VISUALIZATION OF BUBBLE-FLUID INTERACTION BY HYBRID PIV

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Our previous study[1] used simultaneous visualization and three dimensional (3D) image processing of a single particle and the flow field around it to learn particle-fluid interaction by utilizing an hybrid PIV[2, 3] combined with three-dimensional PTV. This study deals with simultaneous visualization measurement of the behavior of a single bubble and the flow field around it.

VISUALIZATION METHOD

The hybrid PIV system employed here was made up of 3D-PTV and PIV. Two sets of a CCD camera and a strobe scope were used in 3D-PTV to take a bubble image by the back light method. The optical lines of the cameras were perpendicular to each other and the CCD cameras took the images simultaneously. The time interval in taking images was 5 ms. After some adjustments of the images, the 3D position of the bubble could be estimated based on the two images. Bubble shape was assumed to be an oblate spheroid. The assumption was reasonable for small bubbles and better than an assumption of spherical shape. Each bubble image was approximated as an ellipsoid[4] and the 3D shape was reconstructed based on the two bubble images[5].

A double-pulse system of Nd-YAG laser was used as a light source for PIV and the third CCD camera took a tracer image in flow. A fluorescent particle was used as a tracer particle. By using the optical filter, it was possible to eliminate the reflection of the laser light on the pipe wall and on the particle[6]. The time interval for PIV was 2 ms to take two images for PIV. A cross correlation method was used for the PIV. The velocity fields were visualized every 70 ms, which synchronized with taking a bubble image.

EXPERIMENTAL RESULTS

A rising bubble in stagnant water in a vertical pipe was measured by the hybrid PIV. A bubble was released at the bottom of the vertical pipe and rose up in the pipe. A test section of 1.35 m was located downstream and both the water flow and the bubble motion were measured in a visual field 6.5 cm long in the test section. The inner diameter of the pipe was 40 mm.

Typical results are shown in Figs. 1 to 3. Figure 1 shows a time series of velocity fields measured by PIV and particle motion by 3D-PTV. The velocity vectors are indicated by arrows. The color in the velocity filed shows a component of vorticity along the perpendicular axis to the velocity filed. The vorticity of red color region has opposite sign to that of blue color region. The time interval between figures was 70 ms. The bubble rose in a zigzag and alternative wake sheddings were observed. The visual axis is perpendicular to the velocity field. The spatial relation between a bubble and a velocity field was given by the hybrid PIV and the 3D shape of the bubble was obtained by the 3D-PTV. A different view of the same point in space and time could thus be

obtained, as shown in Fig. 2. The conditions in Fig. 2 are the same as in Fig. 1, but the angle between the visual axis and the velocity field is ± 20 degrees. As shown in Fig. 2, the velocity field with the bubble can be rotated and the detailed velocity field around it can be investigated.

Figure 3 shows the trajectories of the bubbles projected on the pipe cross-section. The figure shows five trajectories of bubbles with the same equivalent diameter (9.4 mm). These were obtained in the experiments of a single bubble motion. The solid circle is the start point of the bubble's trajectory. Each trajectory of almost a circle suggests the spiral motion of bubble.

Regarding the bubble motion, Figs. 2 and 3 suggest that the spiral motion was caused by a deformation effect of the bubble and the successive change of its attitude or position due to 3D wake shedding. Also, the minor axis of the bubble, approximated by an oblate spheroid, kept always the same direction as the moving one. The vortex in the wake separated at the lower edge of its inclined major axis and changed the moving direction of the bubble[7].

CONCLUSIONS

A hybrid system was developed in order to obtain the spatial relation between a bubble and velocity field. The 3D motion of the bubble and the flow around it were measured simultaneously. The main results are as follows:

(1) The measurements showed the instantaneous velocity field and the 3D position and shape of the bubble.
(2) The interaction between a bubble and fluid was made clear from the time series of the measurement results.
(3) Using the 3D-PTV allowed to discriminate easily whether the bubble's motion was zigzag or spiral.

