Proceedings of CONF-MPCS 2026 Symposium: Theoretic Physics and Plasma Physics
DOI: 10.54254/2753-8818/2026.DL34268

The Effect of Wingtip Devices on Aircraft Aerodynamic Performance

Jincheng Li

School of Intelligent Manufacturing Ecosystem, Xi'an Jiaotong-Liverpool University, Suzhou, China
Jincheng.li23@student.xjtlu.edu.cn

Abstract. Induced drag is one of the main sources of drag acting on a wing, and it comes from the strong vortices that tend to form near the wingtips during flight. This kind of drag not only reduces aerodynamic efficiency but also means the aircraft burns more fuel than it needs to. Wingtip devices have been around for a while now, and they are basically designed to limit how much these vortices affect overall flight performance. In this paper, we take a closer look at several different wingtip device designs and how they each influence aircraft performance. We start by going over the basic mechanism behind wingtip vortex formation and why it leads to induced drag in the first place. After that, we compare both well-established designs like blended winglets and split-tip winglets with more recent ones such as multi-tip and spiroid winglets, using data from numerical simulations and wind tunnel experiments. We also look at how each design performs in terms of lift, drag reduction, and lift-to-drag ratio. Overall, the results suggest that all the devices studied are capable of improving aerodynamic performance to varying degrees.

Keywords: Wingtip Devices, Induced Drag, Aerodynamic Performance, CFD, Lift-to-Drag Ratio

1. Introduction

Researchers and engineers have come to realize that it is very important to optimize the aerodynamic performance of aircraft. Wingtip vortices are strong rotating airflows that form when high-pressure air beneath the wing spills over the wingtip and moves toward the low-pressure region above the wing. Studies have shown that for subsonic aircraft, the induced drag caused by wingtip vortices can account for as much as 30% to 40% of the total drag during cruise conditions [1]. Figure 1 shows the secondary flow around the wing and how wingtip vortices are formed. This secondary flow changes the local airflow direction, creating a downwash effect that tilts the total lift vector backward, which then produces an induced drag component [2].

To deal with the negative effects of induced drag, various wingtip devices have been developed. Ever since Richard Whitcomb conducted his pioneering research on winglets at NASA back in the 1970s [3], a wide range of wingtip device designs have appeared, from simple endplates to more complex three-dimensional shapes. So far, a number of high-performance designs have already been put into use, such as split scimitar winglets, raked wingtips, and spiroid winglets. These devices help improve the lift-to-drag ratio of the wing, while also cutting down on structural weight and reducing

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

friction drag [4]. Basically, the way they work is by weakening the trailing vortices behind the wing, which in turn lowers the induced drag that comes from generating lift [5].

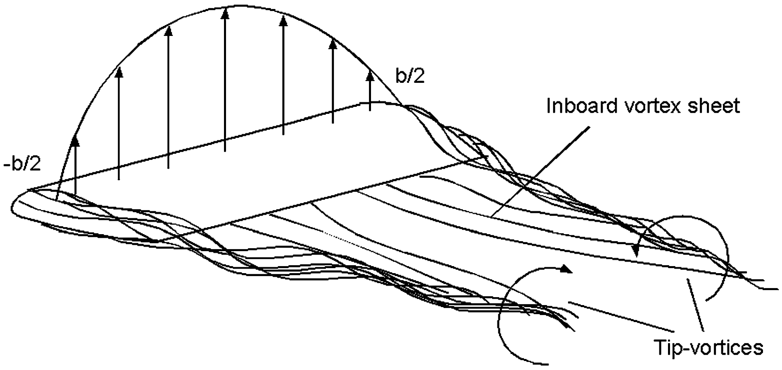

Figure 1. Tip vortex formed by secondary flow

2. Theoretical basis of induced drag

According to the Prandtl lifting-line theory, the downwash field close to the tip of a finite-span wing is reduced at this point because of the presence of wingtip vortices. This downwash effectively reduces the angle of attack of the wing sections by an induced angle of attack, $ai.$Consequently, the total lift vector, which is perpendicular to the freestream flow, tilts backward by this angle. The component of this tilted lift vector aligned with the flight direction is the induced drag, *DI* [6].

The ideal wing has an elliptical distribution of lift, and its induced drag coefficient, *CDi*, is given by the equation:

$$C_{Di} = \frac{C_L^2}{\pi * AR} \tag{1}$$

where C_L is the lift coefficient and AR is the wing's aspect ratio ($AR = b^2/S$, where b is the wingspan and S is the wing area). For a real wing with a non-elliptical lift distribution, an Oswald efficiency factor e (typically $0.7 < e < 1$) is introduced, modifying the formula to:

$$C_{Di} = \frac{C_L^2}{\pi * e * AR} \tag{2}$$

As shown in Figure 2, according to Equation 2, when the lift coefficient is kept constant, induced drag is inversely proportional to the aspect ratio. The role of wingtip devices is to increase the effective aspect ratio of the wing, so that induced drag can be reduced without actually making the wingspan longer. Compared to simply extending the physical wingspan, this approach can avoid a lot of problems related to structural design and ground handling [7].

