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Aerodynamic Analysis of Blended Winglet for Low Speed Aircraft

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Abstract—This paper provides a practical design of a new concept of massive Induced Drag reduction of blended winglets. The designed winglet provides an optimum reduction in drag created by the trailing vortices at the tip of the aircraft wing. To satisfy the no slip boundary condition a velocity gradient was formed in the cross stream wise direction resulting in a virtual shape and dimension for the winglet to yield a huge amount of reduction in fuel consumption. Owing to its simplicity of application and effectiveness we believe that it will enable us to consider this enhanced version for the grid effect of the blended winglet on the deflected mass flow of the wing system. The objective of the analysis was to compare the aerodynamic characteristics of single, two and three winglet configuration and to investigate the performance of the winglets.

Index Terms—Blended Winglet, Induced drag reduction, Outboard wing, Staggered winglet.

I. Introduction

DRAG is generated by the interaction and contact of a solid body with a fluid [1]. The aim of the project is primarily to reduce drag in an airplane or a car that will lead to more velocity and fuel efficiency. This is done primarily to reduce the Induced drag created due to high pressure underneath the wing that causes the airflow at the tips of the wings to curl around from bottom to top in a circular motion, resulting in a trailing vortex which in turn increases the angle of attack that results in an increase in induced drag [2]. An Ideal way to decrease the lift-induced drag is to increase the aspect ratio of the wing, but it is not a great possibility to do the same [3]. An alternative being to develop wing tip devices acting on the vortex, which is the origin of the lift, induced drag. An effective Drag reduction technique involves modification of the wing structure and the angle of attack [4]. Passive techniques include wingtip turbine, wing tip sails, wing grid, winglets etc. Analysis has shown that the passive control technique reduces the viscous flow. Research has indicated that winglets could reduce induced drag [5]. The airfoil was placed in a subsonic wind tunnel with pressure taps along its surface and a pitot probe downstream to measure the flow characteristics. The wind tunnel was operated at a nominal 17 m/s during the coefficient measurements, a Reynold's number of about 232,940 and was analyzed at 0, 5, 10 and 15 degree angles of attack and drag was reduced by twenty percent .In short the reduction of induced drag with an improved C_L without increasing the span is achievable using the technique of blended winglet at low angle of attack.

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II. Methodology

In an existing model for the reduction of induced drag with single winglet results in minimal drag to lift ratio. The blended winglet reduces the induced drag without increasing the span of aircraft [6]. The blended winglet is expected to be more efficient than the conventional one to reduce the flow acceleration that occurs in the cross-flow curvature and to decrease the vortex intensity as important chord variation is avoided. The usage of blended winglet for the reduction of induced drag without increasing the span of aircraft wings was tested in a subsonic wind tunnel using a rectangular, untwisted wing built from NACA 0015 airfoil with a 15% thickness to chord ratio constituted of three winglets, at flow speed 20m/s and placing the wing at angle of attack ranging from -5 to +15 deg. Reynolds numbers from 161,000 to 300,000 range were tested. Wind tunnel balances provided lift and drag measurements, and laser flow visualization obtained wingtip vortex information. And also the wing with no winglet (bare wing) and with single winglet was also tested in the same condition as in the case of blended winglets. The results show that blended winglet system reduced induced drag by 27.9% and improved C_L by 26.5% compared to bare wing. Dihedral spread of the winglets improves lift by taking some of the winglets away from the wing plane, and redistributing the tip vortex into multiple vortices that do not merge in the near wake, thereby reducing the effective downwash at the wing plane. Combining the force measurement results with the flow visualization we observe that negative incidence and geometrically twisted winglets improves L/D by re-orienting the winglet lift vector forward and thus canceling part of the drag.

A. Lift, Drag and moment of a NACA 0015Airfoil

To measure the flow characteristics the wind tunnel was operated at a nominal 17 m/s during the coefficient measurements, a Reynold's number of about 232,940 and was analyzed at 0, 5, 10 and 15-degree angles of attack. The phenomenon known as hysteresis with regards to stall conditions was also observed by varying the angle of attack and wind tunnel velocity. The observation indicates that as a result of the control, higher momentum was drawn towards the wall, which was responsible for delaying separation.

