ARTICLES
THE INFLUENCE OF BLOWER TECHNIQUE ON DELTA-WINGED UAV VORTEX PROPERTIES


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ABSTRACT
The interest in delta wing applications has risen due to its applicability in supersonic speed aircraft and unmanned aerial vehicle. However, the flow on delta wing is complex and only suitable at high angle of attack aircraft design. Complexity flow is occurred due to the primary vortex was developed completely at the sharp edged of the delta wing. This paper presents the effect of blower type active flow control on sharp edge non-slim delta wing to observe the generated primary vortex flow nearest the sharp edged of the delta wing. The wing model was setup as generic delta wing model was tested in low speed wind tunnel, Aeronautics Laboratory, Universiti Teknologi Malaysia (UTM). It has a sharp leading edge, sweep angle of 55° and overall length of 0.99 m. The test was conducted in test section area of 1.5 x 2.0 m², velocity speed is 25 m/s and blowing rate is 35 m/s. The experiment was divided into three blower positions: I, II and III. Two measurement techniques were used in this experiment; steady balance measurement and surface pressure measurement. Balanced data shows that lift increases in blower position III but slightly decreases at position II at moderate angle of attack while the surface pressure data shows the coefficient of pressure increases at certain condition for position II and III.

1.0 INTRODUCTION

The Unmanned aerial vehicle (UAV) is an autonomous aircraft that was initially used in the military applications or operations particularly in the rough area. UAVs have evolved rapidly over the past decade via the active research and development. UAV is now common to be used in the commercial application including scientific, agriculture and surveillance. Generally, research and development conducted aim to obtain optimum configuration of UAV to cater the various need.

The optimum configuration includes the aerodynamic factors of UAV such as lifting force, lifting coefficient, drafting, pitch which are influenced by the geometric design of then UAV. Delta wing generate strong lift because of strong vortex generated at the leading edge which allow the flow to remain attached to the surface even at high angle of attack (Brett & Ooi, 2014). This property makes them desirable in generation of lift compared to conventional wing. The main caveat of delta wing is that they performed poorly at low speed flight as they produced high drag (Kwak & Nelson, 2010). Delta wing aircraft are required to fly at high angle of attack to gain the amount of lift that is required at low speed flight. This is a problematic situation as at higher angle of attack the flow will separate from the surface as mentioned and cause vortex breakdown (Payne, Visser, & Nelson, 2000). The formation of vortex breakdown can lead to wing stall and induced vibrations which are the main causes of buffeting of control surfaces, loss of control and structural damage (Kastantin, Vey, Nayeri, & Paschereit, 2010). By applying continuous or periodic blowing as a form of active flow control on the wing, the jets coming from the nozzle inserted in the wing will add momentum to the vortex allowing it to overcome adverse pressure gradient hence delaying vortex breakdown (Guillot, Gutmark, & Garrison, 1998).

This work aims to investigate the effects of blower type active flow control on sharp edge non-slim delta wing at various positions of blower location and corresponding angle of attack effect to the flow topology. The first position will be at the apex of the wing, this is similar to along the core blowing study conducted by (A. M. Mitchell, Barberis, & Délery, 2000). The second and third position is at 50% and 70% of the model apex. The result will be in the form of aerodynamic coefficient effect versus angle of attack. The results show blowing is the most effective at moderate angle of attack (α = 9° and 12°) and at position where the vortex breakdown occurred, in this case around 45% of the wing apex. At lower angle of attack the vortex has not fully developed hence application of active flow control did not result. At higher angle of attack the intensity of vortex breakdown is too strong. The blowing rate of the active flow control cannot overcome the intensity of the vortex breakdown.
1.1 Background

The usage of delta wing on UAV is favorable because of its features at high angle of attack (Edward Polhamus, 1966). Delta wing also has advantages over conventional design in power efficiency and having lower aspect ratio which results in lower skin drag and better maneuverability (Nakashima, Okabe, Ohsima, Tajima, & Kumon, 2014). Delta wing has the advantage of extra battery installation and aircraft system (Kasim, 2017). Due to its thick spar the whole structure of the UAV can be enhanced, and its simple design will result in less impact being produced during crash thus minimizing damage.

One of the most important factors of maximizing UAVs performance is the wing design. Wing design will decide the flow topology of the UAV wing. Delta wing generates strong lift due to the strong vortex generated at the leading edge which allows the flow to remain attached to the surface at high angle of attack (Buzica, Bartasevicius, & Breitsamter, 2017). This phenomenon resulted in generation of higher lift compared to conventional wing. However, for the sharp-edged delta wing, the flow separation is dominated by two large vortices originated from series of small vortices shed along the leading edge (Gursul, 2004). These small vortices rotate around each other and merged to form large vortices which known as primary vortex.

