FactSheet

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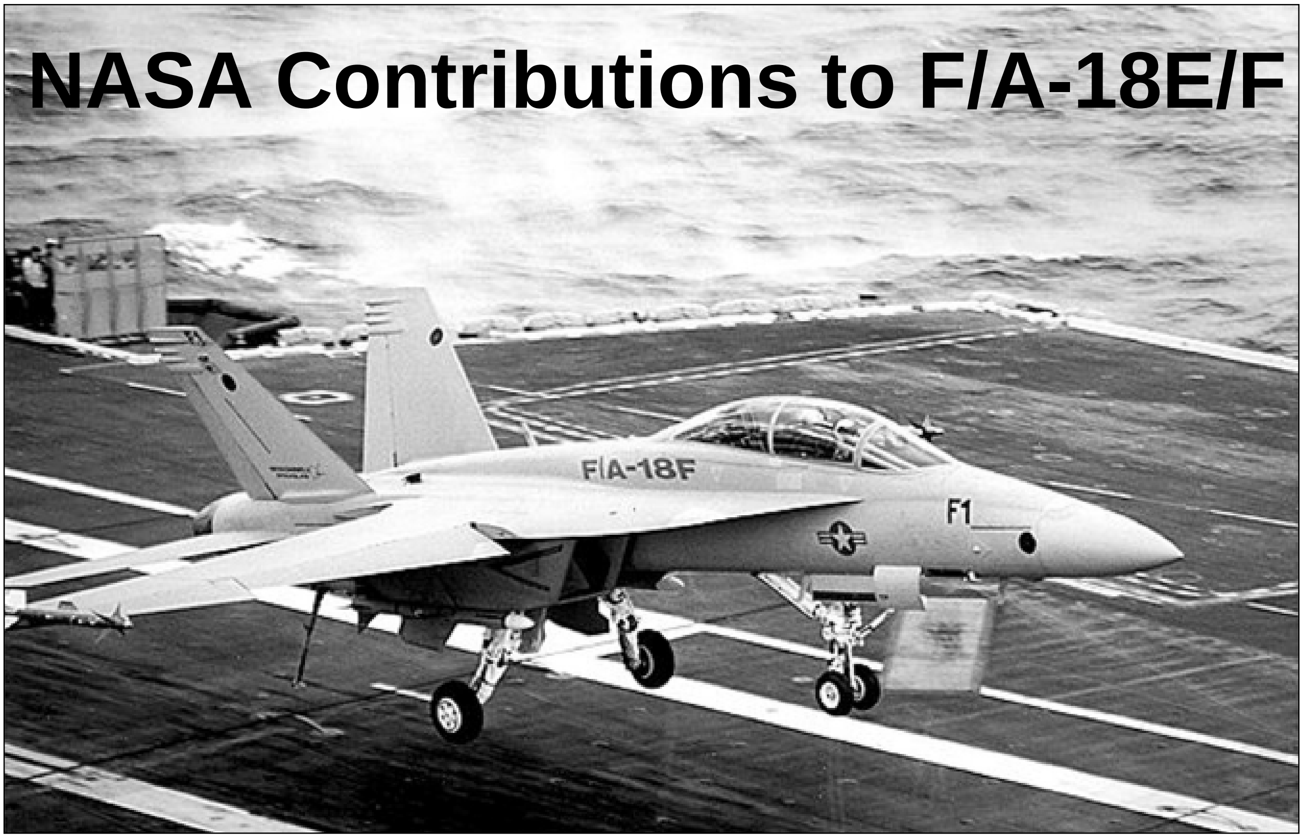
NASA Contributions to F/A-18E/F



An F/A-18F on approach to an aircraft carrier.

