SIMULATION BASED STUDY ON METHODS OF REDUCING INDUCED DRAG ON LOW ASPECT RATIO WINGS

A.L.N.A Perera[1]

[1]Research engineer, National Engineering Research and Development (NERD) Centre, Sri Lanka. E-mail: nipuni_apsara@yahoo.com.

ABSTRACT

Low aspect ratio wing designs are studied, specifically in relation to the reduction of induced drag, with specific reference to the low subsonic flight regime. Attention is given to reducing the drag caused by wingtip vortices and increasing the lift to drag ratio independent of the type of propulsion. The study is conducted using the Clark Y airfoil, a high lift airfoil that is extensively used in the low subsonic flight regime. A literature review is conducted, and solutions are proposed. . Three wingtip designs and five winglet designs are tested via the used of Solidworks® flow simulation, which uses computational fluid dynamics (CFD) to verify the proposed solutions. Recommendations are made for further study.

Keywords: Low aspect ratio, induced drag, winglets, low subsonic flight regime, computational fluid dynamics

1. INTRODUCTION

Low aspect ratio wings (wings with low wing area to wing span ratios) have several distinct advantages. They have a low profile drag due to its low frontal area. Forces in wing are concentrated closer to the wing root, creating a lower wing root bending moment, allowing a reduced structural weight. However, its main drawback is its high induced drag, caused by the high pressure air below the airfoil ‘spilling’ on to the upper surface. This also reduces effective lift.

However, their use is limited to subsonic and transonic aircraft for the most part, where the effect of reduced wave drag is more significant than the increase in induced drag.

However, they have been used successfully in several subsonic aircraft, Notably the Vought XF5U (better known as the flying flapjack). In this aircraft, counter-rotating propellers reduced the above mentioned phenomenon (Paust, 1947), increasing its efficiently greatly.

This study examines the usage of low aspect ratio wings at low subsonic speeds, without necessitating a propeller. The focus is on reducing induced drag by changing the wingtip or by using wingtip devices such as winglets.

2. METHODOLOGY

According to (Whitcomb, 1976), numerous studies have indicated the possibility of reducing induced drag by redesigning the wingtip – more specifically, by the addition of vertical or nearly vertical surfaces at the wingtip. Whitcomb investigated the effects of the addition of winglets using the root bending moment as an indication of the associated structural penalty, on the KC 135. He proposed an optimized winglet design for the said aircraft.

Since then, numerous studies have been conducted of the effectiveness of winglets, multiple winglets, and C-wings in mitigating the effects of induced drag using both simulation and experimental means.
This study focuses specifically on the reduction of induced drag on low aspect ratio wings (Aspect ratio ≤ 1) in the low subsonic regime. Only the wing design is utilized, to make the design less dependent on the propulsion system.

Eight wing designs are tested in total. A straight wing with a ClarkY profile, aspect ratio of 1, and a chord of 1m is used as the base. For winglet designs, the span of the wing is reduced proportional to the area of the winglet.

Three wingtip designs are used: A cut-off tip that acts as a control; a rounded tip, where the upper and lower surfaces are merged into one another smoothly at the tip; and a pointed tip where the end is sharpened. Five winglet designs are also tested: w1, where the winglets have the same chord as the wing; w2 where the chord at the tip of the winglet is 0.5 m; w3 which is similar to w2 but with the winglet turned down; w4 which uses a parallel upper and lower winglet, both with tip chords of 0.5 m; and w5 which uses tandem upper and lower winglet, the lower winglet having a root chord of 0.25 m and a tip chord of 0.1m, the upper winglet having a root chord of 0.75 m and a tip chord of 0.5 m. All winglets are attached to a 0.7 m section of the original wing (reduced to compensate for area of winglets).

The designs were drawn on Solidworks© as single components. These were then tested for their aerodynamic performance in terms of lift and drag on Solidworks© flow simulation. The simulations were carried out at standard sea level atmospheric conditions, using laminar and turbulent flow. External flow was used. All simulations were carried out at a mesh setting of 7/8*.

Each design was tested at velocities of 20, 25, 30, 35, and 40 ms^{-1}, and at angles of attack (AoA) of 0^o, 5^o, and 10^o. The flow was angled rather than the test section for simulation, as this produces more reliable results. Solidworks© flow simulation measures the horizontal and vertical forces on the object under test, and therefore, for angles of attack, this was converted to lift and drag as follows:

$L = CG_y.\cos\alpha - CG_x.\sin\alpha$ [eq.1]

$D = CG_y.\sin\alpha + CG_x.\cos\alpha$ [eq.2]

Where L = lift, D = drag, CG_y = vertical component of force, CG_x= horizontal component of force, α = AoA.

