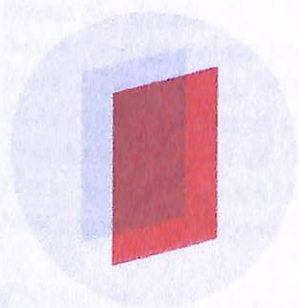


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Numerical Analysis of the Reynolds Number Effect on the Aerodynamic Performance Wing Airfoil Eppler 562 with Wingtip Fence

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Abstract. Wings are a very important part of aircraft. In that section, most of the lift forces are generated on the airplanes. The aerodynamic performance produced by the wing greatly determines how optimal the cruising range of an aircraft. To improve the performance of the wings, researchers have been competing to make wing modifications of an aircraft. One modification that is used at this time is by adding end wall which is often referred to as a winglet. Winglets function as a barrier to fluid flow jumps from the lower surface to the upper surface. This fluid flow jumps is often called as a tip vortex. One type of winglet discussed in this study is the wingtip fence. This study took wing objects on unmanned aerial vehicle with numerical simulation using Ansys 19.0 software with turbulent model $k-\omega$ SST. The freestream flow rate to be used are 10 m/s ($Re = 2,34 \times 10^4$) and 45 m/s ($Re = 1 \times 10^5$). The angle of attack used are (α) = 0°, 2°, 4°, 6°, 8°, 10°, 12°, 15°, 17°, and 19°. The wing model is an Eppler 562 (E562) airfoil with and without a winglet. From this study, it was found that wing aerodynamic performance with Eppler 562 (E562) airfoil was higher at $Re = 2,34 \times 10^4$. Delay of the stall is more effective at $Re = 1 \times 10^5$ compared to the $Re = 2,34 \times 10^4$. But, the aerodynamic performance $Re = 2,34 \times 10^4$ better than $Re = 1 \times 10^5$. Keywords: airfoil, Eppler 562, tip vortex, winglet, forward wingtip fence, rearward wingtip fence

1. Introduction

The times are always accompanied by technological developments. This encourages humans to create something that aims to provide more benefits to humans. In the industrial world, many applications have been found from the flow across the airfoil, for example on wings, propellers and others. In the case of engineering, especially in the field of fluid mechanics, there have been many studies on airfoil both in terms of simulations and experiments that aim to determine the flow characteristics of a fluid. In various literature, there has also been much discussion about the characteristics of flow and vortex shedding across the airfoil.

Several things make it possible to reduce drag and increase lift in the use of aircraft and UAV, including good wing designs, wingtip devices/winglets, boundary layer suction, and others. Winglets have advantages in terms of reducing the occurrence of tip vortex and reducing areas that are not effective because of the flow of flow from the lower surface to the upper surface. This is the concern of many researchers to continue to explore to provide space to research on the application of winglets that can result in a significant reduction in drag.

[1] analyzed the aerodynamic characteristics of multi-winglets that were applied to light aircraft. These winglets have demonstrated the potential for increasing aircraft aerodynamic efficiency by reducing induced drag. This experimental study focused on the half body wing model at $Re = 4 \times 10^5$ with six different multi-winglet configurations. The maximum aerodynamic efficiency improvement for the lift coefficient is 7.3%. Performance analysis was also carried out to reveal the potential for a 12% increase in the maximum climbing ratio. Winglets have led to a significant increase in performance parameters, with a gain of 7.3% in maximum aerodynamic efficiency or 11% in the best conditions. The maximum rate of climbing factor is also increasing by 12%. Analysis in this study also showed a significant reduction in the intensity of tip vortex.

[2] used the NACA 0012 airfoil and blended winglet with several cant angle variations. This numerical study uses the $k-\omega$ SST turbulence model, Courant Friedrichs Lewy Number 1.0, turbulent kinetic energy and an average specific dissipation of 0.8, $V_{inlet} = 55.5$ m/s with a turbulence intensity of 5%. Cant Angle selected are 0° (without winglets), 15° , 30° , 45° , and 60° and $\alpha = 0^\circ, 2^\circ, 4^\circ, 6^\circ, \text{ and } 8^\circ$. Cant angle 60° gives better C_L but also higher C_D . Cant angle 15° provides a good C_L/C_D distribution. It can happen because of the profile drag which is the effect of the viscosity and surface roughness. It is happens also in the pressure drag that occurs at the front of the airfoil but is not same with the rear of the wing.

