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PIBE : a new French project for predicting the impact of wind turbine noise

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Summary

The PIBE project is a new French research project that aims to improve wind turbine noise prediction methods and explore new solutions to reduce noise. The project brings together experts in aeroacoustics, sound propagation, experimental noise characterization and wind engineering. The research program is structured into 3 working groups (WP). The first aims to study amplitude modulation phenomena and focuses particularly on characterization and modelling of the dynamic stall of the flow around the blades, as well as on the conditions for amplitude modulation generation in the receiver. These phenomena are studied both in wind tunnels and in the vicinity of a wind farm. The second WP focuses on quantifying the uncertainties of noise prediction methods. To achieve this objective, the uncertainties and variabilities of the parameters influencing both the emission and propagation of noise are estimated; secondly, an uncertainty propagation model (combined with advanced and appropriate statistical methods) estimates the overall uncertainty. The last WP focuses on new noise reduction devices, using blades with modified leading and/or trailing edges. The effectiveness of the solutions will be characterized in the wind tunnel, both acoustically and aerodynamically. An estimate of their performance potential at a 1:1 scale is also expected during the project. The project is funded by the The French National Research Agency

1. Introduction

Wind energy is one of the promising energy sources to reach the objective set by the French regulation of increasing renewable energies to about one third of the final energy consumption by 2030. In spite of a strong growth of the wind energy sector these last 10 years, and in spite of a solid potential for development, France has fallen behind on this goal. This may be partly explained by the constraint framework in which wind energy is developing, as well as the opposition of wind farm neighbours who very often mention noise as a potential annoyance. In this context, first French collaborative research project on wind turbine noise, the PIBE project (2019-2023) aims to improve prediction methods for wind turbines noise and to explore new solutions for noise reduction.

2. Organisation of the project

The project is structured in three work packages (Figure 1). The first work package (WP) aims to study the amplitude modulation phenomena, which can be a major source of annoyance when they occur. This axis focuses particularly on understanding and characterizing the dynamic stall of the flow around the blades, as well as the conditions of amplitude modulation generation at the receiver. The second WP focuses on quantifying the variability of noise predictions. The last WP of the project aims to study and propose new noise reducing devices, using blades with modified leading and/or trailing edges.

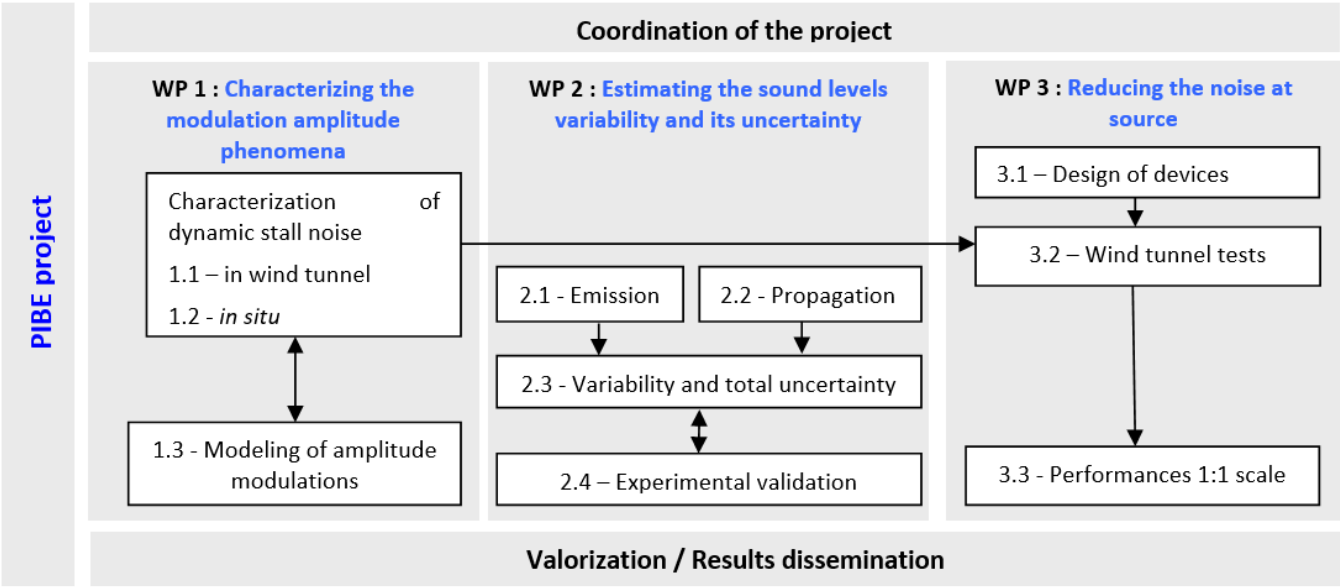

Figure 1: PIBE project organisation

The project is leaded by UMRAE. ENSTA and LMFA are involved in tasks dealing with aeroacoustics, UMRAE and EDF DTG in tasks dealing with experimental characterization of noise and with noise propagation, EDF Renouvelables provides its support in wind turbine engineering.

