# SPORTS FLUID DYNAMICS: AERODYNAMICS OF SPORTS BALLS

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Recently, newer soccer balls named Cafusa, Teamgeist 2, and Jabulani were respectively produced from 32, 14, and 8 panels with shapes and designs dramatically different from those of conventional balls. The newest type of ball, named Brazuca, was produced from six panels and will be used in the 2014 FIFA World Cup in Brazil. There have, however, been few studies on the aerodynamic properties of balls constructed from different numbers and shapes of panels. Hence, we used wind tunnel tests and a kick-robot to examine the relationship between the panel shape and orientation of modern soccer balls and their aerodynamic and flight characteristics. We observed a correlation between the wind tunnel test results and the actual ball trajectories, and also clarified how the panel characteristics affected the flight of the ball, which enabled prediction of the trajectory.

**KEY WORDS:** soccer, ball, aerodynamics, drag.

**DEMONSTRATION FOR AERODYNAMICS OF SOCCER BALLS:** Since the shapes and designs of these balls are specific for each sport, there has been very little change in the designs and shapes of ball surfaces between currently used balls and older ones. The shape and design of soccer balls have, however, changed dramatically in recent years. The panel shape and design of soccer balls, mainly the official balls used in the FIFA World Cup have substantially changed. The Teamgeist 2 ball, the official ball of the 2008 EURO Cup in Austria and Swiss, is comprised of 14 panels and is significantly different from a Conventional soccer ball with the typical 32 pentagonal and hexagonal panels. The 14-panel ball, as opposed to the Conventional 32 (pentagonal and hexagonal) panels, called Teamgeist 2 has attracted a lot of attention for its revolutionary shape. The subsequent 2010 World Cup in South Africa introduced the Jabulani (8-panel ball by Adidas), further modifying the panel shapes of the soccer ball. The 2013 FIFA Confederations Cup in Brazil adopted Cafusa (32-panel ball by Adidas) as the official ball, and this model is used by many professional soccer leagues and international matches. A Cafusa ball consists of 32 panels, the same number as a Conventional soccer ball. While the pentagonal and hexagonal panels are arranged in a simple manner in a Conventional ball, the panels on a Cafusa ball are significantly different in shape according to the panel orientation, which can be roughly classified into 2 categories with 8 panels. Furthermore, the Brazuca (6-panel ball by Adidas) is the official match ball of the 2014 FIFA World Cup which will be held in Brazil.

**Figure 1: Provide concise and clear description of the figure in the caption.**

This test takes place in a closed-circuit wind tunnel (by San Technologies Co., Ltd., Tochigi, Japan) at the University of Tsukuba (Figure 1). The maximum flow velocity of this wind tunnel is 55 m · $s^{-1}$, the blower outlet size 1.5 m × 1.5 m, the flow velocity distribution is within ± 0.5%, and the turbulence is 0.1% or less. The aerodynamic forces were measured at flow velocities ($U$) of 7–35 m · $s^{-1}$ to examine the aerodynamic forces when the panel orientation was changed by rotating the same panel. The panel orientations of respective soccer balls were specified as shown in Figure 2.

**Figure 2: Soccer balls using for the test and their panel orientations.**

**DRAG FORCE IN THS WIND TUNNEL TEST:** First of all, the drag applied to the balls varied substantially according to the ball type (Figure 3). The drag of Cafusa and Jabulani balls also varied greatly depending on their panel orientation. However, the drag variation by the panel orientation was relatively small in Brazuca, Teamgeist 2 and Conventional soccer balls. The drag crisis regime indicating a sudden drag change was lowest in the Brazuca, followed by the Conventional, Cafusa, Teamgeist 2, and Jabulani ball, which was the highest. In the case of the Cafusa ball, the $C_d$ value decreased from ~0.5 to ~0.2 or less at a Reynolds number $Re = 1.7 \times 10^5$ for panel orientation A, and at

