The advent of new-generation aircraft, such as the A320neo and 737MAX, set high standards of performance expectations for operators. Legacy aircraft can still be enhanced, however, to greater benefit for airlines. An overview of the key popular and emerging options is given.

The benefits of winglets and performance enhancing kits

A performance enhancement can be defined as a modification to an aircraft that yields more payload, better fuel consumption or improved range compared to its factory-standard counterpart. These enhancements may involve structural modifications to the airframe, engines or systems. These modifications may also increase the hull or operating weight of the aircraft, which may, in some cases, affect its capacity or load capabilities.

Operators need to determine whether they will sacrifice payload by increasing range when considering whether to make any performance-enhancing or fuel-saving changes to aircraft. If so, they need to decide whether a particular modification is appropriate for popular routes where the aircraft is often full to capacity.

Aircraft coming into service in the near future will have more 'standard' enhancements than before so that they remain competitive for prospective customers. As technology becomes more sophisticated, and improved performance through structural enhancement becomes possible, the expectation for what was an option to become a standard increases. The Boeing 737MAX, for instance, is delivered with advanced technology (AT) winglets as standard, while sharklets are installed as standard on the Airbus A320 new engine option (neo).

Winglets have not been a valid retrofit option until recent years, with original equipment manufacturers (OEMs) installing competitive and incentivising programmes for operators that want to maximise their efficiencies. The number of aircraft operating today with either production or retrofit winglets is testament to the actual benefits produced by these technologies *(see table, page 50)*.

Winglets

The design and shape of a standard 'winglet' has evolved significantly since it was first introduced. Boeing explains that Richard Whitcomb at NASA's Langley Research Centre first developed the idea in 1976. These initial 'first generation winglet' designs were expected to offer a 2.5-3% improvement in fuel burn compared with 'factory standard' aircraft.

Second-generation winglets, such as those found on the 737 Classics, 737NG, 757, and the 767, are larger in design. Second-generation winglets offer 4-6% fuel burn improvements on longer missions, compared to first-generation winglets. Retrofit certification has been granted to most aircraft types, including those no longer in production. It has always been possible only to retrofit the 737 Classic, 737 Split Scimitar Winglet (SSW) programme, 757 and 767. This means that airlines can install winglets post-production to take advantage of the efficiencies offered.

Last, Boeing's AT winglets seen on the 737 MAX airliners are third-generation winglets that offer a 1-2% improvement over second-generation models.

"General construction methods for winglets have not changed much over time, but some upgrades have been incorporated," explains Chip Kiehn, director of sales and marketing at Aviation Partners Boeing. "As early winglets have become more common in service, we have a better understanding of how a lightning strike affects them, for example at the entrance and exit points during a strike. We have therefore incorporated new construction materials to certain areas of the winglet that help dramatically reduce lightning damage and costly repairs.

"Early halogen lighting systems have been upgraded to lighter and more efficient LED systems," continues Kiehn.

As will be disclosed later, winglet designs developed by OEMs have branched out into several variants, including Blended, Split-Scimitar (SSW) and the Sharklet. These differ by size, shape, and the aircraft that they can be installed on.

The use of winglets ultimately reduces fuel burn, meaning that aircraft fitted with them use less fuel on a mission than an aircraft without them. The rationale behind winglet technology is that they reduce the affects of drag along the wing when inflight. This is through the weakening of vortices that are created at the wingtip. These vortices, when experienced on an aircraft not installed with winglets, therefore induce drag by effectively pulling air back and over the wing's surface.

The aerodynamic efficiency of an aircraft's wing can also be improved if the wing is made longer. It is generally known that the longer the wing, the less induced drag occurs. The aerodynamic relationship between wing span and the distance from trailing to leading edge is called the 'aspect ratio'. The higher this ratio, the longer the range achievable at a given distance.

Obviously, the logistics behind increasing wingspan make this counter-productive for OEMs and operators. Larger wingspans limit movements in hangars, terminals and airports. Stand spaces can prove problematic from an operational perspective, for instance. A longer wing also requires structural reinforcements that add weight to the airframe.

