A New Perspective on Cavitation Modeling: Improved bubble growth and transport modeling

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Long Abstract

Introduction

Cavitation relates to many marine applications, pumps designs, rockets, etc. In general, this is undesired physical process that is highly non-linear and strongly impacts performance. For these reasons, modeling cavitation using computational fluid dynamics (CFD) has become an important tool design tool. In the context of CFD, there are various approaches to cavitation modeling. A common approach is based on a volume of fluids (VOF)-like approach, coupled with a model for the exchange from a liquid to vapor phase (evaporation) and vice versa (condensation). These models are commonly referred to as homogenous multiphase models [1]–[3]. These approaches have all improved significantly in their reliability over the years, but still pose challenges in complexity, mesh requirements, and difficult-to-ascertain empirical factors.

In this work, we focus on two features of cavitation. The first aspect aims to improve on recent work [4] evaluating present model formulations with respect to the Rayleigh-Plesset Equation (RPE), which governs the nuclei growth. In this evaluation, it was found that the present modeling approaches are all first-order representations of the cavitation and neglect several terms that lead to inaccuracy. Secondly, our next focus aims to evaluate the impact of the homogenous model assumption. Specifically we ask if modeling the slip between the vapor and liquid phases is important to cavitation modeling. Combining and utilizing these two approaches, we believe we are working to develop an improved cavitation model.

2. Improved Cavitation Model

The first aspect aims to improve cavitation modeling by more faithfully representing the RPE. In the context of a VOF-like formulation, the vapor mass conservation equation can be written as [1], [5], [6]:

$$\frac{\partial(\rho_v \alpha_v)}{\partial t} + \frac{\partial(\rho_v \alpha_v u_i)}{\partial x_i} = \dot{m}_{evap} - \dot{m}_{cond}$$

Using an analytic solution to the RPE, we are able to directly calculate the cavitation rates as:

$$\dot{R} = \sqrt{\frac{2}{3}\frac{(p_v - p_\infty)}{\rho_L}\left[1 - \frac{R_0^3}{R^3}\right] + \frac{2}{3}\frac{p_{G_0}}{\rho_L}\frac{1}{1-\gamma}\left[\frac{R_0^{3\gamma}}{R^{3\gamma}} - \frac{R_0^3}{R^3}\right] - \frac{2S}{\rho_L R}\left[1 - \frac{R_0^2}{R^2}\right]}$$

In terms of the driving terms (in the root), present cavitation models are limited to the first term, $\sqrt{(p_v - p)/\rho}$, and the remaining terms are neglected. One goal of this effort is to evaluate the effect of the remaining terms in the context of analytic solutions to the RPE, then establish their importance in the context of a cavitating hydrofoil.

3. Two Fluid Cavitation Modeling

In the context of developed cavitation, most CFD is carried out using Eulerian continuum mixture (VOF-like) approaches. The second goal is evaluate the validity of *homogeneous Eulerian approaches* where local mixture equilibrium assumptions are assumed (i.e., V_{vapor}=V_{liquid}). It is quite easy to expose their inherent weaknesses for developed cavitation. For example, in Figure 1, are simulation results that highlight the importance of slip using a two-fluid model (b) and (c) compared to a homogenous mixture model (a). In these results for a 2D developed cavitation over a NACA 0012 hydrofoil, the Singhal [3] mass transfer model is used and, for the two-fluid model, a simple bubble drag model and kinematics based local bubble diameter. Even for this simple model (single bubble field, drag only), significant differences are observed between the two, with normalized slip velocities reaching 0.7 adjacent to the re-entrant jet, and significantly more unsteady richness and cavity diffusion arising in the conventional homogenous model. Despite the simplicity of this model, and the obvious implications of neglecting vapor bubble dynamics is apparent. This presents another clear, relatively unexplored avenue to improve cavitation modeling.

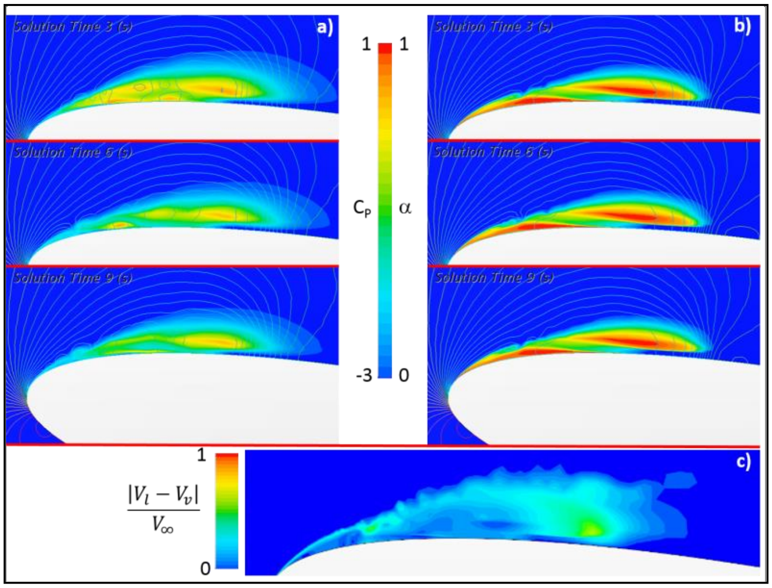

Figure 1. Comparison of a) homogeneous, b,c) 2-Fluid cavitation predictions for a NACA 0012, α=10^o, R_{ec}=5x10^6, σ=2.4. a,b) contours of C_P and gas volume fraction at three corresponding timesteps. c) normalized slip velocity at a given timestep.

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