[3] use NACA 4412 airfoil type swept back wing with blended winglet on the normal wing, 30° winglet, and 90° winglet. This simulation study uses the $K\omega$ model, steady-state, and velocity inlet of 50 m/s. Winglet cant angle 30° gives better performance on $\alpha = 2^\circ$ due to changes in overall flow and variations in the drag coefficient. This simulation study shows that by increasing the design of the winglet, with the correct cant angle variation, it can reduce the induced drag caused by vortex on the wingtip.

[4] researched a numerical simulation on the E420 airfoil on the ATLAS IV UAV wing with $Re = 10^5 - 3 \times 10^5$. The consideration for choosing an Eppler in type airfoil is because it has Low Re airfoil, smooth trailing edge stall, and high lift characteristic and high thickness. In this study, it was found that the addition of winglets can reduce drag coefficient by 2.8% and increase aerodynamic performance by 80% in low angle of attack and 22% in operational regions.

This research will compare the minimum speed and maximum speed commonly used by UAVs so that their effects on aerodynamic performance are known. The maximum speed used refers to the research of [5].

2. Methodology

In this study numerical simulations of wings were used using Ansys 19.0 software. To produce data that is more accurate and does not depend on grid density an independence grid analysis is performed. Grid independence is a convergent solution determined from CFD calculations and is not influenced by the size of the cell meshing. In this study, the independence grid analysis was carried out using six different types of meshing with increasing density levels starting from meshing A to F meshing, which then obtained an error value from each meshing. In each meshing also seen the value of y^+ where in this study the turbulence of the $k-\omega$ SST model which has the value of $y^+ \leq 5$. For all values of drag coefficient (C_D) and y^+ has been tabulated in Table 1.

The flow velocity to be used is 10 m/s ($Re = 2.34 \times 10^4$) and 45 m/s ($Re = 1 \times 10^5$) with $\alpha = 0^\circ, 2^\circ, 4^\circ, 6^\circ, 8^\circ, 10^\circ, 12^\circ, 15^\circ, 17^\circ$ and 19° . Winglets that will be used are wingtip fence with forward and rearward variations. Reynolds Number is determined by chord. In this case, the length of the chord used is 20 cm. Figure 1 represents the domain simulation and the boundary conditions used in the simulation. The test specimen is in the form of an Eppler 562 type airfoil with and without a winglet attached to the tip in the form of a wingtip fence as shown in Figure 2 and the dimensions of the modeling dimensions in Figure 3 [6].

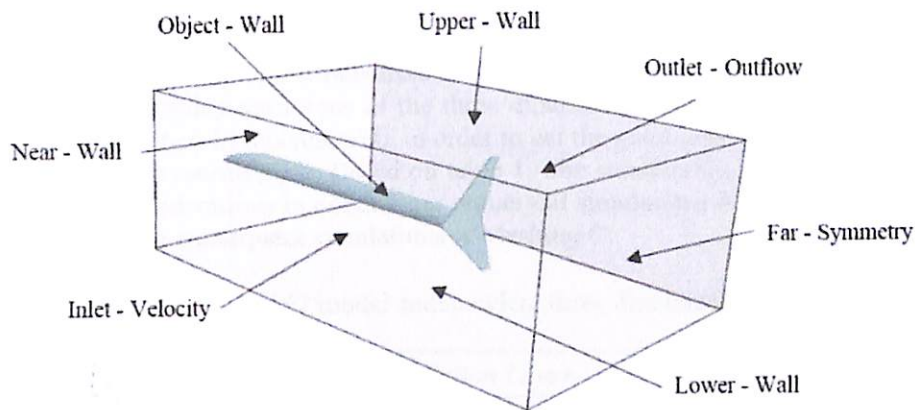
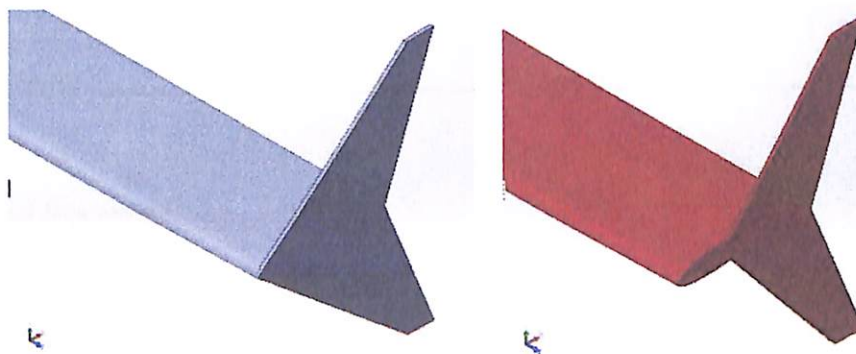


