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Modernisation of Airbus A320 Wingtip Devices To Reduce Induced Drag, Wake Turbulence And Fuel Consumption

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ABSTRACT

Wake turbulence is a phenomenon generated by strong counter-rotating vortices trailing from an aircraft's wingtips, created by the pressure difference between the upper and lower surfaces of the wing. These vortices produce induced drag, reduce aerodynamic efficiency, and pose safety risks to following aircraft due to their persistence and intensity in the wake.

This paper investigates the influence of wake turbulence and induced drag on the aerodynamic efficiency of the Airbus A320 aircraft, as well as possible methods for reducing wingtip vortices through modernization of wingtip devices. The main focus is on comparing blended winglets, split scimitar winglets and raked wingtips in terms of aerodynamic efficiency, structural feasibility and operational limitations. Analysis is based on the principles of the theory of lines of rise, vortex circulation and induced reduction of resistance.

As a suggested improvement for the Airbus A320, it is proposed that existing Sharklets be replaced with split scimitar winglets. The theoretical rationale is based on the variation of span efficiency factor and the redistribution of vortex circulation in the wingtip region. Calculations of the induced drag coefficient, total drag coefficient and estimated fuel saving using aerodynamic relations and empirical assumptions have been performed. The results show that an increase in span efficiency factor of approximately 4% can lead to a decrease in induced drag and fuel consumption of approximately 1.88%.

Additionally, the effect of split scimitar geometry on the wake vortex structure has been considered. It is assumed that the formation of several weaker vortical structures instead of one concentrated vortex core contributes to lower peak vortex intensity and wake turbulence effects. Also identified are the limitations of proposed retrofit, including reduced ground clearance, increased bending moments and airport compatibility requirements.

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INTRODUCTION

Airbus A320, shown in Figure 1, is a narrow-bodied aircraft designed by Airbus in the 1980s to carry 150-180 passengers. The first flight took place in 1987, and operations began in 1988. The aircraft is designed for short- and medium-distance passenger transport and is equipped with a modern digital flight control system (fly-by-wire). The maximum flight duration is about 6-7 hours, while the average flight duration usually varies from 2 to 4 hours depending on the route.

Figure 1: Airbus A320 [7]

Basic Characteristics Of Airbus A320:

Dimensions

Height (m)	11.8
Length (m)	37.6
Wing area (m2)	122.4
Wingspan (m)	34.1 - 35.8

Table 1 [1]

Weight

Maximum take-off weight (kg)	73 500 - 78 000
Maximum landing weight (kg)	64 500 - 66 000
Operating empty weight (kg)	42 100
Maximum zero fuel weight (kg)	61 000 - 62 500
Maximum payload (kg)	16 600

Table 2 [1]

Performance

Range with max payload (km)	6 100
Cruise speed (km/h)	840
Maximum speed (km/h)	890
Maximum operating altitude (m)	11 900

Table 3 [1]

Airbus A320 is a popular aircraft worldwide, as it takes off or lands every two seconds [2]. Since entering into service there have been more than 191 million flight cycles [3]. Given such an enormous scale of operations, it is critically important to maximize flight efficiency and minimize fuel consumption for each flight. With such a scale of operation, ensuring maximum safety in flight becomes extremely important.

Turbulence is the chaotic, irregular motion of air or fluid characterized by eddies and vertical currents, breaking smooth flow into disorderly, unsteady patterns. Turbulence is caused by various atmospheric processes, including the interaction of air masses at different temperatures and speeds, stream flows, storm activity, and influence of terrain relief (mountain turbulence). Turbulence-related emergencies are usually caused by sudden severe overloads resulting in injury to passengers and crew, temporary loss of control or deviations from a specified flight path. Although turbulence is rarely a cause of flight or crash, about 37% of commercial aircraft accidents are caused by turbulence [4].

Turbulence can be caused by many different environmental conditions: (1) *thermal turbulence*: vertical turbulence caused by the uneven heating of the Earth's surface by the sun, creating convective currents due to different densities of air; (2) *windshear turbulence*: caused by a sudden, drastic change in wind speed or direction over a short distance; (3) *frontal turbulence*: caused by the interaction of two air masses with different densities and temperature, that consequently creates friction and vertical instability; (4) *thunderstorm turbulence*: caused by violent, vertical air movements most of time around cumulonimbus clouds (dense, towering vertical clouds, characterized by intense convection, large water content, and anvil-shaped tops, often reaching high into the troposphere); (5) *mechanical turbulence*: caused by physical disruption of smooth airflow by ground-level obstructions; (6) *mountain wave turbulence*: caused by strong, stable air flowing perpendicularly over a mountain range, that creates large-scale vertical oscillations and wave-like patterns on the lee side; (7) *cleat air turbulence*: created by invisible air movements, primarily high-altitude wind shear near jet streams, where fact airflows shear against slower ones, creation intense eddies; (8) *wake turbulence*: caused by wingtip vortices, which are rapid, counter-rotating swirls of air trailing behind an aircraft's wings. [10]

