AERODYNAMIC EFFECTS OF A PANEL ORIENTATION IN VOLLEYBALL FLOAT SERVE

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The study aimed to clarify the aerodynamic and trajectory characteristics of four types of volleyballs using wind tunnel experiments and a hitting robot. The critical Reynolds number (Re_{cr}) changed depending on ball types and panel orientations. Re_{cr} for Mizuno ball (conventional) was ~2.8×10^5 (Drag coefficient; Cd = 0.16) on panel orientation A and ~2.0×10^5 (Cd = 0.20) on panel orientation B. Re_{cr} for Mikasa ball (Olympic Official) was ~2.9×10^5 (Cd = 0.16) in panel orientation A and ~3.3×10^5 (Cd = 0.15) in panel orientation B. The landing position of all volleyballs varied depending on ball type and panel orientation. The molten ball had a longer flight distance than other balls and its landing point was biased toward the left side. The Mikasa ball had a relatively short flight trajectory and its landing point was biased to the right. Therefore during a float serve, the flight trajectory will change depending on the type of volleyball and its orientation.

KEYWORDS: drag, flight, hitting robot, trajectory, volleyball, wind tunnel.

INTRODUCTION: Recently, volleyball-related research has determined that important factors contributing to a team's win include techniques and strategies such as block, attack, serve, and reception (Afonso et al., 2005; João et al., 2010; Palao et al., 2004, 2005; Quiroga et al., 2010), psychological support and weight adjustment (Valliant et al., 2012), and physical preparation (Golik et al., 2011; Trajkovic et al., 2012). In particular, a direct ace has been reported to be one of the important factors for predicting a win (Marelic et al., 2004; Silva et al., 2014; Zetou et al., 2007). Approximately 40% of aces are float serves (Stamm et al., 2016) and hence, float serves have become one of the most important techniques that can determine the outcome of a volleyball game. The trajectory characteristic of float serves is that the ball no- or slow-rotating in flight and tends to suddenly drop or irregular change the ball trajectory; this phenomenon is referred to as a knuckle effect (Mehta, 2009).

There have been significant changes in the form and design of the volleyball surface. Traditional volleyballs are created from a total of six panels with each panel formed using three rectangular panel sections for a total of 18 sections, and these volleyballs have been used in international competitions over a long period of time. However, at the 2008 Beijing Olympics, a new volleyball (MVA200; Mikasa) with 8-sheet dimples was introduced as the official ball. This new ball is used as the official ball in international competitions (e.g., FIVB World League, and Olympics). Furthermore, another new volleyball (V5M5000; Molten) with hexagonal protrusions on the ball surface was developed and used as the official ball in many league games, including the American League (USA Volleyball) and NCAA League.

However, there has been very little aerodynamic research conducted on these new volleyballs although the surface textures and panel shapes are very different compared with the traditional volleyballs. Therefore, in this study, we conducted experiments to understand the aerodynamics of the official balls of the 2016 CEV Volleyball Champion League (MVA200CEV; Mikasa) and 2016 USA Volleyball League (V5M5000; Molten). We investigated the aerodynamics and flight characteristics for two volleyball in comparison to conventional volleyballs constructed from 18 sheets (AV514RB; Adidas, 9OV80027; Mizuno). On the basis of the results of the wind tunnel experiment, the flight characteristics were calculated.

METHODS:

Wind tunnel tests

A circuit flow-type wind tunnel at the University of Tsukuba was used. The maximum wind speed was 55 m/s, blow out size was 1.5 m × 1.5 m, wind speed and turbulence distributions were within ±0.5% and less than 0.1%, respectively. Volleyballs were installed in the wind tunnel. In this experiment, the panel orientation of the volleyball was split into two (orientation A, B; Figure 1) and the aerodynamic characteristics in each orientation were measured. Panel orientation A had the logo at the center front and orientation B had the place wherein the seam intersects at the center front. The air force of each ball was measured in the range of wind speeds (*U*) from 7 to 35 m/s using a Sting-type 6-division detector (LMC-61256, Nissho Electric Works).

Figure 1. Volleyballs and the panel orientations used in this experiment: Adidas (a, b), Mizuno (c, d), Molten (e, f), and Mikasa (g, h).

