Comparison of the winglet aerodynamic performance in unmanned aerial vehicle at low Reynolds number

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Abstract. The Aerodynamic performance of an object is very dependent on the flow of fluid through it and the geometric shape of the object. The use of Unmanned Aerial Vehicle (UAV) demands high aerodynamic performance because it strongly supports the cruising range and fuel or battery used. By reducing drag and increasing the lift optimally, the resulting lift to drag ratio will get maximum results. This study compares the use of winglets in UAVs at low Reynolds numbers. This is very important because generally UAVs are used at low Reynolds numbers. The freestream used is $Re = 2.34 \times 10^4$ on several low to high angle of attack. The type of airfoil used is Eppler 562 which is equipped with a winglet. Winglets used are simple winglets, blended winglets, and wingtip fence. The geometry was analyzed using numerical simulations namely computational fluid dynamic (CFD). The turbulent model used in this study is K-ω SST on Ansys 19.1. From this study it was found that the use of wingtip fence produced the best aerodynamic performance compared to other configurations. In addition, the use of a wingtip fence can delay stall and separation better than simple and blended winglets.

Keywords: lift to drag ratio, unmanned aerial vehicle, blended winglet, simple winglet, wingtip fence

1. Introduction

Winglets have become a significant requirement in aircraft operations. At present, it can be ascertained that all new designs for commercial aircraft will use winglets on their wings. It is a common agreement in various journals and magazines that the first generation of the winglet design was designed by NASA’s Richard Whitcomb in 1976. The design is claimed to have increased efficiency by 2.5-3% in fuel economy compared to without winglets. The second generation has been installed on the Boeing 737 Classics, 737 NG, 757, and 767 where it is claimed to save 4-6% fuel. This is followed by the third generation installed on the 737 MAX which is claimed to have saved 1-2% compared to the second
generation. In the Airbus design, the use of Sharklets is claimed to have reduced wingtip vortices and reduced total drag [1]. Other researchers have also discussed and compared winglets on aircraft, as presented by Jahanmiri [2] and Scholz [3].

The use of other flying objects seeks to continue to improve its performance through the use of winglets. Flying objects that are similar to airplanes include the Unmanned Aerial Vehicle (UAV). Its use has been widely used in traffic monitoring, agriculture, volcano monitoring, pollution monitoring, delivery, military, and others [4]. UAV utilization is very dependent on aerodynamic aspects, although the power source also plays a major role in increasing the range.

During its development, the UAV was not only in the form of a fixed-wing and rotary wing like an airplane but developed into a UAV convertiplane and tail-sitter UAV. This development makes the types and forms of UAV more varied [5].

Belferhat et al examined the effect of cant angle $\beta$ variation on the blended winglet, which was modified at the leading edge[6]. This research was conducted on an airfoil wing NACA 0012 with $\beta = 0^\circ$, $55^\circ$, $65^\circ$, and $75^\circ$. The velocity used in the wind tunnel are 20, 30, and 40 meter/second (Re = 2.35 x 10^5, 2.84 x 10^5 and 3.03 x 10^5). The angles of incidence used are + 0°, + 5°, + 10°, and + 19°. From the results of this study, it was found that $\beta = 55^\circ$ resulted in better aerodynamic performance than other cant angle variations.

Munoz et al conducted a study on fixed-wing UAV[7]. The airfoil used on the wing is NACA 23015 with an Eppler 387 winglet airfoil. Freestream velocity used in the wind tunnel is 30 meter/second (Re = 3.5 x 10^5). From this research, it was found that with wingtip blowing using coanda jet and multi winglet can reduce induced drag. However, for commercial use, it is not recommended because it uses a very large amount of energy. Multi winglets show better results although slightly compared to plain wings. The use of multi-winglets is highly recommended, especially for light aircraft using low velocity.

Xin et al [8] examined the performance of the bionic wing design in UAVs using winglets. The bionic referred to imitates the wing shape of a seagull. The bionic wing is in the form of a plain wing compared to the plain wing which is equipped with a winglet. The use of bionic wings and winglets can increase the pressure distribution on the wing, reduce the drag coefficient, and reduce the separation point on the wing. With a decrease in the drag coefficient, the lift to drag ratio of the wings also increases. Besides, it can be seen that with the winglets, the downwash angle of attack and the downwash velocity can be reduced.

The above studies have provided further inspiration to compare the aerodynamic performance of several types of winglets that can be used in UAVs. The choice of UAV is emphasized because it uses a relatively smaller velocity. This study uses a rectangular or straight wing as the basis for the use of other wing types. The output of this research is the drag coefficient, lift coefficient, lift to drag ratio, and also some wing visualizations that can show the evolution of the fluid flow around it.

