SIMULATION OF BUBBLE EXPANSION AND COLLAPSE BETWEEN A FREE SURFACE AND A RIGID WALL

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I.SIMULATION SETUP

The computational domain is positioned in such a way that the point (0, 0) corresponds to the axis of symmetry at the initial free surface level (see Figure 1). No-slip wall boundary condition[1] is placed at the bottom of the domain and fixed pressure at the open top of the domain (see Figure 2). The 2D rectangular domain spans in the x-direction from 0 to 10 mm and in y-direction from −18/-12/-6 to 20 mm.

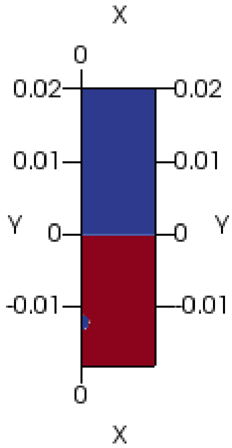

Figure 1: The 2D computational domain used

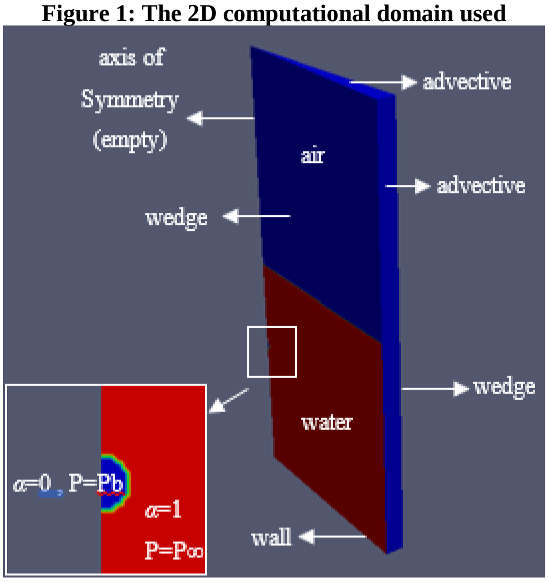

Figure 2: Boundary patches for CFD of single bubble pulsation in a free field

Initial conditions of the bubble pressure were estimated through the traditional Rayleigh-Plesset equation. The standard Rayleigh-Plesset equation[2] was used in the form

$$\rho\left[R\ddot{R}+\frac{3}{2}\dot{R}^2\right]=p_v-p_\infty+p_0\left(\frac{R_0}{R}\right)^{3n}-\frac{2\sigma}{R}-4\mu\frac{\dot{R}}{R} \tag{1}$$

The Volume Of Fluid method was employed for tracking liquid and gas phases while compressibility effects were introduced with appropriate equations of state for each phase. Compressibility effects in both gas and liquid phases are included. Volume fraction equation[3] was in the form

$$\frac{\partial \alpha \rho_1}{\partial t} + \nabla \cdot (\alpha \rho_1 \boldsymbol{u}) = 0 \quad (2)$$

where α represents the volume fraction and ρ_1 the density of the gas phase. In the interface, where α varies from zero to unity, volume fraction averaging is performed for determining the value of viscosity and density.

II.RESULTS

First, simulation results of TNT spherical charge detonation in free field were compared with empirical values. Related data of maximum radius and period can be seen in table 1. Simulations were successful in the prediction of bubble expansion and collapse.

Table 1: The comparation of the bubble radius and the period

W(g)	R_m(cm)			T(ms)		
	Empirical value	Simulation value	Deviation	Empirical value	Simulation value	Deviation
0.055	6.0	6.3	6.18%	11.5	11.2	-2.8%
0.184	8.9	8.3	-6.6%	17.2	14.6	-15.3%
0.437	11.9	10.6	-10.1%	23.0	18.5	-19.5%

Second, simulations were conducted where the underwater bubble expands in shallow water, between two boundaries, a free surface and a horizontal rigid wall. The motion features of both the bubble and the free surface were investigated, via the consideration of two key factors, i.e., the non-dimensional distances from the bubble to the two boundaries. There are two length parameters[4] in the current work, namely

1. the non-dimensional standoff distance from the free surface, defined as $\gamma_f = df / R_{eq.}$
2. the non-dimensional standoff distance from the rigid wall, defined as $\gamma_w = dw / R_{eq}$.

where *df* and *dw* are the vertical distances from the initial center of the bubble to the free surface and the rigid bottom respectively. The two parameters are found to be the major factors affecting the motion features of the bubble and the free surface. An equivalent maximum radius R_{eq} is adopted since in many cases the bubbles develop into non-spherical shapes.

