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REVİEW: AEROACOUSTIC ANALYSIS IN WIND TURBINES

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Abstract: In this study, the aeroacoustic issue in wind turbines used to convert wind energy, which is one of the renewable energy sources, into electricity was investigated. In this context, previous studies and applications were investigated in detail. As a result of these investigations, the parameters effecting the aeroacoustic result were examined and the effects on the result were determined. With this study, a broad content review was revealed.

Keywords: Wind Turbines, Aeroacoustic, Review.

I. INTRODUCTION

Today, the fluctuation of oil prices, the depletion of fossil fuel reserves and the negative effects of fossil fuels and energy production on the environment have led the countries to turn to renewable energy sources. Renewable energy sources are unlimited energy sources that do not create environmental pollution. On the other hand, the use of these resources, which can be found in every country and which are completely free, reduces the dependence of countries on energy.

Among the renewable energy sources today, wind energy is the most widely used. It is also the most economical of the renewable energy resources available. The use of wind energy in the production of electrical energy is constantly increasing in the world. China, which is the world leader in this field, has 148 000 MW of wind energy installed capacity. The USA is followed by 747 MW, Germany 45 192 MW, India 24 759 MW, Spain 22 987 MW and England 13 614 MW (World Wind Energy Association, 2015).

The European Union aims to use the 2030 target to use renewable energy more widely and in different ways; The wind power of 323 GW is determined by its installed capacity (Wind Europe, 2017). Total wind energy generation capacity in the EU 12 thousand 800 megawatts of electricity generation capacity of 28 thousand 900 megawatts, which was commissioned in 2015, or 44 percent of the total electricity generation, was caused by wind power plants. In Turkey, as of the end of 2015, the installed capacity of wind energy has

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reached 4718 MW. The amount of installed power, which is very low compared to the leading countries, is increasing day by day.

Compared to the end of 20015 and the end of 2016, it is one of the countries with a high installed capacity is Turkey with 25.4%. This shows us that the importance of wind energy in Turkey has started to be given. With 88,000 MW of technical potential, Turkey is a country favorable to the development of wind energy. Throughout the world, wind power and electricity generation are becoming more widespread and in the following years, consumption will be met by larger winds.

Wind turbines installed to meet energy needs also have some negative aspects. One of them; the high level sound problem they emit. Due to this problem; wind turbine farms cannot be installed close to cities or habitats. In addition to the noise pollution that people give to their living spaces; this negative phenomenon, which may damage the ecological balance by changing the migration route of seasonal birds, can be solved by presenting aeroacoustic solutions.

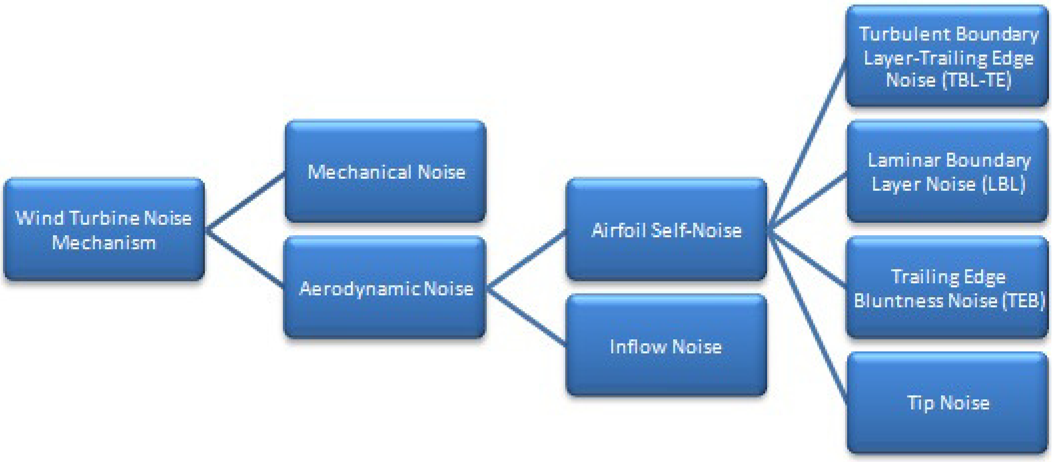

Fig. 1. Sound Generation in Wind Turbines (Brooks ve Schlinker, 1983)

Sound is produced in two ways in wind turbines. These; mechanical noise and aerodynamic noise. Mechanical noise; gearboxes and moving parts inside the generator. The noise occurring in this way can be reduced by using technologies such as acoustic insulation. However, aerodynamic noise sources are more complex and not easy to control.