Winglets, therefore, create the effect of a longer wingspan without the need actually to increase the length of the

WORLDWIDE FLEETS INSTALLED WITH WINGLETS OR SHARKLETS

OEM	Type	Series	In operation (pax config)	With winglet /sharklet mod	Overall % across type
Boeing	Classic	737-300	264	115 Blended	
		737-500	161	55 Blended	40% (737 Classic)
		737-700	1,046	926 Blended	
				36 Split Scimitar	
	NG	737-800	4,211	3,583 Blended	
				508 Split Scimitar	
		737-900ER	411	205 Blended	95% (737NG)
				206 Split Scimitar	
	757	757-200	353	271 Blended	79% (757 Family)
	767	767-300ER	412	246 Blended	60%
Airbus	A320	A319	1,097*	79 Sharklet	
		A320	3,479*	1,098 Sharklet	
		A321	621**	522 Sharklet	33% (A320 Family)

* aircraft with MSN higher than 1200

** aircraft with MSN higher than 5514

Source: Flight Global Analyzer

wing. The wingspan is instead increased vertically, and answers the operational restrictions posed by the concept of a longer wing.

Aviation Partners Boeing

Aviation Partners Boeing (APB) is a joint venture between Aviation Partners, Inc. and The Boeing Company. Created in 1999, APB is responsible for developing all winglet technology available on Boeing manufactured aircraft. This began with Advanced Technology Blended Winglets. As highlighted by APB, the use of either Blended or Scimitar Winglets will enable better climb performance, thereby allowing lower engine thrust settings, reducing fuel burn and allowing greater range capabilities. Winglet-equipped Boeing aircraft are: the 737NG (over 95%), the 737 Classic (42%), the 757 (79%) and the 767 (61%) *(see table, this page).*

Blended Winglets

Blended Winglets first appeared in 2001, on the next-generation 737-800. 'Blended' refers to the region between the outermost part of the wing, which is traditionally designed to accommodate a plain wing tip, and the winglet. APB's Blended Winglet negates the need to redesign the outer wing to accommodate the new winglet structure. As described by APB, the term 'blended' refers to the physical transition area between the horizontal and vertical planes of the winglet. With a Blended Winglet this area is a smooth join, rather than a sharp angular one.

"The 737-700, -800 and -900ER can have Blended Winglets installed on the production line," explains Kiehn. "All other products, including Split Scimitar Winglets, are installed via retrofit." The 737-700 and -800 Blended Winglets can also be retrofitted if they are not installed in production.

While the 737-300, 737-500 and 757-300 were granted certification for Blended Winglet retrofit in 2003, 2007 and 2009, the supply chains for these types have now been discontinued due to the maturing fleet. Meanwhile, Blended Winglets are available as a retrofit on the 737-700, -800, -900; 757-200; 767-300ER, 767-300 Freighter, and the 767-300BCF. While the 900ER SSW is a retrofit-only option, the Blended Winglet on the 737-900ER is standard equipment in-production.

Split Scimitar Winglets

APB's Split Scimitar Winglet (SSW) offers a further performance improvement over the basic Blended Winglets outlined above, demonstrating drag reduction of about 2% compared to its counterpart. Its shape, notably different to the original Blended Winglet, consists of aerodynamic revisions to the wing tip, replacing the aluminium tip with the curved, scimitar-shaped tip cap. A further ventral strake, also scimitar-shaped, is added below.

STC approval for the Split Scimitar Winglet was granted by the Federal Aviation Administration (FAA) in 2014. This commenced with approval for the 737-800 and the -900ER. Supplemental type certificate (STC) approval for all -700 models followed in 2015.

Split Scimitar winglets are available as a design upgrade for the 737-700, -800, -900 and -900ER. Scimitar blended winglets are also available as a retrofit modification to the 757-200.

The standard configuration for a Blended Winglet assembly comprises: an aluminium tip; aluminium trailing and leading edge; graphite spars and ribs; strobe light and forward and aft position light. "LEDs are available on the Split Scimitar Winglet when upgraded from Blended Winglets, if older halogen lights are installed," explains Kiehn. "The LED strobe light is now standard on all Blended Winglets. Various upgrades that were once optional become 'standard', however. These include LED lighting and additional lightning strike protection on Blended Winglets."

