DOI: 10.13009/EUCASS2017-104

7TH EUROPEAN CONFERENCE FOR AERONAUTICS AND AEROSPACE SCIENCES (EUCASS)

DOI: ADD DOINUMBER HERE

Quieter Propellers

Hsiao Mun Lee⋆, *Zhenbo Lu*⋆⋆ *and Heow Pueh Lee*⋆†
⋆*National University of Singapore*
Department of Mechanical Engineering, 9 Engineering Drive 1, Singapore 117576, Singapore.
⋆⋆*National University of Singapore*
Temasek Laboratories, Singapore 117411, Singapore.
mpelhm@nus.edu.sg · tslluz@nus.edu.sg · mpeleehp@nus.edu.sg
†Corresponding author

Abstract

Two propeller blades were fabricated and tested in an anechoic chamber for thrust force and noise measurements in order to investigate the effectiveness of serrations on reducing propeller trailing edge noise. Half flat tip serrations were applied at the trailing edge of the propeller from $0.6R$ until the tip of the blade. The serrated propeller had the best performance at 3000 rpm and it obtained the highest insertion loss at 172 Hz which was about 29.6 dBA. By overall, the serrated propeller obtained the highest noise reduction at 3000 rpm which was about 5.8 dBA. The loss of the thrust force decreased gradually with the increasing of the rotating speed where the serrated propeller lost about 27.1% of its thrust force at 1500rpm.

1. Introduction

Aerodynamic noise is one of the major issues for the wide-spread use of rotating machinery such as wind turbine, propeller and pump. For a modern rotating machinery, aerodynamic noise generated by the blades is generally considered to be the dominant noise source, provided that the mechanical noise is adequately treated. There are two types of aerodynamics noises[1] where the first type is the turbulent inflow noise. This noise is caused by the interaction of upstream atmospheric turbulence with the blade and it depends on the atmospheric conditions. The second type is the airfoil self-noise which is produced by the blade in an undisturbed inflow and it may be caused by several mechanisms such as trailing edge/turbulent boundary layer interaction noise (denoted as trailing edge noise), blade tip noise and trailing edge laminar boundary layer vortex shedding noise. Several methods were developed to overcome the issue of airfoil self-noise such as serrated edges, trailing edge brushes and porous surface. The most common and effective method which is the serrated edges is selected to be studied in the present works.

Hersh et al.[4] interpreted a series of leading-edge serrations as a device for reducing vortex noise radiated from stationary and rotating airfoils in low Reynolds number flow. They concluded that noise levels of the airfoil were reduced considerably with the serrations attached. Dassen et al.[3] explored the noise reducing potential of serrated trailing edges on a series of airfoils and flat plates through wind tunnel measurements. Their results showed that all serrated airfoils yield reduced trailing edge noise levels ranging from 3 dB to 8 dB. The serrated flat plates were found to give reductions up to 10 dB. Howe[5] investigated the sound produced by the low Mach number turbulent air flowed over the trailing edge of a serrated airfoil. He claimed that at high frequencies, the predicted attenuation was about 1 dB and 7 or 8 dB when $\lambda/l \asymp 10$ and λ/l=1, respectively. λ and l were the serrations spanwise length and amplitude, respectively. Oerlemans et al.[10] conducted acoustics field measurements on a 94 m diameter three-bladed wind turbine with one standard blade, one blade with an optimized airfoil shape and one blade with trailing edge serrations. They claimed that both modified blades showed a significant trailing edge noise reduction at low frequencies where overall noise reductions of 0.5 and 3.2 dB were obtained for the optimized and serrated blades, respectively. Ito[6] imitated the serrations at the leading edge of owl wings by attached some jigsaw blades on the airfoil leading edge during his experiments. He claimed that the lift characteristics of the airfoil were improved with fine serrations in low flow Reynolds number.