A heavier aircraft experiences less acceleration from turbulence compared to a lighter one, resulting in a smoother, more stable ride. Heavier aircraft have greater inertia, meaning that they require more energy to move or accelerate. The gust of wind that releases a light aircraft will often be a minor blow to a large airliner, as the turbulent force is less effective in changing the trajectory of a heavier aircraft. Thus, the impact of turbulence on an aircraft is directly related to its weight and inertial characteristics, which determine the degree of stability and handling in unfavorable atmospheric conditions. In this context, the Airbus A320, with its relatively large weight and advanced flight control, demonstrates high resistance to turbulent impacts. providing a smoother change of trajectory and increased safety compared to lighter aircraft. However, despite these advantages, this type of aircraft can also be prone to accidents during severe turbulence. The main disruptive effect on the aircraft is due to wake turbulence caused by a specific effect on the wings.

The main objective of this research is to propose a new wingtip device for the Airbus A320 that reduces induced drag and fuel consumption, while also weakening the wake vortices generated by the aircraft, thereby reducing the hazard it poses to following aircraft. This type of turbulence has the most substantial and potentially catastrophic impact on aircraft's wings due to directly attacking the wing's lift-generating mechanisms, often causing uncontrollable rolling moments that exceed the aircraft's control authority.

The main reason for wake turbulence occurrence is that air always aims to area with lower pressure. Aircraft lift is generated by the creation of a pressure differential over the wing surfaces which causes the lowest pressure to occur over the upper surface of the wing, and the highest pressure under the wing. Consequently air rises outwards under the wing towards the wingtip and curls up and over the upper surface of the wing. Air moves inwards over the wing due to the same pressure differential. At the trailing edge, streams of air that move outward and inward meet to create small trailing edge vortices that move towards the wingtip and become part of the larger wingtip vortex. Swirling air masses trail downstream of the wingtips [8]. The wake vortex is formed with most of the energy concentrated within a few feet of the vortex core. [6]

The development of a circular motion around a core region is a characteristic of vortices, which can vary in size between a few centimeters and a meter or more depending on the type of aircraft. The wake vortex core size for an Airbus A320, which is classified as a "Medium" wake turbulence aircraft, typically features an active vortex core radius of a few meters, often estimated in numerical studies to be in the range of 0.5 to 2 meters (approximately 1.6 to 6.5 feet). [8, 9] The larger and stronger the vortices and their associated downwash, the greater the impact of induced drag. Induced drag from wingtip vortices can account for 30–40% of the total drag on an airliner during the cruise phase of flight. In addition to increasing the induced drag and impacting the efficiency of an aircraft, these vortices can pose a risk to other aircraft, potentially causing wake turbulence that can lead to an unexpected loss of control and altitude of another aircraft flying behind or in its flight path [11].

Figure 2: Crash of the Cirrus SR22 [12]

The example of an aircraft crash caused by the wake turbulence of the Airbus A320 is the crash of the Cirrus SR22 (Figure 2). The National Transportation Safety Board determined that on 16 December 2021, wake turbulence from an Airbus A320 caused a loss of control of a Cirrus SR22 on approach to McGhee Tyson Airport. The SR22 was conducting a training flight and followed the A320 at a distance of about 1.8 nautical miles, while no wake turbulence advisory was issued by air traffic control. At approximately 1000 feet altitude, the aircraft rolled sharply to 120 degrees and entered a steep descent, prompting the pilot to activate the CAPS parachute system. The aircraft impacted the ground and caught fire, resulting in one fatality, with the accident attributed to wake vortex effects at an altitude insufficient for recovery [12].

LITERATURE REVIEW

The reduction of induced drag through wingtip device modification has been an active area of aerodynamic research for over six decades. However, a careful examination of existing literature reveals that despite the volume of work conducted, critical gaps remain, particularly with respect to the Airbus A320 platform and the comparative evaluation of Split Scimitar Winglets as a retrofit alternative to the currently installed Sharklets.

Gharbia et al. conducted the most comprehensive modern overview of wingtip vortex mitigation research, synthesizing six decades of published work across passive and active device categories [15]. Their review establishes that aerodynamic efficiency improvements from wingtip devices range from 1% to 15%, fuel consumption reductions of 3.4% to 10%, and induced drag reductions of 5% to 20% have been documented across various aircraft platforms and flight conditions [15]. Crucially, however, the review does not identify any study that directly compares Split Scimitar Winglet performance against blended winglets on an A320-class airframe under consistent aerodynamic parameters. All documented performance data are platform-specific, meaning that published efficiency figures for one aircraft type cannot be reliably applied to another without independent verification.

