26th International Congress of Mechanical Engineering
COBEM 2021
ABCM Associação Brasileira de Engenharia e Ciências Mecânicas
November 22-26, 2021, Virtual Congress, Brazil

COB-2021-0336
THE QUASI-3D NOISE PREDICTION AND IMPLEMENTATION FOR PNOISE/QBLADE SOFTWARE

Sara Rodriguez
Sao Paulo State University (Poli-USP)
sara.rodriguez@alumni.usp.br

Joseph Youssif Saab Jr.
Maua Institute of Technology
saab@maua.br

Alexandre Martuscelli Faria
Sao Paulo State University (Poli-USP)
martuscellifaria@usp.br

Marcos de Mattos Pimenta
Sao Paulo State University (Poli-USP)
marcos.pimenta@poli.usp.br

Abstract. *The Qblade is an open-source wind turbine design software, with a significant number of downloads, some improvements are being implemented in order to broaden the capacity of the embedded aeroacoustic module, PNoise, which originally consisted of a 2D airfoil trailing-edge noise prediction tool. The inflow noise is in a final implementation state. The laminar-boundary-layer-vortex shedding, trailing-edge-bluntness-vortex-shedding, and the tip vortex formation self-noises are being added to the tool, plus inflow noise modeling and a quasi-3D tool for full rotor noise estimation. The upgrade provides to the user the approximate sound pressure levels and related spectra for all self-noise sources plus inflow noise, for 2D and 3D prediction in a steady flow. The current models available for the calculations are the modified-BPM, with boundary layer data provided by the XFLR5 integrated code for the self-noise sources and the Von Kármán and the modified-Lowson model by the inclusion of the Rapid Distortion Theory model. The quasi 3D method has a recursive nature and it relies on the same underlying boundary layer thickness hybrid calculation of the 2D calculation, but with local flow conditions adjusted to the local Reynolds and Mach number of each spanwise section of the blade as calculated by the Blade Element Momentum method. The method has a resulting accuracy limited by the combined uncertainties inherent to each method, plus the uncertainty deriving from the use of a finite number of blade sections and a discrete number of angular positions of the blade rotating along the azimuthal plane. This paper describes the methodology for both blade and rotor noise prediction and presents the new features that are being implemented in the PNoise module.*

Keywords: *Wind Turbine Noise, Quasi-3D, QBlade, PNoise, self-noise, BPM.*

1. INTRODUCTION

The QBlade (Marten *et al.* (2021)), is a GNU General Public License (GPU) software developed at the Technische Universität Berlin (TU-Berlin) that allows researchers and wind turbine designers to make quick pre project of wind turbine (WT) blades in a user friendly interface based on Qt (The Qt Company (2021)). The software uses XFOIL (Drela and Youngren (2021)) to design customized airfoils, calculates the boundary layer with the XFLR5 (Deperrois (2021)), performs extrapolations in an angle of attack range of 360º and integrates these values for a WT rotor through the Blade Element Momentum (BEM) (Branlard (2017)) and Double-multiple Streamtube (DMS) (Beri and Yao (2011)) correction algorithms.

Due to its aerodynamic and structural modules and in order to make this software more adapted to the new demands of WT manufacturers, a partnership was made with POLI-USP for the inclusion of the wind turbine noise (WTN) module called *PNoise*, and it was created the group *Poli-Wind*.

The 2D noise simulation was based on the simplified or semi-empirical theoretical models of modified-BPM (Brooks *et al.* (1989)) and based on Von Kármán and modified-Lowson models and it was also used for the implementation of quasi-3d noise prediction.

The quasi-3D methodology was implemented in the PNoise module, based on the works of Glegg (1987); Brooks *et al.* (1989); Moriarty and Migliore (2003); Fuglsang and Bak (2004); Zhu (2004); da Conceição Vargas (2008); Kamruzzaman *et al.* (2011), being possible to predict the noise emitted by the WT for the full blade or the complete rotor and not just analyzing a bi-dimensional airfoil. The method encompasses the well-known semi-empirical or simplified theoretical models from the 2D methods, makes a quick simulation of the blade or rotor noise emission, and gives flexibility for the observer position, so the simulations can be easily compared with the Sound Pressure Level (SPL) spectra from the manufacturers, bringing to a next level the prediction of the WT noise.

The quasi-3D method developed for the *PNoise* module was predicted in some Poli-Wind group publications (Saab Jr. and de Mattos Pimenta (2015, 2016); Saab Jr. (2016c); Saab Jr. and de Mattos Pimenta (2017); Saab Jr. *et al.* (2018, 2019)), and the module includes the following features:

- User selection of airfoil self-noise sources to be calculated, according to the BPM method;
- Inflow noise source selection;
- An auto-adjustment for the BEM and XFOIL polar calculations with a warning for the user to verify errors considering the validity limitations in a table view;
- Arbitrary, user-defined observer position;
- Overall and spectral sound pressure level quick estimate;
- User selection of flow conditions specifications and calculation according to the noise models validity range;
- Application for any geometry of airfoil, blade, and rotor;
- User input of the source of the vertical turbulent scale to predict some of the noise sources;
- Open-source, free software download, under the **GPL!** (**GPL!**).

