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NASA Dryden Flight Research Center • P.O. Box 273 • Edwards, CA. 93523 • Voice 661-276-3449 • FAX 661-276-3566 • technology@dfrc.nasa.gov

TF-2004-13 DFRC

The Supercritical Airfoil

Supercritical wings add a graceful appearance to the modified NASA F-8 test aircraft.

NASA Photo E73-3468

An airfoil considered unconventional when tested in the early 1970s by NASA at the Dryden Flight Research Center is now universally recognized by the aviation industry as a wing design that increases flying efficiency and helps lower fuel costs.

Called the supercritical airfoil, the design has led to development of the supercritical wings (SCW) now used worldwide on business jets, airliners and transports, and numerous military aircraft.

Conventional wings are rounded on top and flat on the bottom. The SCW is flatter on the top, rounded on the bottom, and the upper trailing edge is accented with a downward curve to restore lift lost by flattening the upper surface.

At speeds in the transonic range -- just below and just above the speed of sound -- the SCW delays the formation of the supersonic shock wave on the upper wing surface and reduces its strength, allowing the aircraft to fly faster with less effort.

NASA's test program validating the SCW concept was conducted at the Dryden Flight Research Center from March 1971 to May 1973 and showed that the SCW installed on an F-8 Crusader test aircraft increased transonic efficiency by as much as 15%.

Before the program ended, the U.S. Air Force teamed with NASA for a joint program to test a SCW designed for highly maneuverable military aircraft. An F-111, with a variable-geometry wing, was the test aircraft and the basic supercritical research took place between 1973 and 1975. Results were extremely successful and showed the test wing generated up to 30% more lift than the conventional F-111 wing and performed as expected at all wing-sweep angles. The F-111 program, while it did not lead to a SCW retrofit for the entire F-111 fleet, did produce data that is available to the aerospace industry for development of future aircraft.

Supercritical Benefits

When an aircraft with a conventional wing nears a speed of sound (Mach 1), air flowing across the top of the wing moves faster and becomes supersonic. This creates a shock wave on the wing's upper surface even though the aircraft, as a whole, has not exceeded Mach 1. The aircraft, at this point, is flying at what is called the critical speed. The shockwave causes the smooth flow of air hugging the wing's upper surface (the boundary layer) to separate from the wing and create turbulence. Separated boundary layers are like wakes behind a boat -- the air is unsteady and churning, and drag increases. This increases fuel consumption and it can also lead to a decrease in speed and cause vibrations. In rare cases, aircraft have also become uncontrollable due to boundary layer separation.

Supercritical wings have a flat-on-top "upside down" look. As air moves across the top of a SCW it does not speed up nearly as much as over a curved upper surface. This delays the onset of the shock wave and also reduces aerodynamic drag associated with boundary layer separation. Lift that is lost with less curvature on the upper surface of the wing is regained by adding more curvature to the upper trailing edge. Now the aircraft can cruise at a higher subsonic speed and easily fly up into the supercritical range. And with less drag, the aircraft is using less fuel than it would otherwise consume.

Higher subsonic cruise speeds and less drag translates into airliners and business jets getting to their destinations faster on less fuel, and they can fly farther -- factors that help keep the cost of passenger tickets and air freight down.

NASA's two-year SCW flight test program between 1971 and 1973 substantiated predictions of better flying efficiency and reduced operating costs at a time when soaring fuel prices hit the aviation industry hard.

Test data showed that the SCW on the F-8 test aircraft increased its efficiency by as much as 15%. Test results, once calculated, predicted that jetliners with SCWs would realize a 2.5% increase in operating profits over aircraft with conventional wings. For an air carrier with a 280-plane fleet of jetliners, each with 200 seats, this represented $78 million annually in 1974 dollars.

Other calculations indicated that the net gain for air carriers worldwide would be nearly one-half billion dollars -- all due to fuel savings of the supercritical airfoil.

Rockwell, Canadair, and Lear were among the first commercial firms to apply SCW technology to their business-size aircraft in the United States, and in Europe it was Dassault, also a builder of business jets.

Supercritical wing technology is now incorporated into the designs of commercial, business, and military aircraft around the world. They include the 777 jetliner, C-17 Air Force transport, and AV-8B Harrier built by Boeing. Others using SCW technology carry the corporate names of Bombardier, Lear, Challenger, Galaxy, Raytheon, Gulfstream, Cessna, Falcon, Airbus Industries, Dassault-Brequet-Dornier, and Israel Aircraft Industries.