The vortex formation is influenced by angle of attack, Mach number, Reynolds number and the leading-edge type (Kastantin et al., 2010; Meng, Cai, Qiao, Luo, & Liu, 2011). The vortex intensity is increased by the increase of the angle of attack. However, the vortex formation is subjected to breakdown at the higher angle of attack (Furman & Breitsamter, 2013). Vortex breakdown can be described as stagnation of the primary vortex core due to the increasing of adverse pressure gradient along its axis. Vortex breakdown is crucial since it can cause wing stall and induced vibrations that lead to buffetting of control surfaces, loss of control and structural damage (A. Mitchell & Morton, 2001). The vortex breakdown phenomenon, however, can be delayed by applying the active flow control. The effects of blowing type active flow control has been well documented but significant effects has not yet observed. Study done by (A. Mitchell & Morton, 2001) found that for along the core blowing, the increase of mass flow rate will increase the effectiveness of the active flow control, increases the momentum of vortex core and allow it to overcome the adverse pressure gradient and delaying vortex breakdown further downstream. Other method includes the application of blowing at three positions; apex, middle section and trailing edge of their sharp leading-edge delta wing with 76° sweep angle (Cui, Lim, & Tsai, 2007). It is basically along the core blowing technique such as study done by (Wood & Roberts, 1988) with additional blowing location. From the wind tunnel test, they determined the recovery of vortex breakdown is most effective near the location of the breakdown. Most studies regarding flow control focused on sharp edged and slender angle configuration. Knowledge on correlation of flow control on sharp edged wing with non-slender angle is lacking. That study was not enough for knowledge discovery for these issues.

2.0 METHODOLOGY

The experiment was performed in UTM low speed wind tunnel (S. Mat et al., 2014). The test section has dimensions of 1.5m x 2.0m x 6m. The delta wing model used in this experiment has sweep angle of 55° and Mean Aerodynamic Chord (MAC) of 0.4937m. The detail dimensions of this model are presented in Table 1. The model is also equipped with several manual control surfaces such as rudder and elevator.

Two measurement techniques were used throughout the experiments which include steady balance measurement and surface pressure measurement. The steady balance measurement data will be in the form of force and balance in x,y and z coordinates. These data were recorded by the six-axis balance located underneath the wind tunnel test section area as shown in Figure 1 (S. B. Mat et al., 2017). The pressure data was measured using a Scannivalve pressure scanner. The pressure scanner is connected to the wing pressure taps via tubes as shown in Figure 2.

<table>
<thead>
<tr>
<th>Table 1. Reynolds number and wind speed</th>
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<tbody>
<tr>
<td>Specifications</td>
</tr>
<tr>
<td>Overall length</td>
</tr>
<tr>
<td>Overall width</td>
</tr>
<tr>
<td>MAC</td>
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<tr>
<td>Wing area</td>
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<tr>
<td>Wing + fuselage area</td>
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<td>Aspect ratio</td>
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Figure 1: UTM low speed wind tunnel balance measurement system.

Figure 2: Pressure taps locations (Zain et al., 2017).

Figure 3: The experiment full configuration.
In the experiment, the airflow is set up at 25m/s. In order to investigate the effects of blowing at different locations, the blowing was applied at three positions. Position I is at the wing apex or 297mm of the core apex, position II is at 50% of the core apex or at 495mm and position III is at 70% of the core apex or at 693mm. The velocity rate of blowing is set at 35m/s. During the wind tunnel test, the model was attached to six-axes support through two struts support at 1/3 and 2/3 of the wing. The angle of attack is adjusted by moving the strut support vertically. For this experiment, the angle of attack is between 0°-18° with increment of 3°. The clean wing condition was also performed to differentiate the effects of blowing on vortex properties. The full experiment configuration is shown in Figure 3.

In this study, the finite wings analyses were also applied. The aerodynamic coefficients, lift, \(C_L\), drag, \(C_D\), and moment \(C_M\) are not only depending on the angle of attack, but also velocity and altitude, wing area, wing shape and compressibility. From surface pressure measurement technique, the result will be in the form of raw pressure data. The raw data can be converted into coefficient of pressure data using the equation as shown in Eq (1):

\[
C_p = \frac{\Delta p}{\frac{1}{2} \rho V_0^2} = \frac{p - p_0}{\frac{1}{2} \rho V_0^2}
\]

Where:
- \(p\) = Static pressure at the point of interest
- \(p_0\) = Freestream static pressure
- \(V_0\) = Free stream velocity
- \(\rho\) = Free stream density

The aerodynamics force can be calculated via relation data of pressure distribution as Eq. (1), the relation was shown in Figure 4.

\[
L = \frac{1}{2} \rho V_0^2 SC_L \tag{2}
\]

\[
D = \frac{1}{2} \rho V_0^2 SC_D \tag{3}
\]

\[
M = \frac{1}{2} \rho V_0^2 SC_M \tag{4}
\]

Where \(S\) is wing area.

Then, the rearrangement of Eq. (2) to (4) are for calculated of coefficient of lift, drag and moment, respectively as shown in Eq. (5) to (7):

\[
C_L = \frac{2L}{\rho V_0^2 S} \tag{5}
\]

\[
C_D = \frac{2D}{\rho V_0^2 S} \tag{6}
\]

\[
C_M = \frac{M}{\rho V_0^2 S} \tag{7}
\]

3.0 RESULTS AND DISCUSSION

Two measurement techniques were used; steady data measurement and surface pressure measurement. Steady data measurement data are in the form of \(C_D\) and moment \(C_M\) while surface pressure measurement is in \(C_L\).