Existing CFD-based studies on blended winglets for commercial aircraft are similarly limited in their applicability to the A320. Pinto et al. conducted a high-fidelity CFD analysis using the k-ω SST turbulence model in ANSYS Fluent 2024 R1, evaluating blended winglet performance on the Airbus A380 wingtip across cant angles of 0°, 15°, 45°, and 80° [11]. Their results demonstrated a 1.724% drag reduction alongside a measurable decrease in wake vortex size [11]. While this study confirms that blended winglet geometry directly influences induced drag and vortex intensity on large commercial aircraft, it is confined to the A380, a widebody platform with substantially different wing loading, geometry, and operational profile compared to the A320. No equivalent study exists for the A320 family evaluating blended winglets against alternative multi-element configurations.

The closest study to addressing this gap examines multi-element winglet aerodynamics on a commercial airliner in both subsonic and transonic regimes [23]. Kobayashi et al. found that distributing lift across multiple winglet surfaces produces measurable reductions in concentrated vortex energy compared to single-surface configurations [23]. This result provides indirect theoretical support for the expected aerodynamic advantage of Split Scimitar Winglets, whose dual-element geometry redistributes circulation across an upper scimitar element and a lower ventral strake. However, this study does not apply its analysis to the A320 specifically, nor does it evaluate SSWs directly, leaving the platform-specific question unanswered.

Research directly using an A320-style model is limited and focuses exclusively on advanced adaptive technologies rather than passive retrofit options. A CFD-based comparative study modeled passive and active winglet configurations on a narrow-body aircraft based on the A320 configuration, finding that active adaptive winglets achieved a 10.5% improvement in lift-to-drag ratio and up to 6.11% drag reduction during cruise compared to passive fixed winglets, translating to fuel savings of 3.87–6.11% across all flight phases [36]. While this study confirms that the A320's current passive wingtip configuration leaves substantial aerodynamic efficiency unrealized, it evaluates only the contrast between fixed and adaptive systems, not between different fixed configurations such as Sharklets and SSWs. Furthermore, the authors acknowledge that active systems introduce significantly higher structural complexity and maintenance demands, making passive retrofit options such as SSWs a practically relevant intermediate step that the literature has not yet examined for the A320.

The suboptimality of fixed winglets across the full flight envelope is further established by Rajabi and Jahangirian, who optimized winglet geometry independently for takeoff, climb, and cruise phases using a k-ω SST CFD model on a civil aircraft [37]. Their analysis showed that a fixed winglet optimized for cruise conditions achieves up to 70% less drag reduction during takeoff and climb compared to a geometry-variable equivalent [37]. This finding establishes a general limitation of all fixed passive wingtip devices, including both the currently installed Sharklets and the proposed SSW retrofit. It means that any theoretical fuel saving estimate derived from cruise-phase aerodynamics, including the calculations presented in this paper, represents only a partial picture of total flight-cycle benefit and likely underestimates the cumulative efficiency difference between configurations.

From a theoretical perspective, Demasi et al. demonstrated under inviscid flow assumptions that multi-element and closed winglet configurations achieve lower induced drag minima than single-surface designs, given identical wingtip region constraints [38]. Their analysis proves that the bounding curve of the wingtip region defines an upper efficiency limit, and that any single-surface winglet operating within that region is theoretically sub-optimal [38]. This result provides a rigorous aerodynamic foundation for expecting that the dual-element SSW geometry will outperform the single-surface Sharklet in induced drag reduction, but the magnitude of this advantage on the A320 specifically remains unquantified in the existing literature.

Taken together, the studies reviewed above reveal three interconnected gaps. First, no published study directly compares SSW and Sharklet performance on the A320 airframe. Second, existing A320-specific research focuses exclusively on active morphing systems, leaving passive retrofit alternatives, which are more immediately deployable and economically accessible to airlines, largely unexamined. Third, while theoretical frameworks confirm that multi-element winglet geometries offer aerodynamic advantages over single-surface designs, no study has applied these frameworks to quantify the specific Sharklet-to-SSW transition using A320 aerodynamic parameters.

The present study addresses this gap by applying Prandtl's lifting-line theory and span efficiency analysis to the A320's documented aerodynamic characteristics, producing a structured first-principles estimate of the induced drag reduction and fuel saving achievable through an SSW retrofit. The original contribution of this paper is therefore not the generation of experimental data, but the systematic application of established aerodynamic theory to a comparative question that the existing literature has not directly addressed, combined with an assessment of the structural and operational constraints that would govern any real-world implementation on the A320.