Figure 1. Simulation domain and boundary conditions



(a) Forward Wingtip Fence

(b) Rearward Wingtip Fence

Figure 2. Specimen Model

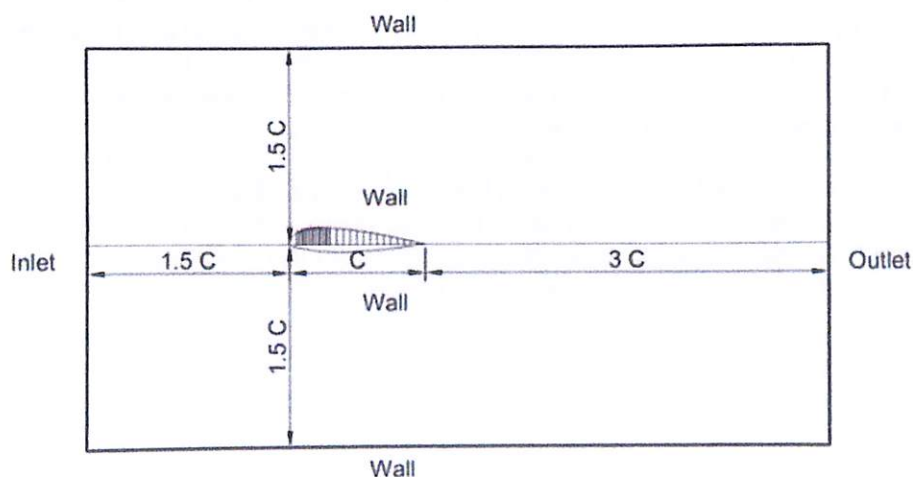


Figure 3. Modeling dimensions and background conditions [6]

The use of CFD application requires data accuracy in the post-processing and pre-processing steps. The grid independence step is needed to determine the level, the best and most efficient grid structure so that the modeling results are close to true. To get more complete information on the area around the wall, it requires the calculation of y^+ on each meshing. The y^+ calculation is based on the flat plate boundary layer theory calculations [7].

In addition to the calculation of y^+ , the inflation layer uses a quadrilateral meshing type so that information around the wall is more accurate. For the calculation of fewer cell numbers, the area far from the wall will use meshing type tetrahedrons.

Table 1. shows the meshing variations of the three dimensional independent test grid model at the 2.34×10^4 Reynolds number. In this research, in order to get the good results, the y^+ used $y^+ < 1$ as was done in the Kontogiannis research [4]. Based on table 1. The smallest C_D value occurs in Meshing C. Besides, One of the considerations in conducting numerical simulations is the time and memory used, then the meshing used for subsequent simulations is Meshing C.

Table 1. Analysis of the E562 model-independent three dimensional grid without winglets

<i>Meshing Type</i>	<i>Cells Number</i>	<i>Inflation Layer</i>	C_D	y^+	<i>Skewness Average</i>
<i>Meshing A</i>	367075	40	0,86	2,1	0,346
<i>Meshing B</i>	469620	40	0,88	1,4	0,347
<i>Meshing C</i>	569233	40	0,90	0,8	0,343
<i>Meshing D</i>	685063	40	0,92	2,1	0,334
<i>Meshing E</i>	768003	40	0,90	0,8	0,351
<i>Meshing F</i>	875962	40	0,91	1,4	0,348

