Airfoil Performance Due To Winglet Configuration On NACA 4412

Muhammad Agung Bramantya, Nicholas Christian, Gesang Nugroho

Abstract: Unmanned Aerial Vehicle is one of many types of aircraft that growing rapidly these days for many uses from farm usage, military usage, and many more. To develop aviation technology in Indonesia, research is done to find a perfect winglet geometry for the airfoil NACA 4412 that used generally. Research is done with Computational Fluid Dynamics method, with ANSYS Fluent to find lift force, drag force, lift coefficient, drag coefficient, and lift-to-drag ratio. The results will be plotted in Microsoft Excel. From this research, it is shown that the usage of a correct winglet will improve wing performance. The usage of a spiroid winglet has the highest value of lift-to-drag ratio at 10° angle of attack, with 5.53% improved performance, but it lacks stability. For now, spiroid winglet is the best winglet for airfoil NACA 4412. It can increase the average performance by 2% - 3.92%.

Index Terms: Airfoil, Computational Fluid Dynamics, Drag, Lift, NACA 4412, Unmanned Aerial Vehicle, Winglet.

1 Introduction

IN this paper, we provide the setting and result of variation configuration of winglet for NACA 4412 using CFD simulation. Four different geometry is used to compare the performance of each winglet. Wing is the main surface to generate the lift, thus the configuration of wing including its winglet gives a direct effect towards the lift, drag, and stability [1]. Winglet is the main focus of this research because it can improve the stability and lift of an airfoil [2], and the objective of this research is to find a perfect winglet for NACA 4412. In the past, researches have been made to find various effect of design parameter on a specific winglet. We use previous research results on design parameter as a reference for each type of winglet and compare them on NACA 4412 as most of the research done on NACA 2412 or NACA 0012 and only a few of them compare the winglet effect on NACA 4412 which is used for smaller aircraft and UAV.

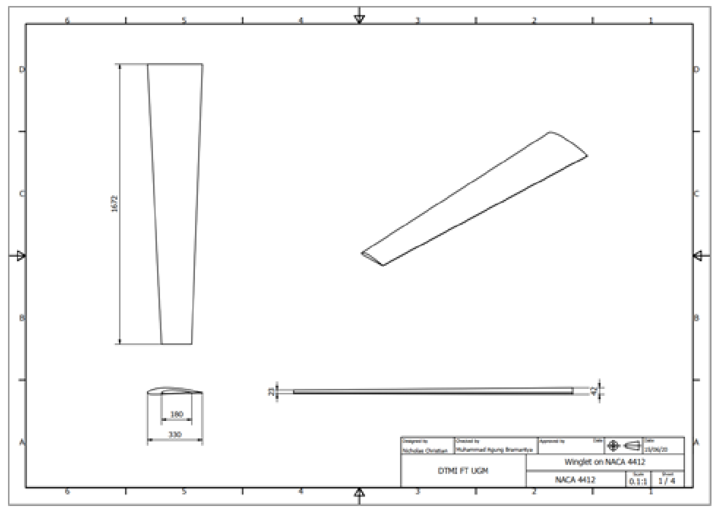

Figure 1. *NACA 4412 without airfoil*

2 Methods

2.1 Initial Conditions

Dimension that used for NACA 4412 on this research is based on UAV Elang Caraka. The variation of winglets used in this research are blended winglet, wingtip fence, and spiroid winglet. All of the dimensions are shown in Figure 1, Figure 2, Figure 3, and Figure 4 below.

