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Numerical Investigation of Winglets Used to Improve the Flying Performance of Unmanned Aerial Vehicle

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Abstract: In this study, the aerodynamic forces, velocity and pressure distributions are analyzed on SD7062 wing profile with CFD program FLUENT. Calculations are made for one clean wing and 3 different winglets named End-Plate, Blended and Scimitar which are added on this clean wing. Each model are analyzed for different angle of attack degrees between -5 and 17. After calculations were ended, it is seen that wings' with winglets aerodynamic performances are increased. Additionally, stall was occurred around 15 aoa degrees.

Keywords: Unmanned Aerial Vehicle, Winglet, Numerical Algorithms, Computational Fluid Dynamics, Turbulence Modeling.

1 Introduction

Aviation industry is more costly compared to other transport sectors. Every step of the production and design of an aircraft requires a high budget. The flight of the aircraft also reveals high fuel costs. This is the reason that at the aviation industry, economy is one of the most important issues. In many universities and some big companies it is being studied to reduce these costs. When an aircraft is considered, research and development studies are carried out in many areas like power, control, structure and aerodynamics. The aim is primarily to improve the performance of the aircraft as well as saving fuel.

Unmanned Aerial Vehicles are today used for many purposes. Because of using different areas, uav became more important. The flying performance like flight duration, distance became important as well. Because of this reason aerodynamic efficiency has become essential. Aerodynamic efficiency can be provided by increasing lift force and reducing drag force. To reduce the drag force it is important to have a smooth wing surface. To increase lift force it can be provided by the two methods. The first is to increase the pressure distribution around the airfoil, and the second is to reduce the thickness of the boundary layer around the wing profile. Various designs and methods have been developed to provide these features. Angle of attack and wing profile's amount of camber are the factors that affect flight performance. Also with the new parts which are added to design like flaps, slats, slots and winglets, improving aerodynamic performance works are made [1]. Winglet at the wing tip is added nowadays is mostly preferred. First winglet idea was put forward by Hemk in the 1920s. Airfoil tip plate (End-Plate) was investigated by Hemk and how it affects the flight [2]. However, the addition of winglets to the wing tips and realization importance of winglets was

provided in 1976 by Whitcomb [3]. There are many types of winglets such as End-Plate, Blended, Scimitar, Sharklet and Spiroid. Academic studies are made for each of these. For example, Rahman and the others investigate the differences about aerodynamic behaviour between wing with blended winglet and without winglet. For this they designed a unique blended winglet which is different from traditional ones. CL, CD, L/D values were compared to clean wing. As a result, they were able to show that more efficient flight performance achieved by observing a reduction of drag force [4].
Reddy and the others added a secondary element to bottom of an existing blended winglet to create a split Scimitar winglet. Winglet geometry was designed using a total of eight variables. As it can be seen here, it was focused on the design criterias such as leading, trailing sweep and cant angle and an optimization study was made. With the Navier-Stokes solver, compressible, turbulent 3 dimensional fluid analysis was made. Free stream mach number is 0.25 and angle of attack is 11 degrees. As a result it was seen that a significant reduction has occurred for vortex through scimitar winglet [5].
Park and the others studied on static height stability and aerodynamic characteristic for end-plate winglet. Numerical analysis was made. Analysis was made for 0-10 angle of attack degrees. As a result of the analysis, it has shown that ground effect increases lift force with high pressure on bottom surface and reduce drag force. Additionally it increases suction power on upper surface. All means that the lift-drag ratio has increased significantly [6].
Yilemmi et al tested experimentally at low Reynolds number SD 7062 and NACA 2412 wing profiles used for unmanned aerial vehicles. Measurement results were compared with the manual method offered by Roskam. Also CFD codes were compared with XFOIL and FINFLO. They aimed to find the effect of low Reynolds number and flat flaps to flights [7].

