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Wind-tunnel experiments and trajectory analyses for five nonspinning soccer balls

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Abstract

We report drag, side, and lift coefficients for two orientations of five non-spinning soccer balls (Brazuca, Cafusa, Jabulani, Teamgeist 2, and Vantaggio), measured using a wind tunnel. The air's speed range was 7 m/s to 35 m/s, covering most of the speeds of kicked soccer balls in real games. Trajectory analyses make use of our aerodynamic wind-tunnel data and show that the five balls we tested behave differently while in flight. We also show that in some cases, changing ball orientation leads to a significant change in flight trajectory. Turning off side and lift forces alter ranges and lateral deflections as fractions of ranges in excess of 10% for some balls. Because we have only two orientations for non-spinning balls, the work we present here is just the preliminary investigation of a much larger project in which we hope to have aerodynamic data for many more ball orientations.

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1. Introduction

We recently published work [1] on wind-tunnel measurements of drag coefficients for non-spinning Jabulani and Brazuca soccer balls, which were the balls used in the past two World Cups. With the help of trajectory analysis, our study showed that Brazuca is a much better ball than Jabulani. Each World Cup has a new soccer ball, so an understanding of ball aerodynamics helps players, researchers, and manufacturers learn what works on a given ball, and what does not work. Jabulani was made by Adidas and used in South Africa for the 2010 World Cup. The reduction from the 14 thermally-bonded panels of the Teamgeist ball used in the 2006 World Cup to the eight thermally-bonded panels of the Jabulani ball meant Adidas had to texture Jabulani's panels to provide enough surface roughness so that the ball would not behave too differently from previous balls. Jabulani ultimately met with controversy because of poor performance [2,3]. Brazuca performed better in Brazil in 2014, partly explained in our aforementioned work [1].

More of our recent work [4,5] has been dedicated to understanding surface effects, including seam length, on aerodynamics for a variety of soccer balls. Though we published a few numerically-determined trajectories in two dimensions in that recent work, we did not evaluate full three-dimensional trajectories determined by drag, side, and

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lift forces. We follow up on our previous work with a much more substantial effort here, highlighted by complete trajectory analyses of five different soccer balls, each in two different orientations, using aerodynamic coefficients determined in our wind tunnel. Our trajectory analyses are presented over a full range of launch speeds, 15 m/s to 35 m/s. We show here that altering the orientation of a non-spinning ball can significantly influence the ball's trajectory.

Four of the balls we studied are made by Adidas: Brazuca (six panels with small dimples), Cafusa (32 panels with small drip texture), Jabulani (eight panels with small ridges), and Teamgeist 2 (14 panels with small bumps). We also tested a ball made by Molten: Vantaggio (32 panels with smooth texture). All balls have the same diameter, $D = 0.22\,\mathrm{m}$, but their masses are different: Brazuca with $m = 0.432\,\mathrm{kg}$, Cafusa with $m = 0.437\,\mathrm{kg}$, Jabulani with $m = 0.438\,\mathrm{kg}$, Teamgeist 2 with $m = 0.431\,\mathrm{kg}$, and Vantaggio with $m = 0.442\,\mathrm{kg}$.

Aerodynamics of soccer balls have been researched extensively over the past couple of decades. Numerous references to work done up through 2012 may be found in a recent review article [6] on sport aerodynamics. More work has been published by other research groups [7–10] since that review article was published.

2. Experimental Technique

Experiments were performed in a closed-circuit wind tunnel (manufactured by San Technologies Co, Ltd, Tochigi, Japan) at the University of Tsukuba. Maximum flow speed of this wind tunnel is 55 m/s. The blower outlet is 1.5 m × 1.5 m; flow speed distribution is within ±0.5%; and turbulence is 0.1% or less. All soccer balls tested had a diameter of 0.22 m, meaning the blockage was roughly 1.7%. We used a traditional rear-mounted technique [11], by which a soccer ball is mounted to a horizontal stainless steel rod, and horizontal air blows over the ball from the opposite direction. Figure 1 shows a Brazuca soccer ball mounted to the rod prior to testing.

We performed wind-tunnel measurements on two orientations for each ball. Of the infinite number of possible ways to orient a ball in a wind tunnel, we selected what we consider to be two considerably different orientations. By that we mean two orientations that present frontal geometries to the oncoming air with significantly different panel and seam orientations on the front and sides. Though our choices are completely subjective, we feel that we have chosen two orientations for each ball that will aid understanding in non-spin aerodynamics. Figure 2 shows photos of the various ball orientations. The orientations for each ball are labeled by A and B. Those designations are merely to distinguish ball orientations and do not represent anything similar among the five balls. Orientation A for Brazuca, for example, has nothing to do with orientation A for Jabulani.

Aerodynamic forces were measured at flow speeds in the range $7\,\mathrm{m/s} \leq v \leq 35\,\mathrm{m/s}$, which corresponds to a Reynolds number range of approximately $10^5 < \mathrm{Re} < 5 \times 10^5$, where $\mathrm{Re} = vD/\boldsymbol{\nu}$ [12], with D the ball's diameter, and $\boldsymbol{\nu} = 1.54 \times 10^{-5}\,\mathrm{m^2/s}$, the kinematic viscosity. Air forces acting on a mounted ball were measured during a 9-s time interval by a sting-type six-component force detector (model number LMC-61256 by Nissho Electric Works Co, Ltd). Data recording was done on a personal computer with an A/D converter board that has a 1000-Hz sampling rate.

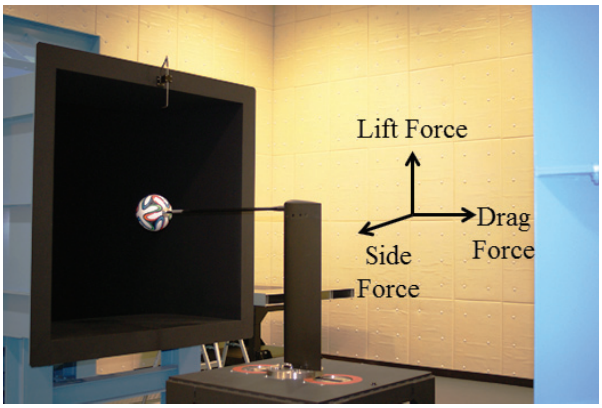

Fig. 1. Adidas Brazuca soccer ball mounted on stainless steel rod prior to wind-tunnel experiment. Axes associated with the various force directions are also shown.