Assessment of Wavelet-based Separation Algorithms on Turbulent Boundary Layer Trailing-edge Noise Prediction

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Abstract: Wavelet-based separation algorithms are evaluated to investigate sources of noise under the turbulent boundary layer around an airfoil. Detailed physical interpretations are made by decomposing the original pressure signal into the hydrodynamic pressure and the acoustic pressure. For this purpose, large-eddy simulations are conducted at an angle of attack of 0 deg and at a Reynolds number of 400,000, and the far-field acoustic computations are performed by solving the Ffowcs-Williams and Hawking equation. First, the predicted flow fields and acoustics will be validated against experimental data in the full paper. Then, three different wavelet-based separation algorithms will be developed and compared with the conventional wavenumber-frequency transform method. The paper will shed light on the true and physical noise sources of trailing-edge noise.

Keywords: Large-Eddy Simulation, Wavelet Decomposition, Separation Algorithm, Trailing-edge Noise.

1 Introduction

Trailing-edge noise is generated when the turbulent boundary layer is scattered at the sharp edge, which inevitably takes place for lifting surfaces utilized in many aerospace applications. Due to stringent regulations in noise levels as it closes to living areas, researchers are motivated to focus on unraveling noise sources and their geneartion mechanism. The acoustic field is divided into incident and scattered fields. In the low frequency in which the wavelength of sound is relatively smaller than the characteristic length, the near-field pressure is mostly dominated by the compact dipole source while the noncompact source is pronounced in mid to high frequency. However, it is challenging to analyze their relative contributions to the far-field acoustics, which resulted in somewhat contradictory conclusions as to the noise reduction mechanism. For example, it was reported that the noise attenuation achieved by serrations results from the destructive interference between the root and tip of serrations [1]. On the contrary, others weighed a decrease in incident wall pressure fluctuations [2]. The present study is inspired by that line and aims at developing and applying the novel wavelet based separation technique to the trailing-edge noise analysis. We decompose pressure signals of total noise into the hydrodynamic and acoustic pressures by using this novel technique and investigate the contribution of each part to the generation and propagation of acoustics.

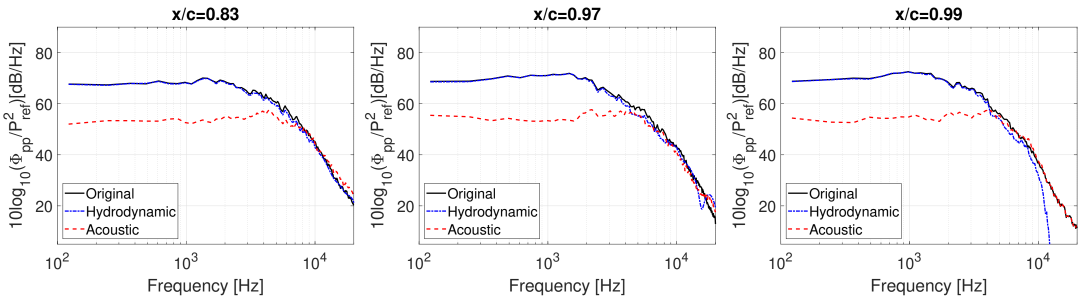

Figure 1: Wall pressure spectra of the original, hydrodynamic and acoustic pressure signals at different streamwise locations.

2 Technical Approach

NACA 0012 airfoil configuration is used in the present study. Structured meshes around near-wall to the far field are created by GMSH opensource software. Spatially-filtered compressible LES is performed using OpenFOAM code and WALE is used to model the subgrid-scale eddy viscosity. Then, PSU-WOPWOP is employed for acoustic computations radiated from the airfoil. As the wavelet-based separation method is a key algorithm to this study, the relevant theoretical background is briefly is provided. A pressure signal is decomposed by a discrete wavelet transform. The discrete wavelet coefficients are given by

$$w_p^{(s)}(n) = \sum_{k=-\infty}^{+\infty} \Psi^s(n - 2^s k)p(k) \tag{1}$$

where s denotes the discretized scale, while the wavelet function $\Psi^s(n - 2^s k)$ is the discretized version of $\Psi^s = 2^{-\frac{s}{2}}\Psi\left(\frac{t}{2^s}\right)$. The wavelet coefficients obtained after DWT are used in a separation algorithm to isolate the hydrodynamic pressure from the acoustic pressure. More detailed explanations will be provided in the full paper.

3 Preliminary Results and Future Work

Figure 1 shows the separated hydrodynamic and acoustic pressures obtained from the wavelet-based separation as well as the original pressure signal. One can observe that the switch in the energy spectral contribution between the hydrodynamic and acoustic pressures moves towards the lower frequency as it closes to the trailing-edge. Further analyses using the wavelet-based separation technique will be extended to the whole surface domain to observe the physical behavior of amplitude and phase differences as the source of noise for each signal. A dynamic mode decomposition will also be tightly coupled with the separation algorithm to examine the acoustic propagation of separated signals at a particular frequency.

References

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