METHODS

The methodology is based on a systematic comparison of the three wingtip designs. The evaluation considers several key criteria: aerodynamic efficiency (drag reduction and wake vortex behaviour), structural effects, compatibility with airport infrastructure, additional weight, manufacturing and retrofit feasibility, as well as economic viability for short- and medium-haul operations. By analysing the strengths and weaknesses of each design in relation to the A320’s wing geometry, flight mission, and operational limitations, this study determines the most suitable wingtip solution and assesses whether replacing the current Sharklets is technically justified.

Blended Winglets

Sharklets is the Airbus brand name for blended winglets on the Airbus A320 family (including neo). They are vertically oriented aerodynamic devices about 2.4-2.5 m high at the ends of the wings, replacing the previous wingtip fences [36].

Figure 3: Blended Winglets (20)

Blended winglets (Figure 3) are a modern wingtip device technology designed to improve aerodynamic efficiency by reducing induced drag and weakening the formation of wingtip vortices. They achieve this by modifying the flow field at the wingtip in a way that minimizes energy losses associated with lift generation. A key feature of this configuration is the gradual geometric transition between the wing and the winglet, achieved through a carefully shaped fillet at the junction. This design ensures a progressive change in chord and thickness distribution, which helps maintain attached flow over a larger portion of the wingtip region. As a result, the blended winglet configuration enhances aerodynamic efficiency and contributes to reduced drag during flight.

Computational fluid dynamics (CFD) analysis of blended winglet designs applied to the Airbus A380 wingtip has shown measurable reductions in wake turbulence intensity and induced drag [11]. Using modern CFD tools, the performance of the winglets was evaluated in terms of lift, drag, and wake vortex patterns, including computational analysis with varying cant angles of 0°, 15°, 45°, and 80°. These winglets function by disrupting the spanwise flow of air from the high-pressure lower surface to the low-pressure upper surface at the wingtip, thereby weakening the trailing vortex structure that generates lift-induced drag.

The simulations, conducted with the k–ω SST turbulence model in ANSYS Fluent 2024 R1, demonstrated a reduction in wake vortex size accompanied by a 1.724% decrease in drag [11]. In addition to these aerodynamic improvements, the numerical setup of the model was carefully constructed to ensure accuracy and convergence. According to the referenced study, the computational domain was designed with sufficiently large upstream and downstream extents to minimize boundary interference, while symmetry or periodic boundary conditions were applied where appropriate to reduce computational cost without sacrificing fidelity.

Despite the established benefits of winglets in drag reduction and wake vortex mitigation, several critical and often under-specified aerodynamic characteristics and inefficiencies exist.
The geometry of wingtip devices, in particular configurations such as blended winglets, significantly influences the formation and early development of wingtip vortices generated by the aircraft. By modifying the wingtip geometry, the pressure distribution in the tip region is altered, which directly affects the roll-up process of the trailing shear layer and the formation of the vortex core. As a result,

instead of a quasi-steady single vortex, a more complex and spatially evolving vortex system may develop, including secondary vortex structures and regions of elevated turbulent intensity.

The resulting flow field is characterized by increased unsteadiness and the presence of co-rotating and counter-rotating vortex interactions (Figure 4).

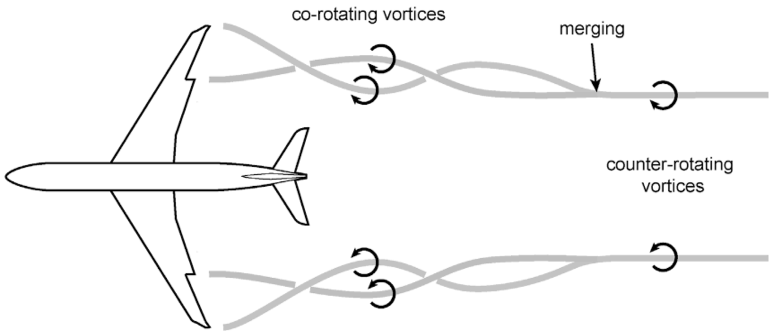

Figure 4: Co-rotating and counter-rotating vortices [27]

This multi-vortex dynamics leads to a redistribution of aerodynamic loads along the wingspan, accompanied by local fluctuations in pressure and velocity. These unsteady loads may increase fatigue stresses in structural components and contribute to aeroelastic phenomena such as vibration.

Split Scimitar Winglets

Split Scimitar Winglets (SSWs) represent an advanced development in wingtip device technology designed to improve aerodynamic efficiency by modifying the structure and dissipation of wingtip vortices. Developed through a collaboration between Boeing and Aviation Partners Boeing (APB), SSWs extend the concept of the earlier blended winglet by introducing a dual element geometry that enhances reductions in induced drag and decreases wake turbulence intensity.

