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Implementation and Verification of an Aeroacoustic Wind Turbine Blade Analysis Tool

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Abstract

A quasi 3D wind turbine rotor aeroacoustic simulation tool IAGNoise has been developed based on the improved TNO-Blake trailing-edge noise prediction model. The model consists of dividing the blades of the wind turbine into two-dimensional airfoil sections and predicting the total noise emission as the sum of the contribution from each blade element. The main input for the noise prediction model is the wall normal distributions of the turbulent boundary-layer parameters. Calculation of these parameters by any aerodynamic simulation codes required local inflow characteristics to the blades. A Blade Element Momentum (BEM) technique is utilized to predict these quantities. Moreover, the simulation tool incorporates with three distinct 2D prediction schemes Xnoise, XEnoise and Rnoise each of which uses different aerodynamic calculation methods XFOIL, EDDYBL finite difference code and RANS solver FLOWer respectively.

The prediction tool is applied to the Bonus 300 kW wind turbine at a wind speed of 8 m/s. The spectra for the trailing-edge noise sources are determined and compared to measurements. A sensitivity study on different design parameters is performed and primary results are encouraging.

1. Introduction

Wind turbine noise is one of the major issues for the widespread use of wind energy. For a modern large wind turbine, aerodynamic/flow-induced noise from the blades is generally considered to be the dominant noise source, provided that mechanical noise is adequately treated. The sources of aerodynamic noise can be divided into airfoil self-noise and inflow-turbulence noise [1]. Airfoil self-noise is the noise produced by the blade in an undisturbed inflow and is caused by the interaction between the boundary-layer and the trailing-edge (TE) of the blade. Self-noise can be tonal or broadband in character and may be caused by several mechanisms, such as turbulent boundary-layer trailing-edge interaction (TBL-TE) noise (subsequently denoted as TBL-TE/trailing-edge noise), laminar boundary-layer vortex-shedding (LBL-LS) noise, blunt trailing-edge (BTE) noise, or blade tip (TIP) noise. Acoustic field measurements within the European research project SIROCCO showed that the

TBL-TE noise is the most dominant noise mechanism for large wind turbines [2, 3]. Thus, accurate prediction and reduction of this noise source is the main focus of the acoustics airfoil design methods for the future generation wind turbine blades. However, the design process principally depends on the development of an accurate theoretical model in which correct modelling of turbulent BL structure plays the key role [4, 5].

At the Institute of Aerodynamics and Gas Dynamics (IAG), University of Stuttgart, different highly efficient and accurate airfoil trailing-edge noise prediction schemes, namely Xnoise, XEnoise and Rnoise have been developed. Theoretical prediction results are extensively validated with measurement data obtained in institute's Laminar Wind Tunnel (LWT), and excellent agreement has been observed [4, 5]. The enhanced prediction schemes are coupled in a Graphical User Interface (GUI) based tool IAGNoise [13]. IAGNoise permits the computation of far-field noise spectra by various methods, and analysis of the predicted and measured data in a user friendly way. So far theoretical prediction models are investigated only for the noise generated by a 2D airfoil model. The main objective of the current study is therefore, development of a quasi 3D simulation tool within IAGNoise for the prediction of noise radiated from a complete wind turbine rotor. This implementation enables verification of the theoretical results with full scale turbine field test measurements.

2. Noise Prediction Model

The key focus of the current study is the trailing-edge noise, because it is the most dominant noise source among other flow-induced wind turbine noise mechanisms. The model considered in the present study is the well-known TNO-Blake model [7, 8, 5], which reads in final form as,

$$S(\omega) = \frac{L}{4\pi R^2} \int_{-\infty}^{\infty} \frac{\omega}{c_0 k_1} \mathbf{P}(k_1, 0, \omega) dk_1.$$

where $P(k_1, k_3, \omega)$ is the wavenumber-frequency spectrum model given as a solution of the simplified Poisson equation for wall pressure fluctuations (WPFs) underneath a turbulent boundary-layer, and is given by following Blake [7] as,

The different parameters, e.g., Φ_{22} is the normalized wavenumber spectrum of the

$$\mathbf{P}(k_1, k_3, \omega) = 4\rho^2 \left(\frac{k_1^2}{k_1^2 + k_3^2} \right) \int_0^{\infty} \Lambda_2(y_2) \left[\frac{dU_1(y_2)}{dy_2} \right]^2 \cdot \tilde{\phi}_{22}(y_2, k_1, k_3) \cdot \phi_m(\omega - k_1 U_c) \cdot \left\langle u_2^2(y_2) \right\rangle \cdot e^{-2|\mathbf{k}|y_2} dy_2. \quad (1)$$

vertical velocity fluctuations $\langle u_2^2(y_2) \rangle$, Λ_2 represents the vertical integral length scale for the eddy field, Φ_m is the moving axis spectrum, R is the distance from the trailing-edge to the observer and L is the wetted length of the trailing-edge. Other parameters such as $U_1(y_2)$ is streamwise mean velocity, y_2 is wall normal coordinate, ρ is the fluid density and c_0 is the speed of sound.

3. Rotor Noise Modelling & Simulation Tool

It is obvious that the accuracy of the noise prediction via Eqn. (1) depends on the accurate modelling of the turbulent noise source terms, i.e. $\Phi_{22}(y_2,k_1,k_3),\Lambda_2,\langle u_2^2\rangle$ etc. For this purpose three different aerodynamic analysis methods namely the coupled panel integral boundary-layer code XFOIL [9], the Finite-difference boundary-layer code EDDYBL [10] and a RANS flow solver FLOWer [11] have been coupled with the TNO-Blake model. As these methods differ with regard to modelling accuracy and output data, for convenience the resulting noise prediction methods are denoted as Xnoise (XFOIL based), XEnoise (EDDYBL based) and Rnoise (RANS simulation based). In detail description about the basics of each prediction schemes can be found in authors previous papers [5].