Madadnia et al.[9] designed some serrations and attached them on the leading and trailing edges of the wind turbine blades in order to proactively control aerodynamic noise. Their results showed that the serrations could reduce noise up to 10% and the serrations were more effective at higher tip speed ratio. Klimchenko and Jones[7] conducted an experimental study to characterize the effects of winglet and serrated tip rotors on the wake dissipation of a small-scale offshore wind turbine using particle image velocimetry system. In their study, the tip vortices of the serrated tip

DOI: 10.13009/EUCASS2017-104

rotor were found to be large and less uniform than the baseline or winglet rotors. Madadnia and Nurdin[8] reported the effectiveness of Owl-wing serrations in minimize the aerodynamic noise generated by a micro model wind turbine. Chen et al.[2] investigated the effects of nine leading edge serrations on the blade laminar boundary layer instability noise from low to moderate Reynolds numbers using experimental method. They concluded that the performances of the serrations were very sensitive to serration amplitude and wavelength where blade with larger serration amplitude and smaller wavelength had better performance which could obtain maximum noise reduction of 30 dB. Intravartolo et al.[2] used serrated trailing edges and proplets to reduce the tip vortices and trailing edge wake of the UAV propeller blades. They found that increasing of the serration depth showed a maximum 28% decrease in the propeller noise while maintained thrust within ±5% of the base APC 9x6E propeller.

It can be seen that the reported studies on serrated leading or trailing edges were mostly confined to wind turbine and airfoil while only limited study was conducted to investigate the case of propeller. Propeller is commonly used in ship, aircraft and boat. Therefore, the main objective of the current effort is to use experimental method to investigate the effectiveness of half flat tip serrations on reducing propeller trailing edge noise. The serrations are applied on the propeller trailing edge instead of leading edge in the present works because airfoil-self noise noise is caused by the interaction between the flow boundary layer and the trailing edge of the blade as mentioned in the previous statement.

2. Experiment set-up

The experiments were consisted of a Bruel & Kjaer microphone (model 4953), a tachometer, a brushless motor, a speed controller and an ATI load cell (model Mini40) as shown in figure 1. The experiments were conducted inside an anechoic chamber. The microphone was positioned on top and at 0.6 m away from the propeller as shown in figure 1. The experiments were conducted for two different propeller blades as shown in figure 2 in order to investigate the effects of half flat tip serrations (see figure 2(b)) on reducing propeller trailing edge noise. The radius (R) of the propeller was about 0.225 m and the serrations were applied at trailing edge from $0.6R$ until the tip of the blade. The λ/l of the serrated propeller was about 1.1 which was estimated to produce noise reduction of 7 or 8 dB according to Howe.[5] The rotating speeds of the propeller were varied by the speed controller from 1500 rpm to 3000 rpm with interval of 500 rpm and was measured using the tachometer. All data were recorded using the microphone from 120 Hz to 12000 Hz with interval of 1.5 Hz. Three samples were recorded for each rotating speed. The thrust force produced by the propeller at each rotating speed was also measured using the load cell.

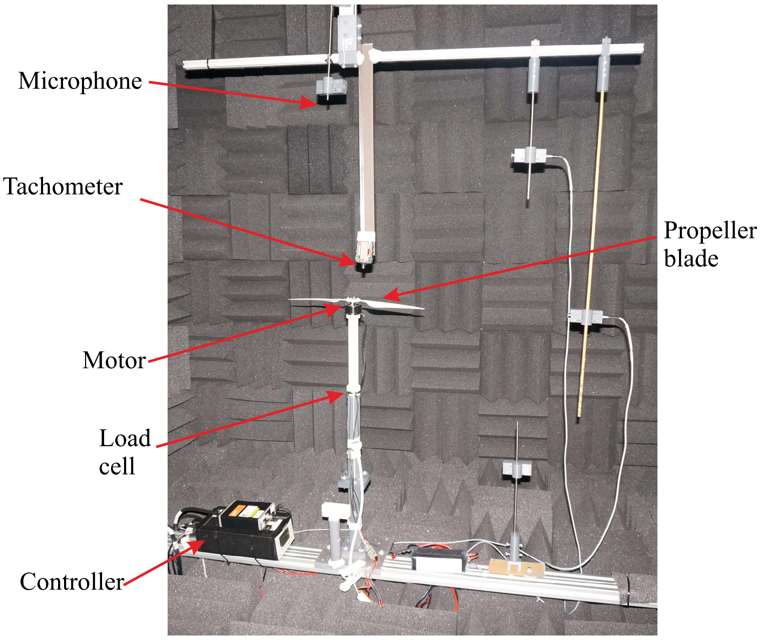

Figure 1: Experimental set-up of the thrust force and noise measurements for the propeller inside an anechoic chamber.

