ABSTRACT

One of the main concerns of the renewable wind energy is their noise emissions, causing public reluctance for its widespread usage. Research into the sound emitted by wind turbine rotor blades specifically during the off-design operating condition such as the turbulent boundary layer flow separation is limited. A particular type of flow control device - the rod vortex generators (RVGs) have been investigated for separation reduction on wind turbines. However, their acoustic impact is unknown.

A fundamental understanding of the physics and mechanisms of sound generation and propagation that enables better design of noise mitigating flow control devices is the main objective of this research work. This was accomplished by developing a general, post-processing, aeroacoustic code for investigating sound predictions of rotating bodies in subsonic motion. It is based on the integral solution derived by Farassat to the exact Ffowcs-Williams and Hawkings (FW-H) acoustic analogy.
The acoustic signal along with its various components (thickness, loading, near and far-field) are validated in great detail against the analytical solutions for elementary sources (monopole and dipole). Additionally, to obtain the analytical solutions, codes for both stationary/moving monopole and dipole were developed for single and distributed point sources. Thus, also enabling preliminary acoustic analysis for new projects.

The code is then utilized for the investigation of low frequency in-plane harmonic noise (LF-IPH) of a model helicopter rotor in hover. A good match of the predicted thickness noise with the literature (University of Maryland) was obtained. A detailed loading noise analysis was conducted through both Reynolds-averaged Navier-Stokes (RANS) simulations and Blade Element Momentum Theory (BEMT) methods. A satisfactory agreement with the signals from literature (another FW-H code) was obtained while the total pressure had the same agreement as the literature code with measurements.

The code is then used to investigate the impact of the RVGs on the noise emitted by the NREL Phase VI wind turbine rotor. The main focus of this investigation was the relative difference in the sound emitted (steady rotational noise) by the rotor blades with/without RVGs. Neither global nor local analysis showed any significant change in the overall sound pressure levels for both near and far-field microphones. Thus, the RVGs do not cause any significant noise penalty while improving aerodynamic performance by reducing turbulent boundary layer separation.

Since only steady rotational noise was analyzed for the NREL wind turbine rotor due to the limited availability of unsteady surface pressure data, the impact of the rods on the separation and broadband trailing edge noise for a wind turbine airfoil (DU96-W-180) was investigated through measurements. The impact of the rods on the boundary layer has been captured through various flow measurement techniques -- surface pressure, oil flow visualization and Particle Image Velocimetry. Utilizing acoustic beamforming technique to analyze measurements from a microphone array, source identification and a comparitive analysis of sound pressure levels at various inflow angles (with separation) were conducted. A reduction in noise was achieved at low frequencies with RVGs implemented. However, the rods generate more broadband noise at mid and high frequencies. RVGs generate an additional self-noise only at higher frequencies. The increase of noise levels by the rods are all within ~2 dB and occurs at total sound pressure levels which are significantly lower than the peak values generated at low frequencies, thus, making it difficult for human perception specifically for wind turbine applications.