL's built and were used by NASA because the unique delta wing design is representative of the type of wing that will probably be used on future supersonic cruise aircraft.

Laminar Flow Background

A certain amount of air turbulence occurs on the surface of most aircraft wings, regardless of the shape and sizeof the wing. As air moves across an airfoil, it is changed by the frictional force between it and the airfoil's surface from a laminar (smooth) flow at the forward area to a more turbulent flow toward the trailing edge. The "perfect" wing would demonstrate laminar airflow across the entire surface of the wing, with no sign of turbulence. This turbulence affects flying performance by increasing aerodynamic drag and fuel consumption.

Front of F-16XL-2 showing wings as modified for flight research. NASA photo EC95-43267-2

Research by NASA to improve laminar flow dates back to around 1930 when NASA's predecessor organization, the National Advisory Committee for Aeronautics (NACA), photographed airflow turbulence in the variable density tunnel at its Langley Research Center in Hampton, VA. Smoke was ejected into the air stream and photographed as it showed visual signs of turbulence (disturbed rather than streamlined flow) on the upper wing surfaces. Early research such as this led to the eventual elimination of protruding rivet heads and other construction and design features that could create turbulence on high-speed aircraft.

Much laminar flow research is carried out with two basic types of experimental devices — active and passive — that are attached to the research aircraft's wing. These devices are commonly called "gloves."

Active test sections contain tiny holes or slots through which most of the turbulent layer of air is siphoned off by an internal suction system built into the wing. This decreases drag and enhances aerodynamic lift by either eliminating the turbulent airflow or reducing its effect.

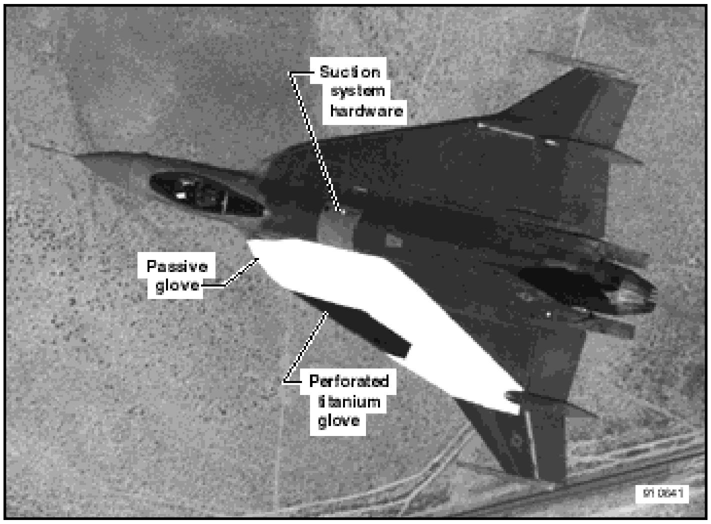
Passive experimental devices also attach to or become a part of the research aircraft's wing, but do not use a suction system to remove the turbulent air. Through careful contouring of the wing's surface, some laminar flow can be achieved naturally.

Both types of laminar flow devices obtain data from sensors and other instrumentation built into or attached to the wing to measure airflow characteristics (especially the region of transition from laminar to turbulent flow) and pressure distribution.

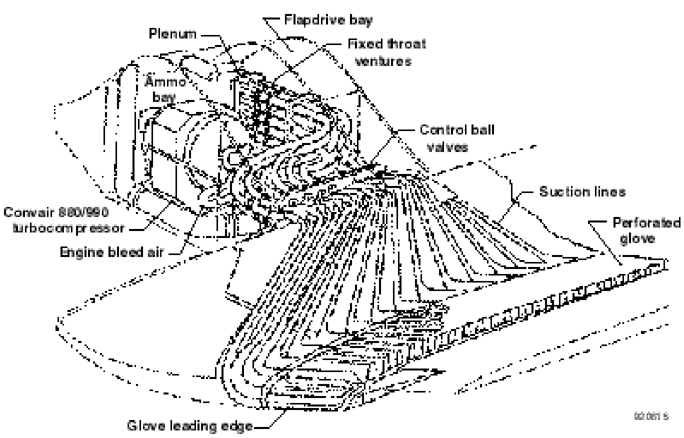
Dryden has conducted laminar flow studies in past years with F-104, F-14, F-15, and F-111 high-performance aircraft, and also with a JetStar business-type aircraft. The projects with the F-16XL, however, were the first that sought to achieve a significant percentage of laminar flow over wings comparable to those of a high speed civil transport. These flight tests were conducted under supersonic flight conditions similar to those such a transport would encounter.

