Proceedings of the 3rd International Conference on Computing Innovation and Applied Physics
DOI: 10.54254/2753-8818/14/20240906

Study on application of winglets in drones

Jiajun Li

College of aeronautics and astronautics, Sun Yat-sen University, Shenzhen, Guangdong, 518107, China

lijj297@mail2.sysu.edu.cn

Abstract. With the rapid development of drone technology, methods to improve drone performance have emerged endlessly. Reducing air resistance can significantly improve drones' fight performance. The winglet is used to control the turbulence and vortices. The widespread application of winglets in the field of military and civil aviation has enabled winglets to be applied to drones to improve flight range and economic efficiency. As different winglets have different impacts on drones' flight performance, this article focuses on the influence of different winglets on enhancing lift and reducing resistance of small civilian drones. In detail, three representative winglets are taken as the specific research objects, including the fusion winglet, the double fork scimitar winglets, and wingtip fence. The aerodynamic characteristics and the structural designs are comprehensively introduced. The importance of winglets in improving aircraft performance, energy saving and environmental protection is briefly explained. This article may offer a reference for the design of drones.

Keywords: Induced Drag, Winglet, Drone.

1. Introduction

With the widespread application of winglets in the field of military and civil aviation, the rapid development of the drone field has also enabled winglets to be applied to drones to improve flight range and economic efficiency. The purpose of winglets is to control the turbulence and vortices. However, the actual application of different winglets, such as fusion winglet, wingtip fence, wingtip end plates and double fork scimitar winglets, will have different impacts on drones' flight performance. If suitable winglets are not selected in the actual application, there will be worse flight quality.

This article focuses on the influence of different winglets on enhancing lift and reducing resistance of small civilian drones. Long-straight wing aircraft is chosen as the subject of discussion. Design suggestions for drone winglets are given by analyzing aerodynamic characteristics, flight performance, and flight range of drones under different types of winglets. This article may offer a reference for the design of drones.

2. Principle of winglets

In aircraft flight, according to the basic principle of lift, when the relative speed of the aircraft and air increases, the pressure difference between the upper wing surface and the lower wing surface will increase. At the tip of the wing, airflow from the lower surface will bypass the tip and flow to the upper surface. The combination of this flow trend and the incoming flow forms a spiral wing-tip vortex. When the airflow is disturbed at the tip of the wing, there will be more airflow that deflects downward from the upper surface of the airfoil, and the effective lift will increase at this time. Although this makes the effective lift closer to the required lift, the increased lift also produces a new component in the horizontal direction: the induced drag. For low speed flights, the induced drag accounts for a very large proportion.

During the movement of the aircraft, strong vortices and swirls will be formed due to the cantilever effect of the main wing and the pressure difference at the wing tips. The design and position of the winglet can accurately influence the flow near the wing tip, reducing the generation of turbulence and the formation of vortex, thereby reducing aerodynamic resistance and improving lift efficiency. The design and optimization of the winglet and future development trends will play an increasingly important role in drone applications. Wind tunnel tests have shown that the induced drag of the entire vehicle can be reduced by about 20% to 35% [1].

Nowadays, with the continuous development and progress of the aviation field, more and more structures of winglets have been proposed. Modern mainstream winglets are broadly divided into several categories: fusion winglets, double fork scimitar winglets, and wingtip fence.

3. Aerodynamic characteristics of different winglets

3.1. *Fusion winglets*

The structure characteristic of fusion winglet is that the winglet is fused with the wing, achieving a smooth transition between the two structures, and effectively reducing their aerodynamic interference. Since the wing is raised upward, the wing tip has a large upper angle, and the strength arm at the tip of the wing is increased, thus giving the aircraft good lateral stability [2].

Each component of the fusion winglet will affect the lifting resistance characteristics. The influence is determined by installation angle, external inclination angle, height, backward angle, sharpening ratio and so on. The installation angle, camber angle and height have relatively large influence, and the effects among them are close. The maximum lift-to-drag ratio is achieved when the winglet height is 70% of the straight wing length, 25° outward inclination, 0.3 sharpening ratio, 30° backward angle, and 3° mounting angle.