3. Result and Discussion

3.1. Drag Coefficients Analysis

Winglets will increase the drag coefficient, especially the increase in drag pressure compared to viscous drag. Adding winglets to the wings increases skin friction drag. However, the role of drag pressure is far greater than viscous drag as research by [8]. In this study, it was seen that the drag coefficient produced by plain wing equipped with winglets was always higher than plain wing at 10 m/s ($Re = 2.34 \times 10^4$) and 45 m/s ($Re = 1 \times 10^5$). The effect of Reynolds number is also seen in this study where an increase in Reynolds number will increase the value of drag. This can be seen in Figure 4 where the Reynolds number 1×10^5 is higher than $Re = 2.34 \times 10^4$. However, the influence of geometry is seen at a high angle of attack both at 10 m/s ($Re = 2.34 \times 10^4$) and 45 m/s ($Re = 1 \times 10^5$). At the rearward wingtip fence, there is a visible increase in the drag coefficient at $\alpha = 15^\circ$ while in the forward wingtip fence there is a decrease at $\alpha = 17^\circ$. This is due to the influence of the geometry of the winglet shape. Allegedly induced drag affects the increase in total drag as well. Induced drag is part of the elevator, which means that as long as the lift is still there the induced drag will remain. Induced drag cannot be ruled out, neither can an elevator. Lift and induced drag can be affected by the physical construction of aircraft wings, for example aspect ratio dimensions. The results of this study were compared with the [5] study. [5] uses $Re = 2,358 \times 10^6$ and y^+ at intervals of $5 < y^+ < 30$. The picture shows that the resulting drag coefficient is higher both on the plain wing and on the wingtip fence.

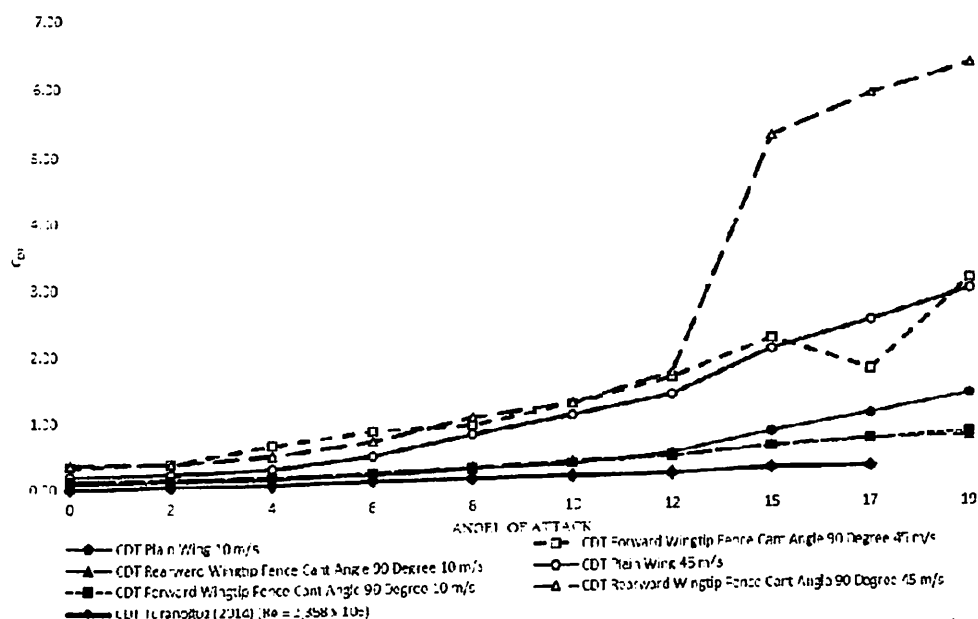


Figure 4. Comparison of the total drag coefficient (C_{Dr}) to α on plain wing and winglet

3.2. Lift Coefficients Analysis

From these lift coefficient results, it is calculated to get the stall angle. Observation of the lift coefficient is done by 3D simulation for plain airfoil and airfoil using winglets. As an initial reference in analyzing the lift coefficient so that it can be seen influence of the Reynolds numbers variation and the addition of the lift coefficient. Figure 5 shows the graph of the relationship of C_L to α for plain airfoil E562 with freestream speeds of 10 m/s ($Re = 2.34 \times 10^4$) and 45 m/s ($Re = 1 \times 10^5$).

In Figure 5 it appears that the lift coefficient increases with increasing angle of attack. It can be seen that using the wingtip fence can delay stalling. At the plain wing $Re = 2.34 \times 10^4$, a stall occurs at $\alpha = 12^\circ$ as in [5] while the addition of fence stall wingtip occurs at $\alpha = 15^\circ$ for rearward wingtip fence and $\alpha = 17^\circ$ for forward wingtip fence.