3. Scientific and technical objectives of the project

3.1 WP1 : Characterizing the amplitude modulation phenomena

Amplitude modulation phenomena, particularly those associated with dynamic stall on wind turbine blades, are a source of intense and intermittent noise that can cause noise annoyance (Lee *et al.*, 2011). WP 1 aims to characterize and understand the relationship between the occurrence of dynamic stalls and the meteorological and operational conditions of the wind turbine on a given site. Three approaches are explored in the project: Characterization of dynamic stall noise in a controlled environment (anechoic wind tunnel measurements), measurement of stall noise in situ and correlation with atmospheric conditions, modelling of wind turbine noise amplitude modulations.

The dynamic stall noise characterization is performed in a controlled environment using an original experimental device, consisting of a pitching airfoil with controlled rotational motion. Low frequency wall pressure measurements using a pressure scanner, and flow visualization around the profile by Particle Image Velocimetry (PIV) is performed. Coupled aerodynamic and acoustic studies is also investigated thanks to wall pressure measurements and acoustic measurements in the far field. In addition to the stall regime, the system is used to study the cyclic variations in trailing edge noise that contribute to amplitude modulation. Several inflow conditions are investigated (velocity, turbulence intensity). This experimental study is to our knowledge the first to study transient (cyclic) aspects such as dynamic stall noise, both aerodynamically and acoustically. These measurements are completed by flow calculations carried out using a CFD software dedicated to finite volume simulations using RANS (Reynolds-Averaged Navies-Stokes) or LES (Large-Eddy Simulation) models for incompressible flows (Archambeau et al., 2004).

In situ acoustic and meteorological measurements will be carried out next to a wind farm in order to identify the situations for which dynamic stall may occur and to characterize the sound levels generated in these situations. Sound spectra and audio signal recordings will be done at several distances, together with meteorological measurements (wind and temperature vertical gradient, turbulence) in order to characterize the acoustic propagation conditions, as well as the aeroacoustic emission conditions at blade level.

A modelling approach of amplitude modulations is also included in the project that consists in developing a time-domain model of wind turbine noise based on the acoustic analogy of Ffowcs Williams-Hawkings. This approach enables to better predict fluctuations in the amplitude of wind turbine noise at the receiver, and to produce sound synthesis that can be used for subsequent perceptual studies. Moreover, it accepts as input data expressions from precise profile theory, experimental results or numerical results. Time-frequency analyses will be conducted to evaluate the potential of a frequency approach with slowly time-varying parameters, based on the same Amiet theory. Predictions will be made from the wall pressure data and the turbulent velocity correlation functions measured or calculated. Indeed, as shown by (Moreau *et al.* 2009) the formulas used for trailing edge noise remain valid when the angle of attack is not too high (partial stall speed regime, noted as "light stall" in Figure 1). In the deep stall regime, however, the location where the pressure fluctuations are created moves away from the trailing edge and it is expected that the model is no longer valid. The simplified model proposed by (Moreau *et al.* 2009) fails in a dynamic regime. The feasibility of a more appropriate model will be studied in the project on the basis of experimental observations and flow simulations.

3.2 Estimating the variability of sound levels and associated uncertainties (WP2)

Wind turbine noise may present some time fluctuations at dwellings located in the vicinity of wind farms, even if the wind speed is stationary. This is often due to the variability of meteorology which may act on noise emission from the blades (see WP1) and on sound propagation between the source(s) and a local resident, as well to temporal evolution of ground acoustic properties. Currently, the acoustic impact studies of a wind farm project do not consider these phenomena, so there is no available information on the uncertainties of predicting the noise levels variability and a scientific and an industrial issue. Solving this problem would enable wind farm developers to estimate more precisely the risk of noise annoyance and to design optimally their wind farms.

To predict noise temporal level fluctuations, we need to estimate the variability related to the influence of the meteorology on the sound emission, in particular on the phenomenon of amplitude modulation. This task is therefore closely linked to WP1 and involve to a specific model that carry out a certain number of calculations, following advanced screening techniques, e.g. Morris, Monte Carlo, FAST, etc. (Saltelli *et al*., 2008). If necessary, especially for reasons of calculation time, a multidimensional metamodel can be developped.

