EXPERT GROUP STUDY REPORT – TASK 39

A priori requirements for wind turbine noise propagation measurement data to be used for model validation (toward “Best Practices”)

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FOREWORD

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PREFACE

Publisher/Authors and Context

This document is published as part of the collaborative work taking place in the IEA Wind TCP (Technology Collaboration Program) Task 39 "Quiet wind turbine technology". The latter convenes experts in the field of wind turbine noise. More specifically, this document has been drafted by the participants of Task 39 - WP3, which focuses on wind turbine noise propagation issues.

Target audience

This document is mainly addressed to researchers and engineers who may be relatively new to the field of outdoor acoustic measurement in general, and of wind turbine noise in particular. It could also be used as a kind of checklist for more experienced individuals. It is assumed that the reader has some basic understanding of wind turbine noise and acoustic measurements.

Objectives

This document aims at providing technical guidance for measuring wind turbine noise, focusing on noise propagation effects. It is however not a step-by-step technical guide on how to conduct a wind turbine noise measurement campaign. Rather, it takes the form of an exhaustive list of information that should be documented in addition to the acoustic measurement data themselves. These information are categorized into a number of topics. The objectives are to improve the content of the resulting measurement dataset (e.g. by increasing its completeness), as well as prepare and facilitate the post-processing of the measured data and their interpretation during a subsequent scientific analysis. Some specifications for the measuring equipment is also provided that should also contribute to the latter objectives.

Scope and Limitations

This document is concerned with the measurement of wind turbine noise in a broader sense, however with a particular focus on validation of models for noise propagation effects. It may also partly be used in the context of the study of the wind turbine noise emission itself, when noise propagation effects can be neglected. It may be a reasonable assumption if measuring sufficiently close to the turbine. Nevertheless, for the measurement of wind turbine noise (e.g. for the purpose wind turbine certification), the reader is referred to the IEC 61400-11 standard[1], which has been approved by a broader international standardization committee. This latter document also describes the measurement technical set-up in more details.

NOTICE:

IEA Wind Task 39 functions within a framework created by the International Energy Agency (IEA). Views, findings and publications of IEA Wind Task 39 do not necessarily represent the views or policies of the IEA Secretariat or of all its individual member countries.

[1] International Standard IEC 61400-11: Wind Turbines - Acoustic noise measurement techniques (Ed. 3), International Electrotechnical Commission (CH), 2012.

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1. INTRODUCTION

Wind turbine noise emission and propagation through the atmosphere is a complex phenomenon, with various physical processes interacting with each other (e.g. atmospheric turbulent flow, air temperature, wind turbine as a noise source with its own specificities). The measurement of wind turbine noise in itself is challenging, as most outdoor acoustic measurements for characterizing a noise source are plagued by ambient background noise which deteriorates the "signal-to-noise" ratio (where "signal" refers here to the noise from the wind turbine and "noise" to the perturbing ambient noise, like vegetation, animals, road traffic, etc). This is notoriously difficult for wind turbine noise in the far-field, where wind turbine noise levels are often of the same order of magnitude as the background noise.

The subsequent analysis of the measured data is also challenging. The complexity of the interacting phenomena mentioned above makes it difficult to isolate the influence of the different physical parameters influencing the measurement data. Therefore, it is important to have access to as much information as possible about the experimental conditions in order to enable a more reliable analysis of the data.

In the following, a series of topics that should be considered for designing a wind turbine noise measurement campaign are reviewed. For each of these, a number of specific details that should be addressed, recorded, and/or documented are provided. Some basic explanation for the necessity of these procedures are provided.

2. GENERAL INFORMATION ABOUT THE TEST SITE

Wind turbine noise propagation will be influenced by the surrounding environment. It is always informative for the person processing the data a-posteriori to be able to have access to as much as possible of the details, in particular if that person has not been participating to the measurement campaign. These include:

- Definition of terrain (elevation map, roughness class)
- Surface cover description (ground impedance if possible)
- Description of the (audio-)surrounding (e.g. presence of nearby roads, trees, etc)

3. ATMOSPHERIC CONDITONS

The main physical factors influencing outdoor noise propagation are related to the atmospheric conditions. These should be measured with appropriate sensors. It is often not possible to obtain a full picture of the three-dimensional atmospheric field, but again, collecting as much as possible of its features is desirable.

- Definition of meteorological conditions:
    - Wind speed and direction
    - Wind and temperature gradient (preferably up to a height of at least 1/10 of propagation distance), wind veer
    - Atmospheric stability

    - Humidity and temperature
    - Turbulence level (possibly at several heights)
    - Using met mast(s) and/or Lidar(s) (specify height of sensor for each measured quantity)
    - General and specific information about atmospheric conditions (e.g. sunny day, windy day, day/night measurement periods, stable/unstable atmospheric conditions…)
    - Specify time-frame for the above information if longer measurement campaign (e.g. if these conditions change significantly)
- Synchronization of noise measurements and meteorological data (specify relation between measurement periods and actual time-stamps)

4. CHARACTERIZATION OF THE NOISE SOURCE(S)

When interested in characterizing wind turbine noise and its propagation (e.g. to the nearby dwellings), it is natural to also collect information on the noise source itself.