Aeroacoustic sources; monopoly, dipole, and quadrupole. Monopoly and dipole sources; it is a strong emitter of acoustic energy. Quadropol sources are welded away from surfaces and are weak emitters. As an example; high turbulent flow around the wind turbine. Aerodynamic noise from a wind turbine; it is caused by the unstable flow on the turbine blades surface, resulting in strong dipole sources.

Brooks and Schlinker (1983); they developed two main aero-acoustic noise mechanisms to facilitate the understanding of complex sources and to apply models in the semi-empirical noise estimation code. The first mechanism is swallowing noise, a function of vortex turbulence. They showed that low-frequency forces in the acoustic noise spectrum were mainly caused by turbulent input.

The second noise mechanism is the sound produced by airfoils, a function of machete geometry. The sound produced by airfoils can be divided into different subheadings. These; The rear edge noise of the turbulent boundary layers can be separated as separation and stall noise, rear edge blindness, swirl oscillation noise, and tip vortex noise.

As an alternative to empirical methods, Computational Flow Dynamics and Computational Aeroacoustic Methods are used. For accurate estimation of noise generation in a wind turbine; Near the surface of the blade requires well-resolved transient flow field data. Methods such as Direct Numerical Simulation (DNS) or Large Eddy Simulation (LES) can be used to calculate the irregular turbulent flow field. These methods; They need very fine mesh particles around the airfoil surface. In order to avoid numerical instability when a thin mesh is used, the simulation requires high solution requirements. The LES solution is cheaper than DNS and yields acceptable results in the aeroacoustic analysis (Wasala et al., 2015).

II. ACADEMIC STUDIES RELATED TO THE SUBJECT

2.1. Experimental Studies

Migilore (2009); did aeroacoustic tests in wind tunnels. The purpose of these tests is; The aim of this course is to investigate the effect of boundary layer effect on acoustic emissions, the effect of end region form and the effect of back edge thickness. These tests were carried out under realistic conditions with 170.000 to 397.000 Reynolds numbers. During the experiments, 6 tip shape, 3 boundary layer height, 2 back edge thickness, and 72 speed/attack angle point were used. In the experiments performed at low speeds (Reynolds Number: 170,000), a difference of 3.8 dB was observed at the total sound pressure level. However, in high-speed experiments (Reynolds Number: 315.000) this difference decreased to 1.3 dB. Based on these results; It is concluded that tip shape rotation is an important factor for reducing noise in wind turbine blades.

Lee et al. (2012); experimentally tested the noise mechanisms of large modern wind turbines. First, they used the sound measurement processes of IEC 61400-11 in the field test and evaluated the noise emissions. They used 1.5-MW stall-control and 600 kW pitch-regulated turbines. Third octave sound levels; they normalized using the speed scale, which is based on the input noise and the sound of the wing itself. They found that the turbulence noise was dominant in the entire frequency range for wind turbines with a capacity of 1.5 MW. For turbines with a power output of 660 kW, the input turbulence noise was not effective.

Mohamed (2016); made an innovative design to reduce noise in vertical wind turbines. Design; As can be seen from the figure below; Each palette was formed using two airfoils leaving spaces between them.

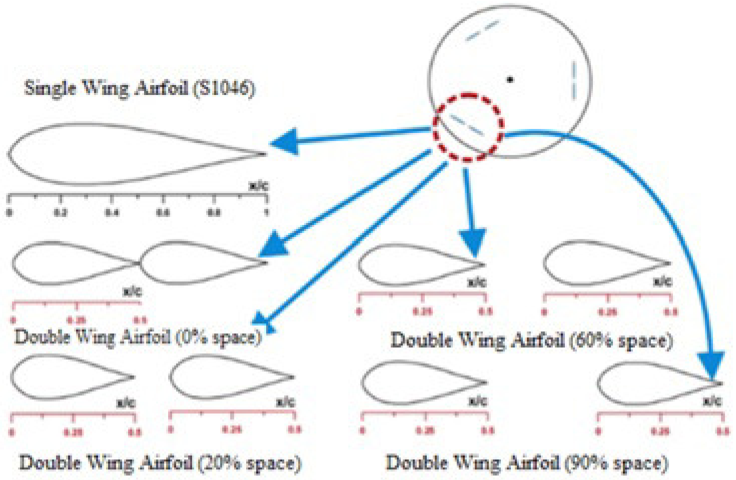

Fig. 2. Wind Turbine Wing Design Using Double Airfoil (Mohamed, 2016)

The results of the analyses carried out for each of the new design double airfoils containing 0%, 20%, 60%, and 90% gap; The double airfoil design created with 60% clearance was the most efficient in terms of aeroacoustic. The new configuration reduced the average volume by 56.55%.

