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CFD Analysis of Aerodynamic Characteristics of Scimitar Winglets in Lighter Aircrafts

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Abstract—*A winglet is a device attached at the wingtip, used to improve aircraft efficiency by lowering the induced drag at the tips of each wing. Winglets work by increasing the effective aspect ratio of a wing without adding greatly to the structural stress and hence necessary weight of the wing structure. This paper describes drag reduction by means of scimitar winglets using CFD 3-dimensional winglets analysis that was performed on a rectangular wing of NACA 4415 cross sectional airfoil. This wing is of 600mm span and 100mm chord length and was analyzed for three shapes of winglets multi, blended, and scimitar winglets. The objectives of the analysis were to compare the aerodynamic characteristics of these winglets and to investigate the performance of the three winglets shape simulated at selected angle of attack and for various velocities. The computational simulation was carried out by CFX solver using finite volume approach. The simulation was done using K- Epsilon solver. A comparison of aerodynamic characteristics of lift coefficient, drag coefficient, and lift to drag ratio was made and it was found that the addition of the scimitar winglet gave a larger lift curve slope and higher lift to drag ratio comparison to the baseline wing alone.*

Keywords*: Aerodynamics, CFD, blended winglet, scimitar winglet, multi winglets.*

1. INTRODUCTION

A winglet device is used to improve the efficiency of an aircraft by reducing the lift induced drag which is caused by wingtip vortices [1]. The device is a vertical and may be also angled extension at the tips of each aircraft wing. Winglet increases the efficiency by scattering the shed wingtip vortex, which will decrease the aerodynamic drag due to lift and highly improves the aircraft wing's lift over drag ratio. Winglets improve the effective aspect ratio of a wing without adding greatly to the structural stress and therefore necessary weight of its structure doesn't affect. Research on winglet technology for commercial aviation was initiated by Richard Whitcomb in the mid 1970's. Small and nearly vertical fin shaped structures were installed on a KC-135A and flights were tested in 1979 and 1980. Whitcomb found out that in a full size aircraft, winglets can provide improvements in efficiency of more than 7%. For airlines, this translates into millions of dollars in fuel costs.

Winglets are being installed in to most new transport aircraft, including business class jets, the Boeing 747-400, airliners and also military transport. The wingtip sail is the first industry application winglet which was studied by the Pennsylvania state university (PSU) [2]. 94-097 airfoil configurations has been designed for winglets on high performance sailplanes and tested in the low turbulence, low speed wind tunnel from Reynolds numbers range of $0.24x10^6$ to $1.0x10^6$. Performance characteristics comparison was made between two well known computer codes and also experimental data and then both are found to generate results that are in good agreement with the wind tunnel measurements. Very recent advancement in winglets was made in unmanned vehicle application where methods for designing and optimizing winglet geometry for UAVs were investigated at Reynolds number of range 10^6[3].the resulting methodology is then applied to existing different UAV platforms for particular performance improvements.

The motivation for this research is to elaborate the efficient shapes for winglet design. While research in winglets has been dominated by conventional winglets, with existing research applied to multiple winglets [4]. Spiroid winglets [5-6] and blended winglets, little is documented on the various shapes of elliptical and semicircular winglets. Lift and drag analysis have been successfully studied experimentally in an aircraft model using elliptical and semi circular winglets. The main objective of this study is to numerically perform a CFD analysis on the baseline wings by different configuration without winglet and using winglets of blended & split-blended shapes and multi- winglets. The analysis was performed on rectangular wing of 600mm span and 100mm chord at various angles of attack and for various velocities. The span of winglet is 50mm. the studies involved obtaining and comparing the aerodynamic characteristics such as lift coefficient, drag coefficient and lift to drag ratio L/D.

