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Investigation of Whitcomb's Winglet Flow Behaviour using PIV and FLUENT

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Abstract – *The flow behavior around Whitcomb winglets were investigated using experimental approach and numerical study. The experimental approach uses PIV (Particle Image Velocimetry) while the numerical study uses FLUENT. The investigation was made for a Whitcomb's winglet at water velocity of 2.34 m/s, at Re = 2.33x106and a clean wing also at the same configuration. This paper focuses on the connections of both and Whitcomb's winglet and a clean wing and the formation of vortex around their winglets. From this investigation, it can be said that the vortex moves in a circular motion, from the bottom part of a winglet, which is the higher pressure part to the upper part of the winglet, which is the lower pressure part of the wingtip device. From this investigation, it was proved that the Whitcomb's winglet produced better results compared to the clean wing in terms of the vorticity produced, thus reducing the induced drag.*

Keywords: Particle Image Velocimetry (PIV), FLUENT, Winglets, Whitcomb's winglet

1.0 INTRODUCTION

The usage of winglet device on airplanes wingtip has been associated with the increasing fuel prices and the environmental issues. In order to save the environment, the aviation industry is keen on finding ways to decrease fuel consumptions and lowering the emissions [1-12]. Winglets are a device that is attached to an airplane wing. It will improve the aerodynamic aspects of an airplane thus increasing the lift-to-drag ratio [2]. Meanwhile, wingtip devices on commercial aircraft have been proven to reduce wing loading, increase the range on the airplane and improving the fuel consumptions [1]. Aircrafts performances are also increased when the induced drag are able to be minimize by designing winglets at the tip of airplanes wing [1].

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A winglet's main purpose is to improve performance by reducing drag [3]. Other than that, flight mechanics are also influenced by winglets, as well as the flutter characteristics and the airplane's low speed performance [4]. This study focuses on two types of winglets, clean wing and the Whitcomb's winglet. The vortex formation on these winglets will be compared in order to see the developed vortices on each winglet type.

2.0 METHODOLOGY

Winglets belong to the class of wingtip devices aimed to reduce induced drag. Selection of the wingtip device depends on the specific situation and the airplane model. In the case of winglets, the reduction of the induced drag is accomplished by acting like a small sail whose lift component generates a traction force, draining energy from the tip vortices [6].

Studies concerning the efforts to decrease the fuel consumptions and lower emissions are the interest of the aviation industry, especially in the era of rising fuel prices and environmental issues. These researches are into a device that will provide longer range and more resourceful fuel consumption rates especially to commercial aircraft. It was found that there are two wingtip devices that will provide better fuel consumption rates and could provide longer range, which are the winglets and the raked wingtips [1].

There is seven percent increase of the aircraft's range at cruise conditions (full speed conditions) for aircrafts with wings designed with winglet compared to wing without winglets. Other than that, wing with winglets or wingtip devices on commercial aircraft are found to have lower wing loading and better fuel consumption rates. All the advantages of the winglets and raked wingtip performances are due to its ability to reduce the induced drag, or the drag generated during take-off by a 3-dimensional finite wing [1].

The induced drag, or the drag generated during take-off is due to the difference in pressure of the upper and lower surfaces of an aircraft wings. The high pressure part is on the lower surface of the wing while the lower pressure part is located on the upper surface of the wing. The difference in pressure on the wing will form a net lifting force that is normal to the free stream airflow [1]. The difference of pressure on a clean wing, (a wing with no wingtip devices), will cause air to flow from the lower surface to the upper surface of the wing at the wingtips. The flow of air from the lower surface of the wing to the upper surface of the wing at the wingtips produces a downwash onto the top of the wing, as illustrated in Figure 1.

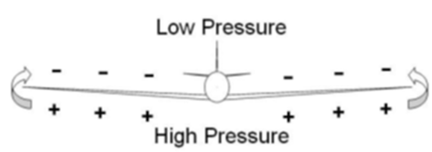

Figure 1: Pressure distribution on an airplane wing

Drag is caused by the induced drag that is created by the downwash of airflow onto the upper surface of the wing at the wingtips thus producing vortices that trail in the aircraft's wake. The most important wingtip devise's functions is reduce the induced drag and consequently, the trailing vortex strength. By minimizing the induced drag, and thus the wingtip vortices produced by an aircraft's wing, the energy required to create the tip vortices can be conserved and the total drag on the wing reduced. The coefficient for the induced drag over a 3-D wing (C_{Di}) is given by:

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$$C_{Di} = \frac{C_L^2}{\pi e AR} \quad (1)$$

where:

CL = lift coefficient
e = Oswald efficiency factor
AR = aspect ratio

2.1 Experimental Rig Apparatus

Experiments were conducted by submerging the winglet devices in a water tunnel. The tunnel was filled with water flowing at constant velocity of 2.34 m/s, with inlet and outlet valves to control its velocity. Laser was focused on the winglet devices while the camera captured the vortex formation along the winglet at certain speed. The experimental setup is illustrated as Figure 2.

