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Aerodynamic Drag of Contemporary Soccer Balls

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Abstract

The advancement of technology, demand for performance and market competition force the sports ball manufacturers to introduce new designs. As a result, spherical soccer ball made of 32 leather panels (stitched) in 1970s have become as low as 6 panels (thermally bonded) ball today. Despite being most popular game in the world, scant data is available on aerodynamic properties of recently introduced Adidas made FIFA approved soccer balls such as Brazuca (used in World Cup 2014 in Brazil) and its comparative aerodynamic behaviour with other FIFA approved Adidas made balls since 2002. Therefore, the primary objectives of this study are to determine the aerodynamic behaviour of these balls and undertake a comparative analysis. The aerodynamic properties such as forces and moments were measured experimentally for a range of wind speeds in the wind tunnel.

Introduction

One of the centre pieces of the FIFA World Cup is the spherical ball which has undergone significant changes since its inception. The growing popularity and financial strength of the game have driven a number of technological changes to the ball, with each FIFA World Cup becoming a launching pad for a new ball.

Prior to 2006, the football was made of 32 panels (20 panels-hexagonal and 12 panels-pentagonal) using leather. Under an appropriate pressure, the external shape of the ball ressembles closely a sphere. Adidas introduced a 32 panels Fevernova ball at the FIFA 2002 World Cup held jointly in Japan and Korea, which represented a significant shift from the traditional leather made panels to synthetic panels. Following this change, a more radical design change took place in 2006, when Adidas introduced the 14-panels Teamgeist ball (6 panels-screw types and 8 panels-turbines). Initially, the external surface of the Teamgeist II series ball was smooth, whereby later tiny orderly pimples were introduced to the surface of the Teamgiest III series ball to improve the grip. The synthetic panels are bonded and not stitched as done in previous balls. Adidas introduced an 8-panels 'Jabulani' ball at the 2010 FIFA World Cup in South Africa. The Jabulani's 8 panels are thermally bonded. The outer surface of the panels has grooves. The orientation and pattern of the grooves are not symmetrical. More recently, the 6 panels (turbine type) Brazuca (meaning "Brazilian Way of Life") ball has been introduced by Adidas at the 2014 FIFA World Cup in Brazil (see Figure 2). Some characteristic physical features of the balls used at FIFA World Cups from 2002-2014 are shown in Table 1.

Ball Name	Seam No.	Year	Surface Finish	Seam gap (mm)	Seam depth (mm)	Seam Length (mm)	Mass (gram)
Fevernova	32	2002	smooth	2.2	0.8	4050	435
Teamgeist II	14	2006	smooth	1.5	0.6	3450	442
Teamgeist III	14	2008	micro pimple (orderly)	1.2	0.5	3450	444
Jabulani	8	2010	grooves (circular & triangular)	1.5	0.4	2030	440

Table 1. Physical properties of 4 balls used.

Although the aerodynamic behaviour of other sports balls have been studied by Alam et al. [1], Mehta et al. [2] and Smits and Ogg [3], little information is available about the aerodynamic behaviour of recently introduced soccer balls except the experiential studies by Alam et al. [1, 4] and Asai and Kamemoto [5]. Studies by Goff and Carre [6] and Barber et al. [7] provided some insights about the effect of surface structure of 32 panels balls however, no such data is available for new generation soccer balls introduced in 2014 and 2013. Therefore, the primary objective of this work is to experimentally study the aerodynamic properties of four soccer balls made of 32, 14, 8 and 6 synthetic panels.

Methodology

Description of Soccer Balls

A total of 4 balls including recently used FIFA World Cup 2014 Brazuca ball were selected for this study. These balls are: (a) 32 panels Adidas Fevernova (2002), (b) 14 panels Adidas Teamgeist II (2006), (c) 8 panels Adidas jabulani (2010), and (d) 6 panels Adidas Brazuca (2014). All balls are thermally bonded except the Fevernova ball. Its panels are stitched together. The physical panel shape of FIFA 2014 Word Cup "Brazuca" ball is shown in Figure 1. All balls including Adidas Tango with 32 non pentagon and hexagon panels and wind tunnel experimental setup are illustrated in Figure 2.

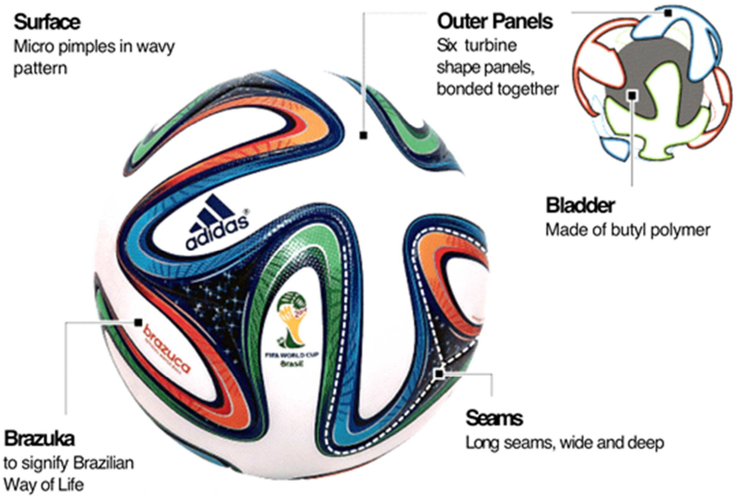


Figure 1. Design features of the Brazuca ball (adapted from the Globe and Mail, Canada).