2. METHODOLOGY

In this project the computational steps consist of three stages as shown in fig. 1. The project starts from preprocessing stage which involves the basic aerodynamics characteristics of the winglets were found

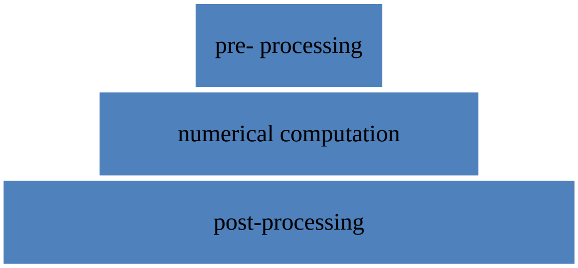


Fig. 1: Three stages of project

Geometry setup was made by using surface design and wireframe to draw the 3-dimensional model of winglet.

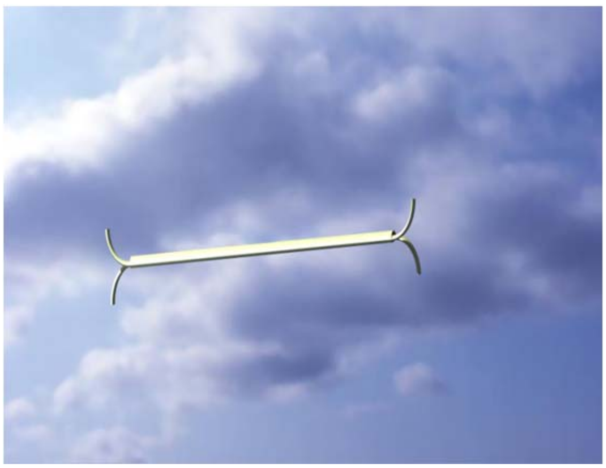


Fig. 2: Split Blended Winglet

The grid generation part was done using ICEMCFD. The 3-dimensional unstructured tetrahedral mesh was utilized for computing the flow around the model. Unstructured mesh is appropriate due to complexity of the model. The advantages of the unstructured mesh are shorter time consumption in grid generation for some complicated geometries and it's potential to adapt the grid to improve the accuracy of the computation. After completing the meshing process, the unstructured mesh was examined. The purpose of examining the meshes was to check on the quality of mesh by observing the level of skewness and unexpected changes in the cell sizes.

Then, the grid generated were developed using size function scheme in ICEMCFD. This will enable finer mesh at the winglet wall and then incrementally increase up to the boundary wall which is bullet shaped. The sizing function scheme will help to reduce the computational time. After the completion of the mesh generation the numerical simulation by the solver was made. The solver formulation turbulence model k-epsilon, boundary condition solution control parameters and material properties were define. The model was initialized after all the parameters were specified according to the necessary data. The initializing and iteration processes stopped after the completion of the computations. The results thus obtained were examined and analyzed.

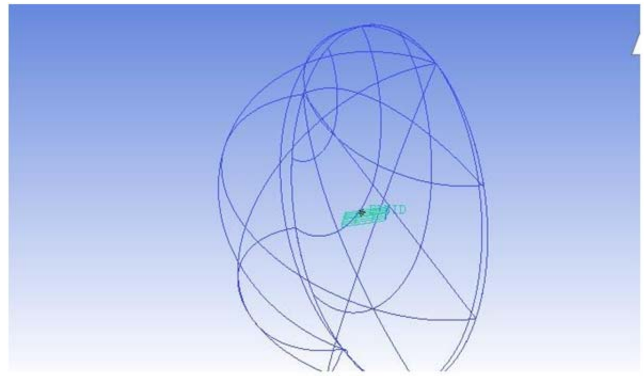


Fig. 3: Bullet shaped boundary wall

3. RESULTS AND DISCUSSION

The result from the 3-dimensional rectangular wing with winglet model was compared with wing without winglet model. The discussions were mainly focused on the aerodynamics characteristics which include drag coefficient, lift coefficient and lift to drag ratio. In addition to that the pressure coefficient contours and stream patterns will also be observed and studied. The simulation was carried out at various velocities 20,30,40,45 m/s and at various angle of attack 0,10,12,15 degrees respectively.