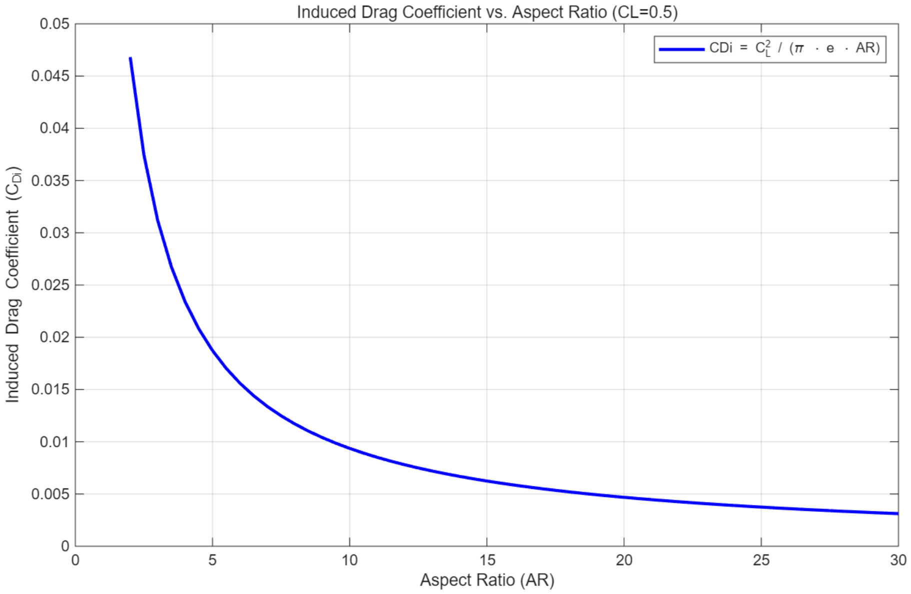

Figure 2. Variation curve of induced drag coefficient with aspect ratio

3. Performance comparison of different wingtip devices

A variety of wingtip devices have been developed in the industry, and each one takes a different approach to suppressing wingtip vortices. Figure 3 shows some common configurations, including blended winglets and split scimitar winglets.

