MEASUREMENT OF WINGLET EFFICIENCY OF FLYING WING AIRCRAFT

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A thesis submitted in partial fulfillment of the

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This thesis is especially dedicated to:

My beloved mother and father,
Khadijah binti Abd Rahman & Abdullah Thani bin Mohd Taib
For their endless love, support and encouragement

My beloved wife and family
and
Whoever provides help and contribution throughout this project

May God Bless You

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ABSTRACT

This research was undertaken to measure the efficiency of winglet of flying wing aircraft. Simulation and experiment method are used to collect and identify the data. By studied on the function of the winglet, it can anticipated potential, function and better design for the winglet of the flying wing aircraft. Airfoil NACA 4412 with one meter span length have been chosen for this project. First method is CFD simulation in order to identify the capabilities of the winglet with velocity, 15 m/s and *Re* 1.0×10^6 to 1.5×10^6. This method to identify the pressure distribution on the whole wing for wing with winglet and without winglet. Flow simulation are run twice times for every angle of attack up to 10^0. Once data collected, graph of Coefficient of Pressure are plotted and its show the different on upper and lower surface of the wing are much different for wing with winglet and without winglet. For experimental method, it is to identify the vibration existed on the wing that are executed inside the low speed open loop wind tunnel in UTM (Aero Lab) with the air speed 3 m/s. Accelerometer (ADXL 345), Arduino UNO and wires are equipment used to generate data when vibration occur. 5 times data are collected up to 20^0 angle of attack for wing with winglet and without winglet. Angle are changed from 0^0 to 5^0, 5^0 to 10^0 and so on. Based on experimental data, displacement and straight line graph are plotted. After the comparison for both data, wing with winglet are less induced drag and vibration compared to wing without winglet.

ABSTRAK

Kajian ini dijalankan untuk mengukur kecekapan plat akhir pada sayap pesawat terbang. Kaedah simulasi dan eksperimen digunakan untuk mengumpul dan mengenal pasti data. Dengan mengkaji fungsi plat akhir, ia dapat menjangkakan potensi, fungsi dan reka bentuk yang lebih baik untuk sayap dengan plat akhir pada sayap pesawat terbang. Airfoil NACA 4412 dengan panjang sayap sepanjang satu meter telah dipilih untuk projek ini. Kaedah pertama ialah simulasi CFD untuk mengenal pasti keupayaan sayap dengan kelajuan, 15 m / s dan Re 1.0×10^{6} to 1.5×10^{6}. Kaedah ini untuk mengenal pasti pengedaran tekanan di seluruh sayap untuk sayap dengan plat akhir dan tanpa plat akhir. Simulasi aliran dijalankan dua kali untuk setiap sudut serangan sehingga 10^{0}. Sebaik sahaja data yang dikumpul, graf Pekali Tekanan diplot dan menunjukkan yang berbeza pada permukaan atas dan bawah sayap adalah jauh berbeza untuk sayap dengan plat akhir dan tanpa plat akhir. Untuk kaedah percubaan, ia adalah untuk mengenal pasti getaran wujud di sayap yang dilaksanakan di dalam gelung angin gelung terbuka kelajuan rendah di UTM (Aero Lab) dengan kelajuan angina sebanyak 3 m/s. Accelerometer (ADXL 345), Arduino UNO dan wayar adalah peralatan yang digunakan untuk menjana data apabila getaran berlaku. 5 kali data dikumpulkan sehingga 20^{0} sudut serangan untuk sayap dengan plat akhir dan tanpa plat akhir. Sudut diubah dari 0^{0} ke 5^{0}, 5^{0} hingga 10^{0} dan seterusnya. Berdasarkan data eksperimen, anjakan dan graf garis lurus diplotkan. Selepas perbandingan untuk kedua-ua data, sayap dengan plat akhir kurang menyebabkan drag dan getaran berbanding sayap tanpa plat akhir.

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LIST OF SYMBOLS

ρ	=	Density
V	=	Velocity
Cp	=	Coefficient of Pressure
Re	=	Reynolds Number
µ	=	Dynamic viscosity
^{o}	=	Degree of Angle
%	=	Percentage

LIST OF ABBREVIATIONS

IATA	=	International Air Transport Association
CFD	=	Computational Fluid Dynamics
C_D	=	Drag Coefficient
C_L	=	Lift Coefficient
NACA	=	National Advisory Committee for Aeronautics of the U.S.
Kg	=	Kilogram
mm	=	Millimeters
m	=	Meters
AOA	=	Angle of Attack
S	=	Second
N	=	Newton
UGP	=	Undergraduate Project
UTM	=	University Technology Malaysia
CO_2	=	Carbon dioxide
m/s	=	meter per second
UAV	=	Unmanned Aerial Vehicle
RPM	=	Revolution per Minute
L	=	length of tip chord in meter

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Increasing globalization has totally brought the world closer together to us. Based on statistic from IATA, there were 37.4 million flights scheduled in 2014 [1]. That shown the numbers of airplane around the world. When the technology become advanced in aviation manufacturing, new design will applied in order to compete with the competitor.

They are trying to give the best performance, comfort ability to their passengers in terms of safety and convenience. Flight software have been used to control the aircraft for the electronic system in the latest ways to lift the plane, however there are still need mechanical devices to support the lifting. There are simple physics that contributed from mechanical device as call as wings. Not so much changes have been innovated in the airplane wing itself, probably winglets are the simplest innovation with the greatest benefit to the plane.

Wing is the main part that's function to lift the plane or aircraft. Meanwhile the winglets is the supporting bent tips to increase the lifting efficiency and performance of the plane (Md Saifuddin Ahmed Atique et al, 2015). Manufacturers make various claims about the performance gain achieved due to their winglets [2]. The performance can be analyses based on incidence angle of the winglets. Winglets usually can be found on large plane with the long wings. Long wings make the airplane of the aircraft become heavier, more difficult to move.

Winglets is a device used to improve efficiency of aircraft by lowering the lift induced drag caused by wingtip vortices (Yates J. E. and Donaldson, 1986). It also can improve the aircraft handling. It is some bend tip extension at the tips of wings on vertical or angled direction. The tip is functioning to block air pressure from bottom to top. The wingtip devices increase the lift generated at the wingtip and reduced the induced drag caused by wingtip vortices. Winglets improve efficiency by diffusing the shed wingtip vortex, which in turn reduces the drag due to lift and improves the wing's lift over drag ratio (M.A. Azlin et al, 2011).

Figure 1.1 Winglet on a United Airlines Plane (www.latimes.com)

To complete the research, I will conduct an experimental testing with open wind tunnel (induction flow) at Aero Lab in UTM when Undergraduate Project 2 started. The experimental will be execute with one side of wing with winglets that design from Styrofoam and carrying payloads navigation as well as the existing electronic parts such as accelerometer and wires The purposes of this research and experimental are to measure technique to quantify forces and wing vibration, measure the performance of wing by using wind tunnel testing and analyze the forces produce at different aircraft's pitch angle up to 40 ^{o}.

1.2 Problem Statement

There are many factors that influence airplane accident, one of that are causes by availability of winglets. Performance decreasing, vibration and induce drag increasing are some of the effect on plane that stemmed from the winglets function.

Vibration is the main problem that will affect the plane lifting, it because unstable pressure that are circulated from bottom to top. Vortex will occur at the wingtip of the plane with the long wings. When high pressure on the lower going up to upper surface of airplane wings, energy will be loss and plane can be flip by the vortex. Although the plane can lift up, vibration will exist at the both side wings. Due to vibration, it will cause poor handling and cause the plane brake out. To change the airflow, reduce the wingtip vortex, suitable design of winglets are required for each plane based on their overall performance and application.

Without the proper design of winglets, some of the performance and efficiency for the plane will be decrease. It will affect the lift coefficient, load, cost and pressure drag on the wings and plane. When it starting to lift, more power are required and at the same time unstable pressure for the both wings also will exist. The more fuel combustion used, the more Carbon dioxide (CO_2) are released. It effected the fuel cost and environmental.

When the plane are lift and fly with the high speed, induced drag will heat at the both wings of plane due to force distribution across the wings. If the wing are too long without the winglets, it can cause poor handling also. To reduce the induce drag, winglets are important part as per function.

1.3 Purpose of the Study

The main purpose of this research is to identify what is the efficiency and best design of the winglets for the flying aircraft. In order to complete the research study, some of the winglets shapes and sizes will be doing analysis with SolidWorks. Once the best design are selected, fabrication, experimental and data collection will be done to get the results.

1.4 Objective of the Study

The objectives of this study are on flying aircraft that already exist with winglets in order:

i. To quantify the forces and vibration on the wing.
ii. To measure the performance of wing with winglet by using UTM open wind tunnel testing.
iii. To analyze the forces produce at different aircraft's pitch angle up to 40 degree.

1.5 Scope of the Study

The scope of study have been set in order to achieve the objective. It have been determined as follows:

i. Literature review will be studies on the shapes, sizes and configuration of the winglets that have been used on flying aircraft.
ii. The experiment will be executed at wind speed ranging from 0 to 20 meter/second. (Until the vibration occur).
iii. The aircraft wings will be design from Styrofoam and carrying payloads navigation as well as the existing electronic parts such as accelerometer and wires.

1.6 Significant of the Study

The result of this study is important to know what is the best design of winglet that can give improvement in terms of efficiency and performance of the flying aircraft. This study also can determined how much the forces and vibration occur on the wing with different angles. Furthermore, this study can be used for future design of winglet on the flying aircraft.

CHAPTER 2

LITERATURE REVIEW

2.1 History of Wingtip Devices and Winglets

First wingtip device was designed and patented by Fredrick W. Lanchester, British Aerodynamicist in 1897. But, his theory could not reduce the overall drag of aircraft even reducing the induced drag. The increase in the viscous drag during cruise conditions outruns the reduction in induced drag (R. T. Whitcomb, 1976). Winglet could be described as the small wing like bend tip extension at the tips of wings on vertical or angled direction. In the research on winglets, 20% reduction in induced drag when compared to tip extension and also improved lift-to-drag ratio (R. T. Whitcomb, 1976).

2.2 Types of Winglets and Wingtip Devices

After the invention of winglet by Whitcomb, many types of winglets and tip devices were developed by aircraft designers. Some of the inventions of winglets by the respective aircraft manufacturer are discussed in the figure bellow. For each design they have their own advantages and disadvantages.

In figure 2.1 (a) wingtip are patent by Wolfgang Liebe in 1938 as Wing Fence (boundary layer fences) where the design with flat plate which is attached perpendicular to the wing and in line with the free stream air flow. It have been used at Airbus aircraft A300 and A310. That design can prevent the entire wing from stalling at once and increase aerodynamic efficiency. At the same time it can reduce the air flow that directly come over to wing surface and reduces the amount of potential energy lost because of the pressure difference between the upper and lower surface. Disadvantages, just can used on low speed swept wing aircraft because it increasing the contribution of skin friction to total drag, weight and handling characteristic.

Hoerner (Lippisch ears) figure 2.1 (b) patent by Alexander Lippisch in 1994 with crescent shaped geometry with slightly upward and wing tip with the continuing the surface on the upper wing. It can increasing the wing effective span, better diffusion of tip vortex compared with round tips conventional.

