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A study of aerodynamic drag of contemporary footballs

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Abstract

Most modern footballs possess varied surface characteristics which can affect the flight trajectory of the football. Although the aerodynamic behavior of other sports balls have been studied well, little information is available about the aerodynamic behavior of newly introduced footballs with varied seam configurations and number of panels. Therefore, the primary objective of this study is to understand the surface characteristics mainly the seam depth and seam height and their effects on aerodynamic of a range of new generation balls. Four new generation footballs: Kapanya, Cafusa, Tango and Brazuca were selected for this study. Seam length and depth of seam for each ball were measured using 3D scanning technology and also manual measurement. Additionally, the aerodynamic drag forces were measured using wind tunnel over a range of wind speeds for two positions of each ball. It was found that the seam length and depth of seam have influence on the aerodynamic drag of these modern footballs. Results also indicate that the sideway variation of aerodynamic drag is minimal for the Brazuca ball. As a result, this ball may have better stability in flight. The lowest aerodynamic drag was found for the Cafusa ball at high speeds which indicates that this ball is suitable for long distance pass. However, it has highest sideway drag variation that may cause instability in flight.

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Keywords: Football; aerodynamics; wind tunnel; drag coefficient; seam length; depth of seam.

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1. Introduction

The flight trajectory of the ball depends on its aerodynamic characteristics. Depending on the aerodynamic behavior of a ball, it can deviate from its anticipated flight path and as a result the flight trajectory becomes unpredictable. Lateral deflection in flight, commonly known as swing or knuckle, is well recognized in cricket, baseball, golf, tennis, and volleyball. However, there is still lack of knowledge in understanding the effect of surface characteristics of football on its aerodynamics behavior. The understanding of aerodynamic behavior of a football is important not only for players and coaches/trainers but also for the regulatory bodies, manufacturers and even the spectators. Over the years, the design of the ball has undergone a series of technological changes to make the ball more spherical by utilizing new surface design and manufacturing processes, Alam *et al.* [1, 4].

Adidas, the official supplier of footballs to FIFA, has applied thermal bonding replacing traditional stitching to make the seamless surface design by using 6 curved panels instead of 32 panels in its 2014 FIFA World Cup ball in Brazil. The surface structure (texture, grooves, ridges, seams, etc.) of the ball has also been altered in the process. Although the aerodynamic behavior of other sports balls have been studied well by Mehta *et al.* [2] and Smits and Ogg [3], little information is available about the aerodynamic behavior of new footballs except few studies by Alam *et al.* [1, 4], Asai and Kamemoto [5]. Studies by Goff and Carre [6] and Barber *et al.* [7] provided some insights about the effects of the surface structure of 32 panel balls. No such data is available for new generation footballs. Hence, the primary aim of this study is to measure aerodynamic drag of

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recently introduced Adidas made FIFA approved balls and understand the impact of their surface characteristics on aerodynamic parameters such as drag.

Nomenclature

A	projected frontal area (m^2)
C_D	drag coefficient (dimensionless)
D	aerodynamic drag force (N)
Re	Reynolds number (dimensionless)
V	wind speed (m/s)
μ	dynamic viscosity of air (Pa.s)
ρ	air density (kg/m^3)

2. Methodology

2.1. Physical Features of Selected Balls

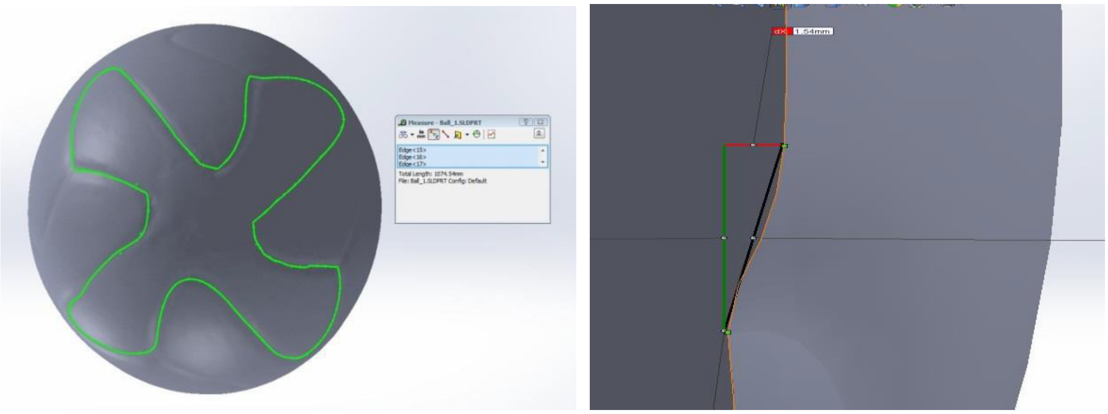
Four footballs (Cafusa, Brazuca, Tango and Kopanya) - all manufactured by the leading sports equipment manufacturer Adidas were chosen for this study. The physical parameters of these balls are measured. These parameters are shown in Table 1.

