5th International Conference
on
Wind Turbine Noise
Denver 28 – 30 August 2013

Aeroacoustic Noise Mitigation Investigation for Wind Turbine Blades

Michael Asheim Colorado School of Mines[1]
E-mail: masheim@mines.edu
Patrick Moriarty National Renewable Energy Laboratory[1]
Email: Patrick.Moriarty@nrel.gov
David Munoz Colorado School of Mines[2]
Email: dmunoz@mines.edu

Summary

As wind turbine rotors continue to grow, one of the constraints designers face is the noise limitations of the blades. The blade aeroacoustic noise sources scale by the 5th and 6th powers of the local flow velocity which forces designers to limit the rotational speed of machine to keep the noise at warranted levels. Past studies suggest that the interactions between the unsteady flow and the trailing edge seems to constitute the largest portion of the overall sound levels. Modifications to the trailing edge geometry will change how the fluid interacts with the trailing edge and can be used to change the resulting noise emission.

In a collaborative research effort between the National Renewable Energy Laboratory and the Colorado School of Mines a study investigated the effect passive trailing edge devices have on the overall noise emission of an industrial scale wind turbine. Through adding devices to sharpen the trailing edge of the test turbine, a noise reduction of nearly 1 dB_A was measured. The use of TE brushes reduced the overall noise level on the turbine by over 2 dB with a 3-4 dB reduction seen at higher wind speeds.

1. Introduction

The need to increase power performance and reduce noise of wind turbines has resulted in increased research activity surrounding noise mitigation strategies. These include design modifications to the airfoil geometry, turbine operational changes and the addition of aeroacoustic noise mitigating devices. A majority of the noise generated by the blades comes from the interactions of turbulence with the trailing edge of the blades. This also means that there is greater potential for aeroacoustic noise emission reduction through the modification of the trailing edge geometry. This paper will explore the theory and methodology that lead to the investigation of reducing aeroacoustic noise emissions through the use of trailing edge (TE) geometry modifications.

[1] National Renewable Energy Laboratory, 15013 Denver West Parkway, Denver CO 80401
[2] Colorado School of Mines, 1600 Illinois Street, Golden CO 80401

2. Experimental design

2.1 Background

The need to improve both the aerodynamic and acoustic performance of the blade has pushed trailing edges to be as sharp as possible. Results from a JOULE II project also showed that reducing the trailing edge thickness greatly reduced the tonal aeroacoustic emissions that are a result of the vortex shedding behind the blunt trailing edge[1].

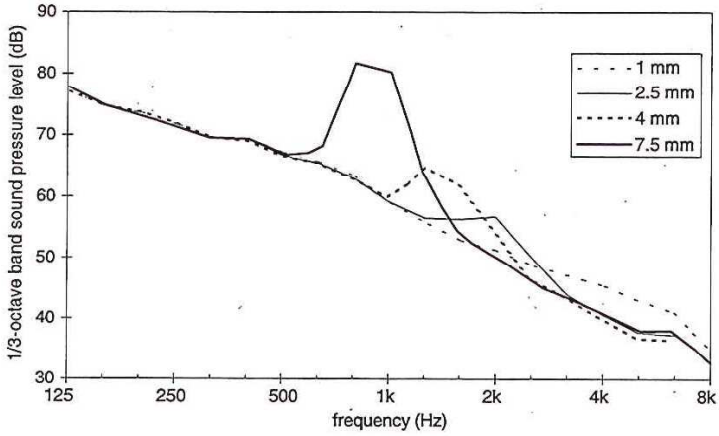

Figure 1: Bluntness Trailing Edge Noise Reduction due to Trailing Edge Sharpness[1]

Blake showed that the acoustic intensity of the trailing edge noise emissions is proportional to the $\cos^3$ of the angle between the local flow streamlines and the angle of the trailing edge[2]. He showed that the acoustic radiation efficiency of the noise emission off the trailing edge is maximized when the trailing edge is orthogonal to the flow streamlines, as it is for most wind turbine blade designs.

