Tomography Systems and Sensor Applications
Flow Visualization Above Blunt-Edged Delta Wing

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Abstract

This paper highlights the flow characteristics of the VFE2 blunt-edged delta wing profile by using flow visualization method. On the upper surface of the wing, a phenomenon called as vortex is developed and the flow physics in that region is very complicated. The vortex flow on the sharp-edged wing develops in the Apex region of the wing. The vortex on the blunt-edged wing is not developed in the apex region but at a certain cord-wise position based on angle of attack, Reynolds number and leading edge bluntness. The primary vortex moved upstream if the angle of attack is increased. This study has been performed in order to verify either the primary vortex developed in the apex region for the blunt-edged wing if the angle of attack is increased. The experiments were conducted at Universiti Teknologi Malaysia Low Speed Tunnel (UTM-LST) with maximum speed of 83 m/s. A measurement technique called it as tuft method was used to verify the complexity of the flow at high angle of attack. The experiments were performed at Reynolds number of 1×106 and 2×106 respectively. The result shows that the primary moves upstream closed the apex at high angles of attack.

Keywords: Tuft Technique, VFE-2 Wing, Aerodynamics & Primary Vortex

1. Introduction

In the 80’ a research group called it as Vortex Flow Experiment 1 has been established to study the flow above blunt-edged delta wing. At the end of the campaign, Euler methods has been able to calculate to vortex above the blunt-edged wing (Dietrich Hummel, 2008). There were some limitations at that time such as the formation of the secondary vortex is not well defined. (Dietrich Hummel, 2008).

In order to resolve these problems, another team called as Vortex Flow Experiment (VFE-2) has been established. The main purpose of VFE-2 was to validate the results of Navier-Stokes calculations with experimental data (Willy Fritz, 2013). More Numerical and Experimental studies were performed based on VFE-2 profile started in 2003 till now.

1.1 Literature Review

The first experiment on Vortex Flow Experiment (VFE-1) model was conducted in the early 1980's (between 1984 until 1986). The purpose of this experiment was to obtain a good experimental data in order to validate the Euler method codes [1]. However, there were some limitations in the results of the VFE-1 experiments. It was found that even for the sharp leading edges, the Euler codes were not able to calculate properly the pressure distribution on a slender wing. This situation happened because the secondary separation line was not modeled in the coding [1]. Thus, some of the objectives of the VFE-1 experiments were not been achieved. Few years later, a new research group is established to further investigate the flow structure on the blunt-edged delta wing, the team was called as Vortex Flow Experiment (VFE-2). The main objective of the VFE-2 test was to validate the results of Navier-Stokes calculations with the experimental data. Several configurations of VFE-2 model were tested include sharp-edged wing and several series of blunt-edged wing [1-3].

Many data had been published data on blunt-edged VFE-2 profile in early 2010 [3-7]. The results obtained from VFE-2 are summarized in Figure 1 below. The flow on blunt-edged wing exhibits different flow physics compared with the sharp-edged wing especially in the region near the leading edge and the apex. The main difference was due to the attached or non-separated flow covering the wing apex region. The flow stay attached to the wing surface. At certain chord-wise position, the vortex is generated above the wing. The characteristics of the vortex depend on Reynolds number, angle of attack, Mach number and the leading edge profile itself.