Table 1. Physical parameters of different balls

Ball name	Ball Picture	Seam Length (mm)	Seam Depth (mm)	Number of Panels	Events
Brazuca		3,220	1.54	6	FIFA World Cup 2014 (Brazil)
Cafusa		3,600	1.52	32	Confederation Cup 2013 (Brazil)
Tango 12		3,530	1.22	32	UEFA Cup 2012 (Europe)
Kopanya		3,450	0.52	14	Confederation Cup 2009 (South Africa)

In order to determine each ball’s seam length and seam depth, two different methods (manual and numerical) were used. In numerical method, a 3D laser scanner was used to obtain the dimensions of all balls including the total seam length and seam depth. GeoMagic software was used to refine the mesh surface and SolidWorks was used to measure the depth and seam length of each ball. A print screen of the measurement process using software is shown in Fig. 1.

In the manual method, a rope was used to measure the seam length. Plasticine was used to determine the seam depth for all the balls. The dried unplugged plasticine was put to a shadow machine to find out the seam height (or depth). The largest seam length was found to be 3600 mm for the Cafusa ball and the smallest was 3220 mm for the Brazuca ball. The highest observed seam depth was 1.54 mm for the Brazuca ball and the minimum depth was 0.52 mm for the Kopanya ball. The inflated air pressure (0.8 bar = 11.6 psi) was maintained for all the balls during investigation.



Edge<15>
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Total Length: 1074.54mm
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Fig. 1. A screen shot of SolidWorks for seam length measurement

Table 2. Measurements of seam length

Football	Seam Length (mm)		Difference (%)
	Numerical Method	Manual Method	
Tango 12	3,530	3,550	0.56
Cafusa	3,600	3,580	-0.56
Kopanya	3,450	3,470	0.58
Brazuca	3,220	3,270	1.53
Average	3,450	3,468	

As shown in Table 2, a significant variation between numerical and manual method in the measurement of seam lengths was found. The minimal difference for the seam length was noted for the Tango 12 ball and the largest difference was found for the Brazuca ball. In regard to the seam depths, the largest difference was found for the Kopanya ball. In contrast, the smallest difference was noted for Tango 12 ball as shown in Table 3.

Table 3. Measurements of seam depth

Football	Seam Depth (mm)		Difference (%)
	Numerical Method	Manual Method	
Tango 12	1.22	1.15	6
Cafusa	1.52	1.25	22
Kopanya	0.52	0.40	30
Brazuca	1.54	1.35	14
Average	1.20	1.04	

2.2. Aerodynamic Measurements

To measure the aerodynamic drag acting on the ball, a mounting system was developed. It is made of a steel sting to hold the test ball on the force sensor in the wind tunnel test section. A closed return circuit wind tunnel with an octagonal 1 m^2 test section was selected for this study. The maximum wind speed of the tunnel is approximately 150 km/h. An aerodynamic fairing was used to minimise the effect of any aerodynamic force acting on the mounting system. A multi-axis force sensor (JR3) along with a purpose made data acquisition software was used to digitise and record the drag force data. The sample length of each set of data was 30 seconds with a sampling rate of 20 Hz to minimise the electrical interference and data fluctuation errors. Multiple data sets were collected at each speed (tested) and the results were averaged for minimising the errors further. Fig. 2 shows the schematic of the experimental setup used the wind tunnel. Two panel orientations (side 1 and side 2) of each ball were investigated at the same wind speed to quantify any variation due to any asymmetry existed as shown in Fig. 3 for the Kopanya ball.