B. Induced drag Reduction using Blended Winglet

The drag reduction provided by blended winglets improves fuel efficiency and thereby reduces emissions. The paper shows, how taking into account grid effect of blended winglets on the deflected mass flow of a wing system within linear models exhibit much smaller induced drag. The blended winglet is expected to be more efficient than a narrow one to reduce the flow acceleration that occurs in the cross-flow curvature and to decrease the vortex intensity as important chord variation is avoided [7]. The results for the Split-Wing configuration tested in parallel experimentally were obtained by calculating the true force free vortex sheets leaving the wing, including partial rollup, in the near field a few chord lengths downstream using iterative wake relaxation. Induced drag was obtained using the classic Trefftz plane. Interpreting the fanned winglets as a true grid, the additional deflected mass flow delta using the Betz grid deflection coefficient κ with the grids t/c is calculated. The blended winglet provides a transition region between the outboard wing, which is typically designed for a plain tip, and the winglet. Without this transition region, the outer wing would require aerodynamic redesign to allow for the interference between the wing and winglet surfaces [8].

C. Aerodynamic Analysis

A CFD 3-dimensional winglet analysis that was performed on a rectangular wing of NACA653218 cross sectional airfoil is shown. The wing is of 660 mm span and 121 mm chord and was analyzed for two shape configurations, semicircle and elliptical. The objectives were to compare the aerodynamic characteristics of the two-winglet configurations and to investigate the performance of the two winglets shape simulated at selected angles of 0, 45 and 60 degrees. The computational simulation was carried out by FLUENT solver using finite volume approach. The simulation was done at low subsonic flow and at various angles of attack using Spalart-Allmaras couple implicit solver. A comparison of aerodynamics characteristics of lift coefficient C_L, drag coefficient C_D and lift to drag ratio L/D was made and it was found that the addition of the elliptical and semi circular winglet gave a larger lift curve slope and higher lift-to-drag ratio in comparison to the baseline wing alone. Elliptical winglet with an angle of 45 degree was the best overall design giving about 8 percent increase in lift curve slope and the best lift-to-drag ratio.

III. DESIGN

Research based on the materials of winglet manufacturing led us to the use of Medium density fiber board (MDF) for its cost efficiency on comparison with other materials and the ease of fabrication.

Fig 1: NACA0015 wing

Table I: Parameters of Bare Wing

Parameter	Value
Wing Span	400mm
Wing Chord	200mm
Aspect Ratio	2

Fig 2: NACA0015 wing with blended winglet

Table II: Parameters of blended wing

Parameter	Value
Winglet Chord	60 mm
Winglet Span	100 mm

Fig3: NACA0015 wing with multi winglets

Table III: Parameters of multi winglet

Parameter	Value
First winglet deflection	-75°
Second winglet deflection	0°
Third winglet deflection	75°
Winglet chord	40 mm
Winglet span	100 mm

IV. OBSERVATION

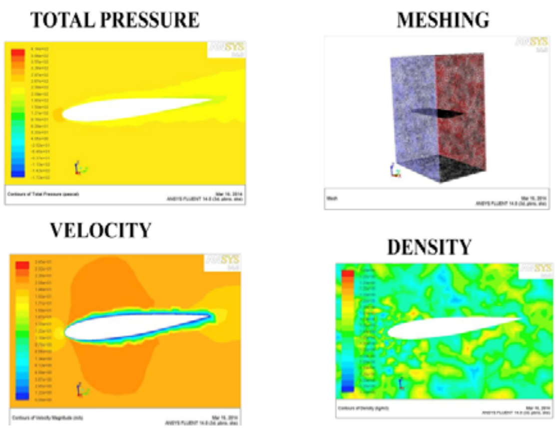

Fig 4: Contours of wing without winglet

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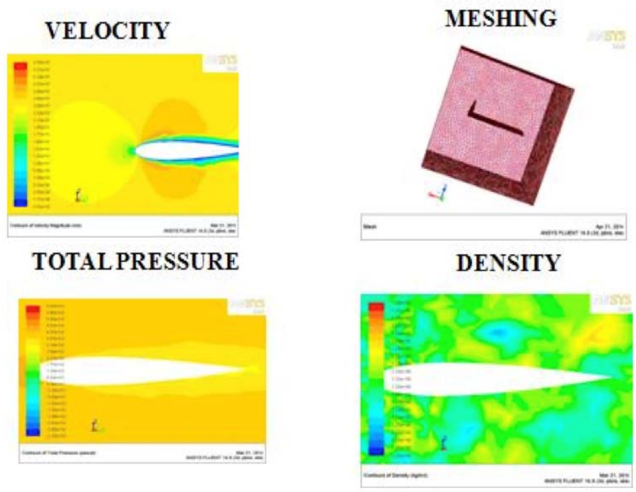