$$I \propto \rho_o c_o^{\,3} \cos^3(\bar{\theta}) M^5 \frac{sl}{r^2} \alpha^2 \cdot \sin(\varphi) \sin^2(\frac{\theta}{2}) \qquad \text{Equation 1}$$

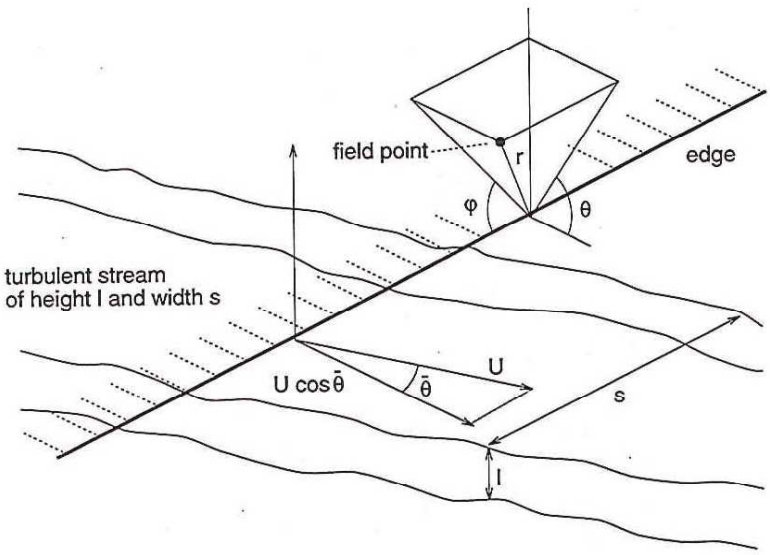

Figure 2: Geometry Corresponding to Equation 1[2]

Modifying the trailing edge angle to reduce the acoustic emission efficiency has lead to the use of serrated trailing edges, which has been verified both in the wind tunnel and on operational turbines in the field. In the SIROCCO project, serrations were examined with the use of an acoustic phased array of ~150 microphones [3]. The measurements seen in figure 3 show 1/3 octave bands of three different blade configurations. Through this project, it was seen that the serrated blade realized a 3.2 dB broadband reduction in aeroacoustic noise. The Sirocco blade was designed with special aeroacoustically quite airfoil design. Unfortunately the results of the measurements showed only marginal benefits from changing the airfoil shape (~0.5 dB broadband noise reduction), but the sirocco blade would benefit additionally from the use of TE devices to reduce the noise further.