Centerpiece of US Navy's Carrier-Based Fighter/Attack Fleet Updated with NASA Aeronautics Technology

The F/A-18 E/F — the single-seat E and the two-seat F — are the latest high-performance aircraft that have benefitted from a rich history of cooperation between NASA, the Department of Defense (DoD) and U.S. industry. NASA's contributions to development of the F/A-18E/F were many and varied, from taking part in early technology assessments to helping with a vexing aerodynamic problem during critical flight tests. NASA research inspired a solution to the highly-publicized "wing drop" problem that threatened to delay Congressional funding.

The Aircraft

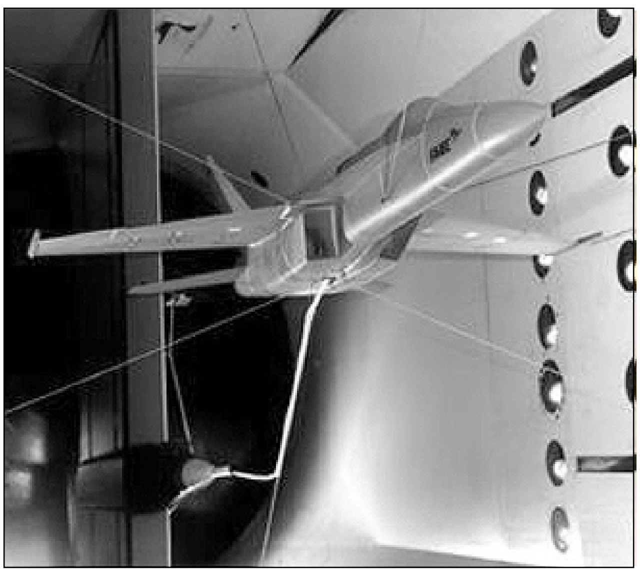
The F/A-18 Hornet is the centerpiece of the US Navy's carrier-based fighter/attack fleet. The F/A-18E/F Super Hornet is a larger version of the F/A-18C/D Hornet. The E/F is roughly 25% larger than the C/D, with a 25% increase in operating radius and a 22% increase in weapons load capability. The single seat F-18E fighter is intended to replace the F-18C and the two-seat F/A-18F attack airplane will eventually replace the F-14.

The F/A-18E/F, designed and built by Boeing (formerly McDonnell Douglas), recently completed engineering and manufacturing development flight testing at Patuxent River Naval Air Station, Maryland.

NASA Knowledge Called Upon Early

NASA's involvement with the F/A-18E/F began in the early stages of the proposed aircraft development when the Office of the Secretary of Defense became concerned with range estimates for the vehicle. A three-member NASA/DOD/industry team conducted an independent review of fighter-escort mission range estimates in April 1992. A NASA Langley engineer was a member of this team. Favorable results from this review were critical to the airplane program proceeding forward to the Defense Acquisition Board for funding advocacy.

A series of tests in a Langley wind tunnel (8-Foot Transonic) the following month indicated that a spoiler on the leading-edge extension, designed to improve stability at high angles of attack* and reduce aerodynamic buffeting of the vertical tails, caused unacceptable reductions in maximum lift. As a result of these tests, a reassessment of the leading edge extension design was begun.



Langley structural-aerodynamic tunnel tests increased confidence in the E/F.

Redesigning the leading edge extension was the job of a 15-member national team of experts, which included three Langley engineers. This team was active through the first six months of 1993. Initially the team explored small modifications to the size and shape of the extension to regain the required lift and improve stability. Subsequent wind tunnel tests showed that this incremental approach would not be successful. Langley engineers then proposed more radical design options that, based on prior research with other configurations, would potentially satisfy these requirements. Favorable wind tunnel results led to further refinement of one of the design options and a configuration that met all design goals. This configuration is the wing leading edge extension on the production F/A-18E/F.

The leading edge extension redesign effort is an example of the value that NASA provides as a center for national corporate knowledge in high-angle-of-attack technology and its application to solve major problems in the development of U.S. fighter/attack aircraft.