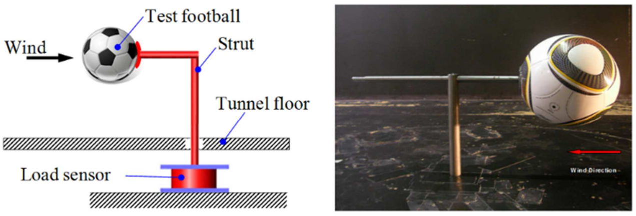
a) Experimental set up of Brazuca ball in RMIT Industrial Wind Tunnel

b) Adidas balls since 2002

Figure 2. Adidas made soccer balls with various panel and surface configurations since 2002.

Experimental Setup

The experimental study was undertaken using RMIT Industrial Wind Tunnel. The tunnel is a closed return circuit wind tunnel with a maximum speed of approximately 150 km/h. The rectangular test section's dimension is 3 m (wide), 2 m (high) and 9 m (long), and it is equipped with a turntable to yaw the model. Each ball was mounted on a six component force sensor (type JR-3) as shown in Figure 3, and purpose made computer software was used to digitize and record all 3 forces (drag, side and lift forces) and 3 moments (yaw, pitch and roll moments) simultaneously. More details about the tunnel and its flow conditions can be found in Alam et al. [8]. A strut support was developed to hold the ball on a force sensor in the wind tunnel, and the schematic of experimental setup with a strut support is shown in Figure 3. The aerodynamic effect of the strut support was subtracted from the mount with the ball. The distance between the bottom edge of the ball and the tunnel floor was 300 mm, which is well above the tunnel boundary layer and considered to be out of significant ground effect.



a) Schematic of experimental st up

b) Experimental set up with Jabulani ball

Figure 3. Experimental setup in RMIT Industrial Wind Tunnel (Alam et al. 2014).

The aerodynamic drag coefficient (C_D) and Reynolds number (Re) are defined as:

$$C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A} \tag{1}$$

$$\mathrm{Re} = \frac{\rho V d}{\mu} \tag{2}$$

Results and Discussion

Each of 4 balls as well as a smooth sphere was tested at 20 km/h to 120 km/h with an increment of 10 km/h. The aerodynamic drag was converted to non-dimensional drag coefficient, C_D as defined in equation 1. The wind speed was converted to non-dimensional parameter Reynolds number (Re) using equation 2. The smooth sphere was made of stainless steel. The influence of the support on the ball was checked and found to be negligible. The repeatability of the measured forces was within ±0.01 N and the wind velocity was less than 0.027 m/s (e.g. 0.1 km/h). The C_D variations with Reynolds numbers for all balls and the smooth sphere are shown in Figure 4. The flow transition for the sphere was noted at approximately Re = 1.00×10^5 which agreed well with the published data by Achenbach [9]. The airflow reached supercritical Reynolds number at approximately 3.50×10^5.

The Adidas Fevernova begins transition shortly before at Re = 1.00×10^5 and becomes fully turbulent at 2.00×10^5. The drag coefficient at the beginning of the transition is about 0.44 while in the turbulent region it is initially 0.23 before rising to 0.25. Transition occurs between 6.7 and 13.5 m/s (24.1 - 48.6 km/h).

The critical Reynolds number for Adidas Teamgeist II occurs at about 1.37 × 10^5 at a drag coefficient of 0.5. The flow is observed to be fully turbulent at 3.52 × 10^5 and the drag coefficient is around 0.22. The Teamgeist III ball which was introduced by Adidas in late 2008 undergoes flow transition between Re = 1.04 × 105 and Re = 3.5 × 10^5. The flow transition for Teamgeist III occurs much due to its relatively rough surface compared to Teamgeist II. For Jabulani ball, the critical Reynolds number occurs at Re = 1.37 × 10^5 and the flow is fully turbulent at 3.91 × 10^5. The drag coefficient at the beginning of transition is 0.44 and is 0.23 at the completion of transition. The drag coefficient in the turbulent regions continues to increase to a value of about 0.25 at about Re = 8.00 × 10^5. Transition occurs between 9.5 and 14 m/s (33-50.4 km/h). The transition for Brazuca ball occurs shortly before Re = 9.00 × 10^4 and the flow becomes fully turbulent at Re = 2.00 × 10^5. The drag coefficient at the beginning of transition was observed at 0.43. The minimum C_D value (0.11) was achieved at Re = 2.00 × 10^5 (supercritical region) and thereafter the value increases gradually in transcritical region. The pattern of C_D value for Brazuca ball resembles to that of 32 panels Fevernova ball. The critical speed range for Brazuca ball is from 25 km/h to 50 km/h. This ball possesses minimal aerodynamic drag at speed of 50 km/h.

