INCE EUROPE

9th International Conference

Wind Turbine Noise 2021

Remote from Europe

Tuesday 18th - Friday 21st May 2021

www.windturbinenoise.eu

Programme Book

Version 4. 29th April 2021

Contents

Welcome to Wind Turbine Noise 2021

Welcome to the Ninth International Conference on Wind Turbine Noise organized by INCE/ Europe. This is our first wind turbine e-conference, but not the first one for INCE/Europe as we hosted Quiet Drones 2020 last October in collaboration with CiDB in Paris.

One of the biggest problems with an e-conference is scheduling for time zones. Inevitably there will be some people who can only watch live sessions at thoroughly unhospitable times. Over 70% of our authors and delegates are from Europe and we are a European organisation so puts us squarely in the European working day. This conference, at the time of writing, only has 5% of delegates in Asia/Pacific but 22% in the Americas. That means we will operate the conference in the afternoons European time. But those of you who are in the Asia/Pacific area, don't forget that almost everything will be recorded and, as a delegate, you will be able watch during the conference and for two weeks after.

All times are Central European Summer Time (CEST) which is UT+2

As a delegate you will have access to the delegates area from about two weeks before the conference until about two weeks after. In the time before the conference you will have access to the full papers and be able to read them in advance so that you can ask questions or make comments at the live session. For everything else you will have to wait for the live sessions. After each live session is complete recordings will be available for you to watch. The presentations of the papers will be available immediately after the end of the session in which they are given; the discussions and conversations will take longer to be available as they have to be processed.

This Programme Book is available free to anyone from our website and contains the programme for the conference and all the abstracts of papers submitted.

The International Energy Agency Wind Task 39 is holding a parallel e-conference on the Tuesday morning of the conference. The goal of Task 39 is to accelerate the development and deployment of quiet wind turbine technology.

Organisation

Chair

- Dick Bowdler, UK

INCE-Europe

- Jean Tourret, France, President
- Geoff Leventhall, UK

Administrator

- Cathy MacKenzie, UK

Committee members

- Mark Bastasch, USA
- Franck Bertagnolio, Denmark
- Norm Broner, Australia
- Sylvia Broneske, UK
- Matthew Cand, UK
- Kristina Conrady, Germany
- Christophe Delaire, Australia
- Malcolm Hayes, UK
- Michaela Herr, Germany
- Cordula Hornung, Germany
- Brian Howe, Canada
- Simon Jennings, Ireland
- Damian Kelly, Ireland
- Soogab Lee, Korea
- David Michaud, Canada
- Bo Søndergard, Denmark
- Frits van den Berg, Netherlands
- Wouter van der Velden,
- Sabine von Hunerbein, UK

Co-Hosts: Technical operation of the conference

- Payam Ashtiani
- Matthew Cand
- Krispian Lowe
- Andy McKenzie

WTN 2021 Programme of Sessions

All times are Central European Summer Time (CEST) which is UT+2

Tuesday 18th May

13:00 - Introductory Conversation

	Dick Bowdler and Jean Tourret
	Meet the other delegates and the organisers. Find out how the conference operates.

14:00 - Session 1 - Source Noise Analysis and Prediction

Session Chairs	**TBC**
Martuscelli Faria	A review on the development of airfoils for wind turbine blades
Hornung	Turbulence inflow noise prediction of wind turbine rotors: The physically correct representations of the Simplified Amiet and Lowson Model
Hasheminasab	Effect of grid resolution on airfoil self-noise prediction by large eddy simulation
Bortolotti	Validation efforts of an open-source aeroacoustics model for wind turbines
Rodriguez	The Quasi-3D blade and rotor noise prediction methodology for the PNoise code and preliminary results
Bertagnolio	A tower wake model for Low-Frequency Noise of downwind turbine rotors
	Extended Discussion

16:00 - Break and Networking

16:30 Session 2	**Large Blades - Do They Pose Special Acoustic Problems?**
Session Chairs	**Franck Bertagnolio and TBC**
Seel	Numerical study of the impact of vortex generators on trailing edge noise
Suryadi	Identifying the flap side-edge noise contribution of a wind turbine blade section with an adaptive trailing-edge
Saab	Developing new airfoils for larger wind turbine blades
	Extended Discussion

18:00 - Meet in the Wonder Room

	Go to the Wonder Room and meet the other delegates

Wednesday 19th May 2021

13:00 – Conversation Task 39. Update on International Energy Agency progress

14:00 Influences	**Kristina Conrady on the Wind**
	Kristina will be telling us about Low Level Jets and Low Level Wind Maxima – what they are and how they affect wind turbine noise.

14:45 – Break and Networking

15:05 Session 3	**Propagation and Modelling**
Session Chairs	**Matthew Cand and Susanne Martens**
Kayser	Calculation of wind turbine noise uncertainty for downwind conditions
Søndergaard LS	Long distance noise propagation over water for an elevated height-adjustable sound source
Clark	Comparison between modelled and measured noise impact with varying ground factors
Halstead	A study of the relationship between wind direction and sound level for wind turbines measured in the far-field
Elsen	Different sound source setups in the simulation of wind turbine sound propagation
Dutilleux	Meteorological effects on wind turbine noise at the receptor location
Bolin	Wind sector management using Beilis Tappert Parabolic Equation
	Extended Discussion

17:05 – Break and Networking

17:25 - Session 4	**Impact Studies and Regulations**
Session Chairs	**Mark Bastasch and Andy McKenzie**
Søndergaard B	On the need for improved prediction models and updated noise regulations to utilize the advanced controls strategies that are available for modern wind turbines
Palmer	Stymied by Standards? Arguments for wind turbine noise standards that actually measure irritant drivers
Tam	A characterization of wind turbine and background noise distributions in far-field receptor testing of wind turbine facilities
	Extended Discussion

18:30 – Meet in the Wonder Room

Thursday 20th May 2021

13:00 Conversation

Frits van den Berg talks to Mirjam Davidson and Anne Struijs of RWE about working with neighbours

13:45 - Break and Networking

14:05 Session 5	**Noise Measurement and Assessment**
Session Chairs	**Payam Ashtiani and Sabine von Hunerbein**
Ashtiani	A review of different methodologies for the measurement of sound pressure level from wind farms
Finez	Robust noise indicators using Gaussian Processes
Gloaguen	Estimation of the sound emergence of wind turbines by semi-supervised learning technique
Broneske	Development of IEC/TS 61400-11-2: Measurement of wind turbine noise characteristics in receptor position
Summers	Further experience of reviewing noise assessments for wind farms in Scotland and the implementation of the IOA Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise
Bartolazzi	A model to calculate the delta between internal noise with open windows vs external noise
	Extended Discussion