Thousands of Hours of Tunnel Testing

Extensive testing of the F/A-18E/F with the redesigned leading edge extension was conducted in a variety of NASA and industry wind tunnels to completely define its aerodynamic characteristics. Data from these tests were used to generate the aerodynamic database used for flight simulation and to develop the flight control software for the airplane. NASA engineers worked closely with engineers from McDonnell Douglas and the U.S. Navy to assure that design requirements and national goals were met.

The vehicle's performance at subsonic and transonic speeds was validated in a series of wind tunnel tests at NASA Ames (11-Foot Transonic Tunnel, 1991-94). During approximately 3,000 hours of tunnel occupancy, data were obtained on four different scale models to determine performance and stability and control characteristics. The tests included aerodynamic measurements to evaluate a series of aircraft design options, such as engine inlet studies.

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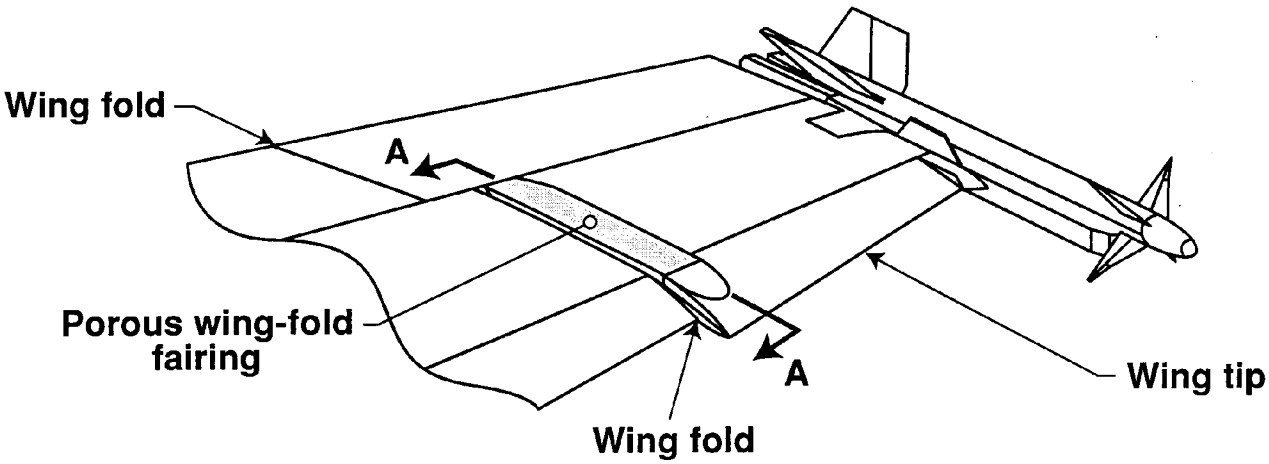
* "Angle of attack" describes the angle of an aircraft's body and wings relative to actual flight path. During maneuvers, pilots often fly at extreme angles of attack — with the nose pitched up while aircraft flies in original direction — often resulting in loss of lift needed to maintain altitude and control.



Tiny holes in a small section of the wing redirect airflow to delay loss of lift.

Stability and control characteristics at high-angle-of-attack flight conditions were evaluated in numerous wind tunnel tests at Langley (approx. 1,500 occupancy hrs in 30- by 60-Foot Full Scale Tunnel, 1993-4). Free-flight testing was also conducted to provide confirmation of the stability and flight dynamic characteristics. In this test technique, a tethered model powered by high-pressure air is flown in the tunnel in a flight control simulation consisting of a team of pilots and a representative flight control software package. The control system logic used was similar to that in the actual aircraft, providing validation of the flight control system at high-angle-of-attack prior to full-scale flight demonstration.

Hundreds of free-spin tests quantified aircraft spin modes, determined the acceptable spin chute size and identified the optimal spin recovery procedures prior to flight test (Langley 20-Foot Vertical Spin Tunnel, 1993-96). Motion time histories from these tests were used by McDonnell Douglas to validate their spin simulation. Data from rotary balance tests conducted in this facility provided an analytical assessment of spin modes, spin-recovery characteristics and a database for incorporating rotational aerodynamic characteristics into the flight simulation.