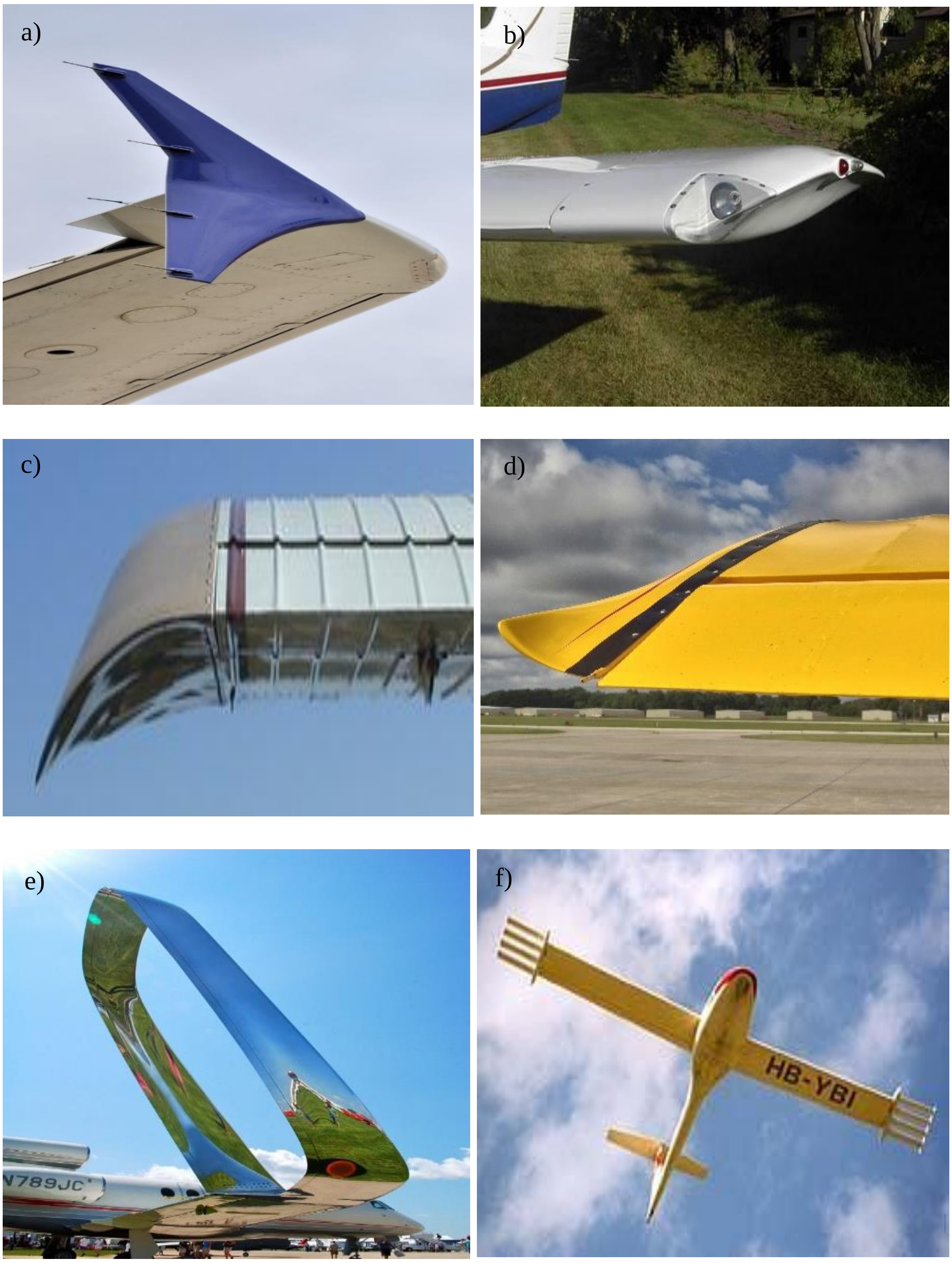
Martine Daude in 1982 had patent design a plate with curve pointing downward and upward names as dropped and upswept in figure 2.1 (c) and (d). Advantages of this design it can increase the wing effective span, giving better diffusion of the tip vortex and performance better than round tip conventional.

Figure 2.1 (e) Sprioid (non-planar) tip are designed with angled upwards in polyhedral wing configuration that attach on horizontal of the wing or tail plane. It patent by Gratzer in 1992. The design give benefits on wake control with less parasitic drag penalty, eliminates concentrate wingtips vortices and reduced the induced drag. By reduced induced drag fuel consumption are saved around 6-10%. Extensive optimization is necessary because the tip often to swept back and this tip need to design properly before attach to wing or tail plane.

Wing grid in figure 2.1 (f) was an endplate that have two distinct operating regimes which is when it below critical angle of attack (above a specific design speed) span efficiency is between 2.0 and 3.0 with full effect and above critical angle of attack (below a specific design speed) the effect of reduced induced drag fades out, it act as a slit wing with very high stall resistance. Design patent by Dr Ulrich La Roche in 1933. The segmented circulation is transferred to the end of the wing grid, increasing the far field vortex spacing. The lift distribution can be reduce due to reduction on induced drag up to 50% based on the span efficiencies, velocity and design.

Raked tip or a tip with higher wing sweep in figure 2.1 (g) are patent in 2000 by Herrick. This design have been used at Boeing 777-200ER/300ER/Freighter. Advantages of this design it can reduce drag by 5.5% compared to 3.5%-4.5% for conventional winglets, reduce wingtip vortices and decrease lift on induced drag. Due to that it can increase effective on wing aspect ratio at the same time improve fuel efficiency, take off and climb performance. But the advantages of the sweep wing, bending moment can become greater because span are increased at root chord.

On 1994, blended winglet in figure 2.1 (h) are developed by Gratzer from Seattle. It a bend tip with smooth curve and no sharp edge at the winglet. It also allows optimum aerodynamic loading and avoids vortex concentrations. This wingtip have been retrofitted in Boeing B737. It can reduce the adverse flow at winglet junction, at the same time fuel consumption are decrease about 4%-6% and aspect ratio can be up to 60%.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b)
c)
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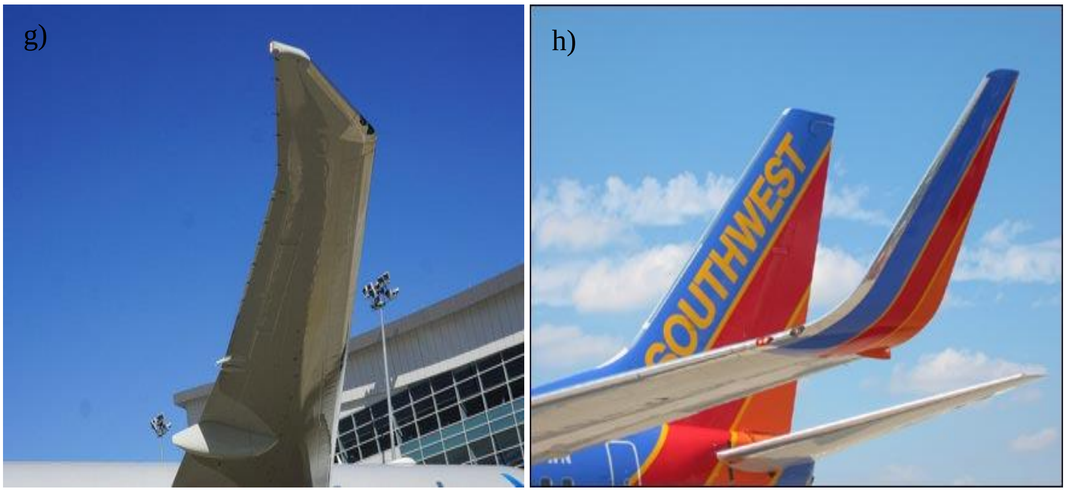


Figure 2.1 Type of Wingtips.

2.3 Induced Drag Phenomena

In Aerodynamics, they have four main forces which act on aircraft when flutter which is Lift, Drag, Thrust and Weight. Drag is one of the most critical phenomena amongst all and is the opposing force of aircraft's forward motion. It could be classified briefly in to parasite drag (not due to lift) and lift induced drag (L. R. Jenkinson et al., 1999). In a civil transport aircraft, frictional drag and induced drag together contributes more than 80% of the total drag, but the other forms of drag could not be excluded certainly as represented in figure 2.3 (P. Thiede, 2001).

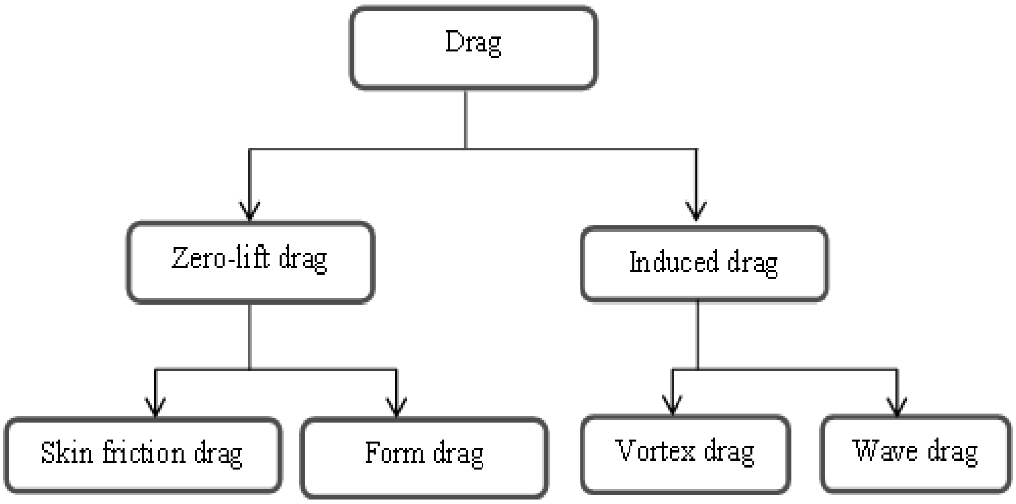


Figure 2.2 Different Form of Drag

2.4 Parameters Considered in Design of Winglet

Winglets produce an especially good performance boost for jets by reducing drag, and that reduction could translate into marginally higher cruise speed. It are small wing, likes structures at the wingtip used to enhance the aerodynamic efficiency of aircraft by decreasing the induced drag (Hossain et al., 2011). Some of the parameter need to be consider for each design of the winglets likes Cant Angle, Sweep Angle, Taper Ratio, Toe Angle, Twist Angle, Airfoil Section, Height, Span and Blend Radius (for blended winglet only). All the parameters shown in figure below:

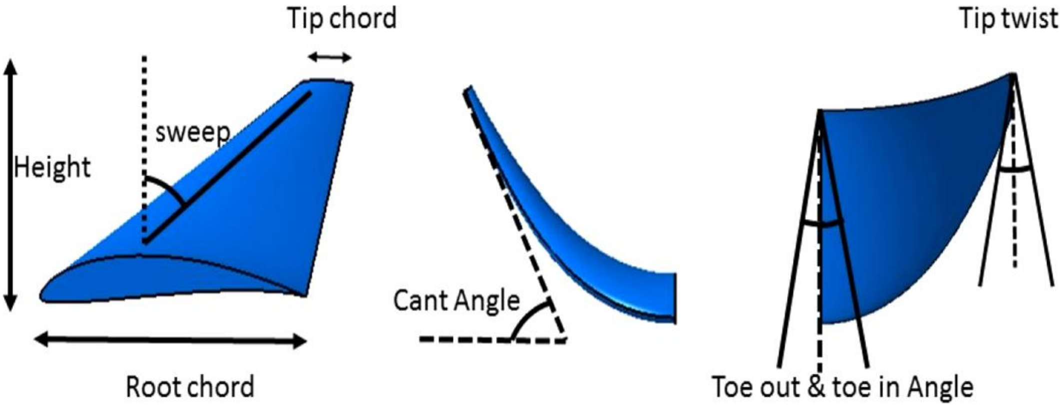


Figure 2.3 Parameter Constitute on Winglets Design

2.4.1 Cant Angle

Cant angle is a determinative and the most important winglet parameter to assess the aerodynamic efficiency of the wing and the winglet. As (Takenaka et al. 2008) stressed in their work, cant angle and span length have dominant effect for drag reduction. In this study, cant angle is the decisive parameter that will determines the shape of the winglet.