16:05 - Break and Networking

16:25 - Session 6 - Tonality

Session Chairs	**Sylvia Broneske and Robin Woodward**
Old	Wind turbine sound quality rating
Busse	The (psychoacoustic) basics of tonality perception
Søndergaard LS	Tonality content analysed with both 1/3 octave band and narrowband methods with comparison to listening test
Woodward	An implementation of ISO/PAS 20065:2016 for the analysis of wind turbine sound at receptor distances
Munro	Comparison of tonality analysis methods for wind turbine receptor based long-term monitoring data sets
	Extended Discussion

17:55 - Short Break

Thursday 20th May 2021

18:05 Session 7	**Amplitude Modulation**
Session Chairs	**Sarah Large and TBC**
Mascarenhas	Physics-based auralization of wind turbine noise
Pies	Assessment and rating of wind turbine noise immission at dwellings - the influence of amplitude modulation, aerodynamic noise sources and the Doppler effect **POSTER – no presentation but see poster on the poster page
Lotinga	Subjective responses to wind turbine noise amplitude modulation: pooled analysis of laboratory listening studies and synthesis of an AM character rating penalty
	Extended Discussion
19:05 - End	

Friday 21st May 2021

13:00 Conversation

Frits van den Berg talks to Aileen Jackson and Rosemary Milne about what it is like to live near wind turbines

13:45 Session 8	**Infrasound**
Session Chairs	**TBC**
van den Berg	Audibility and health effects of infrasound
D'Amico	Prediction of wind turbines infrasound from meteorological parameters
Leventhall	If they are not being made ill by infrasound, then what is it?
	Extended Discussion

14:50 – Break and Networking

15:10 - Session 9	**Perception and Health**
Session Chairs	**Irene van Kamp and David Michaud**
Liebich	A meta-analysis on the impact of wind turbine noise on sleep using validated objective sleep assessments
Søndergaard LS	Wind farm neighbourship investigated by a daily app questionnaire combining weather, noise and annoyance
Preihs	Assessing wind turbine noise perception by means of contextual laboratory and online studies
Ollson	Establishing sound limits for wind energy: What is the role of annoyance?
	Extended Discussion

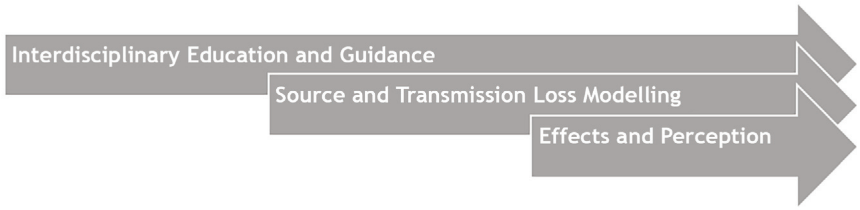
16:45 Conversation and Closing – We need your feedback

Jean Tourret and Dick Bowdler discuss the advantages and disadvantages of e-conferences with the delegates – and what plans are for 2023.
Give us your feedback.

17:30 Conference Closes

WORKSHOP: Presentation of the IEA WIND TCP Task 39 - Quiet Wind Turbine Technology

The International Energy Agency Wind Technology Collaboration Programme (IEA Wind TCP) is an international co-operation that shares information and research activities to advance wind energy research, development and deployment in member countries. The goal of IEA Wind TCP Task 39 is to accelerate the development and deployment of quiet wind turbine technology. The task group comprises an international expert panel to exchange learning, identify and report best practices in the prediction, measurement and assessment of noise.



WP1 - Interdisciplinary Education and Guidance

- Sharing information and dissemination of knowledge through workshops and publications.

WP2 - Analysis and reduction of wind turbine noise emission

- Specific physical noise generation mechanisms and their mitigation are investigated, through the benchmarking of models and their validation against experimental data.

WP3 - Noise propagation modelling

- The complex phenomenon of noise propagation over longer distances and from offshore turbines are investigated through modelling and validation.

WP4 - Assessing and managing the noise effects on health, well-being and consent

- This WP will investigate the subjective perception of wind turbine noise, potential mechanisms of noise-induced annoyance and the role that noise and annoyance play in the generation of health, wellbeing and consent effects. Studies will be conducted in a variety of settings from the laboratory (neuroscience, psychophysics and psychoacoustics) to the field (survey and other online methods).

WP5 - Characterizing non-noise influences on Noise Perception and its effects

- WTN annoyance is intricately related to social acceptance of wind turbines. In concert with assessing noise effects in WP4, this WP focuses on the role of social acceptance in sensitizing or habituating to WTN and characterizing the various routes through which social acceptance influences WTN annoyance and its downstream effects.

During this workshop, the general aspects of IEA TCP Wind framework and its goals are explained. Past activities and the planned new work programme for the next 3 years are presented. An open discussion will allow attendees to ask questions about the Task 39 in general and develop possible future activities in this international collaborative context.

Agenda:

13:00-13:10 Introduction to IEA Wind TCP and Task 39 (Eugene McKeown)

13:10-13:20 Review of Phase 1 (Franck Bertagnolio)

13:20-13:40 Presentation of the work programme for Phase 2 (Franck Bertagnolio & Denis O'Hora)

13:40-14:00 Open discussion

Contacts – Task 39 Operating Agents:

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| Book of Abstracts

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A Review on the Development of Airfoils for Wind Turbine Blades

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Sara Rodriguez (University of São Paulo)
João Paulo Barreto (University of São Paulo)
Marcos de Mattos Pimenta (University of São Paulo)

Airfoil geometry is key to fulfill two important requirements while designing utility-size wind turbine equipment: (i) aerodynamic performance for high power coefficients during energy conversion and (ii) low noise generation for compliance with sound pressure level limits. Contrary to the classic structural trade-off, a low noise requirement does not seem to pose an antagonistic design objective with aerodynamic efficiency, at least in the range of audible noise frequencies and yet, airfoils designed for low noise emissions seem to be an exception to the rule, at least within the published literature. This review paper reports on the results of several airfoil development research for large-size wind turbine blade application, covering geometries developed solely with aerodynamic performance in mind and those few also concerned with noise emission from the inception. A reference table with data of the airfoils discussed is provided along with the associated design Reynolds numbers, whenever available. Finally, a selected sample of design criteria for large-size wind turbine airfoils is briefly discussed.

