International Journal of Heat and Fluid Flow 000 (2016) 1–10

Contents lists available at ScienceDirect

International Journal of Heat and Fluid Flow

journal homepage: www.elsevier.com/locate/ijheatfluidflow

Influence of ice accretion on the noise generated by an airfoil section

Robert-Zoltan Szasz*, Matilda Ronnfors, Johan Revstedt

Dept. Energy Sciences, Lund University, PO Box 118, 22100, Lund, Sweden

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Acoustics
Airfoil
CFD
Immersed boundary
LES
Wave equation

ABSTRACT

We investigate the noise generated by an airfoil section. Three cases are considered, one with a clean airfoil and two cases with airfoils with ice accretion. The amount of ice is the same in the two cases with ice accretion, but the surface of the accreted ice layer is smoother in one of them. The noise is computed using a hybrid approach. First the flow and the acoustic sources are computed. Second, the noise propagation is predicted by solving an inhomogeneous wave equation. The results indicate that in this case the accreted ice layer leads to a decrease of the radiated noise levels, especially in the lower frequency range.

© 2016 Published by Elsevier Inc.

1. Introduction

With the increasing number of installed wind turbines, there are less and less available areas for the installation of new turbines. As a consequence, new turbines are often built in cold climate areas (Nordic regions or high altitudes). A recent review of the status of wind energy in cold climate is presented in Laakso et al. (2010). Even if the available wind resources in such areas are often superior to the ones available at warmer climate, icing is a severe issue having several negative effects.

Beside the changes in the aerodynamic shape of the blade (directly influencing the blade performance), the extra added mass causing vibrations of the structure, and ice throw, changes in the radiated noise are an issue which gathers more and more focus (Laakso et al., 2010). Even wind turbines with clean airfoils may emit noise levels which cause annoyance for people living in nearby residential or recreational areas (see e.g. Pedersen, 2003; 2007). As a result, several countries introduced strict limits on the maximum allowed noise emission levels of a wind turbine. For wind turbines, the major part of the radiated noise is generated aerodynamically. In the presence of ice accretion not only the aerodynamic performance but also the radiated noise pattern is changed. An improved understanding of these changes is important to avoid the radiated noise levels exceeding the prescribed limits. Furthermore, such knowledge has the potential to be included in ice detection algorithms.

There are a large number of measurements of the noise emitted by wind turbines. Fujii et al. (1984) measured the noise emitted by wind turbines having different tower leg cross sectional shapes. The results showed that a slender elliptic cross-section would be the quietest for the operating parameters considered. Björkman (2004) carried out long-time noise measurements in the vicinity of existing wind-turbines showing an increase in the high-frequency range with increasing wind speed. Recently, Oerlemans et al. (2007) used a microphone array to identify the virtual location of the noise sources. The conclusion was that, except a small contribution of the hub, the noise is mainly generated by the rotor blades and practically all noise emitted towards the ground is produced during the downward motion. Another conclusion is that broadband trailing edge noise is the dominant one for the studied wind turbine. Extensive measurements were carried out around the NREL Phase VI turbine by Hand et al. (2001); Schreck and Robinson (2004), providing a database for comparison with numerical computations (see e.g. Johansen et al., 2002; Schmitz and Chattot, 2006).

Experimental measurements, however, have several drawbacks. Due to varying atmospheric conditions the experiments are not repeatable and have to be carried out over a long time period. It is difficult to isolate the contribution of the wind turbine, or the contribution of different components. Although wind tunnel testing is possible and gives control over the boundary conditions, this approach is very expensive and the scaling of the results is not straightforward.

Numerical methods supplement the experimental measurements and with the increase of the computational power the detail of the results grew substantially during recent years. Due to the similarity of wind turbines to helicopter rotors, early computations were based on methods used in aviation. A thorough review of different computational methods is presented by Hansen et al. (2007).

* Corresponding author. Tel. +46462220480.
E-mail address: robert-zoltan.szasz@energy.lth.se (R.-Z. Szasz).

http://dx.doi.org/10.1016/j.ijheatfluidflow.2016.06.006
0142-727X/© 2016 Published by Elsevier Inc.

Please cite this article as: R.-Z. Szasz et al., Influence of ice accretion on the noise generated by an airfoil section, International Journal of Heat and Fluid Flow (2016), http://dx.doi.org/10.1016/j.ijheatfluidflow.2016.06.006

There are several numerical methods to determine the sound generated by turbulent flow fields. Solution of the compressible Navier–Stokes equations by Direct Numerical Simulations (DNS) or Large Eddy Simulations (LES) would predict both the flow and the acoustic fluctuations and their propagation. This approach, however, is not efficient for low-Mach number flows, such as the one around a wind turbine, and where noise propagation to long distances is of importance. The first numerical predictions were based on semi-empirical methods, however, these methods turned out to be very sensitive to model parameters. Glegg et al. (1987) showed that the assumption of right turbulence length scales is crucial for accurate predictions.