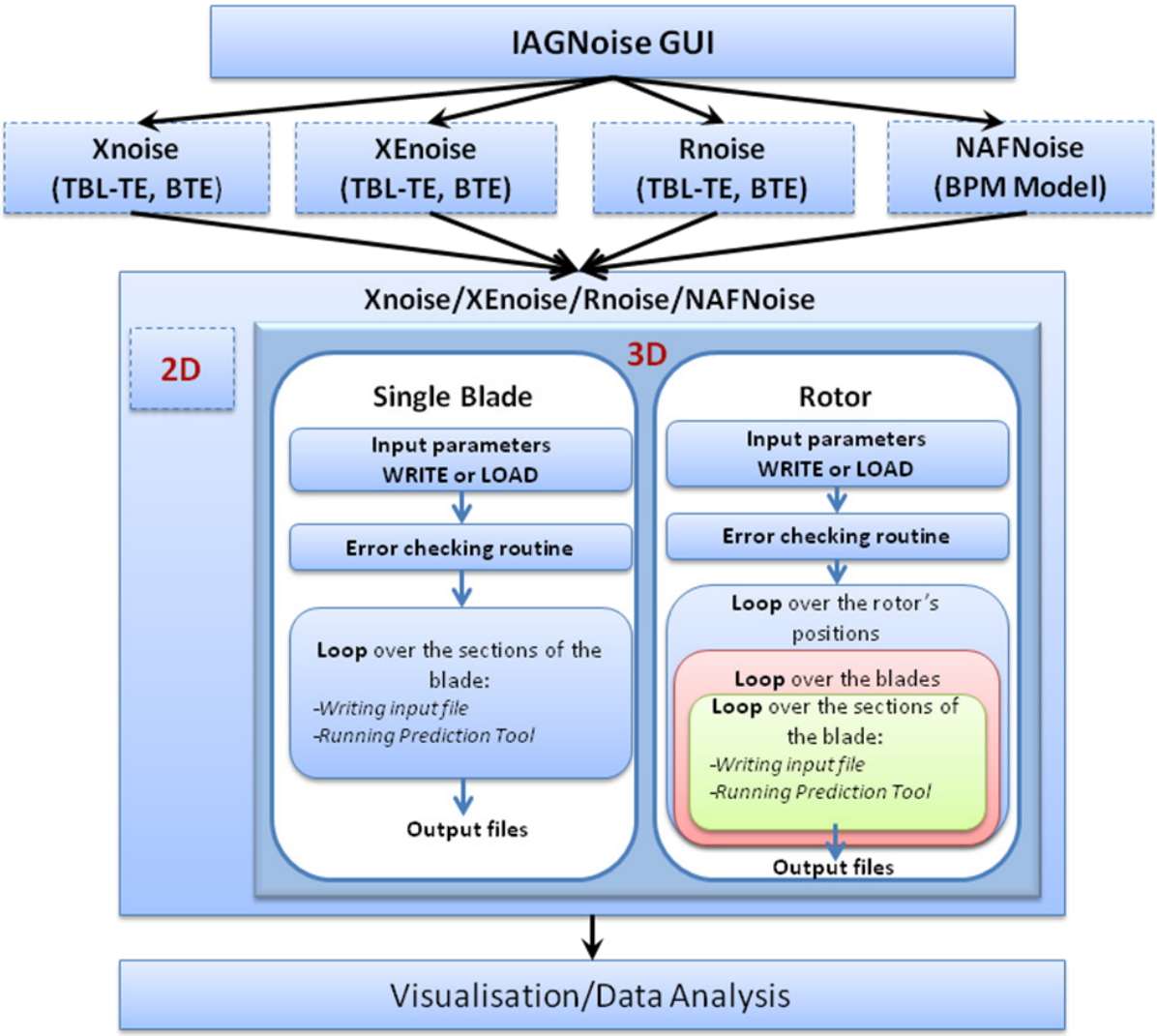

Figure.1: Overall flow chart of the 3D extension of the IAGNoise GUI.

3.1 Airfoil Self Noise Prediction Tool- IAGNoise GUI

The Xnoise, XEnoise and Rnoise prediction schemes are written in Fortran 77 and each of this code has an user defined input file which consists of different flags/options. The prediction schemes are coupled with different aerodynamics analysis codes, thus, before starting the noise computations it is necessary to perform aerodynamic simulations. In order to combine all these prediction schemes in a single platform, a routinely design aerodynamics and aeroacoustics prediction tool called IAGNoise GUI has been implemented [13, 14, 15]. IAGNoise program is a stand alone Windows ® application written in Microsoft ® Visual Basic ® 2005. All the noise prediction codes (i.e. Xnoise, XEnoise, Rnoise) executables are integrated in the tree structure of the IAGNoise framework. IAGNoise permits the computation of far-field noise spectra by various methods, and analyzed the predicted and measured data in a user friendly way. Note that besides in-house prediction codes, the 2D-NAFNoise tool [16] developed by National Renewable Energy Laboratory (NREL), USA has been also included within IAGNoise platform. NAFNoise is an XFOIL airfoil analysis based airfoil self noise prediction tool which uses BPM and TNO-Blake TE noise model.

The prediction schemes which operate by IAGNoise GUI actually provide 2D results related to a 2D airfoil model. To develop a quasi 3D wind turbine noise prediction tool, the 2D-NAFNoise scheme has been extended further as a part of Masters thesis of Francois Broux [15]. In current study, Xnoise, XEnoise and Rnoise schemes are integrated to the IAGNoise framework. The improved IAGNoise tool offers the possibility of a 3D noise computation for a complete wind turbine blade or a rotating turbine. Figure.1 depicted the implementation approach, code structure and the 3D extended main flow chart of the IAGNoise prediction tool.

