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CITATION X GROWS WINGLETS

>>> The fastest civilian airplane now climbs higher and faster with graceful new winglets.

BY J. MAC McCLELLAN / PHOTOS COURTESY OF CESSNA

IN MANY WAYS the Cessna Citation X is an extreme airplane. Its radically swept wing, huge wing-to-fuselage fairing and enormous vertical fin are unique in the business jet world. The X looks like it does because that's what it took to reach the goal of being the fastest civilian airplane now in service.

With its limit speed of Mach .92 the X can cruise up to about 528 knots true airspeed. A more typical fast jet cruise speed is around Mach .82, which equals about 470 knots. And lots of jets, particularly the extremely popular Boeing 737, cruise well under Mach .80, which is 459 knots. The Citation X does stand out.

The Citation X hits its top speeds, like any jet does, at lighter cruise weights and at altitudes below maximum fuel efficiency. But the X has the range to cross the country at top speed, and that's what many passengers want. When you buy the fastest airplane available, why throttle back? But there are trips that require longer range than the X's typical 3,000 miles. And there are warm temperatures aloft that rob cruise efficiency from any jet. As many jet makers have shown, the way to improve on both of those situations is with carefully designed winglets, and now the X can have them.

A winglet is actually a very clever way to make a wing behave as though it has greater span without adding all of the structural loads the longer span requires. Winglets are not a free lunch, for takeoff and landing. But for climb and cruise, a long slender wing dominates jet design.

A successful winglet captures some of the energy of the high-pressure air under a wing that is escaping at the tip. The shape of the winglet is, of course, critical, and so is its angle from the vertical. The more a winglet tilts outward away from the fuselage, the more lift it can generally add. But that tilt transfers bending loads back into the wing, so more structure and weight are required to carry them. The optimum tilt of a winglet is the angle that gives the most added lift for the least structural load on the wing.

Another key issue in winglet design is reducing the induced drag — the drag caused by generating lift — while minimizing overall drag of the extra area. If a winglet increases lift substantially so that a jet can climb to higher, more efficient altitudes faster, that's good. But if in the process it adds so much drag that top speed is reduced at lower altitudes, that's not a good trade.

So the challenge for Cessna and its partner Winglet Technology was to create a winglet for the Citation X that

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but they can pay for themselves in terms of fuel savings and avoiding en route fuel stops.

In general, the longer the span of a wing the more efficient it is in climb and high-altitude cruise. Think of gliders with their fundamental requirement for efficiency since they have no engine. A glider wing is extremely long and thin to extract the most lift from the air for the lowest drag penalty.

The modern jet wing is much like a glider's, with long span and narrow chord. Huge trailing-edge flaps and often leading-edge slats transform the jet wing into a different shape and add wing area for the low speeds needed

allowed the airplane to climb more quickly to very high cruise altitudes without robbing any of the top speed in the middle altitudes. That wasn't easy, and the project was in the works for several years.

The shape of the winglet, as well as its size and tilt, are the keys to success. Winglet Technology calls its patented shape "elliptical" to describe the shape that transitions from the horizontal wing surface up to the winglet. Shapes are very subtle, and other designers claim equal success with winglet shapes that only an expert — or patent attorney — can tell apart. The proof of success on the X is that, with the winglets, the airplane at 34,000 pounds — just 2,100 pounds below maximum — can climb directly to 47,000 feet in 27 minutes compared with about 93 minutes to step climb without winglets. That direct climb to FL 470 adds at least 160 miles of range. With above-standard temperature conditions at cruise, the winglets can add well over 400 miles of range.

The added lift of the winglets can also get the X out of high-elevation airports on hot days when engine-out climb restrictions are the limiting factor. With winglets the X can carry 1,200 more pounds of payload on the same hot day, or can depart with

Why Mach Matters

> Mach 1 is, of course, the speed that sound travels through air. Why does the speed of sound matter to an airplane in flight? It is because sound — which is actually pressure disturbances — travels at the maximum efficient speed without pushing air molecules ahead of it.

When an airplane moves through the air at speeds below Mach 1, the air ahead of it is not disturbed because pressure disturbances can't move fast enough. But at Mach 1 the airplane's pressure field is pushing air molecules faster than they can get out of the way, and a sharp pressure wave forms on the leading edges of the airplane. This wave creates tremendous drag, and the airplane must have sufficient power to push the wave along.

It is, however, wrong to think of Mach 1, the "sound barrier," as being an on-off switch because the local airflow over parts of the airplane are always moving faster than the airplane itself is. Air must accelerate to pass over the nose and fuselage, and over and under the wing. At some airspeed this "local airflow" will accelerate to Mach 1 while the entire airplane is moving much more slowly. This speed where local airflow hits Mach 1 is called the critical Mach because there is a big jump in drag.

Up to about 300 knots true airspeed there are no issues with Mach, but at higher airspeeds it takes careful design of the airplane to defeat, or delay, the drag rise of Mach effects. It is delaying, or controlling, the Mach effects of local airflow that the design of the Citation X is all about.

