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The numerical simulation of propeller sheet cavitation with a new cavitation model

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Abstract

According to the mass transport equations of vapor and liquid, and Rayleigh-Plesset equation, a cavitation model based on a single-fluid multi-phase flow method is proposed, which especially considers the nonlinear variety of the bubble radius and is expected to deal well with cloud cavitating flow.The proposed cavitaion model was validated against a benchmark database for 2D NACA66MOD hydrofoil and experimental photos of E779A propeller sheet cavitation shape. The overall results suggest that the present proposed cavitation model is practicable for simulating cavitating flows.

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1. Introduction

Cavitation generally occurs when the local pressure drops below its vapour pressure. Cavitation presents complex unsteady, turbulent and multi-phase flow phenomena with a large density difference and mass transfer. These features result in a unique challenge for the simulation of cavitating flows.

Numerical method is highly important approach for studying the cavitating flow. Computational methods for cavitation have been studied since over two decades ago. In general, the methods can be largely categorized into two

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groups: single-phase modeling with cavitation interface tracking and multi-phase modeling with cavitation interface capturing.

2. The derived process of a cavitation model

The cavitation modeling based on mass transport equation is to introduce the concept of volume fraction, and the source term of the mass transport equation is used to model the evaporation and condensation transition, the mixed density is calculated using the volume fraction.The mass transport equations of vapor and liquid and the mixed density are written as:

$$\frac{\partial \alpha\rho_v}{\partial t}+\frac{\partial\left(\alpha\rho_v u_i\right)}{\partial x_i}=S=\dot{m}^{+}+\dot{m}^{-}, \tag{1}$$

$$\frac{\partial(1-\alpha)\rho_l}{\partial t}+\frac{\partial\left[(1-\alpha)\rho_l u_i\right]}{\partial x_i}=-S=-(\dot{m}^{+}+\dot{m}^{-}), \tag{2}$$

$$\rho=\alpha\rho_v+(1-\alpha)\rho_l, \tag{3}$$

where α is the vapor volume fraction, ρ_v , ρ_l and ρ are the density of vapor, liquid and mixed density, S is the source term, $\dot{m}^{+}$ and $\dot{m}^{-}$ respectively express condensation and evaporation process.
Adding Eq.(1-2), the mixed phase continuity equation is written as follow:

$$\frac{\partial\rho}{\partial t}+\frac{\partial\left(\rho u_i\right)}{\partial x_i}=0, \tag{4}$$

Eq.(1)$\times\rho_l$ + Eq.(2)$\times\rho_v$, we can get that:

$$S=\frac{\rho_v\rho_l}{\rho_l-\rho_v}\frac{\partial\left(u_i\right)}{\partial x_i}. \tag{5}$$

Extending Eq. (4):

$$\frac{\partial\rho}{\partial t}+\frac{\partial\left(\rho u_i\right)}{\partial x_i}=\frac{\partial\rho}{\partial t}+u_i\frac{\partial\left(\rho\right)}{\partial x_i}+\rho\frac{\partial\left(u_i\right)}{\partial x_i}=\frac{D\rho}{Dt}+\rho\frac{\partial\left(u_i\right)}{\partial x_i}=0 . \tag{6}$$

Using Eq. (6), we can get Eq. (7):

$$\frac{\partial\left(u_i\right)}{\partial x_i}=-\frac{1}{\rho}\frac{D\rho}{Dt}. \tag{7}$$

Substituting Eq. (7) into Eq. (5), we can get Eq. (8):

$$S=-\frac{\rho_v\rho_l}{\rho_l-\rho_v}\frac{1}{\rho}\frac{D\rho}{Dt}. \tag{8}$$

Deriving Eq. (3), yielding a relation between the mixture density and vapor volume fraction:

$$\frac{D\rho}{Dt}=-(\rho_l-\rho_v)\frac{D\alpha}{Dt}. \tag{9}$$

Substituting Eq. (9) into Eq. (8), we obtain the relation between the source term and volume fraction fraction:

$$S=\frac{\rho_v\rho_l}{\rho}\frac{D\alpha}{Dt}. \tag{10}$$

The vapor is assumed to consist of mimi spherical bubbles. Therefore, the vapor fraction can be calculated by Eq. (11).