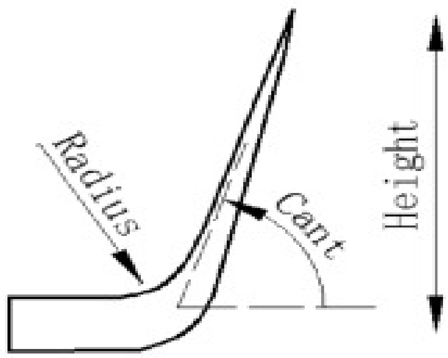


Figure 2.4 Direction of Cant Angle

2.4.2 Twist and Toe Angle

Twist angle is utilised to provide a uniform load distribution on the winglet. Toe angle is used to achieve an effective lift force in different flight conditions (Weierman and Jacob, 2010). This angles are tried separately for the winglet that has the best Lift and Drag force ratio.

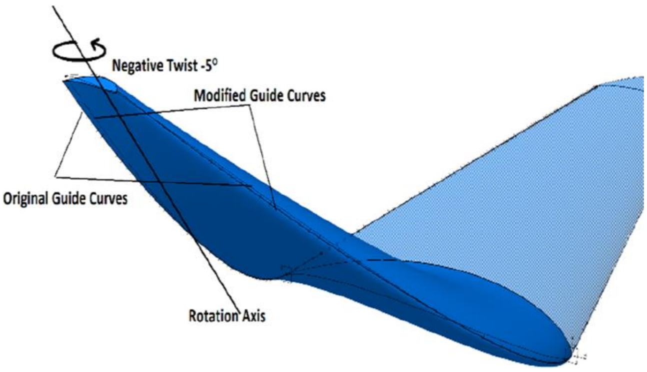
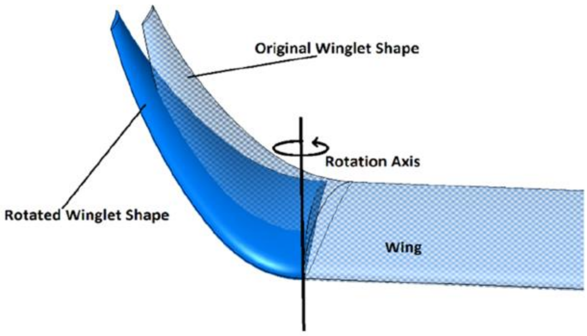


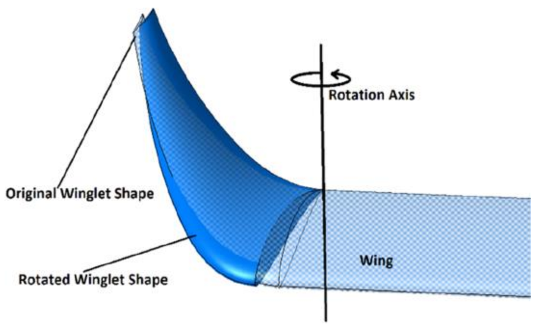
Figure 2.5 Winglet with twist angle -5

The winglet was rotated to the vertical lines passing through the wingtip leading edge and the trailing edge points to generate toe-in and toe-out angles as shown in Figure 2.6 and 2.7:



(a)

Figure 2.6 Toe in or Positive Toe Angle



(b)

Figure 2.7 Toe out or Negative Toe Angle

2.4.3 Taper Ratio and Sweep Angle

Aircraft static directional stability increases with the winglet sweep angle (Conley, 1980). Because the winglet's leading edge sweep angle changes the winglet taper ratios, aft sweep angle was used as a design parameter. The wing sweep affects the slope of the lift curve, maximum lift coefficient, induced drag coefficient, drag divergence, wing weight and the tip stalling.

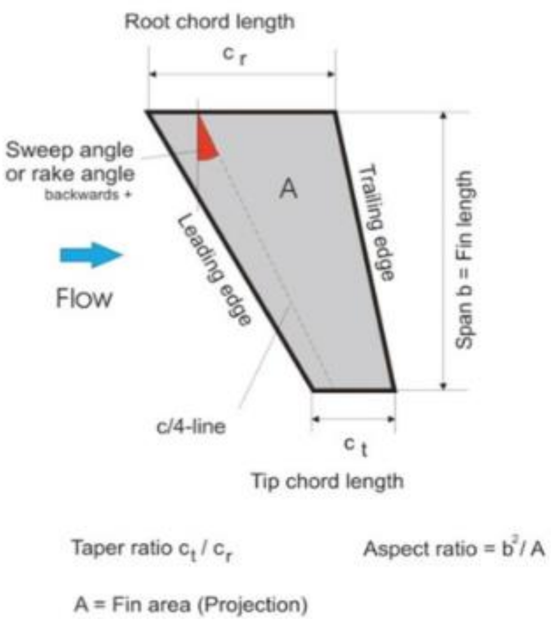


Figure 2.8 Sweep Angle and Taper Ratio

2.5 Winglet Height, Span and Airfoil

They are compulsory to consider an aero structural optimization approach if there is a span constraint, and wing with winglet to get the optimal (Jansen et al. (2010). Unlike the other design parameters, winglet span was be kept constant for all conditions even other parameters change.

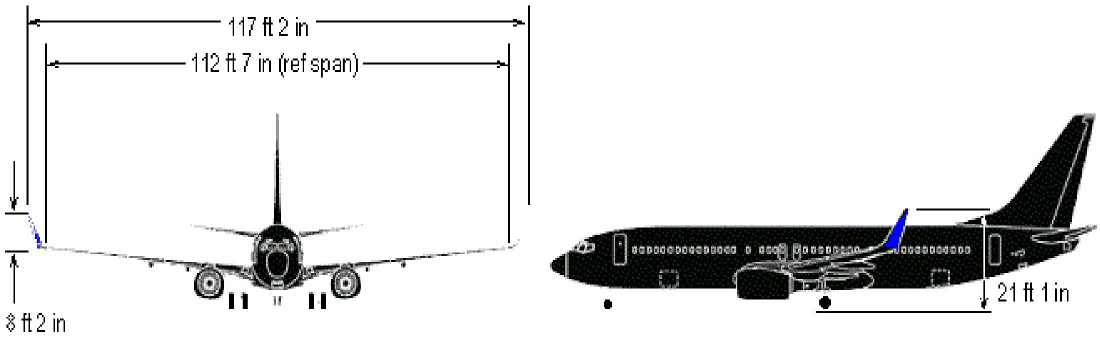


Figure 2.9 Winglet Height, Length of Span and Airfoil Design

2.6 Aerodynamics Performance

Airfoil characteristic in terms of performance can be assessed as the data obtained from *Cp*, *CL* and *CD*. While *Re* represents the operating condition in which the airfoil experience depending on the fluid velocity and geometry size of the airfoil. In this report, *Cp* and *Re* are only used to calculate. The equation for Coefficient of pressure is given by equation (1), where:

$$Cp = \frac{P - P_{\infty}}{0.5 \rho_{\infty} V_{\infty}^{2}} \quad (1)$$

Cp = Coefficient of Pressure.

P = Static Pressure (Pa).

$P\infty$ = Static Pressure in freestream ($kg.m^{-3}$).

$\rho\infty$ = Freestream air density ($kg.m^{-3}$).

V = Velocity of air ($m.s^{-1}$)

Equation (2) is the Reynolds number equation which is the ratio the scale of inertial forces to viscous forces. Where the number to determine for better velocity to use on the SolidWork simulation, where:

$$\mathrm{Re} = \frac{\rho v L}{\mu} \tag{2}$$

Re = Reynolds number

ρ = Density of air (kg.m^{-3})

V = Velocity of air (m.s^{-1})

L = Chord length (m)

μ = Dynamic viscosity (N.s.m^{-2})

CHAPTER 3

METHODOLOGY

3.1 Introduction

Research methodology characterized how the study will be done to achieve all the objective of the study. An efficient arrangement and thorough comprehension of the methodology of the research is essential to accomplish the study accordingly. Method and approach of the study will be described in this chapter. Data collected from simulation and experimental will be used for further analysis.

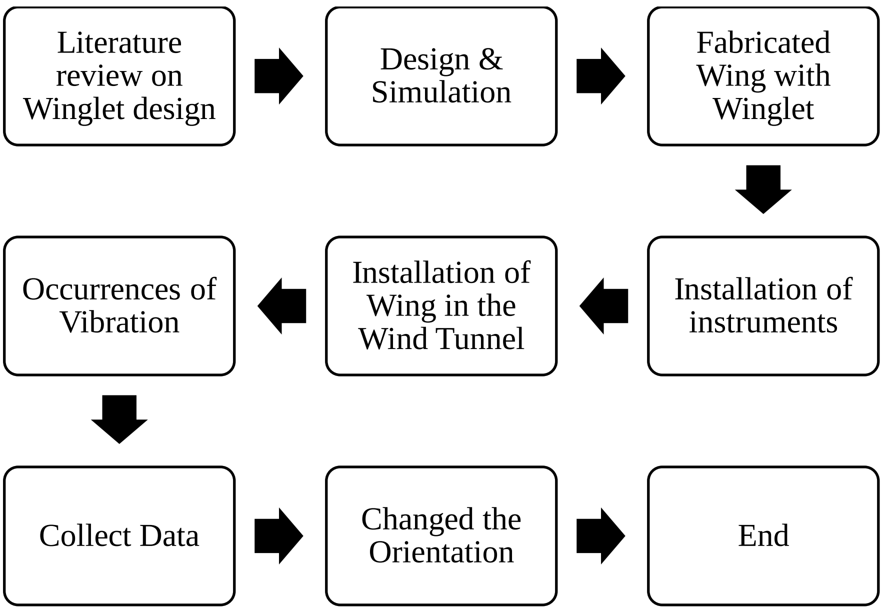


Figure 3.1 Methodology of Data Collection

3.2 In-site Data Acquisition

Aircraft performance is highly affected by induced drag that caused by wingtip vortices. Aircraft designer and manufacturer giants, Boeing and Airbus are working on the development of adjustable winglets during aircraft flight (P. Marks, 2009). A bend tip with vertical or angled extension at end of wing, (winglet) used to minimize the vortices that have been created in order to improve fuel efficiency, handling and lift coefficient.

Experimental with wind tunnel and CFD simulation is the famous methods to measure the efficiency of the winglet and predict the flow behavior around the wingtips. Result as *CL*, *CD* and *Cp* can be analyses with both experiment. CFD simulation will be investigate the effect of the mesh size on the solution results. On this paper, computational and experimental will be done to analysis the pressure and vibration.