$Re = 1.5 \times 10^5$ for panel orientations B (Figure 3b). Also, the critical Reynolds number of the Cafusa were ~$2.9 \times 10^5$ ($C_d \approx 0.14$) for panel orientation A, ~$2.4 \times 10^5$ ($C_d \approx 0.16$) for panel orientation B. The panel orientation B of the Jabulani ball in the critical Reynolds number was ~$3.6 \times 10^5$ ($C_d \approx 0.12$), which was less than ~$3.6 \times 10^5$ ($C_d \approx 0.16$) of panel orientation A, and less than the results of the other soccer balls (Figure 3c). The drag coefficient variation by the panel orientation was found to be small in the Brazuca, Teamgeist 2 and Conventional balls (Figures 3a, 3d and 3e). The critical Reynolds number of the Brazuca ball was recorded as ~$2.5 \times 10^5$ ($C_d \approx 0.15$) for panel orientation A and ~$2.2 \times 10^5$ ($C_d \approx 0.16$) for panel orientation B. The critical Reynolds number of the Teamgeist 2 ball was recorded as ~$3.0 \times 10^5$ ($C_d \approx 0.17$) for panel orientation A and ~$2.8 \times 10^5$ ($C_d \approx 0.15$) for panel orientation B. The critical Reynolds number of the Conventional ball was recorded as ~$2.5 \times 10^5$ ($C_d \approx 0.16$) for panel orientation A and ~$2.8 \times 10^5$ ($C_d \approx 0.17$) for panel orientation B. It was further revealed that the drag on the Jabulani ball varied substantially by panel orientation in the $Re = 3.0 \times 10^5$ to $Re = 5.0 \times 10^5$ regime, indicating that it was affected more by its panel orientation than the other balls were.

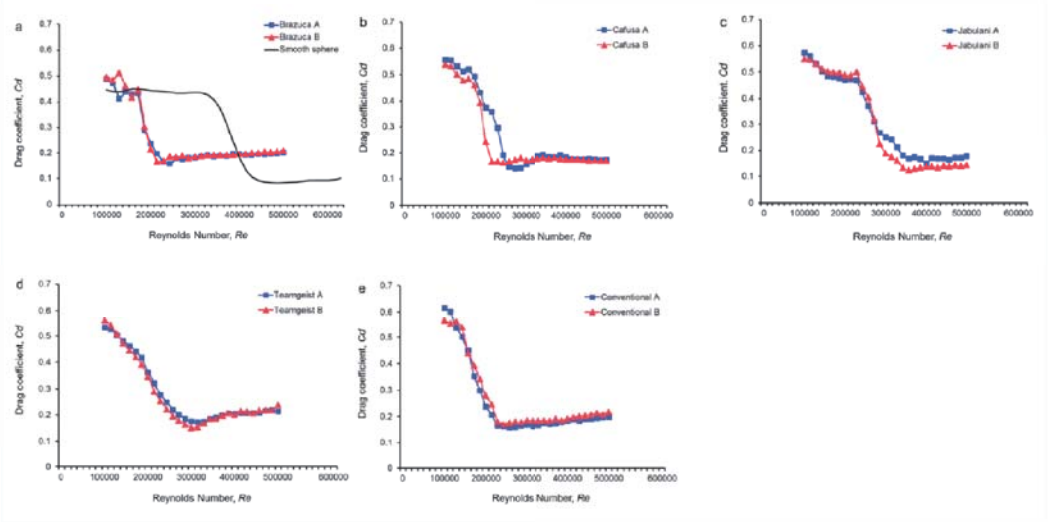

**Figure 3: Variation of the drag coefficient with the type of ball and panel orientation: (a) Brazuca, (b) Cafusa, (c) Jabulani, (d) Teamgeist 2, (e) conventional ball.**

**SIDE AND LIFT FORCES IN THE WIND TUNNEL TEST:** The scatter diagrams of the lift and side forces applied to the soccer balls when the panel orientation was changed (Figure 4). These indicate that the irregular fluctuations increase as the flow velocity increases from 20 m · s-1 to 30 m · s-1. The same trend was observed even when the ball panel orientation was changed. The change in irregular fluctuations from increased speed was smaller in the Teamgeist 2 ball than those in other balls (Figures 4g-1 and 4h-1), while panel orientation A of the Jabulani ball showed the greatest change (Figure 4f-1). The irregular fluctuation was more prominent for the Conventional ball when the flow velocity increased. The *SD* of the side and lift forces also increases with the flow velocity increased (Figures 4k and 4l). This trend was also observed even when the panel orientations were changed. The Jabulani ball showed a tendency that the *SD* of the forces was larger at the flow velocity of 20 m · s-1 than those of other balls, and the irregular fluctuations were observed at the intermediate velocity. The SD of the side force for panel orientation A of the Jabulani ball did not increase despite the increase in flow velocity. Furthermore, the *SD* of the side and lift forces for panel orientation B of the Jabulani ball decreased despite the increase in flow velocity, highlighting the difference from the other soccer balls.

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