High-Speed Video Image Analysis of Air Flow around a Table Tennis Ball

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ABSTRACT

We tried to visualize the air flow around a flying table tennis ball and analyze the flow velocity field and vortex shedding using PIV. The images of the air flow were visualized by oil mist and a laser light sheet with a metal halide light and recoded by a CMOS type of high speed video camera at a rate of 1,000 to 10,000 fps. Our objective is to discuss from the viewpoint of fluid mechanics if a knuckle ball trajectory flickers with a zigzag motion of inward and outward curves, or not. The final goal of this study is to present scientific information about knuckle ball trajectory to table tennis players and coaches who are struggling to develop new tactics and skills.

Keywords: Visualization, Ball trajectory, Knuckle ball, Air flow, Vortex shedding

1. INTORDUCTION

The highest speed of the table tennis ball hit by the world-top player is around 40m/s (144Km/h). The highest spinning speed is around 150rps, and then the peripheral speed reaches around 19m/s. Very high spinning speed ball changes the curvature of the ball trajectory largely and causes a big change in the directions just before and after the bouncing on a table. Such changes in the trajectory makes many table tennis players feel difficult to return the spin ball.

The highest Reynolds number (Re= $Re=vd/\nu$: ball speed v =40m/s, ball diameter d=0/04m, kinetic viscosity of air $\nu=1.5\times10^{-05}m^2/s$) is estimated around 1.0×10^5, and then the air flow behind a flying ball is turbulent even in still air.

The completely no-rotating ball and/or very low spinning speed ball at a low flying speed is called “knuckle ball”. A part of players say that the trajectory of knuckle ball flickers with a zigzag motion of inward and outward curves, but other part say that it does not flicker. Here “flicker” means that the trajectory depicts first a curve to right (left) and then another curve to left (right) and moreover to right (left) repeatedly. Here we distinguish “flicker” from “ripple” due to the non-symmetry of ball shape like an elliptic ball. A part of players feel difficult to hit the flickering ball due to the unexpected change in trajectory and speed. Therefore some players use knuckle ball for the tactics in their match. To the contrary the other players do not feel difficult to hit knuckle ball because it flies at low speed without such unexpected changes. The two opinions are quite opposite.

In other sports, such as foot ball, volley ball and base ball, the flickering motion of knuckle ball can be observed [1,2,3]. The Reynolds number for foot ball and volley ball reaches a critical value of around $(3.8\sim4.0)\times10^5$, which is much higher than that for table tennis ball, and makes “flicker”. The issue of “flicker” is very interesting for researchers in the fields of fluid mechanics and sports science.

We have never found any papers which present visualized images of air flow and the velocity fields around a flying table tennis ball. In this study we try to visualize the air flow around a knuckle ball and analyze the velocity field. The objective of this paper is to discuss the trajectories of a knuckle ball focusing on “flicker” with the image analysis.

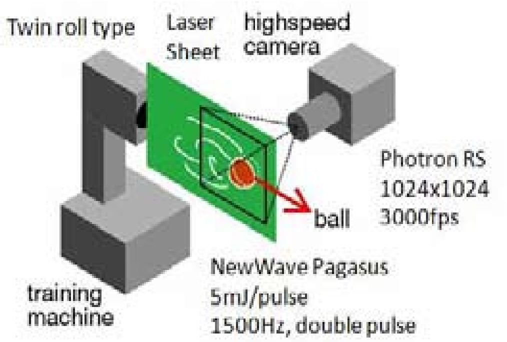

Fig.1 Experimental setup for visualizing air flow around a table tennis ball

2. EXPERIMENTAL METHOD

Fig.1 shows our experimental setup for visualizing air flow around a table tennis ball. Knuckle balls were supplied from a twin roll type of robot machine, which can control accurately both the flying speed and spinning speed with a remote controller. The camera window is fixed at the locations just before and after the ball bouncing on the table. The window size was 500mm in width.