The lift-to-drag-ratio is calculated to determine the effectiveness of the winglet as follows:

Lift to drag ratio = L/D [eq.3]

These are then tabulated to find the relative performances of the various platforms.

3. RESULTS

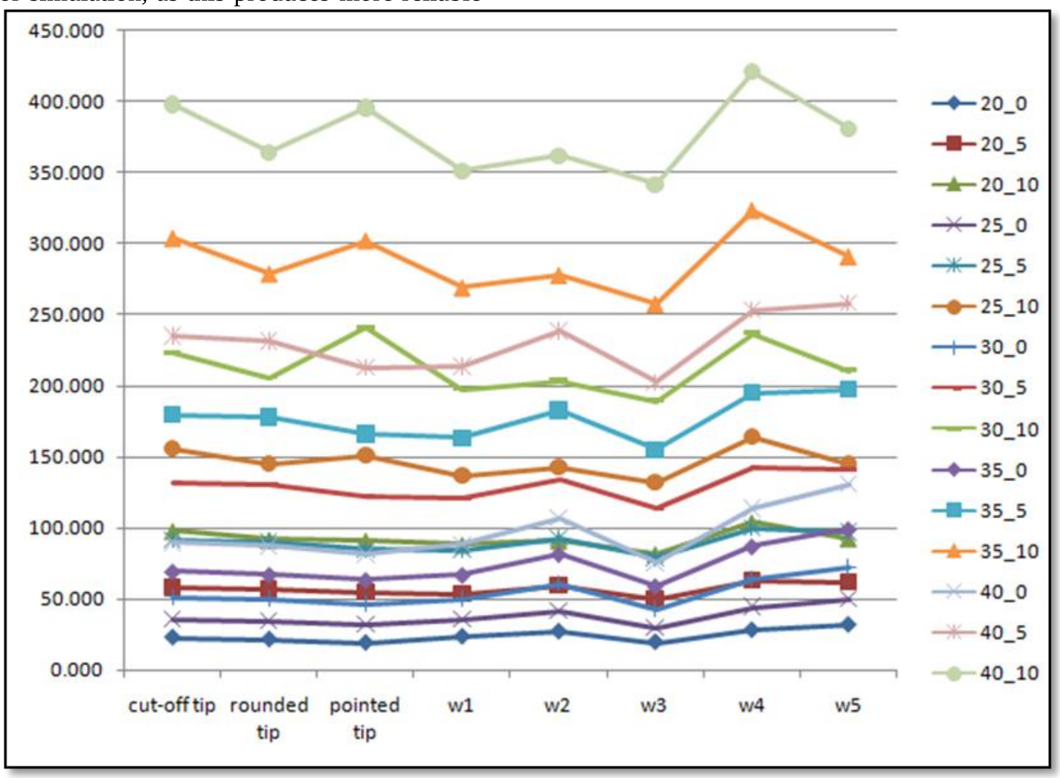

Figure 01: Lift generated / N. The velocities are indicated as velocity_angle of attack – i.e., 35_5 indicates a flow at 35 ms^{-1} at an angle of attack of 5^o.

*The Mesh setting in Solidworks affects both the convergence of the goals and the fineness of the mesh: The higher the setting, the stricter the conditions for convergence and finer the mesh. On average, for these models, about 500000 elements are generated and the solving time ranges from an hour to two hours.