The following sections will present the methodology applied for the *quasi-3D*, the implementation on the *PNoise* module, and the validation tests.

2. METHODOLOGY

The PNoise bidimensional (2D) module calculates the noise in a given airfoil, which is a segment of the blade. The quasi-tridimensional (3D) method, the object of this paper, consists of a new approach to the 2D noise prediction methodology, considering not just a blade segment, but different spanwise blade segments, with quantitative-rotation positions or angles in the azimuthal plane.

For each noise source selected by the user, it will be calculated the spectrum in $1/3$ octave band for each radial blade segment, considering a fixed observer position related to the corresponding segment. The PNoise uses BEM (Branlard (2017)) to obtain input data such as angle of attack (AOA), Mach and Reynolds numbers, and iterative calculates for each blade segment the radial and axial induction factors and other factors, like tip loss, 3D rotational augmentation and others, to correct the WT self-noises calculations.

In the 2D noise prediction method the observer position is referenced in relation to a position lagged to the trailing-edge (TE), and the observer rotates according to the rotational movement of the blade, presented in figure 1.

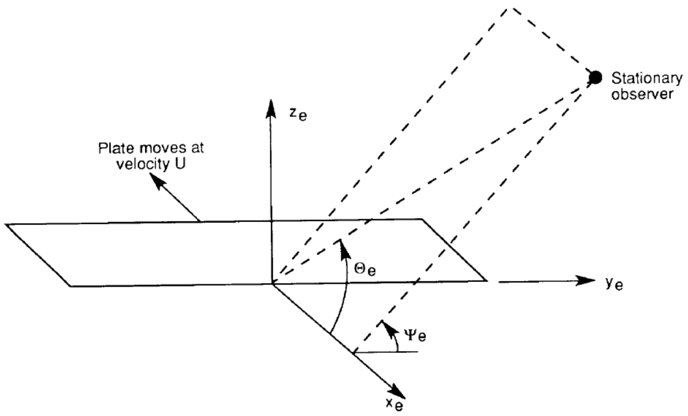

Figure 1. The 3D coordinate system postponed related to the TE considering a moving plate of a velocity $\mathbf{U}$ in the opposite direction of the abscissa $\mathbf{x}_\theta$ and position angles $\mathbf{\Theta} \rightarrow \theta$ and $\mathbf{\Psi} \rightarrow \phi$. Source: Brooks *et al.* (1989).

On the other hand, the PNoise quasi-3D method allows the user to position the observer according to his needs, given the fact that transformation matrices are performed to enable this flexibility. The PNoise quasi-3D method is subdivided into blade and rotor, in the first case the observer's coordinate rotates with the blade and in the second case, the base of the observer's coordinate system is fixed in relation to the ground, according to the input data given by the user.

The average SPL spectrum for the quasi-3D method is calculated according to the directivity factors. For the quasi-3D blade case the SPL is obtained by the logarithmic sum of all noise spectrum contributions of each blade segment and, for the quasi-3D rotor, it will be applied for all moving blades, according to equation 1. If the observer position is in the far-field, a propagation model shall be employed.

$$SPL_{avg} = 10 \cdot \log \left(\frac{1}{n} \left(\sum_{i=1}^{n} 10^{SPL_i/10} \right) \right), \tag{1}$$

where i is each of the noise sources defined by the user. The SPL_{avg} is presented in a graphic mode and the Overall Sound Pressure Level (OASPL) is also calculated and presented in a table view.

2.1 Reference System

The transformation matrices used in the PNoise script for the quasi-3D method was initially proposed by Saab Jr. *et al.* (2019), based on the Germanischer Lloyd Industrial Services GmbH (2010) in a simple and didactic way compared with other reference systems (Broux (2008); da Conceição Vargas (2008); Zhu (2004)). There are considered five reference systems for the quasi-3D blade and ten for the quasi-3D rotor, where for each transformation step is used only one operation, this can be a translation or rotation between two adjacent systems.

Certain simplifications have been made, such as the absence of the rotor axis tilt-rotor and cone angles, so that the blade and chord coordinate systems have one axis aligned with the blade pitch axis. Another advantage is that the consideration of pitch axis intersects the chord line of all the blade sections at 25% of its length from the TE, and the simplification of the pitch axis intersects the thickest section of each airfoil, or close to it.

For the quasi-3D blade and rotor we have the following transformation systems:

1. Blade Reference System (see figure 2);
2. Section Reference System (see figure 3);
3. Rotated Section Reference System (see figure 4);
4. Trailing Edge Reference System (see figure 5);
5. Rotated Trailing Edge Reference System (see figure 6).

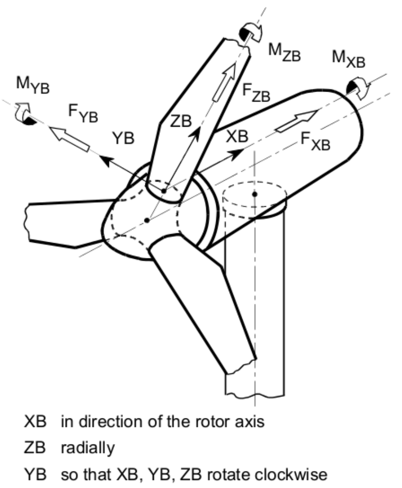

Figure 2. Blade Reference System. Source: Germanischer Lloyd Industrial Services GmbH (2010), p. 4-31, fig 4.A.1.

