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Experimental Investigation of Surface Roughness Effect over Wind Turbine Airfoil

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Abstract

The present study ensures an experimental investigation of NACA4412 wind turbine blade airfoil prepared with the sandpaper as a roughness device in order to control its flow. The smoke-wire and hot-wire experiments were carried out at low Reynolds number ranging from 25000 to 75000 and angle of attack of 8°. As geometrical parameters, height of sandpaper and it location over the airfoil were conducted. It was positioned 15%-25% chord length. Height of sandpaper was selected 0.5 mm. The experimental results revealed that the flow over NACA4412 was affected when sandpaper was utilized because either amount of lift apparently increased or the location and size of laminar separation bubble (LSB) were changed. As a result, it was shown that the use of sandpaper provided passive flow control and it was an effective way in terms of delay or suppress separation over NACA4412 airfoil.

Keywords: Low reynolds number, Laminar separation bubble, Surface roughness, Passive flow control

Rüzgar Türbini Kanadı Üzerindeki Yüzey Pürüzlülüğü Etkisinin Deneysel İncelenmesi

Öz

Mevcut çalışma, akış kontrolü sağlamak için pürüzlülük elemanı olan zımpara kağıdı ile hazırlanmış NACA4412 rüzgar türbini kanadının deneysel çalışmasını sağlamaktadır. Duman teli ve Sıcak-tel anemometresi deneyleri 8° hücum açısında ve 25000 ile 75000 arasında değişen hücum açılarında gerçekleştirilmiştir. Geometrik parametre olarak, kanat üzerindeki pürüzlülüğün yeri ve yüksekliği ele alınmıştır. Pürüzlülük %15-25 kord boyuna yerleştirilmiştir. Zımpara kağıdı yüksekliği 0,5 mm olarak seçilmiştir. Önceden deneysel çalışmalar NACA4412 kanat profilinin aerodinamik performansı açısından iyi sonuçlar gösterecek mi şeklinde düşünülmüştü. Gerçekten, deneysel sonuçlar zımpara kağıdı kullanıldığı zaman NACA4412 kanat profili üzerindeki akışın etkilendiğini ortaya çıkardı, çünkü ya

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kanadın kaldırma miktarında belli bir artış vardı ya da laminer ayrılma kabarcığının konumu değiştirilmişti. Sonuç olarak, zımparanın kullanılması pasif akış kontrolü sağladığını ve NACA4412 kanat profili üzerindeki akış ayrılmasını ertelediği ya da yok ettiğini göstermektedir.

Anahtar Kelimeler: Düşük reynolds sayısı, Laminer ayrılma kabarcığı, Yüzey pürüzlülüğü, Pasif akış kontrolü

1. INTRODUCTION

The global growth in wind energy procurement has made aerodynamic researchers do investigations on performance of blade aerodynamic since the end of last decade. Thus, new opportunities for innovation have been occurred to obtain the value of wind energy such as clean resource and low cost. Either different airfoil models [1] were searched or flow phenomenon over the airfoil operating at low Reynolds number such as laminar separation bubble (LSB), flow separation, transition [2-7] were studied. It was concluded that the LSB negatively exhibited major role on aerodynamic performance. It was seen that LSB effected the performance by not only increasing drag and reducing lift [8,9] but also producing noise and vibration [10,11]. In order to diminish the negative effects of LSB, some researchers used membrane to observe the impact of flexibility [12,13]. Some of them preferred to utilize the acoustic control methods [14,15]. Furthermore, the passive control devices such as vortex generators (VGs) or surface roughness elements were studied numerically and experimentally. Xue et al. [16] studied to VGs by using computational fluid dynamics (CFD) and they concluded that both aerodynamic performance was increased and lower acoustic noise was obtained by VGs. Øye [17] indicated as a result of tests that wind turbine power increased almost 24% as VGs was used. Lin [18] investigated various type of VGs. Aside from the type, it could be said that location, shape, size with the inclusion of length, height and spacing among adjacent VGs play key role on aerodynamic performance. These variables quite important so that it affects the flow characteristics over the airfoil because VGs properly impresses the separated boundary layer and change LSB formation, delay the stall phenomena and increase maximum lift coefficient by giving high momentum flow to blade surface.

