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DIRECT NUMERICAL SIMULATION OF CAVITATING FLOW NOISE

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ABSTRACT

Cavitation bubbles formed by a breakdown of cavitation sheet or collapse of vortex cavities are often responsible for the generation of loud noise and erosion damages, especially when they collapse coherently. Cavitation experiments are usually quite difficult and even more so for the cavitation noise.

In this study, a direct numerical simulation procedure for the cavitating flow noise is presented. The compressible Navier-Stokes equations are written for the two-phase fluid, employing a density-based homogeneous equilibrium model with a linearly-combined equation of state [1]. This density-based cavitation model is found quite suitable to direct simulation of the cavitation noise because the governing equations are strictly in a hyperbolic system so that generation and propagation of the waves can be resolved with the high-order numerical schemes used in computational aero-acoustics (CAA). On the other hand, a numerical scheme should also be able to capture the steep gradients of flow variables at Mach numbers varying from very low subsonic to supersonic, while a high-order accuracy is required to resolve the acoustic waves with minimizing the dispersion and dissipation errors. In this regard, a sixth-order compact central scheme is utilized with the selective spatial filtering technique to simultaneously resolve the linear and non-linear waves in the flow field.

The present cavitation model and numerical methods are first validated for two benchmark problems: linear wave convection and acoustic saturation in a bubbly flow [2]. The cavitating flow noise is then computed for a 2D circular cylinder flow at Reynolds number based on a cylinder diameter, 200 and cavitation numbers, $\sigma = 0.7 \sim 2$. As demonstrated in two benchmark problems, the present computational methodology is valid and effective to treat the macro-scale dynamics of the two-phase cavitating flow. Especially, the compressible Navier-Stokes equations for the mixture fluid allow us to use the high-order numerical scheme with the selective filtering, to resolve not only the transient characteristics of the complex two-phase flow physics (e.g. formation, detachment, convection, and collapse of the cavitation bubble clouds) but also the generation and propagation of the linear and non-linear waves in the entire field. The direct numerical simulation of the cavitating flows noise from a 2D circular cylinder shows that, at sub- and super-critical cavitation numbers ($\sigma = 1$ and 0.7), the shock waves generated

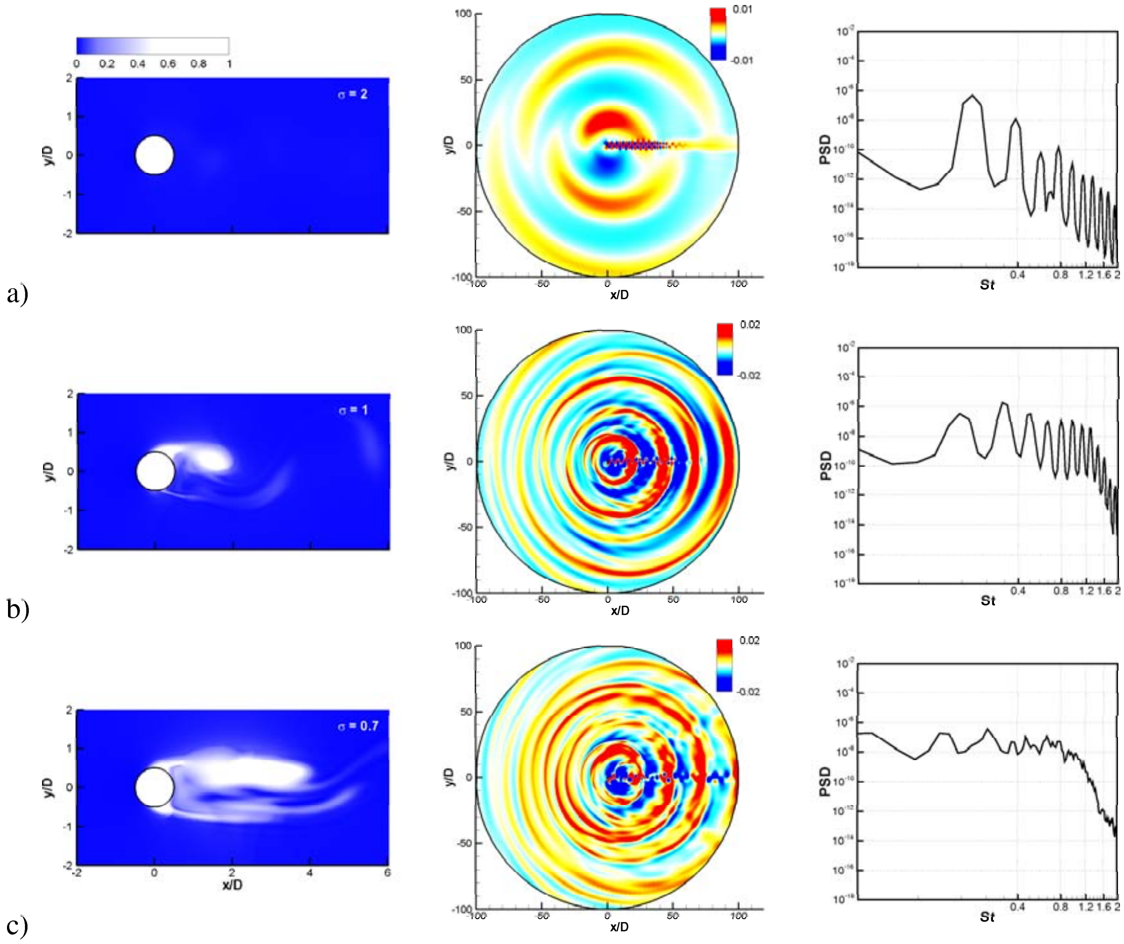

Figure 1: Two-phase flow over a 2D cylinder for cavitation numbers, a) $\sigma = 2$, b) $\sigma = 1$, c) $\sigma = 0.7$; left: void fraction, middle: pressure fluctuation fields, right: power spectral density of pressure fluctuations at $r = 70D$; pressure is non-dimensionalized by $\rho_0 u_0^2$ and $St = fu_0/D$.

by the coherent collapse of cloud cavitation in the wake significantly change the aerodynamics and the aerodynamic noise, including alteration of the vón Karman vortex shedding frequency (see Fig. 1). The present direct simulation results are verified by an acoustic analogy composed of monopole and dipole sources. The far-field noise predicted by direct simulation is in excellent agreement with that of acoustic analogy, and it also confirms the f^{-2} decaying rate in the spectrum, as predicted by the model of Fitzpatrik and Strasberg [3] with the Rayleigh-Plesset equation.

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