The fusion winglet can reduce the needed engine thrust by 3% during takeoff and 3.4% during cruising, and increase landing stability. Under the same angle of attack, the lift coefficient of the wing with the fusion winglet increases, the resistance coefficient decreases slightly, the lift-to-resistance ratio increases significantly, the maximum lift-to-drag ratio increases by 1.0, and the low head torque increases with respect to the fuselage bending moment [3].

3.2. *Double fork scimitar winglet*

Compared with the fusion winglet, the double fork scimitar winglet is installed below the tip of the wing. It is equivalent to add a lower angle at the tip of the wing, which can increase lateral static stability and heading stability to a certain extent, and is superior to the fusion winglet in terms of improving stability [4].

The position of the lower wing of the double fork scimitar winglets has a great influence on the overall aerodynamic efficiency. The lower wing with a smaller opening angle and an upper position will increase aerodynamic efficiency. The lower winglet can reduce the maximum induced drag and achieve the maximum lift-to-drag ratio in the front area of the inner wing surface of the winglet.

Due to the addition of the lower wing, the blocking effect of the winglet on the lateral airflow is further enhanced, so that the reduction in induced drag is further increased. Since the side wash flow generated by the upper wing in the flow field decreases, the local angle of attack is reduced to a certain extent and the lift is reduced [5]. While this configuration increases the lift-to-drag ratio, there is no obvious increase in the bending moment of the fuselage. However, the installation of the lower wing still increases the overall weight of the fuselage, which will increase the fuel consumption of the aircraft to a certain extent. The complexity of the design will increase at the same time.

3.3. Wingtip fence

Wingtip fence is an auxiliary wing surface composed of multiple sails mounted on the tip of the wing. The chord length of the sail is usually much smaller than the wing-tip string. Like a sail on a yacht, this auxiliary wing surface uses lateral wind to synthesize airflow to increase thrust, and at the same time disperses the strongly concentrated vortices at the tip of the wing into discrete weak discrete vortices to reduce induction resistance. Through wind tunnel tests, it has now been proven that wingtip fences have an obvious effect of reducing drag, and are able to reduce the aircraft's induction resistance factor by 21.49% or more [6]. The difficulty in using wingtip fence as winglet is the complex design because there are multiple sails in the structure [7].

In terms of the design of wingtip fence, as far as reducing induced drag is concerned, the greater the number of sails, the better the drag reduction effect. However, at the same time, it also increases frictional resistance and the overall weight of the aircraft. In terms of design, the main parameters that affect the aerodynamic effect of the sail are: the angle of torsion of the sail, the installation angle, the length of the sail, and the installation position of the sail in the direction of the tip of the blade [6]. Designing the sail into a linear twisting airfoil can avoid severe flow separation between the upper and lower surfaces of the sail and reduce processing difficulty. Interference between the airflow between the sails will greatly reduce the drag reduction effect, so when selecting the installation angle and installation location, the influence of the front sails on the rear sails should be considered. After determining the front sail, it is necessary to re-measure the subsequent local flow declination change law, and then select the installation angle and installation position of the rear sail.

4. Economic performance of winglets

The winglet has played a significant role in reducing fuel consumption. Over the past decade, the hybrid winged systems can generally save 4% to 6% of fuel, reducing carbon dioxide emissions by 6% and nitrogen oxides by 8%. It has saved global airlines 200 million gallons of jet fuel, reducing carbon dioxide emissions of nearly 210,000 tons [8].

In an actual case, the average flight segment distance of 38 aircrafts with modified winglets in a airline is 1,600 km. Each aircraft consumes 2.5t per hour of fuel. After installing the wing tips, fuel is saved about 77.5kg per hour. It saves a total of 9801.27 tons of fuel per year and reduces carbon dioxide emissions of about 27702.63 tons per year [9].

Economically, winglets can clearly extend the flight time of the aircraft, help reduce fuel consumption and extend flight time, meaning that it can fly longer distances or carry more cargo within the same distance range [10]. The winglet is significantly helpful in high-range drones.