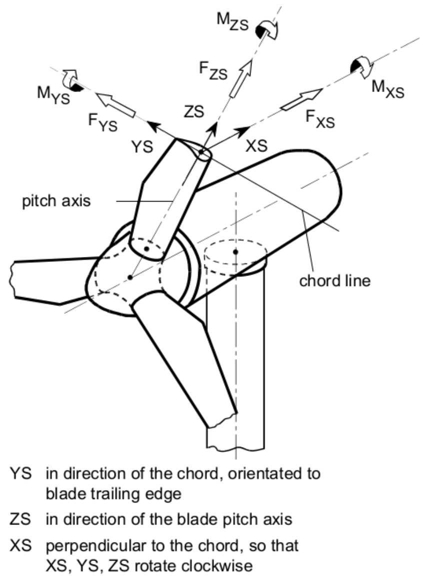

Figure 3. Section Reference System. Source: Germanischer Lloyd Industrial Services GmbH (2010), p. 4-31, fig 4.A.2.

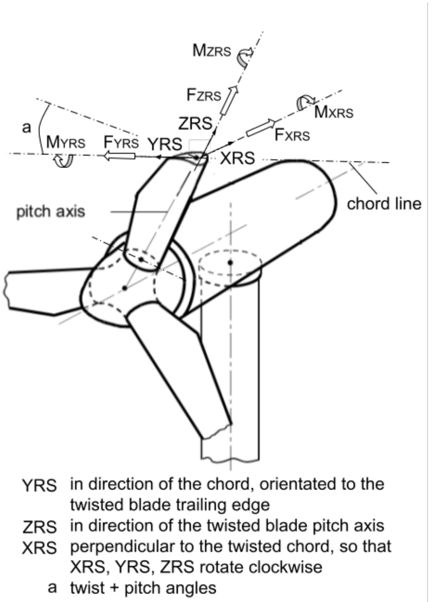

Figure 4. Rotated Section Reference System.

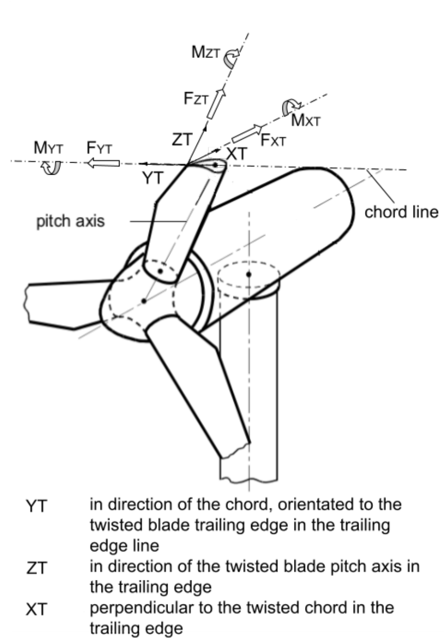

Figure 5. Trailing Edge Reference System.

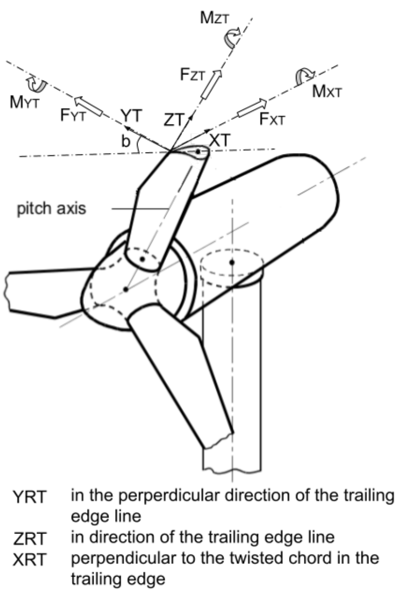

Figure 6. Rotated Trailing Edge Reference System.

For the quasi-3D rotor we have also the following transformation systems:

6. Lower Tower Reference System (see figure 7);
7. Upper Tower Reference System (see figure 8);
8. Yaw-Bearing Reference System (see figure 9);
9. Hub, Fixed Coordinate System (see figure 10);
10. Rotor, Rotating Coordinate System (see figure 11).

2.2 Aerodynamic Self-Noise

The PNoise module was initially designed to predict the aerodynamic WT self-noise of the TE of an airfoil according to the BPM model (Brooks *et al.* (1989)). This initial module, implemented by Saab Jr. (2015, 2016b); Saab Jr. *et al.* (2018), includes the separation-stall and the TBL-TE pressure and suction sides. The current downloadable version of the QBlade includes this calculation.

The turbulent inflow noise was implemented after this first stage, this model follows Amiet's theory and it was presented by Faria *et al.* (2020, 2018, 2019a,b). This model gives the user the option to calculate according to the Von Kármán or by the Rapid Distortion Theory (RDT).

After the previous implementations, the laminar-boundary-layer-vortex shedding (LBL-VS), trailing-edge-bluntness-vortex-shedding (TE-Blunt-VS) and tip vortex formation noise sources were included in the PNoise module for 2D. Finally, the quasi-3D blade and quasi-3D rotor were coded for the self-noise models presented.

