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Numerical Investigation of Cavitation Interacting with Pressure Wave

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Abstract. A computational fluid dynamics solver based on homogeneous cavitation model is employed to compute the two-phase cavitating flow. The model treats the two-phase regime as the homogeneous mixture of liquid and vapour which are locally assumed to be under both kinetic and thermodynamic equilibrium. As our focus is on pressure wave formation, propagation and its impact on cavitation bubble, the compressibility effects of liquid water have to be accounted for and hence the flow is considered to be compressible. The cavitating flow disturbed by the introduced pressure wave is simulated to investigate the unsteady features of cavitation due to the external perturbations. It is observed that the cavity becomes unstable, locally experiencing deformation or collapse, which depends on the shock wave intensity and freestream flow speed.

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Key words: Isentropic cavitation model, cavitating flow, pressure wave.

1. Introduction

Cavitation is fairly widespread in numerous engineering applications and is an undesired phenomenon in most situations. For operating underwater devices, the cavitation bubble collapse is usually accompanied by huge pressure surge, which will cause material erosion, noise, vibration, loss of efficiency, etc. Therefore, the prevention of cavitation occurrence has been the subject of a large body of research for the past many decades. However, the cavitation may also be beneficial to reduction of drag on underwater weapons such as that found for supercavitating torpedo.

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A number of numerical difficulties are encountered in the modeling of cavitation and can be attributed to several reasons. First, the liquid flow is usually in low Mach number (Ma) regime. To speed up the convergence of numerical solution, some acceleration techniques like preconditioning have to be adopted. Second, there are large discontinuities in fluid properties including the density and Mach number across the cavitation boundary. This may lead to numerical instability and spurious pressure oscillations. In addition, a variety of complex physical procedures occur on the interfacial region such as phase transition, heat and mass transfer, etc. and modeling these physics is not easy. One class of cavitation models that gain wide use is built by including source terms in the governing equations to account for the finite rate phase transition between liquid and vapour [5, 7, 8, 13, 14, 19]. This kind of methods is physically reasonable but may not be accurate as expected because many parameters involved the models have to be determined empirically. Another popular class of models is based on the assumption that the phase transition occurs instantaneously [4, 6, 9–11]. The appropriate equation of states (EOS) are used to close the models. This type of methods appears simpler. However, the stiffness of EOS may pose severe numerical difficulties in simulation.

The majority of existing cavitation models ignore the liquid compressibility and are built based on the incompressible Navier-Stokes equations. This is consistent with experimental observation that the density of liquid element almost does not vary as long as there is no phase change and the flow velocity is not very high. This treatment is proved to be valid for a wide range of steady state problems [10, 11]. However, in this study, we are concerned with the unsteady dynamics of cavitation impacted by the pressure wave. Hence, the wave propagation and compressibility effects of liquid must be taken into account. The prediction and understanding of pressure wave propagation and its interaction with cavitation bubble and the resulting unsteady flow features are of great importance to stability of cavitation and the possible prevention of its collapse. Unfortunately, few works on this topic are found in the literature except for say [20]. This is the motivation of the present study. Here, the cavitating flow is governed by one-fluid homogeneous cavitation model which is based on the compressible Euler equations. The thermodynamic behaviors of pure liquid and liquid-vapour mixture in cavitation region are described by Tait EOS and isentropic cavitation model, respectively. The governing equations are discretized using a second-order accurate finite volume method. The cavitating flow driven by the introduced pressure wave is resolved and the unsteady features of supercavitation are investigated and analyzed.

The paper is organized as follows. In Section 2, the physical model and numerical method are described. In Section 3, the numerical results are presented and discussed. The conclusion is given in Section 4.

2. Physical model and numerical method

2.1. Governing equations

To model wave dynamics and wave-cavitation interaction, the cavitating flow must be assumed to be compressible and thus the time-dependent Euler equations are em-