Fig 5: Contours of wing with blended winglet

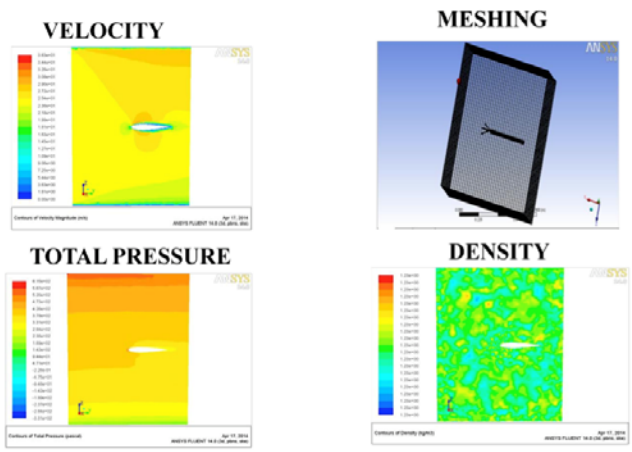

Fig 6: Contours of wing with blended winglet

V. RESULTS AND DISCUSSION

A. Experimental and Theoretical value of wing without winglet

Table IV: Comparison of experimental and theoretical value at 0°

Velocity (m/s)	α =0°	Theoretical Value	Experimental Value
15m/s	C_l	0.000205	0.00048
	C_d	0.00425	0.004
	C_{di}	$9.5554*10^{-9}$	$5.23*10^{-8}$
20m/s	C_l	0.0023	0.000205
	C_d	0.004	0.0065
	C_{di}	$1.2028*10^{-8}$	$9.539*10^{-9}$

Table V: Comparison of experimental and theoretical value at 5°

Velocity (m/s)	α =5°	Theoretical Value	Experimental Value
15m/s	C_l	0.00704	0.00105
	C_d	0.004603	0.00325
	C_{di}	$1.1269*10^{-5}$	$2.5*10^{-7}$
20m/s	C_l	0.00703	0.00816
	C_d	0.00497	0.00586
	C_{di}	$1.1237*10^{-5}$	$1.511*10^{-5}$

Table VI: Comparison of experimental and theoretical value at 10°

Velocity (m/s)	α =10°	Theoretical value	Experimental Value
15 m/s	C_l	0.01288	0.0095
	C_d	0.0044	0.0025
	C_{di}	$3.77204*10^{-5}$	$2.048*10^{-51}$
20m/s	C_l	0.01324	1.0154
	C_d	0.00478	0.0054
	C_{di}	$3.9858*10^{-5}$	$5.383*10^{-5}$

B. Experimental and Theoretical value of wing with Blended winglet

Table VII: Comparison of experimental and theoretical value at 0°

Velocity (m/s)	α =0°	Theoretical Value	Experimental Value
15m/s	C_l	0.0001264	0.00126
	C_d	0.004676	0.00468
	C_{di}	$3.6327*10^{-7}$	$3.603*10^{-7}$
20m/s	C_l	0.00081	0.0095
	C_d	0.00502	0.00311
	C_{di}	$1.498*10^{-7}$	$2.0048*10^{-5}$

Table VIII: Comparison of experimental and theoretical value at 5°

Velocity (m/s)	α =5°	Theoretical Value	Experimental Value
15 m/s	C_l	0.00889	0.0089
	C_d	0.00414	0.0041
	C_{di}	$1.797*10^{-5}$	$1.789*10^{-5}$
20m/s	C_l	0.0086	0.0091
	C_d	0.00447	0.0057
	C_{di}	$1.6816*10^{-5}$	$1.879*10^{-5}$