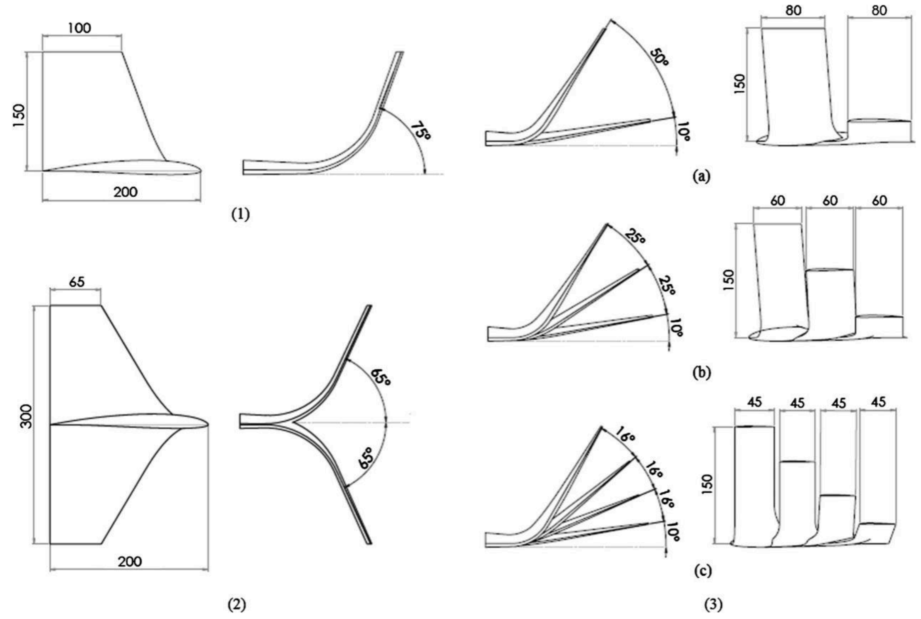

Figure 3. Comparison diagram of different types of wingtip devices

3.1. Conventional and improved winglets

Blended winglets and forked winglets are probably the most widely used designs on modern commercial aircraft. According to the study by Narayan and John [1], compared to a baseline wing, a blended winglet can improve the lift-to-drag ratio by around 3.5%. On top of that, the dual-tip wing design, which is structurally similar to the forked winglet, can push that improvement up to as high as 14.8%. The reason forked winglets tend to perform better is that their split structure breaks up one single strong wingtip vortex into two weaker ones, which allows the airflow energy to dissipate more efficiently. In a CFD study carried out by Mkgantsi et al. [8] on a UAV wing, their results showed that a blended winglet with a cant angle of 60° outperformed other configurations, achieving a 20.2% improvement in lift-to-drag ratio compared to a plain flat wing. These findings suggest that even more traditional winglet designs can still make a noticeable difference in improving the aerodynamic efficiency of an aircraft.

3.2. Advanced concepts: multi-tip and spiroid winglets

To better reduce drag, we can adopt the scheme above. As shown in Figure 4, the two designs are the multi-tip winglet and the spiral winglet respectively.

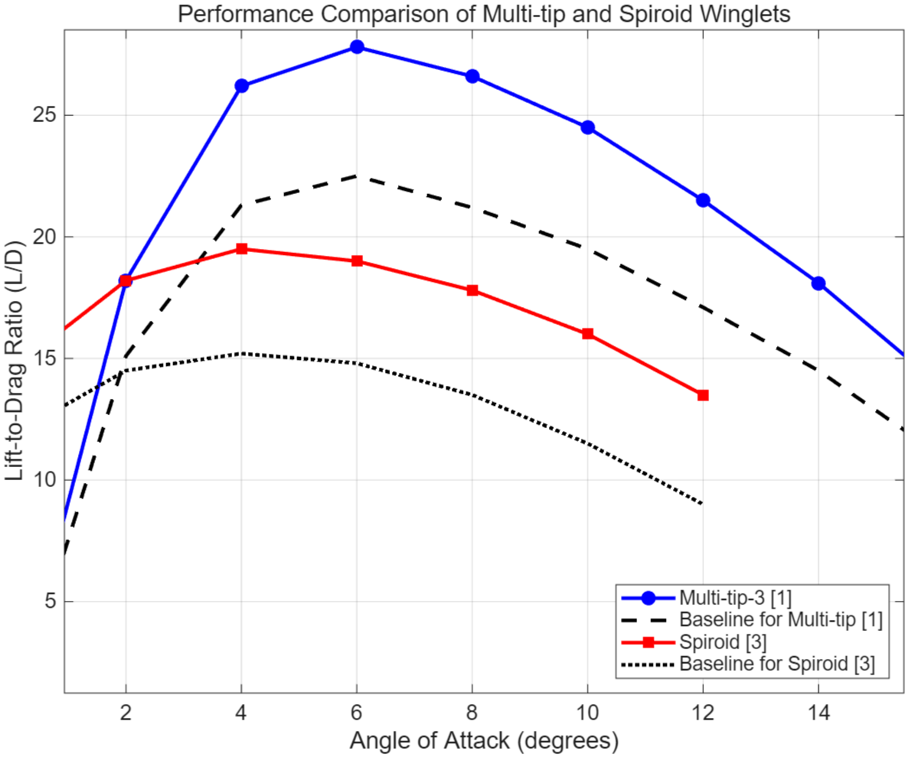

Figure 4. Comparison between multi-tip and spiral winglets

The basic idea behind multi-tip winglets is to break the main wingtip vortex into several smaller and weaker ones. Studies have shown that while increasing the number of tips does raise the lift coefficient, it also leads to a larger wetted area and higher friction drag. Taking all these factors into account, the three-tip configuration turns out to be the sweet spot-it gives the most balanced performance improvement and can boost the lift-to-drag ratio by up to 22.59% [1].

Spiroid winglets belong to the closed-loop type of wingtip devices, and this design has gone through a good deal of refinement and optimization over the years. By forming a rigid closed loop at the wingtip, spiroid winglets are able to more effectively prevent spanwise airflow from spilling over. Guerrero and his team [5] ran a series of comparative experiments and found that spiroid winglets could increase the maximum lift-to-drag ratio by 7.1%, with a pretty significant reduction in wingtip vortex strength as well. Similarly, Sundara et al. [9] looked at three different winglet types- blended, split, and spiroid-and concluded that the spiroid winglet delivered the best overall aerodynamic performance across all angles of attack. Table 1 summarizes the performance gains associated with each type of winglet.