Predicting the variability of sound levels requires estimation of the variability associated with the influence of meteorology on sound emission, as well as that related to the influence of weather conditions and ground absorption variabilities on sound propagation. Total uncertainty is determined based on different classes of weather-type / ground / source-receiver positions. Today's scientific knowledge and numerical tools now make it possible to quantify the uncertainties coming from a large number of environmental parameters. The general approach in this project is to perform multiple numerical acoustic computations with a MWAPE model that takes into account the effects of ground and micrometeorology on propagation in a inhomogeneous medium (Lihoreau *et al*., 2006; Cotté and Tian, 2015). The results will highlight the most influential sound propagation parameters, as well as quantify the uncertainties associated with these parameters on sound pressure level prediction.
Finally, an uncertainty propagation method of the input data on the output (sound level) is applied. For this, a sensitivity analysis of the global system to the different input parameters is carried out. This sensitivity analysis and estimate of the propagation of uncertainties throughout the prediction process makes it possible to quantify the relative influence of the parameters in relation to each other. Finally, a global uncertainty database on sound level predictions is obtained; these uncertainties will be related to both emission and propagation, depending on multiple parameters such as the state of the atmosphere (emission and propagation conditions), the nature of the ground (typology and acoustic impedance) and the source-receiver positions.
The same uncertainty propagation method will be adapted and applied to one or more engineering model(s). A parametric calculation tool will be developed within open source codes (www.code-tympan.org and www.noise-planet.org/noisemodelling.html). This will serve a dual purpose: On the one hand, it will improve knowledge of the global uncertainties inherent in engineering simulation methods, which represents a significant advance in the current state of the art; on the other hand, the developed tools will be made available to the open source community, thus contributing to the improvement of existing acoustic engineering practices and tools.

In order to validate the numerical results obtained, a large-scale *in situ* experimental campaign will be carried out on a wind farm. It will combine long-term acoustic measurements, measurements of ground absorption properties (Hess *et al*, 1990) and micrometeorological measurements (meteorological mast, 3D ultrasonic anemometers, wind LIDAR). The acoustic measurement campaign will last 1 year, at several distances from the wind farm. These points will be supplemented by other points during 2 intensive observation periods during the observation year. The database of these measures will be made available to the public *via* an Internet page. The purpose of the measurements will consist in particular in comparing the

uncertainties of the sound pressure levels measured with those estimated by the reference model and which will have been previously fed by the uncertainties observed on the main influence parameters (ground, meteorology, etc.) during the measurement period.

3.3 WP3: Reducing noise at source

WP 3 focuses on research and design of systems that minimize the generation of aerodynamic noise. The systems considered in the project are retrofit type. In order to reduce trailing edge noise, different serration shapes have been proposed in the literature, with variable acoustic and aerodynamic performance and potentially high frequency noise regeneration. Alternative innovative solutions that reduce turbulence noise and also delay stall regime (static or dynamic) that has not been tested for wind turbine applications will be investigated in the project. Indicators based on acoustic performance, feasibility and aerodynamic performances of the devices are used in the project to rank the best devices.

The specific designs will be prototyped on a reduced scale in a laboratory and the devices thus manufactured will be integrated on defined airfoil. The conformity of the finished products will be ensured by rigorous metrological analysis. Measurements of parietal pressure and acoustic measurements with an array of 13 microphones will be done, and will enable to evaluate the aerodynamic performance of the devices, and in particular to identify the lift losses generated. The acoustic array will measure the radiated noise for different flow conditions and angle of incidence. A careful to ensure similarity conditions between the model of the trailing edge device and the 1:1 scale model of a complete wind turbine. We will evaluate the robustness of the solution(s) obtained under the various initial flow and device positioning conditions via an experimental design.

Transposing the acoustic performance of a scale model measured in a wind tunnel at a scale of 1:1 can be tricky if similarity rules between the two scales are not respected. Indeed, the same flow regime on a small and full-scale physical system will not generate the same aerodynamic effects as boundary layer separation or the generation of turbulent structures for example. Thus, extrapolation of an acoustic gain obtained in a wind tunnel could prove erroneous if similarity criteria based on dimensionless constants (Reynolds number and Mach number) are not taken into account when designing the scale models. The project proposes to analyze the scale effects of a trailing edge noise reduction device (serration type) between a scale model measured in a wind tunnel and a wind turbine at scale 1:1.

The possibility of relying on numerical simulations of relative boundary layer thicknesses at different scales on the same profile to justify transposition laws will be evaluated. The acoustic gain of the model and the wind turbine will then be deduced from the measurements taken at both scales. Finally, transposition rules between the scale model and the full-scale device will be defined.

4. Project outcomes

The main outcomes of the project will be:

- Development of a model for predicting amplitude modulation
- A database of experimental data on the wind tunnel characterization of noise due to dynamic stall at wind turbine blades.
- A database of experimental data on wind turbine noise propagation
- A database and a model for estimating the uncertainties of wind turbine noise predictions
- The evaluation and the development of new solutions for reducing wind turbine noise at source**.**

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