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Turbulence Inflow Noise Prediction of Wind Turbine Rotors: The physically correct Representations of the Simplified Amiet and Lowson Model

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The sound in the lower frequency range of a wind turbines spectrum is increasingly gaining importance. The main aerodynamically induced contribution within the audible range of the lower frequencies is turbulence inflow noise. A number of papers is available addressing the prediction of inflow noise. Almost all of them are based on the theory of Amiet and Paterson, who provide a simplified and a complex version of their theory on the prediction of turbulent inflow noise at an airfoil. Many researchers employ the simplified approach in their models. However, a in depth literature research revealed that a number of equations are available, which differ considerably in applied constants as well as in the way the models are utilized. The goal of this paper is to sketch out potential points in the model prone to inconsistency and present a valid form of the simplified equation by deriving it from the original paper by Amiet and Paterson. The derived equation is then combined with an adjusted version of the Lowson model, consistent in its formulation to tackle the lower frequency deviations. The effect of airfoil thickness is taken into account via the thickness model proposed by Moriarty.

Subsequently, the corrected models are applied to predict the noise of a full size wind turbine. In order to verify the enhanced models – pure Amiet model and Amiet-Lowson model - a variation of length scale and turbulence intensity is performed, showing the expected physical behavior.

Finally, the results of the enhanced model are validated with measured spectra of a full-size multi megawatt turbine. In addition, they are compared to predictions determined with the complex model of Amiet. It can be shown that when employing the correct model equation, the simplified form can keep up with the complex form with respect to prediction accuracy.

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Effect of grid resolution on airfoil self-noise prediction by large eddy simulation

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Airfoil self-noise is one of the dominant sources of wind turbine noise. This paper presents the results of numerical investigations exploring the airfoil self-noise prediction employing large eddy simulation (LES). In the first step, an incompressible large eddy simulation of fluid flow around a NACA0012 airfoil at zero angle of attack with a chord-based Reynolds number of 6.4×105 is performed. In the second step, the far-field noise is predicted by Ffowcs-Williams & Hawkings (FW-H) model using the LES solution. Two different grid resolutions are used to investigate the effect of grid resolution on the accuracy of acoustic results. The results are compared with experimental data of wind tunnel tests and noise measurements through microphones. The comparison shows that the grid resolution has a significant effect on the acoustic predictions and by increasing the number of grid points in the spanwise and streamwise direction, numerical noise predictions approach the experimental results. In some frequencies, by increasing the number of the grid points, the differences between numerical and experimental results are increased to less than 5 dB.

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Validation Efforts of an Open-Source Aeroacoustics Model for Wind Turbines

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Jason Roadman, National Renewable Energy Laboratory, USA
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Carlo R. Sucameli, Technical University of Munich, Germany
Franck Bertagnolio, DTU Wind Energy, Denmark

The open source aeroservoelastic wind turbine solver, OpenFAST, now includes an aeroacoustics model, which is described here and validated against experimental measurements recorded on a GE 1.5-MW wind turbine installed at the Flatirons Campus of the National Renewable Energy Laboratory in Boulder, Colorado. The validation demonstrates satisfactory agreement between numerical predictions and experimental recordings, with discrepancies up to 7 dB in the overall sound pressure levels at low wind speeds and a better agreement around the rated wind speed of the turbine.

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The Quasi-3D Blade and Rotor Noise Prediction Methodology for the PNoise Code and Preliminary Results

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Owing to the large and steady number of downloads of the Qblade open source wind turbine design environment, 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 (TE) noise prediction tool. The laminar-boundary-layer-vortex shedding (LBL-VS), trailing-edge-bluntness- vortex-shedding (TE-Blunt-VS) 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 aim of the upgrade is to provide the user with the approximate sound pressure levels and related spectra for all self-noise sources plus inflow noise, for 2D and 3D prediction in 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. Due to the recursive nature of the quasi 3D method, 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, along with the preliminary results for the predicted blade and rotor noises calculated for a 31 m diameter WT rotor.

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A Tower Wake Model for Low-Frequency Noise of Downwind Turbine Rotors

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In this contribution, a simplified model for the turbulent wake of a wind turbine tower interacting with the rotor blades, in the case of a downwind rotor concept, is proposed. The goal is to model the effect of the vortex shedding and associated turbulent flow vortices on the noise emissions.

The proposed model consists of 2 parts. The first one is a CFD simulation of the flow field around a circular cylinder accounting for the vortex shedding and turbulence structures. This model is limited in term of resolution for obvious computational requirements. In addition, a temporal and spatial sampling is used to store the flow data to manageable file sizes.

The second part of the model consists of using the above data to recreate the flow features to a realistic level so that it can be used for the prediction of Low-Frequency Noise emissions from a wind turbine rotor located downstream of the tower.

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Numerical Study of the Impact of Vortex Generators on Trailing Edge Noise

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The continuous increase in rotor size of horizontal axis wind turbines leads to a chain of structurally-driven aerodynamic adaptations. Especially the increase of airfoil thickness necessitates a strong and steep pressure recovery in the rear part of the airfoil. Thus, modern wind turbines are increasingly equipped with Vortex Generators (VGs) to reduce the risk of separation due to the strong adverse pressure gradients. Those vane-like passive aerodynamic devices fixed on the blade's surface induce streamwise vortices to reenergize the lower part of the boundary layer. In terms of aeroacoustics, VGs reduce airfoil noise for high angles of attack by delaying separation and consequently stall noise. In attached flow conditions the VGs, however, may lead to an increase in trailing edge noise due to their influence on boundary layer development. In this paper the influence of the VGs on trailing-edge noise is investigated with numerical methods and compared with published experimental results. For this purpose, a NACA0018 airfoil with counter rotating common down vortex generators is simulated using RANS-methods. The output is utilized to compute the trailing-edge noise with the inhouse acoustic code IAGNoise+ based on an enhanced TNO-Method. The numerical results show good agreement with the experiment. Especially the increase in sound pressure level in the frequency range up to 5 kHz due to the modified boundary layer shape agrees well for moderate angles of attack. Furthermore, it was found that vortex correction and grid refinement in the propagation area of the VG induced vortices has a significant impact on the computed noise spectrum.