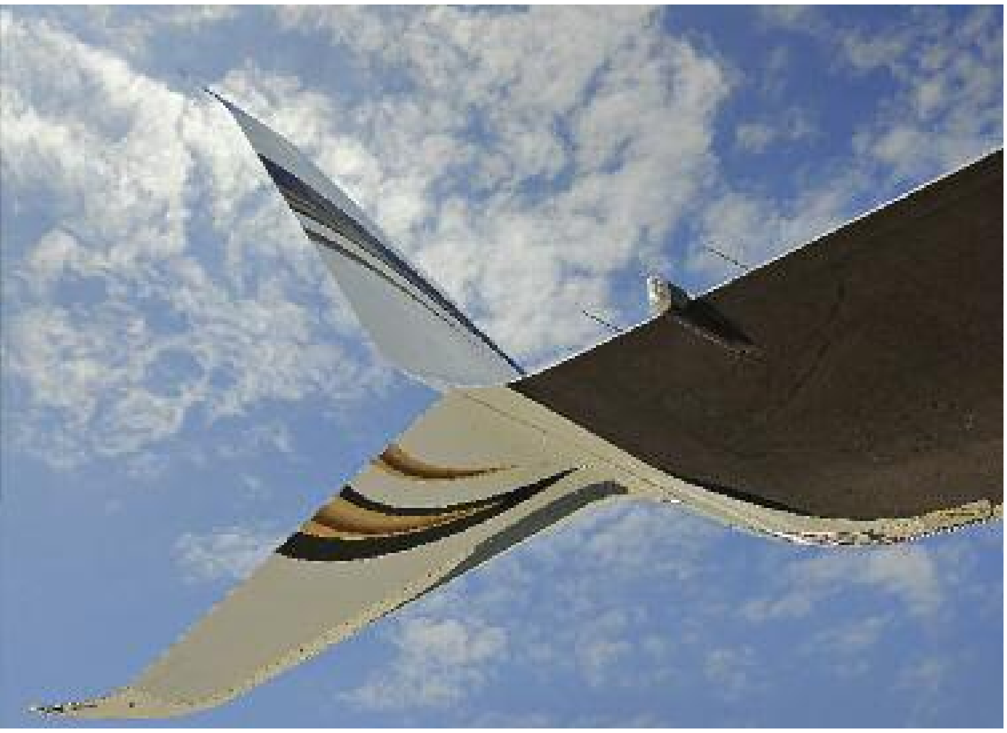
Retrofitting a winglet to the aforementioned aircraft types is a relatively straightforward process. "Wing tips are removed and winglets are bolted directly to the wing end-rib," adds Kiehn. "In most cases, the end rib is also upgraded to accept this connection.

"A significant part of the Blended Winglet and Split Scimitar Winglet modification, however, is in the wingbox where additional reinforcement is needed to accommodate increased wing-loads induced by the winglets," continues Kiehn. "A retrofit modification can range from one day, for example to fit Split Scimitar Winglets to the 737-900ER, to 18 days. This is the general estimate to fit Blended Winglets to a 767-300ER for instance." During this process Boeing maintenance and continued airworthiness documents are also supplemented to accommodate the installations.

As part of a total winglet kit, most modifications include a wingbox reinforcement kit as well. "While the additional weight does have a slight impact on total aircraft weight and balance, it does not impact passenger load," says Kiehn. "Extra payload can be exchanged for longer range if necessary."

Generally speaking, winglet configurations are optimised for the original aircraft mission profile and design. Of course, design can still be limited in size based on the existing wingbox structure. "There are examples, however, where APB has updated existing end-wing configurations, such as with the 757-200 and -300 winglet kits, which include an adapter plug extension that adds 1.5 feet of chord length to the wing before attaching the winglet," says Kiehn.

According to APB, customers value winglets differently. "Obviously fuel savings are the most popular benefit, but increased payload and/or range can also be attractive," adds Kiehn. "Some 757-



Split Scimitar Winglets (SSW) are available as a design upgrade for the 737-700, -800, -900 and -900ER. Scimitar blended winglets are also available as a retrofit modification to the 757-200.

200 and -300 customers, for instance, have launched new routes across the Atlantic, carrying passengers deeper into European destinations that were not accessible with these aircraft before Blended Winglets became an option.

"Other winglet benefits include reduced engine maintenance and airport noise, as a result of reduced take-off thrust, as well as reduced emissions, and increased aircraft residual value. All these benefits offer additional operational flexibility for airlines," continues Kiehn.

List price for Blended Winglets for the 737NG is $1.06 million per shipset, rising to $1.12 million for the 757, and $2.4 million for the 767-300ER. An upgrade to SSW winglets for the 737NG has a list price of $575,000.