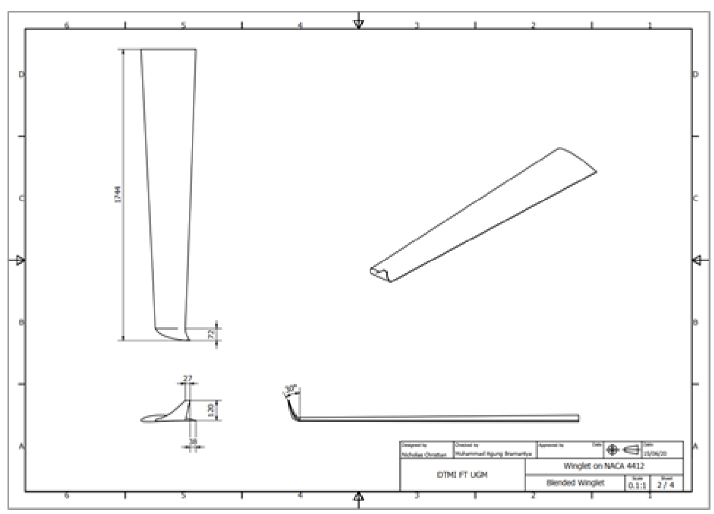

Figure 2. *NACA 4412 with blended winglet*

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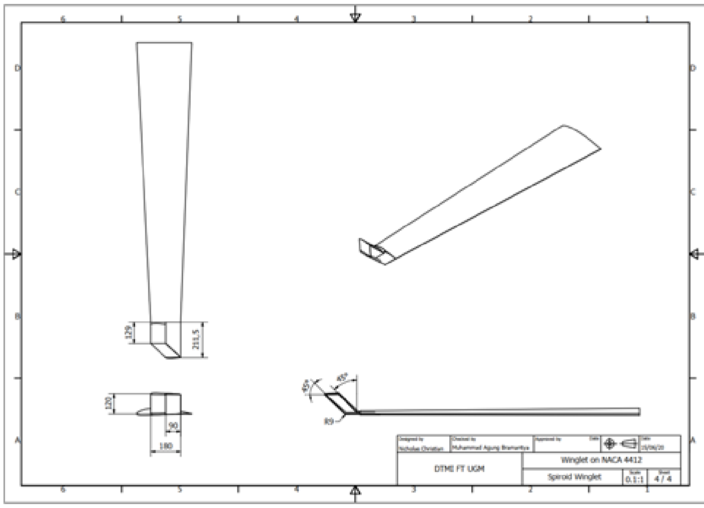


Figure 3. *NACA 4412 with spiroid winglet*

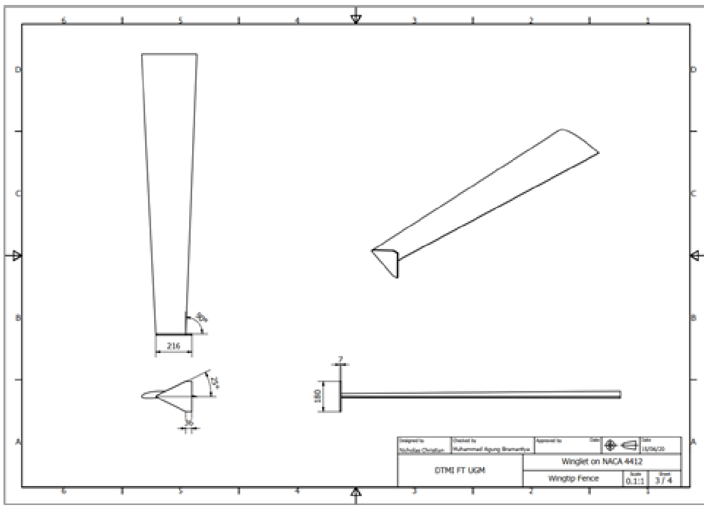


Figure 4. *NACA 4412 with wingtip fence*

Fluid domain (height = 6.6 m, width = 3.3 m, length = 13.2 m) was used to simulate air around the airfoil. The fluid domain dimensions were achieved with trial and error as the results won't converge if the fluid domain not big enough. The simulation was put on the loiter phase of the aircraft where the aircraft carries out its mission with velocity = 20.8333 m/s, altitude = 500 m, and air density= 1.1685 kg/m^3. The results of computation were lift force, drag force, lift coefficient, drag coefficient, and used to compare the performance of each winglet.

2.2 Design Method

Autodesk Inventor Professional 2020 was used to design the Computer Aided Design (CAD) model. Four of geometry combination is shown in Figure 1 consists of airfoil without winglet, airfoil with blended winglet, wingtip fence, and spiroid winglet. The CAD model is shown in Figure 5, Figure 6, Figure 7, and Figure 8.

