Birds change the shape of their wings in flight. Now, aircraft designers have come up with the Mission Adaptive Wing to give aircraft some of the same advantages.

Pilot Report:
AFTI F-111

BY MAJ. SCOTT E. PARKS, USAF

Prior to the jet age, optimizing wing shape was not a concern because of limitations in aircraft altitudes and airspeeds. Later expansion of the flight envelope, with the advent of jet-powered supersonic fighters and bombers, forced designers to recognize the critical need for a variable shape wing. High-performance aircraft need a wing that is efficient at high subsonic and supersonic speeds and that at the same time can minimize approach speeds for landing. Flaps are one answer to this dilemma.

Flaps have been used for many years to allow aircraft to fly at lower approach speeds on landing. As aircraft materials and control systems have been improved, flaps have been automated and their use extended to flight at high speeds and elevated load factor. Flaps used for this purpose are often called maneuvering flaps. A number of current aircraft, including the F-16 and F/A-18, employ maneuvering flaps. These give designers some ability to improve wing performance throughout the flight envelope.
The Advanced Fighter Technology Integration (AFTI) F-111 research program is designed to flight-test a totally new concept called the Mission Adaptive Wing (MAW). This wing, just like the hawk's, optimizes its performance by continuously and smoothly changing shape in flight. The AFTI F-111 is sponsored by the Air Force Flight Dynamics Laboratory (AFFDL) and NASA.

I had the opportunity to be one of the first two Air Force test pilots to fly the AFTI F-111 and was active in the program from March 1984 through my departure from Edwards AFB in July 1987. We began a two-phase flight-test program evaluating the MAW concept in 1985. Phase I, completed in November 1986, met its objectives by determining the feasibility of a MAW on high-performance aircraft. The second phase, currently in flight test at Edwards AFB, is demonstrating potential uses for this unique wing design.

The F-111 aircraft we used for AFTI was flown from 1973 to 1979 in a program called Transonic Aircraft Technology (TACT). TACT tested a unique wing shape called the supercritical airfoil that improved cruise performance in high subsonic flight and verified the performance advantage of this type of wing in cruise flight. An advanced version of this type airfoil became one of the many shapes of the Mission Adaptive Wing.

Testing a New Aircraft

Simulation played an important role in the engineering development of the MAW. Flying simulators is definitely not the most popular part of a program for the pilots, but for every hour in flight, we spent many times that in the simulator.

Prior to first flight, our knowledge of how the aircraft would fly was very limited, thus requiring many hours "in the box" evaluating controllability. In addition, the simulator was extremely useful in developing emergency procedures. For example, we found that under certain flight conditions, the aircraft would be uncontrollable if there were an uncommanded asymmetry between the left and right wings. This knowledge changed our operating procedures to avoid this condition. The flight profile for every test flight is flown first on the simulator, which allows the pilots to make maximum use of available flight time.

We treated the first flight of the AFTI F-111 as if we were flying a new aircraft. Externally, the aircraft looks somewhat like an F-111, but the unique wing and internal changes created many unknowns that required a cautious approach. The flight profile consisted of little more than takeoff, systems checks, controllability evaluation, and landing. It had been flown in the simulator many times prior to flight.

The day before the first flight, a dress rehearsal was conducted with the control room operational and a high-speed taxi down the runway. Control room operation is similar to Houston control for spacelaunches and depends on experts in every facet of the aircraft. One individual is designated NASA 1 and is the only person allowed to communicate with the aircraft.

Lt. Col. Frank Birk (USAF) and Rogers Smith (NASA) manned the aircraft on the first flight, while I flew chase in a T-38. Einar Evoldson (NASA) was NASA 1. The initial takeoff was made toward the dry lake bed at Edwards in case of an abort. To the satisfaction of all involved, the flight went flawlessly and inaugurated Phase I of testing.

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With the Mission Adaptive Wing in the fully cambered position, as in this photo, both the leading and trailing edges move approximately twenty degrees downward. The upper surfaces of both edges are made of high-strength, lightweight composite material that bends when actuated by internal hydraulic systems.

That first flight also established a new flying specialty. The project test pilots who flew in the right seat did not appreciate being referred to as copilot or navigator. Wishing to alleviate the problem, Steve Smith of the Air Force Flight Test Center—joint manager (with NASA's Louis Steers) of flight test—created a new specialty, the Mission Adaptive Wing Systems Operator, or MAWSO. MAWSO became the standard reference for the pilot flying in the right seat.

The objective of the first flight-test phase was to determine the operation and basic aerodynamics of the Mission Adaptive Wing. This included verification of structural integrity and controllability. We accomplished this by cautiously expanding the flight envelope of the aircraft in altitude, airspeed, and load factor, which is measured in G forces. Within that envelope, actual performance data could then be collected.

Results indicate that the potential exists to meet or exceed the performance goals established from wind-tunnel data. Comparing TACT and MAW, the goals include a thirty percent increase in range, a twenty percent increase in sustained turn radius, and a thirty percent increase in usable buffet-free lift.