There are also different methods which are made for development of aerodynamic performance. For instance, Genç, Kaynak and Yapıcı evaluated performance of passing and turbulence models used for estimated of separation bubbles for RANS based CFD methods. Secondly, they tried to suppress laminar separation bubbles using suction or blowing at one wing. It has seen that only in sucking and blowing situation, bubble separation could not completely destroyed but, it has alleviated or moved downwards [8].

In our study, three of most used winglet types named as End-plate, Blended and Scimitar are prepared as close to the size of the conventional types but original designs. Then, winglets are made CFD analysis together with wings. In literature, it is shown that each of winglets is investigated separately. However, as an uncommon type of study in literature 3 different winglet compared with each other in this study. It is determined which provides the best performance in existing designs.

2 Problem Statement

While planes fly in the air, rotating air occurs because of the wing shape. This eddies cause the loss of aerodynamic performance both the aircraft itself and thus affecting aircraft coming after it. As it is known that the principle of flying is about the shape of wing. Velocities of air flow under and top of wing are different. Likewise, pressures are different too. From the tip of wing air tries to go from under to top. This is the reason that rotating air flows occur. These rotating flows are named as vortex. Winglets prevent to escape of air on to wing and thus, vortex is prevented to occur.
It is shown in Figure1 that vortex on a plane [9].

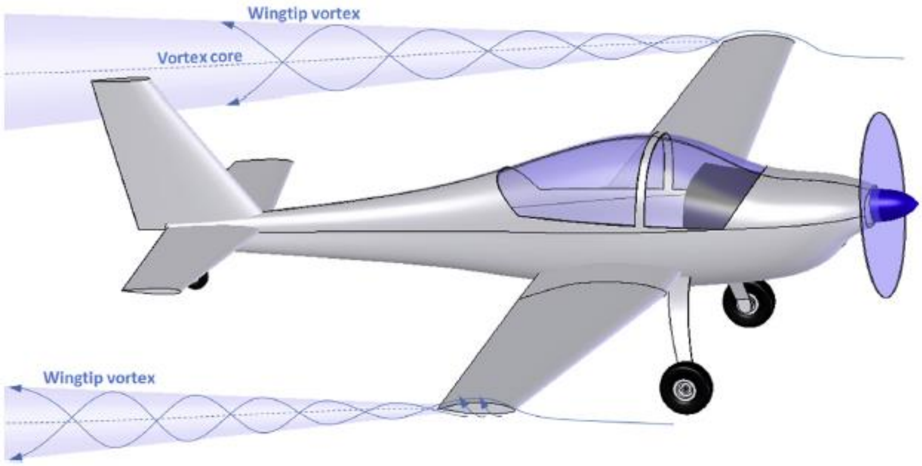


Figure 1: Occuring of Vortex

2.1 Numerical Method

In this study, it is studied the winglets used to improve the performance of unmanned aerial vehicles in flight. It is intended with the study that how commonly used winglets effect flight performance and which model provides greater efficiency. Primarily nowadays most used winglet models were researched and it has seen that there are many types of winglet models. In addition, some models can be changed to different structures in terms of design criteria. Therefore, it can be considered as a different model. For instance, for Blended winglet design stage it is shaped by criteria such as Sweep angle, Cant angle, Base angle. Each of these makes different designs. In this study, the decision has been made on three of all commonly used models. These models are designed in Catia design program as existing in aviation industry but as inventive. It is shown in Figure 2, 3 and 4 that winglet designs prepared on Catia and rendered on Solidworks.

