Effect of Bubble Nuclei Characteristics on a Cavitating Hydrofoil: Numerical Investigation with Homogeneous Cavitation Model

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Long Abstract

Introduction

Numerical simulation considering cavitation is becoming a common tool for the design of hydro-machinery. Many of the models of cavitation are established based on homogeneous flow approach [1-3], and it is well known that the prediction using such models is sometimes poor even for a simple flow around a single hydrofoil [4]. One possible reason for this might be un-tuned parameters of the employed model. Especially, the characteristics of free bubble nuclei, the number density distribution of bubble nuclei, are different for the degree of degassing treatment and also different even from tunnel to tunnel. Actually, the formation and behavior of sheet cavity strongly depend on the number density distribution of free bubble nuclei [5], therefore the effect of characteristics of free nuclei should be considered or be reflected to tune the parameters.

In the present study, the main objective is placed on clarifying the effects of number density and diameter of bubble nuclei on unsteady cavitating flow around an isolated Clark Y-11.7% hydrofoil through numerical simulations using homogeneous cavitation model. Experimentally obtained number density distribution of bubble nuclei is considered and the results are compared with the corresponding experiment.

1. Methods

In this study, both two- and three-dimensional simulations of cavitating flow around a single Clark Y-11.7% hydrofoil are carried out. Incompressible Navier-Stokes equation is solved with considering the mass transfer between liquid and vapor phases by using a commercial code, ANSYS CFX 16.2. Schnerr-Sauer model (SS) [3] and a model developed by our group (Yamamoto et al [6]) are used for the source term in the transport equation of vapor volume fraction. Our model, BD1VF (Bubble-Droplet1 Viscosity Filtering model), considers a virtual liquid-vapor interface at void fraction of α=0.5. In this model, two-phase mixture is treated as dispersed vapor bubbles in continuous liquid phase for α<0.5 and it is switched to dispersed liquid droplets in continuous vapor phase for α>0.5. We may be able to consider the direct mass transfer at the virtual interface with α=0.5, which will be attempted in our future study. In addition to the above treatment, the eddy viscosity of the mixture is also switched depending upon the continuous phase.

In the both models, the number and radius of nuclei are considered as the parameters regarding bubble nuclei. One pair of the number of bubble nuclei per unit liquid volume and the diameter of bubble nucleus, N_{nuc}=1.6x10^{13}m^{-3} and d_{nuc}=2.0x10^{-6}m, is considered, which is often used as a default setting for SS. In addition, another pair estimated from the number density distribution measured by our experiment (Fig. 1) is used, that is N_{nuc}=2.4x10^{8}m^{-3} and d_{nuc}=3.3x10^{-6}m. In these pairs, the order of the nucleus diameter is similar, but the number of nuclei is significantly different by the order of five. Numerical simulations are carried out for the angle of attack of 8 degrees and the freestream velocity of U_{ref}=8.1m/s, which are also the same as in the experiment.

2. Results

Figure 2 shows a typical example of time-averaged pressure distribution around the hydrofoil obtained by two-dimensional numerical simulations with (a) SS and (b) BD1VF models. Cavitation number σ is defined using the upstream pressure p_{ref} as $\sigma=2(p_{ref}-p_v)/\rho U_{ref}^2$, where p_v is a saturated vapor pressure and ρ the liquid density. Also, the surface pressure $p(x)$ is normalized defining the pressure coefficient of $C_p=2[p(x)-p_{ref}]/\rho U_{ref}^2$. Experimental results [7] are also plotted for the reference. It can be seen that, in the both two models, the cavitating region with low pressure (approximately equal to C_p=-σ) is wider and the pressure recovery downstream is steeper in the case with N_{nuc}=2.4x10^{8}m^{-3} and d_{nuc}=3.3x10^{-6}m (red curves) than those with the default setting (blue curves). The latter tendency obtained with the experimentally obtained free bubble nuclei characteristics is similar to the experiment (open circles), although the cavitation zone is wider especially with BD1VF. Since the actual development of sheet cavitation is highly three-dimensional, quantitative comparison/validation apparently necessitates the three-dimensional simulation, which is ongoing and is hopefully reported in our full paper.

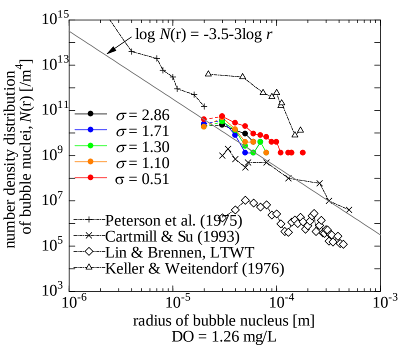
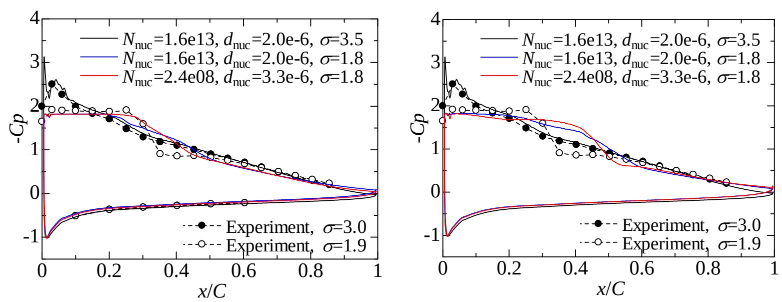


Figure 1. Number density distribution of bubble nuclei



(a) SS model (b) BD1VF model

Figure 2. Pressure distributions on hydrofoil surface

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