Mohamed (2014); In his study on the noise of the Darrieus turbines, which are suitable to be established in the densely populated area of the cities; Using the method based on the Ffowcs-Williams and Hawking's equations; investigated the effect of propeller shape, tip velocity ratio and rigidity. The turbine-induced noise emission decreased by 7.6 dB when the stiffness ratio was reduced from 0.25 to 0.1. Also; The noise reduction between the turbine and the receiver is 5.86 dB per unit.

Kim et al. (2010); 3-blade, with a rotor diameter of 6.4 m, designed an airfoil optimized for 10 kW wind turbines with a nominal speed of 200 rpm and a wind speed of 10 m/s. DU 91-W2-250 and DU 93-W-210 airfoils; optimized for good aerodynamic performance and maximum drift rate. 51% improvement was achieved on the new design airfoil, where the angle of attack was 7 degrees, the ratio of the lift coefficient to the coefficient of friction (C_l / C_d) was 90 and the blade position was 75% from the root. Using

X-FOIL for incompressible flow with Reynolds number $1.02x10^6$ and Mach number 0.145, numerical analysis of the flow and noise analysis using WINFAS were performed. For the optimized wing, an overall decrease of 2.9 dB was found in the SPL.

The results of investigations to assess the effect of turbulence on the micro-scale horizontal axis wind turbine (HAWT) induced noise emission was reported by Rogers et al. (2012). Two experiments were conducted to determine the emission of gas from the micro-wind turbine (MWT). In the first experiment, the first octave sound levels were measured in order to quantify the sound spectrum in MWT. In the second experiment, noise emissions from the same MWT were measured with the effect of turbulence. As a result; turbulence density doubled to 0.3 to 0.6 doubling the volume of sound energy was observed. The reason for this increase in noise propagation was determined as the reason for the rapid changes in wind direction in turbulence regions due to the delay in the rotor monitoring.

Lee et al. (2019); an echo-free room; quarter flat end, half flat end, and rectangular jagged tip were used for comparative experiments to reduce edge noise. They determined the acoustic measurement distance as 0.6 m for the experiments performed at speeds ranging from 1500 rpm to 3000 rpm. They saw that the performance of the quarter-flat winged wing remained weak compared to others. However, they observed that the performance of the half-flathead wing is good at all rotational speeds and in all positions. When the speed of rotation is high (3000 rpm), this type of wings has managed to reduce a large amount of noise (5.8 dBA) in the wide frequency range (1000 Hz to 12000 Hz). The rectangular serrated wing performed well at a rotational speed of 2000 rpm, ranging from 3000 Hz to 8000 Hz, and achieved a noise reduction of up to 3.1 dBA. In general, according to the other two wing geometry of the half-flat tipped wing; It has been observed that it has the best performance in terms of reducing noise. In addition, the loss of thrust force was 16.8% lower than the rectangular tip.

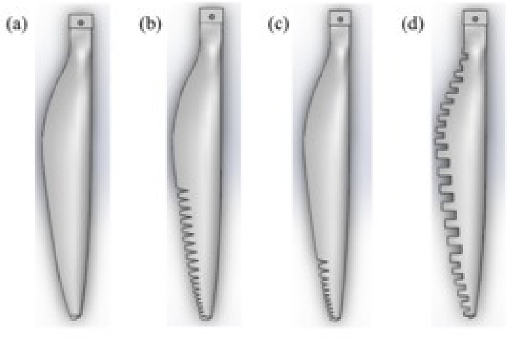

Fig. 3. The geometry of the different propeller blades (a. Basic, b. Half flattened, c-quarter flattened, d. Rectangular Edge) (Lee et al., 2019)

Moreau et al. (2012); using sharp-edged flat plates in the low-to-moderate Reynolds number; studied experimentally the effect of laminar, transitional and turbulent boundary layers on rear edge noise. They measured the mean and unstable speed data on the rear edge in the $Re_C=0.7x10^5-2.7x10^5$ range using hot-wire anemometry. These measured data relate to remote area noise measurements to determine the flow mechanisms responsible for rear edge noise. According to the experimental results, tonal noise is managed by vortexes formed at the rear edge. They found that the noise emitted by the flat plate with laminar and transitive boundary layers was greater than the noise generated by the flat plate having turbulent flow bound to the edge of the structure. They have concluded that the rear edge noise levels generated in the transition flow are due to depressions and flow disturbances in the boundary layer.