Hitting robot tests

The flight characteristics of the volleyball were investigated based on their landing point after being hit. The hitting robot aimed at the center of a non-rotating ball at a set speed of 15 m/s with a target (1 m × 1 m) located on the floor 15 m away. The position at which the volleyball hit the floor was denoted as the landing point with its flight distance (H; horizontal distance) and sideways (L; lateral distance) recorded. Data analysis was performed using the landing point results from 30 throws for each ball (4 types) and panel orientation (2 types) for a total data set of 240 throws.

RESULTS: 1. Drag force of each volleyball

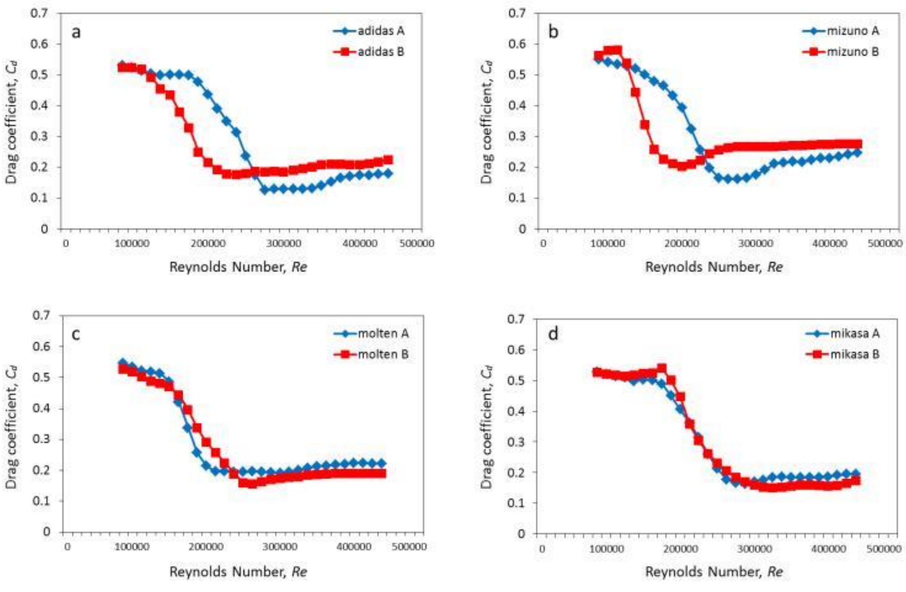

Figure 2. Change in Drag coefficient of modern volleyballs: Adidas A, B (a), Mizuno A, B (b), Molten A, B (c), Mikasa A, B (d).

Drag coefficients (*Cd*) with respect to Reynolds number (*Re*) were measured from wind tunnel experiments (Figure 2). The drag coefficient curves show that drag is dependent on ball type and panel orientation. The panel orientation of each volleyball was described by two positions and the drag coefficient of each was measured. Changes in the drag coefficient value of the Adidas and Mizuno volleyballs, which have been traditionally used in competition, were evident between the two panel orientations (Figure 2a and 2b); in contrast, Molten and Mikasa volleyballs had relatively small changes in drag due to panel orientation (Figure 2c and 2d). The critical Reynolds number (Re_{cr}) also differed depending on panel orientation. For the Adidas ball, Re_{cr} was ~2.8 × 10^5 (*Cd* = 0.12) in orientation A and 2.4 × 10^5 (*Cd* = 0.17) in orientation B. For the Mizuno volleyball, Re_{cr} was 2.8 × 10^5 (*Cd* = 0.16) in orientation A and ~2.0 × 10^5 (*Cd* = 0.20) in orientation B. The Mizuno ball had a higher *Cd* in the orientation B, whereas the Adidas ball had a relatively low *Cd* value in the orientation A when compared with other balls. For the Molten volleyball, Re_{cr} was ~3.0 × 10^5 (*Cd* = 0.19) in orientation A and ~2.7 × 10^5 (*Cd* = 0.15) in orientation B, and for the Mikasa ball was ~2.9 × 10^5 (*Cd* = 0.16) in orientation A and ~3.3 × 10^5 (*Cd* = 0.15).