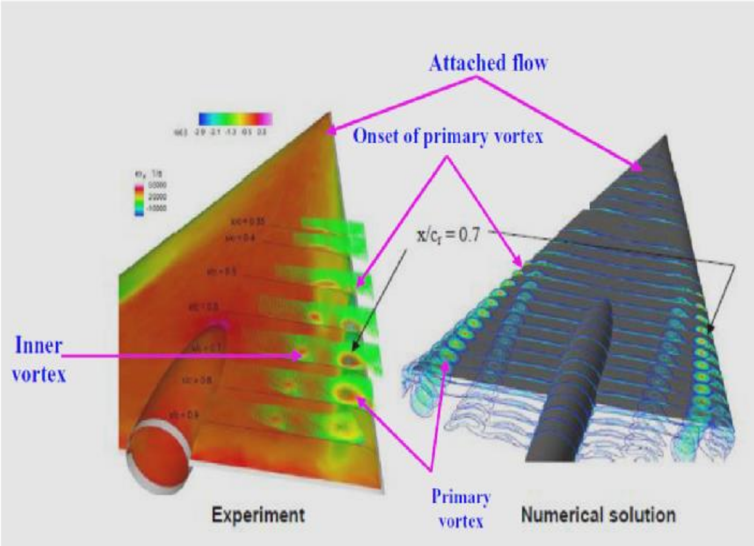

Figure 1. Comparison of experimental measurement and Numerical studies above VFE-2 configurations at α=13° [2]

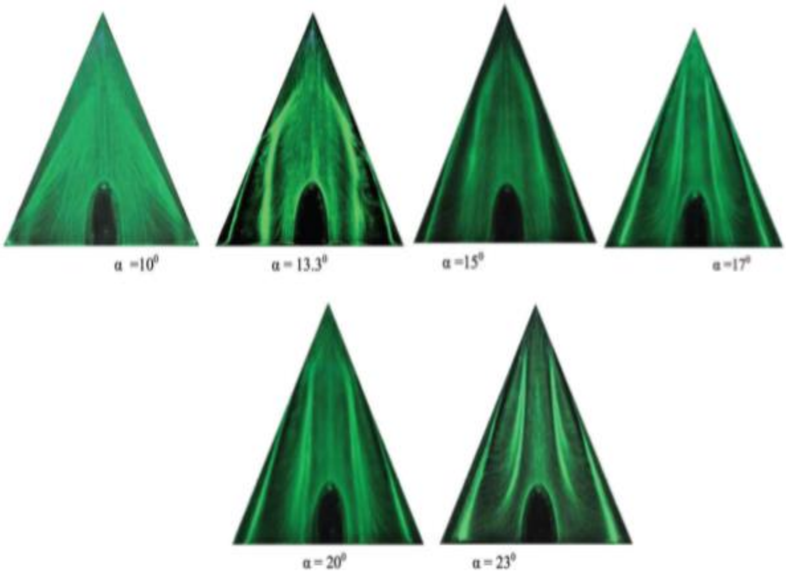

Figure 2. Flow topology above large-edged wing at Reynolds number of 1×106, α varies from 10° to 23° [3,13]

Mat et al. [3] has performed a comprehensive flow visualization studies on blunt-edge delta wing. The example of the results are shown in Figure 2. From the figure the flow attached to the surface of the wing at considerable low angle of attack. At higher angle of attack, the flow in the leading edge region is fully attached extending from the apex to the trailing edge. The primary vortex is then developed at certain chord-wise position and its progress upstream with angle of attack. Interesting flow physics was observed inboard of the wing, from figure 1, another vortex called it as the inner vortex developed. Nevertheless, to date, there is no data in VFE-2 that indicate the vortex progressed up to the Apex region with angle of attack increases [4]. Thus, this paper highlights the current experiments on VFE2 model at higher angle of attack to verify the detail interaction between the primary and the inner.

2. Methodology

In UTM, another VFE-2 model was fabricated based on the original model tested during the VFE-2 campaign. The original model was fabricated with four sets of leading edge profiles representing sharp, small, medium and large radiuses wing. The leading edge profiles over the wing root chord are 0, 0.0005, 0.0015, and 0.0030 respectively. The model was fabricated from aluminum. The installation of the UTM VFE-2 model in Universiti Teknologi Malaysia wind tunnel is shown in Figure 3 below. For this paper the experiments were performed at Reynolds number 1×10^6 and 2×10^6 of respectively. Only one measurement technique was performed to visualize the flow, i.e the tuft technique. The experiment was performed at angle of attack varies from α = 0° to α = 23°.