3. PNoise Simulation Conditions

Simulations were performed in the PNoise module in order to verify and validate the results with those in the literature (Zhu (2004); Fuglsang and Bak (2004); Jakobsen and Andersen (1993)). It was selected the WT Bonus Combi B31/300, with a rated power of $300\,\mathrm{kW}$ with a defined validation range and with the following descriptions:

- Rotor radius: $15.5\,\mathrm{m}$;
- Tower height: $31\,\mathrm{m}$;
- Blade number: 3;
- Rotation speed: 35.2 rpm;
- Airfoil: Profile series NACA 63_1-212, according Jakobsen and Andersen (1993), Appendix 1, p. 67-75;
- Tip pitch angle: -1.0 degree;
- TE-Bluntness: 0.5% $\times$ chord;
- Mean wind speed: 8m/s;
- Cut-in wind speed: $3.5\,\mathrm{m\,s^{-1}}$;
- Rated wind speed: $8\,\mathrm{m\,s^{-1}}$;
- Cut-off wind speed: $25\,\mathrm{m\,s^{-1}}$;
- Ground surface roughness: $10\,\mathrm{mm}$;
- Wind direction: Upwind;
- Receiver (observer) position for quasi-3D simulations: $40\,\mathrm{m}$ in the downwind direction at the ground level;
- Observer positions for directivity simulations: placed at the ground level at the radius of $200\,\mathrm{m}$, $100\,\mathrm{m}$, and $80\,\mathrm{m}$ from the WT.

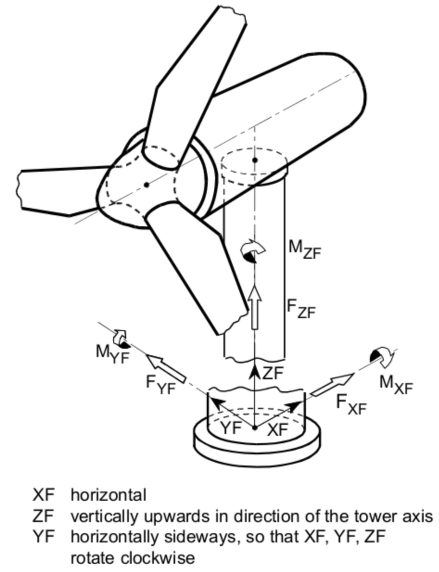

Figure 7. Lower Tower Reference System. Source: Germanischer Lloyd Industrial Services GmbH (2010), p. 4-33, fig 4.A.6.

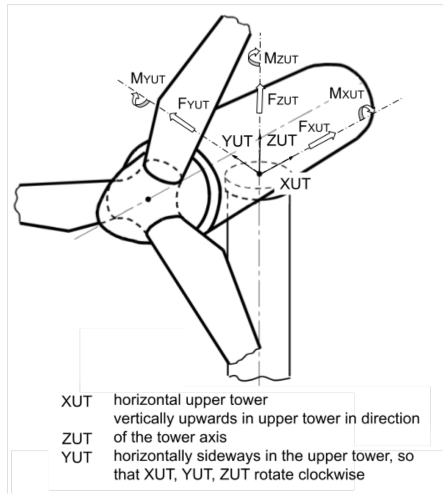

Figure 8. Upper Tower Reference System.

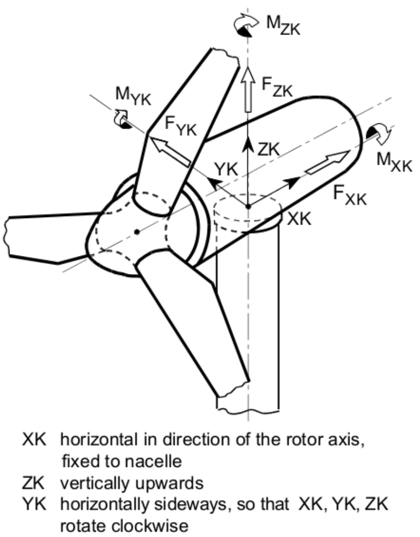

Figure 9. Yaw-Bearing Reference System. Source: Germanischer Lloyd Industrial Services GmbH (2010), p. 4-33, fig 4.A.5.

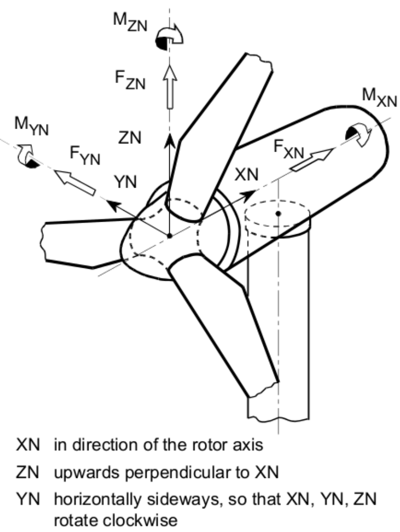

Figure 10. Hub, Fixed Coordinate System. Source: Germanischer Lloyd Industrial Services GmbH (2010), p. 4-32, fig 4.A.3.