Generally, a numerical solution becomes more accurate as more cells are used, but using additional cells also increases the required computer memory and computational time. . In this time, simulation by SolidWorks will be done to ensure the design are capable

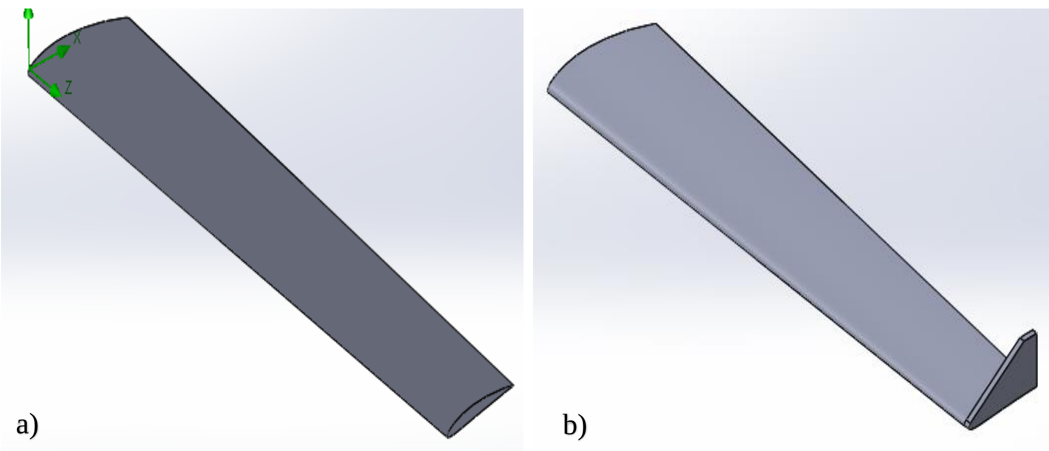


Figure 3.2 a) Plain Wing b) Wing with Winglet

Figure 3.2 shown a design that have been done by SolidWorks 2017. Both designs are been used to analysis the flow over the wing. Design are proportionated based on UAV – RQ7 Shadow (200).

3.2.1 Design Setup

The simulation on CFD analysis will be done in order to know the maximum pressure distribution and actual velocity that can be done through experiment. NACA 4412 airfoil will be used for the structure of wing. The wing design is shown in Fig 3.2. The aircraft wing model has a span of 1.00 m with root 0.23 m and tip 0.145 m. Figure 3.3 was design of wingtip from all views. The design selected based on the parameter that are matching with UAV – RQ7 Shadow.

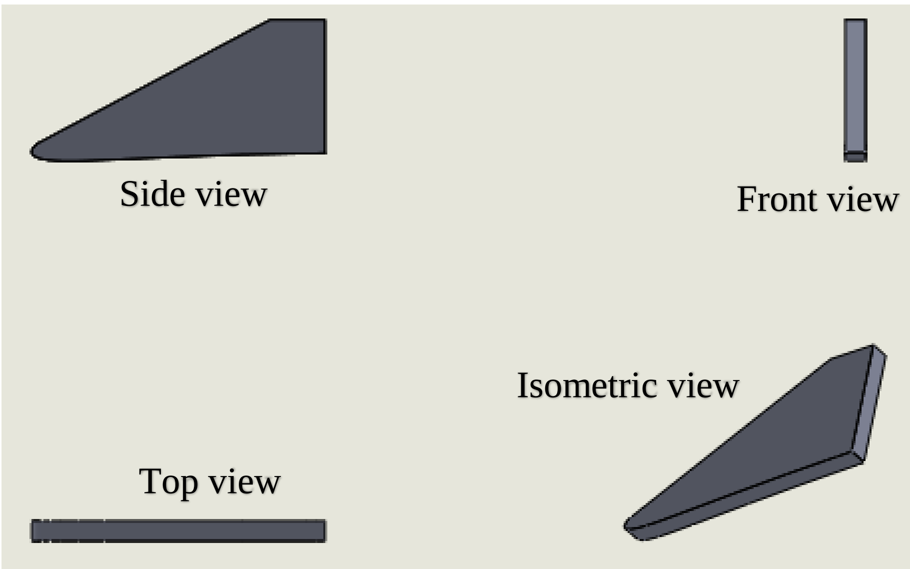


Figure 3.3 Design of Winglet

3.2.2 Wind Tunnel Testing

A wind tunnel is a tool used in aerodynamic research to study the effects of air moving past solid objects. A wind tunnel consists of a tubular passage with the object under test mounted in the middle. Air is made to move past the object by a powerful fan system or other means. The test object often called a wind tunnel model, is instrumented with suitable sensors to measure aerodynamic forces, pressure distribution, or other aerodynamic-related characteristics.

The specimen airfoil was install in test section of wind tunnel. It was vertically mounted on a clamping device at the below of test section. The angle of attack of the airfoil was set at initially zero degree as datum of reference of chord line with the wind flow. The accelerometer inside the wing span than connected to Arduino UNO was used to collect the data once the wing have vibration or movement. The software (RealTerm) was use to capture the data. Then data capturing was then carried out. Process was repeated for variation of angle of attack for the wing with constant velocity. While for variation of the angle of attack was set at 0 degree and increasing up to 20 degree.

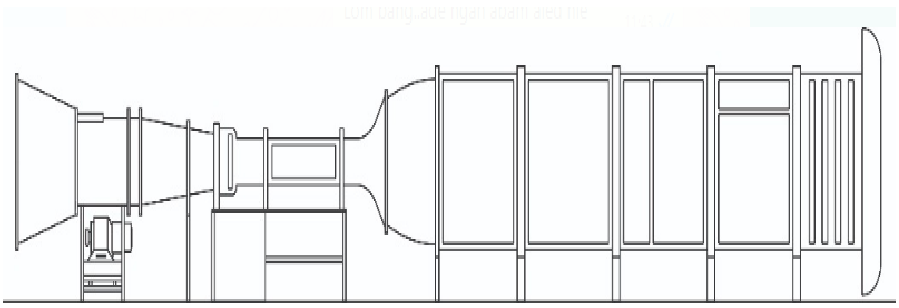


Figure 3.4 Example of Open Wind Tunnel

The advantage of a supersonic flow wind tunnel is the longer run times relative to a blowdown tunnel. The major disadvantage is the increased size and operating costs. Because of that, open wind tunnel have been choose for this experiment.

3.2.3 Device and Tool for Experimental Setup

There have several setup for the testing by wind tunnel in order to collect the data. The flow speed around the winglets at different angle of attack was visualized in the wind tunnel using a VelociCalc anemometer have been shown in Figures 3.5. For 3.6 was visualisation of the wing at angle of attack at 10° and 20°.

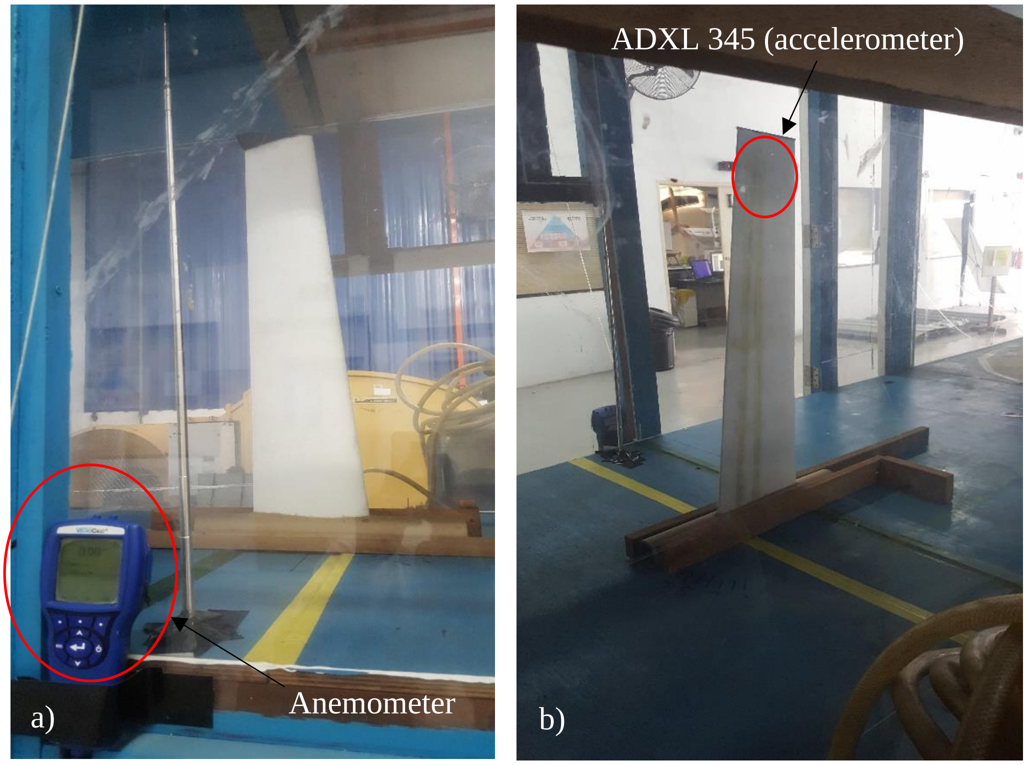


Figure 3.5 Setup for wing inside the wind tunnel. a) front view, b) rear **view**

Figure 3.6 Changed of angle of attack for a) 10° b) 20°

CHAPTER 4

RESULT AND DISCUSSION

This chapter generally presents the results from simulation and experiment were have been carried on the wing with winglet and without winglet. Data collection throughout the study will be discussed and focused on the configuration of span wing with winglet were the wing are completely the orientation up to 10^{o}. Any pattern or trend observe after data collection process will be presented. Lastly in this chapter, the discussion of the result can be achieved the scope of this study either reliable or not.

4.1 Surface Pressure Distribution

Pressure coefficient for each angle of attack (at 0^{o}, 5^{o}, and 10^{0}) is determined from the measured surface pressure and the pressure coefficient are approximated through linear interpolation/extrapolation from the measured boundary values. In Figure 4, distribution of surface pressure coefficient along the wing span at 0˚, 5^{o}and 10˚ is shown for wing with winglet and without winglet. From the figures it is observed that the difference between the upper and lower surface pressure coefficients at 10˚ AOA is higher than those at 0˚ AOA. From there also, it is observed that the difference between upper and lower surface pressure coefficient near the root of the wing with winglet is lower from wing without winglet. But near the tip of the wing, the difference is almost equal. However, at the middle of the wing, the difference is closed for the both at each AOA.

