Wind Turbine Aeroacoustic Noise Prediction Using Computational Models And Comparison To Experimental Measurements

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1 Introduction

Energy from wind turbines has enjoyed a remarkable growth worldwide in the past decades. In Canada, generation capacity has increased dramatically. The issue of noise and wind turbines has become a subject of interest for researchers and acoustics practitioners. For utility scale wind turbines, broadband noise emanating from the trailing edge of the wind turbine blade is a large contributor to the overall noise emission. In order to minimize the noise impact, regulatory bodies often set limits to the noise level observed nearby. Good noise predictive tools are necessary to estimate noise emissions for many reasons including wind farm development.

These tools are developed from computational fluid dynamics (CFD) studies using Large Eddy Simulation (LES) in conjunction with the Ffowcs-Williams and Hawkings (FW–H) acoustic analogy to predict the far field sound. These results are compared to results from the use of existing semi-empirical prediction models. Validation of these predictive tools are compared with experimental measurements of 2D airfoil self noise obtained at the University of Waterloo.

2 Method

2.1 LES simulation

Computing the aeroacoustic noise emitted from a turbine blade requires an understanding of the flow behaviour around the blade. The key parameters needed for acoustic prediction are the pressure and fluid velocity at the surface of the airfoil. For this model, the LES solver in ANSYS Fluent is used with the Dynamic Smagorinsky-Lilly subgrid-scale model [1].

2.2 Simulation geometry and setup

Two different external flow cases were tested to determine the feasibility of the acoustic prediction model: a 2D NACA 0012 airfoil, and a 2D SD-7037 airfoil in an enclosure. The first case is a replication of simulations recently reported by Wasala [2] that compare predicted results to those measured by Brooks *et al.*[3]. The second case predicts both static and dynamic airfoil aeroacoustic noise and compares it to experimental results obtained at the University of Waterloo [4]. Table 1 summarizes the system geometry and key simulation parameters. The receiver location for the NACA 0012 experiments was set a distance off of the trailing edge of the airfoil in a direction perpendicular to the chord line. For the SD-7037 experiments, the receiver was located in the lower wall of the wind tunnel, directly below the ¼ chord.

Table 1: Simulation setup

Parameter	NACA 0012 [2]	SD-7037 [4]
Chord (m)	0.3048	0.0025
Span (m)	0.1143	0.150
Domain Width (m)	0.1143	0.1524
Domain Height (m)	3.658	0.1524
Domain Length (m)	5.487	0.460
Velocity (m/s)	71.3	31
Receiver (m above airfoil)	1.219	-0.0762

The experiments performed on the SD-7037 airfoil include constant angle of attack (AOA) measurements as well as an oscillating AOA case.

2.3 FW-H acoustic analogy

The FW-H analogy is a rearrangement of mass and momentum conservation into an inhomogeneous wave equation that accounts for the presence of an impermeable surface in the flow. The resulting equation has three inhomogeneous terms: a quadrupole term which accounts for sound generated by fluctuating Reynolds stresses, a monopole (or thickness noise) term and a dipole (or loading noise) term. Together, the thickness and loading noise terms represent the sound generated by the body passing through the flow [5]. In the equation below, the quadrupole term contains Lighthill's Tensor (T_{ij}), the loading noise term contains the compressive stress tensor (p_{ij}) and the thickness noise term contains the fluid velocity (u_i).

$$\left(\frac{\partial^2}{\partial t^2} - c_o^2 \frac{\partial^2}{\partial x_i^2}\right)\left(\rho' H(f)\right) = \frac{\partial^2}{\partial x_i \partial x_j}\left(T_{ij} H(f)\right) - \frac{\partial}{\partial x_i}\left(p_{ij}\delta(f)\frac{\partial f}{\partial x_j}\right) + \frac{\partial}{\partial t}\left(\rho_0 u_i \delta(f)\frac{\partial f}{\partial x_i}\right)$$

The function, $f(\vec{x}, t) = 0$, defines the surface of the body and therefore the quadrupole term applies outside of the defined surface, and the thickness and loading noise terms only apply on the surface of the body. In the case of aeroacoustic noise, the quadrupole term is often neglected since the noise generation is dominated by the thickness and loading noise terms [6].