3.2 Wind Turbine Rotor Noise Modelling

The blades of the wind turbine are non-uniformly divided into a number of airfoil sections or blade elements. The two-dimensional noise prediction schemes Xnoise/XEnoise/Rnoise is applied for each blade section and the total noise level is determined by summing up all the noise sources. For the ith blade element,

$$L_{p,i}^{Total} = 10\log_{10}\left[\sum_{j} 10^{0.1\left(L_{p,j}+K_A\right)}\right] \text{ ---------- (2)}$$

where j denotes the different noise sources such as TBL-TE noise, Separation-Stall noise (SEP), Laminar Boundary Layer Vortex Shedding (LBL-VS) noise, Tip Vortex Formation noise (TIP) and Blunt Trailing Edge vortex shedding noise (BTE) etc. K_A is the relative response of the A-weighting filter in dB. The sound pressure level radiated from a single wind turbine is the sum of the sound pressure level from all blade elements,

$$L_p^{Total} = 10\log_{10}\left[\sum_i 10^{0.1.L_{pi}^{Total}}\right] \text{----------(3)}$$

Since the field measurements indicated that trailing-edge noise is the dominant noise source for large turbines, only this noise source is incorporated in the IAGNoise prediction tool, which means that all other noise source as mentioned earlier are excluded in the present study. The calculation can be divided into three steps: blade aerodynamics, 2D trailing-edge noise source strength, and directivity and convective amplification.

3.3 Blade Aerodynamics

For the aerodynamic calculations the blade is first divided into a number of radial segments. Next, for each segment the local Reynolds number and angle of attack are obtained from an aerodynamic wind turbine model, based on the BEM theory [17]. Then, depending on the method being applied i.e. Xnoise, XEnoise or Rnoise the aerodynamic simulation has been performed to calculate the necessary noise source parameters for the model Eqn. (1).

The sound pressure level is approximately proportional to the fifth power of the Mach number, thus, it is important to refine the discretization of the blade into small elements in the region near the tip. At each blade section the relative velocity V_{rel} and hence the local Mach number is determined from a BEM code by iterative method for axial and tangential interference factors a and b of induced velocity by following

$$V_a = (1-a)V_i, V_{rot} = (1+b)\omega r_i$$

where V_a and V_{rot} are the relative axial and azimuthal velocity components defining the local inflow, $V_i = V_0$ is the free-stream wind speed at the ith blade element, and r_i denotes the blade radius at location *i*. The present implementation of the BEM method are identical to Ref. [17, 18], which includes, among other things, a tip correction method to ensure the accuracy of computations near the tip region. Furthermore, the wind velocity V_i is given at each blade element taking into account the shear and tower effect by the atmospheric power law.

3.4 Blade Segment Trailing-edge Noise Source Strength

The aerodynamic simulations have been performed for each radial blade segment using the reference local inflow characteristics provided by the previous step (BEM model) to extract the turbulence parameters necessary for the model Eqn. (1). In the subsequent step, the source spectrum for each segment is calculated applying any of the 2D trailing-edge noise prediction schemes Xnoise, XEnoise or Rnoise. This way trailing-edge sound pressure level for each radial blade segment will be available via Eqn. (2). Note that total noise prediction via Eqn. (1) only calculates the

source strength for an observer at a fixed position with respect to the blade segment; observer directivity and convective effects are discussed in the next section.

3.5 Noise Directivity & Observer Position

The calculation in the previous section yields the trailing-edge source spectrum in 1/3-octave band, for each radial blade segment. In order to obtain the effective source strength for a given blade azimuth angle, as perceived by an observer at a specified position, the effects of trailing-edge noise directivity and convective amplification should be taken into account.