Chong et al. (2013); have done experimental work on unstable noise on an airfoil using a serrated rear edge. They obtained detailed aeroacoustic measurements as a result of experiments using acoustic free-field conditions and low flow rate NACA 0012. Experimentally, the presence of a boundary layer at the 4.2-degree attack angle was defined. According to the results obtained; showed that the sawtooth surface prevented the boundary layer from separating and triggered bypass passage. In summary, they have seen that the serrated rear edge is useful for suppressing end zone instability noise.

Buck et al. (2016); To evaluate the effect of internal flow turbulence conditions on wind turbine acoustics, they conducted a comprehensive experimental study using a 108 m diameter wind turbine. They conducted acoustic data measurements for more than 50 hours. In order to assess the direction of the noise emission, they placed twelve precision microphones in the rotor radius ring. Turbulence densities ranged from 10% to 35%. In order to determine the turbulence conditions in the vicinity of the wings, which are the most turbulent noise generating bodies, they decided to use the accelerometer fitted to the turbine blades. Using this method, they observed a clear positive correlation between turbulence intensity and noise levels. They found that turbulence noise was more dominant at low frequencies and was basically up and down. In low-frequency situations, they measured that turbulence noise increased by about 6 dB.

Leon et al. (2017); During turbulent flow, NACA 0018 examined the broadband noise generated by scattering at the tip of the rear edge region of the airfoil, changing both the angle of attack and the angle of the notch at the tip of the wing. It was observed that the measured noise level was higher than the non-serrated wings. They have found that these values are scaled by the characteristic number of Strouhal, which varies depending on the flow rate and the boundary layer thickness. Based on the high-speed observations made by particle image velocimetry, they stated that the modifications of the hydrodynamic behavior and the increase of the noise are related to each other. They also observed an increase in the energy of turbulent waves. They defined the dominant cause of the increased noise as the pressure of the serrated edges.

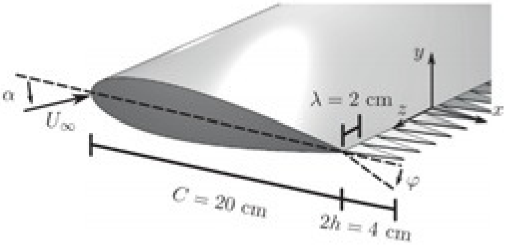

Fig. 4. NACA 0018 rear edge geometry used (Leon et al., 2017)

Carpio et al. (2019); made an aeroacoustic study using NACA 0018 airfoil, which is solid and porous rear edge inserts covering 20% of the body length. They measured remote area noise through a progressive microphone array. These porous attachments; They produced metal foams with 6×10^{-10} and 2.7×10^{-9} m^2 permeability values. While performing the tests, they determined the Reynolds number as 2.63×10^{5} and the attack angle as 0 degrees. They have measured that the lower permeable porous rear edge reduces noise up to 11 dB, and a higher permeability porous rear edge reduces noise up to 7 dB. Considering the results obtained, it was concluded that the use of low permeability metal foam is more acoustically suitable.

In Riso National Laboratory in Roskilde, Denmark, experimental studies were performed by using different parameters on the aeroacoustic noise during wind turbines. One of them is the use of the Vestas V27 type wind turbine to measure the prescribed noise at different tip angles of 8 m/s. In the measurements; aeroacoustic noise caused by an increase in the inclination angle. The following graph shows the change in the total sound level according to the tip zone inclination angle. (Fuglsang and Madsen, 1996)

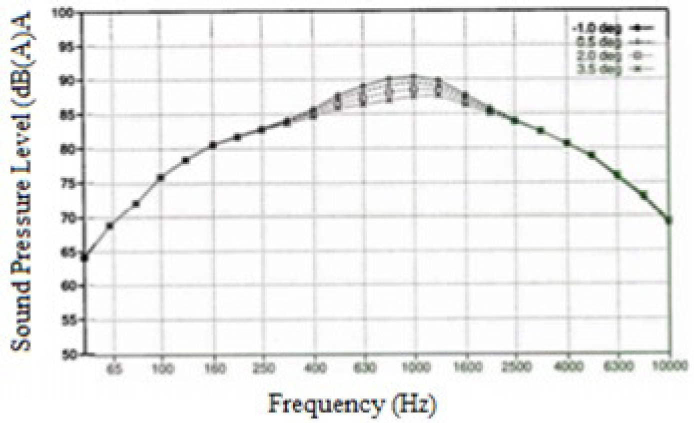

Fig. 5. Effect of Trailing Edge Slope Angle Change on Sound Level (Fuglsang and Madsen, 1996)