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Identifying The Flap Side-Edge Noise Contribution Of A Wind Turbine Blade Section With An Adaptive Trailing-Edge

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Active trailing-edge technology is a promising application for localized load alleviation of large-diameter wind turbine rotors, accomplished using one or more control surfaces in the rotor blade's outer region. This work focuses on identifying noise contributions from the flap side-edge and the trailing edge in a laboratory condition. Measurements were conducted in the Acoustic Wind tunnel Braunschweig (AWB) at the German Aerospace Center's (DLR) Braunschweig site. The small- scale model has a span of 1200 mm and a chord of 300 mm. The control surface, a plain flap, has a span of 400 mm and a chord length of 90 mm. Far-field noise was measured using a phased- microphone array for various flow speeds, angles of attack and flap deflection angles. For sound source identification, two noise reduction addons were installed interchangeably: trailing-edge brush and flap side-edge porous foam. Analysis of the far-field noise reveals that, while changes to the flap deflection angle alter the far-field noise spectra, the trailing-edge noise remains the predominant noise source at deflection angles -5° and 5°. No additional noise level was observed from the flap side-edge within the measurable frequency range at these angles. The flap side- edge noise has an increased role for frequency larger than 2 kHz for the larger flap deflection angles of -10° and 10°. Furthermore, numerical reproduction of the results will also be presented using the FMCAS (Fast Multipole Code for Acoustic Shielding) toolchain developed at DLR.

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Developing New Airfoils for Larger Wind Turbine Blades

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A review on performance data published for selected airfoils of horizontal-axis wind turbines (HAWT) suggests that they were designed for equipment smaller than the current standard and future trends in HAWT sizes. The resulting gap in airfoils readily available for HAWT research and development is further stretching as new equipment is designed for diameters of 200 m and above, which imply in much higher local2 Reynolds number flows. This text briefly illustrates the development process and preliminary results of new, dedicated HAWT airfoils designed for the 7 to 9 million Reynolds number and 0.14 to 0.21 Mach number flows, typical of 100-m diameter HAWTs, achieved with the use of the open-source QBlade platform and its integrated PNoise, TE noise code. The use of the combined codes enabled the design of a new family of airfoils based on the Somers/NREL S830 main airfoil and the first estimates predict preserved aerodynamic characteristics and comparable or lower Trailing-Edge noise emission performance under higher Reynolds and Mach numbers. It is implied that the use of these tools in a combined form might lend themselves to the design of new families of larger airfoils, suitable for 200+ m diameter rotors, with both aerodynamic and aeroacoustic design requirements.

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Calculation of wind turbine noise uncertainty for downwind conditions

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Wind turbine noise variability is significant for outdoor environments because of the influence of atmospheric conditions and ground properties that are both variable in time and space. Thus, realistic prediction of sound pressure levels involves to estimate the overall uncertainty induced by the most influential environmental phenomena on both acoustic emission and propagation. To do so, this study performs a method of propagation of uncertainty by using a quasi-Monte Carlo sampling of input data (i.e. environmental parameters) in order to feed an Amiet emission model coupled to a PE propagation model, and next to calculate the probability distribution of output data (i.e. sound pressure levels). As stochastic uncertainty propagation requires a high number of simulations, a metamodel of the global model (emission-propagation) for wind turbine noise was built using kriging technique in order to drastically reduce calculation duration. The results provide useful statistics and uncertainties information about sound pressure levels at neighborhood of a wind turbine: this information provide a better knowledge of sound pressure variability and will help to a better control of the quality of wind turbine noise prediction for inhomogeneous outdoor environment.

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Long distance noise propagation over water for an elevated height-adjustable sound source

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This paper presents the results of measurement campaigns for downwind noise propagation over water for elevated sound sources. This is relevant for offshore wind turbines, near shore wind turbines or wind turbines on land close to large water bodies. Under certain meteorological conditions, in theory noise spreading over an acoustical hard surface can be approximated by cylindrical spreading as a result of multiple reflections. This theory is evaluated in a measurement setup with a height-adjustable sound source (81 m, 50 m and 30 m above ground) and microphones positioned downwind (at shore and ~100 m inland) of the sound source (~3 km, ~5 km and ~7 km distance from the source) where the sound only propagates over water between the sound source and the microphones placed at the shore.

The meteorological conditions (wind speed, wind direction, atmospheric stability, temperature, humidity, etc.) were monitored continuously at both ends of the setup, utilizing both a tall met mast, a wind profiler and sonic anemometers at multiple heights.

The results have been compared with both the current and the previous propagation models described in Danish regulation for wind turbines for noise propagation over water. The results indicate that the current model better captures the effect of possible multiple reflections at the shore.

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A study of the relationship between wind direction and sound level for wind turbines measured in the far-field

Duncan Halstead, Aercoustics Engineering Limited Hillary Fung, Aercoustics Engineering Limited

This study examines the relationship between wind direction and far-field sound pressure level measured near one or more wind turbine generators. Sound propagation through the atmosphere is a well-studied concept [1] [2] [3] [4], and downwind sound propagation is typically found to be the most efficient. Current standards [1] [2] also suggest that a downwind[1] position from a wind turbine will experience the highest sound pressure levels. Far-field sound levels from wind turbines, however, are seldom the subject of robust study, due largely to the lack of available datasets having appropriate weather conditions or supporting data (wind speed/direction, turbine outputs, etc.) with which to study.

A wind turbine is directive based on the profile of the trailing edge (or other) noise source [3], and the distance to a receiver over which wind turbine noise regularly propagates is typically much farther than the distances at which we have robust verification measurements. Further, the hub height of modern megawatt-scale wind turbines now regularly exceeds 100 m, which is a source height much higher than what is usually considered in empirical research. As such, the effect of wind direction on far-field sound pressure levels warrants further study. This paper presents a review of measurement data collected in different wind directions across a selection of sites in southern Ontario.

Six measurement datasets collected at five different wind facilities are examined, each having a different layout of nearby turbines. All locations chosen for study had close turbines in only one direction, making for a good basis to study the effect of wind direction. The data was collected in 1-minute averages of sound pressure level, wind speed and direction, temperature, humidity, and atmospheric pressure. Data provided by each wind farm are also used in the study, including the outputs of the nearby turbines.