Figure 3. Installation of UTM VFE-2 model at α=0°

The experiment was conducted at two different values of velocity corresponding to two different values of Reynolds number. In order to differentiate the effects of leading edge bluntness, the experiments were also performed at two different leading edges namely the large-edged and medium-edged wing. The angles of attack were varied from α = 0° to 23° and it has been adjusted manually. In order to differentiate the effects of Reynolds number, the experiment was also performed at two speeds of 18 m/s and 36 m/s that corresponding to 1×10^6 and 2×10^6 Reynolds numbers, calculated from Eq. 1 and summarize in Table 1.

$$Re = \frac{\rho V x}{\pi} \quad (1)$$

where the dynamic viscosity, μ, density of air, and length, x were taken as 1.846×10^{-5} kg/ms, 1.18 kg/m^3 and 0.874 m respectively.

Table 1. The values of Reynolds number and velocity

Reynolds number, Re	Velocity, V
1×10^6	18 m/s
2×10^6	36 m/s

2.1 Measurement technique

In order to observe the detail interaction between the primary and the inner vortex, a method called as Tuft method was used. This method was performed by using an array of threads tied to the net which was placed in front of the model as shown in Figure 4 below. The tuft was positioned in front of the model. The covering area of the tuft was 0.8m × 1.8 m., compared to the size of the test section of 1.5 x 2.0m^2. Each thread was 2m long and a total of 400 threads were used. The threads were freely moved on the upper and lower surfaces of the wing under the influence of the air at lower wing tunnel speed. This method provides a better insight to understand the flow above the wing. The arrangement is shown in Figure 4 below.

Figure 4. Tuft set up in front of the model

2.2 Test Configuration

The experiments were conducted at two different values of Reynolds numbers and several angles of attack varied from α = 0° to 23°. The speed was set up at two different test speeds, 18 m/s and 36 m/s that corresponding to $1x10^6$ and $2x10^6$ Reynolds numbers. Table 2 shows the experimental test configurations. In order to capture the vortex above the wing, a high resolution NICON Camera PX has been used. The camera has been set on its tripod and this system has been position on the roof of the test section. During the experiment, the images of the flow structure are captured at 100 images per second.

Table 2. Testing configurations of delta wing

Reynolds number, Re	1×10^6	2×10^6
Leading edge	(i) Large (ii) Medium	(i) Large (ii) Medium
Angles of attack, α	0°,5°,10°,11.5°,12.5°, 13.3°, 15°, 23°,	0°,5°,10°,11.5°,12.5°, 13.3°, 15°, 23°,

3. Result and Discussion

The results will be presented based on angle of attack, Reynolds number and leading edge bluntness.

3.1 The Effects of Angle of Attack

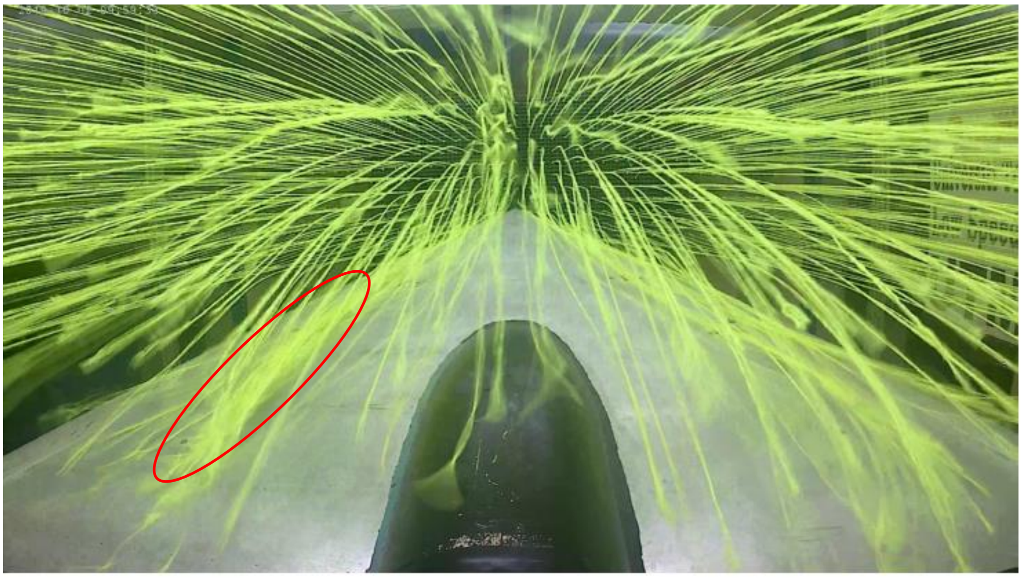

Figure 5. Flow visualization at angle 5°(medium leading edge, speed 18m/s)