Another study is the calculation of noise at different end speeds using the Bonus Combi type wind turbine with a capacity of 300 kW. As a result; Especially at high frequencies, it has been found that all end velocity frequency ranges differ greatly with the sound level. Due to the effect of end zone noise; higher frequencies occurred at higher end rates. Also; turbulent internal flow noise and airfoil's own noise was found to increase with respect to the tip velocity. The change in the total sound level according to the tip speed effect is given in the graph below. (Fuglsang and Madsen, 1996)

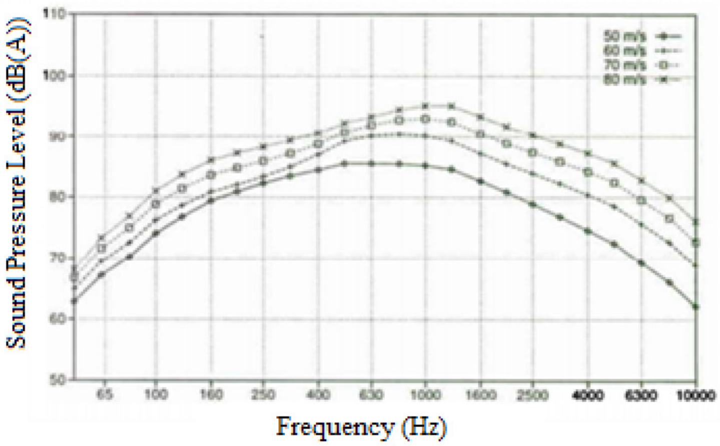

Fig. 6. Effect of a tip velocity change on the sound level (Fuglsang and Madsen, 1996)

In addition, the effect of different types of wind speeds on the noise generation with the bonus Combi type wind turbine was also investigated. As a result of the study, it was seen that the effect of wind speed for low frequencies had a significant effect on the change in noise level, whereas this effect decreased at high frequencies. The following graph shows the change in the total sound level according to the wind speed. (Fuglsang and Madsen, 1996)

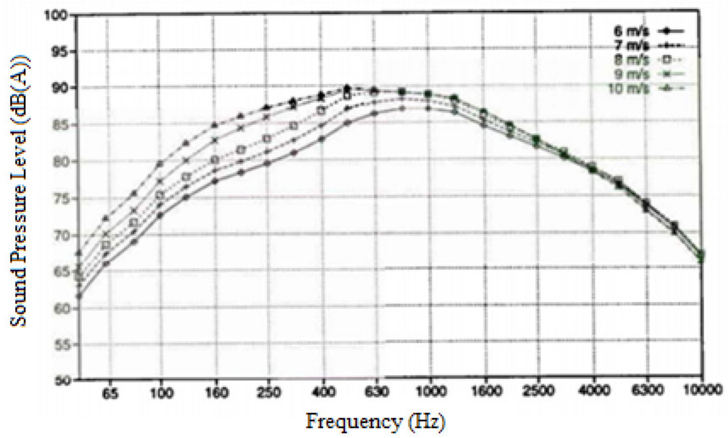

Fig 7. Effect of Wind Speed Change on Sound Level (Fuglsang and Madsen, 1996)

2.2. Numerical Studies

Ghasemian and Nejat (2015); H-Darrieus predicted numerically using the Ffowcs-Williams and Hawking affinity formulation for aerodynamic noise emitted from the perpendicular wind turbine. The simulations they made in this process were carried out for 5 different end-speed ratios. First, the average torque coefficient was compared with the experimental data and a good fit was observed. Then, in the research, they focused on the broadband sounds of the turbulent boundary layers and tonal sounds due to the wing transition frequency. As a result; found a direct relationship between the radiated noise and the rotational speed. This result is graphically indicated as follows.