Flight Research

The initial flight test phase of the Dryden Supersonic Laminar Flow Control project (SLFC) examined the performance of an active experimental wing section on the upper surface of the left wing of the single-seat F-16XL-1. The 1991-1992 tests showed that with active laminar flow control, the aircraft achieved laminar flow over a significant portion of the wing during supersonic flight, although it did not obtain laminar flow on the active glove at the design point of Mach 1.6 (1.6 times the speed of sound) at 44,000 ft. The experimental glove with active (perforated titanium) and passive sections was designed by Rockwell International's North American Aircraft Division, El Segundo, CA. (now a division of Boeing)

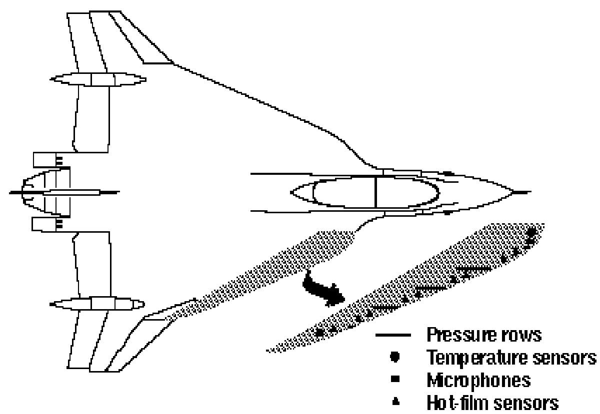


Dryden then used the two-seat F-16XL-2 to conduct a more comprehensive research effort, consisting of two phases. The first phase used a passive glove on the right wing to obtain baseline configuration data that served in the design of the active glove, which was installed over a portion of the left wing. This effort was far more comprehensive than the initial flight phase, and explored regions of transition and the maximum extent of laminar flow obtained over a wider range of supersonic Mach numbers.

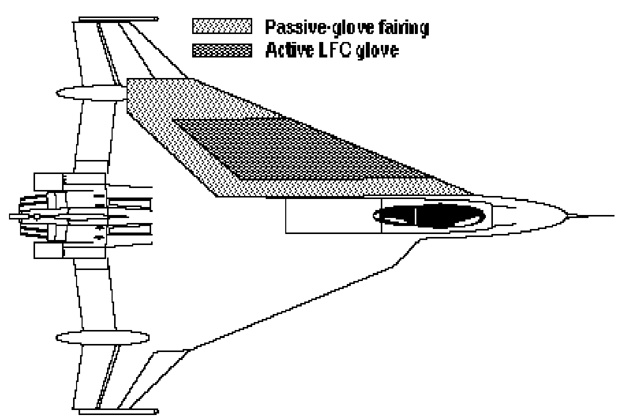


The glove covered about 75 percent of the upper wing surface and 60 percent of the wing's leading edge. It was designed by a NASA and contractor team which included the Langley Research Center, Dryden, Rockwell International, Boeing, and McDonnell Douglas. It featured a titanium suction panel and a foam-and-fiberglass passive fairing. The device was instrumented to measure laminar flow and other variables such as surface imperfections and the acoustic environment that may affect laminar flow at various flight conditions.

The metal surface of the experimental wing panel was perforated with about 10 million nearly microscopic laser-cut holes. Through the tiny holes, a suction system embedded in the wing (and mechanized by a turbocompressor in the fuselage) drew off a very small portion of the boundary layer of air just above the wing's surface, thereby expanding the laminar flow across the wing. The flight engineer used a control panel located in the aft cockpit of the airplane to fine-tune the amount of airflow sucked through the holes. This procedure permitted investigation of the effect of suction volume on the area distribution of laminar flow. Researchers believe that laminar flow conditions can reduce aerodynamic drag (friction) and help reduce operating costs by reducing fuel consumption.



F-16XL single-place aircraft with the SLFC glove installed



F-16XL ship 2 with glove.

The project flew the F-16XL-2 45 times between Oct.13, 1995, and Nov. 26, 1996, obtaining significant amounts of valuable flight research data. NASA research pilot Dana Purifoy flew 38 of the missions, with NASA research pilot Mark Stucky flying the other 7. During the flights, there were few problems with the experimental suction hardware. Because all laminar-flow-related data are restricted, however, the results of the flight research cannot be reported publicly at this time.