The content of this study was to investigate a sandpaper associated with surface roughness device to reduce flow separation or LSB because it was previously suspicious whether the sandpaper would be useful as well as VGs in terms of aerodynamic performance. The detailed experimental investigations including force measurement, smoke-wire and hot-wire experiments were carried out at low Reynolds number and different angle of attacks. The location of sandpaper was chosen 15%-25% chord length and its height was 0.5 mm and 1 mm. Additionally, this study made previous study presented by Koca et al. [19] detailed and validated. As a result of the experiments, passive flow control could be obtained by using sandpaper and it could be said that it influenced the aerodynamic performance of airfoil by ensuring the effects on LSB.

2. EXPERIMENTAL RIG AND MEASUREMENT PROCEDURES

2.1. Wind Tunnel and Flow Conditions

The experiments were performed in wind tunnel installed in the Wind Engineering and Aerodynamic Research (WEAR) Laboratory at the Department of Energy System Engineering in Erciyes University. The wind tunnel is a low-speed suction type and it has 50 cm x 50 cm test section with a transparent plexiglass wall for visualization processes. It has a low free stream turbulence intensity in which it is demonstrated 0.3% at maximum speed (40 m/s) and 0.7% at minimum speed (5 m/s) [5].

2.2. Roughened NACA4412 Airfoil

The roughened NACA4412 airfoil was modelled and fabricated using 3D printer as depicted in Figure 1.

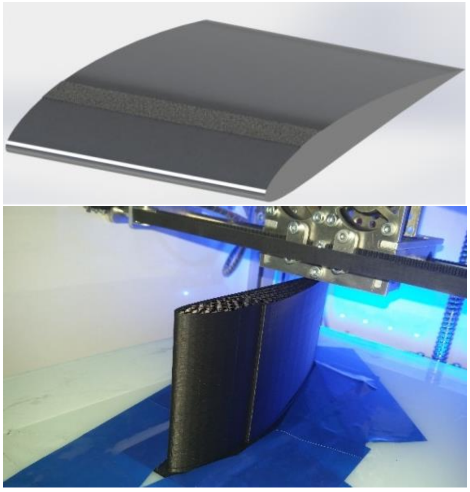

Figure 1. Fabricated process of roughened NACA4412 airfoil

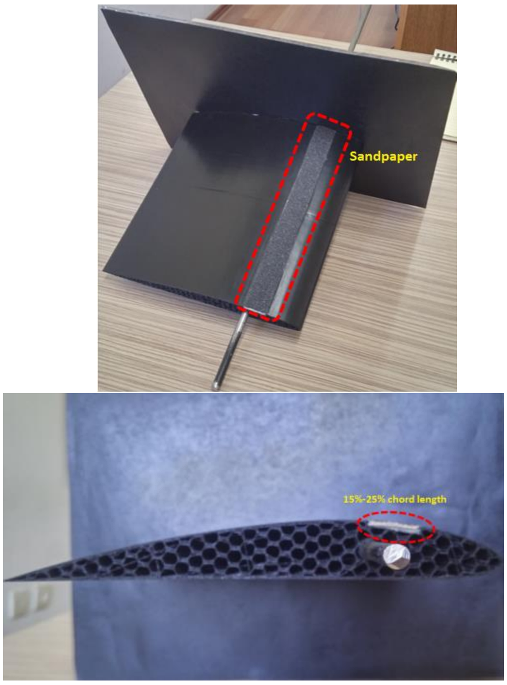

Figure 2. The location of sandpaper over NACA4412 airfoil

It was thought that the location of sandpaper would be suitable at 15-25% chord length as a result of numerical studies carried out in advance [19]. As seen in Figure 2, the sandpaper was mounted at 15-25% chord length. Furthermore, the end plates were used and fixed at each end of airfoil to prevent tip-vortices effects.