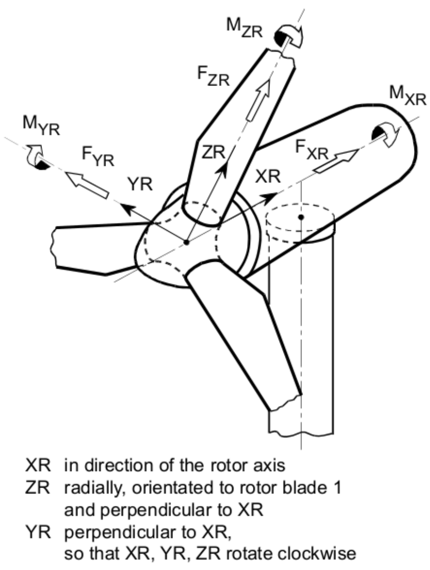

Figure 11. Rotor, Rotating Coordinate System. Source: Germanischer Lloyd Industrial Services GmbH (2010), p. 4-32, fig 4.A.4.

3.1 Directivity

The effect of directivity is responsible for changing the SPL in relation to the position of the observer. Considering that an observer moving a radius of distance around a wind turbine, he will notice a change in the OASPL.

The quasi-3d model in PNoise was validated in relation to its directivity functions through the experimental data presented by Zhu (2004), the results are presented in Figure 12. The WT considered for the simulations is a Bonus Combi B31/300 and the observer is placed according to the conditions presented in the section 3. The directivity curves are dipoles, asymmetrical given the twist of the blades.

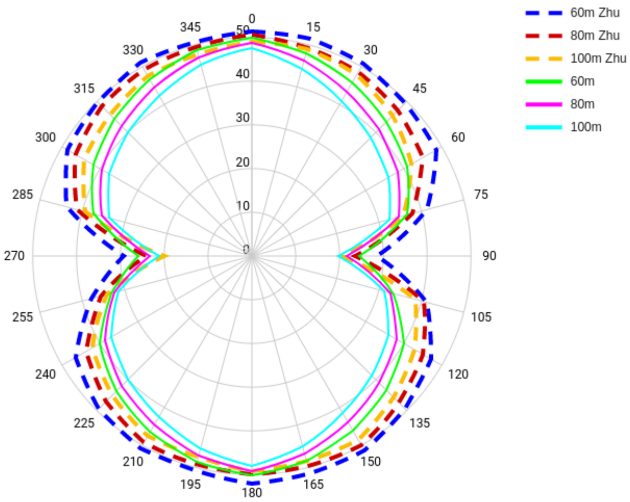

Figure 12. Comparison of the directivity simulation of PNoise and Zhu (2004),p. 57, fig. 5.8

3.2 Quasi-3D Rotor Simulations

The PNoise module allows the user to make the following WT self-noise predictions for quasi-3D rotor:

- Turbulent-boundary-layer-trailing-edge for pressure side;
- Turbulent-boundary-layer-trailing-edge for suction side;
- Separation stall;
- Laminar-boundary-layer-vortex shedding;
- Trailing-edge-bluntness-vortex-shedding;
- Tip vortex formation noise;
- The total sum of the noise source models simulated.

The PNoise quasi-3D rotor simulations was made comparing to the results presented by Stefan Oerlemans (2012) for the Bonus Combi 300 kW WT which used the same experimental conditions performed by Jakobsen and Andersen (1993) presented in the section 3. The compared results are presented in the Figures 13 to 20 according to the graphic presented by Stefan Oerlemans (2012) p. 23. figure 4-2.

Noise from turbulent TE flow is divided into contributions from the suction, pressure, and separation-stall, the last origin from the separation caused by the angle of attack, it was assumed a tripped flow. The Fuglsang and Bak (2004) model was based on wind tunnel measurements, and the *PNoise* model was the modified BPM. Figure 13 shows the comparison of models for the TE suction side which presents a good agreement, with low power in the regions of lower and higher frequencies and peak around 600 Hz.

Figure 14 compares the models for the TE pressure side which shows good consistency, with a growing region starting around 300 Hz and peak with 3000 Hz followed by a decreasing curve.

Figure ref fig: graf-TBL-TE-alpha shows the comparison of separation stall models, with the growing region being more accentuated in the *PNoise* simulation and the peak around $650\,\mathrm{Hz}$ followed by a descending region.

Figure 16 shows the LBL-VS noise comparison results in a rather narrow band, both models being concordant in the main peak region, around $900\,\mathrm{Hz}$.

Figure 17 presents the TE bluntness noise considering the thickness of the TE 0.5% of the chord, with a maximum number of $6\,\mathrm{mm}$. It was observed that the *PNoise* model presented a lag according to Fuglsang and Bak (2004) model.

Figure 18 presents the comparison of the models for the tip noise with a peak frequency around $1600\,\mathrm{Hz}$ this noise source has some relevance for higher tip speeds. The models showed reasonable consistency with a certain lag.

The LE noise is calculated considering that the turbulence length scale is $100\ \mathrm{meter}$ and the turbulence intensity is 0.1, the spectrum is broadband with high power in the region of low frequency decreasing towards high frequency. This behavior can be observed in the graph **??**, where both models show similarities, although the PNoise is more linear than the model employed by Fuglsang and Bak (2004).