Airbus

Airbus' product offering for customers desiring further performance enhancement is the Sharklet. A 2.4m tall wingtip device, it is becoming an increasingly popular retrofit option across the A320ceo (current engine option) family. The Sharklet can also be fitted for A320ceos currently on the production line, and is a standard fixture for the A320neo (new engine option). Capable of either enabling operators to increase payload by about 1,000lbs or adding about 100nm to range capability, the Sharklet confers a fuel burn improvement of 2-4% when installed.

For a given take-off weight, the fuel-saving Sharklets allow the aircraft to fly a given range while using less fuel. This means the weight saved by not having to carry as much fuel (for a given mission) can be allocated for carrying more revenue payload instead. In addition, the extra aerodynamic lift provided by the Sharklet wingtip brings better take-off climb performance, which allows the aircraft to carry more payload from a payload-limiting runway, such as short runways or hot-and-high airports.

Sharklets

Airbus explains that by reducing the tip vortex of a wing-tip, Sharklets reduce the overall drag, thereby increasing lift and achieving benefits equivalent to increasing the wingspan of the aircraft. In addition, there is a very slight increase in wing area versus a 'non-Sharklet' wing, which, together with the higher aerodynamic efficiency and reduced drag, further helps to increase the lift in operation. This is especially beneficial during low speeds, and during take-off or landing. The installation and effects of Sharklets are in no way affected by the engine type an aircraft is equipped with. In terms of fuel savings, Airbus points out that since the main benefit from Sharklets comes from the cruise phase in-flight, the fuel savings will be greatest on the longer sectors.

Other key operational enhancements that Sharklet-equipped A320 aircraft benefit from include:

- Improved low-speed performance
- The aircraft's overall residual value
- Commonality with Sharklet-equipped new A320s

Sharklets became an option on the A320ceo in three different stages:

1. Sharklet-equipped new aircraft delivered from the production line:

For new, factory-delivered A320ceos the Sharklet option was publicly launched on 15th November 2009 at the Dubai Air Show, and the first Sharklet-equipped aircraft from the final assembly line was subsequently delivered to AirAsia in 2013.

As of December 2016 about 98% of A320ceo aircraft, or more than 1,500, had been delivered with Sharklets on the assembly line. Inevitably, with the introduction of the A320neo and its standard Sharklet-fitted wings, this number will continue to rise.

2. 'Sharklet Production Retrofit' programme (with Sharklet-ready wing):

The programme for production retrofit aircraft, that is, A320 family aircraft with MSN above 5,514, commenced in 2013. This is referred to as the 'Sharklet Production Retrofit'. This is applicable for aircraft which already have the 'Sharklet-ready' wing structure installed on the production line. JetBlue was the American launch customer for the production retrofit Sharklets in February of that year, while Turkish Airlines followed in December of 2013, with a retrofit on one of its fleet of A321s. Airbus says that for the aircraft with Sharklet-ready wings, the original wingtip fences are removed, the Sharklets are installed and the necessary cockpit computer functions are activated.

3. 'In-Service Sharklet Retrofit' (ISR) programme:

The In-Service Retrofit (ISR) programme was launched in October 2013, applicable to A319 and A320 aircraft from MSN 1,200 upwards (circa year 2000 and newer), covering 3,500 in-service aircraft. A319s and A320s prior to MSN 1,200 cannot be retrofitted with Sharklets, because the early developments in the A320 Family wing structure have been collectively integrated into all wings from MSN 1,200 onwards. Moreover, aircraft post MSN 1,200 have higher take-off weights, so their wings are structurally different to those of the earliest aircraft. JetBlue was the first customer to participate in the ISR programme.

For these aircraft, a wing reinforcement kit is required, which is standard and delivered pre-assembled. Once the aircraft has been assessed for relevant damage the operator is issued

FUEL SAVING ESTIMATE

Aircraft Type	Winglet type	Sector length - nm	Flight time (min)	Typical fuel burn - USG no winglet	Trip fuel saving % with winglet	Fuel saved USG	FC/YR	Annual fuel savings USG
737-500	Blended	530	91	1,313	2.5%	33	1,813	59,518
737-700	Blended	691	96	1,514	3%	45	1,875	85,163
	SSW	691	96	1,514	5%	76	1,875	141,938
737-800	Blended	728	122	1,712	3%	51	1,475	75,777
	SSW	728	122	1,712	5%	86	1,475	126,295
737-900ER	SSW	809	113	1,813	2%	36	1,593	57,759
757-200	Blended	880	120	2,400	3.5%	77	1,500	126,000
	SSW	880	120	2,400	5.5%	132	1,500	198,000
767-300ER	Blended	4,235	559	16,427	5%	821	483	396,716
A319	Sharklet	536	78	1,037	2-4%	41	2,308	47,862-95,723
A320	Sharklet	728	105	1,676	2-4%	67	1,714	57,463-114,926
A321	Sharklet	627	91	1,365	2-4%	55	1,978	54,000-108,000

with an Airbus service bulletin (SB). The ISR process comprises several stages:

1. Removal of the outer wing;
2. Reinforcement of the wing structure;
3. Attachment of the pre-assembled wing reinforcement kit and top-skin;
4. Closing the wing and installing Sharklets

Airbus estimates the total time to perform the in-service retrofit programme at about 25 days, depending on the resources available at the particular modification facility chosen by the operator. Once installed, there is minimal weight increase on the airframe, and any increase is offset by the reduction in fuel required for missions thereafter.

Furthermore, aircraft which undergo the ISR can also benefit from an operating life extension (implemented as part of the wing reinforcements), equivalent to about 36,000 additional flight hours (FH). This could yield more than 10 years of additional operation for some customers.

Possible fuel savings

The data in the fuel savings table *(see table, this page)* gives an approximation of the potential annual fuel saving benefits offered by Winglets and Sharklets on various Boeing and Airbus types. This saving can vary between operators and aircraft types, in accordance to actual utilisation and average mission length.

The figures in this table are based on a variety of assumptions, and should only be treated as a general overview. Route-specific fuel burn figures are applied for the aircraft listed, that have been extracted from previous *Aircraft Commerce* articles. If longer sectors are operated, then the percentage improvements will increase, whereas short sectors will realise a smaller benefit. Annual flight cycle (FC) utilisation is an average figure assumed for each type. This will again vary between operators.

Actual fuel burn will in reality vary between fleets according to a number of factors, such as individual operator utilisation, aircraft modification status, operating environment, and payload. Where possible, percentage fuel savings that are believed to be realistic for the sectors used, are applied. For those sectors where accurate fuel savings cannot be used, a range of possible percentage improvements are provided. These percentages have been taken from OEM websites. Therefore where shorter sectors are undertaken, percentage fuel savings might not be at their optimum.

Additional fuel tanks

A key way to increase range, if needed by the operator, is via additional fuel tanks. Airbus offers these removable 'additional centre tanks' (ACTs) for its A320 Family operators. ACTs are installed in the forward part of the aft cargo hold. A320 Family aircraft that are built today can hold up to two ACTs, whereas the forthcoming A321LR (long-range variant of the A321neo) will be able to hold up to three ACTs. This option for the A321 will be available from 2018.

Edge Aerodynamix

Established in 2011, Edge Aerodynamix Inc. is located in Florida, USA. The company has developed a range of products across fixed wing and rotor aircraft that focus on reducing drag, enhancing performance, and ultimately saving fuel for operators. Its primary offering, the conformal vortex generator (CVG), has recently been granted STC approval on the 737 family following rigorous testing by Edge.

The CVG is described by Edge as an elastomeric adhesive-backed film, which is fixed across the leading edge of the wing. This is very different in design to the rectangular and triangular vortex generators seen traditionally, such as those on the Embraer E-170, and the tail section of the 737 Classic.

These typical vortex generators (VG) are plates or vanes that are placed on the external surface of the aircraft fuselage or wing to improve efficiency by reducing drag at high angles of attack, such as during the climb. This is achieved by generating air vortices, which are rotating currents of air that flow around the axis that is the VG. These air vortices, if positioned correctly due to the size and angle of the VG, energise the air in the boundary layer created by the airflow over the wing, providing greater lift potential and efficiency.

Conformal Vortex Generators

The CVG has been developed by Edge to improve on this design, and provide further performance benefits. "The CVG is formed of Thermoplastic Polyurethane (TPU) and a Pressure Sensitive Adhesive (PSA)," describes Peter Ireland, founder at Edge Aerodynamix. "As an elastomeric material, it increases the strength of the adhesive bond as an unexpected side effect of adhesive processes.