It was found that the influence of wind direction did not affect the sound levels as expected in the sites under study. Notable findings in the data are that the sound levels in the upwind direction were among the louder sound levels measured in five of the six datasets. Further, the direction counterclockwise to the downwind angle of the nearest turbine was louder than the clockwise direction (i.e. the 315-360/0° angle was louder than 0-45° angle, when 0° = downwind). These findings illustrate some interesting areas for further research, and subsequent studies will benefit from an expanded analysis dataset to determine if the findings here are indicative of a general trend.

[1] Wind blowing from the nearest wind turbine to the measurement position.

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Different sound source setups in the simulation of wind turbine sound propagation

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The sound propagation of a wind turbine in complex terrain was simulated using a ray-tracing approach in order to study the effects of different sound source setups on the sound pressure level close to the ground. Apart from the meteorology also the wake of the wind turbine itself was considered within the simulations. Sound source setups were defined with different complexity in terms of spatial resolution and geometry and statistically analysed where the spatial distribution of the sound pressure level was considered in relation to the different wind directions. Whilst, according to theory, in case of flat topography and negligible meteorological effects no differences in the far field sound pressure levels can be found, significant differences in the sound pressure level distributions can be observed between different sound source setups in a more complex simulation. Our simulations suggest, that at least in case of complex terrain and under consideration of meteorology, the sound source setup must be chosen with care.

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Meteorological effects on wind turbine noise at the receptor location

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During the development phase of a windfarm project, assumptions are made as to the acoustic propagation conditions of the wind farm noise. During the operation phase, the results of a wind farm noise measurement can only be compared to the prediction as far as the effective operating conditions match the assumptions made for the acoustic propagation calculation.

The micrometeorology at the wind farm site and at the dwellers locations has a large impact on the acoustic propagation.

Practical and effective methods of collecting information on the micrometeorology have yet to be developed for the specific needs of wind farm acoustics. Hints on possible methods can be derived from the experience gained in the realm of the acoustic assessment of ground-based noise sources.

The height profile of the speed of sound must be considered. It is related to the vertical wind profile and the temperature gradient, which depends on the cloud cover and the solar radiation but the question arises how to collect detailed site-specific information.

After many years using for wind farms, and their noise sources at high height, the same methods which have been developed for ground-based noise sources, some discrepancies have appeared which called for justifications or for more specific assessment methods. In several countries, detailed investigations have been performed which show how the results of an acoustic propagation calculation depends on the assumptions on the properties of the atmosphere as a propagation medium.

Collecting detailed information especially about the vertical temperature gradients and the wind shear is recommended during wind farm noise measurements.

Wind sector management using Beilis Tappert Parabolic Equation

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This paper investigates the possibility to optimise the operation of wind turbine by allowing increased power output when favourable sound propagation occurs and decrease the power when unfavourable sound propagation can be expected, so called wind sector management. The study is performed by using sound propagation calculations using a terrain dependent sound propagation algorithm, the Beilis Tappert Parabolic Equation and meteorological input from weather forecast data. The site is a wind farm in Sweden that already implement Wind sector management with a ray tracing method (Nord2000) and the Parabolic Equation results are compared to the ray tracing to investigate similarities and differences.

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On the need for improved prediction models and updated noise regulations to utilize the advanced controls strategies that are available for modern wind turbines

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Modern wind turbines have a capacity for operating flexible according to specific requirements. Simple operating conditions like running in a discrete low noise mode during nighttime with low noise demands have been possible for many years. Wind turbines of today can change operation continuously and hence the sound output similarly if the conditions change. It is possible based on feedback from the environment (wind speed, wind direction, wind shear, temperature, temperature gradient etc.) to operate a wind farm to an optimized power production with constraints on the noise level in the surroundings whether the noise constraints are a constant level or a wind speed dependent noise level. What is required is a reliable prediction model, that can handle the meteorological variations, a detailed set of noise output data for the wind turbines and noise regulations that allows for using these principles. The principles behind and corresponding requirements will be discussed.

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Stymied by Standards? Arguments for wind turbine noise standards that actually measure irritant drivers

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Reviews of wind turbine noise standards in many jurisdictions have been previously reported at Wind Turbine Noise Conferences by Fowler, [1] Cooper, [2] and others. The reviews show that the criteria for acceptability is usually based on a dBA sound level rating at the home of a resident, sometimes conditioned by time of day, or by tonality. However, soundscapes assessed as acceptable by current standards are often identified by residents as very irritating and disruptive to sleep. This paper presents the analysis of different soundscapes assessed as acceptable in the vicinity of different types of wind turbines and in the natural environment. Examination of differences that are neither readily perceived by A-weighting nor by tonal assessment per IEC 61400-11 [3] are presented to demonstrate that the currently accepted criteria may miss factors that are contributors to irritation reported by residents. Recommendations for revisions to noise standards to address adverse human impacts are made to assist legislators and regulators. The advantage of adopting the recommended revisions to noise standards will be that residents will be less likely to report disturbance from wind turbines and as a result there will be less impediment to proponents planning to install wind turbines as dissent will be reduced.

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A Characterization of Wind Turbine and Background Noise Distributions in Far-Field Receptor Testing of Wind Turbine Facilities

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This study expands on the previous work from the authors regarding the investigation of the variation of measured background sound levels in rural areas. Determinations of the Turbine- Only sound level in far-field sound testing are often challenging, limited by the quality of the measurement data. This study examines statistical factors of a far-field measurement dataset which may impact the analysis. The implications from data skewness, high standard deviation values and uncertainty are discussed.

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A review of different methodologies for the measurement of Sound Pressure Level from Wind Farms

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The measurement of noise immission from wind turbines is often carried out to determine the acoustic contribution of a wind farm in the far-field, often at the dwelling location, or an equivalent point of environmental compliance. In the case of pre-construction noise modelling, the methodologies employed to determine the expected sound levels at these locations are largely similar. They are typically based on one of two noise modelling algorithms, and the difference between employed methods lies in the assumptions for the modelling parameters. However, in the realm of post construction noise immission measurements, there is a relatively wide array of methodologies employed to determine the noise contribution from the wind farm. This paper outlines the major methodologies being employed in the field and evaluates their benefits and drawbacks.