5. Practical application of winglets

The practical application of winglet in unmanned aerial vehicles has important economic value. Through the optimized design and the introduction of winglets, the drones' flight performance and efficiency have been improved, including reducing energy consumption, extending flight time, increasing carrying capacity, and improving maneuverability and stability. The application of winglet has played a driving role in the development of drone technology, providing an opportunity for innovation and breakthroughs in future drone applications.

5.1. Long-lasting high-altitude drone

High-altitude long-flight drones play an important role in tasks such as search and rescue, cruise monitoring, and communication relaying. The application of winglets in such drones can further improve their fuel efficiency and flight time. By reducing aerodynamic resistance and wingspan ratio, the winglets can reduce vortex loss and vortex drag, making it easier for the drone to fly at high altitudes and continue to perform tasks for a longer period of time. The installation of winglets not only improves drone performance, but also brings economic benefits for cruise service providers.

5.2. Environmental monitoring and agricultural drones

The winglet also has important applications in environmental monitoring and agricultural drones. By reducing the wingspan ratio and turbulence intensity, the winglet can improve the stability and flight efficiency of the drone, making it more suitable for tasks such as aerial image acquisition, plant growth monitoring, and soil investigation. The application of winglet can improve the maneuverability and coverage of agricultural drones, provide more accurate and timely environmental information, and help agriculture and environmental protection.

5.3. Underwater and overwater drones

In addition to aerial applications, winglet also has practical applications in underwater and surface drones. Underwater and surface drones often need to overcome the resistance and instability caused by water flow and hydrodynamics to complete tasks such as underwater surveys, marine research, and diving operations. The introduction of winglets can improve the flow field distribution and stability, reduce turbulence and resistance, and improve hydrodynamic performance and underwater maneuverability. The application of winglets can help improve the adaptability and operability of underwater and surface unmanned vehicles.

6. Conclusion

The fusion winglet is simple in design, which can usually save costs in terms of economy. For short ranges, small drones can be equipped with fusion winglets to reduce design difficulty while increasing drone performance. The double fork scimitar winglet is superior to the fusion winglet in terms of reducing drag, but considering manufacturing costs, this type of wingspan can be used on heavy, high-resistance drones such as large wing spans, and can avoid additional increase in fuselage weight. The wingtip fence has a high degree of freedom in design and can be freely adjusted according to actual conditions. However, due to the difficult design, wingtip fences will increase design and manufacturing costs in most cases, so it is not recommended to use wingtip fences in drone design.

Adding winglet to drones improves the range, stability, and energy utilization of the aircraft. It is an effective measure for airlines to improve product performance.

References

[1] Lu Honglei, Liu Tiejun, Ma Tuliang, et al. Analysis of aerodynamic characteristics of modern advanced winglets. Scientific and technological information, 2013, 18: 375-376.
[2] Luo Yue. Study on lifting resistance characteristics and parameter optimization of fusion winglets. Nanchang Hangkong University, 2023.
[3] Ma Yumin, Wei Jianlong. Study on drag reduction effects of fusion winglets. Advances in Aeronautical Engineering, 2018, 9(2): 7.
[4] Wang Dan, Tao Yujin, Li Peifeng, et al. Application of different types of winglets in drone design. Journal of Naval Aeronautical Engineering, 2017, 32(5): 7.
[5] Li Yufei, Bai Junqiang, Guo Bozhi, et al. Design and study of civil transport aircraft wing-tip devices based on FFD technology. Journal of Northwestern Polytechnical University, 2015, 33(4): 7.
[6] Qi Mengka, Chen Mingyan. Study of flow fields near the tip of the wing and drag reduction mechanism of sails. Hydrodynamic experiments and measurements, 1995, 9(1): 38-45.
[7] Zheng Benwu, Chen Mingyan. Optimized design of wingtip fence blades. Journal of Aerodynamics, 1995,013 (1): 105-109
[8] TRIMBLE S. Low-price fuel drag. Flight International, 2016, 189(29):28-29.
[9] Ding Songbin, Fan Jiafeng, Ma Tengyu. Economic analysis of A-type aircraft modified winglets based on cost benefit theory. Progress in aeronautical engineering, 2021,12 (02): 106-111+121.
[10] Jiang Yongquan. The Design of Airplane Winglet. Aeronautical Industry Press, 2009:19-20.