

Winglets



*Close-up of winglet on KC-135 test aircraft, with attached tufts displaying flow of air over winglet surface.
NASA Photo EC79-11481*

Winglets are one of the most successful examples of a NASA aeronautical innovation being utilized around the world on all types of aircraft.

Winglets are vertical extensions of wingtips that improve an aircraft's fuel efficiency and cruising range. Designed as small airfoils, winglets reduce the aerodynamic drag associated with vortices that develop at the wingtips as the airplane moves through the air. By reducing wingtip drag, fuel consumption goes down and range is extended.

Aircraft of all types and sizes are flying with winglets -- from single-seat hang gliders and ultralights to global jumbo jets. Some aircraft are designed and manufactured with sleek upturned winglets that blend smoothly into the outer wing sections. Add-on winglets are also custom made for many types of aircraft.

The concept of winglets originated with a British aerodynamicist in the late 1800s, but the idea remained on the drawing board until rekindled in the early 1970s by Dr. Richard Whitcomb when the price of aviation fuel started spiraling upward.

Whitcomb, a noted aeronautical engineer at the NASA Langley Research Center, refined the winglet concept with wind tunnel tests and computer studies. He then predicted that transport-size aircraft with winglets would realize improved cruising efficiencies of between 6% and 9%. A winglet flight test program at the NASA Dryden Flight Research Center in 1979-80 validated Whitcomb's research when the test aircraft -- a military version of the Boeing 707 jetliner -- recorded an increased fuel mileage rate of 6.5%.

The Benefits of Winglets

Since the 1970s, when the price of aviation fuel began spiraling upward, airlines and aircraft manufacturers have looked at many ways to improve the operating efficiency of their aircraft. Winglets have become one of the industry's most visible fuel-saving technologies and their use continues to expand.

Winglets increase an aircraft's operating efficiency by reducing what is called induced drag at the tips of the wings. An aircraft's wing is shaped to generate negative pressure on the upper surface and positive pressure on the lower surface as the aircraft moves forward. This unequal pressure

creates lift across the upper surface and the aircraft is able to leave the ground and fly.

Unequal pressure, however, also causes air at each wingtip to flow outward along the lower surface, around the tip, and inboard along the upper surface producing a whirlwind of air called a wingtip vortex. The effect of these vortices is increased drag and reduced lift that results in less flight efficiency and higher fuel costs.

Winglets, which are airfoils operating just like a sailboat tacking upwind, produce a forward thrust inside the circulation field of the vortices and reduce their strength. Weaker vortices mean less drag at the wingtips and lift is restored. Improved wing efficiency translates to more payload, reduced fuel consumption, and a longer cruising range that can allow an air carrier to expand routes and destinations.

To produce as much forward thrust as possible, the winglet's airfoil is designed with the same attention as the airfoil of the wings themselves. Performance improvements generated by winglets, however, depend on factors such as the basic design of the aircraft, engine efficiency, and even the weather in which an aircraft is operating.

The shapes and sizes of winglets, and the angles at which they are mounted with respect to the main wings, differ between the many types and sizes of aircraft produced but they all represent improved efficiency. Throughout the aviation industry, winglets are responsible for increased mileage rates of as much as 7%.

Aircraft manufacturers and makers of add-on winglets have also reported improved cruising speeds, time-to-climb rates, and higher operating altitudes.

The use of winglets throughout the aviation industry in the U.S. and overseas is constantly

growing. Winglets now appear on powerless hang gliders soaring above mountain ridges and from seaside cliffs. Sailplane builders around the world have included blended winglets to their designs and the sleek, graceful gliders are silently soaring farther than ever

Corporate-size Learjet's were the first commercial aircraft to use winglets. Now, several decades later, winglets are incorporated into the designs of many other business jets such as Gulfstreams and the Global Express: a new aircraft built by Lear's parent company, Bombardier.

Retrofitting winglets to existing business jets is also a fast-growing market within the aviation industry itself. Many winglet marketing firms report their products help increase aircraft roll rates and lower approach and takeoff speeds.

Winglets are now quite common on large jetliners and many tower as high as six feet. The first big jetliner to carry the innovation into the air was the MD-11, originally designed and built by McDonnell-Douglas and now part of the Boeing aerospace family. Other Boeing aircraft flying with winglets are the 747-400, the version currently being



One of many McDonnell Douglas (now Boeing) MD-11 aircraft built with winglets in low flight over Edwards AFB during a flight control system demonstration.