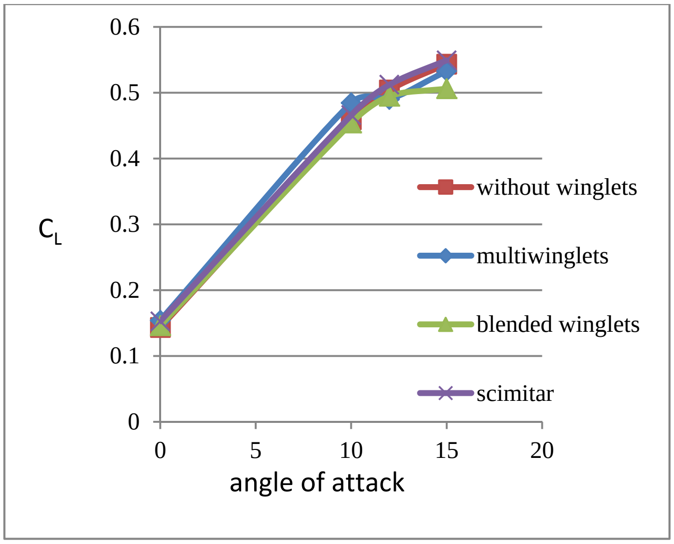
3.1 Lift coefficient, C_L analysis

Table 1 shows lift coefficient changes with angle of attack for all winglet and rectangular wing models at various velocities. Here is the result of C_L at velocity 45m/s is highlighted.

Table 1: C_L at velocity 45m/s

Winglet configuration	Lift coefficient			
	0	**10**	**12**	**15**
Without winglet	0.143	0.459	0.504	0.543
Multi winglets	0.154	0.484	0.49	0.532
Blended winglets	0.1462	0.454	0.494	0.506
Split-blended winglets	0.152	0.466	0.512	0.549

The following graph shows the variation in lift coefficient values among different winglet configurations.



Graph 1: The graph is plotted between angle of attack and lift coefficient values.

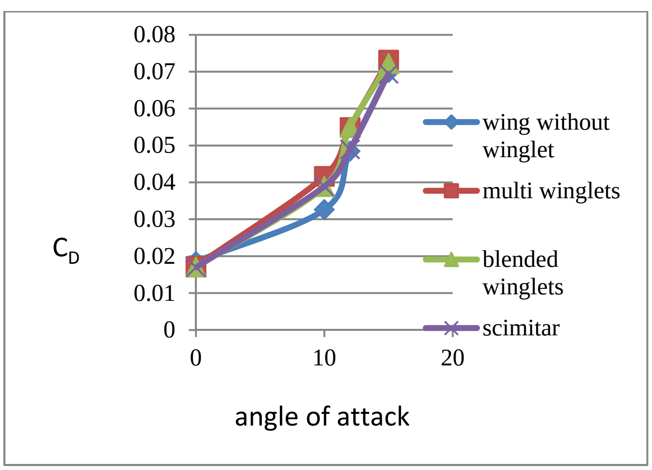
3.2 Drag coefficient, C_D analysis

Table 2 shows the drag coefficient changes with angle of attack for all winglet and rectangular wing models at various velocities. Here the results at velocity 45m/s are highlighted.

Table 2: C_D at velocity 45m/s

Winglet configuration	Drag coefficient			
	0	10	12	15
Without Winglet	0.018	0.032	0.04	0.06
Multi winglets	0.017	0.041	0.05	0.07
Blended	0.017	0.038	0.054	0.07
Scimitar Winglets	0.016	0.038	0.048	0.068

The following graph shows the variation in drag coefficient values among different winglet configurations.



Graph 2: The graph is plotted between angle of attack and drag coefficient values.