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Robust noise indicators using Gaussian Processes

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In some countries, acoustic regulations regarding wind turbines require to compare the noise in “on” & “off” conditions at nearby dwellings. As all wind conditions are hardly met in a few weeks of measurement campaign, it is often necessary to estimate the noise in rare conditions from the measurements. In other cases, measured noise indicators are obviously misleading : for instance in cases of negative emergence (the noise index with the “windfarm on” is lower than with the “windfarm off”), or if the background noise indicator at low speed is much higher that the noise at higher windspeed. In such cases and in the process of building a curtailment plan, it is necessary to modify measured acoustic indicators to produce more realistic noise levels. Today, this modification is operator dependent and thus relies on his experience.

This contribution deals with establishing a more robust and unbiased procedure. Use is made of Gaussian Processes (GP) and multivariate normal (MVN) distributions as they provide a suitable framework to mix measured data with the “expert feeling”. This vague but meaningful notion is replaced by a database of noise indices measured in past measurement campaigns. Similar measurement are selected to constitute a prior distribution which models “in such conditions what noise curves usually look like”. Conditional laws then allows to deduce the posterior : the site specific distribution knowing the small amount of measured data. Moreover the statistical framework gives access to confidence intervals of this estimates.

The application on wind farm noise assessment show that this technique provides comparable results to the manual expertise. Moreover computed indicators are much more robust than classical binned medians evaluation against the lack of data.

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Estimation of the sound emergence of wind turbines by semi-supervised learning technique

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The sound emergence is the main regulatory estimator for wind turbine noise in France. This criterion aims to limit their noise impact on local residents and is highly dependent on the variation of residual noise over time. Therefore, initially defined curtailment plans can sometimes become inadequate, in which case they cannot easily be updated without leading to significant production losses. Machine learning techniques allow today to consider the continuous estimation by measurements of the sound contribution of wind turbine noise in the ambient noise and thus its noise emergence, without needing to stop the wind farm. This operation makes it possible not only to regularly adapt these reduction plans, thus optimizing electricity production, but also limiting the possible noise annoyance for local residents.

For this purpose, semi-supervised Non-negative Matrix Factorization method is considered, enhanced by a temporal regularity constraint. This approach combines a wind turbine dictionary designed on a learning basis and a free dictionary that allows the adaptation of the method to the variability of residual noise. Tests conducted on simulated measurements reveal satisfactory performances with mean estimation errors lower than 2 dBA for wind noise emergences lower than 5 dBA. Finally, the presence of these two types of dictionaries makes it possible to estimate the wind noise emergence according to one or the other depending on the predominance of the estimated wind turbine noise.

Development of IEC/TS 61400-11-2: Measurement of wind turbine noise characteristics in receptor position

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Following an intensive period of weekly online meetings, the Project Team PT61400-11-2 is very close to submitting a committee draft to the Technical Committee TC 88 of the new Technical Specification IEC TS 6140-11-2 Measurement of wind turbine noise characteristics in receptor position. At the time of writing this paper, it is thought to only require a few more meetings until a first draft can be submitted to the member National Committees of IEC for review by their experts. It is hoped that the review process in the National Committees is under way at the time of the Wind Turbine Noise conference in May 2021.

This paper gives an overview of the work of the Project Team and the topics included in the Technical Specification to describe the sound characteristics of wind turbine noise through measurements and assessment at the receptor position. This includes physical characteristics like amplitude modulation, tonality and sound pressure levels amongst others and their correlation with wind data where applicable.

The methods are presented as ‘operating instructions’ for conducting measurements for authorities and measurement institutes, tailored to the specific intentions of the measurements. The TS will be of particular interest in countries where no guidance on wind farm noise measurements is available but also in countries where guidance and legislation of environmental noise measurements may not be sufficiently adapted for wind turbine noise specifics.

Further experience of reviewing noise assessments for wind farms in Scotland and the implementation of the IOA Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise

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ACCON UK has been carrying out reviews of noise assessments for onshore wind farms submitted in support of planning applications to two Scottish local authorities. This work has enabled us to gain an overview of the similarities and differences between the approaches of the noise assessments for different projects. Following on from earlier work, this paper draws on assessments carried out over the last three years in addition to previous research based on assessments carried out since 2014. The paper considers emerging trends and complexities arising in the noise assessments, many of which relate to the consideration of cumulative noise in the context of UK's Institute of Acoustics Good Practice Guide (GPG) and ETSU-R-97. Consideration is given to whether parts of the GPG might benefit from revision or the publication of supplementary guidance.

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A model to calculate the delta between internal noise with open windows vs external noise

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To evaluate if a receptor is hit by a wind farm it is important that the acoustician measures inside the dwelling. In some countries this is requested by regulation. At least for Italian and French regulations the concept of inside noise with open windows is well known. There is also a secondary concept, inside noise with closed windows. Secondary in the sense that it is easier to handle by increasing the noise absorbing structures.

The difference between external noise and internal noise is present in the literature, but it is subject to large variations.

The possibility to measure inside a building while developing a wind park farm is usually very limited. For this reason, we tend to measure outside the dwelling. Because of that it is interesting to understand what is the difference between the outside noise of the dwelling and inside the dwelling before we have the possibility to measure it. To have an idea of this noise difference between external noise and internal noise we propose to model the building in CadnaA. This calculates what is the noise reduction from outside to inside with given relative positions on the turbines versus the position of the windows.

The model shows the very high importance of the relative position of the window respect to the position of the turbine.

After calculating these numbers, we have performed some tests in order to understand if the model is reliable. Tests show the importance of the position of the sound level meter inside the building and relative to the window. Tests have shown a good reliability of the model.

Wind Turbine Sound Quality Rating

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The current state of practice for wind turbine sound emission rating is specification of the A-weighted sound power and tonal audibility pursuant to IEC 61400-11. While this allows for an accurate characterization of the overall sound emissions of a given wind turbine, there are other metrics that can help inform how a turbine sound. This presentation explores ways that sound quality metrics could be implemented to provide a more comprehensive acoustical rating for wind turbines.

The (psychoacoustic) Basics of Tonality Perception

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This paper gives an introduction to the psychoacoustics of tonality and provides a basis for subsequent papers on Further investigations into a suitable implementation of ISO/PAS 20065:2016 for the analysis of wind turbine sound at receptor distances (Woodward) and An implementation of ISO/PAS 20065:2016 for the analysis of wind turbine sound at receptor distances (Woodward).

