Journal of Research in Engineering and Applied Sciences
**AERODYNAMIC AND EXPERIMENTAL
INVESTIGATION ON A DELTA WING INCORPORATED
WITH WINGLETS AT DIFFERENT ANGLES**

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Abstract

Delta wing has numerous applications across aerospace vehicles. Highly inclined and variable swept back wings have a lot of added advantages in maneuverable fighter airplanes, supersonic cruise airliner; and modern unmanned aerial vehicles that have been equipped with and have deployed low swept back delta wings. Vortex flow across these delta wings is dominant for micro aerial vehicles and mini unmanned aerial vehicles flying at a low speed Reynolds number regime. Many experiments were carried out to study and analyze the aerodynamic flow parameters of delta wings wherein vortex sheet flow patterns were observed and studied at different angles of attack and flow parameters. In this paper we are plotting lift co-efficient and drag co-efficient for a flat delta wing with and without winglets at different angles of attack under low Reynolds numbers. Furthermore, simulations are carried out to draw comparisons between the winglets on the basis of span-wise flow velocity vectors.

Keywords: Delta, Aerodynamics, Winglets, Vortex, Velocity vectors

1. Introduction

We know that the airplane is flying with the help of their wings. The streamlined power applied on a body inundated in a wind current is because of two hands of nature which are in immediate contact with the outer part of the body with weight and shear pressure appropriation acting everywhere throughout the outer part of the body. The streamlined part of the body is increasingly rudimentary portrayed by the powers and coefficient of minute. The power on the wing will obviously rely upon how much the wing is slanted to stream. We need to discover how the lift differs with different parameters acting on the body.

Let us define C_L = coefficient of lift and C_D = coefficient of drag for a given aerodynamic body shape differing with angle of attack, Reynolds and Mach number. The question arises that what are these variations? The answer depends on the shape of the body itself. Aircrafts can be categorized on the basis of wing configuration. There are different types of wing shapes, for example modern airplanes companies like Boeing and Airbus have monoplane designs with wings fixed on both sides of the fuselage, and there are biplanes with two wings one on top of the other. Even in the early aviation era tri planes, quad planes and tandem wing aircrafts with one wing placed slightly aft of the other wing were common. Some aircrafts have swept back wings which can be adjusted during the flight and are called as variable geometry wings and certain flying wing design

concepts which were earlier limited to military purposes have now found a way into commercial aviation.

2. Literature Review

The delta wing is characterized by its ability to generate high values of lift at higher angles of attack. The leading edge suction peak is the primary reason behind its high lift attributes. Because of its high performance attributes, the delta wing is also required to exhibit fast maneuvering characteristics (1).

The flow over the delta wing at any given angle of attack is characterized by 2 bound vortices which are large in magnitude and are generated as a result of the flow separation exhibited by leading edge (2). The physical flow field over the wing exhibits the characteristics wherein the separation observed on leading edge that further leads to the generation of 2 spiral vortex sheets. One would observe that across these the properties of tangential velocity and pressure are discontinuous and continuous respectively. Considering a slender delta, exhibited field has conical characteristics due to no characteristic dimension on which to base variations in any quantity along conical rays through the origin (3).

Flying wings are characterized by the lack of tails. Despite this fact an increase in their efficiency is observable. But there exists many constraints and in order to attain a good amount of efficiency, multiple considerations have to be taken into account. These include the addition of a swept angle. However this

addition leads to few complications as well and leads to an increment in the induced drag. Therefore, even though stability in terms of pitch and yaw is achieved, the net performance is adversely affected. Hence the Bell Shaped Lift Distribution (BSLD) which is characterized by its properties of proverse yaw incorporated with the inherent rolling control will aid in eliminating the need of a sweep angle [4]. Features of BSLD [5] [6]:

- Magnitude and Direction of downwash at the trailing edge is a function of span-wise position.
- A constant downwash trend is exhibited by the Elliptical Span-load, but in the case of Bell Shaped span-load, the trend varies. Here the downwash exhibited is characterized by quadratic function where the maximum value is observable towards the wing-root.
- Relative wind direction at tips is angled towards the upward direction.