The insertion loss (IL) was defined as:

$$\text{IL} = \text{SPL}_{\text{original blade}} - \text{SPL}_{\text{serrated blade}}, \tag{1}$$

DOI: 10.13009/EUCASS2017-104

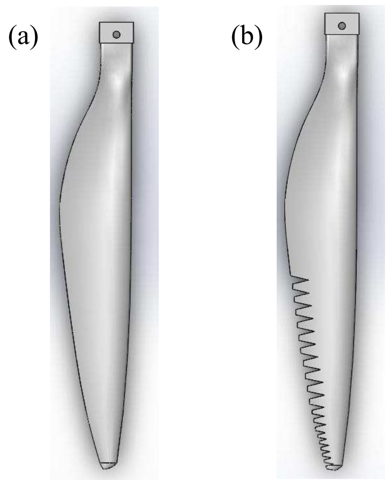

Figure 2: Geometry of the propeller blades. (a)Original blade (b)serrated blade.

Table 1: ΔLA_{eq} obtained by the serrated propeller under different rotating speeds.

Rotating speed (rpm)	1500	2000	2500	3000
ΔLA_{eq} (dBA)	2.6	1.9	0.4	5.8

where SPL is the sound pressure level. Equivalent SPL (LA_{eq}) was calculated for each set of data by taking into account contribution of noise from each frequency which is given by:

$$LA_{eq} = 10Log(\sum_{i=1}^{n} 10^{(\frac{SPL_i}{10})}). \tag{2}$$

After that, reduction of LA_{eq} (ΔLA_{eq}) is obtained by:

$$\Delta LA_{eq} = LA_{eq(\text{original fan})} - LA_{eq(\text{serrated fan})}. \tag{3}$$

The loss of the thrust force (Δf) is defined as:

$$\Delta f = \frac{f_o - f_s}{f_o}, \tag{4}$$

where f_o and f_s are the thrust forces produced by the original and serrated propellers, respectively.

3. Results and Discussion

Figure 3 shows the insertion loss obtained by the serrated propeller under different rotating speeds. Generally, the serrated propeller obtains high IL at low frequencies and then it decreases gradually until 3200 Hz before it increases smoothly to 5300 Hz for all rotating speeds. The trends of the IL are quite fluctuating for all rotating speeds at frequencies higher than 8000 Hz. It is obvious that the serrated propeller has the best performance at 3000 rpm and it obtains the highest IL at 172 Hz which is about 29.6 dBA. The results obtained are opposing with what was concluded by Howe[5] where he claimed that serrated airfoil performed better at high frequencies. Table 1 shows the ΔLA_{eq} obtained by the serrated propeller under different rotating speeds. By overall, the serrated propeller obtains the highest noise reduction at 3000 rpm which is about 5.8 dBA and then followed by 1500 rpm, 2000 rpm and 2500 rpm. Table 2 shows the Δf under different rotating speeds. It can be observed that the loss of the thrust force decreases gradually with the increasing of the rotating speed where the serrated propeller lose about 27.1% of its thrust force at 1500rpm.

Table 2: Δf under different rotating speeds.

