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UNSTEADY STUDY OF A CONTAMINATED WIND TURBINE BLADE SECTION

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Abstract
A series of unsteady low speed wind tunnel tests on a section of a 660 Kw wind turbine blade under construction were conducted to examine the effects of distributed surface contamination on its performance characteristics. The following tests were conducted:

1. Clean airfoil
2. Contaminated Airfoil
3. High free stream turbulence

Model was tested at three mean angles of attack, 5, 10 and 18 degrees and the oscillation dominate of 5 degrees. Tests were done in different Reynolds numbers and oscillation frequencies. Results show that contamination decreases maximum lift coefficient more than 40 percent. However turbulence intensity and Reynolds number have a positive effect on the maximum lift coefficient for the contaminated model.

Introduction
About 20 years ago the first observations were made that wind turbines apparently could have more than one power level in the same wind. The first publication on the phenomenon was made by Madsen [1]. At several turbine parks in California one noticed different power levels, of which the lowest one was about half the design-level. Several initiatives were taken to understand and solve the problem, for example the study of Dyrmose and Hansen [2], the Joule project on Multiple Stall [3] and the analyses published by Risoe [4]. Since then the cause remained uncertain. Contamination of the blade leading edge cannot be avoided, and field measurements have demonstrated large power reductions due to this phenomenon. Pollution of the airfoil nose can even cause multiple stall levels of the rotor [5]. Dirt and contaminations accumulate on the wind turbine blade when it operates in the field. The main sources of the contamination are Insect compacts, ageing, sand impacts and the contaminations that come down with the rain. This contamination has a great role on the rotor performance. When insects, smog and dirt accumulate along the leading edge of the blade, power output can drop up to 40% of its clean value [6].

In this investigation a section of the HAWT rotor blade under construction was selected and various experiments were conducted to examine the effect of different parameters on its performance characteristics. To author's knowledge, no experimental or theoretical information about the performance of this blade is available. Thus a series of tests were conducted to study the blade behavior under various conditions.

Experimental facility
A low speed wind tunnel was used to conduct tests on the airfoil. Schematic view of the tunnel is shown in Figure 1. This closed circuit tunnel had a velocity range from 0 to 100m/s. Nominal test section dimensions were 80cm high, 80cm wide and 200cm long. The turbulence intensity in the test section was always less than 0.1% at all speeds.
The 25cm chord model was mounted horizontally in the test section with its two ends attached to the wind tunnel walls. Attached ends prohibited from tip vortexes generation hence the span wise streams eliminated and the test section flow was approximately two dimensional. There were 67 static pressure holes on the wing surface to measure the pressure on the model. Each hole was connected to a differential transducer and the other side of all transducers was connected to the test section static pressure. The pressure ports are located in an oblique line

so that the upstream holes do not affect the pressure on the downstream ones. The airfoil section and the holes position on the model are shown in Figure 2.
Sine wave forms having amplitude of 5 was used for these tests; the wave form is defined by the equation

$$\alpha = \alpha_m + 5\sin(2\pi ft)$$

Oscillation mechanism was included an inverter, an one hours power A.C. engine, a cam face ahead of engine and follower arm attached to the model support tube behind the wind tunnel wall.