3. Material and Method

Here we use flat delta wing of four type Figure 1 flat delta wing, Figure 2 delta wing with 45° wing-let, Figure 3 delta wing with 45° inverted wing-let and Figure 4 delta wing with 90° wing-let. Material used is hard plastic with thin coating of aluminum and the model was created using CREO parametric version 2.0. Specifications of subsonic wind tunnel as shown in Figure 5- Test section size: 600mm×60mm construction type: 9:1 and equipped with 6 component balance with DAQ software for better result evaluation. These delta wings are used for calculating C_L and C_D to study flow parameters on different shape profiles of delta wing.

Fig. 1. (a) Flat delta wing mounted in the test section of Wind tunnel; (b) Delta wing with 45° wing-let

Fig. 2. (a) Delta wing with 45° inverted wing-let; (b) Delta wing with 90° wing-let

A low speed air stream in a wind tunnel is characterized by the pressure parameter across the test section, temperature, and flow direction settings of test chamber. In order to achieve the desired test result, special attention must be given towards calibration of subsonic wind tunnel and for achieving accurate condition inside the test section following points must be noted while operating the wind tunnel. By following the below mentioned procedure the effectiveness of the flow velocity and Reynolds number achieved can be increased.

- Calibration of true air speed
- Flow angularity (pitch, yaw and side forces) determination
- Flow level turbulence
- Velocity profile across horizontal and vertical axis of the test section to determine the quality of flow
- Wake study and flow calculations across any model

After successful calibration of the wind tunnel, delta wing models were mounted in the test section and placed parallel to axis of this tunnel. 6 component force measuring equipment is used to measure the values of C_L and C_D at various angles of attack and velocities; the Data acquisition software aids in the plotting of the required graphs.

A low-speed wind tunnel experimental study conducted on four different delta wings (flat delta wing, delta wing with 45° winglet, delta wing with inverted winglet at 45° angle and delta wing with 90° winglet) at different flow velocities and at multiple attack angles (0° , 5° , 10° , 15° and 20°) aimed at determining the value of C_L and C_D . Readings were noted and graphs plotted between C_L Vs angle of attack and C_D Vs Angle of attack. Furthermore simulations for the span-wise flow velocity vectors were carried out for comparisons using Simscales as shown in Figure 15 and Figure 16.

Fig. 3. (a) Six component force measurement; (b) Subsonic wind tunnel with six component force measurement set-up

4. Results

4.1 Flat Delta Wing

Table 1. Experimental C_L values at different angles and velocities for a flat delta wing

Angle of Attack	Velocit y (m/s)			
	10	15	20	25
0	0.10	0.07	0.04	0.00
5	0.42	0.59	0.85	0.98
10	0.28	0.70	1.25	1.99
15	0.48	1.30	2.12	2.78
20	0.80	1.65	2.70	4.65

Fig. 4. C_L plotting at different angle of attack and velocities for delta wing

Table 2. Experimental C_D values at different angles and velocities for a flat delta wing

Angle of Attack	Velocit y (m/s)			
	10	15	20	25
0	0.06	0.08	0.02	0.00
5	0.36	0.26	0.22	0.10
10	0.15	0.06	0.00	-0.15
15	0.13	0.04	-0.07	-0.13
20	0.18	0.00	-0.17	-0.44

Fig. 5. C_D plotting at different angle of attack and velocities for delta wing

4.2 Flat Delta Wing with 45 degree wing-let

Table 3. Experimental C_L values at different angles and velocities for wing with 45° winglet