The solution used for this model is Formulation 1A by Farassat [6], which places an impermeable surface on the blade and calculates the sound propagation using a retarded time frame.

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ANSYS fluent FW-H built-in solver

ANSYS Fluent has a built-in FW-H solver that has a similar solution to Formulation 1A [5]. The main difference is the solution uses a semi-permeable surface that can be offset from the airfoil to compute the quadrupole noise for the flow contained within the surface [1]. However, when placed coincident to the airfoil surface, the calculation simplifies to the Formulation 1A solution. The latter method was used for the prediction model.

Validation of acoustic results

The accuracy of the simulated results is determined by comparison with appropriate experimental results as well as with semi-empirical prediction from the National Renewable Energy Laboratory (NREL) program NAFNoise [7].

3 Results

3.1 LES simulation results

Initial simulations of the NACA 0012 experiments indicate good correlation of the flow parameters, including lift coefficient (C_L) and coefficient of pressure (C_p). The simulated C_L is 0.53 compared to 0.6 in previous simulations [2], and 0.58 in experimental results [8]. The lift coefficient is expected to increase to the appropriate value in simulations with finer mesh resolution at the leading edge of the airfoil.

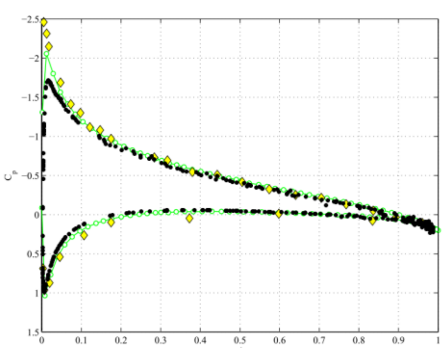

Figure 1: Pressure coefficient plot for an angle of attack of 5.4 degrees. Wasala[2] (□) and Gregory and O'Reilly[9] experiments (◊) and present simulated results (•)

Figure 1 shows the simulated C_p with previous simulations [2] and experimental results [9].

LES simulations are sensitive to the mesh quality and requires a very fine mesh to accurately resolve the flow. This is especially true for the trailing edge portion of the blade. Current computational limitations limit the required mesh sizing and result in slight discrepancies in the results.

3.2 FW-H acoustic results

To date, preliminary simulations for aeroacoustic prediction resulted in sound power levels (SPL) within the expected range. The 1/3 octave spectra results also follow the appropriate trend when compared to experimental results (Figure 2).

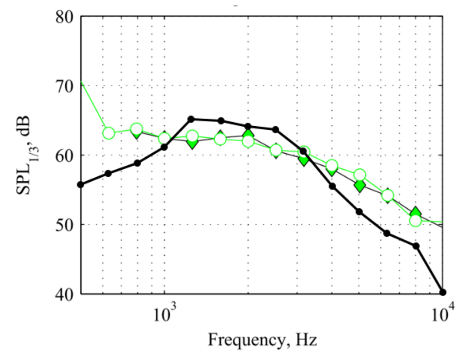

Figure 2: SPL plot for an AOA of 5.4 degrees. Wasala[2] (□) and Brooks *et al*. [3] experiments (◊) and present simulated results (•)

In the time between the submission of this paper and the conference date, there is expected to be significant progress on the static acoustic prediction by improving the mesh parameters for the systems. Preliminary simulations on the dynamic SD-7037 system are also expected to be completed.

4 Conclusion

The developed predictive tools show good agreement with the measured experimental data leading to further development of the predictive tools. The close agreement of CFD flow properties indicates the feasibility of using the ANSYS Fluent LES and FW-H solvers to predict the areoacoustic noise from wind turbine blades. Accurately simulating of both static and dynamic 2D airfoil systems are crucial building blocks to developing more complex models for full turbine acoustic prediction tools.

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