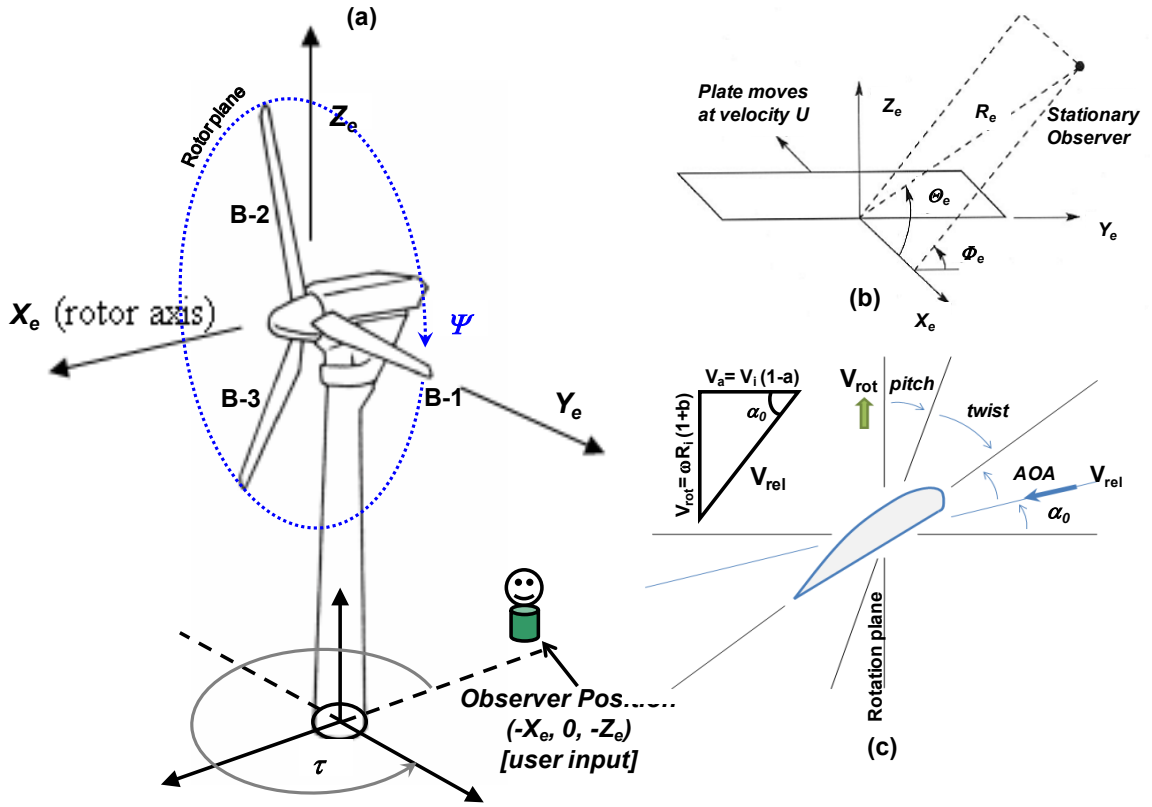

Figure. 2: (a) Rotor & observer coordinates (b) Angles in observer directivity function [19] and (c) Different angles around airfoils.

The directivity of sound is a phenomenon of sound reduction which depends on the position of an observer relative to a noise source. This means that sound has a directional component by having a strong noise amplitude in one direction (two directions in case of a dipolar source, and so on) and in other directions the noise has some reduction degree. In [19] this concept is introduced by the example of a static observer and a flat plate in motion, as shown in Figure.2 (b), where the plate is the noise source to be considered. Also, a local coordinate system is presented with Θ_e and Φ_e being the directivity angles while R_e is the distance between the trailing-edge and the observer position. The sound directivity functions are then given by

following equation. The high-frequency directivity function is valid for all the aerodynamic sources except for the stall situation

$$\overline{D}_H(\Theta_e,\Phi_e) \approx \frac{2sin^2\left(\frac{1}{2}\Theta_e\right)sin^2\Phi_e}{(1+Mcos\Theta_e)(1+(M-Mc)cos\Theta_e)^2}$$

where M is the Mach number for the airfoil section, $M_c = 0.8M$ is the convective Mach number, Θ_e and Φ_e are the directivity angles. The over bar in the equations means that they are "normalized by the TE noise radiated in the $\Theta_e = 90^\circ$ and $\Phi_e = 90^\circ$ direction"[20].

A complete wind turbine rotor noise prediction model requires consideration of some other issues such as air absorption effect, atmospheric and terrain factors, wind farms etc. These factors are not included into the present model and are the topic of future implementation.

3.6 Coordinate Systems

The coordinate system is one of the most important aspects in the 3D extension of the IAGNoise tool. Although the directivity functions $\overline{D_H}$ already account for the observer position relative to blades trailing-edge, the observer is always kept at $(\Theta_e,\Phi_e) = (90^\circ,90^\circ)$ see Figure. 2(b). Therefore, despite of the source being in motion, the observer stays in the same position relative to the blade / wing. So, the first obstacle is to adapt the TNO-Blake prediction model to a real wind turbine model where its blades are in rotation and the observer is motionless. Moreover, because the blades are segmented into separate sections and taken for a single source, it is necessary to know the observer position relative to each segments trailing-edge as demanded by the directivity functions, for each blade rotation step around the rotor axis. For this purpose, a coordinate transformation of the position of the sound source into a global coordinate system is applied. In the present study, four different coordinate systems have been used. The observer position shall be provided by the user at wind turbine coordinate system $B_e = (X_e, Y_e, Z_e)$. Using this information, the retarded distance R_i is found by transformation from coordinate system e to coordinate system i. The directivity angles Θ_i and Φ_i are then found by vector calculus in the coordinate system i. In detail about this implementations can be found in Ref. [15].

In order to analyzed the observer azimuth/directivity effects as it will be described in Section 4.2 the observer position is rotated by τ degrees around the tower vertical axis, Z_e. Hence, the observer coordinates become: $X_0 = -R_0\cos(\tau), Y_0 = -R_0\sin(\tau)$, R_0 is the distance in meters, between the tower vertical axis and the observer, determined by the user. Figure. 2(a) shows the azimuth variation of the observer position and rotor initial position $\Psi = 0^\circ$ (relative to the first blade B1 and Y_e axis.

4. Computational Results & Validations

First, a validation study is performed for the 2D airfoil TE noise spectra in order to investigate the prediction accuracy of the various models. Next, the total rotor noise spectra for a reference turbine the Bonus 300 kW has been simulated by the enhanced prediction tool. The model sensitivity to tripped boundary-layer, local AOAs, trailing-edge BL structure, turbulence scale and observer position for the sound pressure level is analyzed. Comparisons with measurements of the total sound power level are made. The directivity of the sound pressure level around the Bonus300kW turbine is mapped.

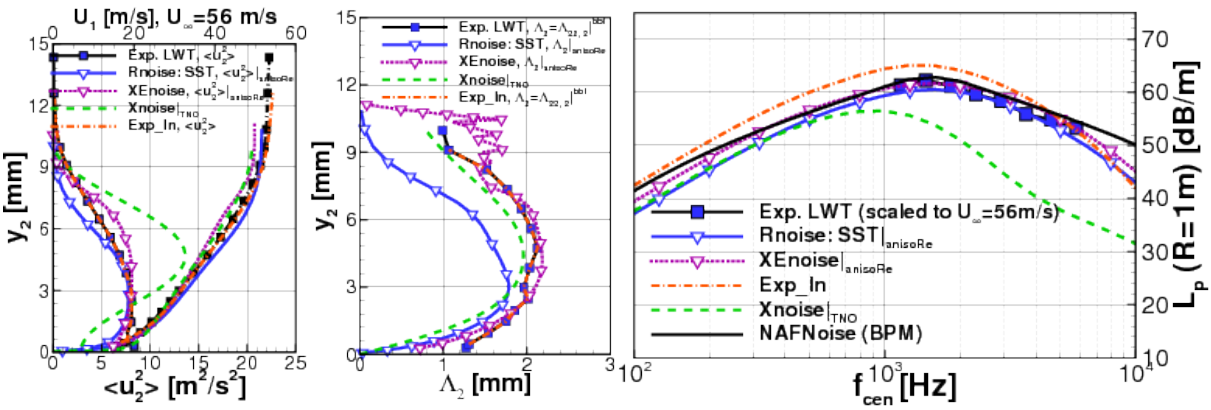

Figure.3: Xnoise, XEnoise, Rnoise and experimental data inside the TNO-Model.