Rotating speed (rpm)	1500	2000	2500	3000
Δf (%)	27.1	24.2	22.2	21.8

DOI: 10.13009/EUCASS2017-104

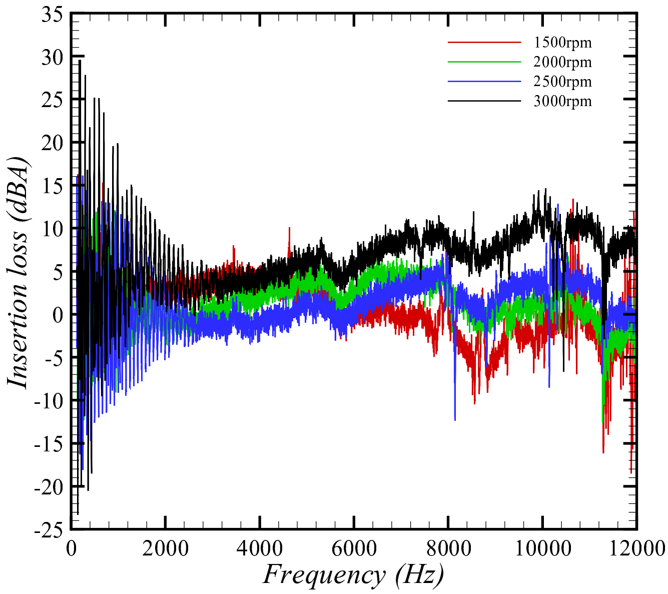

Figure 3: Insertion loss obtained by the serrated propeller under different rotating speeds.

4. Conclusions

Two propeller blades were fabricated and tested in an anechoic chamber for thrust force and noise measurements in order to investigate the effectiveness of serrations on reducing propeller trailing edge noise. Half flat tip serrations were applied at the trailing edge of the propeller from $0.6R$ until the tip of the blade. The propeller were tested under different rotating speeds from 1500rpm to 3000 rpm with interval of 500rpm. The serrated propeller had the similar trend of IL for all rotating speeds. The serrated propeller had the best performance at 3000 rpm and it obtained the highest IL at 172 Hz which was about 29.6 dBA. By overall, the serrated propeller obtained the highest noise reduction at 3000 rpm which was about 5.8 dBA. The loss of the thrust force decreased gradually with the increasing of the rotating speed where the serrated propeller lost about 27.1% of its thrust force at 1500rpm.

5. Acknowledgments

This material is based on research/work supported by the Singapore Ministry of National Development and National Research Foundation under L2 NIC Award No. L2NICCFP1-2013-8.

References

[1] M. F. Barone. Survey of techniques for reduction of wind turbine blade trailing edge noise. *Sandia National Laboratories*, 2011.

[2] W. J. Chen, W. Y. Qiao, F. Tong, W. H. Duan, and T. J. Liu. Effect of leading-edge serrations on boundary layer instability noise. *Hangkong Xuebao/Acta Aeronautica et Astronautica Sinica*, 37(12):3634 – 3645, 2016.

[3] T. Dassen, R. Parchen, J. Bruggeman, and F. Hagg. Results of a wind tunnel study on the reduction of airfoil self-noise by the application of serrated blade trailing edges. *National Aerospace Laboratory*, 1996.

[4] A.S. Hersh, P. Soderman, and R.E. Hayden. Investigation of acoustic effects of leading-edge serrations on airfoils. *Journal of Aircraft*, 11(4):197 – 202, 1974.

[5] M.S. Howe. Aerodynamic noise of a serrated trailing edge. *Journal of Fluids and Structures*, 5(1):33 – 45, 1991.

[6] S. Ito. Aerodynamic influence of leading-edge serrations on an airfoil in a low reynolds number: A study of an owl wing with leading edge serrations. *Journal of Biomechanical Science and Engineering*, 4(1):117 – 122, 2009.

DOI: 10.13009/EUCASS2017-104

[7] V. Klimchenko and A. R. Jones. An experimental study of the effects of winglets and serrations on the wake of a wind turbine. In *53RD AIAA Aerospace Sciences Meeting*, Fluorida, United states, 2015.

[8] J. Madadnia and M. F. Nurdin. Acoustic emission minimization in a wind turbine using trip-wires and owl-wing-serrations. In *ASME 2015 9th International Conference on Energy Sustainability collocated with the ASME 2015 Power Conference*, volume 2, California, United states, 2015.

[9] J. Madadnia, M. Shekeb, and T. Ulluwishewa. Experimental study of aerodynamic noise from the trailing edge and leading edge of blades in a coaxial-double shaft fan. In *ASME 2013 Fluids Engineering Division Summer Meeting*, volume 1 B, New York, United states, 2013.

[10] S. Oerlemans, M. Fisher, T. Maeder, and K. Kogler. Reduction of wind turbine noise using optimized airfoils and trailing-edge serrations. *AIAA Journal*, 47(6):1470 – 81, 2009.