3.3 Performance analysis

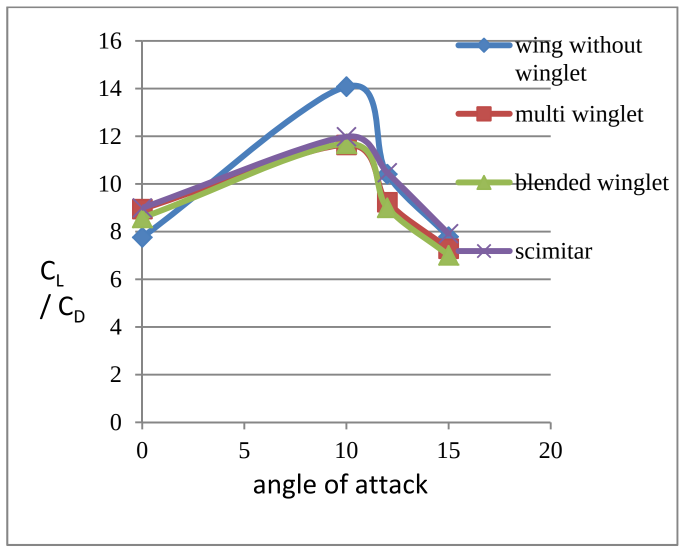
3.3.1 Aerodynamic efficiency

Table 3 shows the lift to drag for all winglet and rectangular wing models at various velocities. Here the results at velocity 45m/s are highlighted.

Table 3: Lift to drag ratio (at velocity 45 m/s)

Winglet configuration	Lift to drag ratio			
	0	10	12	15
Without winglet	7.76	14.07	10.40	7.78
Multi winglet	8.94	11.63	9.23	7.286
Blended winglet	8.58	11.64	9.003	7.01
Scimitar winglet	8.99	11.97	10.47	7.911

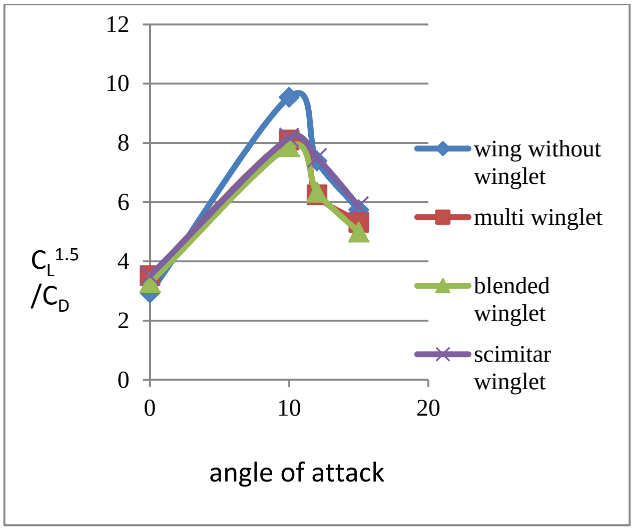
The following graph shows the variation in lift to drag ratio values among different winglet configurations.



Graph 3: The graph is plotted between L/D and angle of attack.

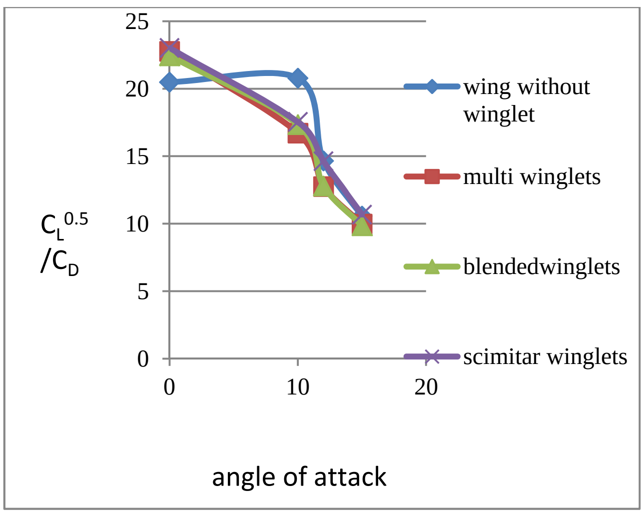
3.3.2 Rate of climb and range influence:

The following graph shows the climb rate factor curve for various winglet configurations. The effect of rate of climb was analyzed by a climb parameter ($C_L^{1.5}/C_D$).



