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AERODYNAMICS OF FOOTBALLS

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ABSTRACT

Ball sports are becoming faster and more demanding than ever before, pushing traditional ball designs to their limits. In order to meet the increasing performance requirements, the ball manufacturers are producing new designs that can display better aerodynamic performance, geometric symmetry and balance. Since the inception of football game-the most popular and widely played game in the world, the centre piece of the game- the spherical ball which has gone through significant structural changes over the decades. A traditional spherical ball made of 32 leather panels stitched together in 1970s has now become only 14 synthetic curved panels thermally bonded (without stitches). Currently Adidas, the official supplier and manufacturer of footballs to FIFA is believed to be more spherical and it performs more uniformly regardless of where it is hit. Therefore, the primary objectives of this study were to evaluate aerodynamic performances of a current Adidas 14 curved panel football ball and a traditional Nike made 32 leather panels football ball. The aerodynamic forces and moments were measured experimentally for a range of wind speeds (20 km/h to 130 km/h) and the non-dimensional drag coefficient was determined and compared

Keywords: Aerodynamics, Football, Wind Tunnel, Drag Coefficient.

1. INTRODUCTION

Aerodynamics plays a prominent role in defining the flight trajectory of all high speed ball sports. Depending on aerodynamic behaviour, the ball can be deviated from its anticipated flight path significantly resulting in a curved and unpredictable flight trajectory. Lateral deflection in flight, commonly known as swing, swerve or curve, is well recognized in cricket, baseball, golf, tennis, volleyball and football (soccer). In most of these sports, the lateral deflection is produced by spinning the ball about an axis perpendicular to the line of flight. Therefore, the aerodynamic properties of a sport ball is fundamental for the players, coaches (trainers), regulatory bodies, ball manufacturers and even the spectators. It is no doubt that the game of football is the most popular in the world. No other game is so much loved, played and excited spectators than football. It is played in every corner by every nation in the world. Although, the football among all sport balls traditionally has better aerodynamic properties and balance, however, over the years, the design of football has undergone a series of technological changes, in which the ball has been made to be more accurate and aerodynamically efficient by utilizing new design and manufacturing processes. Adidas, the official supplier and manufacturer of soccer balls to FIFA (Federation Internationale de Football Association), has applied thermal bonding to replace conventional stitching to make a seamless surface design and an improved carcass shape by using 14 curved panels (making the ball topologically equivalent to a truncated octahedron) instead of 32 panels previously used in the ball since 1970. It is claimed that the ball is more spherical and performs more uniformly regardless of where it is hit. However, no independent studies have been reported in support of this statement. Although the aerodynamic behaviours of other sports balls have been studied by Alam [2, 3, 5, 6], Mehta [5], and Smits & Ogg [6], scant information is available to the public domain about the aerodynamic behaviour of new seamless football except studies by Asai [7, 8]. Moreover, no comparative study of the new ball (seamless, 14 panels) and traditional ball (32 panels with stitches). Therefore, the primary objective of this work is to experimentally study the aerodynamic properties of a new seamless ball and also a traditional 32 panel ball.

2. EXPERIMENTAL PROCEDURE

2.1 Description of Balls

Two new balls: Nike made traditional 32 panel leather ball and a new Adidas made 14 panel thermally bonded synthetic ball have been selected for the study. Both are FIFA approved balls. The diameter of the 32 panel ball is approximately 220 mm which is inflated with three different pressures. The size the ball is 5. The 32 panel ball is stitched together to provide a truncated icosahedron archimedean spherical shape. The 14-panel Adidas ball is thermally bonded machine-pressed ball without any stitches or seams, which is believed to be more spherical compared to a 32 panel ball. The diameter of the ball is approximately 220 mm and the size of the ball is 5. A sting mount was used to hold the ball, and the experimental set up in the wind tunnel test section is shown in Figure 3. The aerodynamic effect of sting on the ball was measured and found to be negligible. The distance between the bottom edge of the ball and the tunnel floor was 420 mm, which is well above the tunnel boundary layer and considered to be out of significant ground effect.

Fig 1. Nike made 32 panels Football (with seam and stitches)

Fig 2. Adidas made 14 panels Football (seamless)

2.2 Experimental Set Up

In order to measure the aerodynamic properties of two footballs experimentally, the RMIT Industrial Wind Tunnel was used. The tunnel is a closed return circuit wind tunnel with a maximum speed of approximately 150 km/h. Two mounting studs (stings) holding the ball with a six component force sensor (type JR-3) in the wind tunnel were manufactured and purpose made computer software was used to digitise and record all 3 forces (drag, side and lift forces) and 3 moments (yaw, pitch and roll moments) simultaneously. More details about the tunnel can be found in Alam [4]. The experimental set up of both balls in the wind tunnel is shown in Figures 3 & 4.