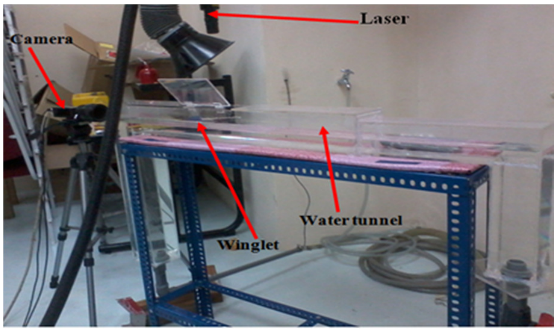

Figure 2: Experimental Setup for PIV

2.2 Experimental (PIV) Technique

The experimental images were recorded after the velocity in the water tunnel stabilized (around 5 minutes). The winglet used was made of acrylic (Perspex), with 3mm thickness and 7 cm length. Meanwhile, the water tunnel was made from acrylic, with 10mm height, 10mm width and 90cm length.

The flow is laminar if Re < 2300, in transition mode if 2300< Re <4000, and turbulent flow if Re > 4000. To construct the water tunnel, the entrance length required for the velocity and the dimensions of the water tunnel has been taken into consideration. The Re used in this experiment was 2.33×10^6.

2.3 Numerical Analysis (FLUENT) Technique

The numerical analysis was performed using two types of software: the two-dimensional modelling using GAMBIT software and a solver using FLUENT 6.3. To analyse the winglet devices problem, the iteration process was used to obtain converged solution.

The time-step chosen for this problem was 0.05 seconds, with a convergence factor of 0.01. The solver used for this problem was Spalart-Allmaras because of its suitability to process flow in a closed area with one cross section.

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3.0 RESULTS AND DISCUSSION

Based on images obtained using PIV and FLUENT on a clean wing, as illustrated in Figure 3(a) and Figure 3(b), it can be seen that the vortex developed are moving in a circular motion, with the vortex moving from the bottom part of the clean wing to the upper part of the wing. It can be seen that the vortex formation is fully developed at the tip of the wing, thus creating more drag on the wing. When the drag is higher, it creates a more drag to lift ratio and becomes harder for the air plane with this configuration to take off and land.

The wing with winglets configuration has lower vorticity magnitudes, compared to the vortices developed on the clean wing. Figure 3(c) also shows that this configuration have effectively reduced the magnitude of vortices, thus reducing the induced drag on the wing.

Meanwhile, based on the images obtained using PIV and FLUENT on a Whitcomb winglet, as illustrated in Figure 3(c) and Figure 3(d), it can also be seen that the vortex developed is moving in a circular motion, with the vortex moving from the bottom part of the clean wing to the upper part of the wing.

There are some differences in these images compared to images from Figure 3(a) and 3(b). The vortex developed around the Whitcomb winglet has weaker vortices. The circular streamlines are not fully developed indicating that this type of winglet is successful in decreasing the drag profile. When the streamline is weaker, the drag is lower thus increasing the performance of the airplane.

Figure 3(b) and 3(d) also indicates the streamline of clean wing configuration and Whitcomb winglet configuration at 2.34 m/s. It can be seen that the velocity at the very tip of the winglet is very low, almost zero, compared to the velocity at the tip of a clean wing.

According to Figure 3(b) and 3(d), the red and yellow colour indicates the high velocity region, while the blue and green colour indicates the lower velocity region. Figure 3(b) and 3 (d) shows that at the tip of these winglets, the velocity is in blue region, which indicates very low velocity. Meanwhile, the red and yellow region appears at the bottom part of the winglet tip, moving in a circular motion towards the higher region of the winglet.

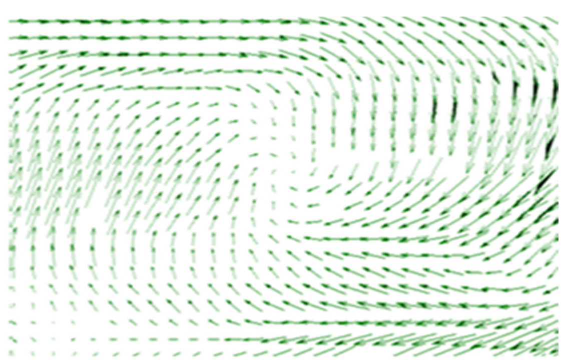

Figure 3(a): Streamline of a clean wing configuration using PIV at 2.34 m/s

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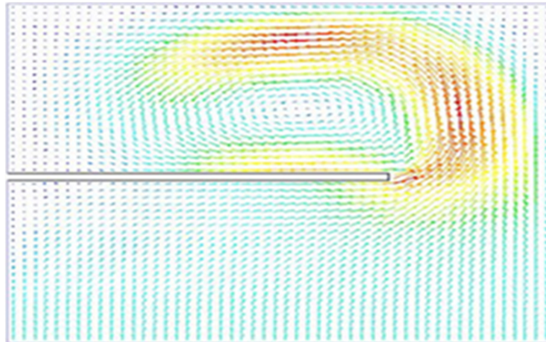