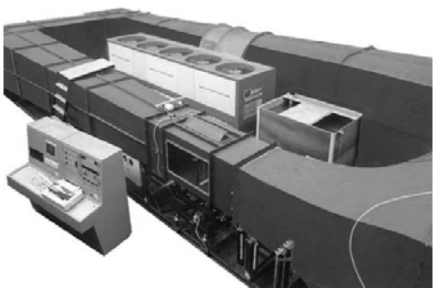

Figure 1- Schematic view of the tunnel

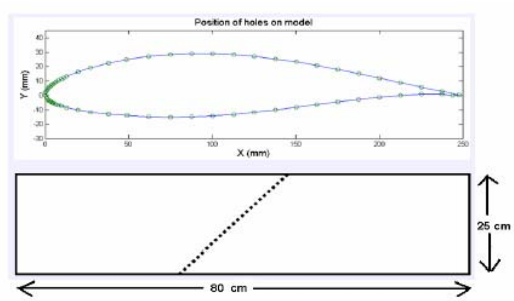

Figure 2- Holes position on airfoil section and wing

Clean model results

In the Reynolds number of 0.85×10^6 the static clean airfoil maximum lift coefficient was about 1.2 and it happed in 10.5 degrees angle of attack. The amount of maximum lift coefficient in the dynamic condition with the frequency of 1.3 was the same as static condition but this maximum lift coefficient took place in the 8.5 and the 12 degrees angle of attack. 12 degrees angle of attack was for upstroke stall and 8.5 degrees angle of attack was for down stroke stall, Figure 3. Down stroke stall happened in a smaller angle of attack because when the airfoil goes downward vertical upward velocity increases the airfoil's effective angle of attack. Upstroke stall was sharper than the down stroke stall and it was because of the existence of the leading edge vortex at the beginning of the down ward motion and the reattachment of the separated flow. When the airfoil's leading edge starts to come down a vortex is generated at the leading edge and it moves along the airfoil upper surface with the free stream. This vortex reattaches the flow. When the airfoil oscillated between the 5 and 15 degrees angle of attack, airfoil downward started at the angle of attack of 15 degrees and in this angle of attack the flow was separated from the most part of the upper airfoil surface so the leading edge vortex decreased the separation effects and caused a smoother stall in the down stroke motion than the upstroke one.
In this specific airfoil the Reynolds number has a negative effect on the maximum lift coefficient and decreases it from 1.35 in the Reynolds number of 0.43×10^6 to 1.2 in the Reynolds number of 0.85×10^6. Reynolds number had no particular effect on the stall angle of attack. Lift coefficient for clean airfoil in different Reynolds number can be seen in Figure 4.

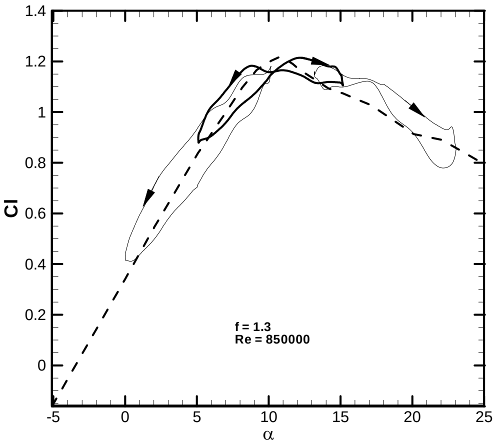

Figure 3- Lift coefficient of the clean airfoil in the 1.3 Hz frequency and the Reynolds number of 0.85×10^{6}

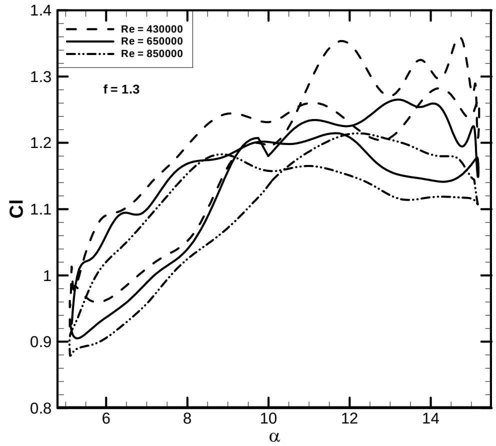

Figure 4- Reynolds effects on the clean airfoil lift coefficient

Contaminated model results

Contamination distribution on the wind turbine blade surface is not a uniform distribution. At the leading edge the contamination is more than the trailing edge due to the airfoil shape and the rotation direction. Leading edge contamination is about 4.5 times more than the trailing edge one. On the present airfoil model with 250mm chord, there are 18 roughness particles in each square centimeter at the leading edge while at the trailing edge there are only 4 roughness particles in each square centimeter. The roughness particles are distributed randomly with no pattern. Figure 5 shows the contamination model which was used on the model.

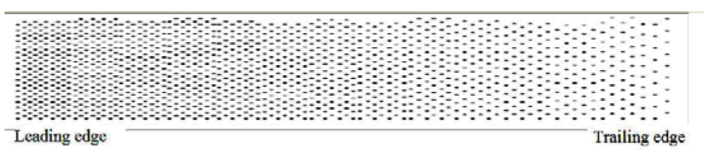

Figure 5- Contamination distribution model on airfoil

This contamination decreases maximum lift coefficient more than 40%, Figure 6. Contaminated blade section has a very smooth stall with respect to the clean airfoil. After stall, the lift coefficient in the clean model decreases rapidly but it is not significant in the contaminated one, so in the post stall region the difference between the clean and contaminated model lift coefficient decreases and they become close together.

To increase turbulence intensity in the test section a metal grid was installed before test section. This grid generates vortex and increases test section turbulence intensity up to 5 times. Turbulence intensity has an important roll in reducing the negative effect of roughness on the airfoil performance (Figure 7). Before the stall and in the linear part of the lift coefficient diagram turbulence intensity has no considerable effect on the lift coefficient on the contrary in the stall region and specially in the post stall region turbulence intensity increases the lift coefficient of the contaminated airfoil. When the turbulence intensity increases the pressure over the airfoil decreases but in the post stall region the pressure reduction on the upper surface is more then the lover surface.

Reynolds number and the oscillation frequency are two important parameters which have an important effect on the blade section performance. Increase in the Reynolds number decreases the effect of contamination on the model performance. Also as the oscillation frequency increases the performance of the contaminated model and in this condition the sensitivity of the model to the contamination decreases. Figure 8 and Figure 9 show the effects of oscillation frequency and the Reynolds number on the airfoil performance. It can be seen that in the Reynolds number of 0.43×10^{6} and the oscillation frequency less than one, the surface contamination decreases the lift coefficient about 43% but in the higher Reynolds number of 0.85×10^{6} and the oscillation frequency of 2.89 hertz this effect reduces to about 28% so in this two condition Reynolds number and the oscillation frequency could diminish the surface contamination effect up to 15%.