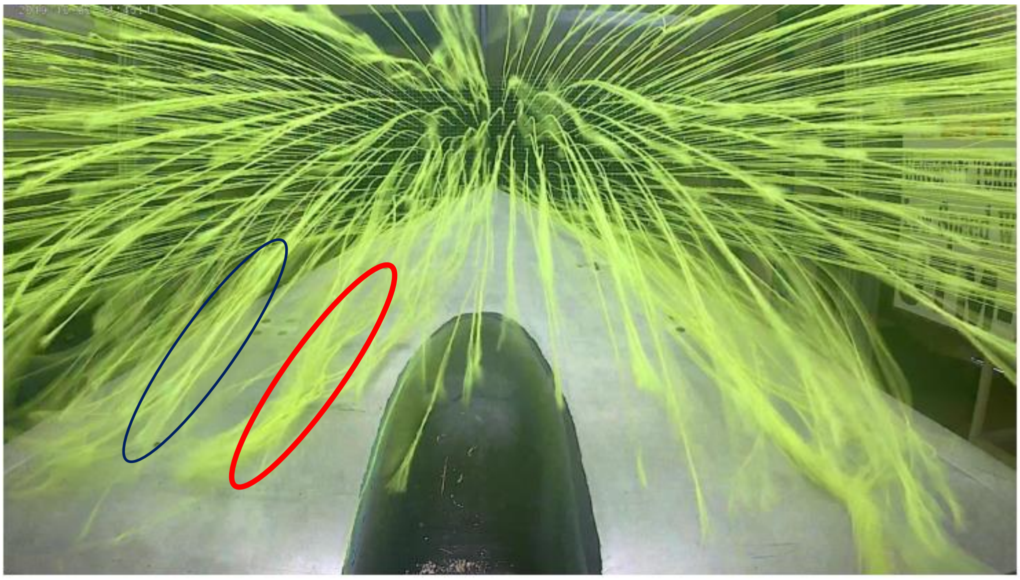

Figure 6. Flow visualization at angle 12.5°(medium leading edge, speed 18m/s)

Figure 7. Flow visualization at angle 15°(medium leading edge, speed 18m/s)

The sample results obtained at angle of attacks 5°, 12.5°and 15° at the speed of 18 m/s on the medium leading edge wing are shown in figures 5, 6 and 7 respectively. The red circle in these figures shows the primary vortex start to develop in the leading. Upstream from this point, the flow is attached to the surface. While the angle of attack is increased to 12.5^0, there were two type of vortices develops in the wing. The blue circle is the primary vortex developed in the leading edge while the red circle is the inner vortex developed inboard of the wing. In Figure 7 shows that the primary vortex indicated by the red circle become bigger. It is not clear either the inner vortex also developed at this condition. Futher aft of the wing, a phenomenon called it as vortex breakdown generated in the wing.