Finally, the 20 graph shows the total of the graphics described before, except for LBL-VS and bluntness noise. It was observed the decreasing behavior with high power at low frequencies and a central peak that occurs around $700\,\mathrm{Hz}$ of $42\,\mathrm{dB}$.

From the graphics presented, it is possible to verify the PNoise results comparing to the work of Fuglsang and Bak (2004), which shows compatibility and consistency with the expected for the models implemented.

4. Conclusion

The work presented the implementation of the quasi-3D noise model for the existent QBlade software developed by the POLI-Wind group in partnership with the TU-Berlin. The quasi-3d method was initially sketched by Saab Jr. (2016a), and after it was coded in the PNoise module.

The aerodynamic noise sources from the BPM method were implemented in the PNoise module for the 2D, quasi-3D blade, and quasi-3D rotor. The first results for the quasi-3D rotor were presented in this work and verified using as reference the work of Zhu (2004) for testing the directivity factors Stefan Oerlemans (2012) for the spectra.

The lack of experimental data for modern and larger WTs has a negative impact and a challenge to validate the results from the PNoise module for the most modern turbines, as well as for researchers in the wind industry.

The quasi-3D method results presented uses low computational time and were consistent with those in the literature, and proved to be a strong choice to make a conceptual design and also to optimize the WT blade shape.

The PNoise is open source which gives flexibility to developers to customize it according to their needs and is possible to implement other methods and tools to improve the researches and contribute to the wind industry to mitigate noise from WTs.

5. REFERENCES

Beri, H. and Yao, Y., 2011. "Double multiple stream tube model and numerical analysis of vertical axis wind turbine". *Energy and Power Engineering*, Vol. 03. doi:10.4236/epe.2011.33033.

Branlard, E., 2017. "The blade element momentum (BEM) method". In *Research Topics in Wind Energy*, Springer International Publishing, pp. 181–211. doi:10.1007/978-3-319-55164-7_10. URL `https://doi.org/10.1007/978-3-319-55164-7\_10`.

Brooks, T., Pope, D. and Marcolini, M., 1989. "Airfoil self-noise and prediction". *NASA Reference Publication*, Vol. 1218.

Broux, F., 2008. *3D extension of the wind turbine noise prediction tool IAGNoise*. Master's thesis, University of Stuttgart.

da Conceição Vargas, L.F., 2008. "Wind turbine noise prediction". *Instituto Superior Técnico, Lisboa*.

Deperrois, A., 2021. "Xflr5". URL `http://www.xflr5.tech/xflr5.htm`.

Drela, M. and Youngren, H., 2021. "Subsonic airfoil development system". URL `https://web.mit.edu/drela/`

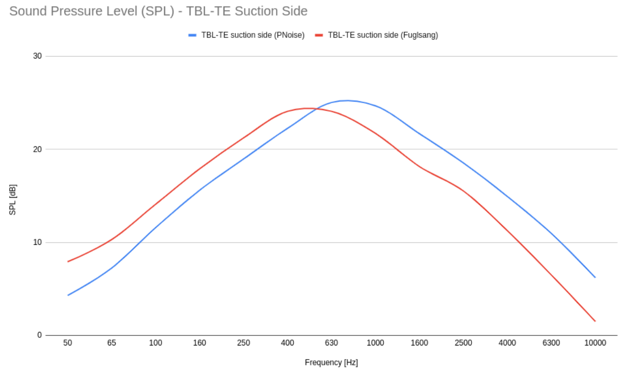

Figure 13. Comparison between Fuglsang and Bak (2004) and PNoise quasi-3D rotor noise for TBL-TE suction.

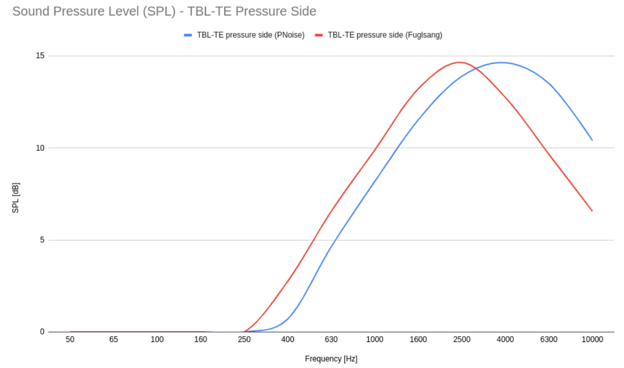

Figure 14. Comparison between Fuglsang and Bak (2004) and PNoise quasi-3D rotor noise for TBL-TE pressure.

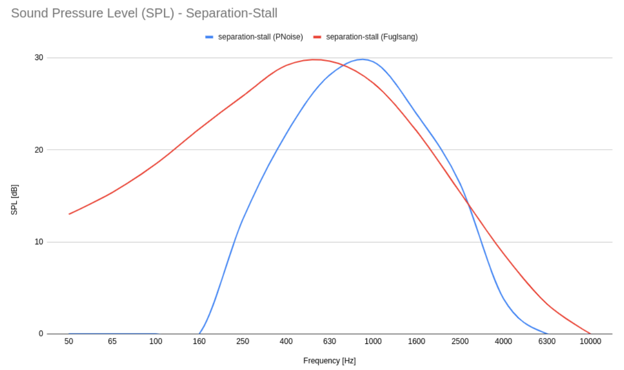

Figure 15. Comparison between Fuglsang and Bak (2004) and PNoise quasi-3D rotor noise for separation-stall.