Table 1. Performance improvement comparison of different winglet types

Winglet Type	Source
Blended Winglet	Makgantai et al. [7]
Split Winglet (BMAX)	Narayan & John [1]
Multi-tip (3 tips)	Narayan & John [1]
Spiroid Winglet	Guerrero et al. [5]
Spiroid Winglet	Sundaramahalingam et al. [3]

4. Influence of key parameters on winglet performance

The effect of any wingtip device is determined by the shape of the wing and the winglet at the same time.

4.1. Influence of aspect ratio

Generally speaking, winglets seem to work better on low-aspect-ratio wings. One study showed that a three-tip winglet improved the lift-to-drag ratio by around 45% on a wing with an aspect ratio of 6, but only by about 22% on a wing with an aspect ratio of 14 [1]. This makes sense when you think about it-on shorter wings, induced drag accounts for a bigger portion of the total drag, so reducing it has a more obvious effect. There is also evidence that simply stretching the wingspan to raise the aspect ratio can cut induced drag by over 20%, which raises the question of whether installing winglets is always the most practical choice for every aircraft type.

4.2. Effect of cant angle

Cant angle is another parameter that has received quite a bit of attention. Research has shown that a cant angle of around 60° tends to strike a good balance between aerodynamic gain and structural load, and in one case this translated into roughly a 10% improvement in flight endurance [3]. When comparing smaller and larger cant angles, the larger ones generally come out ahead in terms of lift-to-drag ratio. A likely reason is that steper cant angles are more effective at disrupting spanwise flow while also producing small forward thrust component. That said, pushing the cant angle too high will eventually create structural problems, so the final choice always involves some compromise [10].

5. Conclusion

Based on the studies reviewed, the effects of different wingtip devices on aircraft aerodynamics can be summarized as follows:

(1) In general, wingtip devices reduce induced drag by weakening or reshaping the wingtip vortex, which improves the wing's spanwise efficiency.

(2) Compared with conventional blended winglets, concepts such as multi-tip winglets (vortex diffusion) and spiroid winglets (closed-loop flow) often achieve a stronger reduction in induced drag and can deliver better overall aerodynamic performance.

(3) Winglet design involves a clear trade-off: it can reduce induced drag, but the extra wetted area increases skin-friction drag. Since these effects counteract each other, the best design often depends on the aircraft's mission and operating conditions.

(4) Winglets tend to give larger benefits on low-aspect-ratio wings. However, in some cases simply increasing the wing aspect ratio may be more effective than adding a winglet. A relatively high cant angle is also a practical option when handling qualities are a priority.

For future work, more attention is needed on how to balance aerodynamic gains with structural weight, aeroelastic constraints, and manufacturing cost. It would also be useful to verify whether current conclusions still hold under a wider range of realistic operating conditions, instead of only the limited cases studied so far.

References

[1] Narayan, G. and John, B. (2016) Effect of winglets induced tip vortex structure on the performance of subsonic wings. Aerospace Science and Technology, 58, 328-340.
[2] Hrúz, M., Pecho, P., Bugaj, M. and Rostáš, J. (2022) Investigation of vortex structure behavior induced by different drag reduction devices in the near field. Transportation Research Procedia, 65, 318-328.
[3] Govardhan, D., Rao, M.V.N., Rao, P.S., Kumar, I. and Nalli, N. (2023) Effect of winglet cant angle on the performance of an aircraft wing. Materials Today: Proceedings.
[4] Panagiotou, P., Kaparos, P. and Yakinthos, K. (2014) Winglet design and optimization for a MALE UAV using CFD. Aerospace Science and Technology, 39, 190-205.
[5] Guerrero, J.E., Maestro, D. and Bottaro, A. (2012) Biomimetic spiroid winglets for lift and drag control. Comptes Rendus Mécanique, 340, 67-80.
[6] Auerbach, D. (2000) Why aircraft fly. European Journal of Physics, 21, 289.
[7] Wieszała, R., Kołodziej, P., Mendala, J. and Kozuba, J. (2022) Relation between wing aspect ratio and induced drag. 2022 New Trends in Aviation Development (NTAD), 257-260.
[8] Makgantai, B., Subaschandar, N. and Jamisola, R.S. (2021) Design optimization of wingtip devices to reduce induced drag on fixed-wings. 2021 International Conference on Unmanned Aircraft Systems (ICUAS), 1459-1465.
[9] Sundaramahalingam, A., Jain, P.S., Rajan, S.S., Dheeraj, V.S., Kruthik, C., Vishaldeep, K.S. and Yuvaraj, L. (2025) Numerical analysis of winglet performance: A comparative study. International Journal of Vehicle Structures & Systems, 17, 587-590.
[10] Kontogiannis, S.G. and Ekaterinaris, J.A. (2013) Design, performance evaluation and optimization of a UAV. Aerospace Science and Technology, 29, 339-350.