Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 6, Issue 4; July-September, 2019, pp. 251-254

http://www.krishisanskriti.org/Publication.html

An Experimental Comparison of Aerodynamic Performance and Flow Visualization of Corrugated Winglet with Conventional Winglet

Anjali Manam[1] and Y. D. Dwivedi[2]

[1]*UG Student, GITAM (Deemed to be University), Patancheruvu, Telangana, India-502329*
[2]*Professor, Institute of Aeronautical Engineering, Dundigal, Hyderabad, Telangana, India-500043*
E-mail: anjali.manam@yahoo.com

Abstract—*The performance of an aircraft wing is highly affected by induced drag caused by wingtip vortices. Winglets are intended to reduce the formation of these vortices. This paper describes the wind tunnel experiments conducted on three wing models i.e. (a) rectangular wing (b) wing with conventional winglet and a (c) wing with corrugated winglet, having NACA 0012 airfoil cross section. The objective of the analysis is to examine the effect of the corrugation of winglets in improving the aerodynamic efficiency of the wing. The experiment was done in a subsonic low-speed wind tunnel. Six Component Balance was used to obtain aerodynamic characteristics such as Coefficient of Lift (C_l), Coefficient of Drag (C_d) and C_l/C_d at Reynolds number 116000. Smoke flow visualization was done to find vortices and regions of separated flow at Reynolds number 22000. Tuft flow visualization was done to observe regions of strong cross-flow, reverse flow, and flow separation at Reynolds number 172000. Both the aerodynamic characteristics and flow visualization results showed that the corrugated winglet performed aerodynamically better than the wing with conventional winglet and rectangular wing.*

Introduction

The wings are the most important lift-producing part of the aircraft. To produce lift, air below the wing is at a higher pressure than that of the air above the wing, this pressure difference causes air to flow from the lower surface around the wingtip towards the upper surface, leading to the formation of vortices along the wing tip. These vortices quickly roll up to produce wingtip vortices, thereby causing induced drag [1].

In order to increase the aerodynamic efficiency, wings are required to produce low induced drag. Theoretically, a wing with infinite aspect ratio would produce no induced drag. However, since this is not practically possible, the use of wing tip extensions or winglet was proposed. These winglets reduce the formation of wing tip vortices by increasing the effective aspect ratio [2].There have been many investigations and experiments conducted on the shape and usage these winglets [3-9].

The recent computational and experimental study on bio-inspired corrugated surface of the wing revealed that the corrugation delayed the flow separation, enhanced the lift and reduced the drag [10-13]. The flow behavior of these bio-inspired corrugated wings for micro air vehicles is of great interest today.

It was proved from the previous work [14-17] that the corrugations are very effective and efficient in the low Reynolds number flows, i.e. regimes in which micro air vehicles are generally used. The current work on this topic is initiated to combine the concepts of winglet and corrugation and assess the aerodynamic performance of a winglet with corrugation at low Reynolds number flight. To fully analyze this effect, the obtained results were compared with the aerodynamic performance of a rectangular wing and wing with conventional winglet, having the same planform area. The flow visualization by smoke and tuft were done to understand flow behavior of the different wings. Results revealed that the wing with corrugated winglet performed better than the rectangular wing and wing with conventional winglet.

Methods

The wing geometry was designed using NACA 0012 airfoil profile, having span length of 0.36 m and chord 0.1 m. All the three wings have the same planform area, chord and aspect ratio, which allow the aerodynamic characteristics of the three wings to be compared. The geometries of the wing and winglets were designed using CATIA V6 software. Based on this design all the models were hand cut from Medium Density Fiber (MDF) wood. Photographs of the models during the design and during manufacturing process are shown in Figure 1 and figure 2 respectively.