- Characterization of the wind turbine noise emission, e.g.
    - IEC-type noise measurements for 1 turbine
    - Noise directivity pattern if possible
    - Noise curve, e.g. SWL as function of wind speed
- If measuring a wind farm, same as above for each turbine
- Characterization of the background noise (e.g. using regular shutdown of the turbine(s)) at the time of measurements
- "Reasonable" Signal-to-Noise Ratio (min. +3dB, 6dB preferable)
- If measuring a wind turbine, position of potential nearby turbines/farms (possibly causing spurious noise)
- If measuring farm (position of all turbines ./. mics.), and position of potential nearby farms/turbines (possibly causing spurious noise)
- Wind turbine geometry:
    - Hub height
    - Rotor diameter
    - More if available (e.g. blade planform, required for higher fidelity noise emission models)
- Blade add-ons (serration, VGs, etc)
- SCADA data from turbine(s)
    - Rpm
    - Power
    - Yaw position
    - Yaw off-set (in connection with wind direction, see Atmospheric conditions)
    - More if available (e.g. blade pitch)
- Synchronization of noise measurements and SCADA data (time-stamping details)
- If several turbines are involved, possibility of characterizing possible wake interactions

5. NOISE MEASUREMENT SET-UP

All sensors are subjected to measurement uncertainties. Therefore, the audio equipment quality will affect the findings and conclusions that can be drawn from a subsequent analysis of the measured noise data, which is the main quantity of interest in the present context. Details about the acoustic sensors and their installation should be provided.

- Specifics about the microphone measurements:
    - Microphone type (Class 1 preferable)
    - Calibration (frequency response and limits)
    - Directivity properties
    - Height above ground (and installation characteristics, e.g. documented with a picture)
    - Wind screen types (and insertion losses)
    - Acquisition system characteristics
    - Time resolution of raw data
    - Specifications of the stored data (e.g. Leq in time intervals, SPL in octave bands, Z/A-weighted, etc)
- Positioning of microphones relative to turbine(s)

6. LOGBOOK

It is strongly advised (if not compulsory) to record all the details about the measurement set-up, timing of the measurements, specific or unusual/unexpected conditions, etc, in a concise way in a so-called "logbook" document. With this document, it is clear for anyone using the measured dataset what were the specific conditions at the time, and possibly during the different phases, of the measurement period. It should contain (when/if possible):

- Details about the instruments (e.g. serial number, exact location)
- Starting-, end- and down-time of measurement systems
- Running and down-time for the turbine(s)
- Timing for calibration of instruments (e.g. microphones with calibrator)
- Timing and details about events that could affect the quality of the data
    - either specific to the measurement system
    - or in the surrounding (e.g. rain, traffic)

It is also recommended to take pictures of the experimental set-up and surrounding to get a good overview of the experimental conditions, in particular for those who did not participate to the measurement campaign. Note that such logbook is not only aimed at informing persons who would not have been attending to the measurement campaign themselves. It is very useful for those who have been conducted the measurements as well, as it is virtually impossible to remember the whole sequence of events, especially during long term measurement campaigns.

7. CONCLUSIONS

A list of items to consider for the design and the completion of a wind turbine noise measurement campaign is provided in the present document. This list is meant to be as exhaustive as possible, and can surely not be implemented in reality as the requirements would be too great to be all met at the same time. Nevertheless, this can be used as a guidance for conducting such experiment. Indeed, all these items, if feasible/achievable, are aiming at facilitating and improving the quality of the analysis of the acoustic measurement data at a later stage.

Note that the topic of the curation of the acquired experimental data has not been addressed in the present document. It is advised here to comply with the FAIR Guiding Principles as initially published by Wilkinson et al (2016)[2]. This effort has been followed by further collaboration work on the topic (see, e.g., https://www.go-fair.org).

The next step in the editing of the present document would be to prioritize some elements over the others. The suggestions for conducted an experiment are only listed here, without evaluating their respective actual impact on the intrinsic quality of the measurement dataset.

Finally, the present document would need further additions in order to be considered as a Recommended Practices or Best Practices document. In particular, more specific procedures should be provided for the different items that were identified as important in the present document. Nevertheless, many of them could be addressed by referring to earlier work and existing standards.

[2] Wilkinson, M., Dumontier, M., Aalbersberg, I. et al. The FAIR Guiding Principles for scientific data management and stewardship. Sci Data 3, 160018 (2016). https://doi.org/10.1038/sdata.2016.18