Modeling for incompressible LES using a DNS-based sub-grid model for bubble cloud dynamics

CaFE Innovative Training Networks

HORIZON2020 Marie Skłodowska-Curie actions

Objective

❖ Most approaches to simulate cavitating flows relies on a rudimentary mixture assumption of vapour and liquid, that does not account for the dynamics of bubbles in cloudy cavitation.

❖ This PhD project aims to develop a sub-grid mixture model for incompressible LES, that implements mixture properties for vapour clouds, extracted from DNS data, coupled with Lagrangian bubble models for very sparse clouds.

❖ The new model will yield a more realistic condensation process, derived from vapour cloud dynamics, with seamless transition to micro-bubble dynamics. This allows for incorporating the radiated acoustic pressure wave due to bubble collapse and its rebound can be estimated, which is applicable in surface erosion estimation.

Eulerian vs. Lagrangian

➢ **The Eulerian approach:**

Utilizes the asymptotic form of the Rayleigh-Plesset equation of bubble dynamics

Beneficial where vorticity and pressure gradients of pressure are of moderate size [1]

Limited to modeling of structures larger than the computational cell; Requires high grid resolutions

Unable to resolve cavitation nuclei and bubbles

➢ **The Lagrangian approach:**

Based on the more accurate form of Rayleigh-Plesset equation of bubble dynamics

More accurate for flows with large values of vorticity and pressure gradients [1]

Spherical bubbles assumed to be much smaller than the computational cell

Unable to model large-scale non-spherical structures

Highly computationally expensive

Methodologies

The first step: To develop a model that is capable in both resolving the large vapour structures and capturing the small bubbles following Vallier et al. [2] & Tomar et al. [3]; a muti-scale approach which benefits the advantages of both methods

➢ **Eulerian modeling:**

Volume of Fluid (VoF) method

Schnerr-Sauer model to consider phase change

➢ **Lagrangian modeling:**

Discrete Bubble Model (DBM) to track bubbles

Four way coupling

Evolution of the spherical bubble diameter based on the Rayliegh-Plesset equation

❖ **A new OpenFOAM solver:**

Couple interPhaseChangeFoam solver with the Lagrangian library

Detection of vapour structures at each time step

Transition between the two methods based on the number of computational cells and a threshold vapour fraction value

Results

Three cases were studied to validate the new solver qualitatively:

1- The collision of two solid particles in a stationary fluid, which shows the four way coupling in the modified particle trajectories and induced velocity vectors (figure 1)

2- Collapse and rebound of a cavity, which shows the transition from an Eulerian vapour structure to a Lagrangian bubble. Also the bubble rebound demonstrates the effect of considering the Rayleigh-Plesset eq. in the bubble dynamics (figure 2)

3- Cavitation in a venturi: In this simulation, the new solver calculates various vapour structures including cloud shedding, collapse and rebound of a cavity and re-entrant jet in a rather complicated flow field (figure 3)