4.1 2D Airfoil Trailing-edge Noise Validation

The wall normal distributions of the Xnoise, XEnoise and Rnoise predicted turbulence noise source parameters such as $\langle u_2^2 \rangle$, Λ_2 and U_1 at chord position $x/c = 0.999$ and associated trailing-edge noise spectra for NACA0012, $\mathrm{Re} = 1.5 \times 10^6, Ma = 0.166, AoA = 0$ are compared with wind tunnel measurement data and depicted in Figure 3. From the left most plot it can be clearly seen that the agreement of the wall normal U_1 distribution is reasonably good, with a small shift. The same plot shows suction side $\langle u_2^2 \rangle$ distribution. For the XEnoise and Rnoise excellent agreement is visible, whereas for the Xnoise case a huge disagreement exists. Note that this improved results of the XEnoise and Rnoise is due to the recently developed turbulence anisotropy modelling [5]. Examining the integral length scale Λ_2 distribution at the middle plot, clearly, for this particular case, a reasonably good agreement is visible. The impact of each input noise source parameter into the total predicted far-field noise levels at *R*=1m distance can be seen in the right most plots of Figure. 3. The Xnoise variants under predict the measured spectra significantly, which is nothing but due to the inaccurate turbulence parameters modelling as observed in the left most two plots. The anisotropic Rnoise and XEnoise provide significantly improved results, which reflect the shape of the measured spectrum perfectly. It can be realized easily, that this is a result of the more realistic distribution of the anisotropic vertical velocity fluctuations and length

scales. Best agreement is achieved, when the measured BL parameters are fed into the prediction model (1) (line legend "Exp_In"), which makes the far-field spectrum practically collapse to the measured spectrum, with slightly overestimation. The BPM model result for the same case is also presented with line legend "NAFNoise (BPM)". Agreement is excellent as expected because the model is developed based on NACA0012 measurement data base.

In summary it can be concluded that, the numerical far-field radiated noise model (Eqn. 1) capture the measured peak amplitude level as well as peak position remarkably well, if the turbulence noise source parameters are estimated properly including turbulence anisotropy effects. Among all the investigated methods the RANS based prediction scheme Rnoise shows most promising results. This encouraging outcome of the 2D results motivated us further development of a 3D prediction tool and is the topic of the next section.

4.2 Wind Turbine Rotor Noise Validation

Reference Wind Turbine Description

In order to validate the present 3D IAGNoise tool for the case of noise generated from a real wind turbine a comparison is made with the work of Zhu and Vargas [17, 18] where a Bonus 300kW wind turbine was used. The standard simulation parameters are exactly same as references [17, 18], only computation has been performed by Xnoise, XEnoise and Rnoise prediction schemes for TE noise only by IAGNoise.

The results under this section have been computed assuming: three bladed rotor, same airfoil NACA0012 along the span, tripped boundary-layer at 5% of the chord, induced velocities contribution via BEM, flat tip, observer is at 40m downwind direction at ground level (-40, 0, -31), constant airfoil bluntness angle (14) and no air absorption effects. The blade noise consists of *Ns*=8 segments and the frequency spectra of *Nf*=33 center frequencies in 1/3-octave band. The total SPL value computation, as mentioned before, consists of gathering the all information i.e. number of points depends on the blades rotation angle, Ψ which will translate in N_Ψ blade increments and on the number of blades segments, *Ns*. However, for each point, the pressure is computed for multiple frequencies, *Nf*. So, the number of computed pressure values is $Np = N_\Psi \times N_s \times N_f$. The processing time is naturally affected by this final number.

Moreover, to gain a uniform basis for comparison, the IEC Ref.~88/48/CDV recommends the calculation of the sound power level, L_w, for an equivalent single noise source at the rotor center as

$$L_w(f) = L_p^{Total} + 10\log_{10}\left[\frac{4\pi R_w^2}{S_0}\right]$$

Where L_p^{Total} is the total sound pressure level corrected for back ground noise, where the rightmost term is the geometrical attenuation, which accounts for the attenuation

of a spherical sound wave at the distance R_w and $S_0 = 1\ m^2$ is a reference area. Note that R_w is the distance from the measurement observer point to the rotor center.

The transition to turbulent BL for a NACA0012 profile is usually between 1e5 and 1e6. As TE noise are related to the turbulent BL, consequently, for the total rotor noise evaluations the blade segments which correspond to the Re larger than 1e6 are considered only. In the present reference case it was found that after the rotor radial position > 0.35 the local Re > 1e6. This behaviour is also consistent with field test measurement of Oerermens el at. [2], where the most dominant TE noise source was found also from outer part of the blade. Note that observing the validation of 2D case in Figure. 3, all the predicted Xnoise results ar shifted with +8dB.

Example of Typical Noise Spectra of Wind Turbine

In Figure.4, computed noise spectra of Bonus 300 kW wind turbine are plotted for all source mechanisms. The contributions from the various source mechanisms can be seen from the individual spectra. For this particular case, the turbulent inflow noise is dominant at low frequency region; the TBL-TE noise and the SEP noise are the most important self-noise sources; the TEB-VS noise may also play a role in case that the blade thickness at the trailing edges is large. However, present study focus only the TBL-TE noise spectra, other noise source mechanisms are excluded.