Boeing's 757 and 767 jetliners, and the new generation of 737 aircraft, also have wings designed with some form of applied supercritical technology.

Several military aircraft in testing and development stages are being built with SCW technology. Among them are the Lockheed-Martin F-22 advanced technology fighter, and the two aircraft that will be considered for the U.S. military Joint Strike Fighter production contract, the Boeing X-32 and the Lockheed-Martin X-35.

From Sketch to Test

Dr. Richard Whitcomb, a renowned aeronautical engineer at Langley, developed the concept of a supercritical wing. He was one of many engineers in the 1950s and 60s fascinated by the transonic speed regime.

The X-1 research aircraft had become the first to fly faster than the speed of sound (Mach 1) in 1947 and eliminate fears of the so-called sound "barrier." But there was still much to be learned about the behavior of air just below and just above the speed of sound, and the shockwaves that form on the top of wings.

In the 1950s, Whitcomb created the area rule (wasp waist) design that gave supersonic aircraft the "pinched look" to reduce aerodynamic drag and increase transonic speed without added power. He then turned his attention to investigating different airfoils to weaken the shockwave and reduce the boundary layer separation. This, he believed, would also improve transonic performance, especially for transport aircraft.

Whitcomb's engineering instincts led him to concentrate on the "upside down" airfoil, which he refined on models in wind tunnels at Langley. On a final series of tests, a SCW wing model was swept rearward 35% and tested in a wind tunnel to Mach .90 -- just under the speed of sound -- and it generated 5% less drag than conventional airfoils.

The success of Whitcomb's wind tunnel and design studies led to approval in February 1969 of a SCW flight test program at Dryden. A $1.8 million contract to build the test wing was awarded to the North American Aircraft Division of Rockwell International, and the completed wing was delivered to Dryden in December 1969.

The test aircraft was an F-8 Crusader obtained from the U.S. Navy. It was the ideal SCW testbed, because the aircraft’s standard variable-incidence wing was easily removed and the test wing could be installed without major structural changes. The main landing gear also retracted into the fuselage, leaving the test wing without any obstructions. With a top speed of Mach 1.7, the F-8 had a full transonic range.

Originally, the test wing was going to be built without any flight control surfaces -- ailerons and flaps -- to achieve the best possible aerodynamic performance. This would mean modifying the flight control system to give the stabilizers asymmetric rolling capability would produce the only roll control. When studies showed that the rolling tail might not have provided adequate control at low speeds, the ailerons were returned to the design.

The decision to build the wing without flaps remained, however, giving the test aircraft a longer-than-normal takeoff roll and a landing speed of 195 mph. The landing speed was too fast for the conventional 15,000-foot runway at Edwards, because the aircraft did not have antiskid capabilities in its braking system; so all landings were on Rogers Dry Lake.

NASA's SCW project pilot was Tom McMurtry. The first flight on Mar. 9, l971, lasted 50 minutes and verified the basic stability and handling qualities of the sweeping, graceful wing design. McMurtry was the first of 10 pilots who eventually flew the SCW aircraft before the 86th and final flight on May 23, 1973.

Throughout the entire flight program, the test aircraft and its supercritical wing displayed good stability and control at all transonic speeds and at altitudes up to nearly 50,000 feet.

Before the flight research program reached the halfway mark, test data confirmed wind tunnel forecasts of faster subsonic cruising speeds and greater fuel efficiency, prompting early interest in the SCW concept by aircraft manufacturers and airlines.

In 1974, about one year after the final research flight, Dr. Whitcomb received the Wright Brothers Memorial Trophy from the National Aeronautic Association for his SCW design work.

The SCW Test Aircraft

The F-8 Crusader used as the SCW test aircraft was built by LTV Aerospace, Dallas, Tex., for the U.S. Navy. F-8s were the first carrier-based aircraft with speeds over 1,000 mph. A total of 1,261 F-8s were built between 1955 and 1965.

Designation: NASA 810; Navy Bureau of Aeronautics 141353

The aircraft's engine was a Pratt and Whitney J-57 turbojet that produced 13,750 lbs of thrust.

The aircraft had an original wingspan of 35 ft. 2 in. Wingspan with the Supercritical Wing was 43 feet. The overall length of 54 ft. 6 in. and maximum height of 15 ft. 9 in. at the tail were unchanged with the wing modification.

LTV received the Collier Trophy for the design and development of the F-8.

The SCW F-8 is publicly displayed at NASA's Dryden Flight Research Center, Edwards, Calif.

NASA Photo EC95-43002-2