2.3. Hot-wire Experiment

To measure the velocity over the airfoil, turbulence intensity and Reynolds stress, hot-wire experiment was carried out at different Reynolds number and angle of attacks. It was measured using two dimensional hot-wire probe as shown in Figure 3. The probe was run from 0.1c to 1.1c thanks to traverse system. For more data about velocity, 10 cm top of airfoil was chosen and the probe was approached as possible as close to surface as seen in Figure 3.

Figure 3. The hot-wire experiment

2.4. Flow Visualization with Smoke-wire Experiment

For more detailed information about flow over the airfoil, it was visualized as flow sheets at low Reynolds number. The technique was formed with one slim wire, electrical resistive heating, the oil, a camera and spot lamps. The wire was located in front of 50 cm of airfoil. The electrical resistive heating was performed when small drops of oil were drained. After sheets of smoke were occurred and they were visualized with camera.

3. RESULTS AND DISCUSSIONS

3.1. Velocity Measurement Results over NACA4412 Airfoil

Velocity over the airfoil was experimentally measured by means of hot-wire experiment at low Reynolds number ranging from 25000 and 75000. The results of clean airfoil which means there was no roughness device over surface was showed at Figure 4 (a), (c) and (e), respectively. On the other hand, at Figure 4 (b), (d) and (f), the results of roughened airfoil were depicted at same Reynolds number. The roughness device was located at 15%-25% chord length and its height was 0.5 mm. Meanwhile, angle of attack was 8° at both experiments. As demonstrated in Figure 4 (a), the flow separated over the airfoil but the separated flow vanished when the Reynolds number was increased at Figure 4 (c) and (e) because inertial forces exhibited dominant role more than the viscous forces. As depicted in Figure 4 (b), the separated flow was also observed over roughened airfoil but both amount of separation was less than clean airfoil and separation point went to the trailing edge. Furthermore, the velocity apparently increased at roughened airfoil. Thus, it could be concluded that the amount of lift coefficient increased more than clean airfoil because the pressure over surface was less. At Reynolds number 50000 and 75000, the same cases were observed like Reynolds number of 25000. Either the laminar separation bubble size decreased or its location was changed when the roughness device was used on airfoil.

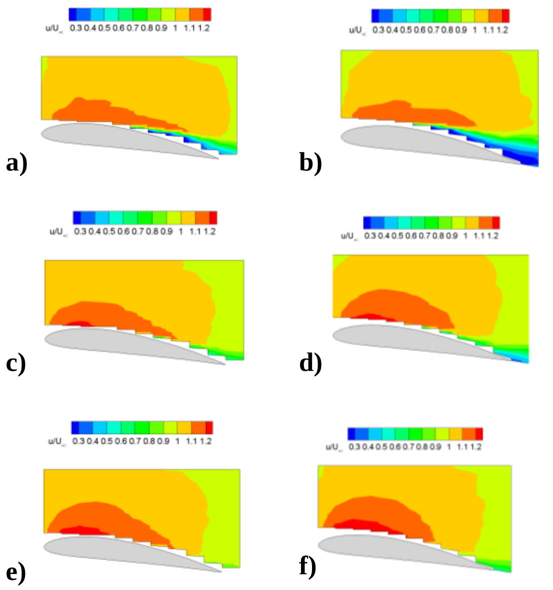

Figure 4. The hot-wire experiment results, α=8°, a) 25000, clean. c) 50000, clean. e) 75000, clean. b) 25000, roughened. d) 50000, roughened. f) 75000, roughened

Turbulence intensity and Reynolds stress over surface of roughened airfoil were also evaluated with operating hot-wire experiment at low Reynolds number and angle attack of 8° as indicated in Figure 5 and Figure 6. In Figure 5(a), (c), (e), it was observed that turbulence intensity was progressively decreased because of the fact that raising of inertial forces and decreasing of vortices effects on airfoil were occurred by increasing Reynolds number ranged from 25000 to 75000, respectively. As the similar result, the values of Reynolds stress derogated when Reynolds number was enhanced. On the other hand, the amount of turbulence intensity at roughened airfoil was more than clean airfoil. The flow gained energy and high momentum thanks to using roughness device and it easily passed the turbulence region on surface of airfoil. Thus, unsteady cases observed at transition region could be minimized by passing through turbulence region. As shown in Figure 6, same cases were occurred when the roughness device was utilized at different Reynolds number.