Fig 3. Experimental setup of a 32 panels football in the test section of RMIT Industrial Wind Tunnel

Fig 4. Experimental setup of a 14 panels football in the test section of RMIT Industrial Wind Tunnel

Each ball was fixed to the sting with an adhesive in order to make it very rigid. Three forces (drag, lift and side force) and their corresponding moments were measured simultaneously under a range of speeds (20 km/h to 130 km/h within an increment of 20 km/h). The aerodynamic forces are defined as drag (D) acting in the opposite direction to the wind, lift (L) acting perpendicular to the wind direction, and the side force acting (S) sideways based on a frontal view. The measured aerodynamic forces were converted to non-dimensional drag coefficient (C_D), the lift coefficient (C_L) and the lateral-force coefficient (C_S), using the formula as defined in Eqs. 1 to 3.

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 A} \quad (1)$$

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 A} \quad (2)$$

$$C_S = \frac{S}{\frac{1}{2}\rho V^2 A} \quad (3)$$

Here, ρ is the density of air ($1.2\ kg/m^3$), V is the flow velocity (m/s) and A is the projected area of the soccer ball ($A = \frac{\pi D^2}{4}$ where D is the diameter of the ball).

3. RESULTS

3.1 Flow Visualisation

In order to understand the flow structure around a 32 panel ball and a 14 panel seamless ball, the airflow was visualised using smoke (see Figures 5 and 6).

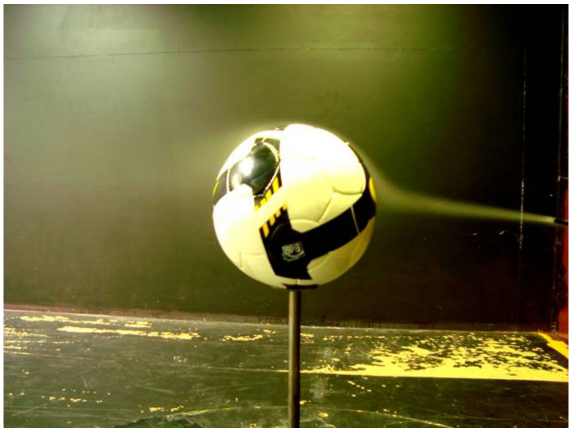

Fig 5. Airflow structure around a 32 panels football

Fig 6. Airflow structure around a 14 panels football

Due to the roughness created by the seams in 32 panel ball, the airflow over ball became turbulent and subsequently generated favourable pressure gradient and delayed flow separation as shown in Figure 5. The airflow appears to be separated at around 100° from horizontal direction. Generally, the flow separates at around 90º from the horizontal for a smooth surfaced sphere. For the 14 panel seamless and stitch-less ball, the surface is more spherical and smooth. The ball behaviour is very similar to a smooth sphere. As shown in Figure 6, the airflow separates at around 90º from the horizontal as in the case of a smooth sphere. Therefore, the 14 panel ball can potentially generate more aerodynamic drag at low speeds.

3.2 Aerodynamic Drag

The aerodynamic drags for the 32 panel Nike ball under 14.5 pound per square inch (PSI) air pressure, 14 panel Adidas ball under two different air pressures (13 and 14.5 PSI) and a sphere for a range of Reynolds number varied by wind speeds are shown in Figure 7. Two different pressures were chosen to see if there was any significant effect of pump up pressure on aerodynamic properties. There is no notable variation in drag for the Adidas ball. Both balls have similar trend, however, a minor fluctuation of drag was noted for the 32 panel Nike ball. The Nike ball displayed more aerodynamic drag compared to the Adidas ball in the range of 60 km/h to 120 km/h. No transition was noted for both types of balls. The aerodynamic drag for the smooth sphere has clearly demonstrated notable variation and also undergone transition from laminar to turbulent flow.

The drag coefficient, C_D for the Adidas, Nike and a sphere is shown in Figure 8. The average C_D value for both balls is around 0.23 at speeds above 60 km/h. The transition (laminar boundary layer to fully turbulent boundary layer) for both balls occurs in the range of Reynolds numbers 1.1×10^5 to 3.2×10^5. In contrast, the boundary layer undergoes transition for a smooth sphere at Reynolds numbers of 2.9×10^5 to 4.6×10^5 (see [1]), which is notably different from flow regime around a football.

The boundary layer transition for a football is occurred much earlier compared to a smooth sphere. The results from this study have agreed well with the published data [7, 8]. Although, the Nike 32 panel ball displays relatively higher C_D between 60 to 120 km/h speeds, the variation in drag coefficients for the Adidas 14 panel ball and Nike 32 panel ball was not significant. It is clear from Figures 8 and 9 that the C_D for the 32 panel ball fluctuates more compared to the C_D value of the 14 panel Adidas ball as it is believed to be more spherical than the Nike 32 panel ball.

The small variation in pump up pressure has minimum effect on the aerodynamic drag as shown in Figure 10.