Comparison results of the IAGNoise BPM model predicted TE noise spectra with experiment and Ref. [18] BPM model total noise spectra are depicted in right hand plot of Figure. 4. A clear offset can be seen, which is nothing but due to the inflow noise dominant contribution as shown in the left hand plot.

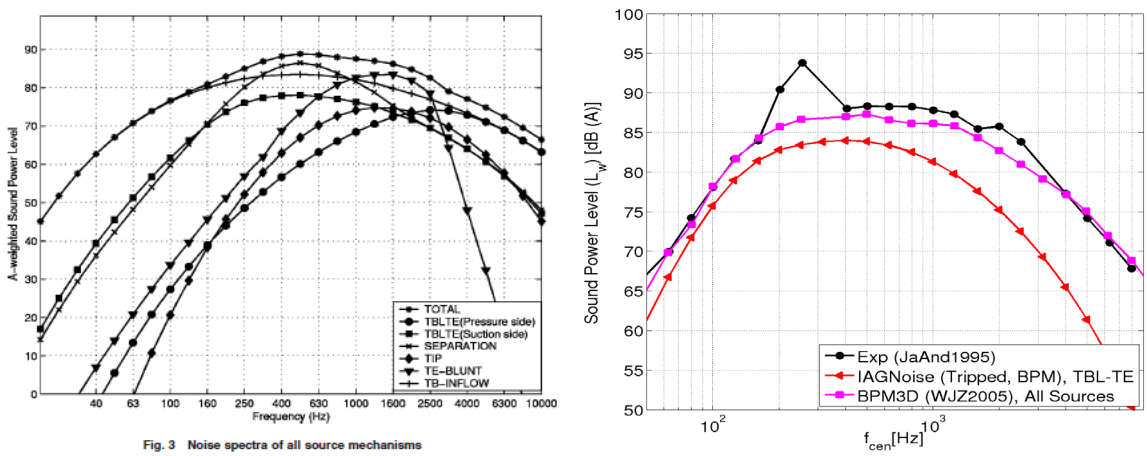

Figure.4: BPM model noise spectra of all source mechanisms of Bonus 300 kW wind turbine collected from Ref. [18] (left). IAGNoise predicted BPM model trailing-edge noise spectra only (right).

Induced Velocities & Angle of Attacks

The induced wind velocity and angle of attack of each section are calculated from the incoming wind speed, the rotor velocity, the radial position of the section, the pitch and the twists angles by BEM method.

Computational results of the relative velocity and AOAs at each blade sections along the radial positions are depicted in Figure. 5. In this computations a variation of the blade element radial position and corresponding twist, chord distribution were made while keeping constant the other parameters: incoming wind speed: ~ 9m/s, pitch angle: -1°, rotor velocity: 35.2 rpm. Decrease of AOAs increasing relative velocity from the root to the tip region is clearly visible as expected. The normal and tangential induced velocities, which can be determined inside the BEM method, are compared with the prediction results of Vargas [17]. After examining the induced velocity trends in Figure. 5 [right], it is noticed that the tangential induced velocity behaves similarly for both models but the normal components evolve slight disagreement. This can be due to the dissimilar tip correction formula.

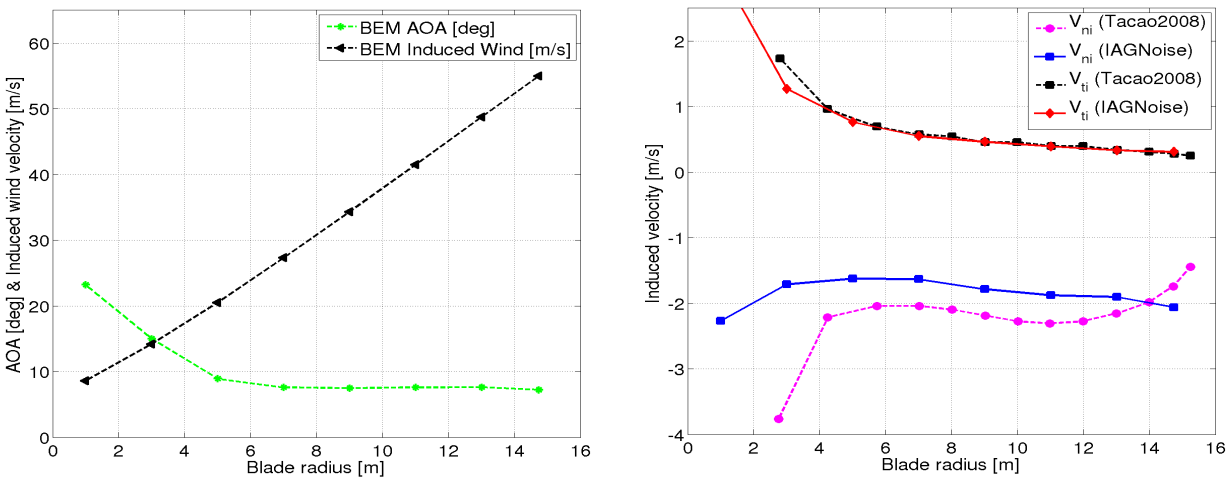

Figure.5: IAGNoise predicted AOAs and induced wind velocity as a function of blade radius- incoming velocity $V_i \approx 9\,{}^{m}\!/_{s}$, $pitch = -1°$, rotor velocity 35.2RPM (left). Induced tangential and normal velocity compared with Vargas2008 [17] data.