The design of a Split Scimitar Winglet (Figure 5) consists of two integrated components forming a continuous aerodynamic structure. The first component is an upper primary winglet with a pronounced rearward sweep, known as the scimitar element due to its curved blade-like shape. This element increases the effective aspect ratio of the wing, which reduces the strength of the primary bound vortex generated at the wingtip. The second component is a lower outward canted strake that extends forward and downward from the base of the main winglet. This element functions as an additional lifting surface that generates a counter rotating vortex. The resulting secondary vortex interacts with the primary wingtip vortex in a partially destructive manner, reducing its rotational energy. As a result, the overall intensity of the wake system is significantly decreased, leading to improved aerodynamic performance and fuel efficiency.

Figure 5: Split Scimitar Winglet [22]

This dual-vortex interaction is the key mechanism by which SSWs reduce wake turbulence. Traditional winglets primarily diffuse and move the vortex away from the wing, but they do not actively weaken its core strength as effectively. In contrast, the SSW's lower strake directly targets the vortex formation process at its source. Computational Fluid Dynamics (CFD) and wind tunnel studies have quantified this effect, demonstrating up to a 35% reduction in the peak tangential velocity within the port vortex core and an approximately 20% acceleration in the axial decay rate of the vortex within the first ten chord lengths downstream of the wing [20, 21]. A weaker vortex with faster decay translates directly into a less hazardous wake for following aircraft.

The efficiency gains from SSWs are a direct consequence of their ability to reduce lift-induced drag, which constitutes a substantial portion of an aircraft's total drag approximately 40% during cruise and a staggering 80–90% during the takeoff phase [23, 25]. By mitigating the energy lost to vortex formation, the aircraft requires less thrust to maintain speed and altitude, leading to significant fuel savings. Empirical flight test data from Boeing and APB on retrofitted Boeing 737-800 aircraft shows a consistent fuel burn reduction of 1.9% to 2.0% under typical cruise conditions [24].
To ensure the relevance and practical applicability of this comparison for the A320 family, the Boeing 737NG family was selected as the primary reference case for comparing blended winglets (analogous to Airbus Sharklets) and split scimitar winglets (SSWs).

The most significant disadvantage of SSWs is their added structural weight and the consequent increase in wing root bending moments. The dual-element geometry comprising both an upper scimitar and a lower forward-canted strake introduces additional mass at the extreme end of the wing. This location is particularly critical because any added weight at the wingtip has a lever-arm effect, significantly amplifying the bending stress experienced at the wing root during flight maneuvers and turbulence. This necessitates a corresponding reinforcement of the wing's primary structure to handle the increased loads, which can lead to a cascading weight increase throughout the airframe. As established in fundamental aeroelastic theory, optimal winglet design must balance the aerodynamic benefit against this structural penalty, as the added weight can partially offset the fuel savings gained from drag reduction. Furthermore, the complex geometry of the SSW makes its manufacturing process more intricate and costly compared to a simpler blended winglet. The precise shaping of the scimitar curve and the integration of the lower strake require advanced tooling and quality control, increasing the unit cost of the component itself.

Another practical disadvantage is the issue of ground clearance and susceptibility to foreign object damage (FOD). The lower strake of the SSW projects downward and forward, bringing it closer to the runway surface than a conventional blended winglet. This increases the risk of the winglet striking the ground during takeoff or landing, particularly in crosswind conditions or on uneven taxiways. It also makes the component more vulnerable to damage from debris kicked up by the landing gear. This concern is especially relevant for aircraft operating in regions with less developed infrastructure or during adverse weather conditions.

Despite these disadvantages, the benefits of SSWs over standard blended winglets are substantial and quantifiable, primarily in the domains of induced drag reduction, wake turbulence mitigation, and overall fuel efficiency. The key innovation of the SSW lies in its active management of the wingtip vortex system. While a blended winglet primarily acts as a barrier to spanwise flow, increasing effective aspect ratio and diffusing the primary vortex, the SSW's lower strake generates a secondary, counter-rotating vortex. This secondary vortex is strategically positioned to interact destructively with the main wingtip vortex, directly weakening its core strength rather than just moving it away. This active cancellation mechanism is far more effective at reducing the total energy lost to vortex formation.

Split Scimitar Winglets were chosen to improve the Airbus A320 model because there is an example of such a change in aviation that has had a positive effect on efficiency. The Boeing 737NG family was selected as the primary reference case for comparing blended winglets (analogous to Airbus Sharklets) and split scimitar winglets (SSWs) due to its high degree of similarity with the Airbus A320 family in terms of aircraft class, operational profile, and design philosophy. Both are narrow-body, single-aisle aircraft optimised for short- and medium-haul routes, operating under comparable airport infrastructure constraints (ICAO Code C) and sharing similar wing loading characteristics, cruise altitudes, and mission lengths. Extensive retrofit programmes by major operators such as Delta Air Lines, Southwest Airlines, and United Airlines have generated large-scale, real-world performance data on the transition from blended winglets to split scimitar winglets on the 737NG. This empirical evidence provides reliable quantitative insights into incremental aerodynamic gains, structural penalties, retrofit feasibility, and economic returns all directly transferable to the A320 modernisation context. Unlike widebody platforms with raked wingtips, the 737NG experience reflects the practical engineering trade-offs relevant to narrow-body aircraft, making it the most relevant and robust benchmark for evaluating the potential upgrade of Sharklets on the Airbus A320 family.

