J2.6 LEVEL SET SIMULATION OF BUBBLE BURSTING PROCESS

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1. INTRODUCTION

Bubble bursting occurring in the wave boundary layer can produce small droplets. These droplets increase the surface area of the ocean and thus enhance the air-sea exchange of momentum, heat, and moisture (Andreas 2002). This paper aims to simulate and study the dynamics of single rising bubbles and bubble bursting using the level set method coupled with the Navier-Stokes solver (Yue et al. 2003a).

First, single rising bubbles are simulated to study bubble deformation over a wide range of Reynolds and Eotvos numbers for code verification and validation. The predicted shapes of rising bubbles are in excellent agreement with those observed in experiments. The bubble bursting process under no wind condition is then investigated. When a rising bubble reaches the free surface, a water jet is formed and breaks into jet droplets. The level set method is able to capture this bursting process. The simulation results further indicate that a strong air jet with a velocity of 10-18 m/s is formed together with the water jet. The bursting process under wind condition is investigated as well. The results show that the water jet curves toward the upwind direction perhaps due to the pressure variation formed around the water jet, which subsequently alters the curvature of the interface to increase the surface tension to balance the increase in the pressure difference.

2. NUMERICAL METHOD

The numerical method couples the incompressible Navier-Stokes equations with the level set method for study of free surface flows (Yue et al. 2003a). The second-order finite volume method is used to discretize the governing equations in a curvilinear coordinate system on a non-staggered grid with a fractional four-step method. The free surface flow problem is converted into a two-phase flow system on a fixed grid in which the free surface is implicitly captured by the zero level set. The surface tension is modeled by the continuum surface tension force of Brackbill et al. (1992) and has been validated against the Laplace law of static bubbles. The coupled system has been applied to travelling solitary wave, dam breaking problems, and large-eddy simulations of free surface flows over fixed periodic dunes (Yue et al. 2003b).

3. RESULTS

The shapes of single rising bubbles are dependent upon two dimensionless parameters: Reynolds number and Eotvos number. Reynolds number (Re) is defined as $g^{0.5}D^{1.5}/\nu_l$ and Eotvos number (Eo) is $gD^2(\rho_l - \rho_g)/\sigma$, where g, D, ρ_l, ρ_g, ν_l, and σ are gravitational acceleration, bubble effective diameter, liquid density, gas density, liquid kinematic viscosity, and surface tension, respectively. For instance of small Eo number (Eo < 1), the bubble is small and spherical because the surface tension is the dominant force. For code validation, two-dimensional single rising bubbles are simulated. Figure 1 shows the predicted bubble shapes over a wide range of Re and Eo. At small Re and Eo, bubbles indeed remain circular. With increasing Re and Eo, bubbles become ellipsoidal, and then spherical cap. At high Re, bubbles become wobbling. These features are consistent with those of Clift (1978). The method is then applied to bubble bursting. Figure 2 exhibits the formation of a water jet and detachment of a water droplet from the jet during the bursting process. The bursting processes of bubbles of differing size are simulated. In Fig. 3, the heights of the water jet are compared with those measured by Spiel (1995) for bubbles of size ranging from 350 to 1500 mm. The jet height depends on the initial distance of bubble from the free surface denoted by L and the bubble radius (R) in Fig. 3. The agreement between them is very good. Notable in Fig. 4 is the air jet formed simultaneously with the water jet. Surprisingly the maximum air jet velocity is much greater than that of the water jet as shown in Fig. 5, perhaps due to the momentum transfer from a high-density liquid phase to a low-density gas phase. In the case of multiple bubble bursting, air jets may constitute a transpired turbulent boundary layer and alter the boundary-layer turbulence structures.

Finally, the bubble bursting process under wind condition is considered. A strong wind shear of 39 s^{-1} is imposed in the vertical direction which runs parallel to the water jet. The instantaneous streamlines are plotted in pink to illustrate the flow field around the jet. Figure 6 shows a time sequence of this bursting event. The water jet evidently interrupts the airflow aloft and gradually tilts toward the upwind direction. This phenomenon may be explained by the pressure drop in the wake region which increases the pressure difference between air and water. As a result, the curvature of the interface facing the wake region is increased to raise the surface tension to balance the pressure difference.

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4. REFERENCES

Andreas, E.L., 2002: A review of the sea spray generation function for the open ocean. *Atmosphere-Ocean Interactions*, Vol. 1, Editor W. Perrie, WIT press, Southampton, Boston (2002).

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Brackbill, J.U., D.B. Kothe, and C. Zemach, 1992: A continuum method for modelling surface tension", J. Comput. Physics 100:335–354.
Clift, R., 1978: Bubbles, drops, and particles. New York : Academic Press.
Spiel, D.E., 1995: On the births of jet drops from bubbles busting on water surfaces. J. Geophys. Res., 100(C3): 4995-5006.
Yue, W., C.-L. Lin, and V.C. Patel, 2003a: Numerical simulation of unsteady multidimensional free surface Motions by level set method. Int. J. for Numerical Methods in Fluids, 42(8):853-884.
Yue, W., C.-L. Lin, and V.C. Patel, 2003b: Numerical investigations of turbulent free surface flows using level set method and large eddy simulation. IIHR Technical report No. 435, Iowa City, Iowa.