### 2. Materials and Methods

Computational Fluids Dynamic numerical simulation in this study using Ansys 19.1. K-\omega SST was used as a turbulent model with a freestream velocity of 10 meter/second (Re = 2.34 x 10^5). This numerical simulation refers to Hariyadi's research [9–11]. Before analyzing aerodynamic performance and numerical visualization, an independent grid is carried out to see the extent of the efficiency of each mesh that will be used. Several types of mesh used can be seen in table 1. Table 1 shows the condition of the model used for running Ansys 19.1.

Table 1 shows the boundary conditions and properties of the model and the flow that passes through the Eppler 562 wing airfoil. Referring to the Kontogianis research [12] on y+ and Anderson [13] regarding the drag coefficient, it is found that Mesh B in table 2 is used in this study. Figure 1 shows the boundary conditions that refer to Mulvany's research [14]. Figure 2 shows the model used in the study.
Table 1. Description of the Model Condition

| Description | Model Condition |
|-------------|-----------------|
| Model       | 3D, Unsteady/Transient |
|             | Plain wing      |
|             | Plain wing with simple winglet |
|             | Plain wing with blended |
|             | Plain wing with forward wingtip fence |
|             | Plain wing with rearward wingtip fence |
| Airfoil     | Eppler 562      |
| Fluid       | Air             |
| Fluids Properties | Density 1.225 kg/m³ |
|             | Viscosity 0.000017894 kg/m·s |
| Boundary condition | Wing Wall |
|             | Outlet Outflow |
|             | Inlet Velocity Inlet |
|             | Wall Wall |
| Reynolds Number | Re = 2,34 x 10⁴ |

Table 2. Grid analysis model E562 three dimensions without winglets

| Meshing Type | Number of Cells | C_D  | y*  | Skewness Average |
|--------------|-----------------|------|-----|------------------|
| Meshing A    | 768.081         | 0.883| 1.4 | 0.347            |
| Meshing B    | 569.313         | 0.902| 0.8 | 0.343            |
| Meshing C    | 469.682         | 0.858| 2.1 | 0.346            |
| Meshing D    | 353.120         | 0.921| 2.1 | 0.334            |
| Meshing E    | 335.582         | 0.933| 2.8 | 0.351            |

Figure 1. Simulation domain and research boundary conditions [14]
3. Result and Discussion

In the numerical simulation output results, the total drag coefficient, lift coefficient, and lift to drag ratio are obtained. Besides, various kinds of visualizations can be generated that can support the lift and drag output. Although the definitions and distribution of drag types differ in some literature, for example in the Kundu [15] and Panagiotou [16], the Ansys 19.1 output results refer to viscous drag and pressure drag. The results of this study show the results of viscous drag and pressure drag.

3.1. Drag Coefficient, Lift Coefficient, and Lift to Drag Ratio

Figure 3 shows the results of the drag coefficient of the plain wing, the plain wing equipped with the blended winglet, simple winglet, rearward wingtip fence, and forward wingtip fence. Figure 3 shows that the addition of a blended and simple winglet increases the total drag compared to the plain wing. In this figure it is also shown that the forward and rearward wingtip fence produces a smaller total drag than the plain wing.

In general, it is shown that as the angle of attack increases, the total drag also increases. The results obtained in this study have higher drag than Turanoguz's research [17,18] which uses Re = 2.356 x 10^6. This is possible because in the Turanoguz study using a higher Reynolds number so that the ability of the flow to resist viscous drag is higher than this study. which uses Re = 2.34 x 10^4.

To see the contribution of viscous drag and pressure drag, it can be explained in figures 4 and 5. Figure 4 shows that the role of viscous drag in the forward and rearward wingtip fence is quite dominant. This is because the surfaces of the forward and rearward wingtip fences are wider than the plain, simple, and blended winglets. Figure 5 shows the effect of drag pressure on the overall drag. The frontal area or cross-sectional area of the winglet configuration to the direction of flow will determine how much flow resistance the geometric configuration accepts. Therefore, the amount of drag pressure is not determined by the side view area of the wing because the flow is assumed to come from the direction of the X-axis of the flow.
Figure 3. Total Drag Coefficient Comparison of the Research Model

Figure 4. Viscous Drag Coefficient Comparison of the Research Model

Figure 6 shows the lift coefficient of the plain wing, the plain wing equipped with the blended winglet, simple winglet, rearward wingtip fence and forward wingtip fence. The lift coefficient produced by Turanoguz's study [17,18] is higher than this study. Again, this is because the Reynolds number used is higher than this research. The thing of concern is the ability of the winglet to delay the occurrence of a stall compared to the plain wing.