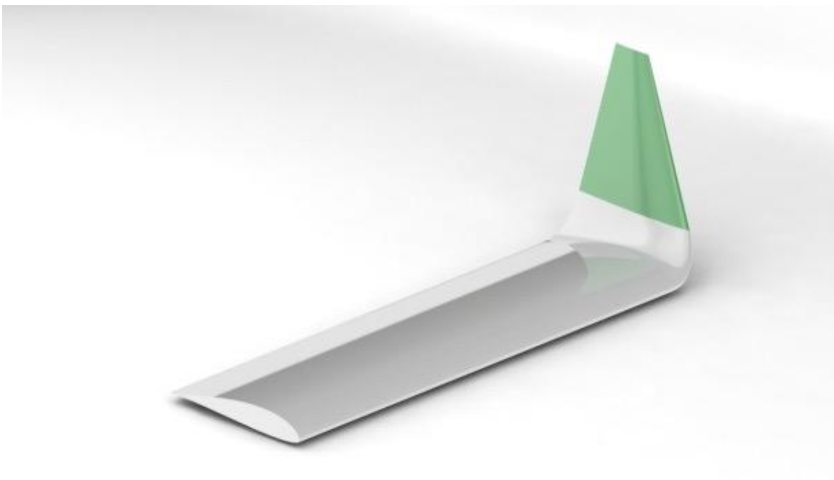


Figure 2: Wing with Blended Winglet

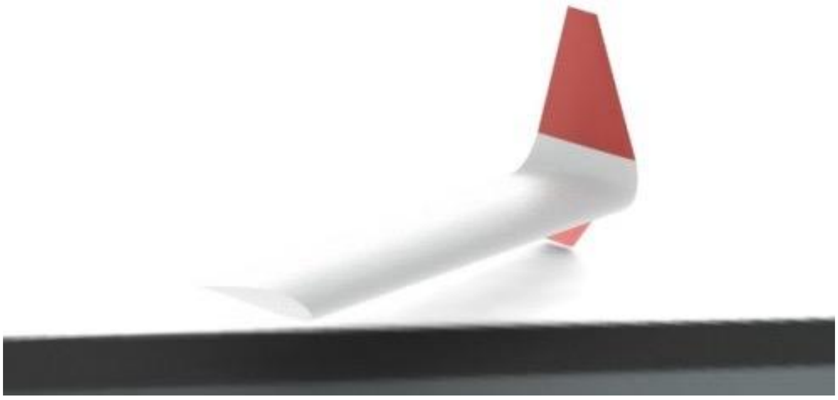


Figure 3: Wing with Scimitar Winglet

Figure 4: Wing with End-Plate

CFD analysis made with ANSYS Fluent program. In Fluent a volume must be designed around the part to be analyzed. It has drawn two body that one is inner and one is outer for each of wing designs. It is shown in Figure 5 that the bodies prepared with sizes.

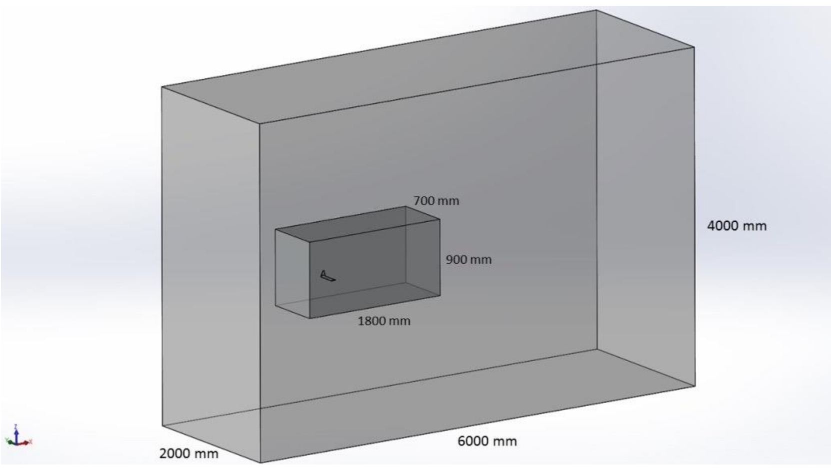


Figure 5: Bodies with Sizes

Mesh structure has been prepared for analysis in ANSYS Fluent. All mesh structure made can be summarized as follows:
The innermost surface of the wing and the edges were formed in 1 mm size. From here with 1.2 growth rate mesh is formed up to 20 mm at inner body. Outer body has been established growing up from 30 mm to 50 mm mesh sizes. Thus sensitive and critical regions have small size and precise mesh structure while other regions with no need critical analyze have become larger. Therefore, computer will make analysis in shorter time at the same time desired mesh structure has been created to analyze with the sensitivity of important areas.