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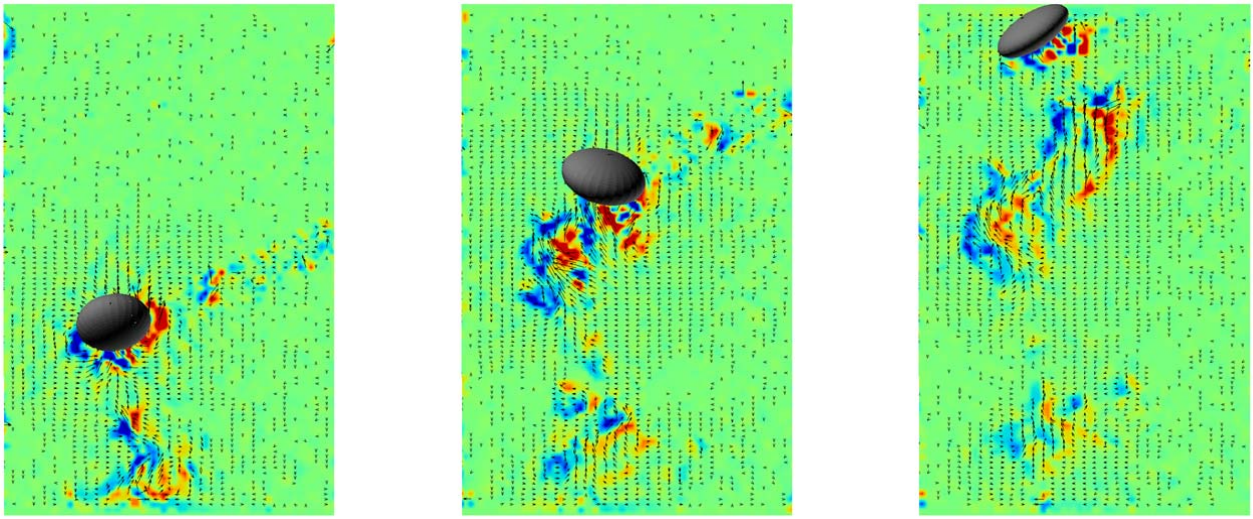
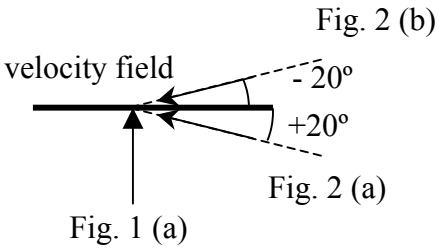
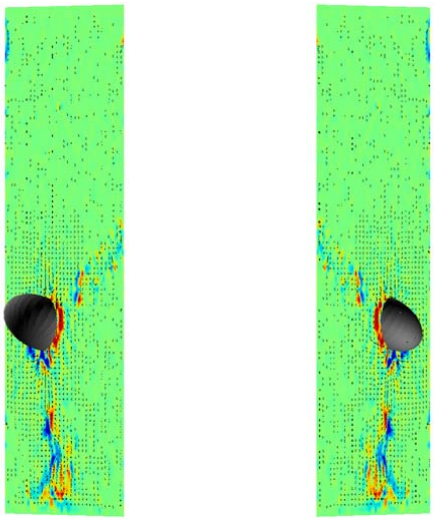


(a) t = 0 ms (b) t = 70 ms (c) t = 140 ms

Fig. 1 Typical example of motion of a bubble and flow around it. The equivalent diameter of the bubble is 9.4 mm. The velocity vectors are indicated by arrows. The color on the velocity field shows the vorticity. The visual axis is perpendicular to the velocity field.



Relation between the visual axis and the velocity field



(a) +20º (b) - 20º

Fig. 2 Inclined velocity field

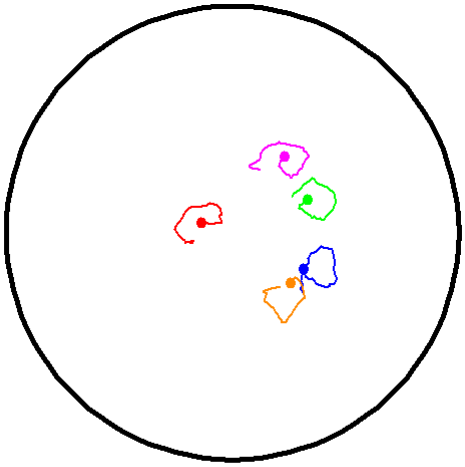


Fig. 3 Trajectories of bubbles projected on the cross-section. A dot is the starting point of bubble motion.