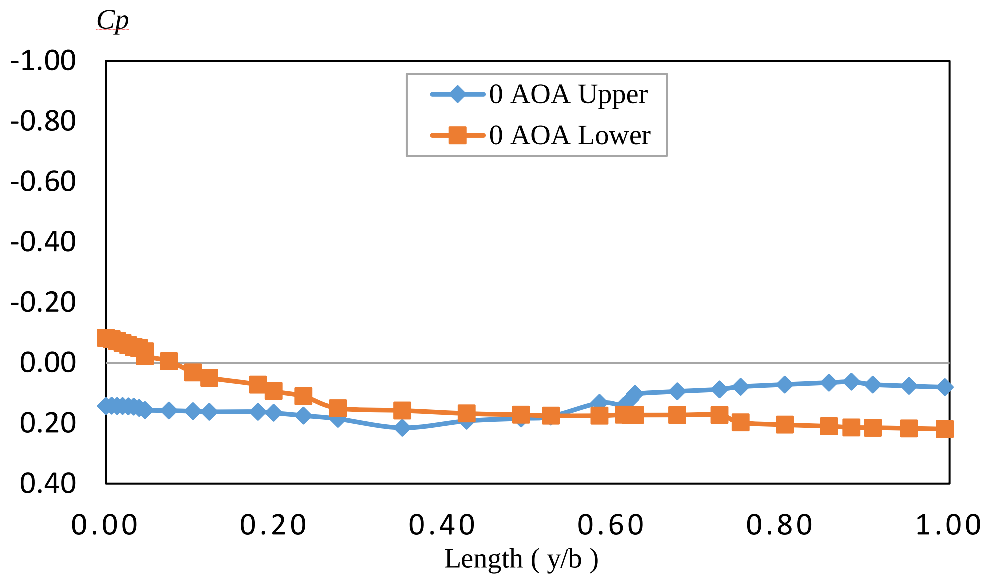


Figure 4.1 Coefficient of Pressure for Wing without Winglet at 0^0 AOA

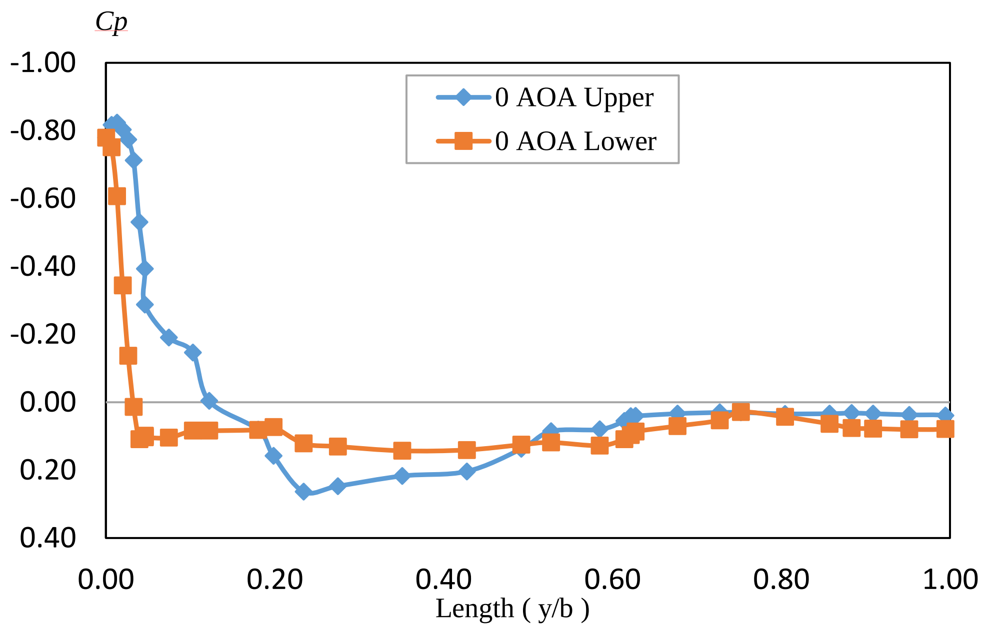


Figure 4.2 Coefficient of Pressure for Wing with Winglet at 0^0 AOA

Figure 4.1 shown the different between upper and lower surface are not much different compare than Figure 4.2 where the different are more when at root area the *Cp* are in negative value. Because the pressure distribution along the wing are more on the root area. In order to reduce the pressure distribution, area at the root area need to be reduce.

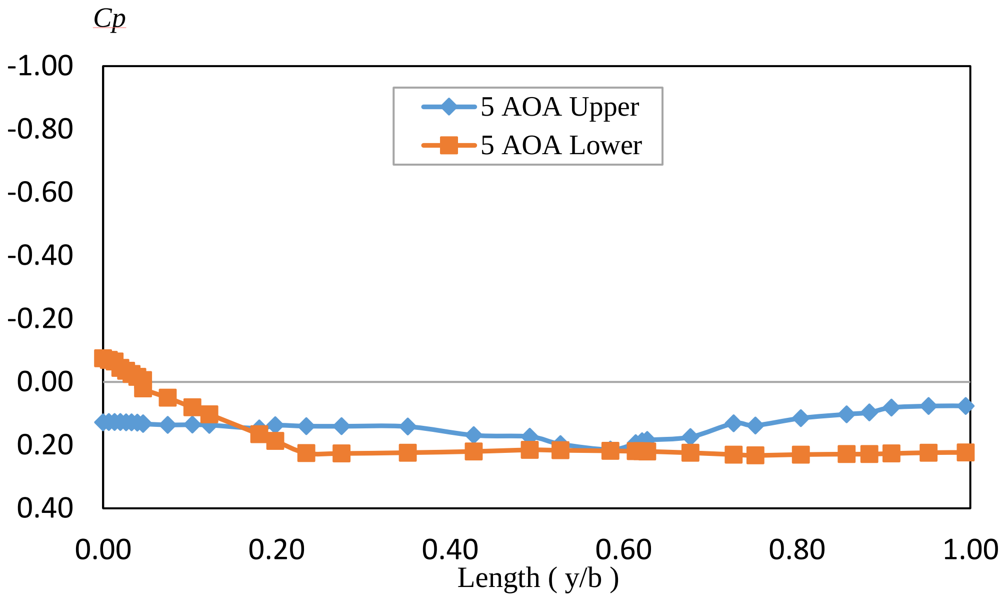


Figure 4.3 Coefficient of Pressure for Wing without Winglet at 5^0 AOA

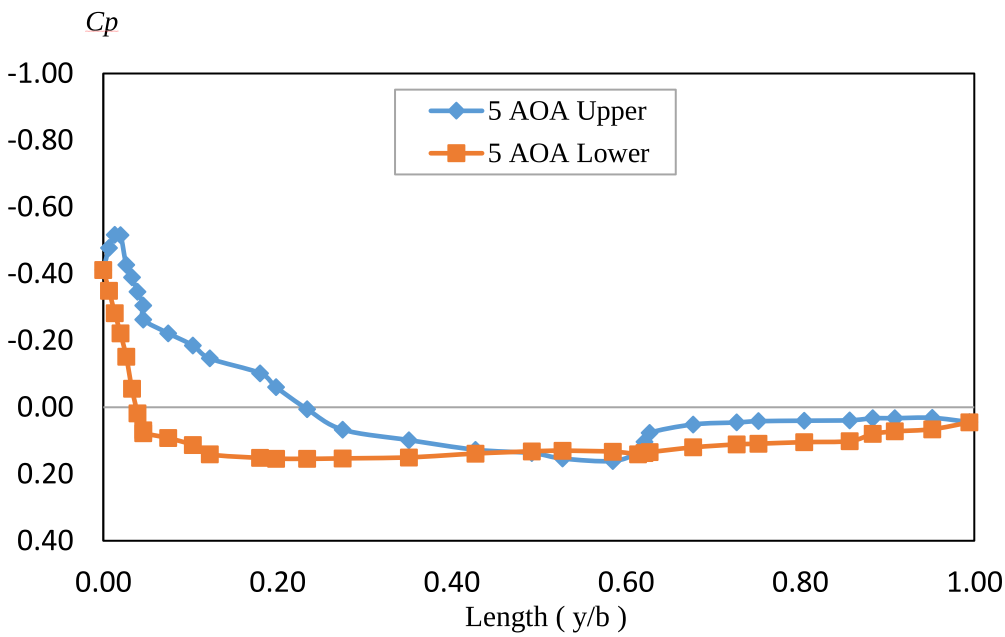


Figure 4.4 Coefficient of Pressure for Wing without Winglet at 5^0 AOA

Based on the Figure 4.3 and Figure 4.4 the different not so much compare between upper and lower surface. At the middle of the wing length, both the graph shown the *Cp* are at the same pressure. It probably due to vortex circulation at tip chord area make the pressure are closed when changed AOA.

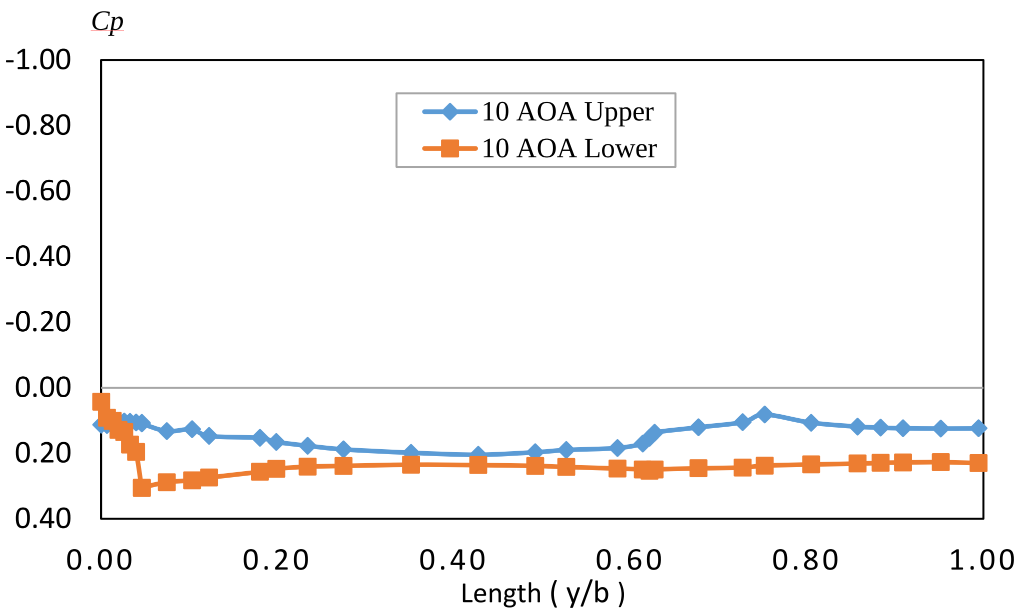


Figure 4.5 Coefficient of Pressure for Wing without Winglet at 10^0 AOA

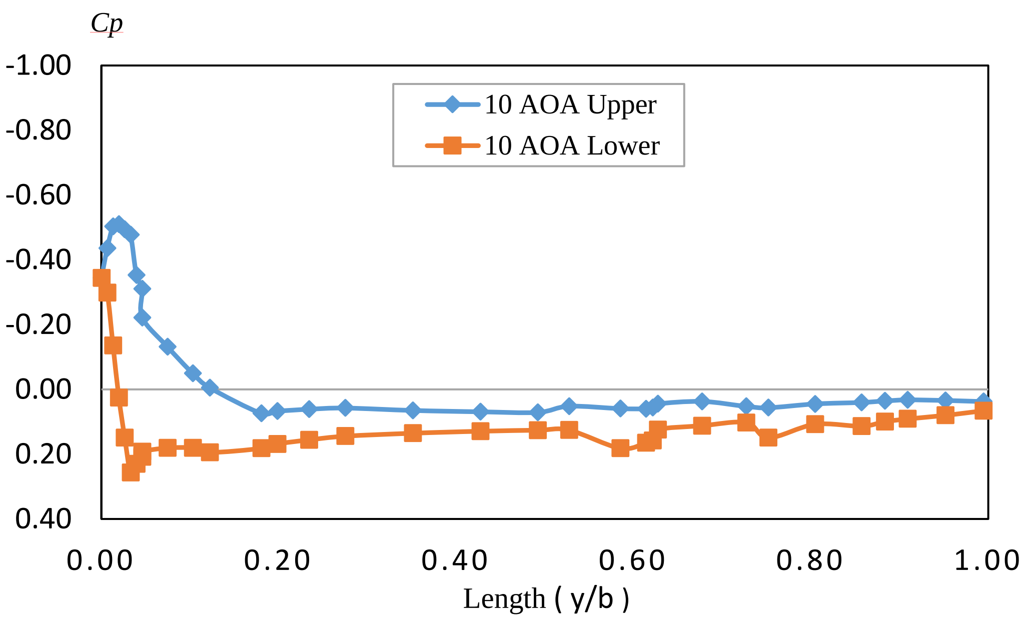


Figure 4.6 Coefficient of Pressure for Wing without Winglet at 10^0 AOA

Figure 4.5 and Figure 4.6 shown the different are increased for upper and lower surface. The *Cp* for wing with winglet have more different at the root and become closed at tip area. Along the span length also there don't have the clash *Cp*. The different increased because when changed the AOA, the pressure will be more stable for both surface for wing with winglet.