Below in Figure 6 detailed mesh structure is shown around the wing.

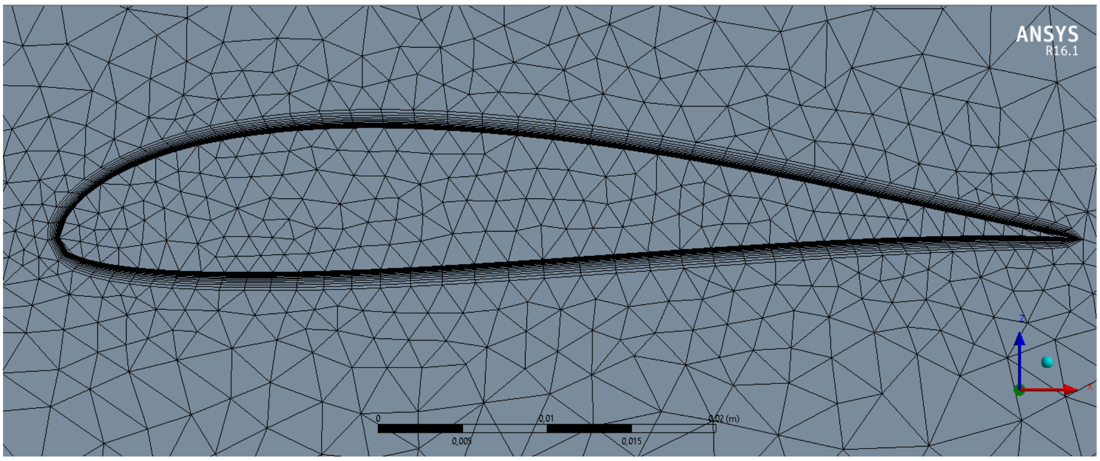


Figure 6 : Detailed Mesh Structured

Mesh Structure Features for clean wing is shown in Table 1 below.

Mesh Structure	Tetrahedral Grid
Grid Type	Unstructured
Nodes	1029049
Elements	5324892
Skewness	0,95832
Y+	0,906563

Table 1: Mesh Structure Features

Analysis were performed based on the weather conditions at sea level. Sea level reference values are given in Table 2.

Area (m^2)	0,012
Density (kg/m^3)	1,225
Enthalpy (j/kg)	0
Length (m)	0,06
Pressure (Pa)	101325
Temperature (K)	288,16
Velocity (m/s)	74
Viscosity ($kg/m.s$)	1,81E-05
Reynolds	300000
Mach	0,218