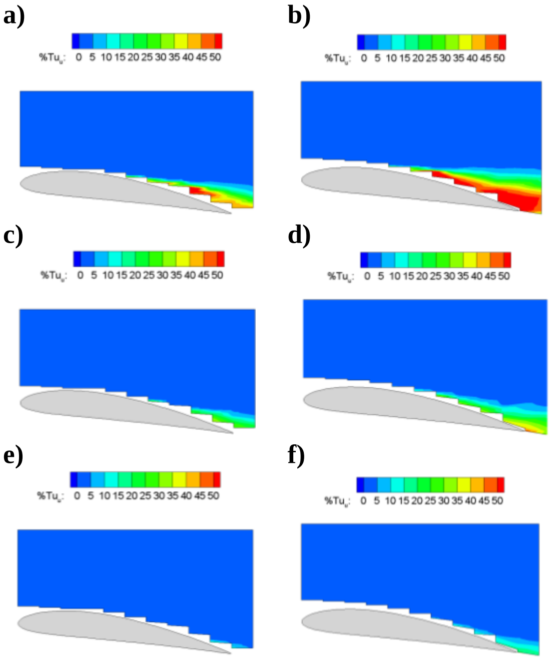

Figure 5. Turbulence Intensity results, α=8°, a-c-e) Clean, b-d-f) Roughened, a-b) 25000, c-d) 50000, e-f) 75000

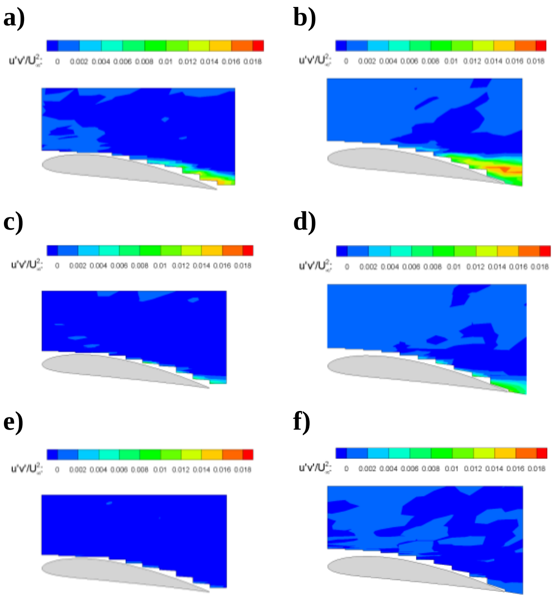

Figure 6. Reynolds Stress results, α=8°, a-c-e) Clean, b-d-f) Roughened, a-b) 25000, c-d) 50000, e-f) 75000

3.2. The Results of Smoke-Wire Experiment

Flow visualization with smoke-wire experiment was performed at Reynolds number of 25000 and angle of attack of 8° as depicted in Figure 7. Figure 7(a) referred to clean airfoil whereas Figure 7(b) mean to roughened airfoil. As seen at smoke sheets, the flow started to separate 0.3 chord length and reattached almost 0.7 chord length at Figure 7(a). Thus, long bubble occurred over the surface. Nevertheless, the flow separation was also observed at Figure 7(b) despite the roughness device was utilized but bubble size was apparently minimized with using of it.