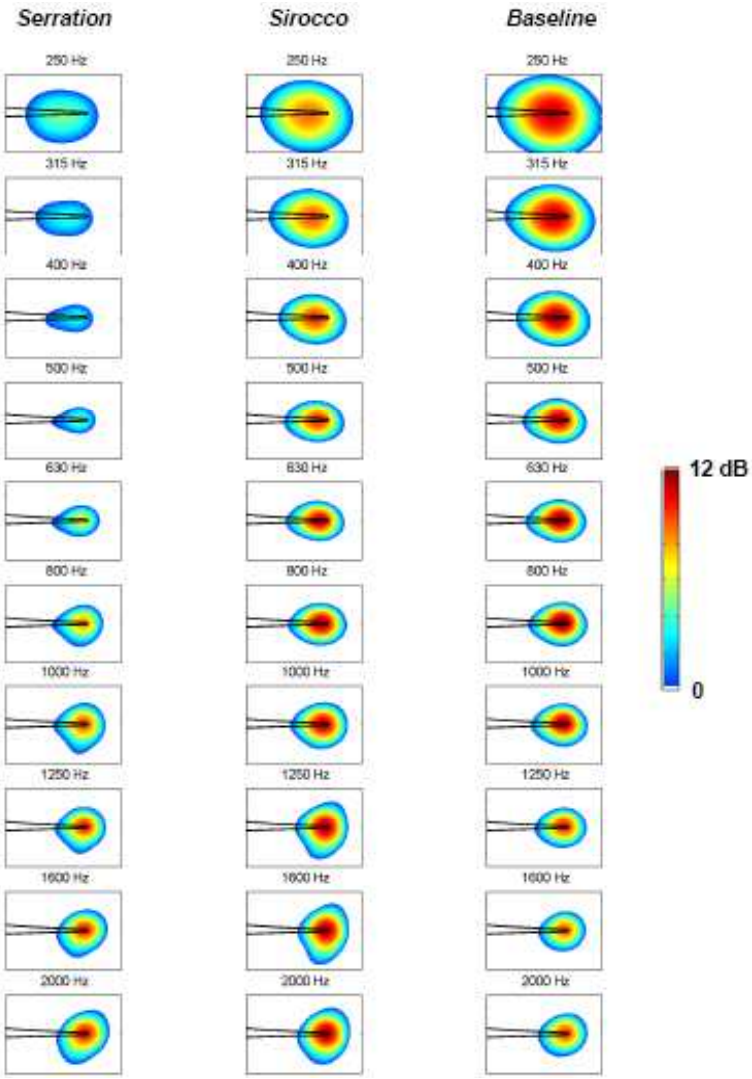

Figure 3: SIROCCO Noise Reduction Evaluation through the use of Acoustically Optimized Airfoils and TE Serrations

The German National Lab, DLR, has also investigated the use of trailing edge brushes to reduce the noise emissions of the turbine blades. In this experiment, Herr was able to see a broadband noise reduction of up to 10 dB on a flat plate test section[4], which is potentially a much greater reduction than those possible from trailing edge serrations.

The main focus of this paper is testing of trailing edge brushes would perform on an operational wind turbine in the field.

2.2 Methodology

In order to investigate trailing edge brushes on a turbine blade, the blades of the CART2, the two bladed Controls Advanced Research Turbine, located at the National Wind Technology Center (NWTC), were modified to include brush trailing edges.

Figure 4: CART 2 Test Turbine at the NWTC

The CART 2 is a two bladed, variable speed 600 kW Westinghouse HAWT. The hub height for the machine is 36.5 meters and if flies 21 m long blades. The turbine has variable speed operation in region II wind speeds, is torque controlled in region 2.5 and is pitch controlled in region 3. The main rotor spins with a max of 43 rpm, which equates to a max tip speed of 93 m/s (Mach number of 0.273). The blades of this turbine have a relatively thick trailing edge on the outboard 35% of the blade [from 7.62 mm (0.3” or 1% chord) to over 19.05 mm (0.75” or 1.6% chord) at 65% rotor radius]. The high tip speed and thick trailing edge make this the loudest turbine on site at the NWTC and a suitable candidate for noise mitigation testing.

The acoustic measurements made were conducted under the guidelines of the IEC 61400-11, “Wind Turbine Noise Systems: Acoustic Noise Measurement Techniques” [5]. This measurement technique requires the blades to be in the same aerodynamic and aeroacoustic configuration. This means that both blades need to be modified in the same way in order to get an averaged sound power level for each configuration tested. Although the measurements were performed in line with what is generally accepted as the standard measurement technique, it will have some inherent errors in the data due to the non repeatable atmospheric and wind inflow conditions. In order to reduce this uncertainty, multiple measurements were made on multiple days throughout the measurement campaign and the results shown below represent an average over all measurements for a given configuration.

3.0 Preliminary results

3.1 Baseline Measurement and Sharp TE configuration

The first set of tests performed on the CART2 looked at the effects of sharpening the trailing edge of the blade, which is relatively thick. In order to reduce the noise level due to the TE bluntness noise, sharpening “tacos” were applied to the trailing edge (TE) of the blades, as seen in figure 5. This has the benefit of creating blade trailing edge thickness ratios that are more consistent with modern wind turbine design (TE thickness to chord ratios of under 0.2%).