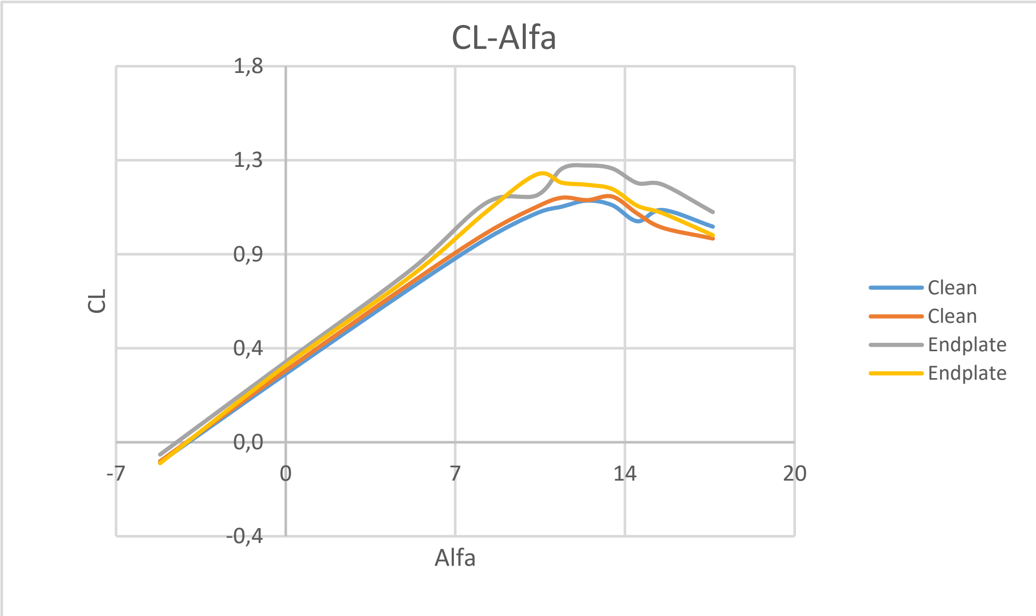
Table 2: Reference Values

SST k-omega (2 eqns) turbulence model is used for the analysis. Additionally Curvature Correction option was set because wing has curved structure. K-omega turbulence model is one of the most widely used models. SST k-omega model is with a solution model RANS based. The purpose of the RANS turbulence model equations to calculate the Reynolds stresses. This model shows the turbulent properties of the flow with two extra transport equations. With this equations, the effects of turbulence at past such as transport and spread energy is also provided to take into account. K shown at first variable is turbulence kinetic energy. The other variable shown as w is spread. That is an indication of the magnitude of turbulence. SST k-w turbulence model is the most commonly used eddy viscosity model. The meaning of SST abbreviation is transport of shear stress [10].

3 Conclusion and Future Work

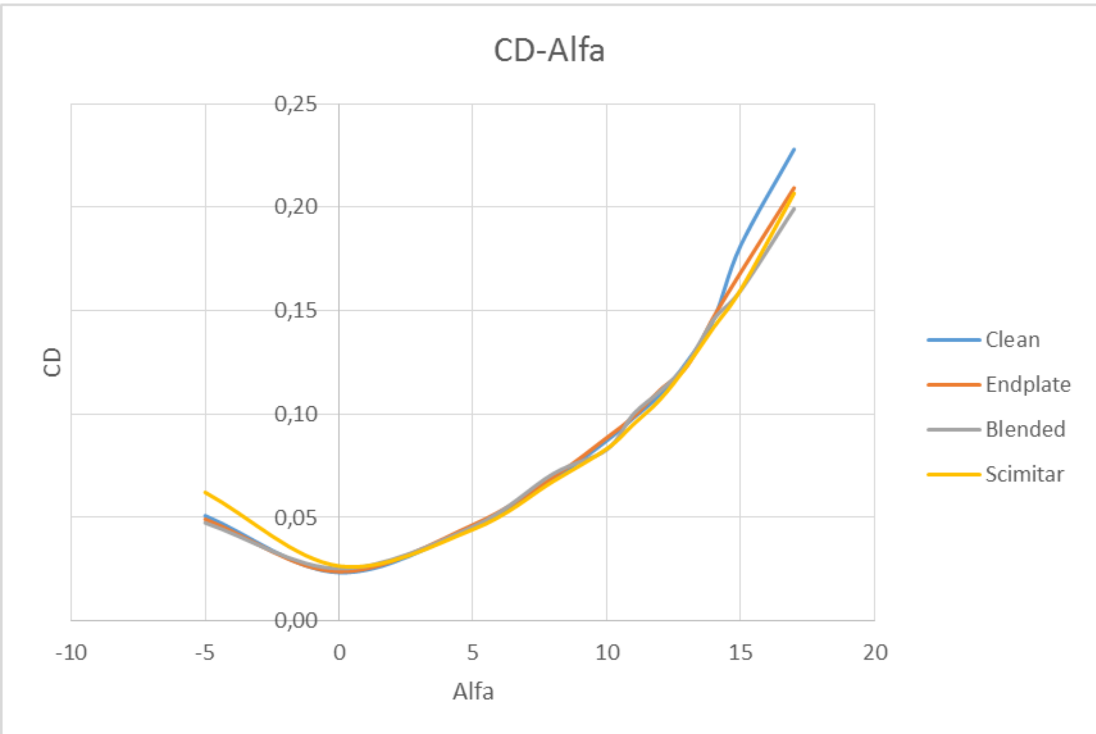
For wing without winglet and 3 types of winglet which are called Endplate, Scimitar and Blended, CFD analysis are made. Between -5 and 17 angle of attack degrees each of these designs were analyzed and Cl-Alpha, Cd-Alpha, Cm-alpha and Cl-Cd graphics were created. These analysis was carried out by following with eyes and it was not depended on the value of any iteration. Iterations were continued until Cl, Cd, Cm values are stable. For the SD7062 wing model our analysis compared with numerical and experimental studies found in literature [11]. It has been shown to coincide with the desired value of literature. Thus, it is convinced that the study done is correct and other designs were analyzed using the same reference values.