As a standardized term, tonality describes the prominence of a tonal component within a noise background. The cochlea within the inner ear of the peripheral auditory system is responsible for a frequency place transformation of any stimulus and can be seen as a less than perfect Fourier analyser of the auditory system. The ability to detect a tone within a complex noise background is determined by frequency selectivity. Frequency selectivity can be demonstrated with masking experiments and shows that the detection threshold of a sinusoidal tone within white noise is dependent on the noise energy within a critical band centred around that tone and the energy of the tone itself. The magnitude of the perceived tonality is also dependent on various aspects of pitch perception elicited by different characteristics of the tonal component.

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Tonality content analysed with both 1/3 octave band and narrowband methods with comparison to listening test

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When analysing signals for tonality content typically either a narrowband method or a 1/3 octave band method is used. This paper presents the results of the analysis of both methods and compares the results with listening test. The stimuli are 31 files, 29 of them which have tones. Twenty-four of stimuli are based on wind turbine noise. The tested 1/3 octave band methods are ISO 1996-2:2017, ANSI S12.9-2005/Part 4 and ANSI S12.9-2013/Part 3. The tested narrowband method is ISO PAS 20065.

When compared to prominence in a subjective listening test the percentage of explained variance of the linear regression (83 %) was good for the narrowband method. For the 1/3 octave band methods it is seen that 10-13 of the 29 stimuli have a tone frequency which falls in the boundary area between two neighbouring 1/3 octave bands. When tones are proximate to the boundary of the band the ability of 1/3 octave band methods on identifying a tone is limited by the implementation of the 1/3 octave band filters. This was an anticipated limitation of the 1/3 octave band methods. With the tested implementation of the 1/3 octave band filters a reasonable correlation is seen with the prominence of the listening test when tones do not fall near the boundary of the band.

While narrowband methods are preferred by many, this finding indicates that for the type of stimuli evaluated in this study the 1/3 octave band methods may also be effective provided that the tone frequency is not near the boundary of the band. If one can ensure that the tone frequency will not be in the boundary region, the 1/3 octave band methods are simple to implement, particularly when evaluating large long-term datasets.

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An Implementation of ISO/PAS 20065:2016 for the Analysis of Wind Turbine Sound at Receptor Distances

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This paper gives an overview of an implementation of the tonal analysis methodology found in ISO/PAS 20065:2016 for use on wind turbine sound at receptor distances. This implementation has been developed by an expert group on tonality formed by the IEC TC88 subcommittee PT61400-11-2, made up of some of the members of said committee, along with other experts in the field of (wind farm) tonal analysis. This implementation includes clarifications of aspects of the method which are not clear, or open to interpretation, in the PAS 20065 as applied to wind turbine sound; specification of input parameters left either to the practitioners discretion, or as a range of options; some deviations from the PAS 20065 method; specifics on how to combine data and calculate results in relation to wind speed; and specifics of what should be reported and how. In addition some aspects of the method were found to require further investigation to be implemented satisfactorily, and these are described.

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Comparison of tonality analysis methods for wind turbine receptor based long-term monitoring data sets

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The purpose of this study is to assess whether the IEC 61400-11 (IEC) and ISO/PAS 20065 (ISO) standards with different averaging time intervals result in significant variations in tonal audibility results, by comparing an analysis of long-term data sets using both tonality methods for time ntervals of 3, 10 and 60 seconds.

For steady tones, the analysis revealed similar Mean Audibility for different time intervals using a given methodology, and different Mean Audibility results between ISO and IEC, when compared. The study also revealed different Tonal Prevalence Trends for ISO and IEC. For non-stationary tones, the analysis revealed higher Mean Audibility for shorter time intervals for IEC, and variable Mean Audibility for different time intervals for ISO.

To better understand the variation in ISO tonality results for non-stationary tones, the authors examine case studies showing: (1) “tone blur” - where the tones frequency variation causes a tone to blur; (2) “diluted tone” - where high audibilities are diluted from low audibilities at other frequencies; and (3) “crossing tones” - two tones crossing in frequency.

These case studies demonstrate the complex nature of evaluating tonal audibility measured at the receptor location near to wind turbines and the factors that could influence the mean tonal audibilities for different averaging time intervals.

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Physics-based auralization of wind turbine noise

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Amplitude modulation of wind turbine noise is known to be a potential source of annoyance for people living in the vicinity of wind farms. To better understand this auditory annoyance, we propose to auralize the sound that is generated by the wind turbines, rather than to observe a visual representation of the sound levels. It is desirable for the developed auralization tool to be physically-based rather than sample-based. This allows control over the prevailing physical parameters. In our work, the auralization tool is based on Amiet's theory in the frequency domain, and considers the main broadband aerodynamic noise sources, namely trailing edge noise and turbulent inflow noise. For the auralization of the full wind turbine noise, the power spectral density for each blade segment and each position is considered along with the appropriate time shift due to the propagation between the moving blades and the fixed observer. In this study, an efficient method is discussed for the conversion of the frequency-domain power spectral density into a time domain signal. The appropriate time delay due to propagation is accounted for. Finally, a proper implementation of energy conserving cross-fading between consecutive signal grains is proposed. The complete auralized signal for the wind turbine noise in free field is then computed with different receiver orientations and meteorological conditions and compared with the original results in the frequency domain. This auralization tool combined with Virtual Reality/Augmented Reality can help in building the wind farms while also accounting for auditory annoyance factor in the design phase.

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Assessment and rating of Wind turbine noise immission at dwellings – the influence of amplitude modulation, aerodynamic noise sources and the Doppler effect

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The study on the effects of amplitude modulation (AM) is based on multiple long-term measurements of wind turbines (WTG) in Germany. Additional measurements in short distances to wind turbines were performed. In addition to the noise level, the characteristics of aerodynamic noise sources and the Doppler effect are responsible for the annoyance of residents. This effect is called amplitude modulation (AM) and is dependent on the rotation speed and the synchronisation of several wind turbines. The effect can be simulated with calculation models. In addition to the sound pressure level, AM is another noise effect that annoys people in the periphery of WTG. The study shows that the noise effect can be related to the L_{Aeq} and the modulation depth p_{AM5}. p_{AM5} can be derived e.g. using the wavelet analysis. The annoyance can be described in terms of a dose-effect relationship. The results of listening tests show a good agreement to the found relationship. It can also be shown that a surcharge can be determined on the basis of the relationship.

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Subjective responses to wind turbine noise amplitude modulation: pooled analysis of laboratory listening studies and synthesis of an AM character rating penalty

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Laboratory listening studies investigating human exposure-response relationships with amplitude-modulated wind turbine sound are re-examined using a common measure for modulation. Cross-study similarities and differences are observed and discussed within the context of establishing an evidence-based AM rating method for application in noise assessments.