Figure 5*. CAD model of NACA 4412 without winglet*

Figure 6*. CAD model of NACA 4412 with blended winglet*

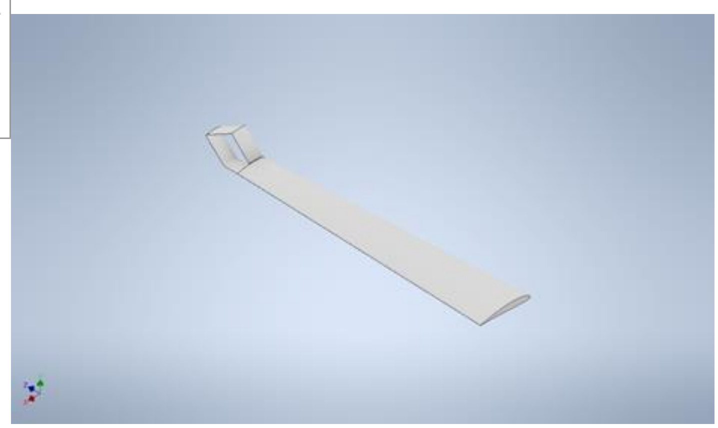


Figure 7*. CAD model of NACA 4412 with spiroid winglet*

After the CAD design was done, ANSYS Fluent used to calculate the force and coefficient. Fluid domain with symmetry function was designed inside the DesignModeler on ANSYS Workbench.

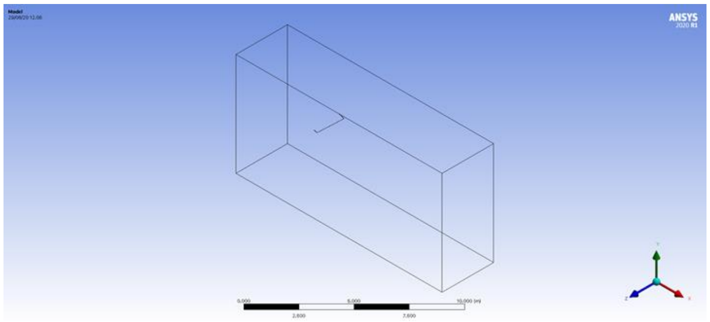


***Figure 9**. Fluid domain*

2.3 Meshing and Mesh Quality

Mesh was created in ANSYS Mesh. After meshing is done, approximate total cell was 9 million for each geometry and various angle of attack. Assembly meshing is used for the meshing method, and to refine the mesh we used sizing on the airfoil, winglet, and edge. The mesh result is shown in Figure 10 and Figure 11.

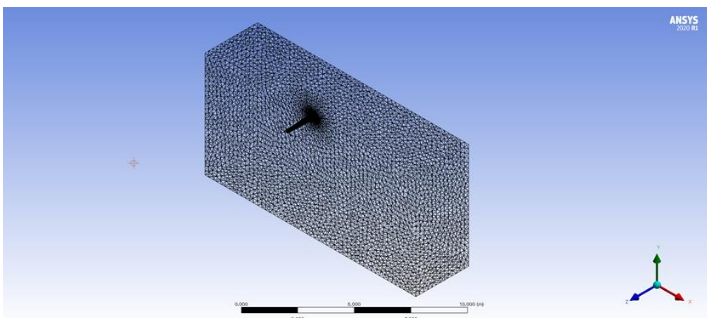


***Figure 10**. Mesh result*

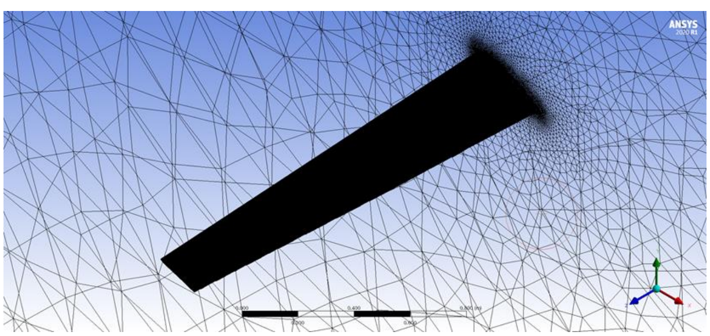
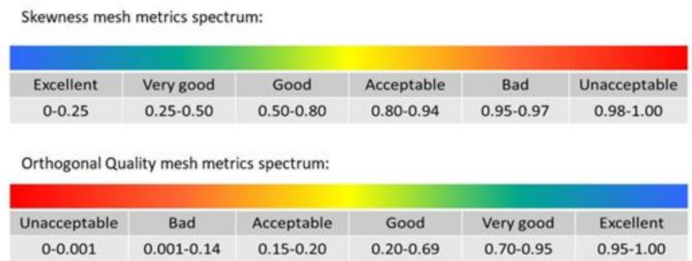


***Figure 11**. A closer look on mesh result*

Mesh quality is determined by the number of cells, skewness value, and orthogonal quality value. The value is compared to the mesh quality spectrum [3] in Figure 12. The average value for skewness was 0.22 which is excellent and orthogonal quality was 0.86 which is very good. Both graphs of skewness and orthogonal quality can be seen in Figure 13 and Figure 14. Quality from the number of cells was determined by mesh independency test which has been done before [4] can be seen in Figure 15. Above 8.5 million cells, the lift and drag deviation are relatively constant. From those three elements, we can conclude that this mesh would produce a valid solution.