3.2 The effect of Reynolds number

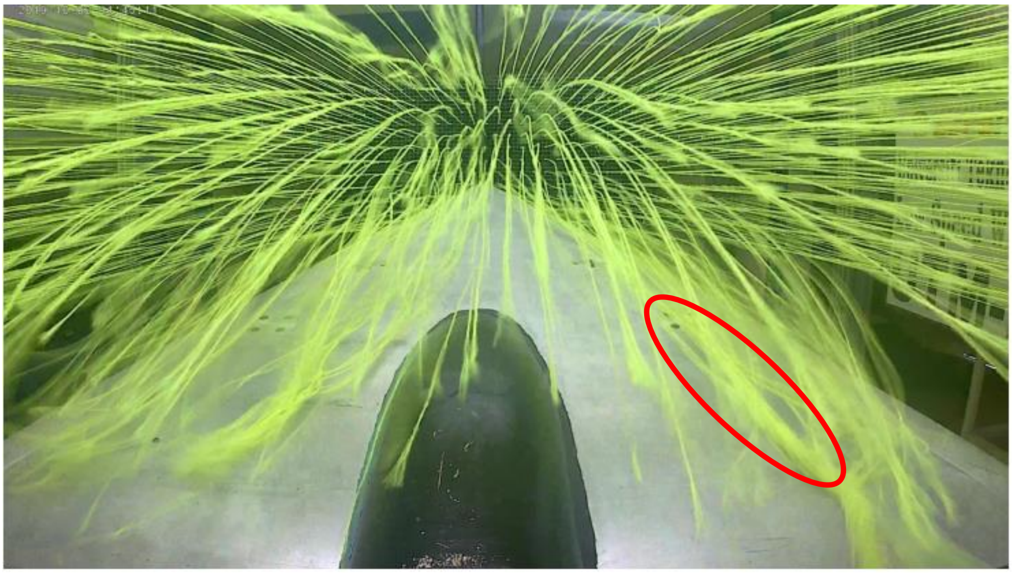

Figure 8. Flow visualization at Reynolds number of $1x10^6$ (medium leading edge, angle at 12.5°)

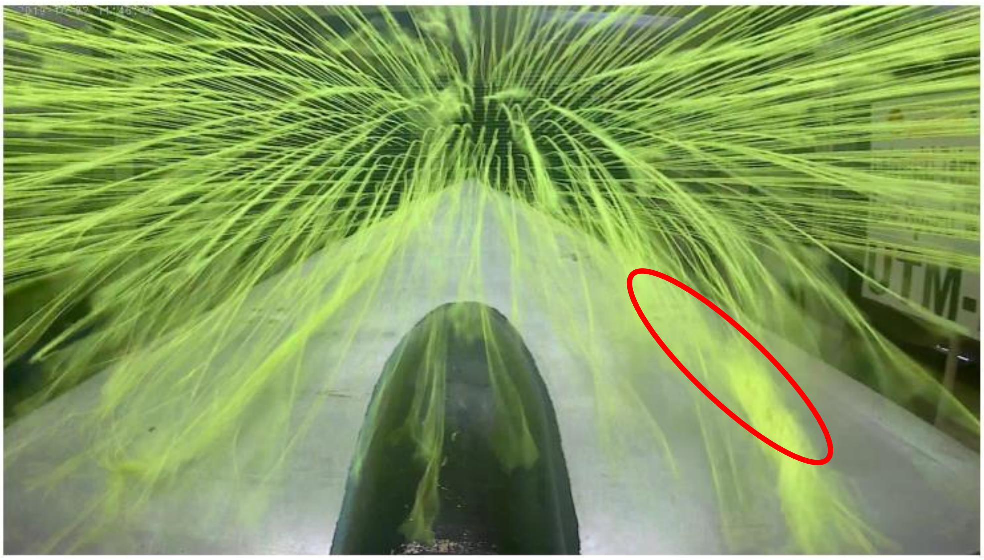

Figure 9. Flow visualization at Reynolds number of $2x10^6$ (medium leading edge, angle at 12.5°)

In order to differentiate the effects of Reynolds number, the sample image at both Reynolds number were compared Figures 8 and 9 at angle of attack of 12.5^0 and on the medium wing. From the figures, Increasing the Reynolds number has reduced the size of the primary vortex significantly. More experimental data are needed to verify this but at this early stage, the status of boundary layer either being laminar or turbulence has caused this. Stronger ability of turbulence boundary layer has reduced the separation at higher Reynolds number.

