# Numerical prediction of small scale cavities using a coupled mixture-bubble model

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**Keywords**: Multi-scale model, Eulerian-Lagrangian model, Cavitation, Homogeneous mixture model

## Abstract

In this study a hybrid Eulerian mixture - Lagrangian bubble model is developed for numerical simulation of cavitating flows. In this model, the large scale cavities are represented in the Eulerian framework using the homogeneous mixture model, while the small sub-grid structures are tracked as Lagrangian bubbles. Also, at each time step small cavity structures in the Eulerian framework are transformed to the Lagrangian framework to be treated as sub-grid bubbles and vice versa. Using this model, it is possible to represent various cavity structures of different length scales with reasonable computational cost.

## Introduction

Cavitating multi-phase flows include an extensive range of cavity structures with different length scales, from micro bubbles to large sheet cavities. Homogeneous mixture models, in which the liquid-vapour mixture is considered as a single homogeneous fluid, are quite common in numerical simulation of cavitating flows. However, they are usually limited in modelling small vapour structures such as sub-grid cavitation nuclei and bubbles. In fact, these models need very fine temporal and spatial resolution to capture such structures and therefore they cannot sufficiently model the inception of cavitation and the last steps of vapour condensation. The other approach in cavitation modelling is the discrete bubble model in which vapour structures are represented as Lagrangian bubbles. In this framework, it is possible to consider different flow forces on vapour bubbles, which makes this approach a more suitable alternative for prediction of cavitation inception and vapour collapse. However, while the bubble sizes can be much smaller than the grid size, these models are sometimes quite computationally expensive, and cannot represent large non-spherical vapour structures. In a recent study by Ghahramani et al. (2019), the performance of the homogeneous mixture and discrete bubble models in the simulation of bubble cavitation were compared with each other. Considering the stated limitations, a hybrid multi-scale model is developed as a solution in this study to represent the large vapour structures through a homogeneous mixture approach, and to track the small-scale structures as discrete bubbles.

The concept of hybrid Eulerian-Lagrangian solvers has gained more popularity in recent years for simulation of multi-scale problems, especially in atomizing gas-liquid flows. This approach can be utilized for cavitating flows as well. For example, Hsiao et al. (2017) and Ma et al. (2017) have developed a model with coupling of a Lagrangian Discrete Singularities Model and an Eulerian level set approach. In these studies, the small Eulerian cavities are directly transformed to Lagrangian bubbles and vice versa, but the bubble volume is spread smoothly over neighboring cells within a selected radial distance. In the current study, the developed model is similar to the work of Vallier (2013), in turn inspired by the study of Tomar et al. (2010). However, new development presented in this study includes improvements in some features including the continuity and volume fraction equations as well as the calculation of mixture properties. Also a novel way is introduced to consider the local pressure effect in the dynamics of Lagrangian bubbles and the model is applied to real case problems.

## Methodology

In the multi-scale solver, the cavities are categorized as either Eulerian structures or Lagrangian bubbles. The Eulerian cavities are modelled using the homogeneous mixture approach (e.g. Asnaghi et al. 2018), while the sub-grid Lagrangian bubbles are tracked via a discrete bubble model. At each time step, small Eulerian cavities (normally representing a cluster of bubbles) that are not resolved by sufficient number of computational cells, are transformed to Lagrangian bubbles. This transformation is schematically shown in a 2D grid in Fig. 1, where the arbitrarily shaped Eulerian cavities are represented by blue cells based on their volume fraction in each cell ($\alpha < 1$) and the bubbly cells are marked in red based

bubble volume fraction in each cell ($\beta < 1$). Further information about the Eulerian-Lagrangian transformation may be found in the recent study by Ghahramani et al. (2018).

The main governing equations are continuity and NS equations, and the mixture properties are obtained from liquid and vapour volume fractions and their corresponding properties. The liquid / vapour volume fraction in the Eulerian mixture model is obtained from a scalar transport equation, and in the Lagrangian bubble model, it is calculated from bubble cell occupancy. Finally, the mass transfer between the phases is based on the Schnerr-Sauer (2003) model.
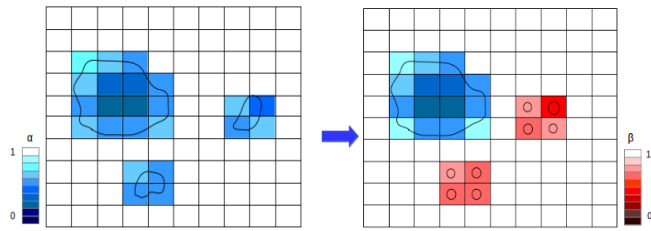


**Figure 1:** Transition of small Eulerian cavities to Lagrangian bubbles

## Result

In Fig. 2 the model performance in representing different cavity structures over a 2D hydrofoil is depicted. As seen in the figure, the large cavities are modelled as Eulerian structures and the small ones are treated as Lagrangian bubbles. In this study, we will present validation of the method for 3D flow cases where experimental data are available. The performance will also be compared with simulations using a standard Eulerian mixture approach. The prediction of small scale structures will be assessed for the two simulation approaches and computational performance will be discussed.
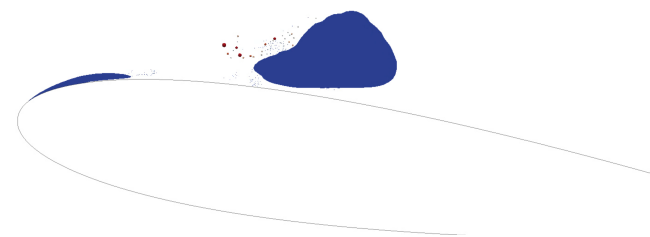


**Figure 2:** Eulerian cavities are Lagrangian bubbles over a 2D hydrofoil.

## Acknowledgments

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