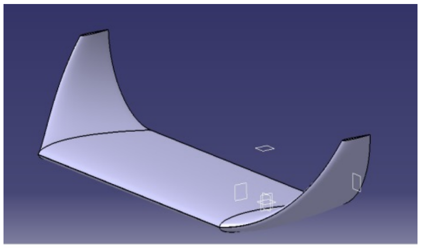


Figure 1: CATIA model of wing with Conventional Winglet

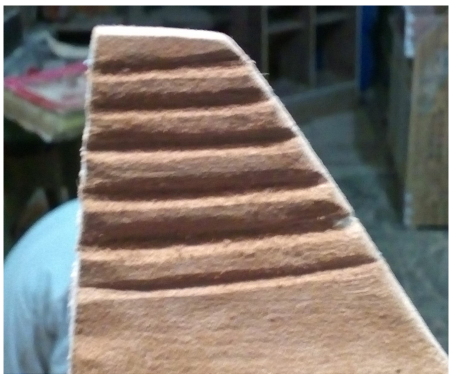


Figure 2: Corrugations of Winglet

The experimental analysis was carried out in an open loop low speed subsonic wind tunnel, with test section dimensions 0.6 m x 0.6 m x 2 m. The forces acting on all the three models were determined using a six component balance (6 component balance instrumentation WBAL-00106; Sunrise Technology Bangalore, having maximum experimental error of 2%) at Reynolds number 116000 and for angles of attack ranging from 0° to 18° at every 2° interval. An average interval of 5 seconds, gain of 421 with voltage accuracy of 0.05 V was taken in the six component balance. Two sets of data have been taken for each wing and the average of the two results has been considered. For smoke flow visualization, the smoke was generated from paraffin oil by using smoke generator supplied by the wind tunnel manufacturer. The regions of flow separation and formation of vortices were observed for the models at angles of attack ranging from -4° to 12° at every 4° interval. For tuft flow visualization cotton tufts of 0.02m length were arranged with a gap of 0.01m between two adjacent tufts, from wingtip to wing center line and the motion of the tufts was observed at $-4°, 0°, 4°, 8°, 10°, 12°, 14°, 16°$ angles of attack.

Results and Discussion

The wind tunnel tests were undertaken at the Department of Aerospace Engineering, GITAM (deemed-to-be) University, Hyderabad. Reynolds number was calculated taking the characteristic length as chord length, 0.1m, operating Reynolds number is 116000. Based on the data obtained from the six component balance, the analysis was focused on the Coefficient of Lift (C_l), Coefficient of Drag (C_d) and their ratios (C_l/C_d). Graphs have been plotted for C_l VS angle of attack (AOA) (Fig. 3), C_d VS AOA (Fig. 4) and C_l/C_d VS AOA (Fig. 5).

From the figure 3, the experimental results indicated that the wing with conventional winglet exhibits the highest C_{lmax} value among the three wings; however it stalls at 8° AOA. On the other hand, even though, the wing with corrugated winglet comparatively has a slightly lower $C_{lmax,}$ the stalling is delayed to 10° AOA. A delay of stall is observed upto 20% on corrugated winglet.