2. Comparison of flight characteristics of each volleyball via landing point measurements.

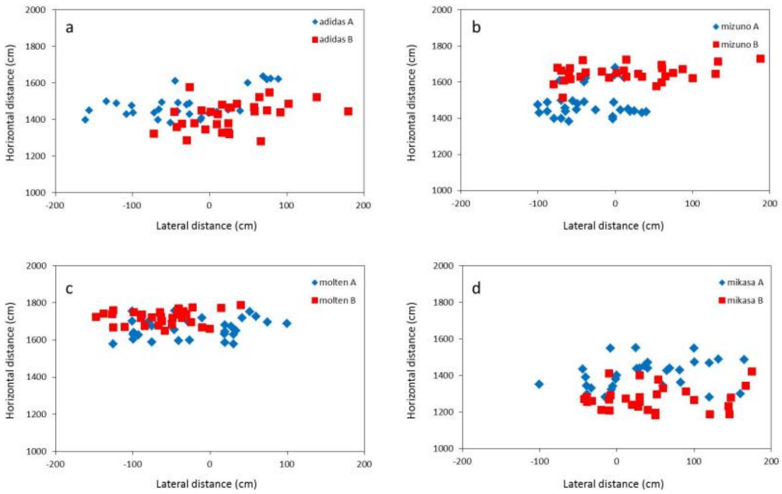

Figure 3. Comparison of landing points of each volleyballs using a hitting robot: Adidas A, B (a), Mizuno A, B (b), Molten A, B (c), Mikasa A, B (d). Blue and red data points are landing points related to orientation A and B, respectively.

We designed a hitting robot to imitate float serves that would be used in competition and designated the point at which the inflight ball hits the ground as the landing point. In this experiment, the hitting robot would generate a serve such that the ball's initial speed would be 15 m/s, with little or no rotation, and for statistical analysis, each volleyball and panel orientation were subjected to thirty hits. Based on our results, it was apparent that the landing point of all volleyballs significantly changed based on the change in panel types and their orientation (Figure 3). The flight trajectory (horizontal distance) of the Mizuno ball varied the most depending on panel orientation when compared with other balls (Figure 3b). In contrast, for the Molten ball, the horizontal distance was similar for both orientations (A and B) and was at a consistent value (Figure 3c). Furthermore, for the Adidas ball, the lateral distance of the landing points leaned toward the left (−31.9 ± 69.3) for orientation A, and the right (28.6 ± 56.0) for orientation B. For the Mizuno ball, the lateral distances leaned toward the left (−33.5 ± 42.3) for orientation A and the right (14.4 ± 71.7) for orientation B. In contrast, with respect to panel orientation, Molten and Mikasa balls had little lateral movement and tended to land on the same lateral side. However, the Molten ball had the longest flight distance with a tendency to land on the left side (A-orientation: −21.8 ± 54.7; B-orientation: −61.1 ± 45.7) compared with the Mikasa ball, which had the shortest flight distance with a tendency to land on the right side (A-orientation: 37.5 ± 66.4; B-orientation: 45.5 ± 64.4).

DISCUSSION: Four types of volleyballs used in various national leagues were tested to compare their aerodynamic and flight characteristics via a wind tunnel and hitting robot. Since Molten and Mikasa volleyballs have relatively small changes in drag force due to changes in panel orientation, a relatively stable flight distance can be estimated. There were small differences between the landing point results obtained using wind tunnel experiment and via the hitting robot. These small differences may be the result of turbulent fluid forces received by the volleyball and further research should be conducted to understand the irregular forces acting on the volleyball float serve. This would involve considering the vortex structures around the inflight volleyball and studying the turbulent fluid forces (knuckle effect) on the inflight volleyball. However, there are other factors such as the number of panels, panels of different shapes, and their depths and widths that can also be studied.

CONCLUSION: The success of a float serve is one of the important factors for determining a team's victory in modern day volleyball games; therefore, the effect a ball type and its panel orientation has on the flight trajectory of the ball is important. This study was an attempt to understand the aerodynamic characteristics of some commonly used volleyballs and then further applied to learn how to serve aces. The newly designed Mikasa volleyball, which is currently used in international competitions (e.g., Olympics), has a shorter flight distance compared with the Molten ball, which exhibited the longest flight distance, and traditional volleyballs and a relatively stable trajectory that does not change with panel orientation. In addition, the Molten and Mikasa balls exhibited consistent flight distances regardless of the panel orientation. In contrast, it was apparent for the Adidas and Mizuno balls that the variability in the medial position was extremely dependent on panel orientation.

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