"The CVG is a flat or conformal vortex generator, and that makes a simple material like TPU ideal, because it simplifies the interaction with the underlying structure's behaviour. This is a factor on a wing, but it is further critical

The list price for Blended Winglets on the 737NG is $1.06 million. An upgrade to SSW configuration has a list price of $575,000. In return, the aircraft will experience a reduction in fuel burn of up to 7%, which can equal in the region of 100,000-150,000 USG per year at typical rates of aircraft utilisation.

on rotors and propellers, or wind turbines," adds Ireland. "While conventional VGs increase drag at low angles of attack, the CVG reduces drag overall, because CVG establishes a flow structure at the bottom of the boundary layer, in what is called the sub-boundary layer, but as a hybrid structure." Ireland explains that this created structure 'fixes' the vortices generated, firmly to the surface of the wing, and retains them there though the suction effect to the boundary layer above.

"Conventional VG flow breaks down rapidly over time and distance downstream, while the CVG does not," continues Ireland. "The effect of the CVG is most noticeable on the shockwave, which normally suffers from instability in location from the shockwave boundary layer interaction (SBLI) feedback between the shock foot and separation in the following boundary layer. The CVG stops the instability."

Customers utilising Edge's CVG can expect general fuel savings in the cruise phase of 1% to 6%, depending on the model and configuration of aircraft.

The CVG was developed by Edge to combat some of the inefficiencies experienced by conventional VGs. "VGs actually tend to increase drag at low angles of attack, and they have limited persistence in maintaining the vortex structure," continues Ireland. "This structure often breaks down due to shear in the boundary layer, caused by unstructured turbulence, for example.

"Damage tolerance can be also an issue with conventional VGs, due to their structures and the way that they are fixed to the wing," adds Ireland. "The CVG, due to its simple attachment to the wing, removes this issue. The CVG also allows boundary layer control (BLC) where it would be imprudent to apply a conventional VG."

Applying the CVG

The CVG can now be used across all 737 series aircraft, having been granted STC approval by the Federal Aviation Administration (FAA) in November 2016. Ireland says that the film is thousands of an inch in thickness, and is cut to length to fit the distance of the slat trailing edge, before being bonded to the wing. Work to incorporate the modification to an aircraft is minor.

"Preparation of the wing is key in order to ensure that the surface is clean of oils and contaminants. The paint condition should be good, because the adhesive is aggressive and will challenge the paint-primer bond if the paint is poorly applied," explains Ireland. "The CVG is then aligned to the retracted slat position. It is provided in a roll, and is handed to each wing, left and right mirrored designs.

"The forward edge of the film incorporates an infill section that is used to give the correct alignment back from the trailing edge of the slat," continues Ireland. "The backing release liner is slit to allow for an initial partial bond to be done assuring simple alignment, and then the remainder of the liner is removed to fully bond the material to the wing."

Once applied, inspection requirements to check the integrity of the CVG remain relatively light. General visual inspections (GVIs) are required to see that the material is in place at edge outlines, and has not peeled off in any part. If damage is observed, the damaged area is simply removed. Operations can be conducted with that section of tape removed, or it can be infilled to repair the damage. "The material will survive on wing without degradation between paint shop visits, and the material itself is replaced free of charge," adds Ireland.

CVGs can be applied to aircraft fitted with winglet and wing-tips also. "The Slat CVG is applicable to any wing, with or without winglets. It is applied behind the location of the slat," says Ireland. Edge is in the process of acquiring a winglet-equipped aircraft to perform the winglet STC itself, which involves applying an elastomeric film to the winglet separately.

"The winglet design has already been flown on the E-175, which has an OEM approval for the application of tape for erosion protection," continues Ireland. "The benefit of the winglet CVG is restoring the lost efficiency gain of the winglet from the step formed by the leading edge protection, and to mitigate vibration from shockwave position instability on the winglet itself."

Regarding installation costs, Edge advises that as part of its offering, Edge personnel can either apply the CVG, or brief the customer's personnel on the installation process while supervised. The eco-friendly CVG can be installed in less than four hours without making major modifications to the aircraft, and does not require any capital investment.

Further approvals

Now that the 737 STC has launched the CVG's appeal and suitability for commercial aircraft, Edge is in the process of testing aircraft acquisition to run STC granted approvals for the Airbus A320, A330 and A340 families. It expects this to commence in February 2017, and conclude approvals by the end of the year.

"Once the A320/330/340 families are approved, we are expecting to achieve approved model list (AML) approval for most types in rapid succession," says Ireland. "The Slat CVG is applicable to all aircraft with slats, which is all types other than the 747 in effect." *- CLD* AC