The large sweep-back angle of the wings and tail, and the shapes of the airfoils, control the drag rise of local airflow as the airplane exceeds 90 percent of the speed of sound, Mach .90. The very long engine nacelles and extremely long wing-to-fuselage fairing also contribute by increasing the fineness ratio. A long, slender object will suffer less Mach effect drag than a fat blunt shape will — think of an arrow, or the Concorde.

Despite the excellent efforts of Cessna engineers, there is still an economic penalty to cruising ever closer to Mach 1 because drag increase is inevitable and more power is required, thus there's higher fuel consumption. So by slowing down just .06 Mach from the X's maximum speed of Mach .92 to Mach .86 — about 34 knots — range jumps way up.

Mach 1 is no longer the "sound barrier" as was believed in the 1940s, but it remains an economic barrier to low-drag cruise efficiency. But with the Citation X leading the way, airplane designers are creeping ever closer to routine cruise speeds very close to Mach 1.

the same payload as the non-winglet airplane can at a temperature 4 degrees C hotter. The net result is more than 400 miles of range increase over the standard airplane.

The winglets on the X look great. These days a jet without winglets looks, well, kind of old-fashioned. For many years winglets were thought by many to be a band-aid to improve an improperly designed wing, so some jet designers, such as those creating the Citations and Falcons, avoided them. But it is now understood that the well-crafted winglet can bring very specific benefits to any airplane, no matter how successful the design of the basic wing. Plus, an airplane with all of the exotic drag-defeating shapes of the X should have winglets to complete its ramp presence.

Winglet Technology builds the winglets from carbon epoxy laminate with polished aluminum leading edges. Cessna conducted icing tests, and there is no need to heat the leading edges of the winglets. The winglets stand 4.2 feet high and extend the tip-to-tip span of the wing 5.3 feet for a total span of 69.2 feet. A new lens covers long-life LED position lights and anti-collision lights in the winglet. The winglets look as though they were born on the X, rather than being an add-on. A non-winglet airplane looks a little stodgy in comparison.

All of the test and demonstration pilots at Cessna agree that the winglets do not change the flying qualities of the X at all. Performance, yes, but the feel of the airplane, no. To see for myself, Cessna director of flight operations Dave Nolte and I saddled up with 11,500 pounds of fuel in the X, plus one passenger, bringing takeoff weight to 34,000 pounds, pretty typical for a transcontinental trip. The winglets with their necessary structural modifications add about 150 pounds to the empty weight, but that penalty can be recovered in fuel savings on most trips of any length.

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Unlike other jets in the Citation family, the X has big-airplane systems with hydraulically boosted flight controls, air starters on the engines and full-time yaw dampers. The Honeywell avionics system is one generation old and still uses CRT displays instead of flat glass, but see the companion story for information on an update there.

The X likes to fly fast, including on the runway where our V_1 decision speed was 126 knots with rotation at 128 knots. Once clear of the speed restrictions, typical climb speed is 285 knots until reaching Mach .83. That means the X is flying faster in climb than most business jets can achieve in cruise.

With only a couple of brief level-offs from ATC on the way up, we were through 38,000 feet in 21 minutes with air temperature above standard the whole way up. As we climbed, the air temp cooled to standard or a little below and the X climbed smartly with an indicated Mach of .83 until we reached 45,000 feet in 28 minutes' total time. At that level we still had 10,000 pounds of fuel in the tanks, the true airspeed hit 490 knots, and total fuel flow was about 1,760 pounds per hour.

Dave told me that the rule of thumb for fuel burn in the X is 2,800 to 3,000 pounds for the first hour up to 43,000 feet, and then about 2,000 pph for additional hours, adding or subtracting 100 pounds for each 1,000 feet of added altitude lower or higher. So with the winglets, an X crew can get to FL 450 without stepping and FL 470 on most days, saving hundreds of pounds in the first couple of hours compared with the airplane without winglets. The X is certified to 51,000 feet and with the winglets can get to that altitude with well over an hour's worth of fuel, plus reserve, left.

Despite the dramatic 37-degree wing sweep and the high Mach cruise numbers, the flying qualities of the X are very conventional. Highly swept wings can cause Dutch roll problems because, as one wing swings forward

Avionics Display Swap

The five displays in the Citation X Honeywell Primus 2000 avionics system are still the television-type CRTs that consume a lot of power, produce a lot of heat and can't show detailed images such as approach charts or Nexrad radar. However, Cessna and Honeywell have a plan to swap the CRTs for cool running flat-panel displays starting with new production airplanes early in 2011.

The new Primus Elite flat panels will be able to display Jeppesen approach charts and XM satellite weather, along with detailed moving maps that cannot be presented on the CRTs. The Citation service centers will offer the same display upgrade for existing airplanes in the second quarter of 2011.

With the flexibility of the new displays available, Cessna and Honeywell are hard at work developing synthetic vision and advanced WAAS-based approach guidance for the X. These advancements are expected to be available in 2012.