Keep non-dimensional standoff distance from the free surface, defined as γ_f=0.91, γ_w=0, 0.91 and 1.82 have been selected to study the effect of rigid wall on bubble motion.

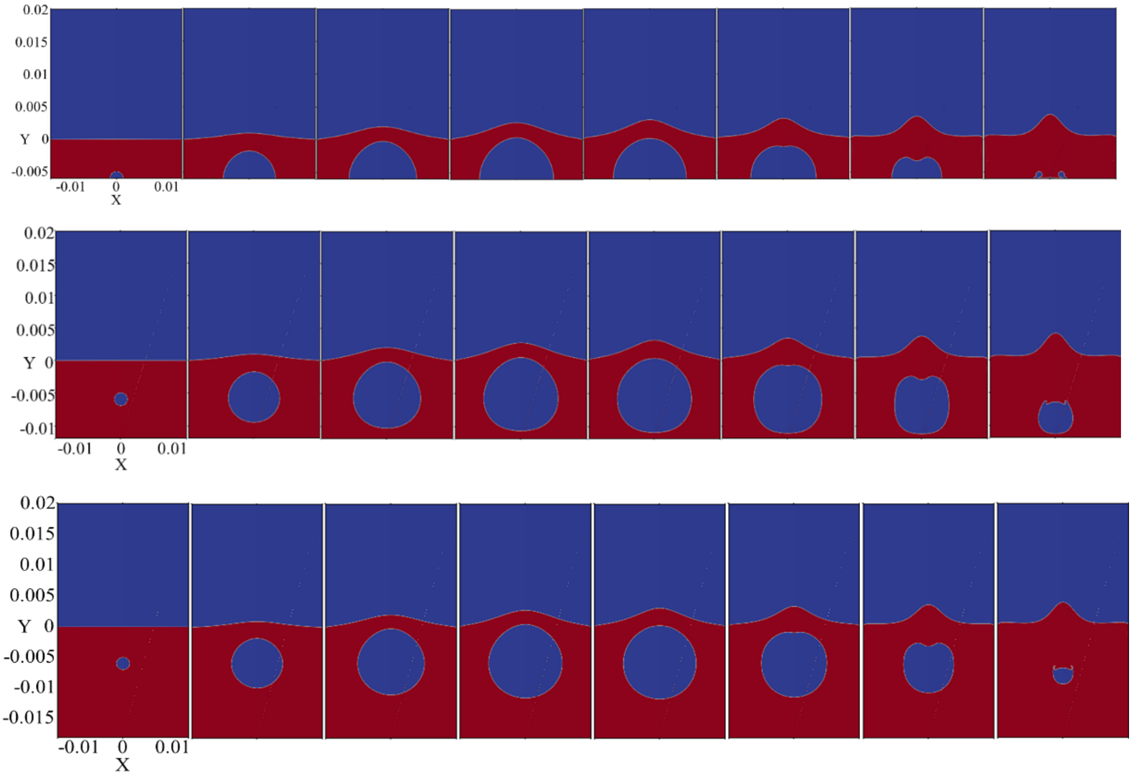

Figure 3: Evolution of single bubble between a free surface and a solid wall, γ_f=0.91, (a) γ_w=0; (b) γ_w=0.91; (c) γ_w=1.82

Keep non-dimensional standoff distance from the free surface, defined as γ_w=0.31, γ_f=0.63, 1.54 and 2.26 have been selected to study the effect of free surface on bubble motion.