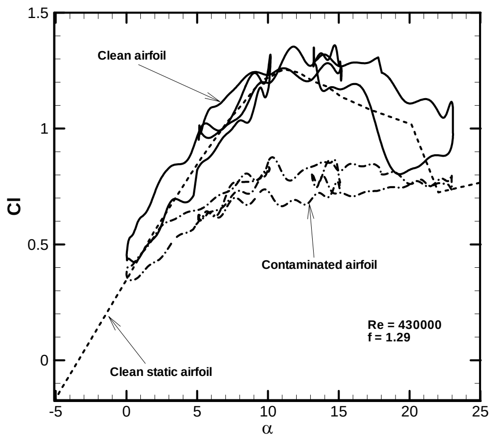

Figure 6- Surface contamination effect

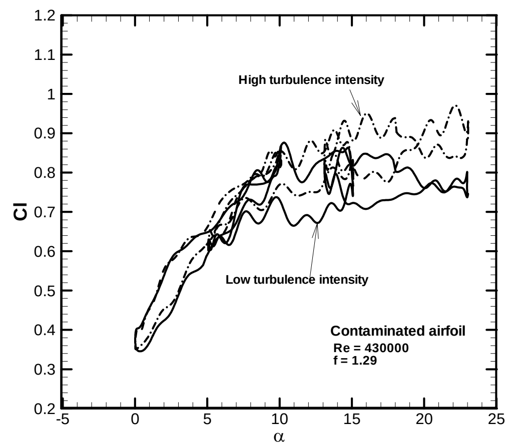

Figure 7- Turbulence intensity effect

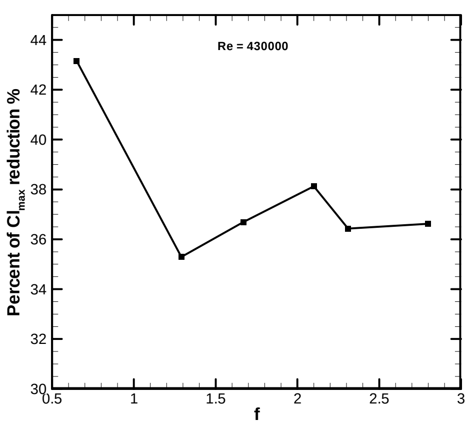

Figure 8- Effect of oscillation frequency on the contaminated airfoil, $\mathrm{Re}=0.43\times10^{6}$

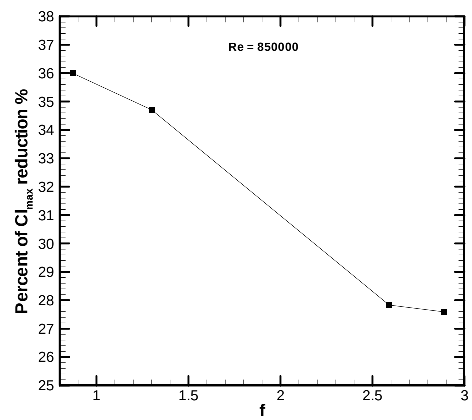

Figure 9- Effect of oscillation frequency on the contaminated airfoil, $\mathrm{Re}=0.85\times10^{6}$

Conclusion

Contamination distribution on the wind turbine blade section has a strong effect on its performance characteristics. It decreases the maximum lift coefficient more than 40% and it is very large amount and should be reduces by design airfoils which are less sensitive to surface contamination. By Increasing the oscillation frequency and the Reynolds number the effect of contamination decreases. Free stream turbulence intensity improves the aerodynamic performance of the blade section. This improvement is considerable in the stall and post stall region. Surface contamination causes realty but smooth stall so in the contaminated model after stall lift coefficient decreases little.

References

[1]. Madsen, H.A., “Aerodynamics of a Horizontal Axis Wind Turbine in Natural Conditions”, *Risoe* M 2903, 1991.
[2]. Dyrmose, S.Z., Hansen, P., “The Double Stall Phenomenon and how to avoid it”, *IEA*, Lyngby, Dec. 3-4 1998.
[3]. Snel, H.; Corten, G.P.; Dekker, J.W.M., et-al, “Progress in the Joule Project: MUST”, *EUWEC*, Nice, France, Mar. 1999.
[4]. Bak, C.; Madsen, H.A.; Fuglsang, P.; Rasmussen, F., “Double Stall”, *Riso*-R-1043(EN), June 1998.

[5]. Corten, G.P., Veldkamp, H.F., ''Insects Cause Double Stall,'' *2001 European Wind Energy Conference*, Copenhagen, Denmark, (2001) 470–474.
[6]. A.C. Hansen, C.P. Butterfield, “Aerodynamics of Horizontal- Axis Wind Turbine”, *Annual Review of Fluid Mechanics*, 25 (1993) 115-149.