Key Performance Comparison Based on Boeing 737NG Experience(Table 4):

Criterion	Blended Winglets	Split Scimitar Winglets (SSW)
Fuel Savings (vs. baseline, no winglet)	4-5%	5.6-7.2%
Drag Reduction	5-7%	6.5-10%
Wake Vortex Peak Tangential Velocity Reduction	5-15%	6-17%
Wake Vortex Axial Decay Acceleration	4-6%	6.5-9%
Added Weight (per aircraft)	218 kg	200-250 kg
Range Increase	3.5-4%	5-6.5%
Number of Aircraft Retrofitted (fleet scale)	5000	1700

Table 4 [39], [40], [41]

These criteria were selected because they encompass the primary technical, operational, and financial factors that determine the practicality of a wingtip retrofit on an existing narrow-body aircraft fleet. Aerodynamic efficiency and resulting fuel savings were assigned the highest weight, as fuel consumption represents the largest operating cost for high-utilization A320 operations.

Split scimitar winglets have demonstrated superior aerodynamic efficiency compared to traditional blended winglets, as evidenced by operational data from the Boeing 737NG family. Retrofit programmes showed that SSWs deliver additional fuel savings of 1.6–2.2% over blended winglets, along with an additional 3% for drag reduction and significantly improved wake vortex dissipation. These results highlight the potential benefits of adopting split scimitar technology for Airbus A320.

However, it should be noted that direct transfer of performance data from the Boeing 737NG to the Airbus A320 is not possible due to differences in wing geometry, airfoil design, wing loading, and structural layout. Therefore, the comparisons presented in this study remain theoretical and indicative; actual results for the A320 would require dedicated computational fluid dynamics (CFD) analysis, wind tunnel testing, and flight validation specific to the Airbus platform.

IMPROVED MODEL

As an improvement to the Airbus A320 model, it is proposed to change wingtips from sharklets to split scimitar winglets. It is assumed that such a change contributes not only to more efficient vortex splitting and reduced induced drag as well as the concentration of tip vortex circulation, but also improved efficiency and lower fuel consumption.

Split scimitar winglets, featuring both upward and downward aerodynamic surfaces (similar to those successfully implemented on Boeing 737NG/MAX families), allow for more effective management of wingtip vortices by distributing the vortex dissipation across two elements. This design typically achieves greater induced drag reduction compared to single upward sharklets, as the lower ventral strake further weakens the vortex strength and optimizes spanwise lift distribution without significantly increasing the overall wingspan.

Empirical data from similar retrofits (e.g., split scimitar on 737) indicate additional fuel savings of approximately $1.5 - 2\%$ over blended or sharklet-style winglets on long-haul sectors, translating to notable operational cost reductions and lower CO_2 emissions [15].

Wingtip vortices are formed due to the pressure difference between the lower and upper wing surfaces. Air flows around the wingtip from the high-pressure region beneath the wing toward the low-pressure region above it, creating a rotating vortex system behind the aircraft. This vortex formation contributes directly to induced drag and wake turbulence. According to Prandtl's lifting-line theory, the induced drag coefficient is calculated using:

$$C_{Di} = \frac{C_L^2}{\pi e A}$$

where:

$C_{Di} - induced\ drag$

$C_L - lift\ coefficient$

$e - span\ efficiency\ factor$

$A - aspect\ ratio$

The lift coefficient is determined from:

$$C_L = \frac{2L}{\rho V^2 S}$$

$L - maximum\ take - off\ weight (mg)$

$\rho - the\ air\ density (0.325\ kg/m^3)$

$V - speed$

$S - wing\ area$

The Airbus A320 with sharklets has a span efficiency factor equal to 0.75 and aspect ratio equal to 9.5 [26]. Consequently, it is possible to find induced drag of Airbus A320 by previously finding lift coefficient (C_L) at the maximum operating amplitude($11900\,m$) and with maximum speed ($890\,km/h = 247\,m/s$).

$$C_L = \frac{2\times78000\times9.8}{0.325\times247^2\times122.4} = 0.63$$

$$C_{Di} = \frac{0.63^2}{\pi\times0.75\times9.5} = 0.01773$$

The total drag coefficient is calculated as:

$$C_D = C_{Di} + C_{D_0}$$

where C_{D_0} is the zero-lift drag coefficient.