Table IX: Comparison of experimental and theoretical value at 10°

Velocity (m/s)	α =10°	Theoretical Value	Experimental Value
15 m/s	c_l	0.0176	0.00176
	c_d	0.00366	0.00366
	c_{di}	$7.0432*10^{-5}$	$7.031*10^{-5}$
20 m/s	c_l	0.0173	0.0165
	c_d	0.004117	0.00542
	c_{di}	$6.7938*10^{-5}$	$6.18*10^{-5}$

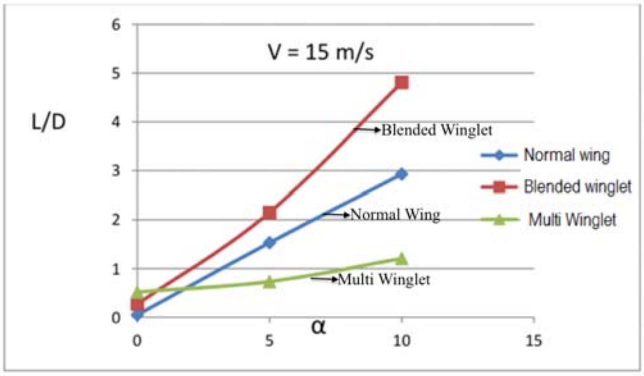

Fig 7: Graphical comparison (theoretical) of wings L/D Vs α at 15m/s

C. Experimental and Theoretical value of wing with Multi winglet

Table X: Comparison of experimental and theoretical value at 0°

Velocity (m/s)	α =0°	Theoretical Value	Experimental Value
15m/s	c_l	-0.002	-0.00154
	c_d	-0.0038	-0.00754
	c_{di}	$8.63*10^{-7}$	$5.383*10^{-7}$
20m/s	c_l	-0.0024	-0.0095
	c_d	-0.0048	-0.00125
	c_{di}	$1.31*10^{-6}$	$2.048*10^{-5}$

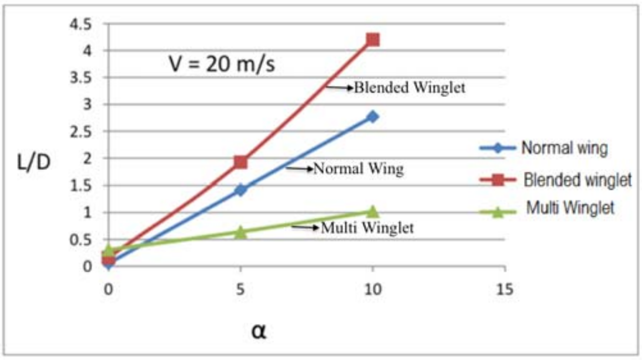

Fig 8: Graphical comparison (theoretical) of wings L/D Vs α at 20m/s

Table XI: Comparison of experimental and theoretical value at 5°

Velocity (m/s)	α =5°	Theoretical Value	Experimental Value
15m/s	c_l	0.0065	0.0063
	c_d	0.0089	0.00956
	c_{di}	$9.59*10^{-6}$	$9.009*10^{-6}$
20m/s	c_l	0.0063	0.0054
	c_d	0.0098	0.0084
	c_{di}	$9.03*10^{-6}$	$6.61*10^{-6}$

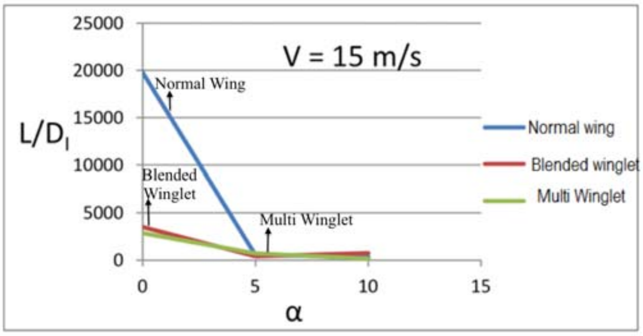

Fig 9: Graphical comparison of wings L/D_I Vs α at 15m/s

Table XII: Comparison of experimental and theoretical value at 10°

Velocity (m/s)	α =10°	Theoretical Value	Experimental Value
15 m/s	c_l	0.0094	0.0094
	c_d	0.0078	0.0087
	c_{di}	$2.005*10^{-5}$	$2.005*10^{-5}$
20m/s	c_l	0.0098	0.00124
	c_d	0.0096	0.0091
	c_{di}	$2.18*10^{-5}$	$3.49*10^{-7}$