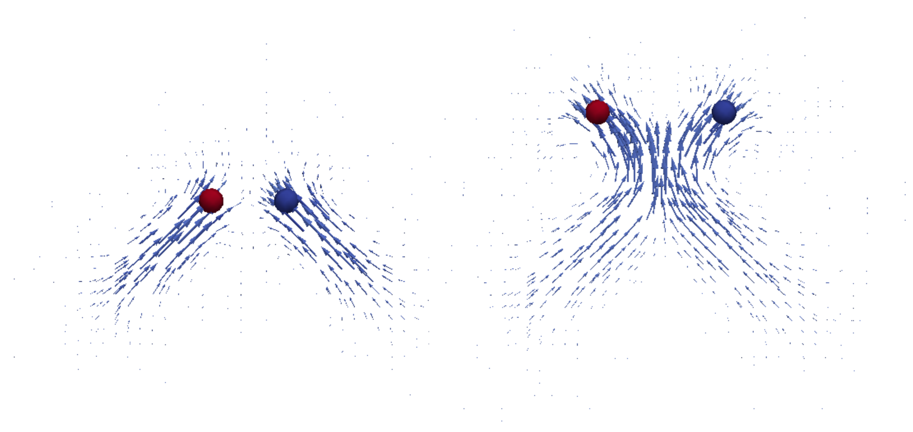

Figure 1. Collision of two particles in a stationary fluid

Figure 2. Collapse and rebound of a cavity

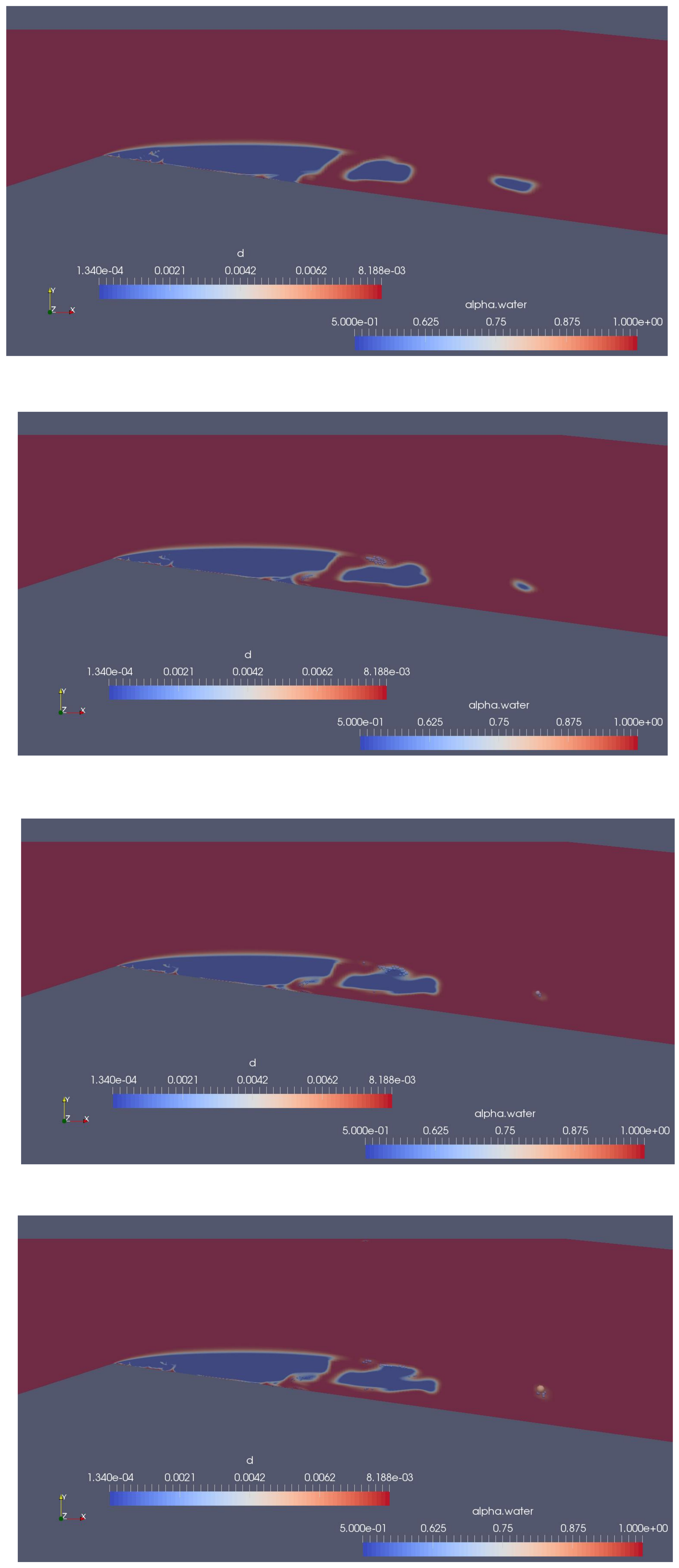

Figure 3. Cavitation in a venturi

Discussion

An extensive range of scales are resolved in the new solver

Bubble growth and collapse due to the variations of the surrounding pressure are captured

❖ **Benefits in erosion prediction**

Incorporation of the radiated acoustic pressure wave due to bubble collapse and rebound can be used in surface erosion estimation

The residence time of the bubbles also gives a less expensive estimation of the regions exposed to successive collapse and rebound

Future Work

The Lagrangian library can be improved to include the effect of different forces on bubble trajectory and bubble-wall interaction

Bubble-bubble coalescence need to be considered

Developing a bubble-bubble interaction model based on DNS data (from ESR1)

Improving the Eulerian mixture model considering cloud cavitation dynamics based on DNS data (from ESR1)

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References

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2. Vallier, A., Revstedt, J, Nilsson, H. "A new multi-scale approach for modelling cavitation on hydrofoils", *Submitted to International Journal of Numerical Methods in Fluids*

3. Tomar G., Fuster D., Zaleski S. and Popinet S. (2010) "Multiscale simulations of primary atomization", *Computers & Fluids*, 39(10): 1864-1874,