For the calculation of zero-lift drag coefficient, data are used for the Airbus A320 about the total surface area of the aircraft exposed to airflow, typically the wing planform area and an empirical value representing total skin friction.

$$C_{D_0} = \frac{C_{fe}\times S_{wet}}{S_{ref}}$$

$S_{wet} = 750\,m^2\ (Wetted\ Area)$

$S_{ref} = 122.6\,m^2\ (Reference\ Area)$

$C_{fe} = 0.003\ (Equivalent\ Skin - Friction\ Coefficient)$

$$C_{D_0} = \frac{0.003\times750}{122.6} = 0.0183523$$

Thus, the total drag coefficient for the baseline Sharklet configuration is:

$$C_D = 0.01773 + 0.0183523 = 0.0361$$

Based on studies of advanced wingtip devices on Boeing 737 MAX and 787, multi-level or scimitar wingtips can increase span efficiency factor(e) by 4 – 6% and reduce induced drag by 6 – 10% [15, 27]. While Airbus-specific data is limited, these figures provide a reasonable basis for estimating potential improvements on A320.

It can be estimated that by changing sharklets to split scimitar wingtips the span efficiency factor will increase by 4%.

The modified span efficiency factor becomes:

$$e_{new} = 0.75 \times 1.04 = 0.78$$

Consequently, the new induced drag coefficient is:

$$C_{Di_{new}} = \frac{0.63^2}{\pi \times 0.78 \times 9.5} = 0.01705$$

$$C_{Di_{new}} < C_{Di_{old}}$$

The estimated fuel saving associated with the reduction in induced drag may then be approximated by:

$$Fuel\ Saving\ (\%) \approx \frac{\Delta C_{Di}}{C_D}$$

$$Fuel\ Saving\ (\%) \approx \frac{0.01773 - 0.01705}{0.0361} \times 100 \approx 1.88\%$$

A typical Airbus A320 family aircraft performs approximately 2,500 to 3,000 flight cycles per year, corresponding to an annual utilisation of around 2,800–3,500 flight hours depending on the operator and route network. In terms of fuel consumption, an average A320 without Sharklets burns between 2,200 and 2,500 tonnes of jet fuel annually, while the installation of Sharklets provides fuel savings of up to 4%, resulting in an annual reduction of approximately 90–100 tonnes of fuel per aircraft (equivalent to 280–320 tonnes of CO_2) [42, 43].

With an additional 1.88% increase in fuel saving, the annual reduction in fuel consumption could theoretically increase to 130-150 tons of fuel. As a result, the company's theoretical annual fuel costs could fall by more than $100,000 per aircraft based on the average market price of the Jet A-1 in the range of $800-950 per ton projected for 2026-2030. [44].

In addition to reducing induced drag, split scimitar winglets may also influence the structure of the wake vortex system. According to the Kutta–Joukowski relation,

$$L' = \rho V_{\infty} \Gamma$$

the vortex circulation Γ is directly related to lift generation. Conventional Sharklets primarily generate a dominant concentrated vortex core, while split scimitar winglets introduce additional lower lifting surfaces that redistribute circulation into several weaker vortical structures:

$$\Gamma_{total} = \Gamma_1 + \Gamma_2 + \Gamma_3$$

As a result, the peak vortex intensity may decrease, reducing wake turbulence concentration. Since vortex energy is proportional to the square of circulation,

$$E \propto \Gamma^2$$

multiple weaker vortices possess lower concentrated energy compared to a single strong vortex. Therefore, the split scimitar geometry may theoretically contribute not only to lower induced drag and reduced fuel consumption, but also to weaker and more distributed wake vortex structures.

LIMITATIONS AND FEASIBILITY

One potential operational limitation of implementing split scimitar winglets on the A320 is reduced ground clearance of the lower ventral strake. During landing in crosswind conditions or on uneven runways, there is an increased risk of the lower tip contacting the ground [35]. This parameter must be carefully evaluated using Airbus ground clearance diagrams and dynamic landing simulations. Preliminary estimates suggest that additional design constraints (e.g., restricted bank angle or reinforced lower tip) may be required to maintain safe margins.

To evaluate the operational feasibility of retrofitting split scimitar winglets on the Airbus A320 in place of the existing sharklets, one of the most important limitations is the significantly reduced ground clearance of the lower ventral strake. This analysis is based on data from the official Airbus A320 Aircraft Characteristics – Airport and Maintenance Planning (AC) manual, particularly the Ground Clearances - Sharklet diagrams, combined with operational parameters and comparison with the Boeing 737 split scimitar design. In the Airbus AC manual, the sharklet wingtip height above ground in landing attitude (at maximum landing weight with compressed struts and typical pitch) is typically in the range of approximately 4.5 to 5.5 meters, depending on aircraft weight, center of gravity position, and exact configuration. The sharklets themselves add a vertical extension of about $2.4 - 2.5$ meters [31]. For the proposed split scimitar design, the lower ventral strake is assumed to be similar to the Boeing 737 implementation, where this downward element has a length of approximately 1.37 meters and the bottom tip maintains about 3.1 meters of static ground clearance on that aircraft.