Skewness mesh metrics spectrum:

Excellent	Very good	Good	Acceptable	Bad	Unacceptable
0-0.25	0.25-0.50	0.50-0.80	0.80-0.94	0.95-0.97	0.98-1.00

Orthogonal Quality mesh metrics spectrum:

Unacceptable	Bad	Acceptable	Good	Very good	Excellent
0-0.001	0.001-0.14	0.15-0.20	0.20-0.69	0.70-0.95	0.95-1.00

***Figure 12**. Mesh quality spectrum*

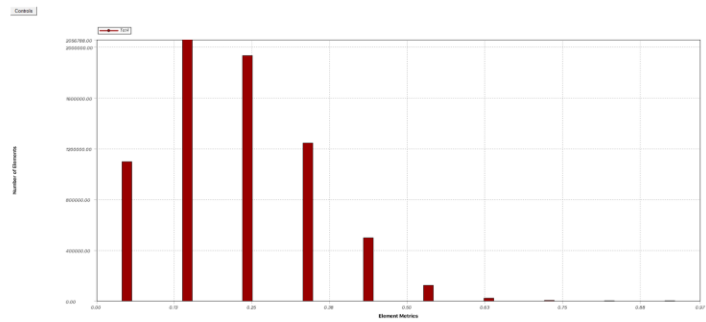


***Figure 13**. Skewness graph*

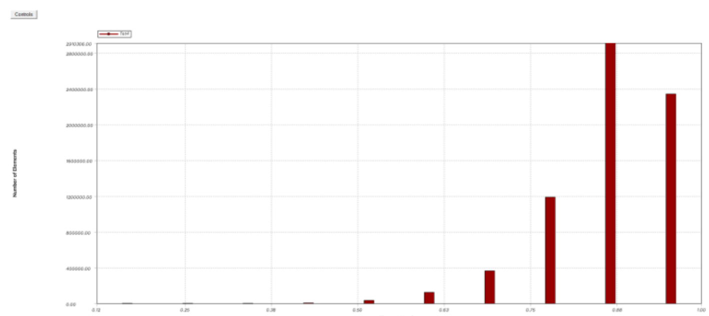


Figure 14. Orthogonal quality graph

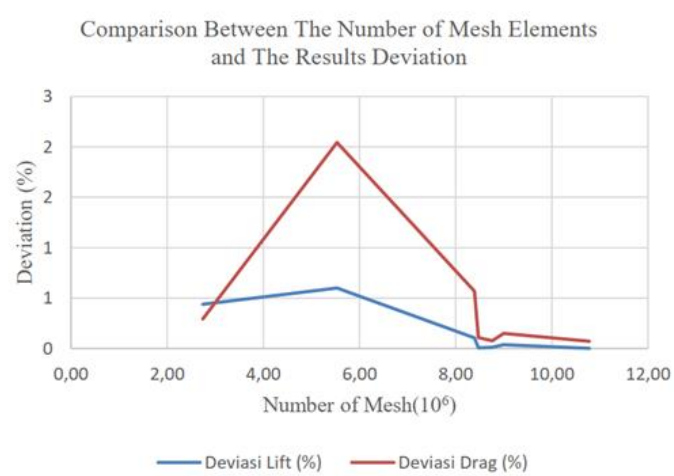


***Figure 15.** Mesh independency test*

2.4 Solving Method

The solving process was done in ANSYS Fluent. The airfoil simulated as if it was loitering on a ceiling of 500 m altitude at 20.8333 m/s. The air property was based on the altitude.

Three dimensional type solver was used with parallel processing up to 4 processes. The general equation configuration is shown in Figure 16.

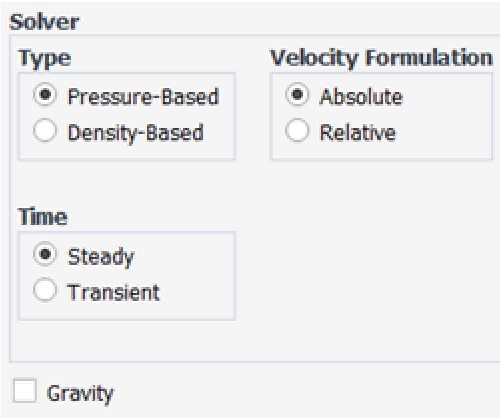


Figure 16. *General equation configuration*

The next step is determining the viscous model that will be used in this calculation. We used k-omega SST (k-ω SST) viscous model to simulate the external flow. The solution method configuration is shown in Figure 17.