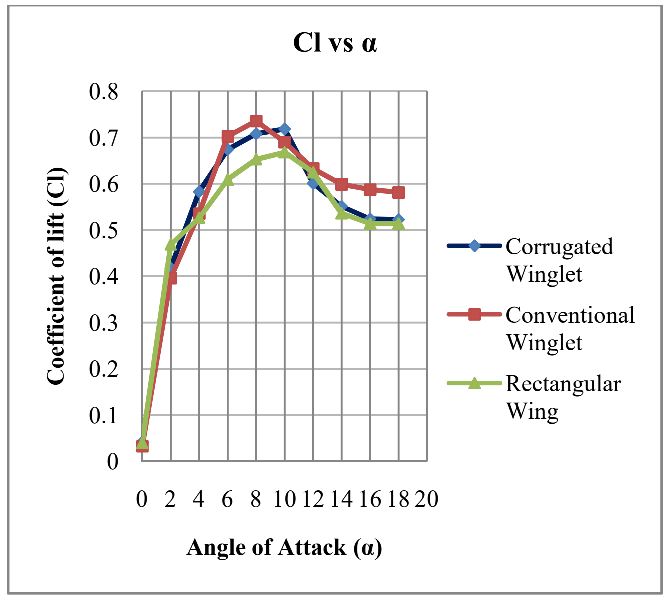


Figure 3: Coefficient of lift versus Angle of Attack

Figure 4, clearly shows that the amount of drag coefficient produced in the wing with corrugated winglet was significantly lower than the other two wings at all the tested angle of attack. It is also noticed that from 2° to 10° AOA, the value of coefficient of drag is significantly lower than the other tested wings; it is noteworthy that at these angle of attack (0^0-10^0) the aircraft is likely to consume least propulsive power. It can also be noted that at the cruise flight angles of attack of an aircraft which are normally between 4^0 to 8^0 AOA, the wing with corrugated winglet performed exceptionally well.

Figure 5, shows the result of aerodynamic performance C_l/C_d versus AOA. The results indicate that the performance of the wing with corrugated winglet was found significantly higher at all the tested angles of attack. Particularly at 4° AOA, the ratio of C_l/C_d was exceptionally high, nearly 21, this gives high gliding capabilities in case of engine failure, cruise flight condition.

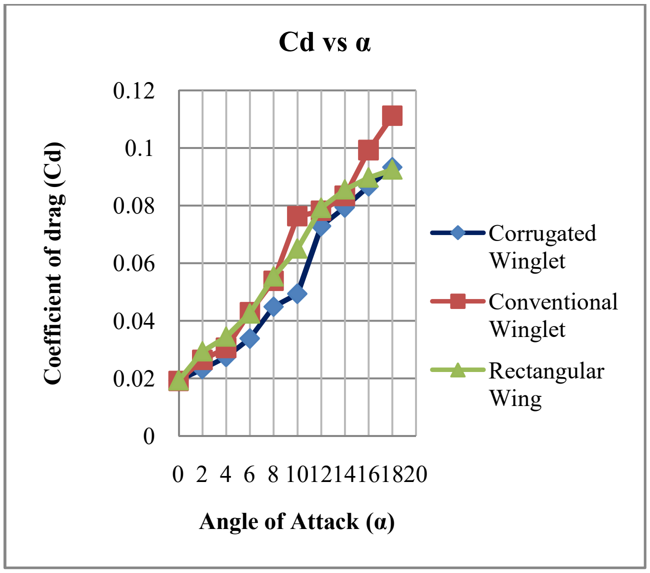


Figure 4: Coefficient of drag versus Angle of Attack

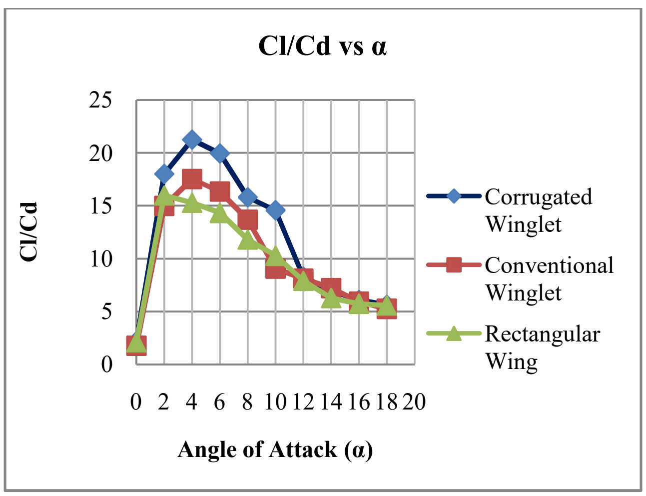
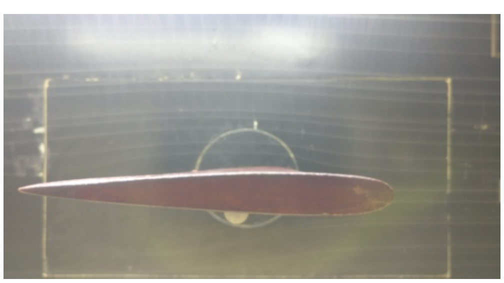