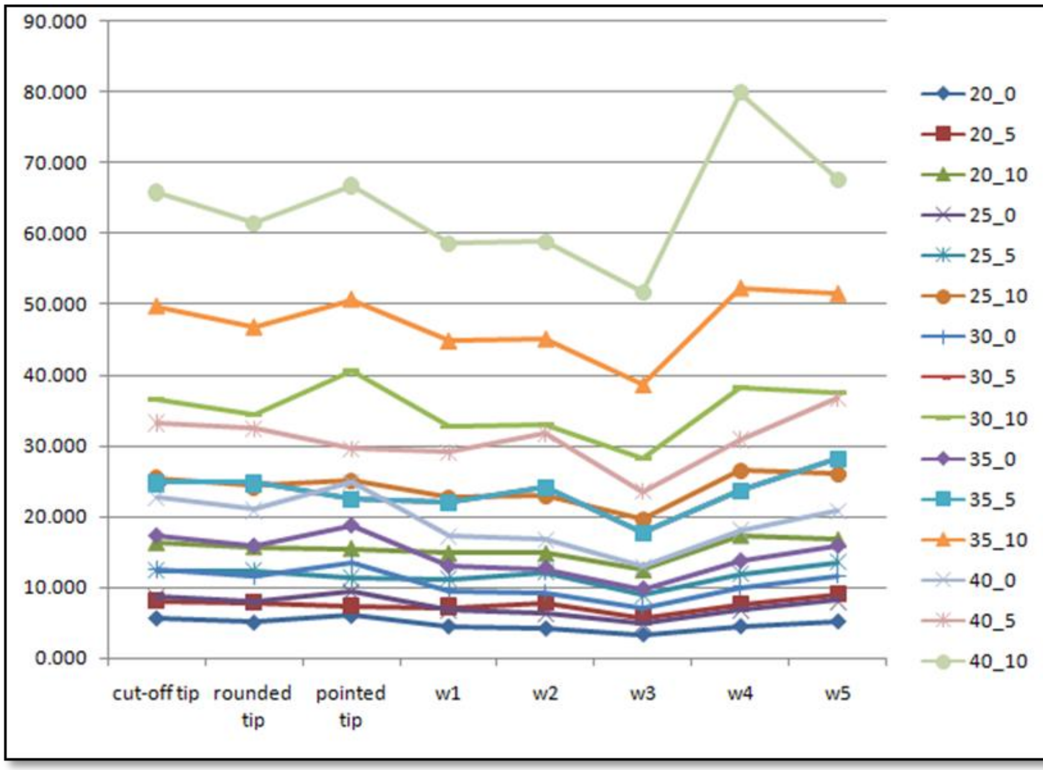

Figure 02: Drag / N

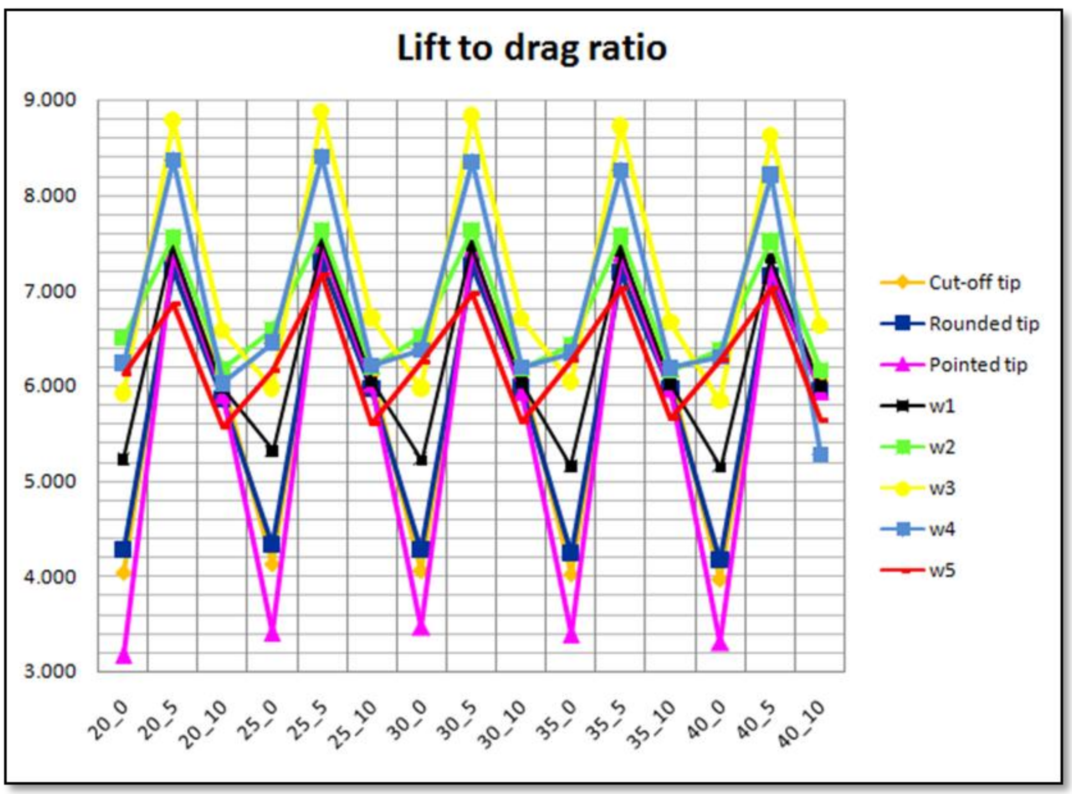

Figure 03: Lift to Drag ratio

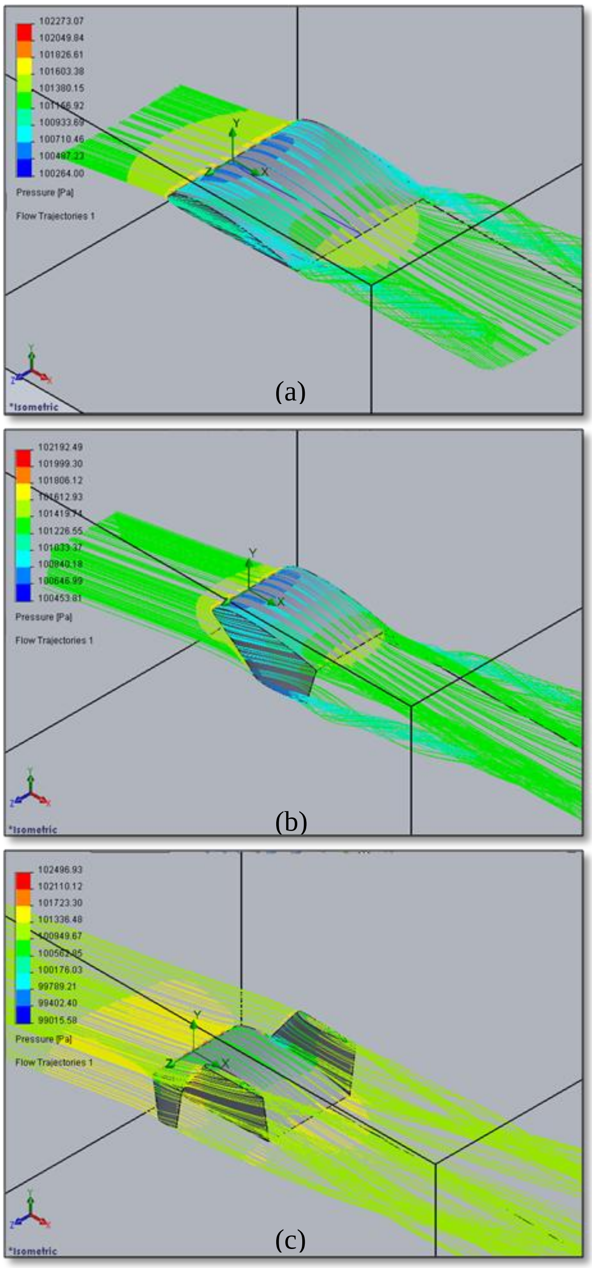

Figure 04: flow trajectories. (a) – cut-off tip, (b) – w3, (c) – w5

4. CONCLUSIONS

Of the designs, it can be seen that the winglet designs generate more lift, though both designs that utilize both upper and lower winglets have an associated drag penalty. However, all winglet designs have a higher lift to drag ratio, which is the main concern in aircraft design.

In addition, winglets serve to dissipate the wake vortices, reducing the energy wasted in them (as shown by the increased lift to drag ratios) and reduces the effect on following traffic.

Therefore, properly designed winglets can decrease the effect of induced drag on low aspect ratio wings, making them a viable option for aircraft design.

However, further study is required regarding the gain in structural weight when using a low aspect ratio wing with winglets. Only one airfoil, Clark Y is studied; this is a typical low subsonic airfoil, but the effects of using other airfoils merits further study. In addition, the design was not pushed to its limits due to the constraints of the software used; further studies are required at maneuvering and near stall conditions to prove that the design provides an advantage over more conventional designs.