Citation X passengers will also see technological advances next year with availability of Aircells' high-speed Internet system, which will provide enough bandwidth for most functions while flying above the Aircell network that is located across the 48 states. Advanced passenger cabin displays and controls will also be part of the upgrade.

>>> The winglets are not cheap, but at least one used-airplane value authority believes 100 percent of the cost will be returned at resale.

as the airplane yaws, it generates a great deal more lift than the retreating wing does. That extra lift converts to roll toward the retreating wing. With a straight wing, Dutch roll is typically damped naturally, and after a few swings back and forth the airplane stabilizes. But with highly swept wings, the yawing and rolling can become divergent and actually increase in amplitude. The solution is an automatic yaw damper system that moves the rudder quickly to stop the yaw so Dutch roll cannot develop. The X has a split rudder and independent yaw damper systems to be sure everything remains stable.

Because the flight controls are hydraulically boosted as power steering is in most cars, Cessna was free to set the control forces the pilot feels at almost any level, and I think it did a good job. The force required to maneuver the X is not what I would call light, but is enough to let you know you're flying a substantial, and very fast, airplane. Unlike in some jets with boosted controls, I never have the urge to grab the wheel with both hands.

Flying fast is great, but any airplane also needs to be able to slow down, and the X has five spoiler panels per wing to handle that. All spoiler panels are available on the ground for landing and rejected takeoff, but the others are modulated in flight by a large handle beside the throttles so that pilots can add as much or as little drag as necessary.

Landing the X

The Citation X does, however, have one unusual flying quality, and that is on landing. The airplane has a long-stroke trailing-link main landing gear, so it's pretty easy to make a smooth touchdown, but that's when the fun begins.

For some reason — maybe the sweep of the wing, the geometry of the landing gear or even the placement of the gear relative to the wing — the X wants to hop back into the air after touchdown. I had flown the X several times over the years and had never mastered the good landing, but Dave assured me he could show me the way.

The key is to immediately extend the spoilers after touchdown. The spoiler control handle is just to the left of the throttles, and as soon as you feel the mains start to roll, immediately reach over and extend the spoilers, which help to kill residual lift.

The other key is to relax back pressure on the yoke at touchdown. It's not really a push forward, but you want to let that nose start coming down right away. The Boeing 727 is famous for this sort of landing maneuver, or should I say infamous, and it works in the X. With Dave's coaching I was able to make three very acceptable landings and, I think with a little more practice, would have the procedure down cold.

Winglet Installation

The winglets are an STC conversion of the X and are approved for the entire fleet. The installation takes place at the Citation service center and requires about four weeks of downtime. The original wingtip, and the end rib, are removed. A new end rib, some new skin and structural reinforcements are added. The wing spars are not modified.

The conversion fits into the Citation X approved maintenance procedures, including all new performance information for the airplane flight manual. The winglets are covered by a five-year warranty, including the installation work, and the conversion does not change the underlying original Cessna warranty. The all-up installed cost for the conversion is $593,000. So far, more than a dozen of the 304 Citation X's have been converted and the change has been approved by the Canadian and European authorities, as well as the FAA.

The winglets are not cheap, but at least one used-airplane value authority believes 100 percent of the cost will be returned at resale. And with an overall average fuel savings of 5 percent, and the ability to avoid a number of expensive en route fuel stops, the conversion will help pay for itself.

The X is still a unique airplane with its total emphasis on high speed, but the winglets can extend the range and improve efficiency without reducing the 500-plus-knot dash speed most owners love. More range when you want it without losing any speed is a darn good trade. ✈

Cessna Citation X

The airplane flown for this report was equipped with Winglet Technologies winglets as an aftermarket STC modification installed by Cessna at its service center. Existing X's and new production airplanes are eligible for the modification. All information is from the airplane flight manual and reflects standard day conditions at maximum weights unless noted.

Typical price (new, with winglets)	$22,295,000
Engines	Rolls-Royce AE3007C1, 6,764 lbs each
TBO	4,500 hrs
Passenger seats (typical)	9
Cabin height	5.7 ft
Cabin width	5.5 ft
Cabin length	23.9 ft
Baggage volume	82 cubic ft
Length	72.3 ft
Height	19.3 ft
Wingspan	69.2 ft
Wing area	539 sq ft
Wing sweep	37 degrees
Wing aspect ratio	8.9
Max ramp weight	36,400 lbs
Max takeoff weight	36,100 lbs
Basic operating weight (includes two pilots)	22,250 lbs
Zero fuel weight	24,400 lbs
Max payload	2,150 lbs
Max fuel capacity	12,931 lbs
Payload, max fuel	1,219 lbs
Max landing weight	31,800 lbs
Wing loading	66.9 lbs/sq ft
Power loading	2.7 lbs/lb
Ceiling (certified)	51,000 ft
8,000 ft cabin @	51,000 ft
Pressurization	9.1 psi
Takeoff runway	5,104 ft
Climb to 45,000 ft	27 min
Max cruise	525 kts
Long range cruise @ 45,000 ft	470 kts
NBAA IFR range	3,230 nm
Landing runway	3,400 ft
VMO/MMO	350 kts/Mach .92

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