Systems evaluations are also con-
ducted to verify proper operation of the MAW and its interface with the aircraft. Operation with one hydraulic system or one engine out was of particular concern, and a significant amount of ground testing was required to determine if the wing could operate under these adverse conditions. An unplanned test of this was almost conducted on the aircraft's third flight and my first flight-test program and has never been brought up to the production standard. This poses some interesting problems for the maintenance team. Replacement parts have sometimes been difficult to come by, and unique "work-around" procedures have had to be devised.

While the aircraft is already non-standard, modifications made for the MAW test program make it truly unique. The existing wings are replaced with Mission Adaptive Wings, and the fuselage is modified to allow the new wings to sweep aft without interference. Extensive instrumentation is added to the weapons bay to monitor every facet of the wing's operation. Computers for controlling the wing are housed in the nose.

Clearly, the most significant modification to the aircraft is the wing itself. It is designed with a completely smooth upper surface and actuation mechanism housed totally within the wing. The center portion of the wing (wing box) is fixed in shape, with only the leading and trailing edges capable of deflection.

The wing box was also used in the TACT program. The leading edge of the wing is a single-span surface, while the trailing edge consists of three panels capable of independent motion.

Both the leading edge and trailing edge move approximately twenty degrees in their fully deflected positions. The upper surface of the leading and trailing edges is made of a composite material that actually bends to change the wing shape.

Power for actuation of the wing comes from the dual hydraulic systems found on the standard F-111. Each system is upgraded to increase its capacity and is capable of independently operating the wing. The eight hydraulic drive units, two for the leading edge and six for the trailing edge, are capable of very fast response and require no mechanism external to the wing. Designing an entirely internal mechanism was a difficult but not insurmountable task.

**How the Wing Works**

The F-111 used in the research program is a preproduction A model that was used in the original F-111 flight-test program and has never been brought up to the production standard. This poses some interesting problems for the maintenance team. Replacement parts have sometimes been difficult to come by, and unique "work-around" procedures have had to be devised.

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Control of the wing is via dual digital computers with two analog computers used for backup. Each digital computer commands one of the two drive units for each surface. The analog computers take over if the commands from the digital computers do not agree or if any errors are detected. Without these high-capacity digital computation devices, control of the Mission Adaptive Wing would be nearly impossible.

Selection of manual and automatic modes is accomplished via a control panel located between the pilot and the MAWSO. With the wing operating in manual mode, the single leading edge and three trailing edge sections on each wing can be independently positioned symmetrically to any desired position. In addition, through the pilot’s control stick inputs, the midspan and outboard trailing edge panels can move asymmetrically to assist in roll control.

The fleet F-111 uses spoilers to accomplish the same function. All automatic modes can be engaged independently, and some modes can be engaged jointly via the control panel. For example, maneuver camber control and maneuver load control could be selected in order to complement each other.

The control panel also provides cockpit warning of any MAW-related malfunctions and the ability to lock in place symmetrically each set of movable panels. The gun trigger on the control stick is modified, in the event of a malfunction, to position the wing immediately to the shape tested during TACT. This gave us a very quick way of shaping the wing to a known configuration should something unexpected occur.

What Can the Wing Do?

Current wing designs are a compromise involving many factors. Some of these include maneuverability, cruise performance, and strength. Wings are optimized for one flight condition and then modified to obtain satisfactory characteristics throughout the flight envelope.

These compromises create a particular problem with fighter aircraft that have a large altitude and airspeed range and are required to possess maneuver capability up to high G levels. As G is increased, a wing designed for level flight cruise becomes less efficient, which limits the sustained G capability of the aircraft. The farther from design condition the aircraft is maneuvered, the greater the loss in efficiency.

Flaps have been used for many years to allow a wing optimized for cruise flight to also provide reasonable approach speeds for landing. The increased drag associated with these surfaces and their structural design limits minimized their usefulness for cruise and maneuvering flight.

As strong, lightweight materials became available, maneuvering flaps were designed that could be operated throughout most of an aircraft’s flight envelope. Improvements in flight-control systems allowed operation of maneuvering flaps to be automated. Current-generation fighter aircraft use maneuvering flaps to improve performance during such maneuvering flight as air combat. For example, the F/A-18 automatically deflects both its leading and trailing edge flaps when the wing reaches high angles of attack. The great disadvantage of these surfaces is relatively high drag (compared to that of a smooth surface) when they are in operation.

The Mission Adaptive Wing solves this problem. An F/A-18 operating with the maneuver camber control described previously would have its wing continuously changing shape as a function of flight condition. This would provide the pilot higher sustained G capability and higher overall energy level. Both of these are important to aerial combat.

Another example of improved maneuverability that could be provided by the Mission Adaptive Wing is a concept called “direct lift.” When a pilot commands a change in pitch, the wing deflects in combination with other control surfaces to produce a change in flight path. This mode allows the aircraft to be more responsive to pilot inputs and can increase a fighter’s ability to generate instantaneous G.