Figure 3(b): Streamline of a clean wing configuration using FLUENT at 2.34 m/s

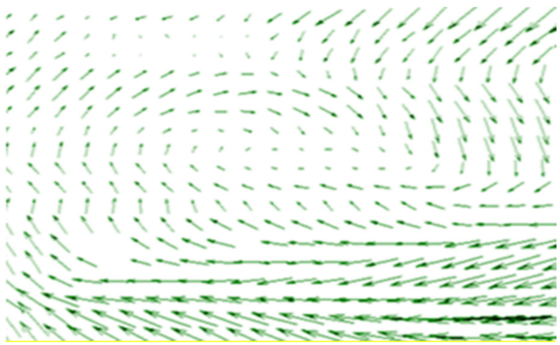

Figure 3 (c): Streamline of a Whitcomb winglet configuration using PIV at 2.34 m/s

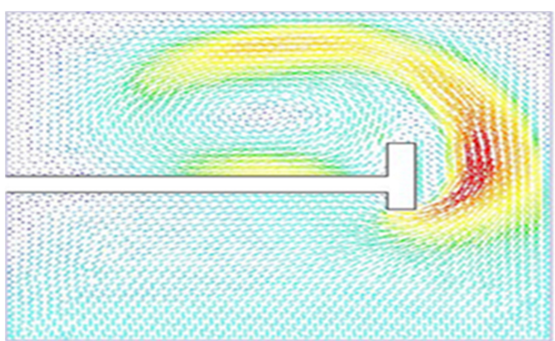

Figure 3 (d): Streamline of a Whitcomb winglet configuration using FLUENT at 2.34 m/s

Figure 4 indicates the graph of velocities at the tip of winglets configuration at 2.34 m/s. Figure 4(a) illustrates the velocity at the tip of the clean wing configuration. As can be seen, the velocity at the tip of the wing is zero. However, the highest velocity is 6 m/s which is almost at the tip of the wing. Figure 4 (b) illustrates the velocity at the tip of blended winglet. The highest velocity recorded was 8 m/s, while Figure 4.8 (d) illustrates the velocity at the tip of Whitcomb winglet.

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This results in good agreement with the study conducted by Babigian and Hayashibara [1]. The Whitcomb winglet illustrates the highest velocity, 8 m/s at position 8. Meanwhile, the highest velocity recorded for the clean wing is 7.25 m/s.

From these results, it can be said that the Whitcomb winglet configuration produces the highest velocity farthest from the tip of wing. It also indicates that the best configuration for wing type is the Whitcomb winglet, since even though it produces the highest velocity; the velocity is farthest from the tip of wing, resulting in less induced drag produced.

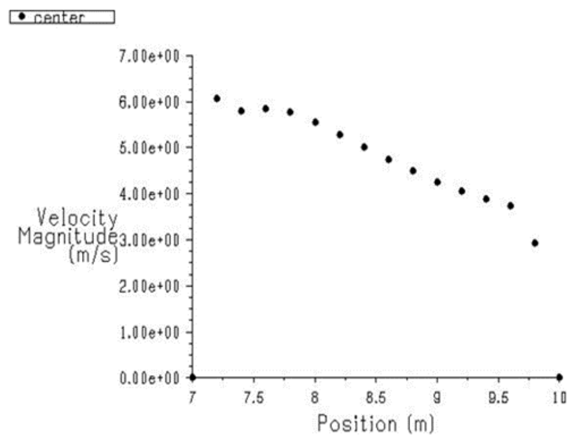

Figure 4 (a): Graph of tip velocity of clean wing at 2.34 m/s

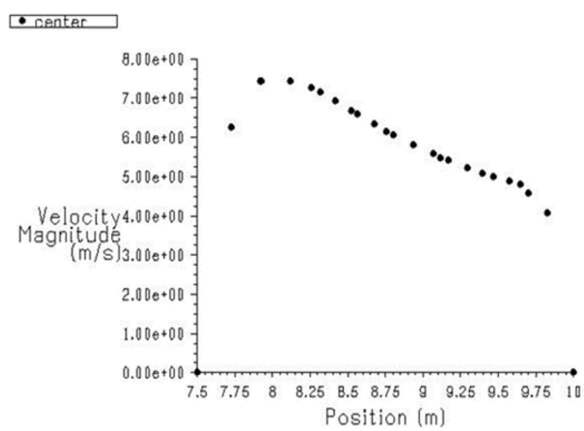

Figure 4 (a): Graph of tip velocity of Whitcomb winglet at 2.34 m/s

5.0 CONCLUSSION

Based on the investigation of the flow behaviour around winglets, it can be said that the flow behaviour of the wingtip devices can be successfully studied using PIV and FLUENT. It was also found that the developed vortices are moving in a circular motion surrounding the wing tip. The vortices moves from the higher pressure region (lower part of wing) to the lower pressure region (higher part of wing) thus creating a circular shape vortices.

It was also found that for one type of winglet, the strength of vortices increases as the velocity increases. This indicates that as the velocity increases, more streamlines moves along the vortex. It can be seen that the vorticity magnitude at the tip of Whitcomb's winglet is the lowest, thus reducing the induced drag.

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