A Parallel CFD-CAA Computation of Aerodynamic Noise for Cylinder Wake-Airfoil Interactions

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ABSTRACT

Aerodynamic noise (broadened tone & broadband components from 500Hz to 10kHz) from the cylinder wake-airfoil interactions at M=0.2 and Re_D=46,000 is computed by solving the linearized perturbed compressible equations (LPCE) [1], with the acoustic source and hydrodynamic flow variables computed from the incompressible large eddy simulation. The computational domain includes a cylinder and NACA0012 airfoil in tandem and employs 3.14 million grid points with 32 blocks (30 cells used in the spanwise direction for a span of three times the cylinder diameter). The incompressible LES is solved by an iterative fractional step method (Poisson's equation for pressure). The momentum equations are time-integrated by a four stage Runge-Kutta method and spatially discretized by a sixth-order compact finite difference scheme. The LES computation covers 40 to 50 cycles of Karman vortex shedding from the rod to have reasonable spectral-statistics.

The acoustic field is computed by solving the linearized perturbed compressible equations (LPCE) with the same numerical schemes (for space and time) mentioned above. For acoustic calculation, an overlaid grid system is employed because aeroacoustic computation requires grid resolutions for sound waves different from LES. At the overlaid grid interfaces, a higher-order interpolation is used and an ETA (energy transfer and annihilation) boundary condition is used at the far-field boundaries. A 2D LPCE calculation is conducted at the zero spanwise wave-number (k_z=0) with an assumption of statistical homogeneity in the spanwise direction. Then, a 2D Kirchhoff method is used to extrapolate the sound field at the acoustic far-field boundary (40D) up to the micropohne location (185D away from the airfoil chord center at the mid-span plane). Finally, a far-field sound pressure level (SPL) for actual span (30D) is predicted by Oberai's correction method for 3D spectral acoustic pressure and spanwise coherence function for the wall pressure.

The computational results for flow and acoustics are validated with the experimental data [2] measured at the Ecole Centrale de Lyon. From this study, the computational methods descibed

above are critically assessed in the aspects of spectral accuracy on the broadened peaks and broadband components. Flow physics of vortex shedding and its interactions with the airfoil are also discussed, including spanwise coherence of the wall pressure in the noise source region.

Figures 1-4 show some preliminary results of LES and LPCE calculations for the hydrodynamic field as well as the pressure fluctuation field. Figures 3 and 4 show the comparison of wall pressure and far field acoustic spectra with the experimental data [2]. A dominant noise source is the pressure change at both surfaces of the NACA0012 airfoil (St=0.2). This comes from the interactions between the shed Karman vortex and the airfoil, and majorly creates C_L fluctuations for the cylinder and airfoil (dipolar nature). The overall pressure level, however, comes from many other sources, incluidng a quadruple source (e.g. eddy-to-eddy interactions).

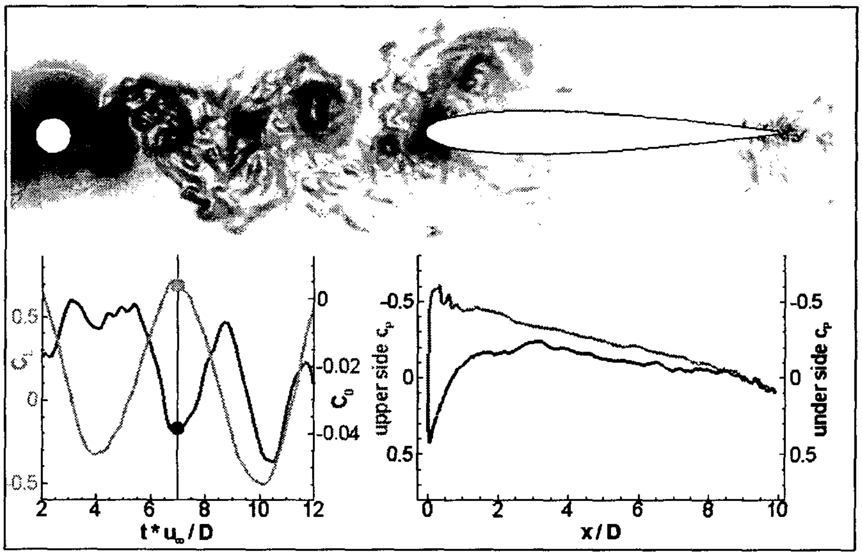

Fig. 1 Instantaneous spanwise vorticity field (spanwise-averaged) with colors representing the pressure(from low to high: blue-green-white-red), time history of C_D and C_L, C_P distributions at the upper and lower surfaces (NACA0012 airfoil); Re_D=46,000.