Drag forces were measured for each ball including a smooth sphere using the wind tunnel under a range of wind speeds from 20 to 120 km/h with an increment of 10 km/h. The repeatability of the measured forces was within ±0.01 N and the wind velocity was less than ±0.5 km/h. In this paper, only drag force is presented. The measured aerodynamic drag force (D) on the football was converted to dimensionless parameter: drag coefficient (C_D) and Reynolds number (Re) defined as:

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

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

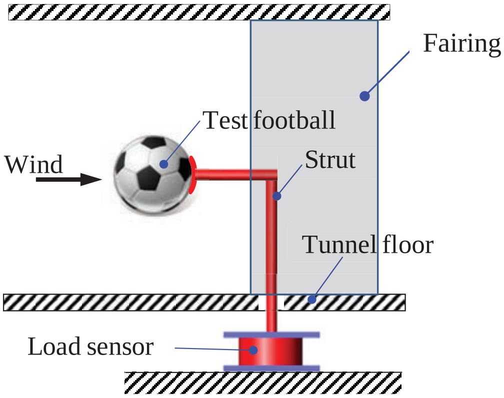

Fig. 2. Schematic of the experimental setup


Side-1

Side-2

Fig. 3. Two panel orientations: side 1 and side 2 (front view)

3. Results and Discussion

The C_D variations of two sides for all balls as a function of wind speeds and selected speed range are shown in Tables 3 and 4. As shown in the tables, the Brazuca has the smallest difference of C_D (5%) at low speeds (below 40 km/h). However, the difference increases to around 13% between 80 to 90 km/h speeds. At speeds over 90 km/h, the variation of C_D reduces significantly to around 2.3% which agreed well with the published data by Alam et al. [8]. The average C_D variation of two sides over the entire speed range (20–120 km/h) is around 5%, the lowest difference among all the balls tested. The Cafusa ball has the longest seam length and large seam depth. The average C_D variation of two sides of this ball is the highest (around 13%). It has also relatively higher differences in 40–70 km/h, 80–90 km/h and 100–120 km/h speed ranges as shown in Table 4. At high speeds (100–120 km/h speed range), the Cafusa ball has highest difference (around 8%). Hence this ball can have unstable flight path than the other three balls. Kopanya also has huge differences of C_D value between two panel orientations. However, the value is lower than the Cafusa ball. The average difference of C_D values for this ball is approximately 9% for all speeds tested. The minimal variation was noted at high speeds (around 5%). The variation of C_D values for Tango 12 ball is lower than the Cafusa ball but higher than the other two balls (Brazuca and Kapanya). The average variation is around 6%, which is the second lowest value noted. However, at high speeds, it has the second highest variation of C_D value (6%) compared to all other balls used in this study.

Table 3. Variation of drag coefficient (C_D) of two sides over entire speed ranges tested in percentage

Speed (km/h)	Kapanya (%)	Cafusa (%)	Tango (%)	Brazuca (%)
20	13	10	-8	5
25	10	11	-4	1
30	10	10	-10	5
35	9	14	11	6
40	8	12	14	5
45	7	11	9	4
50	10	12	11	5
60	10	15	5	10
70	11	19	16	12
80	12	20	13	7
90	10	16	7	5
100	7	13	6	3
110	4	7	6	2
120	3	5	5	2
Average	9	13	6	5

Table 4. Drag coefficient variation between two sides in percentage

Speed Range (km/h)	Kapanya (%)	Cafusa (%)	Tango (%)	Brazuca (%)
40–70	9	14	11	7
80–90	11	18	10	6
100–120	5	8	6	2

The comparative study indicates that Brazuca and Kapanya have the minimal differences in drag coefficient (C_D) with different panel orientations at high speeds. The average difference is 5% for the Brazuca ball, 6% for the Tango 12 ball, 9% for the Kopanya ball and 13% for the Cafusa ball. Cafusa has rougher surface than Tango 12, causing the drag coefficient variation that can affect the ball’s flight trajectory and stability in flight. In contrast, the Brazuca ball has the lowest variation which indicates that this ball will have more stable flight compared to all other balls used in this study.