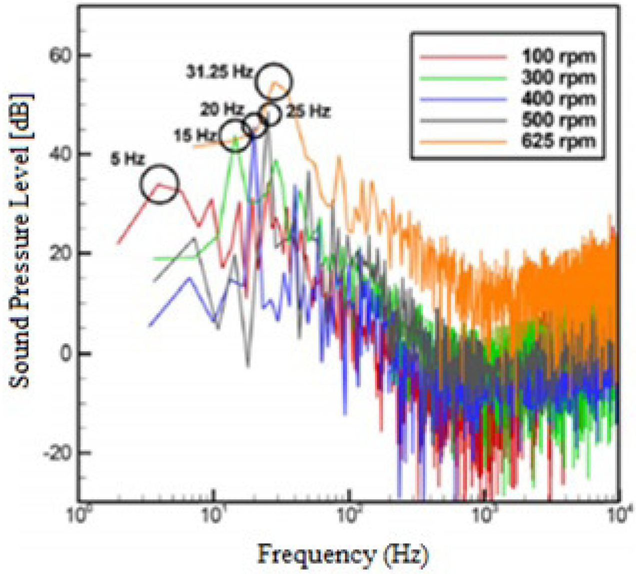

Fig. 8. Variation of Rotation Speed with Spreading Noise (Ghasemian and Nejat, 2015)

Also; The effect of receiver distance on the General Sound Pressure Level was investigated. As a result; They found that the overall Sound Pressure Level and the receiver distance changed logarithmically.

Clifton-Smith (2010) presented a method using the power method to reduce noise. Differential evolution (DE) technique to estimate power performance; It was combined with an empirical noise estimation model by means of pala-moment-momentum analysis. In order to improve low wind speed performance, the start time was reduced. It was found that the best trade-offs for the 1% decrease in power coefficient were 4% (2 dB) and 6% decrease at the total sound pressure level (SPL) and baseline. To reduce turbulent input noise from the two most important sources of noise, the appropriate thin rear edge thickness was calculated using DE results and a back edge thickness of about 1 mm was found to be reasonable to reduce noise.

Wasala et al. (2015); To estimate distant field noise, the Ffowcs-Williams, and Hawking's acoustic simulations were used to analyze Large Eddy Simulations. As a result of their analysis; the main source of noise of the wind turbine blade that rotates in high turbulence environment at high attack angle; have seen that there is edge noise.

Mohamed et al. (2015); At low wind speeds, Darrieus calculated numerical modeling of rotor performance using ANSYS Workbench and tried different blade types to achieve the best performance. As a result; they observed that the angle of inclination was the best in comparison to the angles of the wing. Also; They concluded that the analysis using SST-k var was most accurate.

Morris et al. (2004); presented computational methods for the estimation of aeroacoustic sounds. The basis of the methods; it is based on low-frequency noise from the rear edge noise. Using unstable flow simulations, the Fowcs Williams-Hawkings formulation combined noise field propagation. They used linearized Euler equations for long-range noise propagation estimates.

Noise emission for the Siemens SWT-93 wind turbine with a power of 2.3 MW. Leloudas et al. (2007). The data obtained from the turbine were compared with simulations using a semi-empirical acoustic model. A good fit was observed between the predicted and measured noise levels. By changing the end zone velocity and the tip region inclination angle of the acoustic model; The performance/noise value of the wind turbine is to be optimized. It was observed that the inclination angle and the rotational speed correlate with the noise values. They found that the noise level increased when they switched to higher rotational speeds. Also; determined that the increase in noise value at the continuous rotation speed when the inclination angle decreases.

Jianu et al. (2012); has reviewed recent developments in the area of noise pollution from wind turbines. His work primarily focused on analyzing and comparing different methods used to reduce sounds, focusing on the noise coming from the rear edge. They also talk about suppression of sounds from mechanical sources such as generators, transmission and hydraulic systems using vibration suppression, vibration isolation, and fault finding techniques. According to this study; Prevention strategies such as wing modeling methods in wind turbines can reduce the dominant noise.

Velden et al. (2016) examined both the flow area and the noise emission at the inclined rear edge both experimentally and numerically. A calculation was made using the Lattice Boltzmann equation with the Ffowcs William Hawking aeroacoustic analogy and noise estimation was obtained. To verify this methodology used for background edge noise estimation, the low Mach number flow around the flat plate with a 25 degree inclined rear edge was analyzed. The data obtained from the experimental analysis were compared and the results obtained showed a good fit.

Avallone et al. (2017) designed a serrated rear edge and examined the remote area noise and the flow area. They obtained the spectrum of the remote area broadband noise and the flow area from numerical calculations using compressible Lattice-Boltzmann. They compared the new design with the conventional saw-type rear edge with triangular geometry. They adopted both geometries to NACA0018 airfoil at a 0 degree attack angle. As a result; found that the serrated geometry reduced the noise of the broadband by about 2 dB compared to the conventional sawtooth design. The reason for this was the fact that the serrated edge reduced the scattered noise in the root.