Figure 17. *Solution method configuration*

ANSYS Post Processing was used to obtain the velocity contour and pressure contour of the airfoil. This was done to visualize the velocity and pressure around the airfoil and match it with the fact.

3 Results and Discussions

The results from the calculation are compared to each other to find the best winglet geometry for NACA 4412. We compared the lift, drag, and also lift-to-drag ratio. The comparison was done on Microsoft Excel. From the graph in Figure 10, it can be seen that spiroid winglet generates the highest lift in amongst all winglet variations, with the wing without winglet is the lowest to generates lift. On the other hand, generates more lift means it generates more drag as seen in Figure 11. Spiroid winglet generates the highest drag amongst all winglet variations, and the wing without winglet is the lowest to generate drag.

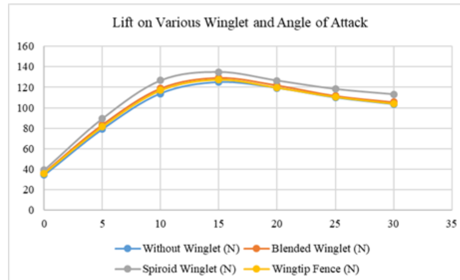


Figure 18. *Lift on various winglet and angle of attack*

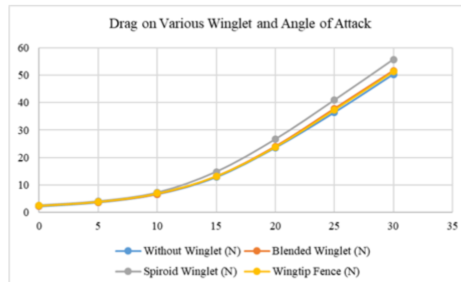


Figure 19. *Drag on various winglet and angle of attack*

The wing performance is not determined by solely looking at its lift or drag but from the lift-to-drag ratio. Lift-to-drag ratio can be obtained by dividing the lift force by the drag force, or dividing the lift coefficient by the drag coefficient since it will produce the same results. In this case, we divide the lift force and drag force to obtain the lift-to-drag ratio and compare them.

$$ratio = \frac{L}{D} = \frac{C_L}{C_D} \quad (1)$$

From Figure 20, we can see that blended winglet and spiroid winglet is generating more lift-to-drag ratio than the others. We compare the value on Table 1 to get a more precise analysis.

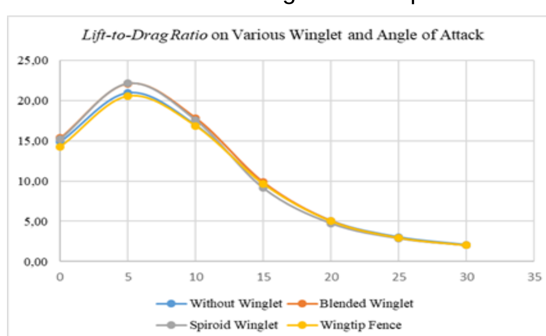


Figure 20. *Lift-to-drag ratio on various winglet and AoA*

Table 1. *Lift-to-drag ratio on various winglet and AoA*

AoA (°)	Without Winglet	Blended Winglet	Spiroid Winglet	Wingtip Fence
0	14,87	15,34	15,22	14,27

5	20,97	22,08	22,13	20,52
10	16,94	17,80	17,56	16,83
15	9,64	9,86	9,12	9,64
20	5,04	5,08	4,75	5,01
25	3,01	2,96	2,89	2,96
30	2,06	2,05	2,03	2,03

From Table 1, the highest performance occurred at 5° AoA on spiroid winglet, but if we take all AoA into account, blended winglet is the most stable compared to others. If blended winglet is compared to the airfoil without a winglet, it can improve the performance up to 3.92% assuming the airfoil is operating before stall AoA.

4 Conclusion

From the simulation that has been run on NACA 4412 with various winglet geometry which are blended winglet, wingtip fence, and spiroid winglet, we can conclude that the addition of winglet geometry to NACA 4412 in general can improve the overall performance depending on the winglet geometry and angle of attack. For now, blended winglet is the best winglet for NACA 4412 since it gives more lift and stability compared to others with overall performance enhancement up to 3.92%.

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