Key A320 parameters include a wing dihedral of approximately 5.2 degrees [32], typical landing pitch attitude at touchdown of 4 to 7 degrees nose-up (with a tail strike limit of 11.7 degrees when the main landing gear is fully compressed), operational bank angles up to $5 - 8$ degrees in crosswind landings, and main landing gear strut compression of $0.3 - 0.5$ meters or more under heavy load. Wing flex under load further lowers the outer wing.

Using a kinematic approximation, the minimal lower tip clearance is calculated as the base sharklet tip height minus the vertical projections caused by pitch ($h = L_{lower} \times sin(\theta_{pitch})$), bank angle effects, strut compression, wing flex, and a safety margin of at least $0.3–0.5$ meters. In a conservative example with a base sharklet tip height of around $4.8–5.2$ meters, a lower strake length of 1.4 meters, 6-degree pitch, 5-degree bank, and combined strut plus flex losses of 0.4–0.6 meters, the lower tip clearance can drop to 3.0–3.8 meters nominally and potentially below 2.5–3.0 meters in worst-case scenarios such as heavy landing weight, strong crosswind, or runway unevenness.

This reduction creates a risk of the lower strake contacting the ground during landing, which would require design modifications like shortening the strake, adding operational restrictions on bank angle or crosswind, or reinforced tips. Full dynamic simulation with Airbus OEM data is strongly recommended for accurate certification assessment. Sources include the Airbus AC A320 manual (July 2025 revision for Ground Clearances figures), Boeing 737 split scimitar dimensions from Aviation Partners Boeing documentation, and Airbus FCOM data for pitch and tail strike limits. This limitation represents an important engineering trade-off that must be carefully weighed against the expected aerodynamic improvements and fuel savings.

CONCLUSION

Based on the analysis of existing wingtip devices, a comparison was made between blended winglets, raked wingtips and split scimitar winglets for the Airbus A320.
The theoretical analysis showed that existing Sharklets provide a reduction of induced drag by increasing effective aspect ratio and reducing vortex intensity. However, split scimitar winglets have additional aerodynamic advantages due to dual element geometry, which includes upper scimitar element and lower ventral strake.

Based on lifting line theory and calculations of the induced drag coefficient, it has been determined that an increase in span efficiency factor of approximately 4% can lead to a decrease in the induced drag coefficient from 0.01773 to 0.01705. The estimated fuel saving rate was approximately 1.88%, which demonstrates potential aerodynamic efficiency improvement when using split scimitar winglets on Airbus A320.

Additionally, structural and operational limitations proposed for retrofit were considered. The main disadvantages are increased wing root bending moments, additional structural weight and reduced ground clearance of lower ventral strake. The analysis showed that in unfavorable planting conditions there is a ground contact risk, which requires additional design optimization and assessment of certification feasibility.

Thus, split scimitar winglets can be considered as a promising direction of the Airbus A320 upgrade in terms of induced drag reduction, wake turbulence mitigation and fuel efficiency improvement. For further research, it is recommended to perform a more detailed aerodynamic analysis using CFD models and numerical simulations that quantitatively assess vortex dynamics, wake decay characteristics, and the real aerodynamic benefits proposed wingtip configuration.

However, it is essential to emphasise that all findings and quantitative estimates presented in this study are purely theoretical. The analysis relies on secondary literature, simplified application of Prandtl's lifting-line theory, and performance data transferred from the Boeing 737NG platform. Due to significant differences in wing geometry, airfoil design, wing loading, and structural architecture between the two aircraft families, the actual aerodynamic benefits on the Airbus A320 may differ considerably from the calculated values. The estimated 1.88% additional fuel saving should therefore be treated as an indicative figure with notable uncertainty. The study lacks dedicated CFD modelling, wind tunnel testing, or flight validation specific to the A320 airframe, which limits the reliability of vortex dynamics predictions and fuel consumption estimates. Furthermore, the structural and operational limitations (particularly ground clearance of the lower ventral strake) require comprehensive dynamic simulations and certification assessment. Future research should include high-fidelity CFD analysis using the k–ω SST turbulence model on a detailed A320 geometry, wind tunnel experiments, and ultimately flight test campaigns to obtain accurate, platform-specific data and confirm the real-world feasibility and benefits of implementing split scimitar winglets on the Airbus A320 family.

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