Journal of Visualization, Vol. 10, No. 1 (2007) 9

Schlieren and "Focused" Shadowgraphy Visualization of the Shape and Wake of Single Air Bubbles Freely Rising in Quiescent Water

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Received 30 November 2006

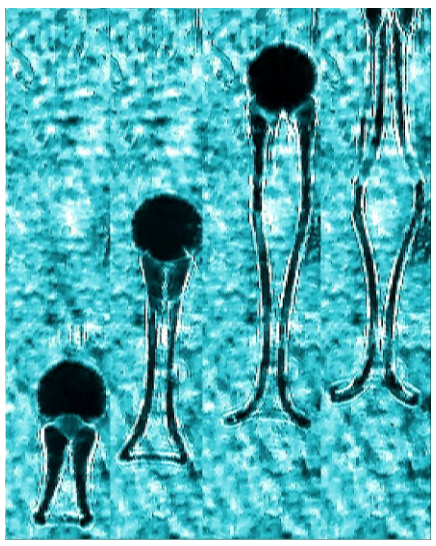

Fig. 1. Wake development shown in temporal sequence.

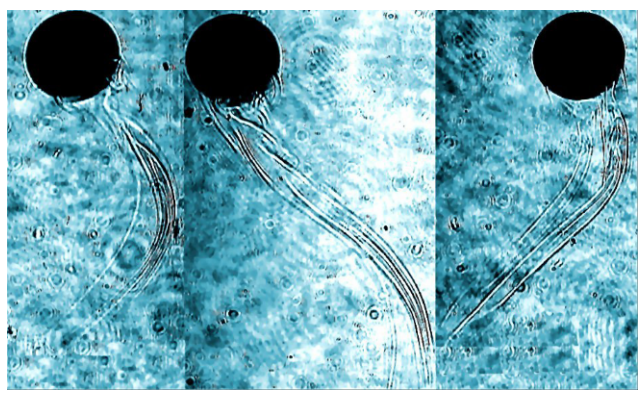

Fig. 2. One-view images of 2.0 mm diameter gas bubbles and wakes (bright-field circular filter in the schlieren cutoff plane).

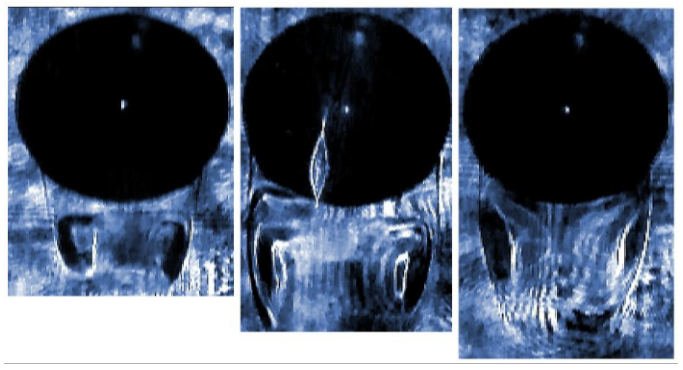

Fig. 3. Images of bubbles and wakes observed by "focused" shadowgraphy.

Fig. 4. Examples of two orthogonal views (a and b) of shape and wake of 0.8 mm diameter bubbles (dark-field circular filters in the schlieren cutoff planes).

Schlieren is a succinct name for gradient disturbances of inhomogeneous transparent media. Schlieren technique allows the visualization of refractive index gradients. "Focused" shadowgraphy (parallel-light shadowgraphy) was performed using a schlieren setup without spatial filtering in the cutoff plane.

Schlieren and "focused" shadowgraphy were used as visualization methods with the aim of giving experimental support to the understanding and numerical modelling of the behaviour of single bubbles freely rising in a quiescent fluid, as well as of the near and far flow field around them.

NaCl-solution, present at the bottom of the test cell, dragged in the wake of the bubble up to the observation area, acted as tracer. As the refractive index of air and water are different, the methods captured the bubble shape as well. Results of bubble and wake one-view imaging are shown in Figs. 1-3. Above all, the observation of very fine hairpin-like wake structures could be performed.

The methods proved also appropriate for the observation of bubble and wake from two orthogonal directions simultaneously, which is mandatory for the validation of 3D simulation codes (Fig. 4).

The experimental visualizations allowed the correlation of the path of single rising bubble with the wake behind it. For a rectilinear path, the wake consisted of a single-threaded axisymmetric wake; after a path instability set in, the bubble movement was either a zigzag or a spiral, double-threaded wakes being observed for both zigzagging and spiralling bubbles.