Angle of Attack	Velocit y (m/s)			
	10	15	20	25
0	0.20	0.22	0.30	0.42
5	0.25	0.54	0.86	1.52
10	0.33	0.66	1.25	1.96
15	0.38	0.78	1.60	2.48
20	0.52	1.01	1.97	3.11

Fig. 6. C_L plotting at different angle of attack and velocities for wing with 45 degree wing-let

Table 4. Experimental C_D values at different angles and velocities for wing with 45 degree winglet

Angle of Attack	Velocity (m/s)			
	10	15	20	25
0	0.18	0.18	0.17	0.16
5	0.15	0.09	0.02	-0.05
10	0.20	0.12	0.04	-0.02
15	0.15	0.08	-0.02	-0.07
20	0.14	0.07	-0.08	-0.26

Fig. 7. C_D plotting at different angle of attack and velocities for wing with 45 degree wing-let

4.3 Flat Delta Wing with 90 degree wing-let

Table 5. Experimental C_L values at different angles and velocities for wing with wing-lets at 90 degrees

Angle of Attack	Velocity (m/s)			
	10	15	20	25
0	0.15	0.18	0.20	0.29
5	0.21	0.32	0.46	0.61
10	0.21	0.66	1.08	2.60
15	0.84	1.32	2.09	3.29
20	0.81	1.50	3.25	4.20

Fig. 8. C_L plotting at different angle of attack and velocities for wing with 90 degree wing-let

Table 6. Experimental C_D values at different angles and velocities for wing with wing-lets at 90 degrees

Angle of Attack	Velocity (m/s)			
	10	15	20	25
0	0.19	0.21	0.18	0.14
5	0.18	0.11	0.08	0.01
10	0.14	0.06	0.00	-0.07
15	0.13	0.06	-0.01	-0.07
20	0.12	0.01	-0.07	-0.20

Fig. 9. C_D plotting at different angle of attack and velocities for wing with 90 degree wing-let

4.4 Simulation of delta wing with 45 deg and 90 deg winglets

Fig. 10. Span-wise flow velocity vectors for delta wing with 45 degree winglet

Fig. 11. Span-wise flow velocity vectors for delta wing with 90 degree winglet

5. Conclusions

Most of the airplanes fly at 3° to 5° angles of attack during cruise mode and beyond these values during takeoff and landing procedures. Here, after careful analysis of the data we found that drag is least for the delta wing with 90° degree winglet at above mentioned flight regime which coincides with the theoretical part that introducing winglets/blended wings improves the efficiency of the aircraft and reduces wing tip vortex strength which further reduces induced drag which is one of the evils in flight that cannot be eliminated but only reduced by introducing winglets. So out of the four samples we will prefer to use delta wing with 90° degree winglet which is providing least amount of resistance in flight which enhances performance criteria. The solution is shown to well predict the behavior of the flow on and off to the surface and gives good amount of coefficient of lift and drag values for these wings. Thus, we conclude that for a flat delta wing we got 4.65 N C_L and C_D is -0.44N and for a flat delta with 90° deg winglet we found the C_L is 4.2 and C_D is -0.2 . Furthermore the simulations (between the two best winglets among the three, done at velocity 80m/s) also showed that 45° deg winglet is characterized by many high span velocity vectors even in the tip and trail, however in the 90° degree winglets, the tip exhibits high span velocity vectors that actually diminishes towards the end (trailing edge of the winglets) which in turn means less vortex formation (span-wise flow combined with backward flow primarily leads to vortex generation). This in turn means that in the 90° deg winglets, less span-wise flow, less vortices and better stabilization with less induced drag components is observable. It also aids in reducing fuel consumption and increasing efficiency. Our main objective was to find out which angle of the winglet in a flat delta wing will yield us the best result and with the experimental and computational analysis we got maximum lift and minimum drag value and better efficiency for a flat delta wing with 90° degree winglet.

Acknowledgment

The authors would like to express their gratitude to the Department of Mechanical Engineering of Lovely Professional University, Phagwara for their support in preparing this work.

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