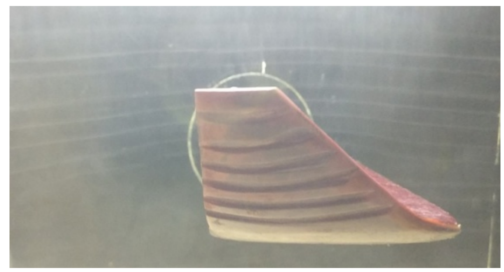
Figure 5: C_l/C_d versus Angle of attack

From the smoke flow visualization, it can be observed that at 0° AOA the flow pattern was almost the same for all the three wings (Figure 6- a, b, c). However, after 8° AOA, the formation of vortices of the rectangular wing was more compared to the other two wings.



(a) Rectangular Wing

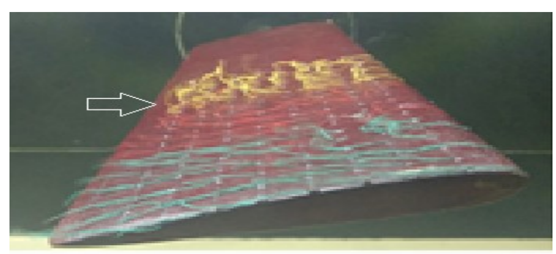
(b) Wing with Conventional Winglet



(c) Wing with Corrugated Winglet

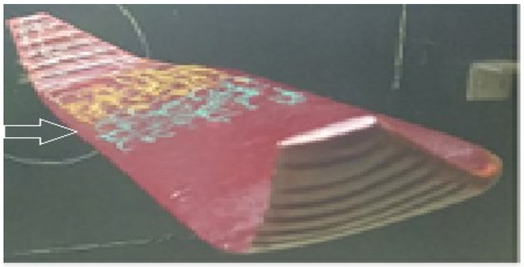
Figure 6: Smoke flow visualization at 0° AOA

During tuft flow visualization a slightly higher rate of disturbances was observed near the wing center as when compared to the wing tip. This indicates the presence of spanwise flow over the wing. At 0° and -4° AOA there were no disturbances observed in the tufts on the rectangular wing but there was a slight movement observed at the trailing edge of the other two wings. From 8° AOA onward the motion of air around the trailing edge caused flow reversal. At 12° AOA, this flow reversal of the tufts was very prominent only near the center line of the rectangular wing but the same movement was observed throughout the span of both the other wings (Figure 7- a, b, c).



(a) Rectangular Wing

(b) Wing with Conventional Winglet



(c) Wing with Corrugated Winglet
Figure 7: Tuft flow visualization of at 12° AOA (Arrows show regions of flow reversal)

Conclusions

The experimental results showed that the wing with corrugated winglet displayed best aerodynamic performance in comparison with the rectangular wing and wing with conventional winglet. This is observed because the corrugations produce leading edge vortices; these vortices circulate inside the corrugated valleys and reduce drag.

- Maximum coefficient of lift for the wing with corrugated winglet occurred at 10° AOA and was found to be 2.3% lesser than the wing with conventional winglet and 6.9% higher than the rectangular wing. However both the wing with corrugated winglet and rectangular wing stall at 10° AOA, whereas the wing with conventional wing stalled at 8° AOA.
- The coefficient of drag for the wing with corrugated winglet was significantly lower than the other two wings at almost all the tested angles of attack.
- Maximum C_l/C_d ratio was observed for the wing with corrugated winglet at 4° AOA.
- Smoke flow visualization indicates that formation of vortices for the wing with corrugated winglet and wing with conventional winglet was comparatively lesser than the rectangular wing.
- Tuft flow visualization results showed that in all the three wings tested, flow fluctuation was observed at the mid portion of the wings. Less fluctuation of flow was observed near the wing tip in the corrugated wing was due to blockage of tip vortices.