Audibility and health effects of infrasound

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A range of residential health effects are attributed to the presence of wind turbines. Infrasound is sometimes mentioned as a possible cause of these effects, also when the infrasound levels are very low or unknown. Acoustically, infrasound is different from sound at higher frequencies: it is attenuated less over larger distances and through building façades. But does infrasound have effects on people that are different from effects of normal sound? Does infrasound sound deserve special consideration with respect to the effects of wind turbine sound?

Infrasound hearing thresholds are known to be very high and at 20 Hz joins the higher frequency thresholds. The audible range of infrasound is known to correspond to a small range of sound levels when compared to higher frequency sound. In a 2017 review report we concluded there were no clear indications that infrasound has health effects that are essentially different from effects of 'normal' sound. Since then a number of studies have shed some light on the relation between infrasound and brain activity and the sense of balance. This included sound above and below the hearing threshold. The recent studies give more insight in how the brain processes infrasound. As yet, the studies largely confirm conclusions based on earlier studies.

Prediction of wind turbines infrasound from meteorological parameters

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Infrasound exposure has become a main cause of opposition towards new wind turbine projects. In order to assess its relevance, the data from a long-term measurement campaign was used to develop a prediction scheme for wind turbine infrasound using regression models and neural network techniques. Therefore, a measurement campaign at close distance from a wind turbine was conducted using a low-frequency microphone. An ad-hoc designed and validated wind- shielding dome was used to improve the signal-to-noise ratio in the infrasonic frequency range. The acoustic measurements were accompanied by meteorological data at three heights, high- frequency wind measurements and wind turbine operational data. The blade passing frequency was accurately predicted using the operational data. In the on-going study, the prediction of the blade passing frequency levels yielded a determination coefficient of 79% using the regression approach and of 89% using the neural network model, allowing to identify the most significant atmospheric variables on the infrasound immission.

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If they are not being made ill by infrasound, then what is it?

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Distress, assumed to follow exposure to wind turbine infrasound, has reduced, but not ceased and there remain groups of neighbouring residents who genuinely believe that their problems are due to wind turbine infrasound. Infrasound has been investigated both in the laboratory and in the field, but effects have not been confirmed, leading to the suggestion that alternative explanations for residents' problems should be explored. This paper offers one such explanation, based on what residents believe, how their beliefs may have developed and the influence of belief on health and wellbeing.

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A meta-analysis on the impact of wind turbine noise on sleep using validated objective sleep assessments

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Very little is known surrounding the impact of wind turbine noise on sleep. Previous research is limited to cross-sectional study designs reporting on self-reported and anecdotal impacts on sleep rather than commonly used and validated objective and subjective sleep assessments. More recently, experimental studies using the gold standard measure of sleep, polysomnography as well as actigraphy and validated sleep questionnaires have been conducted. This paper provides a quantitative summary of data on the meta-analytical findings of wind turbine noise effects on sleep using validated objective sleep assessments. Search terms involved "wind farm noise", "wind turbine noise", "wind turbine sound" "wind turbine noise exposure" and "sleep". Eligible studies for inclusion needed to be published in English after the year 2000 and had to use either polysomnography or actigraphy measures to assess sleep in the presence of wind turbine noise and uniform outcomes were meta-analysed. Five studies were eligible for a meta-analysis. Meta-analyses (Hedges g; 95% confidence interval [CI]) revealed no significant differences in objective sleep onset latency (0.03, 95% CI -0.34 to 0.41), total sleep time (-0.05, 95% CI -0.77 to 0.67), sleep efficiency (-0.25, 95% CI -0.71 to 0.22) or wake after sleep onset (1.25, 95% CI -2.00 to 4.50) in the presence versus absence of wind turbine noise (all $p > .05$). This suggests that wind turbine noise does not significantly impact some of the key indicators of objective sleep parameters. Given the variable measurement methodologies, limited sample sizes and mixed wind turbine noise interventions, cautious interpretation remains warranted. Well controlled experimental studies with reasonable sample sizes and ecological wind turbine noise exposures are needed to give more conclusive evidence surrounding the impact of wind turbine noise on objective sleep measurement.

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Wind farm neighbourship investigated by a daily app questionnaire combining weather, noise, and annoyance

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A socio-acoustic study of wind farm annoyance was conducted with 68 participants across 14 locations in Denmark. All participants lived within a 2-km radius of one or more >2MW wind turbines and reported their daily wind turbine noise annoyance for five consecutive weeks, both in terms of current annoyance and annoyance within the last 24 hours. Additional questionnaires provided information on dependent factors, such as age, sleep patterns, other noise sources, noise sensitivity, etc. All data were collected using the ExpiWell smartphone app which allowed for collection of valuable metadata, such as tracking of participant GPS position while answering and time of day. The questionnaire data were enriched with Nord2000 noise predictions based on hourly simulated meteorological data and production data from neighbouring wind turbines in 10-minute means. Collected data included wind turbine and neighbour locations, turbine data and settings (produced power, noise-mode, power-curves, noise-curves, nacelle wind speed and calibrated yaw position) and simulated data (wind speed, wind direction, temperature, relative humidity and Obukhov length). The study focused on establishing knowledge of how annoyance is influenced by factors that could affect the daily operation of wind turbines to the benefit of both owners and neighbours.

Assessing Wind Turbine Noise Perception by means of Contextual Laboratory and Online Studies

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In the course of an interdisciplinary research project at Leibniz University Hannover, perceptual properties of wind turbine noise were investigated. In this scope we conducted a series of listening experiments for assessing wind turbine noise perception under controlled and reproducible conditions in an immersive and context-sensitive laboratory setup. Due to the corona pandemic situation we were not able to perform continuative large scale laboratory studies and therefore were forced to switch to online surveys.

In this paper we report about our methodology and the general layout of the studies, including the collection of empirical data and the assessment of the participants' attitude towards wind energy as well as the calibration of the respective playback systems. We show how our stimuli were collected, preprocessed and reproduced. Our work focuses especially on the maintenance of ecological validity of the stimulus presentation including correct levels, non-acoustic context and participant attention. We address specific advantages and drawbacks of both laboratory and self-reporting online studies. Finally, we show some exemplary results and draw some final conclusions from our study designs.

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