The stall point on the plain wing occurs at an angle of attack of 12°, as in Turanoguz's research. Likewise, the plain wing which is equipped with a simple winglet. The plain wing which is equipped with a blended winglet shows that the stall occurs at an angle of attack of 15°, while the rearward wingtip fence occurs at 16°. The forward wingtip fence shows the best result by showing the stall occurred at 17° angle of attack.
From the results of the drag coefficient and the lift coefficient, the lift to drag ratio is obtained as shown in Figure 7. Plain wings equipped with blended and simple winglets produce lower performance than plain wings. The rearward wingtip fence produces better performance than the plain wing from an angle of attack of 10°, while the forward wingtip fence is better than the plain wing from the angle of attack of 6°. The important thing to note is that the aerodynamic performance for each velocity is different from the other velocity. In this study using the minimum velocity used by the UAV. This refers to the research of Panagiotou [16,19–21], Turanoguz [17,18], and Kontogianis [12,22].
3.2. Pressure Contour

Figure 8 shows the comparison of the evolution of the pressure contour on the upper side of the plain wing, the plain wing equipped with the blended winglet, the simple winglet, the rearward wingtip fence, and the forward wingtip fence at $\alpha = 15^\circ$ and $\alpha = 17^\circ$. The plain wing shows that the wingtip tip has lower pressure, both at $\alpha = 15^\circ$ and $\alpha = 17^\circ$. The low-pressure area tends to expand to the surrounding area as the angle of attack increases, although the value is slightly higher than the wingtip area. The blended winglet shows that the pressure with a low value has shifted to the winglet. It can be seen that the blended winglet serves as an extension of the wing. The pressure value in the wingtip area is slightly higher than that of the plain wing.

The simple winglet shows that the pressure contour has a lower value and the area is wider than the plain and blended winglets. In the area on the inside of the winglet, there is an area of pressure that is higher than the surrounding pressure. This requires further discussion because it is thought to be an area with a more complex secondary flow. The forward wingtip fence shows the wingtip area with higher pressure compared to other configurations. Although the existing geometry configuration is similar to the simple winglet, the area on the side of the fence does not show pressure with a higher value than the other areas. In the rearward wingtip fence $\alpha = 15^\circ$, it shows signs that pressure with a low value is starting to form at the end of the leading edge. Although the area is not as large as the simple winglet, the area with this low value is quite clear and broad compared to other configurations. At $\alpha = 17^\circ$, it can be seen that the area with this low value extends towards the wingspan and is connected to the wing root. This area has a low value and is the most extensive compared to other configurations. The area that is formed in the simple winglet is not visible on the inside of the fence. As with the simple winglet, the area with a lower area is interesting to discuss further because it involves secondary flow which is broad and complex.

From the winglet configuration used in this study, it can be seen that there is an effect of flow leakage at the end of the wingtip from the leading edge. An area of pressure with a low value is an indication of a leakage flow from the lower side to the upper side. The simple winglet and rearward wingtip fence are configurations that have a wider area with a low value. The shape and geometry of the winglets greatly influence the extent to which they can withstand the leaps and leaks of the fluid flow.
Figure 8. Pressure Contours Comparison on the Upper Side of the Research Model at $\alpha = 15^\circ$; $\alpha = 17^\circ$
4. Conclusion

In this study, the comparison for several types of winglets have been carried out. From the research results above, there are several things that need to be considered. The viscous drag and pressure drag play an important role in the formation of total drag. With the addition of a winglet to the plain wing, the addition of the forward and rearward wingtip fence results in higher viscous drag compared to other configurations. In this case, the blended and simple winglet produces greater value than other configurations. Also, the forward and rearward wingtip fences provide better aerodynamic performance than others. This can be seen from the resulting lift to drag ratio. The rearward wingtip fence produces better performance than the plain wing from an angle of attack of 10°, while the forward wingtip fence is better than the plain wing from the angle of attack of 6°. While the leap of fluid flow from the lower surface to the upper surface cannot be completely eliminated but can be reduced as much as possible. Furthermore, the shape and geometry of the leading edge on the wingtip greatly affect the ability of the winglet to withstand the leap of fluid flow. Forward wingtip fence and blended winglet indicate a relatively smaller low-pressure area. This suggests that both configurations are better able to withstand flow leakage at the wingtip. The results of this study require a follow-up study, mainly on the secondary flow around the winglet and its effect on the flow towards the mid span. The flow dynamics around the winglets and their effects on the flow in the mid span require further study and a more detailed discussion.

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