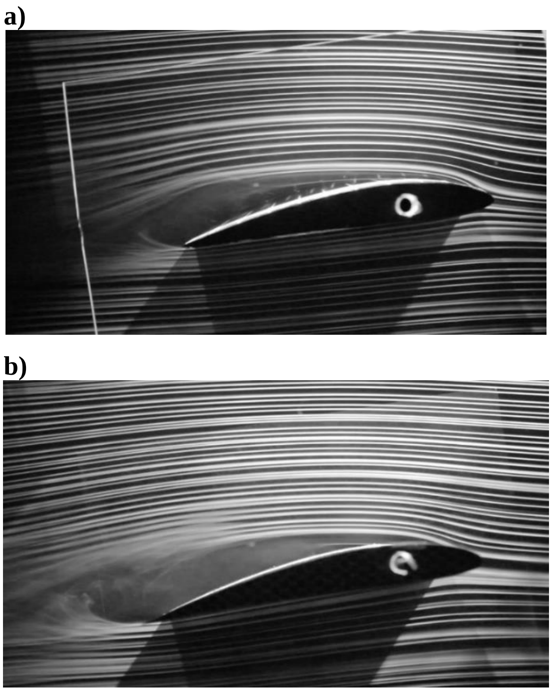

Figure 7. The flow visualization with smoke-wire experiment at Reynolds number of 25000, α=8°, a) clean, b) roughened

The laminar separation bubble size at Figure 8(a) was smaller than Figure 7(a) because of raising the inertial forces. Also, the flow almost separated at 0.4 chord length. As indicated in Figure 8(b), the laminar separation bubble continued to getting smaller when roughness device was used on surface.

a)

b)

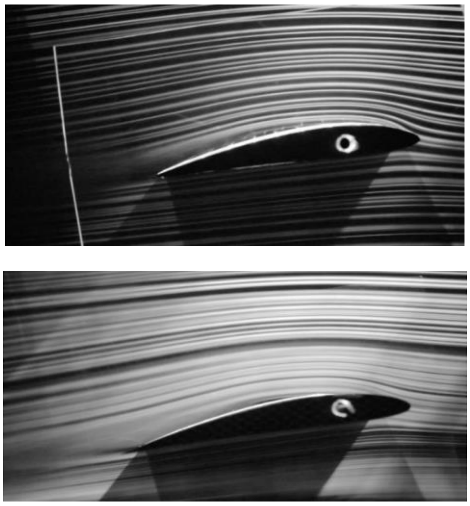

Figure 8. The flow visualization with smoke-wire experiment at Reynolds number of 50000, α=8°, a) clean, b) roughened

At Figure 9, same cases were happened despite of the fact that smoke sheets were weak owing to inertial force. Both the flow separation and the laminar separation bubble were observed at Reynolds number of 75000 as seen in Figure 9(a). At Figure 9(b), both the flow was more steady and the size of laminar separation bubble decreased by utilizing the roughness device.

a)

b)

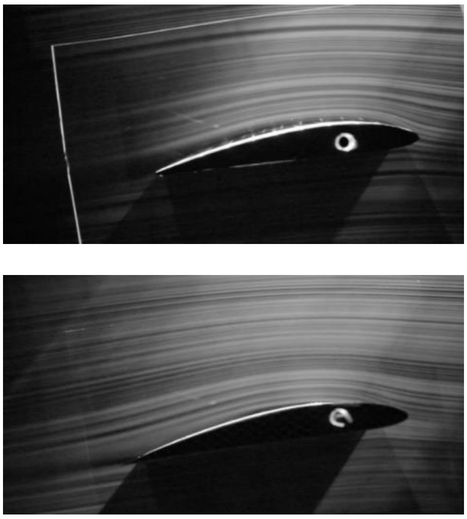

Figure 9. The flow visualization with smoke-wire experiment at Reynolds number of 75000, α=8°, a) clean, b) roughened

4. CONCLUSIONS

In order to flow control over NACA4412 wind turbine blade, experimental investigations including hot-wire and smoke-wire in conjunction with a roughness device mounted at surface of airfoil were carried out at Reynolds number ranging from 25000 to 75000 and angle of attack of 8°. According to the numerical studies in advance, the roughness device was located 15%-25% chord length and its height was selected 0.5 mm. As observed at both hot-wire and smoke-wire experiments, the flow phenomenon caused negative effect in terms of aerodynamic performance of airfoil like the laminar separation bubble or flow separation were affected when the roughness device was utilized because either the size of LSB was minimized or its location was changed by using of roughness device. As a result, it was shown that the use of sandpaper provided passive flow control and it was an effective way in terms of delay or suppress separation over NACA4412 airfoil.

5. ACKNOWLEDGEMENTS

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