Graph 4: Climb rate factor curve

The following graph shows the range factor curve for various winglet configurations. The effect of range factor was analysed by a climb parameter ($C_L^{0.5}/C_D$).



Graph 5: Range factor curve

3.3.3 Streamlines

The following figures shows the streamline pattern of flow over baseline wing, wing with blended winglets and wing with split blended winglet at 45 m/s velocity and maximum of 15 angle of attack.

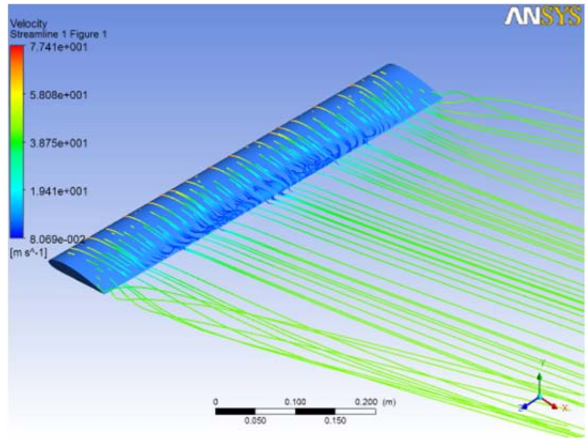


Fig. 4. Streamline pattern over wing without winglet configuration

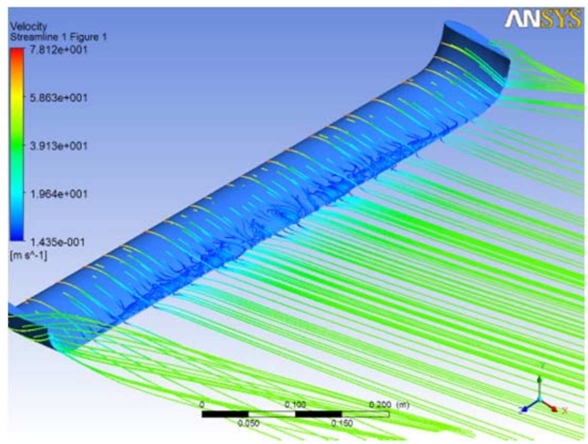


Fig. 5. Streamline pattern over wing with blended winglet

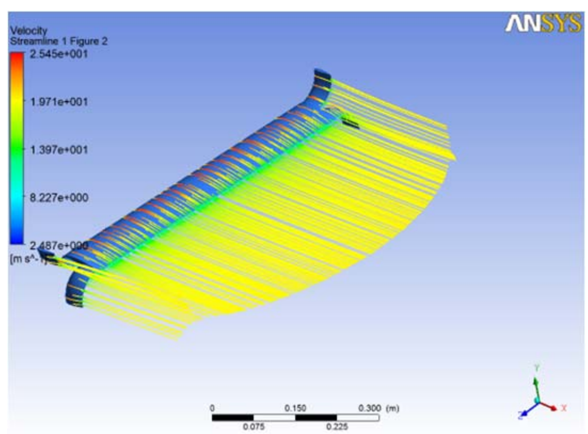


Fig. 6. Streamline pattern over wing with split blended winglet

4. CONCLUSION

This project proposes alternatives in the design of winglet from the conventional designs. An improved winglet design will significantly yield a better performance of an aircraft and reduce the fuel consumption. By using CFD to predict the performance of the winglets, huge amount of time and money can be saved before testing the winglets in the wind tunnel. Modification can also be done at this stage, thus shortening the time cycle before actually coming out with the optimum design.

Despite the benefits of winglets there are some drawbacks that need to be addressed. For example, the bending moment at the wing root is higher, and may require additional structural reinforcement of the wing. Winglets although can produce a drag wing, they add to the cost and complexity of construction. They also modify the handling and stability characteristics. The viscous drag of the winglet can be too big, nullifying the reduction of the induced drag. Winglets have to be carefully designed so that these and other problems can be overcome.

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