The trailing edge thickness was changed for the outboard 35% of the blade. At the tip the TE thickness was reduced from 7.6 mm (0.30”) to 1.5 mm (0.06”). This TE sharpening treatment continues inboard to 65.5% radius where the TE thickness was reduced from 16 mm (0.63”) down to 1.5 mm (0.06”). The results of the background corrected baseline and sharp TE case are shown in figure 6.

Figure 5: Sharpening Metal “Tacos” applied to outboard 35% of the blade

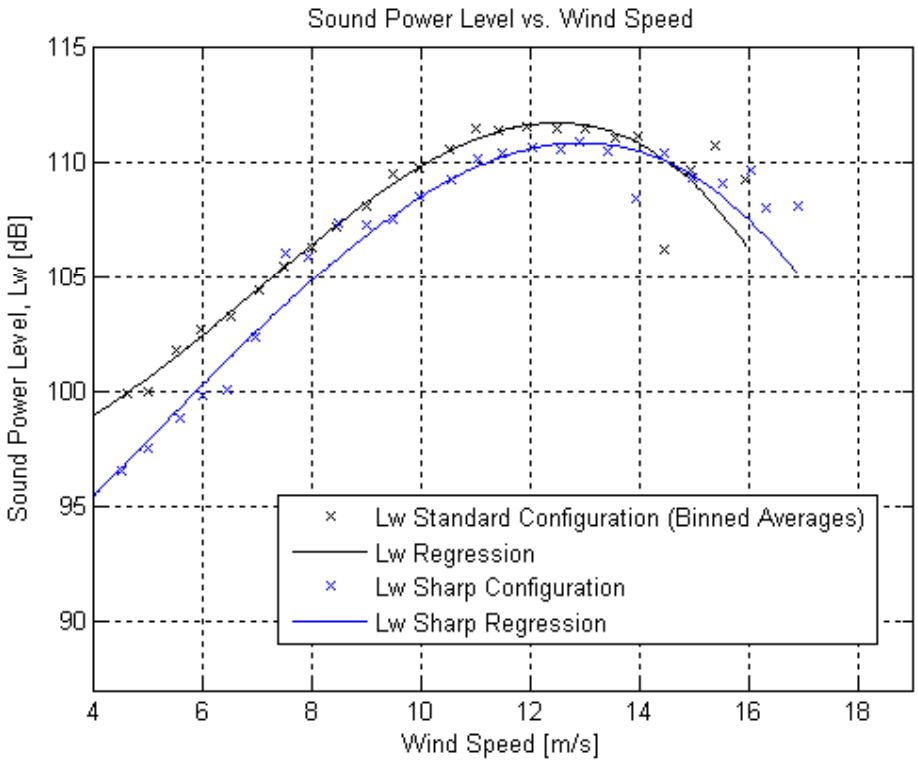

Figure 6: Background Corrected Noise Curves vs Wind Speed

The addition of trailing edge "tacos" to the CART 2 blades shows a noticeable reduction in the noise levels of the turbine, bringing the overall background corrected sound power levels down from 111.7dB$_A$ to 110.8 dB$_A$, an overall reduction of nearly 1dB.

3.2 Brushed Trailing Edge Measurements

The investigation into the use of trailing edge brushes began by adding a brush made of 0.025 inch diameter (0.635 mm) polypropylene fibers to the trailing edge of the outboard 35% of the blade span.

Figure 7: TE brushes installed on CART 2 Turbine

The brushes were tested at a length of 15% relative chord. Figure 8 shows the result of adding brushes to the blade.