Hybrid approaches are based on the assumption that, for low Mach number flows, the acoustic perturbations are small and the flow variables can be decomposed in a hydrodynamic and an acoustic part. Using hybrid approaches, the acoustic noise will be determined in two steps. First, the incompressible set of Navier–Stokes equations are solved which provides the turbulent flow field. Second, based on the turbulent flow field, the acoustic sources are determined and the acoustic field is resolved. Such approaches provide the possibility to use dedicated solvers for the flow and acoustic governing equations, with the possibility of using different timesteps, domain sizes and mesh resolutions. Although there have been attempts to account for turbulence using Reynolds Averaged Navier–Stokes (RANS) based models in the flow solvers (see e.g. Bailly et al., 1996; Page et al., 2003), LES (or DNS) is more appropriate to capture the dynamics of the acoustic sources. Ewert and Schröder (2004) applied a hybrid method based on LES of compressible flow and acoustic perturbation equations to predict trailing edge noise.

The goal of this paper is to analyze the effect of the accreted ice layer on the flow-field and on the noise emitted from an airfoil section. This geometry was chosen since a full wind turbine simulation would require exhaustive computational resources. Furthermore, the noise generated by the airfoil section can give insight into some of the mechanisms influencing noise generation in the full scale wind turbine as well. A hybrid approach (described in Section 2) is used to achieve this goal. Three cases are presented. The reference case is a configuration with a clean airfoil. This case is compared to two cases with ice accretion, matching one of the icing events recorded in Hochart et al. (2008). The amount of accreted ice in the two cases is the same, the difference being only that in the last case the shape of the ice layer is smoothed. The results indicate that the shape/roughness of the accreted ice layer has a noticeable effect on the radiated noise.

2. Methods

A hybrid approach is used to determine the radiated noise. The flow variables are decomposed in a semi-compressible (the density is depending on the temperature only, but not the pressure) part and an acoustic part. Consequently, there is a flow solver resolving the semi-compressible Navier–Stokes equations and an acoustic solver solving an inhomogeneous wave equation for the perturbation density. Both solvers are nondimensionalized, using the chord length as a length scale and the inlet velocity magnitude as velocity scale.

2.1. Flow solver

The incompressible Navier–Stokes equations (Eqs. (1), (2)) are discretized on an equidistant Cartesian grid using finite differences.

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{1}{Re}\frac{\partial^2 u_i}{\partial x_j^2} + S_i \tag{2}$$

The temperature variations being assumed small the energy equation is not resolved to reduce the computational effort. Note, that when full-scale wind turbine computations are sought, or glaze-ice icing conditions have to be modeled this assumption is not valid any more. A staggered grid arrangement is applied, the velocity components are stored on cell faces, whereas the pressure is stored in cell centers.

For spatial discretization a third order upwind scheme is used for the convective part and a fourth order central scheme for the diffusive term. To improve efficiency and stability, the high-order accuracy is achieved by applying a single-step defect-correction approach (Gullbrand et al., 2001): at each time-step, the solution is first computed with lower order discretization schemes (first and second order for the convective and diffusive parts, respectively), then it is corrected with the high order discretization schemes to achieve better accuracy.

Implicit integration is used in time, accelerated with a four-level multigrid approach. The relaxation scheme within the Multigrid solver involves point wise relaxation of the momentum equations coupled with a point wise smoothing of the continuity equation. At the latter step, both the velocity vector and the pressure are corrected so that the residuals of the momentum equations shall not be changed as the continuity equation is satisfied, similarly to the approach used in Fuchs and Zhao (1984).

The flow solver handles the turbulence by using LES. No explicit SGS model is used; instead the third-order upwind scheme used for the convective terms accounts for the additional diffusion due to the sub-grid scale stresses.

The geometry of the airfoil is accounted here by the Immersed Boundary Method (IBM) described in Revstedt (2013). Surface meshes are generated for the solid objects. In the cells located in the vicinity of the surface meshes an additional source term (see Eq. (3)) is included in the momentum equations to force the local velocity, u_{iL}, to converge towards the target velocity, u_{iT}. In Eq. (3) S_i is the source for the ith momentum equation, d the distance from the cell center to the surface mesh and $C_{1,\,2}$ are model constants. C_1 is a relaxation factor to improve efficiency or stability and was set to unity in the present computations. C_2 is used to adjust the decay rate of the source term and was set to $C_2 = 6/\Delta x^2$. To improve efficiency, the distance from the surface mesh, d, was initialized to a large number (1e+6) everywhere in the domain and updated to the real distance only in the vicinity of the surface mesh. In this manner, the source terms are practically deactivated at distances larger then two cell sizes from the solid boundary.

$$S_i = C_1 (u_{iT} - u_{iL}) e^{-C_2 d^2} \tag{3}$$

The approach is implemented in our in-house LES well validated solver (Gullbrand et al., 2001; Olsson and Fuchs, 1996). The code is parallelized using the MPI library. The shape of the ice layer for the iced cases has been determined as part of a previous work (Szasz and Fuchs, 2013). As a consequence the ice accretion module was not activated in the present computations. Nevertheless, a brief description of the modeling approach is given in the followings.

The Lagrangian Particle Tracking (LPT) approach is used to track the transport of water droplets in air. The liquid water content (LWC) and the median volume diameter (MVD) of the droplets being typically small, only one-way interactions are accounted for and droplet-droplet collisions are neglected. The droplets' motion is determined by the drag force, the other forces commonly used in LPT are estimated to be small and neglected. The injected droplets have uniform size equal to the MVD. To reduce the computational effort, the droplets are not injected at the inlet, but at a certain

Download English Version:

https://daneshyari.com/en/article/4993325

Download Persian Version:

https://daneshyari.com/article/4993325

Daneshyari.com