Below graphics are shown created with the data obtained by analysis.



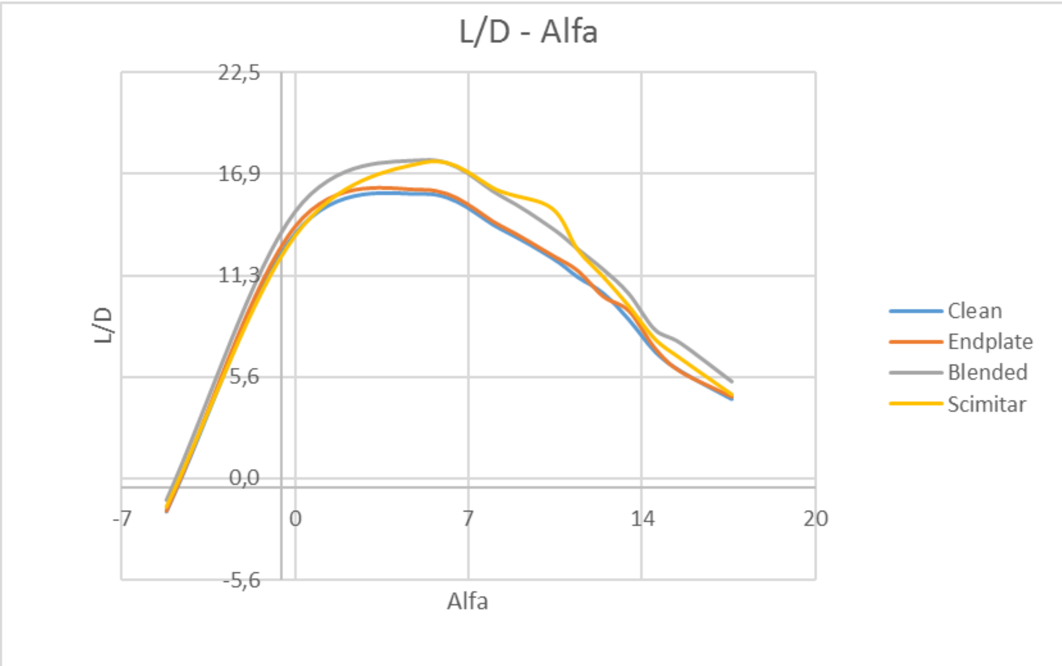
Graphic 2: Lift Coefficient - Alpha

As seen from Graphic 1 all wings increase the amount of lift force similarly at 0-5 degree angle of attack. From this degree, winglets increase lift force obviously compared to wing without winglet. When winglets are compared each other, it is shown that Blended winglet increases the maximum lifting force.