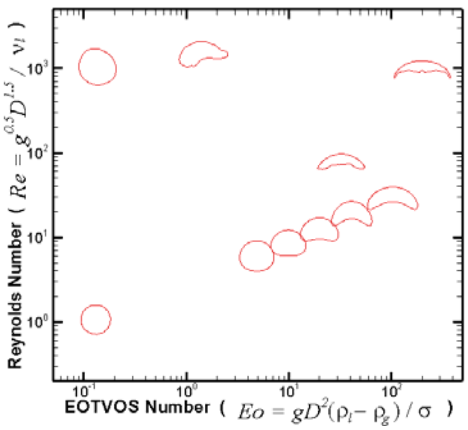

Fig. 1. Shapes of 2D single rising bubbles

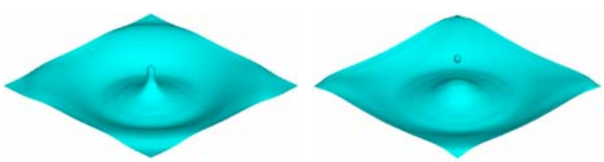

Fig. 2. A time sequence of bursting of a bubble with radius of 850 µm: (a) Formation of a water jet, (b) detachment of a water droplet from the jet.

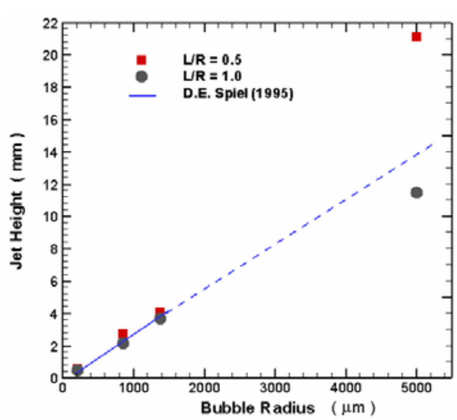

Fig. 3. Comparison of predicted jet heights with those of Spiel (1995).

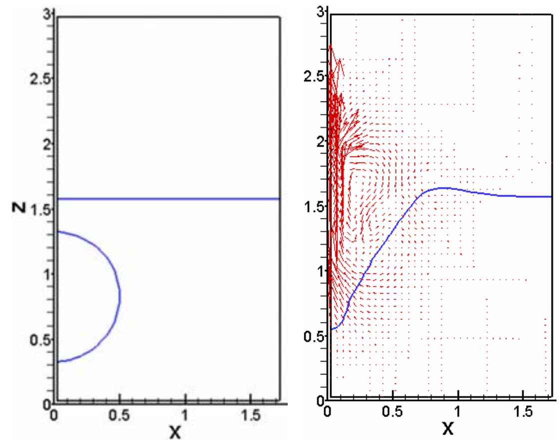

Fig. 4. Formation of an air jet. (a) Initial position of the bubble, (b) velocity vectors of the air jet.

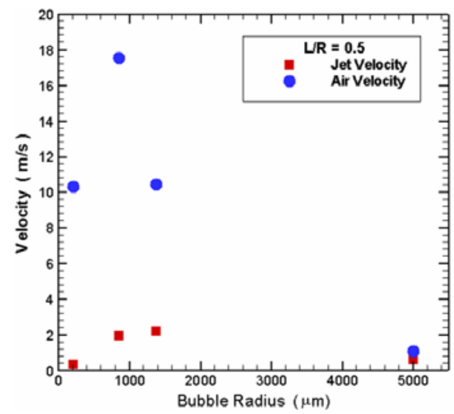

Fig. 5. Velocities of air and water jets as a function of bubble radius.

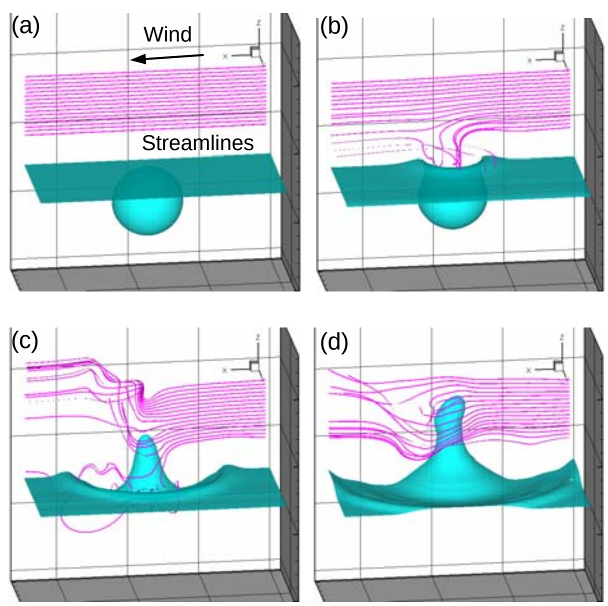

Fig. 6. A time sequence of bursting of a bubble with radius of 850 µm subject to a wind shear.