4.2 Frequency of the Vibration

In this subtopic, discussion more on the vibration results of displacement on the wing are explained with the graph results. Open loop Subsonic Low Speed Wind Tunnel at UTM (Aero Lab) have been for this experimental testing in order to collect the data. Tunnel's fan was set to a constant velocity, 3 m/s with RPM around 1100 to 1200. Data with 1 minute vibration are collected. To validate the data, every AOA will be run twice and make the comparison for the both data. In Figure 5, comparison between displacements against time graph are shown with 2 direction axis for wing with winglet and with winglet. AOA are changed for 0˚, 5°and 10˚. From the figures it is observed that the difference between wing with winglet and without winglet are more when changed the AOA. However, by increased the AOA the vibration will be more to the wing.

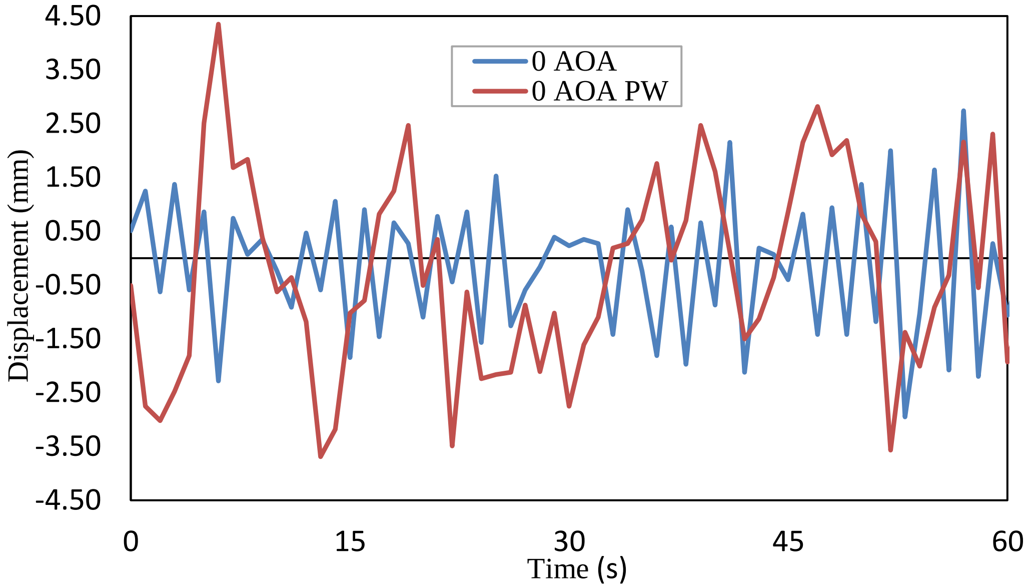


Figure 5.1 Displacement vs Time on X-Direction

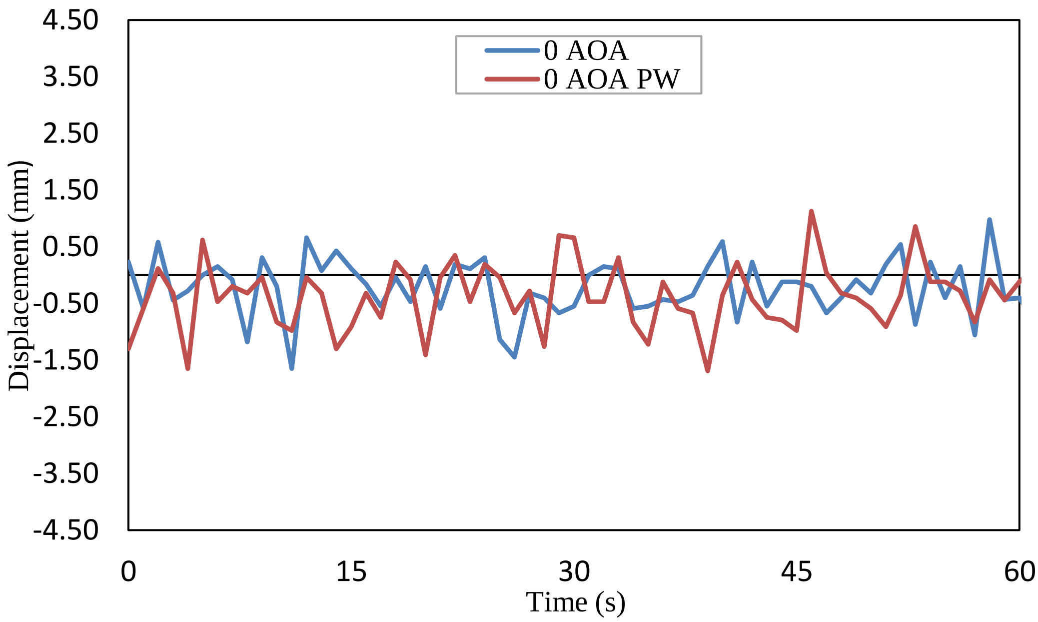


Figure 5.2 Displacement vs Time on Y-Direction

Figure 5.1 and Figure 5.2 shown the movement of the wing for wing with winglet and without winglet. The different between that are more for the x axis due to the axis are parallel to the wind speed. It can be conclude without changed AOA, the vibration already occur to the wing. The more times taken the different will be more.

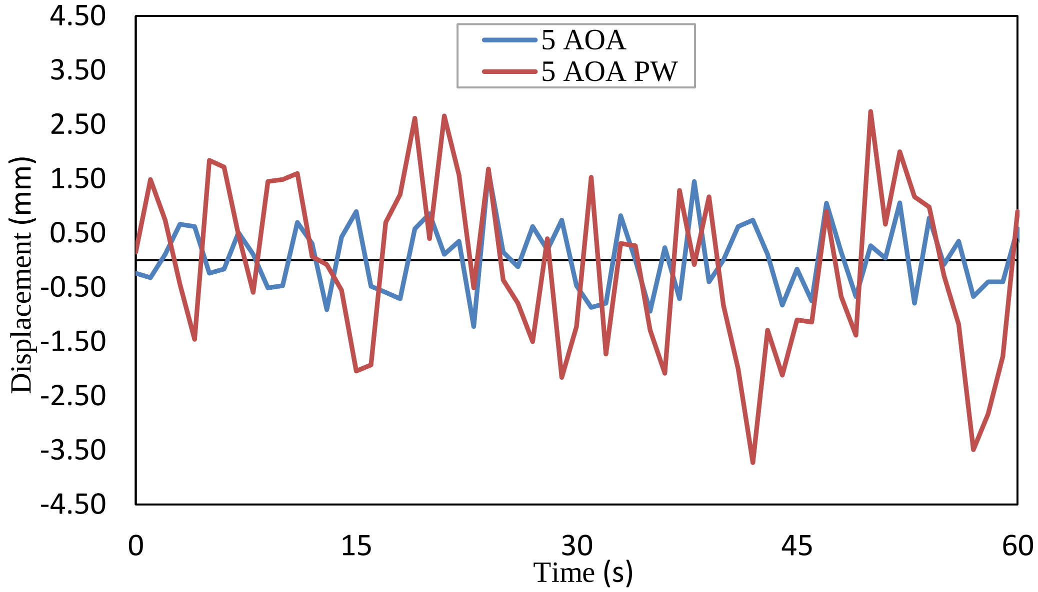


Figure 5.3 Displacement vs Time on X-Direction

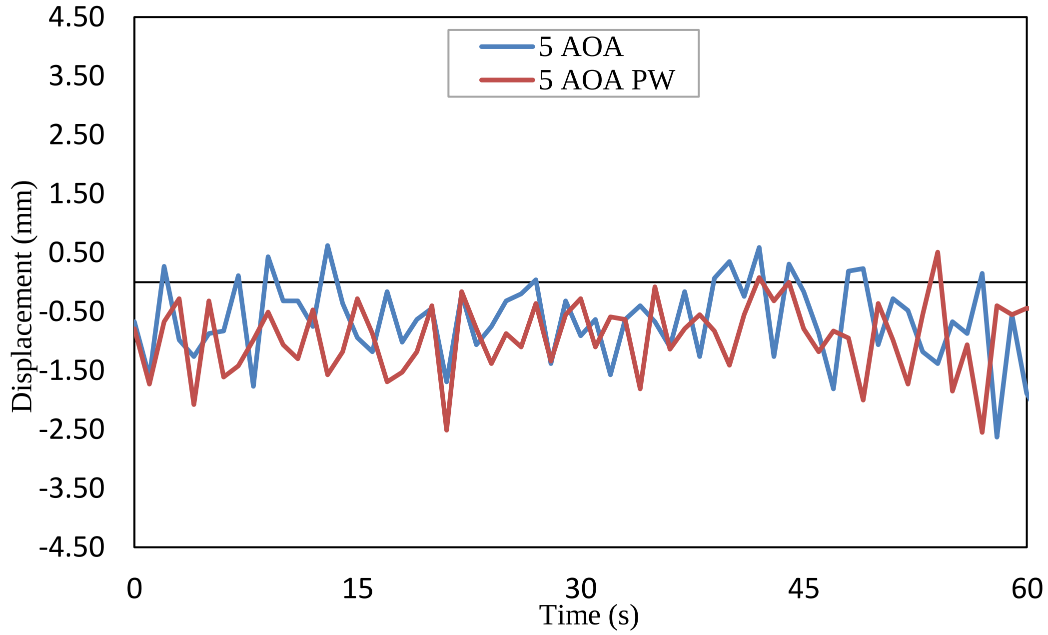


Figure 5.4 Displacement vs Time on Y-Direction

Based on Figure 5.3 shown the vibration are increased when AOA are changed from 0^0 to 5^0. That also happen at Figure 5.4 even it at the different direction. The different between that are still more.