References

[1] John D Anderson Jr., “Introduction to Flight”, McGraw Hill 6th edition, 2010.

[2] Bento S. de Mattos, Antonini P. Macedo, Durval H. da Silva Filho, "Considerations about Winglet Design", AIAA-2003-3502, June 2003.

[3] A. Beechook, J. Wang, "Aerodynamic Analysis of Variable Cant Angle Winglets for Improved Aircraft Performance", IEEE, Sept 2013.

[4] Andrew Shelton, Agnivesh Tomar, Jvr Prasad, Marilyn Smith, Narayanan Komerath, "Active Multiple Winglets for Improved Unmanned-Aerial-Vehicle Performance", Journal of Aircraft, 2006.

[5] Mohammad Ilias Inam, Mohammad Mashud, S. M. S. Selim, "Induced Drag reduction for Modern Aircraft without Increasing the Span of the Wing by Using Winglet", International Journal of Mechanical & Mechatronics Engineering, 2010.

[6] M. Smith, N. Komerath, R. Ames, O. Wong, J. Pearson, "Performance Analysis of a Wing with Multiple Winglets", AIAA-2001-2407, June 2001.

[7] E V Laitone, "Wind tunnel tests of wings at Reynolds numbers below 70 000", Springer, 1997.

[8] YD Dwivedi, Patil Mauli Pratap, Donepudi Jagadish, "Design and Aerodynamic Analysis of Different Winglet”, IJIET, 7(2), 2016.

[8] YD Dwivedi, B Parvathavadhani, Nirmith, K Mishra, “Design of Supersonic Wind Tunnel using method of characteristics”, Int. J. Adv. Transport Phen, 1(1), 2012.

[9] Masatoshi Tamai, Zhijian Wang, Ganesh Rajagopalan, Hui Hu, Guowei He, "Aerodynamic Performance of a Corrugated Dragonfly Airfoil Compared with Smooth Airfoils at Low Reynolds Numbers", AIAA 2007-483, 2007.

[10] YD Dwivedi, W.H Ho, D. Jagadish, and PMV Rao, "Spanwise Flow Analysis of Gliding Bio-inspired Corrugated Wing", Journal of Advanced Research in Dynamical & Control Systems: 12-Special Issue, August 2017.

[11] YD Dwivedi, V Bhargava, “Aerodynamic Characterization of Bio- inspired Corrugated Wings”, MOJ App Bio Biomech, 3(1), 2019.

[12] VK Sridhar, YD Dwivedi, “Effect of Peak Shape in Bio-inspired Corrugated Wing”, ATSMDE2017.

[13] Jeffery T. Murphy, Hui HU, "An experimental study of a bio-inspired corrugated airfoil for micro air vehicle applications", Springer, August 2010.

[14] YD Dwivedi, "Aerodynamic Performance and Stability Analysis of Bio-Inspired Corrugated Wings for Micro Air Vehicles", PhD, thesis submitted to VFSTR University, Guntur, 2018.

[15] YD Dwivedi, Donepudi Jagadish, V K Sridhar, “Aerodynamic Analysis of Corrugated Winglet for Improved MAV Performance”, Lamsys2016, ISSE & SDSC, SHAR, ISRO, Sriharikota, 2016.

[16] YD Dwivedi. V. Sridhar, P.M.V Rao , D. Jagadish, "Computational Study of Fluid Flow Behavior Over Bio-Inspired Corrugated Airfoil for Micro Aerial Vehicles", International Conference on Advances in Thermal Systems, Materials and Design Engineering (ATSMDE 2017), VJTI Mumbai, Dec 2017.