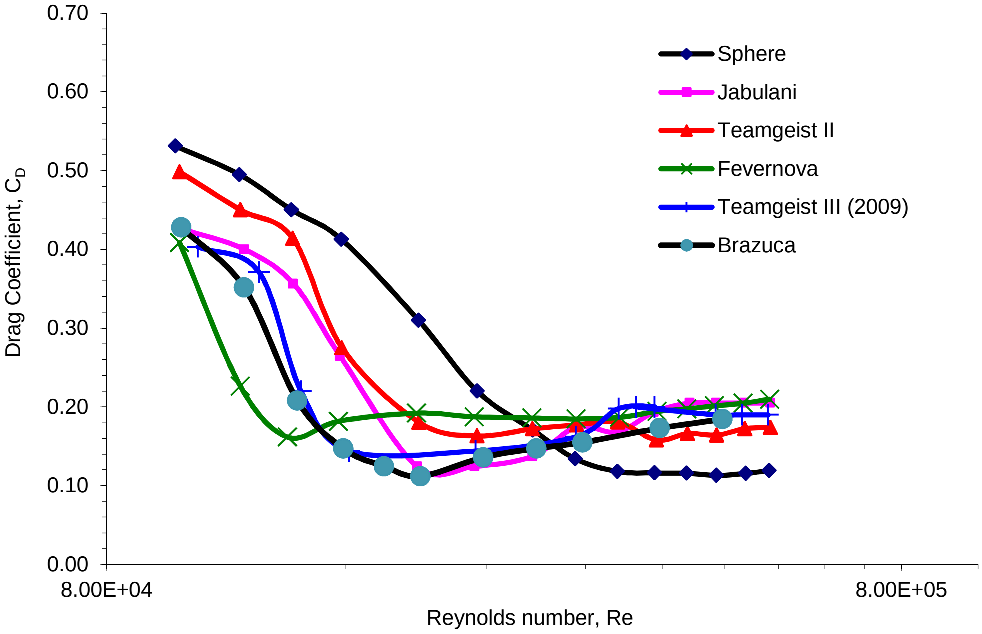


Figure 4. Drag coefficient (C_D) variation with Reynolds number (Re) for all ten balls and a smooth sphere.

Effects of Altitudes

The average altitude of four cities out of 12 cities hosting the FIFA 2014 World Cup games in Brazil is around 1000 meters above sea level. At high altitude, the air pressure and air temperature are lower, and so is the air density affecting the drag (resistance) and lift of the ball. The ball will travel faster at high altitude compared to sea level or at low altitude stadiums, thus causing the ball to travel faster. The effect of altitude study indicates that high altitudes will have significant effect on the ball's aerodynamic drag and in-flight speed. For example, at 90 km/h ball speed in calm wind condition at high altitude stadiums at Brasilia (~1.2 km high) in Brazil, the Barzuka's air resistance can be around 10% less compared to the sea level stadium in cities like Rio de Janeiro, Porto Alegre and Salvador. As a result, the ball can travel at 5% higher speed on average in high altitude cities (Brasilia, Curitiba, Belo Horizonte and Sao Paulo). Therefore, the player can overshoot the ball during long pass, free kick or long shot to the goal post if approached in the same manner.

Concluding Remarks

Among other balls, the Teamgeist II maintains a lower drag coefficient than all other Adidas balls at high speed (high Re) as it possesses less surface disturbances. The Fevernova experienced a much lower drag coefficient at transition and throughout the early stages of turbulent flow. However, the Brazuca ball possesses the C_D value at transcritical zone compared to all other balls. The Teamgeist III displays similar behavior between critical and super critical zone as Brazuca ball. The variation of drag coefficient between the two sides of the 8 panel Jabulani ball is around 9% whereas the 6 panels Brazuca ball has only 2% to 3% which is very close to the Fevernova ball and lower than the Teamgeist III ball. This means that the Brazuca ball will have a more predictable flight in calm air than its predecessors, the Jabulani and Teamgeist III balls.

It may be noted that the Brazuca ball has micro rectangular pimples produced in a wavy pattern on its surface along with wide and deep seams between the panels. The length of seam is almost 40% larger than the length of 8 panels ball 'Jabulani'. As the airflow passes over the ball, the wide seams generate turbulent airflow creating an early flow transition from laminar to turbulent flow similar to a 32-panel ball thus generating less aerodynamic drag (resistance) at low speeds compared to the Jabulani and Teamgeist balls.

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