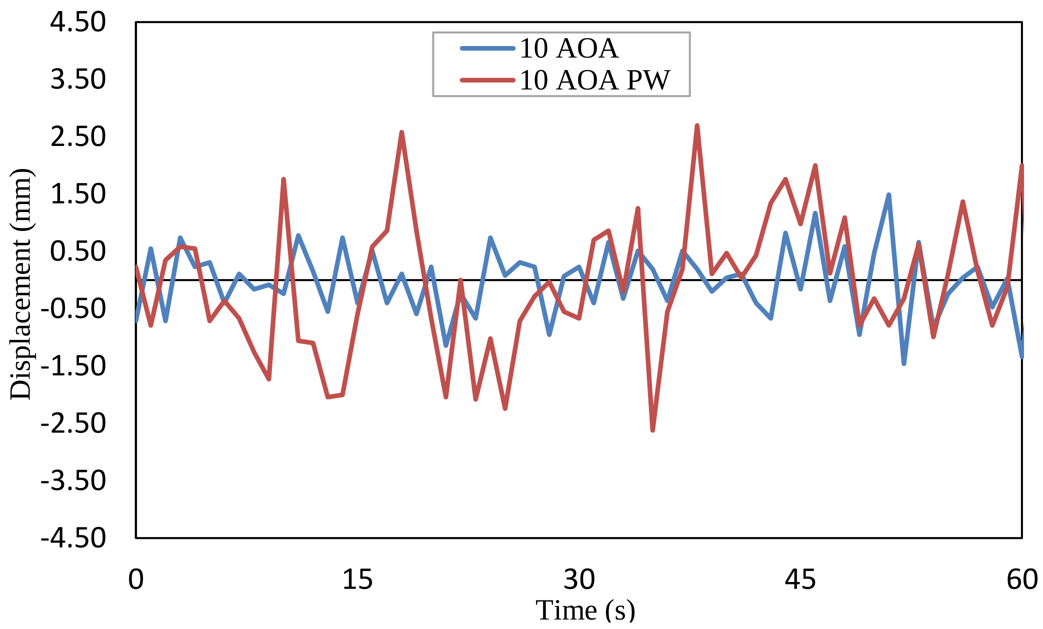


Figure 5.5 Displacement vs Time on X-Direction

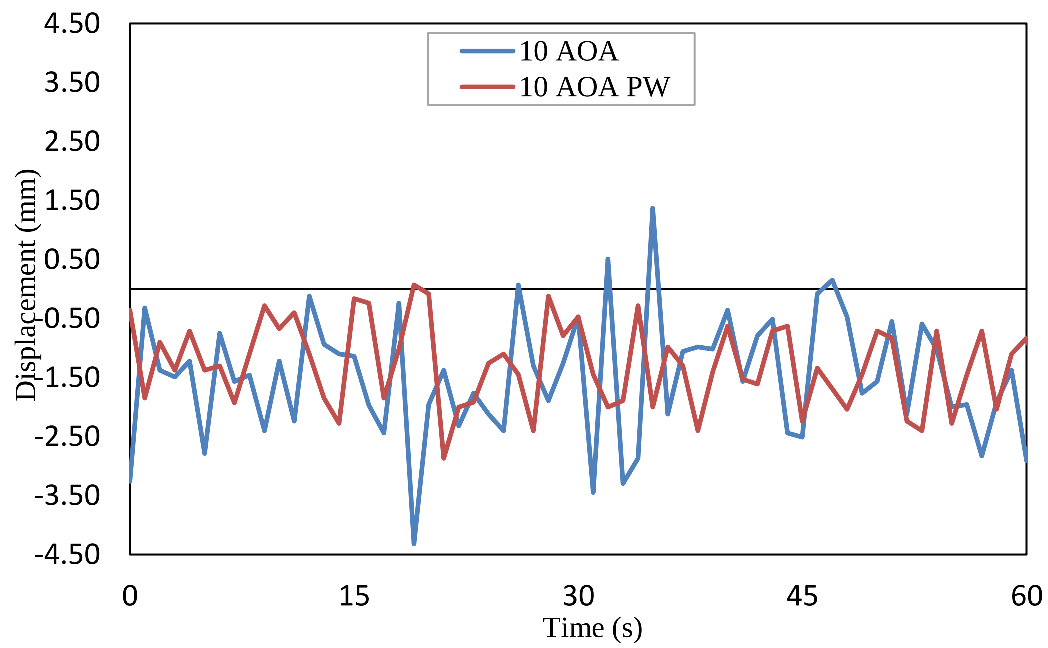


Figure 5.6 Displacement vs Time on Y-Direction

For Figure 5.5 and Figure 5.6 shown the vibration are increased for both direction when AOA on 10^{o}. This is because when changed AOA, the pressure will be more at the surface area of the wing.

4.3 Rate of Change

In this subtopic it will discuss the average results for the data collection on displacement vs AOA. After validated the data, average data for each AOA will plot the straight line graph to in order to find the rate of change for the wing with winglet and without the winglet.

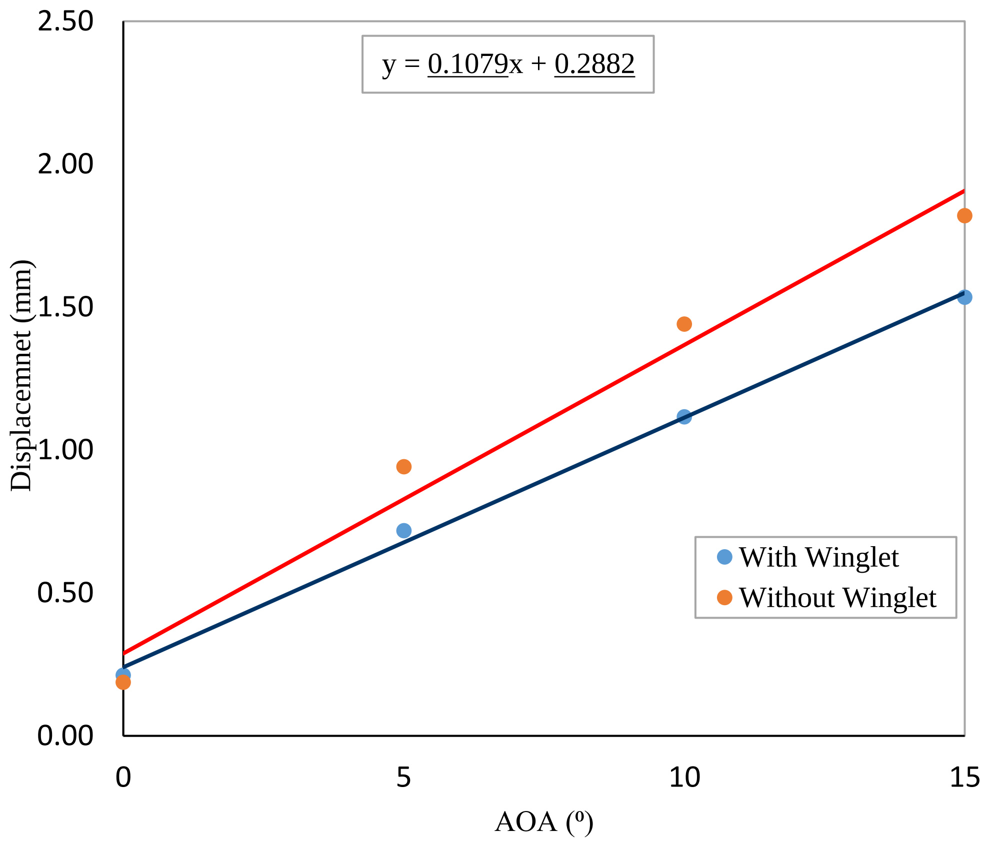


Figure 6.1 Rate of change for wing with winglet and without the winglet

Figure 6 shown the rate of change are increment for the wing with winglet and without winglet. The intersect shown the different around 5%-10% for each AOA. Meanwhile the gradient are look like consistent when AOA are changed. Graph also show the vibration will be more for the wing wthout winglet. The vortex circulation are also given more pressure to the upper surface of the wing without winglet when changed AOA because there don’t have the blockage air flow.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter will discuss the conclusion and summarized from the overall objectives of the project work. This chapter will also discuss recommendations for future researchers to study more deeply and systematically.

5.1 Conclusions

In conclusion by using SolidWork software to analyse the CFD was found that there is still a gap that make the need to retake for a few times to make sure the data either valid or not. SolidWork also have some limitation to analyse overall the data such as mesh and streamline. Below are several specific conclusions:

I. By increasing the surface area near root chord, it can make the high pressure distribution at that area. Due to pressure distribution are high, it can increase the induced drag.

II. At the specific angles of attack, length of the constant pressure is decreased either for wing with winglet or without winglet. Because of that, the vibration of the wing are reducing.

III. The important parameter before design the wing and winglet need to consider and selected properly because some of the parameter are effected the overall of the wing such as tip chord, root chord, sweep angle and so on.

IV. An end plate causes a blockage effect on the flow, thus affecting the pressure distribution compared to a wing without winglet.

5.2 Recommendation

For future research to identify the efficiency of the winglet, the study should be carried out by some following recommendations:

I. Before select the design for the wing and winglet to do experiment, multiple design need to do analysis in order to give the better performance and capabilities to the wing and winglet.

II. Using a better software to do CFD simulation to study more about the structure such as ANSYS @ FLUENT.

III. In order to get a better data for analyze the vibration, experiment with high speed velocity are recommended to be done.

IV. The different for root and tip cord cannot be more than 25% different.

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APPENDICES

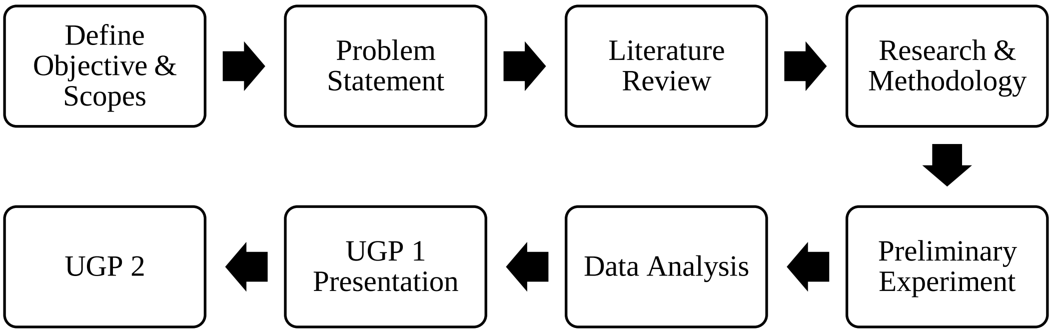
Gantt Chart for UGP

No	Task		Week (UGP1)																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Registration	Plan																	
		Actual																	
2	Problem Statement	Plan																	
		Actual																	
3	Objective & Scope	Plan																	
		Actual																	
4	Literature Review	Plan																	
		Actual																	
5	Research & Methodology	Plan																	
		Actual																	
6	Design & Analysis	Plan																	
		Actual																	
7	Presentation	Plan																	
		Actual																	

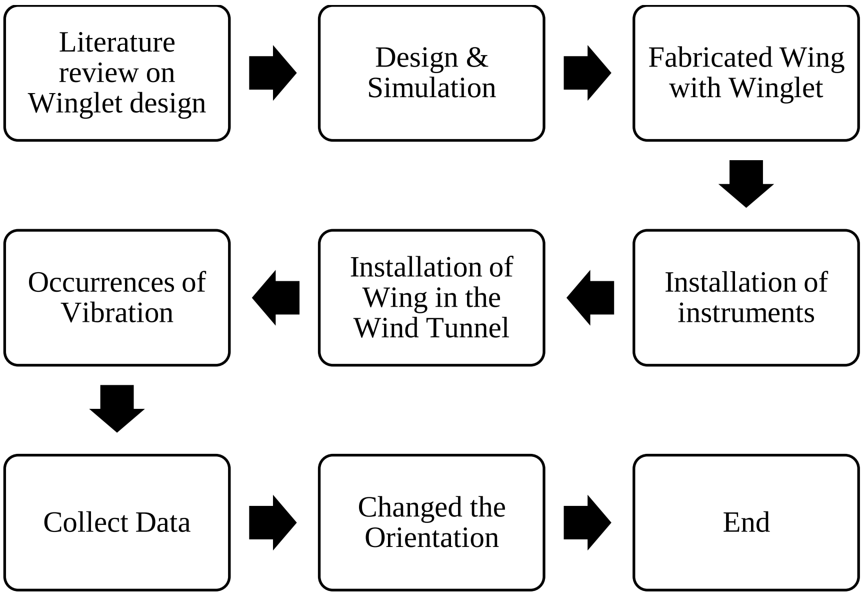
No	Task		Week (UGP2)															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Design,Fabricate,Experimental & Data Collection	Plan																
		Actual																
2	Discussion	Plan																
		Actual																
3	Conclusion/ Recommendation	Plan																
		Actual																
4	Thesis Writing	Plan																
		Actual																

