Recent Developments in Understanding the Sound Radiation from Rotors Operating Near Rigid Surfaces

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Sound radiation from rotor operating in a turbulent flow has been studied extensively following the pioneering work of Sevik in the water tunnel at Penn State. Sevik measured the sound from a rotor operating in a homogeneous turbulent flow downstream of a rectangular grid. He also outlined a procedure to predict the unsteady loading and the radiated sound from the rotor based on the wavenumber spectrum of the turbulent inflow. This problem has been reconsidered many times over the years since Sevik's early experiment and, with suitable modifications to Sevik's theory, rotor noise caused by homogeneous or quasi homogeneous turbulent inflows is well understood, providing that the wavenumber spectrum of the turbulent inflow can be suitably modeled, and turbulence lengthscales estimated using Rapid Distortion Theory (RDT). Example studies have been completed on helicopter rotors, wind turbines and fans operating in a duct wall boundary layer as well as in grid turbulence. However, the problem of an inhomogeneous turbulent inflow, for which the wavenumber spectrum of the flow is undefined, has received less attention. Over the last few years a series of theoretical, experimental and numerical studies have been carried out to advance the understanding of this problem by specifically considering the sound radiation from a rotor that is placed close to a flat wall, and ingests the wall boundary layer over a limited part of the rotor disc plane. This is a challenging problem for numerical methods such as LES or URANS because the fixed wall is in close proximity to the moving blades and the unsteady flow between the blade tip and the wall is crucial to the physics of the problem. This leads to a complex moving mesh problem embedded in a fully developed turbulent flow and, it appears, LES studies of this flow have yet to be undertaken. From the analytical modeling perspective the inhomogeneity of the turbulence in the wall boundary layer, and the mean flow shear make traditional approaches based on RDT and a Von Karman wavenumber spectrum of the turbulence unsuitable for the problem, and the rotor response needs to be related to more general definitions of the inhomogeneous turbulence.

In this paper we will review a study of sound radiation from a rotor operating near a wall that included a series of experiments in the Virginia Tech Stability wind tunnel, and the development of a theoretical approach for rotor noise that is suitable for arbitrarily inhomogeneous inflows\cite{1-5}. The experimental results show a far field noise spectrum that is relatively smooth at low rotor speeds, but becomes increasingly dominated by broad haystacked tones close to blade passing frequency as the speed is increased. Detailed measurements were made of the two point cross correlation function of the inflow turbulence and these were used in the rotor noise model to accurately predict the far field sound at low rotor speeds (see Figure 1). However, at high thrust conditions (low advance ratio), the prediction methodology failed to give good results (see case D in Figure 1). Detailed RANS calculations and PIV
measurements showed that the high thrust cases were dominated by coherent vortex structures that were formed between the wall and the rotor blade tip, and this introduced a blade vortex interaction that dominated the far field sound. Modeling of the sound radiation from the BVI gave results that were consistent with the measurements at high thrust. The effect of yawing the rotor relative to the mean flow was also studied [3], and this was found to also impact the BVI and the general level of broadband noise. This paper will summarize the main conclusions from this study and illustrate the complexity of the rotor inflow for this problem, and how it is related to the sound radiation.

![Graphs of sound pressure level (SPL) vs. frequency for different advance ratios J]

Figure 1: Prediction of sound from a rotor operating near a wall and ingesting a turbulent boundary layer at four different advance ratios J for a microphone in the forward arc using the methods described in reference 1.

References