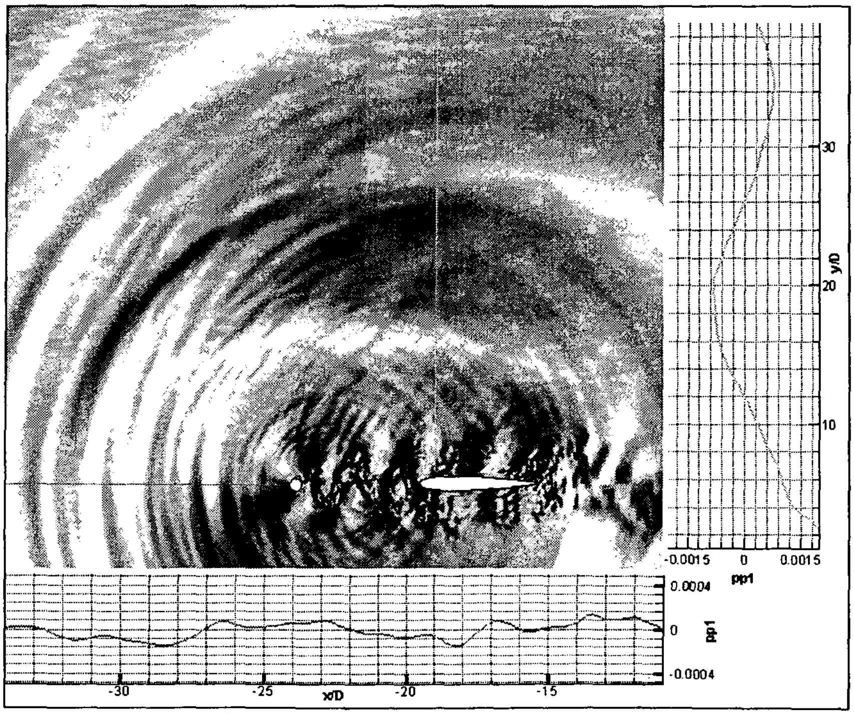

Fig. 2 Instantaneous pressure fluctuation field (spanwise-averaged) with colors representing the level (from low to high: blue-white-red); M=0.2 and Re_D=46,000.

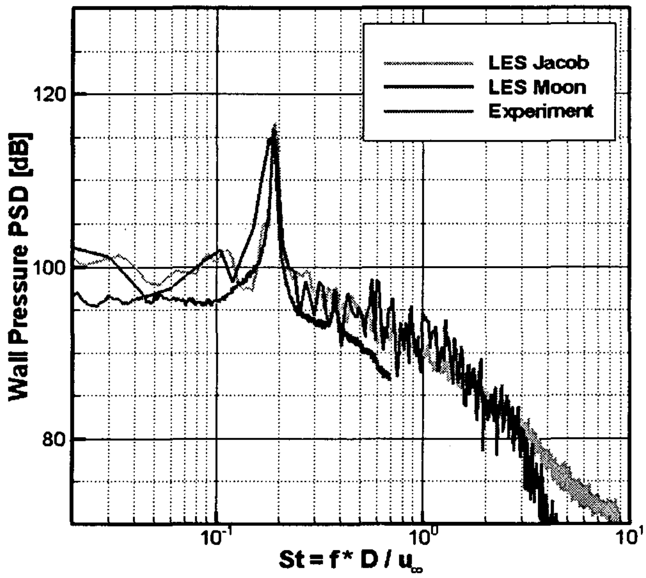

Fig. 3 Comparison of wall pressure PSD spectrum at Re_D=46,000.

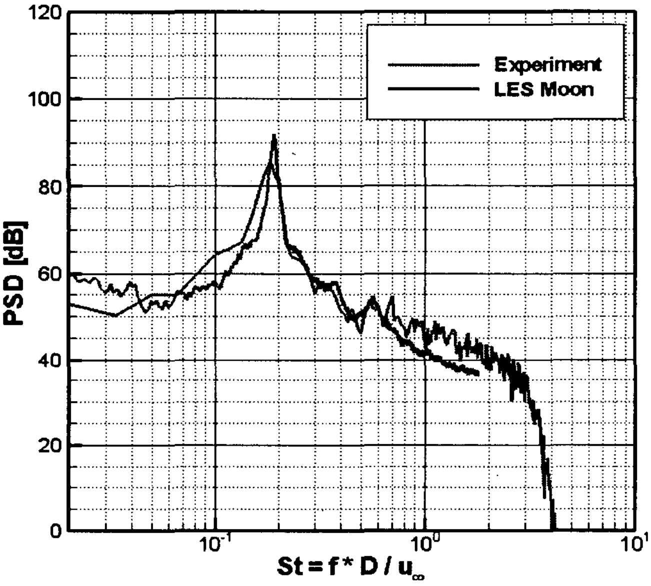

Fig. 4 Comparison of far-field acoustic PSD spectrum at M=0.2 and Re_D=46,000.

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