Project Management

The F-16XL flight project office was located at the NASA Dryden Flight Research Center, Edwards, CA. The NASA Langley Research Center, developed and coordinated F-16XL experiments. Project managers at Dryden were Marta Bohn-Meyer and Carol Reukauf.

Aircraft Specifications

The F-16XL aircraft were built by General Dynamics Corp., at Ft. Worth, TX, as prototypes for a derivative fighter evaluation program conducted by the U. S. Air Force between 1982 and 1985.

The aircraft were developed from basic F-16 air-frames, with the most notable difference being the delta (cranked arrow) wing, which give the aircraft a greater range because of increased fuel capacity in the wing tanks and a larger load capability due to increased wing area.

Crew size: F-16XL-2, used in the second phase of the laminar flow project, has a two-seat cockpit.
F-16XL-1, used in the 1991-1992 tests, is a single-seat aircraft.

Size: Length, 54.2 ft (16.52 m); wingspan, 34.3 ft (10.45 m); height at vertical tail, 17.7 ft (5.39 m).

Max. weight: 48,000 lb (17,915.60 kg)

Engines: The two-seat aircraft at NASA Dryden has a General Electric F110-GE-129 engine (with afterburner) rated at 29,000 lb thrust. The single-seat F-16XL is powered by a Pratt and Whitney 100-PW-100 engine (with afterburner), rated at 23,830 lb thrust.

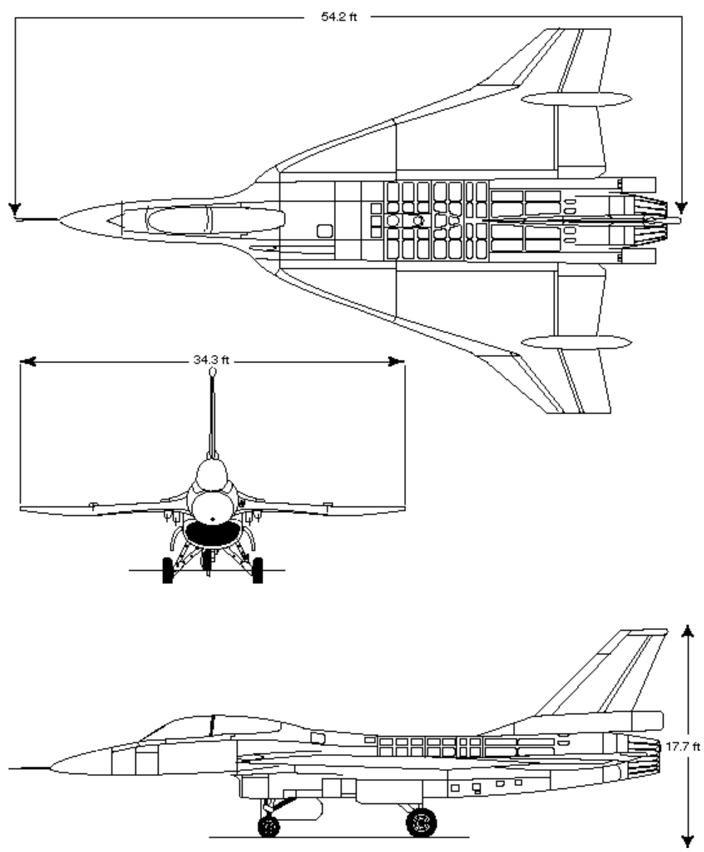
Controls: Both aircraft featured an analog fly-by-wire electronic flight control system during the laminar flow research. The single-seat aircraft now has a digital flight control system.

Wing construction: The delta (cranked arrow) wings on both aircraft are manufactured of advanced graphite composites to provide strength for high wing loads during flight.

Design load: Baseline F-16XL: 9 “Gs”. Modified F-16XL: 3 “Gs”)

Maximum Speed: F-16XL-2, Mach 2 (approx. 1,400 mph) (2,253 k/hr); F-16XL-1, Mach 1.8 (approx. 1,260 mph)

Range: Over 2,500 nautical miles (4,630 k), without in-flight refueling, and unlimited with in-flight refueling



Three-view of F-16XL-2.