The flying speed of the ball was around 16m/s (57Km/h), and then the Reynolds number was Re=0.43

$\times 10^5$. We put oil mist with the size of around 10μm in the air for the visualization. A laser light sheet of 2mm thickness (Yag, 200 to 300mW, green; or New Wave Pegasus, 5mJ/pulse, 1,500Hz, Double pulse) with/without two metal halide lights (250W, white) was used for the illumination. We employed a CMOS type of color high speed video camera (Photron SA1.1; or RA). The frame rate was 2,000 to 10,000fps, and the number of the pixels was 1024×1024. We took 10,000 frames of images consecutively for a trial of the test and transferred the images to a PC. We replayed the images on the PC and then necessary images were saved in a hard disc.

We could successfully capture clear images of the air flows and ball trajectories, and then applied the particle image velocimetry (PIV) to analyze the velocity fields of air flow around a flying ball with time interval of 1/000s. Our PIV algorithm was based on the brightness distribution cross-correlation technique between two consecutive images.

3. EXPERIMENTAL RESULT and DISCUSSION

Fig.2 shows a velocity map, although any post-processing procedures are not applied for removing erroneous vectors. We can recognize vortex shedding from the surface of the ball into the wake flow. This is a useful data to analyze the flow field by a computational fluid dynamics (CFD). Although we analyzed the frequency characteristics of the vortex shedding using a time-serial velocity maps, we have not obtained any sufficient results about it yet.

Fig.3 is constructed by overlapping a time-series images of a flying ball just before and after the ball bouncing on a table. We can see non-rotation of the knuckle ball before the bouncing change to top spin after the bouncing. The trajectory is very smooth and we cannot recognize any flicker from such a horizontal view. Fig.4 shows spin change from the back spin to the knuckle at the bouncing. Also the trajectory is smooth without flicker. It can be seen from Fig.5 that the longer trajectory is also a smooth parabolic curve.

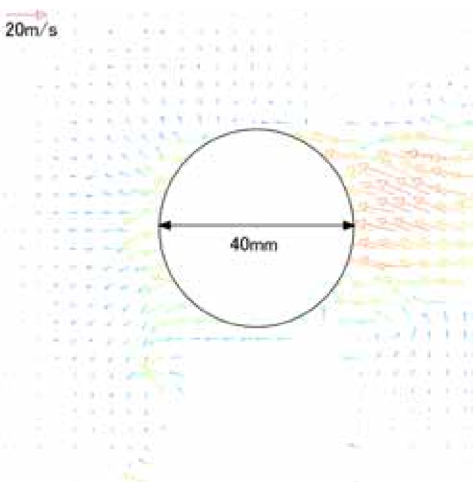

Fig.2 An example of velocity vector map of air flow around a table tennis ball.

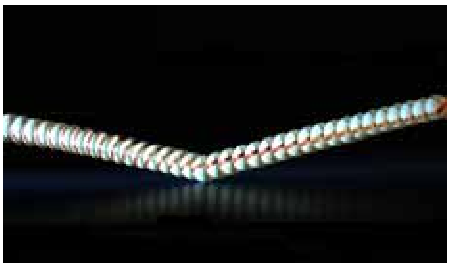

Fig. 3 Overlapped ball images show a spin change from knuckle to top spin at bouncing on the table. The ball flies from right to left.

Fig.4 Spin change from back spin to knuckle

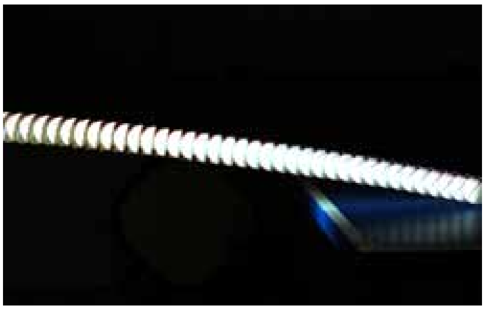

Fig. 5 Overlapped ball images show a parabolic trajectory

4. CONCLUSION

We could successfully visualize the air flow around a flying ball and could obtain the velocity field with vortex shedding using a PIV technique. As a result, we could discuss the changes in trajectory of a knuckle ball. We did not recognize any flicker at the present stage. In our future work, we will compute both values of friction coefficient and bouncing coefficient from such changes in velocities and angles at bouncing, and capture the images of ball trajectory from the vertical view to discuss the motion of “flicker”.

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