Other features inherent in the design of the Mission Adaptive Wing have the potential to improve fighter, bomber, and transport performance. One of these is the ability to change the distribution of air loads along a wing while in flight.

For long-range missions, it is desirable to increase the ratio of a wing’s length to its width (chord), thus increasing its aspect ratio. The ability to do this is limited by structural loads at the wing root, which increase as a function of wing length. The stiff, low-aspect-ratio wings of most fighter aircraft result from their need to achieve high G and the resulting high wing loads. Even in cruise flight, the aspect ratio of a wing is limited by the need to provide a safety factor for protection from gusts. A limited solution to this problem is employed by such aircraft as the U-2, in which the pilot can manually reposition the outboard sileron to reduce the loads at the wing root. A Mission Adaptive Wing can carry this concept much further.

The MAW, with its digital control system and fast response time, can continuously compute the loads at the wing root and change the camber of the outboard section of the wing as required to control those loads. For fighters, this means wings that have lower structural weight or can achieve higher maximum G. In transport and bomber designs, the higher-aspect-ratio wings allowed by the concept of load control can produce improved fuel consumption and longer range and endurance.

All aircraft, regardless of mission, cruise during some portion of their flight profile. The traditional fixed-wing shape is suitable for aircraft, such as transports, that cruise at a fixed speed and altitude. Other aircraft, such as strategic bombers and fighters, which must cruise at a high altitude and must ingress to a target area at low altitude and high speed, would benefit from the Mission Adaptive Wing concept.

The MAW with cruise camber control deflects the trailing edge of the wing until maximum forward velocity is obtained regardless of flight condition. This is especially effective for an aircraft, such as the Advanced Tactical Fighter, that must cruise in both the subsonic and supersonic flight regimes. This concept may also allow aircraft to achieve higher maximum altitudes, which may be important for recon-
prepared to develop new airfoil shapes for each of the flight conditions that future aircraft will encounter. Result: a more complex design process, with a need for structures, flight controls, and other elements to work closely together.

Another benefit is the MAW's capability to provide maximum performance even when carrying external stores. The gust-alleviation mode is especially important for aircraft that must cruise at low altitude and high speed. Good low-level ride quality is generally associated with aircraft that have high wing loading (force per unit area) on the wing—for example, the production F-111. The disadvantage of high wing loading is a large rate of energy loss when the wing is subject to G. The Mission Adaptive Wing can achieve the same ride quality with lower wing loading.

What's the Catch?
The first thought most everyone has is that the MAW must be heavier, more complex, and more costly to maintain than existing wing-flap designs. This is not true. Ron DeCamp, AFFDL program manager for the AFTI F-111, provides excellent answers to these common misconceptions. Using the F-111 as an example, Mr. DeCamp states that replacing the existing complex arrangement of slots and flaps with a production version of the MAW would actually save approximately 600 pounds. Also, maintenance costs may actually be reduced for an MAW aircraft.

Current aircraft with slots, slats, and flaps have crevices that collect dirt, ice, snow, etc., that can jam the sliding tracks and hinges. The MAW mechanisms, on the other hand, are completely sealed, which Boeing estimates may reduce maintenance requirements by as much as thirty-five percent. As to complexity, the MAW is no more complex than the maneuvering flap designs found on current generation fighters. Another misconception is that the MAW mechanisms extend into the wing fuel cavity and thus reduce aircraft fuel capacity. Not true! All mechanisms of the MAW leading and trailing edges are confined to areas formerly occupied by high lift devices.

The higher approach speeds used on the AFTI F-111 research vehicle were dictated by the production F-111 design, which limits the landing angle of attack to prevent the tail from making contact with the runway. Designers could use one of two approaches on future aircraft to provide satisfactory speeds for landing. The most desirable approach is to design the aircraft to land at a higher angle of attack, taking advantage of the higher stall angle of attack available with the Mission Adaptive Wing. The second approach is to add existing high-lift devices to the MAW. This alternative is less desirable because of the added weight and complexity.

In short, the "catch" is that designers must be ready to develop a new airfoil shape for each of the many flight conditions that future aircraft will encounter. This will make for a more complex design process, one in which all disciplines (structures, flight controls, aerodynamics, etc.) must work more closely together.

The first phase of testing, completed in November 1986, proved the functional capability and aerodynamic potential of the Mission Adaptive Wing. The current phase of testing, slated for completion in 1988, is evaluating the automatic modes and the ability to maintain aerodynamic efficiency and operational flexibility without adding to pilot work load or interfering with other pilot tasks.

Future applications of the MAW include improved aircraft maneuverability, control of load distribution on the wing, better ride qualities, and improved cruise performance. This equates to enhanced range and payload for bombers and increased G capability and reduced energy loss during maneuvering for fighters.

The AFTI F-111 test program is just the first step in proving the concept of the Mission Adaptive Wing. While there are unquestioned performance benefits, they will have to be weighed against the wing's added design complexity. As with any new idea, it must be integrated in light of real-world constraints. There is much work yet to be done, but the AFTI F-111 is a giant first step.

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