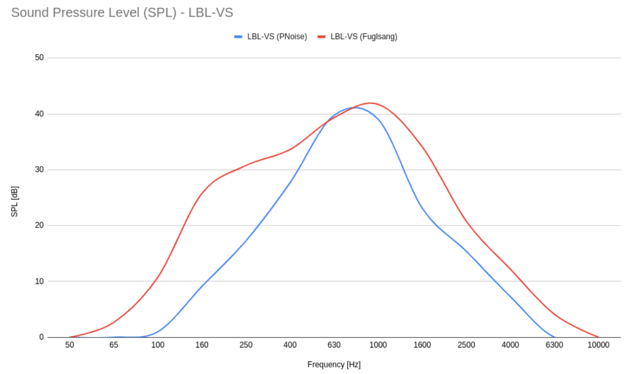

Figure 16. Comparison between Fuglsang and Bak (2004) and PNoise quasi-3D rotor noise for LBL-VS.

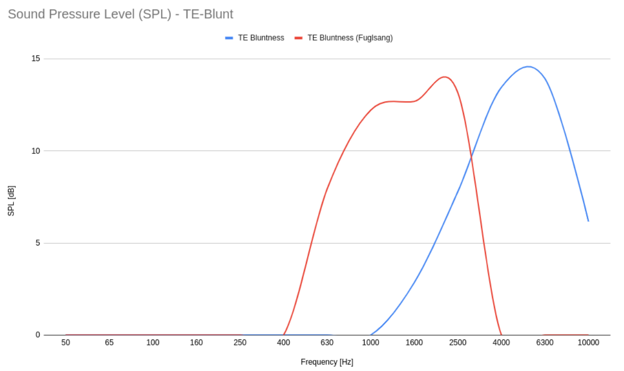

Figure 17. Comparison between Fuglsang and Bak (2004) and PNoise quasi-3D rotor noise for Bluntness.

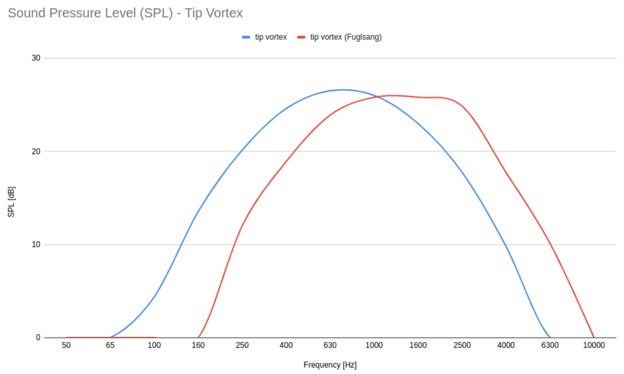

Figure 18. Comparison between Fuglsang and Bak (2004) and PNoise quasi-3D rotor noise for Tip Vortex.

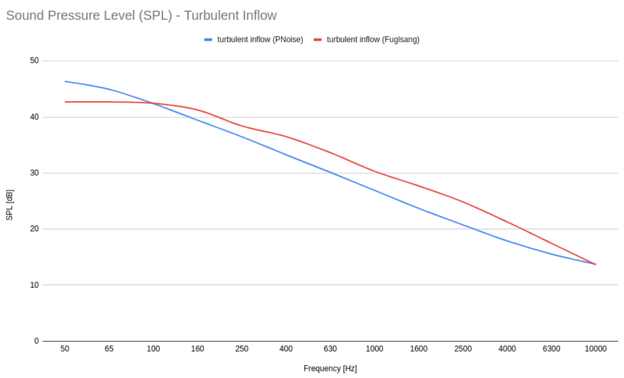

Figure 19. Comparison between Fuglsang and Bak (2004) and PNoise quasi-3D rotor noise for Leading-edge.

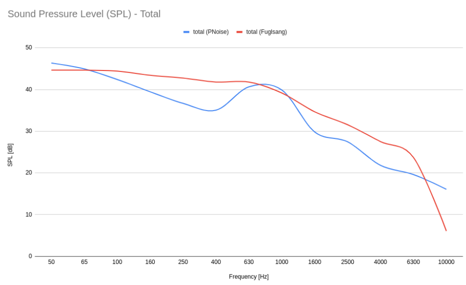

Figure 20. Comparison between Fuglsang and Bak (2004) and PNoise quasi-3D rotor noise for the total noise.

Public/web/xfoil/.

Faria, A.M., de Matos Pimenta, M., Saab Jr., J.Y. and Rodriguez, S., 2018. "Selection of a leading edge noise prediction method for PNoise". *The Academic Society Journal*, pp. 214–223. doi:10.32640/tasj.2018.4.214. URL https://doi.org/10.32640/tasj.2018.4.214.

Faria, A.M., Saab Jr., J.Y., Rodriguez, S. and de Mattos Pimenta, M., 2019a. "Airfoil le noise prediction supplement for pnoise code". *INCE Europe - Wind Turbine Noise*. URL https://www.researchgate.net/publication/333732198_Airfoil_LE_Noise_prediction_supplement_for_PNoise_Code/references.