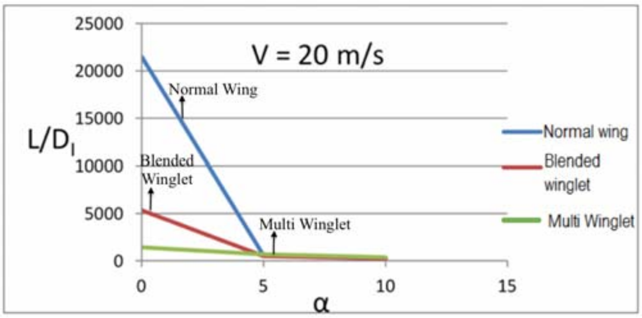

Fig 10: Graphical comparison of wings L/D_I Vs α at 20m/s

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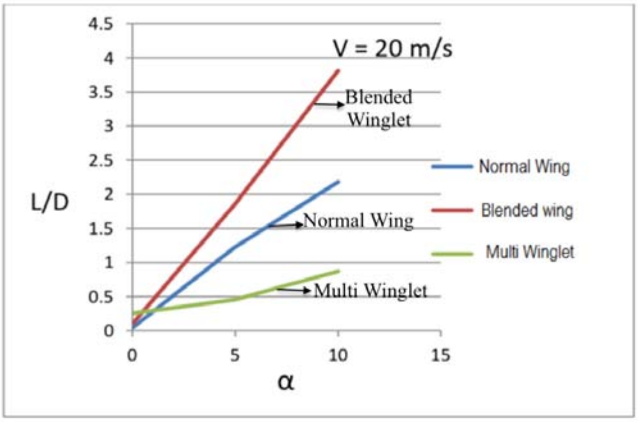

Fig 11: Graphical comparison (experimental) of wings L/D Vs α at 20m/s

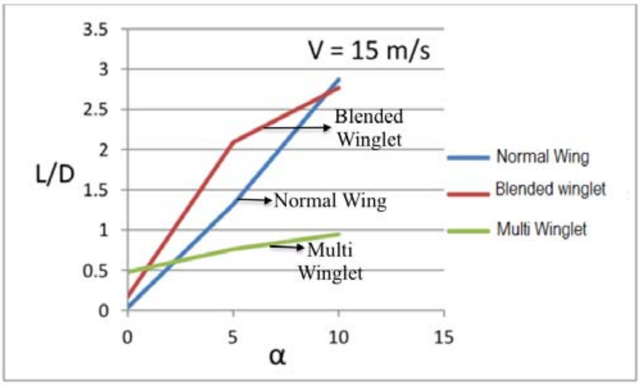

Fig 12: Graphical comparison (experimental) of wings L/D Vs α at 15m/s

VI. COMPARATIVE DATA

Table XII: Comparison of theoretical and Experimental values

At 15 m/s
L/Di

	0°		5°		10°	
	Theoritical	Experimental	Theoritical	Experimental	Theoritical	Experimental
WITHOUT WIGLET	21456.98	19767.67	677.7	534.45	468	358
BLENDED WINGLET	3469.17	3497.08	495.26	411.35	249.8	153.25
MULTI WINGLET	2259.56	2860.73	677.78	699.3	935	728.25

Table XIII: Comparison of theoretical and Experimental values

At 20 m/s
L/Di

	0°		5°		10°	
	Theoritical	Experimental	Theoritical	Experimental	Theoritical	Experimental
WITHOUT WIGLET	19153.4	21490.72	626	540.04	311.17	286.085
BLENDED WINGLET	5807.74	5344.98	511.4	484.323	254	245.65
MULTI WINGLET	1832.6	1423.6	6998	687	449	374.2

VII. CONCLUSION

In this work, theoretical and experimental calculations were done and the performance parameters were investigated to obtain the following results. Blended winglet configuration reduced the wing-induced drag and improved L/D by 15-30% compared with the baseline 0012 wing. Stall angle for blended winglet system is much higher than conventional system. At high angles of attack blended winglet system produces better C_L. Blended winglet can reduce the induced drag in more percentage compared to conventional winglet system at low angles of attack.

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