Boundary-layer Tripping & Integral BL Parameters

It is known that the sound pressure level changes with the tripping of the BL. In general the noise spectral peak level and position will depend on the position of the BL transition. A clear over prediction at the high frequency for the untripped BL case are visible from Figure. 6 (A). This behaviour can be due to the error from XFOIL predicted BL parameters, because for some flow conditions XFOIL results do not converse properly. The calculated displacement thickness (δ_1) as a function of radius is shown for each segment in Figure 6(B). These results represent conditions close to the average experimental conditions, i.e. incoming wind speeds of 8.0 m/s, RPM values of 35.2, and pitch angle of -1.0° respectively. For the untripped case pressure

side δ_1 is lower due to the fact that BL remain laminar along the chord. The suction side tripped and untripped values are close to each other because for the untripped case BL transition appears approximately at the same position as tripped case i.e. 5% of the chord. Examining the right hand plot which shows the over all TE noise from each section it can be concluded that most dominant source is the outer part of the blade (close to the tip). The PS untripped results are not reliable because it is related to the laminar BL.

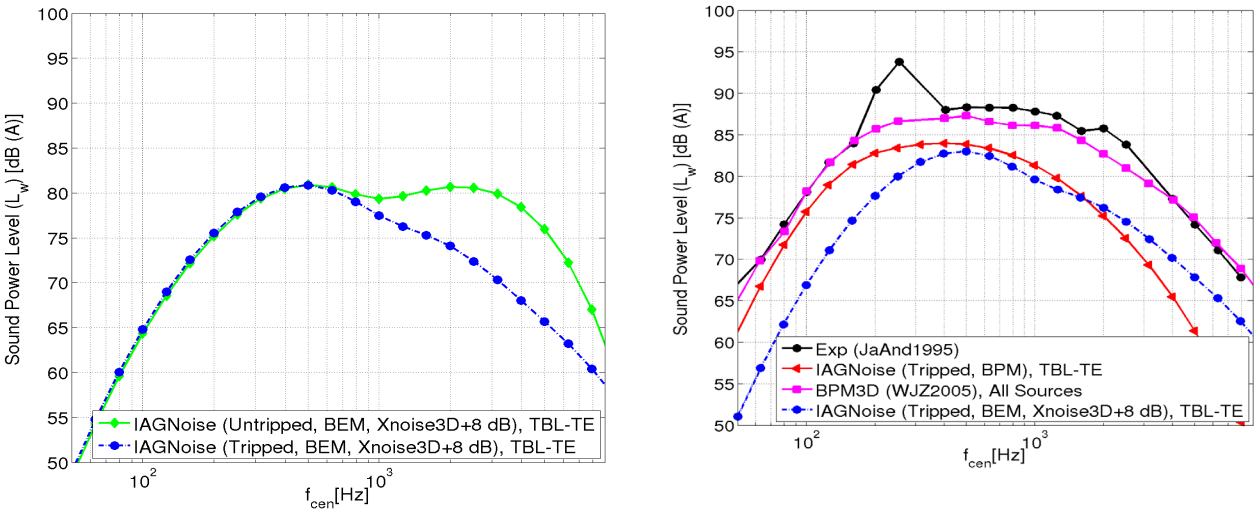

Figure.6 (A): Impact of tripping on predicted SPL (left). Comparison of the different prediction codes calculated sound power level using NACA0012 airfoil with measurement (right).

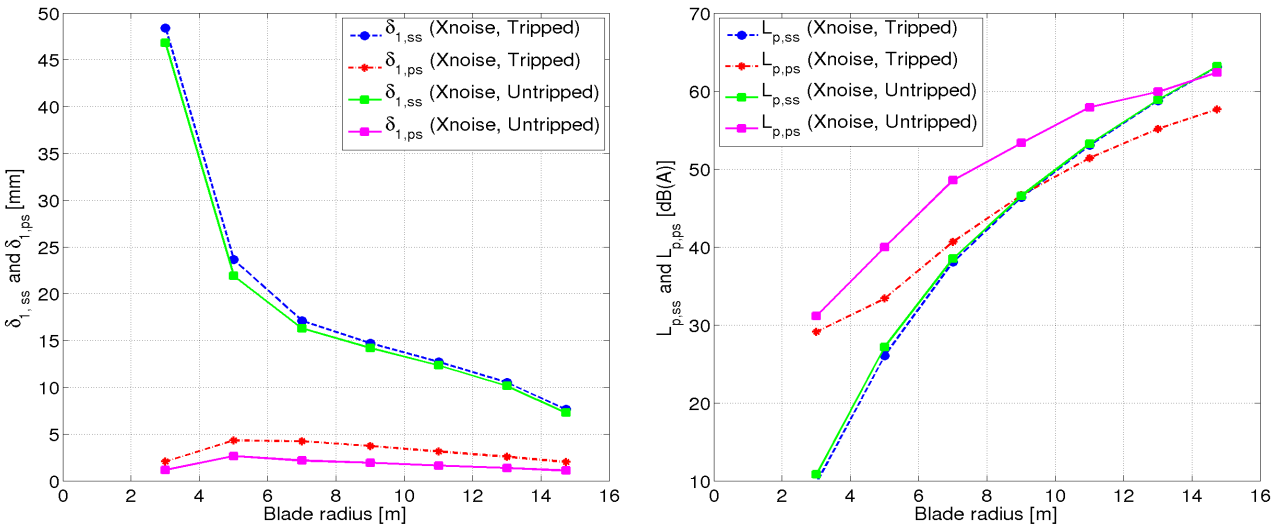

Figure.6(B): Calculated trailing-edge integral BL displacement thickness on suction and pressure side as a function of rotor radius (left). Section total TE noise spectra in dB (right).

