COMPUTATION OF ROTOR NOISE GENERATION

IN TURBULENT FLOW USING LARGE-EDDY SIMULATION

Abstract

by

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A computational study is carried out to investigate the noise generated by a ten-bladed rotor ingesting low-Mach-number turbulent flow. Two types of turbulent inflows are considered: homogeneous and isotropic turbulence mimicking grid-generated turbulence in a previous experiment and a turbulent cylinder wake. A hybrid computational approach combining LES with Lighthill's aeroacoustic theory is employed to predict the aeroacoustic response of the rotor. LES based on incompressible flow equations provides the unsteady loading on the rotor blades, and the Ffowcs Williams-Hawkings extension to the Lighthill theory is used to calculate the radiated acoustic field.

The rotor acoustic response to grid-generated turbulence is calculated at two advance ratios and validated against the experimental data of Wojno et al. (AIAA J., 40(1), 2002) The noise spectra are broadband with small peaks at the blade passing frequency and its harmonics. The turbulence ingestion noise is much stronger than the rotor self noise. It is found that decreasing the rotor advance ratio at fixed free-stream velocity increases the sound pressure level. Turbulence distortions by the rotor are insignificant, and blade-to-blade correlations of the acoustic dipole sources are weak.

The noise of rotor ingesting a turbulent cylinder wake is studied at several advance ratios and wake striking positions. The computed sound pressure spectra agree very well with the experimental measurements at Virginia Tech (Alexander et al., AIAA paper 2016-2994) over a wide frequency range. The broadband acoustic spectra exhibit a strong tonal peak at the cylinder vortex-shedding frequency and minor peaks at the rotor blade passing frequency and trailing-edge vortex-shedding frequency. A closer examination of flow and acoustic fields reveals that the strength of the blade acoustic source increases significantly with the radial distance to the hub, and the trailing-edge self noise is generated in the outer region of the blade near the tip. It is shown that the spectral level and source correlations of the ingestion noise increases with increasing rotation speed (decreasing advance ratio). The centerline and 75% off-center wake striking position cases produce similar sound pressure levels, which are slightly higher than that of the 100% off-center case. Wake turbulence distortions induced by the rotor are more significant compared to the grid-generated turbulence ingestion case, and the Sears theory is shown to provide a reasonable prediction of the rotor turbulence ingestion noise over most frequencies.