Legend	
Plan	
Actual	

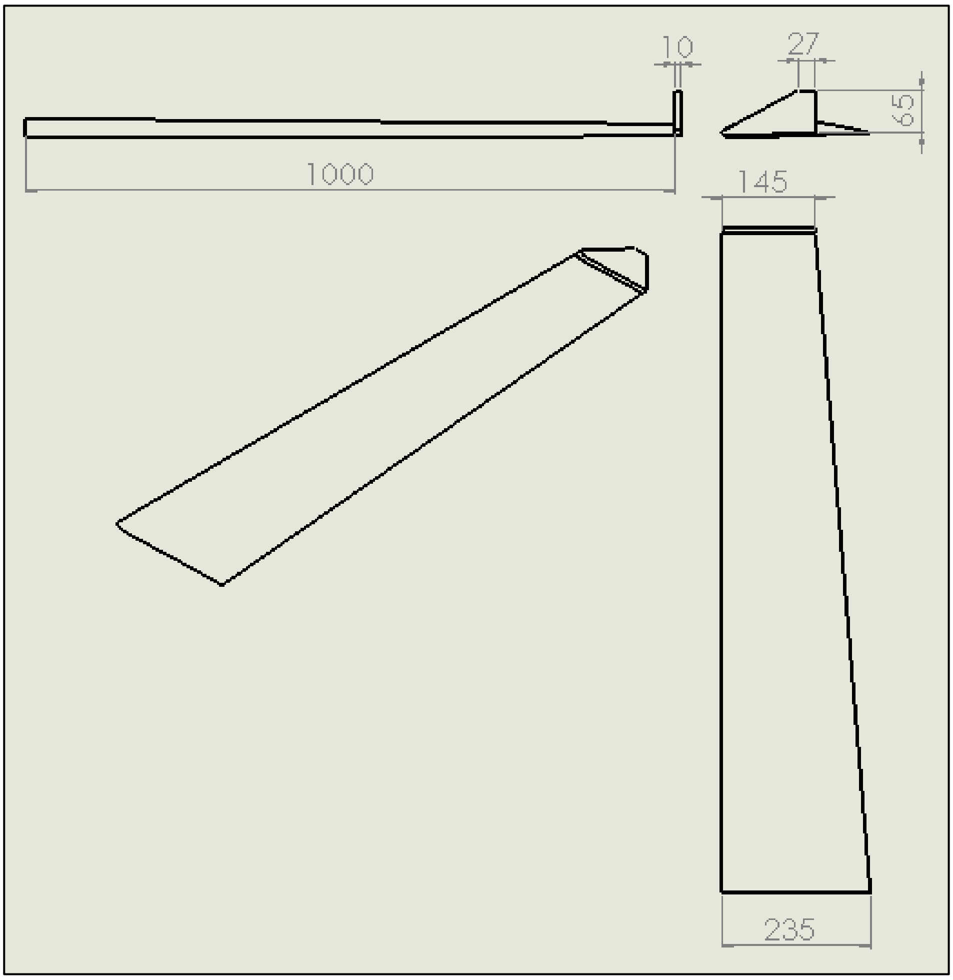
Flow Chart of Methodology UGP 1



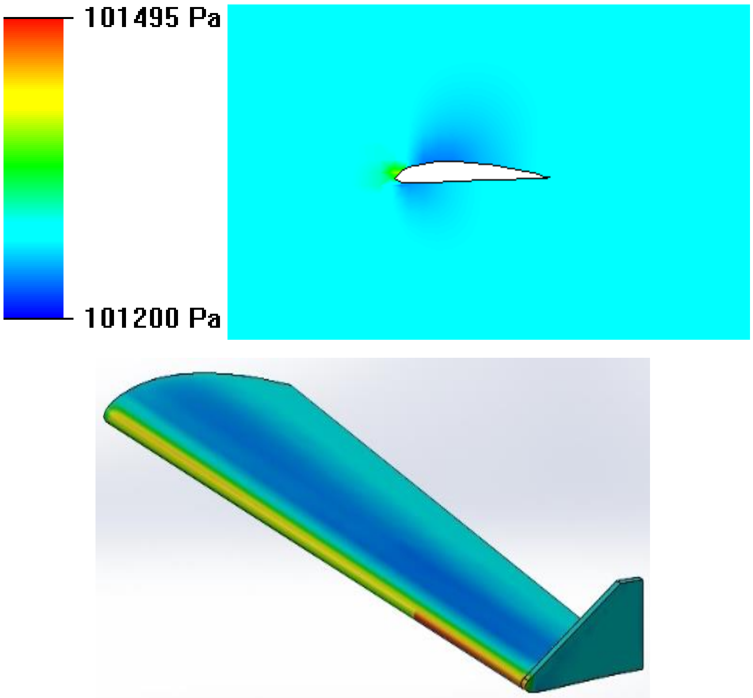
Flow Chart of Methodology UGP 2



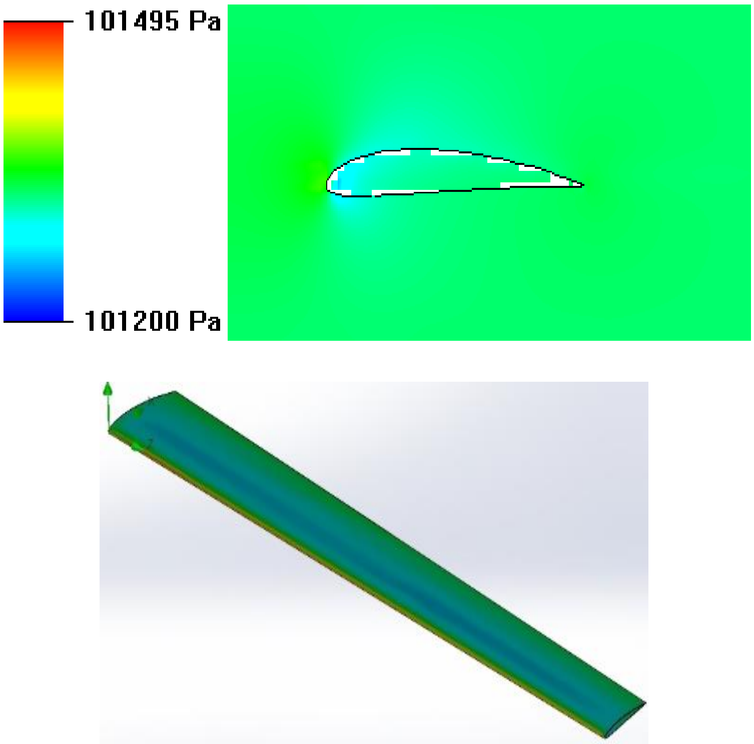
1st Angle view for Wing Design (units in mm)



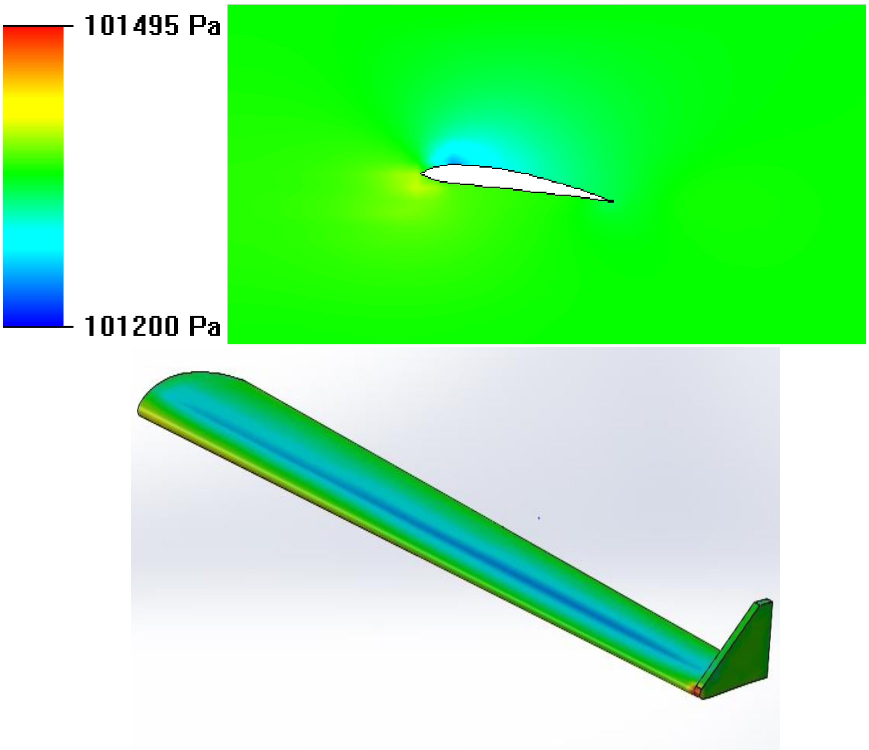
Example of Simulation Results by SolidWorks



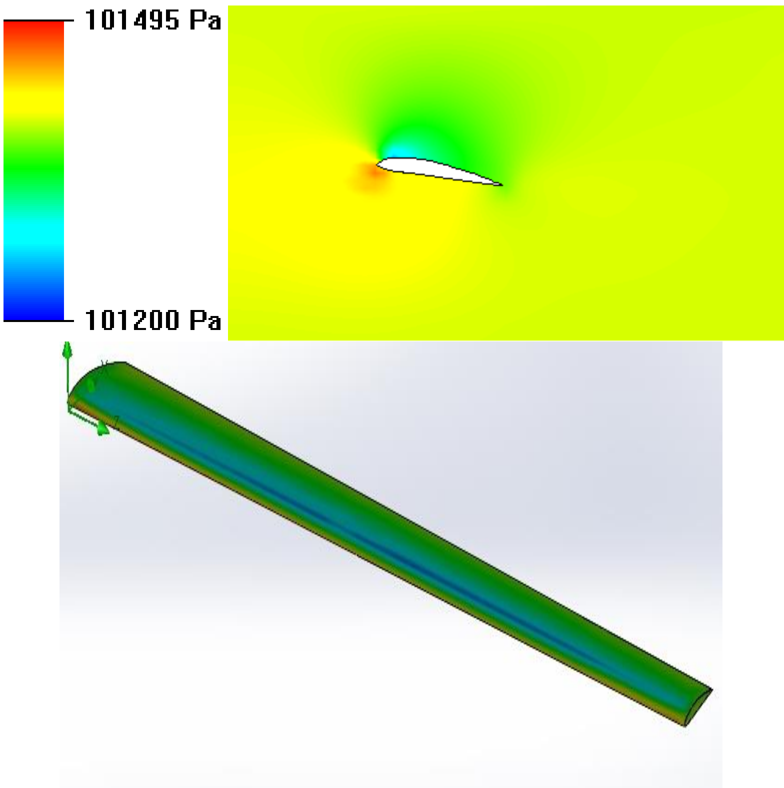
Pressure Results at 0^0 for Wing with Winglet



Pressure Results at 0^0 for Wing without Winglet



Pressure Results at 10^0 for Wing without Winglet



Pressure Results at 10^0 for Wing without Winglet

Testing Section Area for Tunnel

Wind Tunnel	Open Loop
Test Section Dimension LxWxH(m)	3.6 x 1.5 x 1.5
Maximum Wind Speed	7 m/s
Driven System	Axial Fun Driven by 15kW DC motor
Insturment/Measuerment Systems	Multi-tube manometer / accelerometer

Technical Spectcification of the Low Speed Wind Tunnel