Computational Aeroacoustics for Wind Turbine Noise

Simulation of Turbulent Flow and Acoustics for Wind Turbines

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In Short

- Wall-resolved large-eddy simulations of the flow around wind turbine blade sections
- Investigation of noise generation mechanisms
- Simulation of the propagating sound waves with volume discretization approaches to take into account effects of the wind turbine's surroundings
- Developing a method for the accurate acoustic prediction of wind turbine noise, with a focus on far-field noise

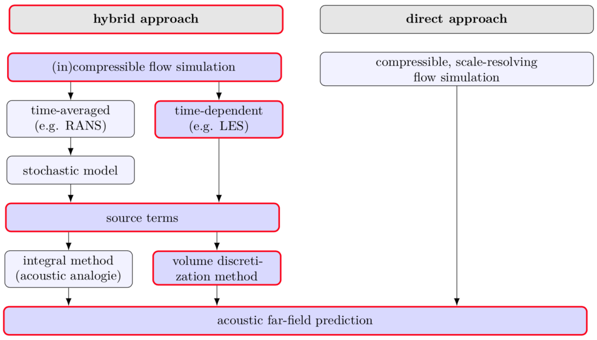

Figure 1: *Hybrid and direct approach for aeroacoustic noise prediction; the pursued path is framed [5].*

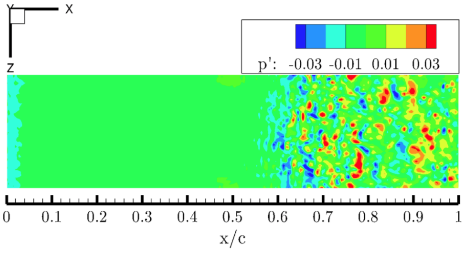

Figure 2: *Normalized wall pressure fluctuations on the section of a wind turbine blade, obtained by WRLES with OpenFOAM, needed to derive the acoustic source terms as input for the simulation of the propagation [5].*

Germany's energy transition goals led the federal government to decide that by 2050 80% of its energy demands ought to be met via renewable energy, and greenhouse gas emissions ought to be reduced by at least 80% [1]. To enable the expansion of wind energy technologies, however, social acceptance is of crucial importance. The impacts of wind turbines on human health and well-being are among the most-mentioned concerns, and they are known to impose essential barriers [2]. The development of reliable methods that allow for acoustic emissions to be estimated is a key strategy to increase public support and to open up new locations. Therefore, the project's objective is embodied by the ambition to provide detailed insights into the mechanisms of flow-induced sound generation and its propagation via hybrid Computational Aeroacoustics (CAA).

In contrast to a direct noise computation (DNC) the hybrid approach separates the computation of sound generation and propagation, providing the opportunity to employ tailored numerical methods for each field [3] (see Figure 1). Since the simulated turbulent fluctuations are rather sensitive to the quality of the grids used [4], special attention is paid to accurately capture the velocity and pressure fluctuations in wall proximity (see Figure 2), which are essential to derive the acoustic source terms. Therefore, incompressible, scale-resolving and time-accurate wall-resolved large-eddy simulations (WRLES) of the unsteady turbulent flow will be conducted with the open-source code OpenFOAM [6,7] meeting the grid requirements for WRLES suggested by Piomelli and Chasnov [8]: $\Delta x^+ = \mathcal{O}(50-150)$, $y^+ < 2$, $\Delta z^+ = \mathcal{O}(15-40)$. Using blade-resolved simulations for the extraction of acoustic source terms makes it possible to not only predict broadband noise but also tonal sounds, which are perceived as significantly more disturbing [9]. Current approaches using Reynolds-Averaged Navier Stokes (RANS) simulations in combination with stochastic models can only capture broadband noise [10]. The effect of different varying angles of attack (AoA) and turbulence intensities of the incoming flow on the acoustic source terms will be investigated. For this purpose a special source-term formulation [11–13] for injecting artificial inflow turbulence will be implemented, prohibiting that the synthetically generated turbulence is damped out by numerical dissipation before it reaches the leading edge.