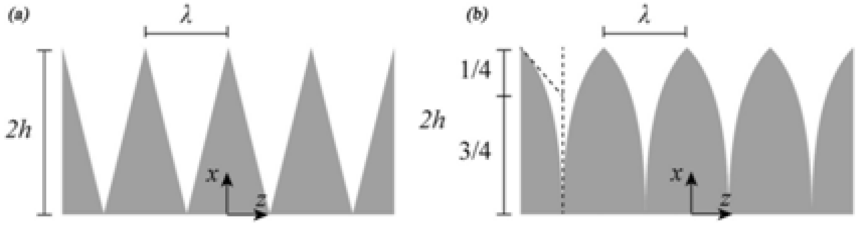

Fig. 9. Different rear edge designs used; a)Knurled Rear Edge, b)Saw Back Rear Edge (Avallone et al., 2017)

Botha et al. (2017) developed a method for estimating aerodynamically generated broadband noise by the Vertical Axis Wind Turbine (VAWT). In making calculations, both internal turbulence and airfoil have taken into consideration their own noise mechanisms. Airfoil noise estimates based on aerodynamic input data were computed using the computational fluid dynamics (CFD) program. They identified the sources of noise and identified the location of the primary sources and stated that the internal turbulence noise was the dominant source of the noise. For turbulence noise sources, the turbulence observed that the turbulence produced by the wing is more dominant than the atmospheric flow turbulence. They calculated that the noise source was 20 dB higher than the turbulent boundary layer noise.

Lehmkuhl et al. (2013) used non-structural grids to analyze the flow of aerodynamic profiles using different turbulence models of Large-Eddy Simulation in computational fluid dynamics (CFD) program and compared their results with experimental data. In their analysis using NACA 0012, the Reynolds number was determined to be 5×10^4 and the attack angles were chosen in 2 different ways between 5^o and 8^o. According to the data obtained, the most appropriate result from the experimental data was obtained from the analysis with the VMS-WALE model.

Kim et al. (2015) examined a symmetrical airfoil internal flow noise that interacts with homogeneous and isotropic turbulence, with a focus on the effects of airfoil geometry. They used a numerical method based on computational aeroacoustic techniques using finite difference schemas that maintain a high degree of distribution-relationship to solve two-dimensional linearized Euler equations. Comparing the acoustic power spectrum and flow field properties of airfoils; investigated the effects of airfoil thickness, anterior region radius and Mach number on internal flow noise. As the airfoil thickness increased, turbulence velocities were found to deviate from the acoustic power levels of the wings in the high-frequency range due to the greater deviation in the stationary areas near the leading edge. They found that this deviation was associated with the inclination angle of the constant average flow line near the leading edge. As a result; stated that increasing the edge radius in the fixed wing profile thickness causes a decrease in the acoustic power level.

Hashem et al. (2017) made an aeroacoustic noise assessment using Ffowcs Williams-Hawkings (FW-H) equation for the lens wind turbine. Through the computational fluid dynamics program Ansys Fluent, they achieved a number of results by performing 3-dimensional analysis using the non-sluggish Reynolds average Navier-Stokes (URANS) equations. As a result of their analysis, it was seen that lens wind turbines produced higher intensity noise. While non-lens wind turbines produced an average sound pressure of 53.06 dB, they calculated that this value was higher for wind turbines with the lens. They found the average sound pressure level for Aii type lens wind turbines as 64.38 dB and 68.81 dB for Cii types. Based on their different analysis, they found that the effect of changing the tip-speed ratio on the aeroacoustic noise in the lens wind turbines was low.

Luo et al. (2015) used CFD (Computational Fluid Dynamics) program to reduce the aeroacoustic noise produced by a vertical axis wind turbine. Three-dimensional vortex dynamics and aeroacoustic properties around the horizontal axis wind turbine; Large Eddy Simulation and wind tunnel measurement. They have found that noise generation and acoustic radiation are directly related to the vortexes generated when the wind turbine rotates periodically. Based on these results, they said that more attention should be given to the tip area to improve wind turbine performance and reduce noise.

Kim et al. (2012), in their study, they investigated the effect of the flexibility of the barbs used in wind turbines on the aeroacoustic noise. To consider the fluid-structure interaction, we use the NVCM method for aerodynamic analysis; applied nonlinear composite beam theory for structural dynamic modeling. In the homogeneous flow with a speed of 8~12 m/s, it was observed that the noise produced was in the range of 1.5-2.5 dB, which is a low gap compared to the solid material palate. While the wind speed was over 12 m/s, the noise was not significantly changed due to the flexibility of the barbs. This research has shown that the bending of the elastic blades reduces the angle of attack and reduces the noise of the broadband.