3.3 Effect of leading edge bluntness

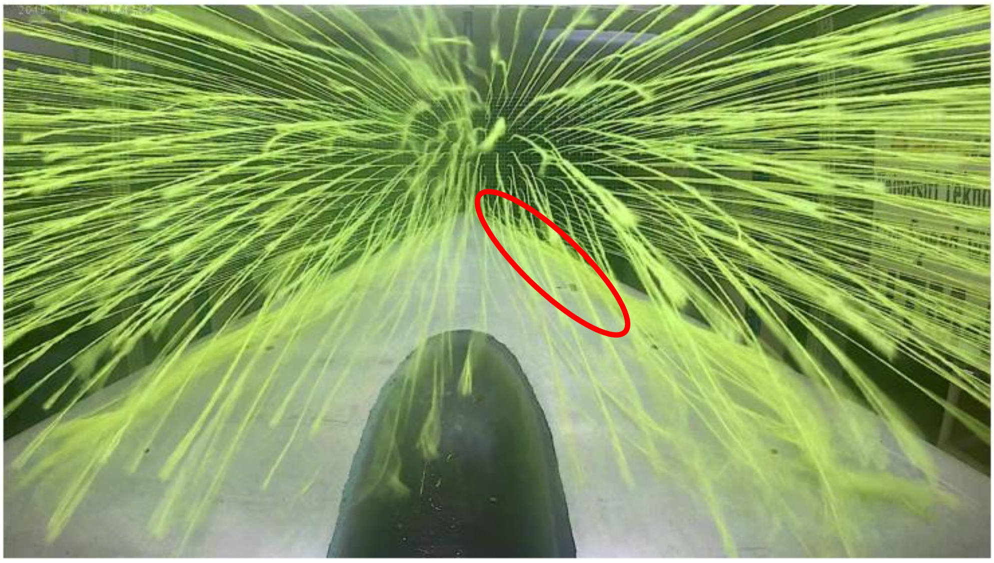

Figure 10 Flow visualization for large-edged (speed at 18m/s, angle at 10°)

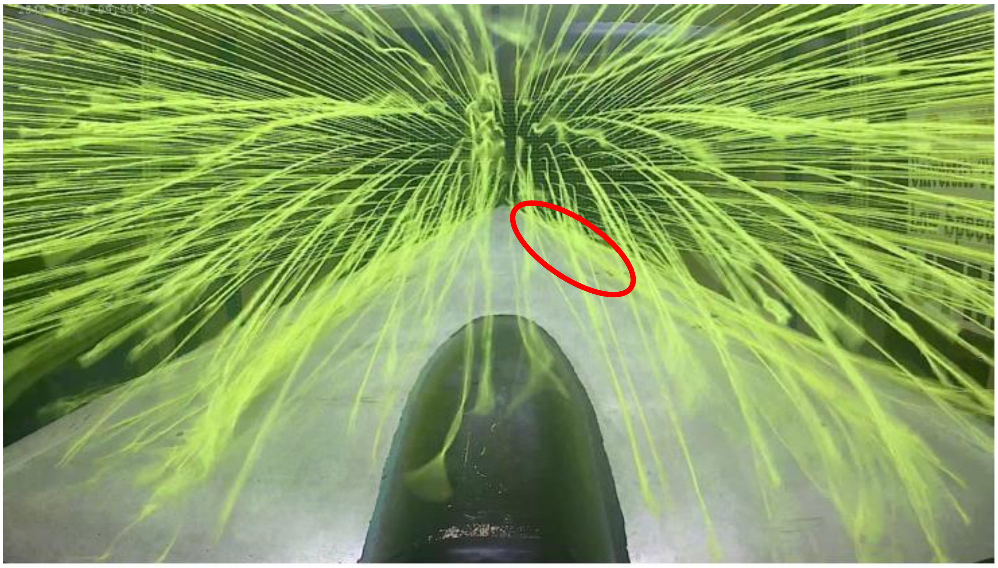

Figure 11 Flow visualization for medium-edged wing (speed at 18m/s, angle at 10°)

The final comparison is for the leading edge bluntness. The images at large-edge wing and medium0edged wing were compared in figures 10 & 11. The comparison was made at constant Reynolds number and angle of attack. The figures show that the development of primary vortex has been delayed when the leading edge bluntness reduces. This phenomenon happen because of the weakened primary separation resulting from the short run of attached flow region that formed from the increasing leading edge radius

4. Conclusion

The flow topology above blunt-edged delta wing is very complicated, unstructured and unresolved. The data on a blunter wing of large-radius wing of VFE-2 is very limited. The results obtained here shown that the primary vortex above the wing has depended upon the Reynolds number, Angle of attack and leading edge bluntness itself. The results from the tuft measurement in only give the data on the flow visualization only, more details experiment need to be done.

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