Volume discretization methods will be used for the calculation of the propagating sound, as they provide the ability to take into account effects of the wind turbine's surrounding on the propagating sound waves, like diffraction, absorption, reflection or scattering. Due to the great disparity in length and energy scales between the flow and the acoustic field, CAA is a challenging multiscale problem. Especially the simulation of propagating sound over long distances demands for numerical schemes with a high order of accuracy. The FLEXI framework [14,15] will be used for this purpose as it is based on a highly accurate and computationally efficient Discontinuous Galerkin Spectral Element Method (DGSEM). The focus of the first project phase is on WRLESs of the flow around sections of a wind turbine rotor blade. Moreover, initial acoustic propagation simulations with the FLEXI code will be run for noise created by a loud speaker in order to validate the correct consideration of the effect of the surroundings in the simulations and to investigate the influence of the computational domain width. The numerical results will be validated via measured data.

WWW

https://www.fh-kiel.de/index.php?id=oneumann

More Information

[1] Bundesministerium für Wirtschaft und Energie: Ein gutes Stück Arbeit - Die Energie der Zukunft - Vierter Monitoring-Bericht zur Energiewende. Brochure. Berlin. (2015)

[2] Aakre, S. and Leiren, M. D. and Linnerud, K.: Deliverable 2.3: Taxonomy of social acceptance drivers and barriers. Version 5. EU project WinWind. European Union. (2019)

[3] Schoder, S. and Kaltenbacher, M.: Hybrid aeroacoustic computations: State of art and new Achievements. In: Journal of Theoretical and Computational Acoustics 27, p. 1950020. (2020) doi:10.1142/S2591728519500208

[4] Neumann, S. O., Uddin, N., and Weigand, B.: Grid sensitivity of LES heat transfer results of a turbulent round impinging jet. In: High Performance Computing in Science and Engineering '10, Berlin, Heidelberg: Springer, pp. 307-325. (2011) doi:10.1007/978-3-642-15748-6_24

[5] Pabst, H. A.: Simulation of a Turbulent Airfoil Flow with an Eddy Resolving Method Based on a Finite-Volume Code. Master's Thesis. Kiel: University of Applied Sciences Kiel. (2021)

[6] Weller, H. G. et al.: A tensorial approach to computational continuum mechanics using object-oriented techniques. In: Computers in Physics 12, pp. 620-631. (1998) doi:10.1063/1.168744

[7] OpenCFD Ltd (ESI Group): OpenFOAM The Open Source CFD Toolbox https://www.openfoam.com (2020)

[8] Piomelli, U. and Chasnov, J. R.: Large-eddy simulations: Theory and applications. In: Turbulence and Transition Modelling. Vol. 2. ERCOFTAC Series. Dordrecht: Springer, pp. 269-336. (1996) doi:10.1007/978-94-015-8666-5_7

[9] Davy, J. L., Burgemeister, K. A., Hillman, D. R., and Carlile, S.: A review of the potential impacts of wind turbine noise in the Australian context. In: Acoustics Australia 48, pp. 181-197. (2020) doi:10.1007/s40857-020-00192-4

[10] Ewert, R. et al.: CAA broadband noise prediction for aeroacoustic design. In: Journal of Sound and Vibration 17, pp. 4139-4160. (2011) doi:10.1016/j.jsv.2011.04.014

[11] Breuer, M.: Effect of inflow turbulence on an airfoil flow with laminar separation bubble: An LES study. In: Flow, Turbulence and Combustion 101, pp. 433-456. (2018) doi:10.1007/978-3-030-04915-7_46

[12] De Nayer, G., Schmidt, S., Wood, J. N., and Breuer, M.: Enhanced injection method for synthetically generated turbulence within the flow domain of eddy-resolving simulations. In: Computers & Mathematics with Applications 75, pp. 2338-2355. (2018) doi:10.1016/j.camwa.2017.12.012

[13] Schmidt, S. and Breuer, M.: Source term based synthetic turbulence inflow generator for eddy-resolving predictions of an airfoil flow including a laminar separation bubble. In: Computers & Fluids 146, pp. 1-22. (2017) doi:10.1016/j.compfluid.2016.12.023

[14] Krais, N., Bolemann, T., Hindenlang, F., Hoffmann, M., Kuhn, T., Sonntag, M., Munz, C.-D., Beck, A., Frank, H., Flad, D., and Gassner, G.: FLEXI: A high order Discontinuous Galerkin framework for hyperbolic-parabolic conservation laws. In: Computers & Mathematics with Applications 81, pp. 186-219. (2021) doi:10.1016/j.camwa.2020.05.004

[15] Numerical Research Group; University of Stuttgart: Flexi - High Performance Open Source CFD. https://www.flexi-project.org (2020)

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