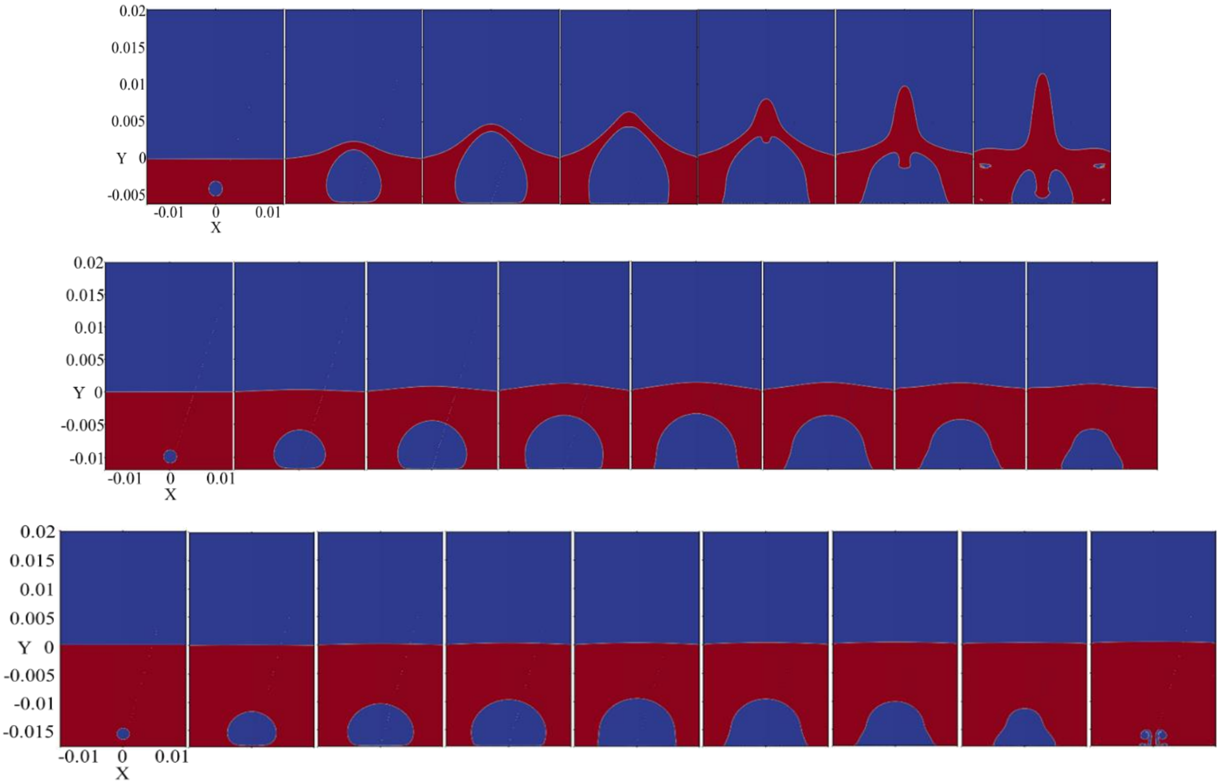

Figure 4: Evolution of single bubble between a free surface and a solid wall, γ_w =0.31, (a) γ_f=0.63; (b) γ_f =1.54; (c) γ_f =2.26

The dynamics of the bubble and the free surface have been experimentally studied using high-speed photography. The bubbles are generated by underwater electric discharge and pulsate in the vicinity of the free surface and/or a horizontal rigid boundary, with varying bubble-boundary distances (γ_f and γ_w). Intriguing motion features have been found with both single and double boundaries. Most of the motion features observed in the double boundary cases are inherited from the single-boundary cases but change in speed, height, etc. Therefore, additional considerations are required in bubble applications with multiple boundaries, especially those of different nature.

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References

[1] C. M. Christian, E. G. Paterson, A. A. Fontaine, "Modeling Laser-Generated Cavitation Bubbles", M.S. Thesis, Dept. Mech. Eng., Penn State Univ., PA, 2012.

[2] J. P. Franc, J. M. Michel, "Fundamentals of Cavitation", Springer Netherlands, 2005.

[3] A. Prosperetti, G. Tryggvason, "Computational methods for multiphase flows", *International Journal of Multiphase Flow*, vol. 34(11), pp. 1096-1097, 2008.

[4] A. M. Zhang, P. Cui, Y. Wang, "Experiments on bubble dynamics between a free surface and a rigid wall", *Experiments in Fluids*, vol.54(10), pp. 1602, 2013.