Faria, A.M., Saab Jr., J.Y., Rodriguez, S. and de Mattos Pimenta, M., 2019b. "Discussion on turbulence inflow noise prediction". *Brazil Windpower*.

Faria, A.M., Saab Jr., J.Y., Rodriguez, S. and de Mattos Pimenta, M., 2020. "A rapid distortion theory-based airfoil turbulent inflow noise prediction method". *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, Vol. 42, No. 8. doi:10.1007/s40430-020-02468-2. URL https://doi.org/10.1007/s40430-020-02468-2.

Fuglsang, P. and Bak, C., 2004. "Development of the risø wind turbine airfoils". *Wind Energy*, Vol. 7, No. 2, pp. 145–162. doi:10.1002/we.117. URL https://doi.org/10.1002/we.117.

Germanischer Lloyd Industrial Services GmbH, 2010. "Guideline for the certification of wind turbines". *Germanischer Lloyd, Hamburg*. www.gl-group.com/GLRenewables.

Glegg, S.A.L., 1987. "Significance of unsteady thickness noise sources". *AIAA Journal*, Vol. 25, No. 6, pp. 839–844. doi:10.2514/3.9709. URL https://doi.org/10.2514/3.9709.

Jakobsen, J. and Andersen, B., 1993. "Aerodynamical noise from wind turbine generators - experiments with modification of full scale rotors". *Delta acoustics & Vibration Danish Acoustical Institute*.

Kamruzzaman, M., Lutz, T., Nuebler, K. and Krämer, E., 2011. "Implementation and verification of an aeroacoustic wind turbine blade analysis tool". *Fourth International Meeting on Wind Turbine Noise, INCE Europe, Rome*.

Marten, D., Pechlivanoglou, G., Weinzierl, G., Moesus, N. and Wendler, J., 2021. "Qblade wind turbine design and simulation". URL http://www.q-blade.org.

Moriarty, P. and Migliore, P., 2003. "Semi-empirical aeroacoustic noise prediction code for wind turbines". Technical report, National Renewable Energy Lab., Golden, CO. (US). doi:10.2172/15006098. URL https://doi.org/10.2172/15006098.

Saab Jr., J.Y., 2015. "Displacement thickness evaluation for semi-empirical airfoil trailing-edge noise prediction model". *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, Vol. 38. doi:10.1007/s40430-015-0341-5.

Saab Jr., J.Y., 2016a. "Inclusion of 2d and 3d aero acoustic noise prediction functionalities into the qblade software".

Saab Jr., J.Y., 2016b. "Trailing-edge noise: development and application of a noise prediction tool for the assessment and design of wind turbine airfoils". doi:10.11606/T.3.2017.tde-14032017-140101.

Saab Jr., J.Y., 2016c. *Trailing-Edge Noise – Development and Application of a Noise Prediction Tool for the Assessment and design of Wind Turbine Airfoils*. Ph.D. thesis, University of Sao Paulo - EPUSP. http://www.teses.usp.br/teses/disponiveis/3/3150/tde-14032017-140101/pt-br.php.

Saab Jr., J.Y. and de Mattos Pimenta, M., 2015. "Displacement thickness evaluation for bpm-type airfoil-te noise prediction model". *INCE Europe 6th International Conference on Wind Turbine Noise, Glasgow*.

Saab Jr., J.Y. and de Mattos Pimenta, M., 2016. "Displacement thickness evaluation for semi-empirical airfol trailing-edge noise prediction model". *Journal of the Brazilian Society of Mechanical Sciences and Engineering*.

Saab Jr., J.Y. and de Mattos Pimenta, M., 2017. "Verification and validation of the "pnoise" airfoil trailing-edge noise prediction module inside "qblade"". *INCE Europe 7th International Conference on Wind Turbine Noise, Rotterdam*.

Saab Jr., J.Y., de Mattos Pimenta, M., Faria, A.M. and Rodriguez, S., 2018. "Determination of local flow conditions and preliminary investigation on the validity of the PNoise code for large-size wind turbine". *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, Vol. 40, No. 10. doi:10.1007/s40430-018-1412-1. URL https://doi.org/10.1007/s40430-018-1412-1.

Saab Jr., J.Y., Rodriguez, S., Faria, A.M. and de Mattos Pimenta, M., 2019. "The quasi-3d te rotor noise prediction tool of the pnoise code". *INCE Europe 8th International Conference on Wind Turbine Noise, Lisbon*.

Stefan Oerlemans, P.F., 2012. "Low-noise wind turbine design". URL http://www.ewea.org/events/workshops/wp-content/uploads/2012/12/EWEA-Noise-Workshop-Oxford-2012-1-1-Stefan-Oerlemans.pdf.

The Qt Company, 2021. "Qt designer manual". URL https://doc.qt.io/qt-5/qtdesigner-manual.html.

Zhu, W.J., 2004. *Modelling of noise from wind turbines*. Ph.D. thesis, Technical University of Denmark. Lyngby, Denmark.

6. RESPONSIBILITY NOTICE

The authors are solely responsible for the printed material included in this paper.