An F/A-18E/F structural vibration — or flutter — clearance test program was also conducted at Langley (Transonic Dynamics Tunnel, 1993- 95). Phase one testing insured that each pair of dynamically-scaled surfaces (wings, horizontal tails, and vertical tails) was clear of flutter throughout the scaled flight envelope. The second phase of tests was with and without stores (bombs, fuel tanks, etc.) mounted to the wings. These tests used the tunnel's unique two-cable mount system, which allows the model to actually fly in the center of the tunnel with assistance from a pilot in the control room. The tests verified that the aircraft was free from aeroelastic instabilities including flutter within its flight envelope.

The E/F's new engine inlet system was analyzed for icing characteristics at NASA Glenn (formerly NASA Lewis). The analysis determined the sensitivity of the inlet to icing and determined the best location for an icing sensor in the inlet. Critical icing tests followed (Icing Research Tunnel, 1994).

Glenn also provided advice on thermal problems encountered in the accessories gearbox for hydraulic and electrical power — specifically, how to manage oil flow in the gearbox to provide lubrication and cooling flow in critical areas where heat is generated.

The Flight Test Phase

As a result of NASA's corporate knowledge of the airplane's aerodynamics gained from the efforts mentioned above, the U.S. Navy requested direct NASA involvement when the F/A-18E/F moved into the flight test. NASA continued to work closely with the U.S. Navy and Boeing during the engineering and manufacturing development phase. NASA support included flight test planning and data evaluation, especially in the high angle-of-attack regime.

One example of NASA's contribution to high-performance aircraft flight technology is the development of a method for predicting and evaluating the complex out-of-control flight mode known as “falling leaf.” Initiated at Langley in 1995, this research was performed as a result of the flight mode observed on the F/A-18A, B, C and D versions of the aircraft. The fundamental cause of the phenomena on the A through D versions was identified, and a prediction and evaluation methodology was defined. This technology, applied by Boeing engineers in F/A-18E/F program, contributed to alleviation of the mode for the aircraft, as proved using the evaluation methodology during the flight test phase.

Helping to Resolve Wing Drop

During the winter of 1997-98, the Navy asked NASA for assistance in resolving a phenomenon known as “wing drop,” which was a growing concern during flight tests. Wing drop is an abrupt, uncommanded rolling motion of the aircraft during certain flight conditions. Although not a safety of flight issue, the roll-offs occur during high-speed, high-g maneuvers and prevent the pilot from performing close-in tracking maneuvers on potential adversaries.

Having identified wing drop as a problem in early 1996, the Boeing/Navy team performed wind tunnel tests and computational fluid dynamic (CFD) studies in an effort to identify the root cause. Though the cause of the wing drop was determined, knowing how to moderate the air flow separation differences between the left and right wings was not. A wide variety of solutions were explored.

During this period, Langley engineers suggested that the flight program apply a NASA-developed technology — passive porosity— to a small section of the upper surface of the wing at the point where the wing folds for aircraft carrier operations. This solution, refined by the NASA and Boeing team, resolved the wing drop problem and permitted the Department of Defense to authorize continued production of the aircraft.

To contrast the airflow patterns between the F/A-18E/F and earlier F-18’s, NASA Dryden flew an F-18B to visualize in-flight wing surface flow field data. The data verified that there are significant differences between airflow characteristics of the two aircraft. NASA engineers also served on a Department of Defense blue ribbon panel convened to review the approach taken by Boeing to resolve the wing drop, and participated on various Boeing/Navy “tiger teams” created to resolve issues related to the wing drop problem.

Drop Model Testing

Risk reduction for the high-angle-of-attack part of the flight test program is provided by a drop model operated by NASA Langley at the NASA Wallops Test Range. These tests, using a one-quarter-scale remotely-piloted model, supplement the aircraft flight test program by providing flight dynamics data for the airplane at conditions outside the planned operating envelope.

Remotely piloted drop model tests probe the limits of the flight envelope.

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