NASA Photo EC95 433355-2

built, Boeing BBJ business jets which are custom-built 737s, and the C-17 military transport. Boeing is also offering winglet options on new advanced models of the 737 series of passenger jets.

Most prominent foreign carrier of winglets are the many models of the 300 series of jetliners designed and built by Airbus Industries. The future A3XX Airbus, a huge intercontinental double-deck jetliner now under development, will also utilize winglet technology.

The first homebuilts with winglets on the general aviation market were the Vari-Eze and Long-Eze models designed by Burt Rutan, a pioneer in aircraft design innovations. Now, the majority of homebuilt aircraft coming out of shops, garages, and hangars around the world display winglets of varying shapes and sizes.

During 1979 to 1983, a pair of remotely piloted test aircraft called HiMAT, Highly Maneuverable Aircraft Technology, was flown at Dryden to study high-performance fighter design and construction technologies. Each of the subscale vehicles had blended winglets that generated data for a program that has helped in the development of many military, commercial, and business aircraft.

Testing Winglets

The winglet test program conducted at Dryden in 1979-80 followed several years of wind tunnel tests and analytical studies by Dr. Richard Whitcomb at NASA Langley.

Whitcomb had studied the original winglet concept developed by British aerodynamicist F.W. Lancaster in the late 1800s. Lancaster's patented concept said a vertical surface at the wingtip would reduce drag. Whitcomb took that concept a step further by making the vertical surface a refined airfoil that reduces drag by interacting with the wingtip airflow circulation and vortex.

Studies at Langley also included tests of a DC-10 model in a wind tunnel that showed that the winglets on the model reduced overall drag by 5% compared to the model without the devices. These tests were followed by a Boeing engineering study of a 747 with winglets, and a prediction that a 4% drag reduction would result. These positive conclusions, coupled with Whitcomb's work, prompted the U.S. Air Force to consider the possible installation of winglets on KC-135 and C-141 transport aircraft.

The winglet flight test program brought together NASA, the U.S. Air Force, and Boeing, which began the effort with configuration studies and contractual work to design and manufacture the test articles which measured 9 feet high and 6 feet across at the base. Wind tunnel studies were carried out at Langley where researchers tested the winglet models at various air speeds and also in a variety of flap and aileron configurations to validate the design work. Wind tunnel results predicted a 6% drag reduction on the winglet-equipped test aircraft.

The U.S. Air Force furnished the KC-135 test aircraft. It was delivered to Dryden in late 1977 for the installation of sensors and recorders that would obtain in-flight performance data. The winglets and the test aircraft's modified outer wing panels arrived at Dryden from Boeing in May 1979, setting up an installation and checkout period that climaxed with the program's first test flight on July 24, 1979.

During the 48-flight test program, the winglets -- designed with a general-purpose airfoil that remained the same from root to tip -- could be adjusted to seven different cant and incidence angles to give researchers a broad picture of their performance in a variety of flight conditions.

The major areas of study during the program were aerodynamic loads on the winglets; distribution of air pressure over their surfaces; how they affected the test aircraft's stability and control; susceptibility to buffeting and flutter; and drag reduction.

Flight conditions in which test data was obtained included a cruise speed of about 500 mph at altitudes of 30,000 to 35,000 feet; push-over and pull-up maneuvers; steady-state sideslips with the nose both left and right; accelerated turns and banks; and elevator, rudder, and aileron raps to set up flutter and buffeting conditions. During these test conditions, the aircraft handled and behaved as predicted and expected.

Among the seven cant and incidence angles tested, the combination that produced the best results was a 15-degree cant angle and a minus 4-degree incidence angle.

Test results closely matched the original predictions of Whitcomb and data produced in the pre-flight wind tunnel studies: winglets on the KC-135 test aircraft increased its fuel mileage rate by 6.5% -- better than the 6% projected by the wind tunnel studies.

The positive results of the joint NASA-Air Force-Boeing test program are not limited to paper reports. The results can be seen on the wings of aircraft flying into and out of airports all over the world.



Air Force KC-135 test aircraft in flight during NASA winglets study.

NASA Photo EC79-11484