The average C_D values of two sides for all the balls and a smooth sphere as a function of Reynolds number (varied by wind speeds) are shown in Fig. 4. There is a huge variation in C_D values among four balls and the smooth sphere. As shown in Fig. 4, the drag coefficient of the smooth sphere is dropping significantly from Reynolds number of 1.0×10^5 to 2.0×10^5 where it reduces to 0.1 from 0.4. This reduction is due to the flow regime change i.e., the flow transition from laminar flow to turbulent flow.

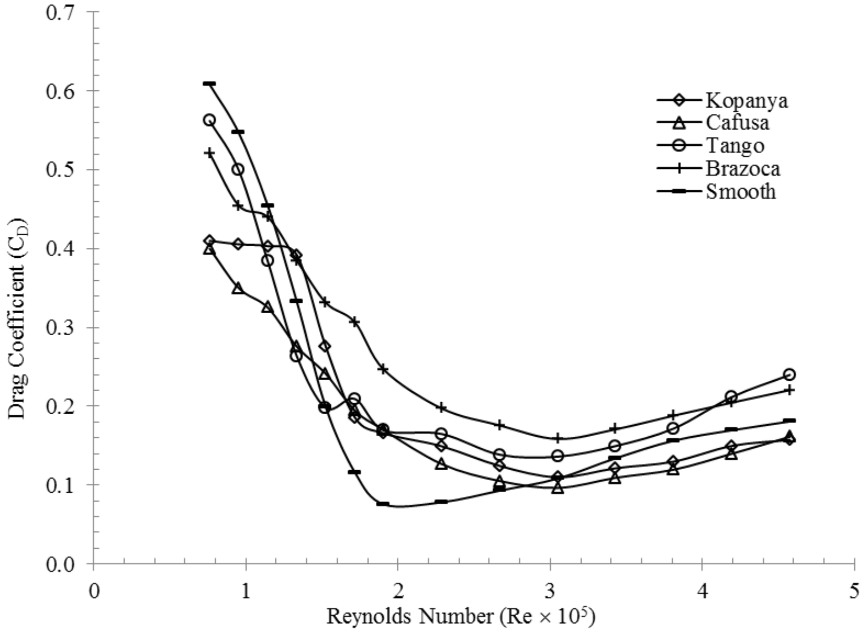

Fig. 4. Variations of drag coefficient with Reynolds number

The Cafusa ball has the lowest C_D value (0.40) at low Reynolds number. It achieves the lowest value at super critical Reynolds number of 2.86×10^5. Thereafter, the C_D value slightly increases (at trans-critical Reynolds number) till the maximum Reynolds number having roughly C_D value of 0.15. This means that the Cafusa ball is suited well for a long distance kick. In contrast, the Brazuca and Tango 12 balls have C_D values close to each other which are 0.48 at Reynolds number (4.6×10^5). The Tango 12 tends to have slightly lower C_D value and fluctuates more often. However, the Brazuca ball tends to have smoother decrease in C_D value without any noticeable fluctuation. Both the Tango and Brazuca balls have the highest drag at the highest Reynolds numbers (trans-critical Reynolds number). The Kopanya ball begins with a higher C_D value (~0.59); however, as the Reynolds number increases the drag coefficient decreases rapidly from 0.59 to 0.15.

4. Concluding Remarks

Seam depth and seam length affect the aerodynamic parameters specially the aerodynamic drag. With a larger seam length and depth, the flow behavior around a soccer ball become more complex as the larger seam and depth increases the surface roughness which creates asymmetric airflow around the ball. The sideway variation of aerodynamic drag is minimal for the Brazuca ball which indicates that this ball will have better stability in flight. The lowest aerodynamic drag was found for the Cafusa ball at high speeds which indicates that this ball is suitable for long distance pass. It also experiences a lower drag coefficient at trans-critical region of the flow. However, the Cafusa ball has highest sideway drag variation that may cause instability in flight.

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