Cavitation simulation using a new simple homegeneous cavitation model

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Long Abstract

Introduction

The cavitation CFD (Computational Fluid Dynamics) is becoming popular to be used in the design of hydraulic machinery. Many cavitation models have been developed and even implemented into commercial CFD software, whereas they often fail to predict the cavitation performance even in simple cases of cavitating hydrofoil. The development of cavitation model with the robust prediction accuracy is still an important issue. In our previous study [1], a new simple homogeneous cavitation model was developed considering two extreme dispersed flow conditions, dispersed vapor bubbles in continuous liquid phase for low void fraction and the dispersed droplets in continuous vapor phase for high void fraction. To enhance the unsteadiness of cavitation due to the instability at the cavity interface, the turbulent shear stress is modified depending upon the continuous phases in combination with the proposed cavitation model, which drastically reduces the turbulent viscosity for high void fraction region. In the present paper, this simple cavitation model is applied for simulations of cavitating flow in/around two types of two-dimensional geometry; a convergent-divergent nozzle and a single Clark Y-11.7% hydrofoil.

1. Methods

A numerical simulation is carried out by using an open source software, OpenFOAM. Several cavitation models are implemented in OpenFOAM, among which we employ interPhaseChangeFoam (IPCF) as a base solver. This solver is an incompressible Navier-Stokes one with homogeneous cavitation model considering the phase change between liquid and vapour phases. Besides the mass and momentum equations of the mixture and the transport equations of turbulence properties, the IPCF solves the following mass conservation of liquid phase.

$$\frac{\partial \alpha_l}{\partial t} + \frac{\partial}{\partial x_j}\left(\alpha_l u_j\right) = \frac{1}{\rho_l}\left(\dot{m}^+ + \dot{m}^-\right)$$

where x_j is a Cartesian coordinate, u_j velocity component in the x_j direction, ρ_l the liquid density, α_l the local volume fraction of liquid phase. The source terms in the above equations, $\dot{m}^+$ and $\dot{m}^-$, are mass transfer rates between two phases due to condensation and evaporation, which should be modelled to close the problem.

Most of homegneous cavitation models proposed already consider mass transfer through surfaces of dilute tiny bubbles, although the application of such dispersed bubble model for large void fraction regions seems to be inappropriate. In our model, we consider another extreme case in which vapour phase contains more or less liquid droplets. When the local void fraction is close to unity, we treat vapour phase as a continuum media, and mass transfer through surfaces of dilute tiny droplets is considered, as shown in Fig.1. This model virtually considers the interface between liquid and vapor phases as the iso-surface of void fraction $\alpha_{v,int}$, and in this study $\alpha_{v,int}$ is set to be 0.5 for simplicity. The mass transfer between vapour and liquid are dominated by that occurs at the surfaces of the bubbles/droplets, then the mass transfer rates $\dot{m}^+ + \dot{m}^-$ are switched depending upon the local void fraction α_v. In the present model, Schnerr-Sauer (SS) model [2] based on simplified Rayleigh Plesset model is adopted for $\alpha_v < \alpha_{v,int}$, while for $\alpha_v > \alpha_{v,int}$ the phase change model through the surfaces of droplets is considered using Schrage's mass flux [3]. Although it is known that key unsteady cavitation phenomena such as a re-entrant jet which develops beneath the sheet cavity and the formation of cloud cavity can never be simulated with incompressible RANS turbulence model, we still use it for simplicity but switch the eddy viscosity as well as the molecular viscosity by referring only the continuum phase. This treatment may look similar to well-known Reboud correction [4], while in this study the turbulent and molecular viscosities are modified based on the fluid properties of continuum phase only, which is suitably applied in combination with our proposed cavitation model.

Since the cavity interface can be virtually treated, the mass transfer at the cavity interface is supposed to be possibly treated, which remains for our future study.

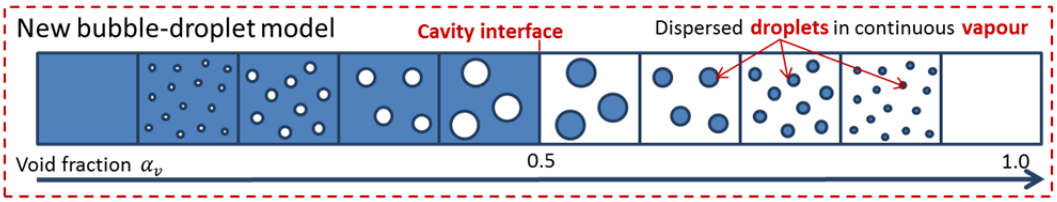
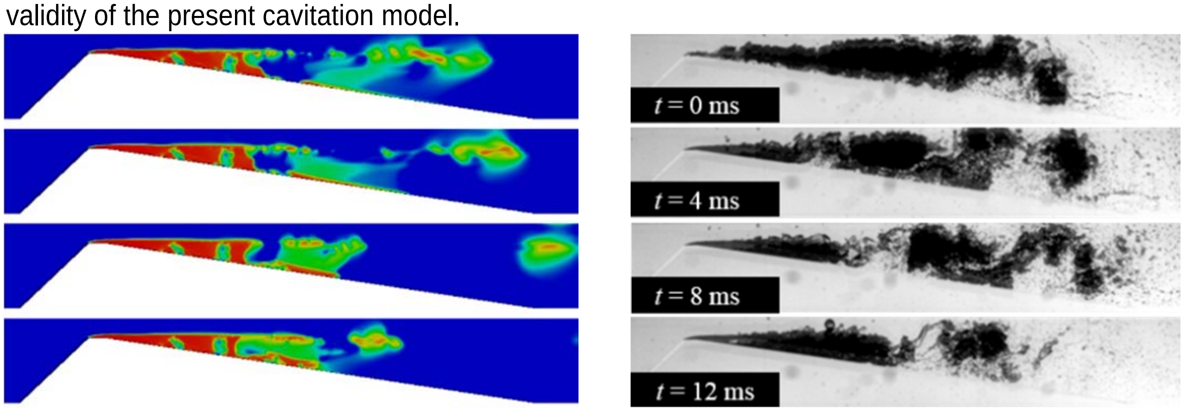


Figure 1. Conceptual drawing of bubble-droplet model

2. Results

Figure 2 shows a typical example of the simulated cavitating flow in a two-dimensional convergent-divergent nozzle, being compared with the experimental observation [5]. It can be seen that the unsteady motion of cavities looks well simulated by the present model. Further results not only for this nozzle but also for a two-dimensional hydrofoil will be presented in our full paper to examine the validity of the present cavitation model.



(a) Numerical simulation (b) Experiment [5]

Figure 2. Typical example of simulation of 2-D convergent-divergent nozzle flow

References

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