Sound Directivity Pattern

It is known that the sound pressure level changes with the observer position. For the Bonus 300 kW wind turbine, sound pressure level at different locations is shown in Figure. 7 (right). In the figure, the receiver positions are distributed on circles of radius between 60 and 200 m from the wind turbine centre and the wind is coming from left to right. From the figure, it is seen that the noise radiation from the wind turbine behaves as a dipole sound source with slightly non-symmetrical properties since blades are twisted. This behaviour is almost similar as previous studies reported in references [17, 18].

In order to analyze the influence of blade position on noise propagation, the overall sound pressure level is plotted in Figure. 8. Here the observer location is fixed on the ground and 40 meters downstream of the wind turbine. The result shows that the maximum change of sound pressure level at different azimuthal angles is about 1 dB during the rotation. The pressure difference will be significant if the observer stays closer to the tower, which corresponds to the Ψ =90° as clearly shown in figure. The general trend of the rotor azimuth vs noise level during the rotation from each blade can be seen from the left hand plot of Figure. 7. Clearly, relative to a stationary observer at (-40, 0, -31), during rotation (clockwise direction) Blade-1 increase the level while Blade-3 decreased. This behaviour is physically consistent, because the noise from downwash rotation will be always higher due to the closer to the observer.

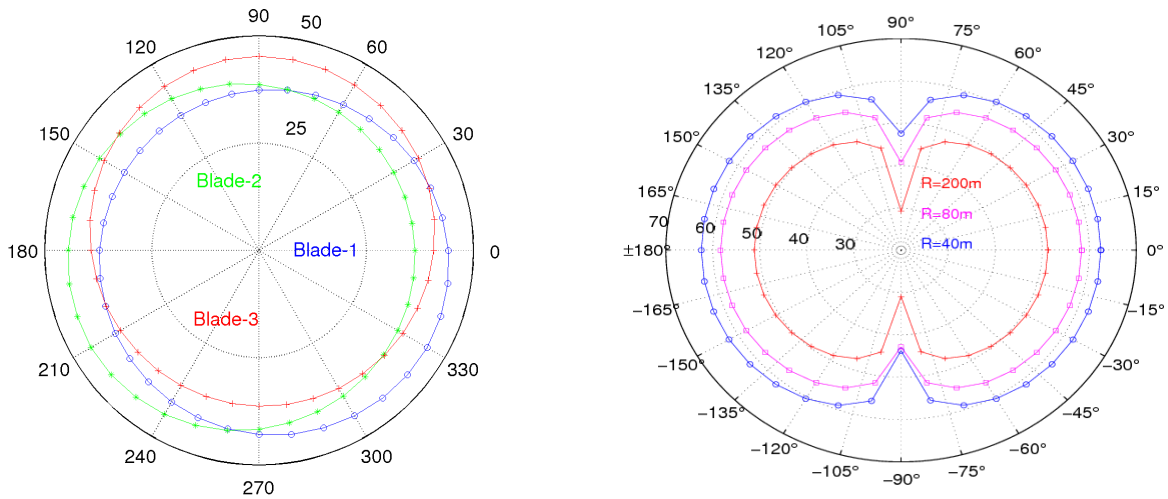

Figure.7: Each blade sound pressure level observed by a stationary receiver at (-40, 0, -31) function of rotor azimuth angles (left). Observer azimuth distribution of the rotor noise levels (right).

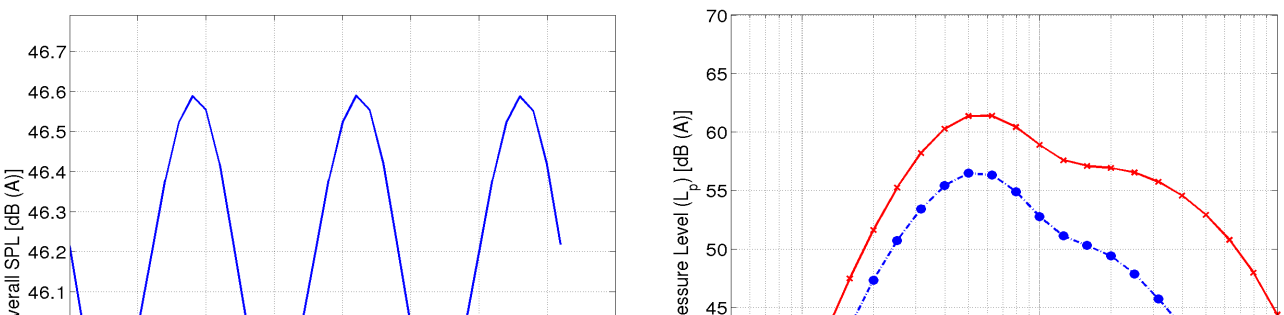

Figure.8: SPL at ground level 40 meters downstream for one revolution period (left). Total sound power level predicted by different methods (right).

5. Outlook

Most accurate RANS based TE noise scheme Rnoise predicted result for the most dominating segment (@95% of span) is compared with XFOIL based Xnoise data in right hand plot of Figure. 8. It can be seen that Rnoise result is excellent. This scheme will be implemented further for the 3D rotor noise computation.

6. Conclusions

A quasi 3D aeroacoustics simulation tool IAGNoise for computing noise emission from wind turbines, based on the TNO-Blake trailing-edge model has been developed by three different aerodynamics methods taking into account the turbulent boundary-layer structure of the actual airfoil shapes and the local wind speed at the blade positions. The model has been tested for the Bonus 300 kW wind turbine at a wind speed of 8 m/ s. Comparisons of the total trailing-edge noise spectra with overall rotor noise measurements shows a clear offset of approximately 6-10dB. Examining the BPM model predicted all noise source spectra exhibits turbulent inflow noise is dominant. However, the IAGNoise BPM and Xnoise predicted trailing-edge noise spectra are in good agreement with other prediction code results. RANS based prediction code Rnoise provide promising 2D results, which will be implemented in the 3D framework in future.

7. Acknowledgements

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