3.1 Steady data

The coefficient of lift \(C_L\), drag \(C_D\) and moment \(C_M\) are shown in Figure 5. Figure 5(a) shows the lift increase as angle of attack increase for conditions clean wing without blowing task. For position II blowing, the coefficient of lift decreases compared to clean wing at \(\alpha = 9°\), 12° and 15°. This situation happened because blowing force has increased the momentum of the flow as stated by Mitchell et al. (2001). The increasing velocity of flow could result in decreasing the pressure on the wing hence decreasing the lift but this applicable only at moderate angle of attack. For blowing at position III, the coefficient of lift, \(C_L\) increases compared to clean wing at \(\alpha = 9°\), 12° and 15°. It seems that blowing at the rear has pressurized the flow. This result is similar to Zain et al. (2017) experiment which uses rear propeller to pressurize the flow on the wing model. The coefficient of lift however does not show any changes at maximum angle of attack (\(\alpha = 18°\)) as the effect of vortex breakdown is too strong.

Figure 5(b) shows the coefficient of drag, \(C_D\). The drag coefficient shows no significant change for all conditions. It seems that blowing does not have any effect on drag for this wing configuration.

Figure 5(c) shows the pitching moment coefficient of the model. The \(C_M - \alpha\) graph shows that the coefficient of moment, \(C_M\) increases as angle of attack increases. Data at position II exhibit lower pitching moment or lower nose down moment at \(\alpha = 9°\), 12° and 15° compared to clean wing. This means that blowing at position II increase the size of primary vortex and create nose up moment. For blowing at position III, coefficient of moment data shows increases in nose down moment at \(\alpha = 12°\).
Figure 5: $C_L$, $C_D$ and $C_M$ versus $\alpha$. 
3.2 Pressure data

The raw surface pressure data obtained from the wind tunnel test had been converted into coefficient of pressure \( (C_p) \). The coefficient of pressure was plotted in chord wise position of the wing width. The clean wing data were compared to differentiate the effect of blowing on vortex properties.

It is observed that most of the flow is attached to the wing surface at low angle of attack, \( \alpha = 3^\circ \). The blowing applied at all three positions give no significant changes as illustrated in Figure 6. This phenomenon occurred because the vortex has not fully developed at low angle of attack hence the application of blowing shows no changes.

![Blower I](image1)

![Blower II](image2)

![Blower III](image3)

**Figure 6:** Coefficient of pressure at \( \alpha = 3^\circ \).

At higher angle of attack the attached flow was starting to separate and move towards the leading edge where the suction peak was located at medium angle of attack. Figure 7(a) shows that at \( \alpha = 6^\circ \) the effect of blowing is not significant present except for position I blower which is located near the apex of the wing. At this position, blower was weak to the vertical flow and pushes it towards the surface. This phenomenon occurred because the vortex has not fully developed. The increase of vortex intensity is observed at \( \alpha = 9^\circ \) and \( y/cr = 40\% \) and 65\%, as shown in Figure 7(b). At \( y/cr = 65\% \) the primary vortex slightly shifts inboard. The same phenomenon occurred at \( \alpha = 12^\circ \) in Figure 7(c) but the vortex shifts can also be observed at \( y/cr = 40\% \) and the intensity also increases at \( y/cr = 20\% \). Blowing at position II and III show changes in the form of increase in vortex intensity) at \( y/cr = 90\% \). This result agrees with Okada et al (2004) which state that blowing at position where vortex breakdown occurred is the best location to increase and recover energy loss from the. However, other position shows no changes of \( C_p \). Position I show no changes in pressure coefficient for both angles 9\(^o\) and 12\(^o\).

![Blower I](image4)

![Blower II](image5)

![Blower III](image6)

**Figure 7:** Coefficient of pressure at \( \alpha = 6^\circ \) (a) and \( \alpha = 9^\circ \) (b).

At higher angle of attack; \( \alpha = 15^\circ \) and 18\(^°\), the vortex sizes have increases at the wing leading edge as shown in Figure 8. The flow has separated from the wing and the suction peak has increase significantly. However, the effect of blowing only shows at position II of \( \alpha = 15 \) in Figure 8(a) and 18\(^°\) in Figure 8(b). For both \( \alpha = 15^\circ \) and 18\(^°\), position II blowing exhibit increases in coefficient of pressure at \( y/cr = 20\%, 40\% \) and 65\%. Position I and III shows no changes in coefficient of pressure for both angles 15\(^°\) and 18\(^°\).
4.0 RESULTS AND DISCUSSION

Two measurement techniques were used; steady data measurement and surface pressure measurement. Steady data measurement data are in the form of $C_D$ and moment $C_M$, while surface pressure measurement is in $C_L$, blowing at position II as the primary vortex velocity is faster and this will also affect the nose down pitching moment of the model.

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