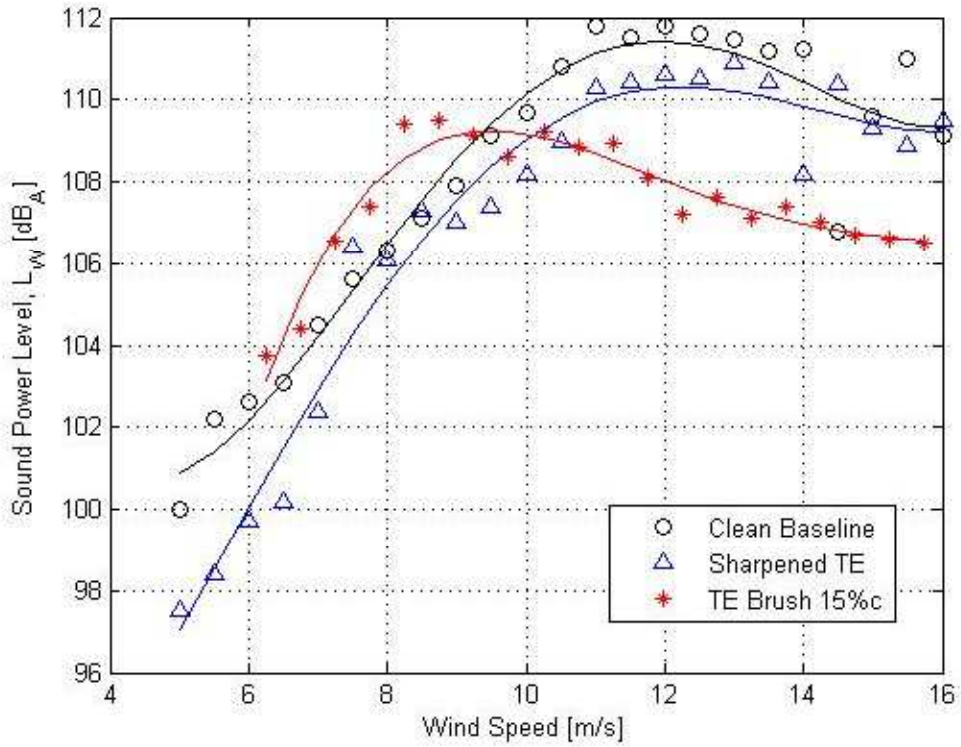

Figure 8: Comparison between TE configurations

The maximum level for this rotor operating with brushes was about 109.1 dB_A, but the max level is also reached at a much lower wind speed. This might be explained by added self noise of the brush fibers rubbing together. This effect is most pronounced in the lower wind speeds, where the rotational speeds are lower and background noise less .

After the main noise peak, the brushes offer a 3-4 dB reduction of the overall sound power level over most of the higher wind speeds.

4.0 Conclusions

The result of the trailing edge brushes is encouraging for future research. The brushes were able to reduce the maximum rotor level by 2.6 dB_A compared to the baseline blade or a reduction of 1.7 dB_A compared to the sharpened TE case.

More interesting is the relative shift of the acoustic levels for a given wind speed. The blade with the brushes is louder in the IEC measurement position at lower wind speeds, when the background noise levels are lower. The brushes begin to have a beneficial acoustic effect after 10 m/s hub height winds.

Additional work needs to be done to optimize the fiber diameter and length to use for optimal aeroacoustic noise mitigation

References

[1] Klug, H. et al “Aerodynamic Noise from Wind Turbines and Rotor Blade Modification.” Joule II, Project JOU2-CT92-0233, Final Report, DEWI-V-950006, November 1995

[2] Blake, W.K., “Mechanics of Flow-Induced Sound and Vibration, Vol. II: Complex Flow Structure Interactions. Academic Press Inc., Harcourt Brace Jovanovich, Publishers, pp. 426-973, 1986

[3] Oerlemans, S.; Fisher, M.; Maeder, T.; Kogler, K. “Reduction of Wind Turbine Noise using Optimized Airfoils and Trailing-Edge Serrations” AIAA Aeroacoustics Conference 2008, AIAA-2008-2819, 2008

[4] Herr, M. “Experimental Investigations in Low-Noise Trailing-Edge Design” AIAA Journal Vol. 43, No. 6, June 2005

[5] International Electrotechnical Commision’s: IEC 61400-11 “Wind Turbine Noise Systems: Acoustic Noise Measurement Techniques” First edition 1998-09.