5. REFERENCES

[1]. Anderson, J. D. (1999). Aircraft performance and design. Mc Graw-Hill.

[2]. Anderson, J. D. (2001). Fundementals of Aerodynamics, 3rd Edition. McGraw-Hill.

[3]. Azlin, M. A., Mat Taib, C. F., Kasolang, S., & Muhammad, F. (2011). CFD Analysis of Winglets at Low Subsonic. Proceedings of the World Congress on Engineering.

[4]. Ning, S. A., & Kroo, I. (2009). Tip extensions, winglets and C-wings: Conceptual Design and optimization. American Institute of Aeronautics and Astronautics.

[5]. Paust, G. (1947, May). The Flying Flapjack. Mechanix Illustrated .

[6]. Smith, M., Komerath, N., Ames, R., Wong, O., & Pearson, J. (2001). Performance analysis of a wing with multiple winglets. American Institute of Astronautics and Aeronautics.

[7]. Weird Wings - Chance Vought V-173 / XF5U 'Flying Flapjack'. (2005). Retrieved February 2014, from Unreal aircraft: http://www.unrealaircraft.com/wings/cv_flapjack.php

[8]. Whitcomb, R. T. (1976). A design approach and selected wind-tunnel results at high subsonic speeds for wing-tip mounted winglets. Hampton: Langley Research Centre.