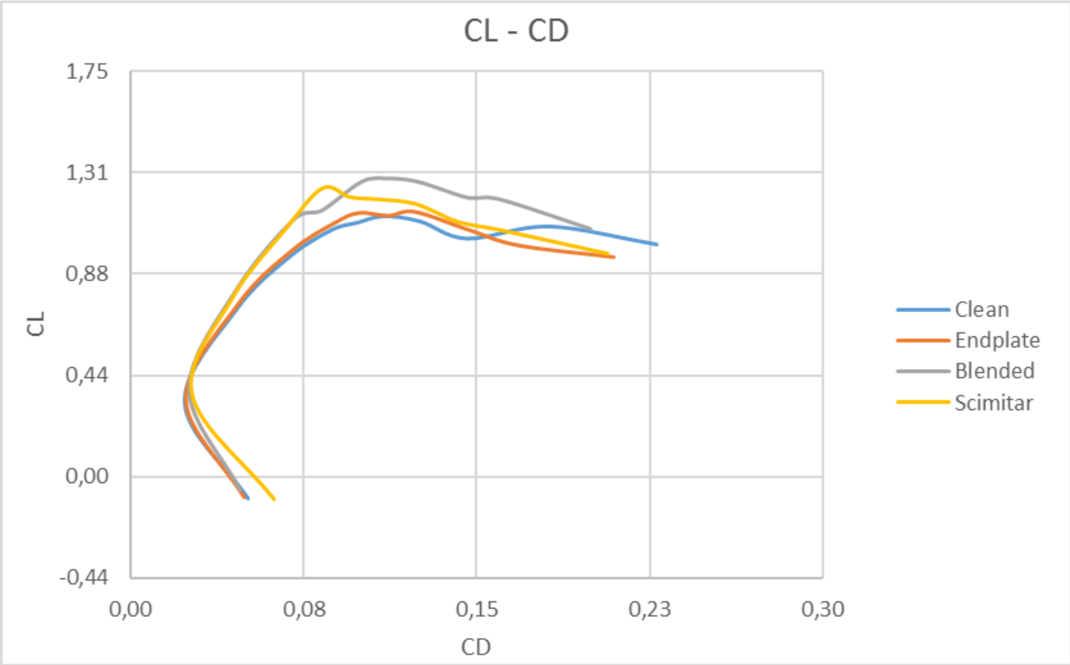
Graphic 2: Drag Coefficient - Alpha

Graphic 2 shows drag coefficient change according to angle of attack for simple wing, wing with end-plate, wing with blended and wing with scimitar winglets. It is seen that between 014 angle of attack degrees all designs gives similar drag coefficient values. After 15 degrees apparent differences start to occur. Clean wing from this aoa constitutes more drag force. Between the three winglets blended provides at least drag forces. It means that the first required condition which is decreasing drag force is provided by blended winglet and it shows that the best winglet is it in this area.



Graphic 3: Lift/Drag – Alpha

L/D according to angle of attack graph shows directly which winglet is more efficient. At 0 degree and increasing degrees it is seen that the most efficient model is blended winglet. Scimitar winglet has also been provided overall efficiency. However, it is seen that while the model with end-plate has provided efficiency according to clean wing, in comparison with other winglets efficiency is remained less.



Graphic 4: Lift Coefficient – Drag Coefficient

As a result, it is shown that wing with blended winglet is the model of 3 different types providing maximum efficiency in a very large part of the angle of attack values. This model gives the most Cl/Cd ratio. It means that the biggest ratio of lift coefficient to drag coefficient is blended winglet model. Furthermore it is seen that whatever type of winglet, in each case winglet is used, flight performance gives better results.

According to data obtained from the analysis results the most efficient winglet is blended so it is decided that it is likely to be focused on this winglet for the future works. Blended winglet design criteria (Taper Ratio, Cant angle, Twist, Sweep angle, Base angle, Toe angle and Taper angle etc. [12]) can be changed and prepared the most efficient design.

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