Maizi et al. (2018) investigated the effect of the shape of the pin tip on the noise emitted by the horizontal axis wind turbine. In this research, to minimize the tip noise; Using aerodynamic and aeroacoustic methods, they tested 3 different tip configurations using S809 airfoil. In the CFD program, they use for 3D flow simulations; Unstable Reynolds Mean Navier-Stokes (URANS) and Detached Eddy Simulation (DES) have used turbulence models. The National Renewable Energy Laboratory (NREL) modeled the 12% scale dimensions of the wind turbine used in the Phase IV experiment and made the necessary analyzes. To estimate the sound produced by the turbine, the Ffowcs Williams-Hawkings (FW-H) analogies were compared with experimental data. They stated that the results obtained from the DES model were more accurate than URANS. As a result, the shark end model found a 7% noise reduction rate and best results for noise emission in terms of the wind turbine blade.

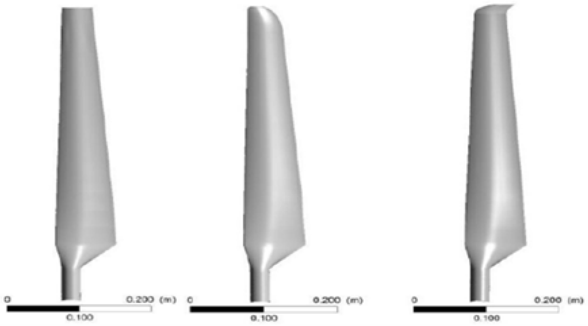

Fig. 10. Different blade tip shapes used for S809 airfoil (Maizi et al., 2018)

Solís-Gallego et al. (2018); In the low Reynolds issue, using the FX-63-137 airfoil for four different angles of attack, they studied using Large Eddy Simulation (LES) for aeroacoustic-induced noise analysis. They obtained the acoustic data using the volumetric analogy (FW-Hall) of Ffowcs-Williams and Hall. They have confirmed the aeroacoustic results by experimental measurements performed in an anechoic wind tunnel using the frequency analyzer. As a result of the comparison of experimental measurements and analysis; They found that the FW-Hall method was successful for collecting acoustic data. They reported that the analyses conducted for the FX-63-137 airfoil at an angle of 7.5^{o} gave the closest results to the experimental data and that the least noise was generated in the analyses carried out at an angle of 2.5^{o}.

Kaviani et al. (2017); They have made aeroacoustic noise optimization by using the WindPACT wind turbine with 1.5 MW horizontal axis. They used S 818 from 3 different airfoil models used in WindPACT turbines and provided the necessary optimization. They have reduced the angle of inclination at the leading edge of the wing profile they have optimized, but they have hardly changed the leading edge radius.

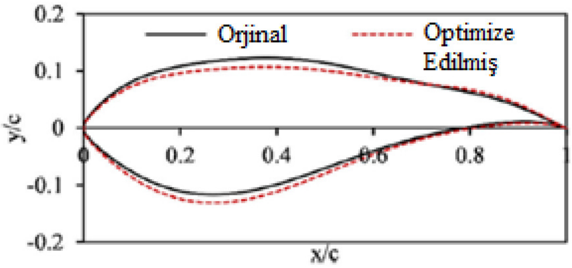

Fig. 11. Airfoil Geometry of S818 (Kaviani et al., 2017)

The aeroacoustic result of this wing profile obtained; 11.5 m/s wind speed and 20.5 rpm. They have calculated the rotation speed parameters by using the Large Eddy Simulation in Ffowcs Williams and Hawkings acoustic simulation in the CFD program they have used.

As a result, the optimized WindPACT had a noise reduction of about 1 dB in the wind turbine.

III. RESULTS

Dominant aeroacoustic sounds cannot be completely eliminated but can be minimized. This minimization; It can be done by changing the angle of attack or by improving the edge, end zone velocity, and tail shape. In order to establish small-scale wind turbines in places where crowded populations such as inner cities live, detailed experimental and simulation results are of great importance. (Tummala et al., 2016)

In these periods when the orientation towards renewable energy sources is extremely popular, every study related to the subject is of great importance. Wind turbines that can be equipped with aeroacoustic optimization can be installed in the city and thus can be power generation facilities in all settlements.

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