At plain wing $Re = 1 \times 10^5$, a stall occurs at $\alpha = 15^\circ$ while the addition of wingtip fence a stall occurs at $\alpha = 12^\circ$ for rearward wingtip fence, and $\alpha = 19^\circ$ for forward wingtip fence. The lift coefficient produced in this study is lower than that of [5]. However, it appears that the stall delay in this study resulted in a better angle of attack.

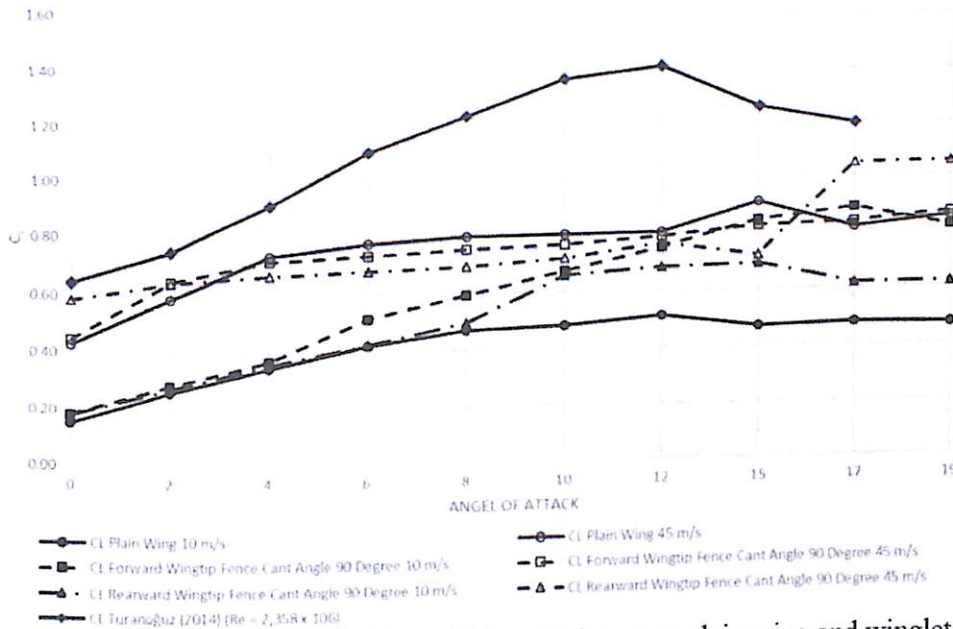


Figure 5. Comparison of the lift coefficient (C_L) to α on plain wing and winglet

3.3. Lift to Drag Ratio Analysis (C_L / C_D)

Improved aerodynamic performance can be seen in the C_L/C_D comparison image. Increased C_L/C_D can occur among others due to the effective area of the wing better or reduced drag. Tip Vortex from the lower surface of the wing contribute to reducing effective area and also increase the induced drag of the wing. If the winglet can function effectively, it can hold the tip vortex.

Figure 6. shows the ratio of lift to drag ratio (C_L/C_D) on a plain wing and with a winglet at several angles of attack. It shown that the addition of winglets will increase the coefficient of lift and show a trend that increases with increasing angle of attack. Figure 6. also showed that the addition of winglets with freestream 10 m/s ($Re = 2.34 \times 10^4$) would improve effective wing performance at $\alpha = 6^\circ$ at the forward wingtip fence and $\alpha = 10^\circ$ at the rearward wingtip fence. At freestream 45 m/s ($Re = 1 \times 10^5$) it shows a decrease in aerodynamic performance both on the plain wing, forward wingtip fence and rearward wingtip fence.

On the forward wingtip fence freestream 10 m/s ($Re = 2.34 \times 10^4$) results in higher performance compared to other wing geometries at $\alpha = 6^\circ$ while the rearward wingtip fence produces a better performance at $\alpha = 10^\circ$. Aerodynamic performance on freestream 10 m/s ($Re = 2.34 \times 10^4$) is also better than [5] research on both the plain wing and wingtip fence.

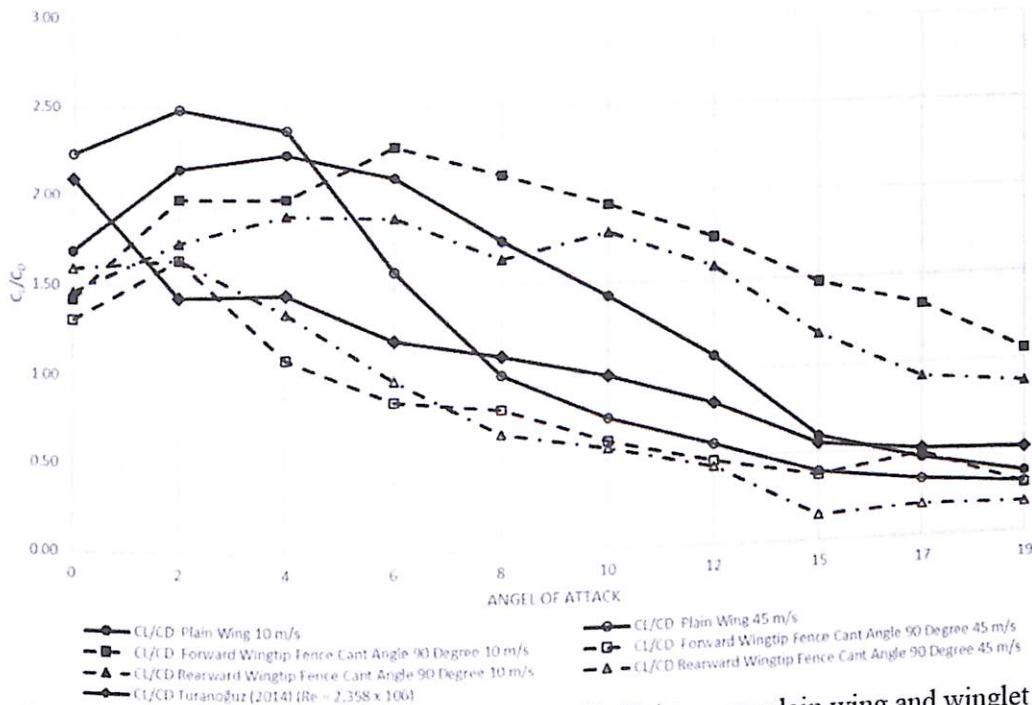


Figure 6. Comparison of the lift to drag ratio (C_L/C_D) to α on plain wing and winglet

4. Conclusion

From the results of numerical simulations that have been carried out about the effect of variations in Reynolds number and geometry on the characteristics of fluid flow through the E562 airfoil, it can be concluded that the use of winglets can improve wing performance but also the addition of winglets will increase drag as the angle of attack increases. From numerical studies it was found that the use of winglets can produce several flow characteristics, namely:

- With increasing Reynolds number and angle of attack will increase drag coefficient and lift coefficient. A higher Reynolds number increases a higher drag and a higher lift
- The use of winglets produces a drag coefficient and a lift coefficient higher than the plain wing. This applies to forward wingtip fence and rearward wingtip fence
- With the use of the wingtip fence, it can delay stalling. At plain wing $Re = 2.34 \times 10^4$, stall occurs at $\alpha = 12^\circ$ while the addition of a fence stall wingtip occurs at $\alpha = 15^\circ$ for rearward wingtip fence and $\alpha = 17^\circ$ for forward wingtip fence.
- At the plain wing $Re = 1 \times 10^5$, the stall occurs at $\alpha = 15^\circ$ while the addition of the wingtip fence stall occurs at $\alpha = 12^\circ$ for the rearward wingtip fence and $\alpha = 19^\circ$ for the forward wingtip fence.
- In the use of winglets, stall delays are better at freestream 45 m/s ($Re = 1 \times 10^5$) than freestream 10 m/s ($Re = 2.34 \times 10^4$)
- The aerodynamic performance produced by the addition of winglet geometry at freestream 45 m/s ($Re = 1 \times 10^5$) is lower than freestream 10 m/s ($Re = 2.34 \times 10^4$). At freestream 45 m/s ($Re = 1 \times 10^5$), the aerodynamic performance of plain wing is better than using winglets
- Adding winglets in freestream 10 m/s ($Re = 2.34 \times 10^4$) improves performance at $\alpha = 6^\circ$ at the forward wingtip fence and $\alpha = 10^\circ$ at the rearward wingtip fence. At freestream 45 m/s ($Re = 1 \times 10^5$) it shows a decrease in aerodynamic performance both on the plain wing, forward wingtip fence, and rearward wingtip fence. However, the forward wingtip fence improves performance at $\alpha = 15^\circ$ compared to plain wing.

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