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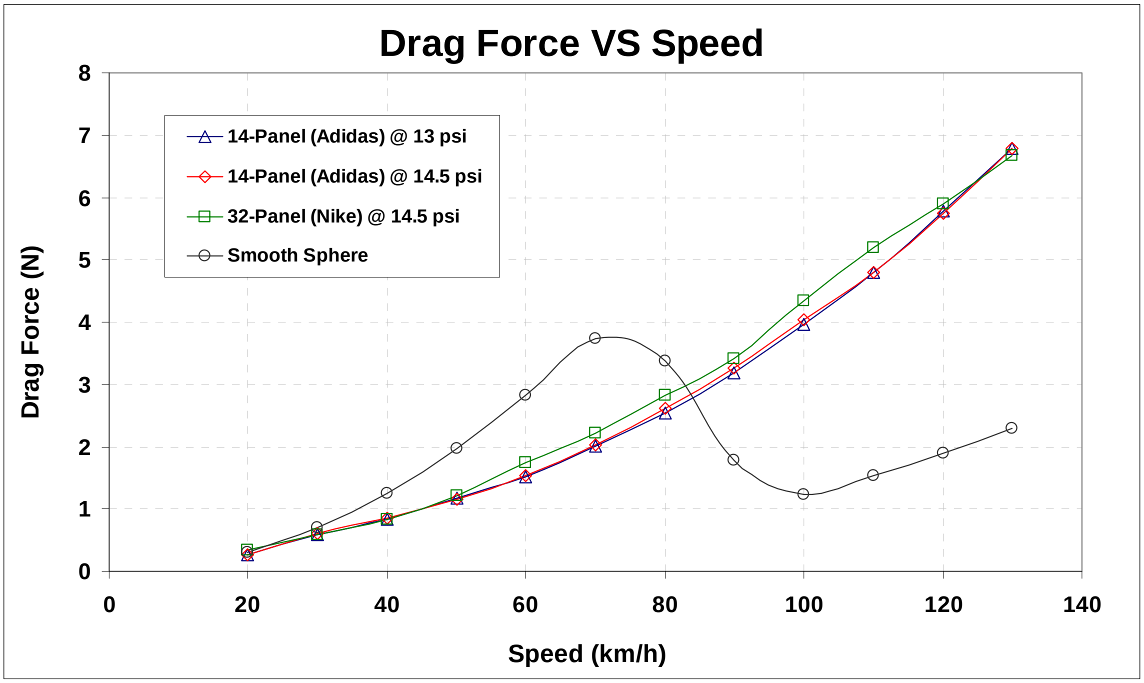

Fig 7. Aerodynamic drag of balls and a smooth sphere

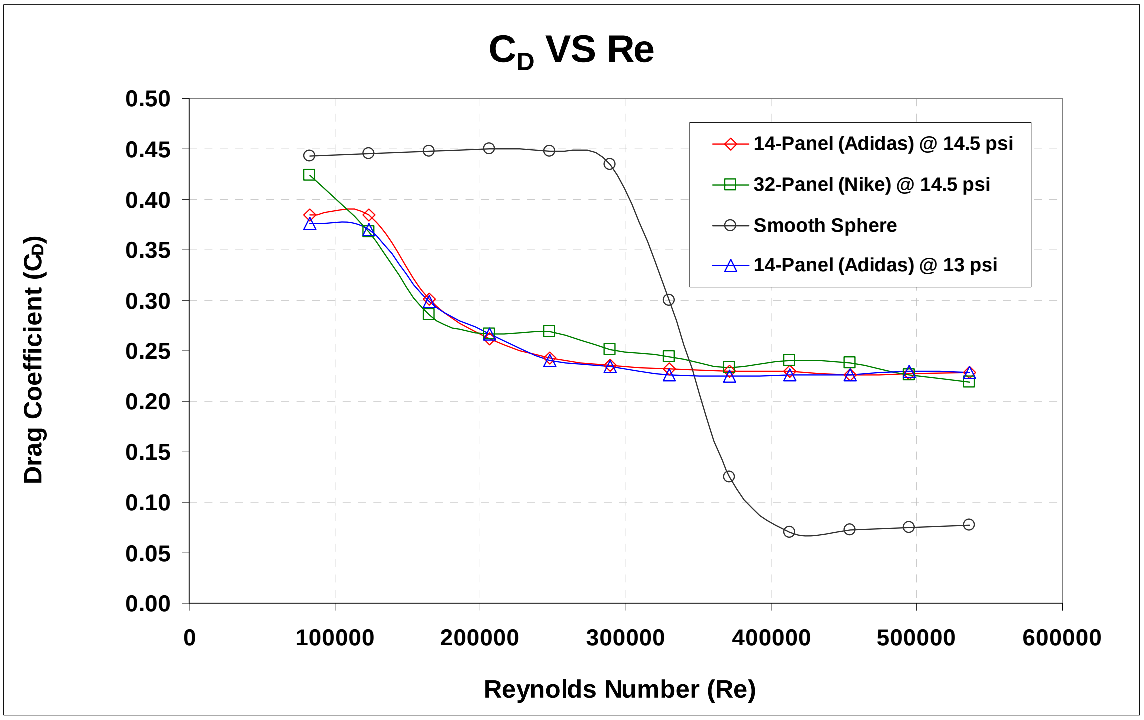

Fig 8. Drag coefficients of balls and a smooth sphere

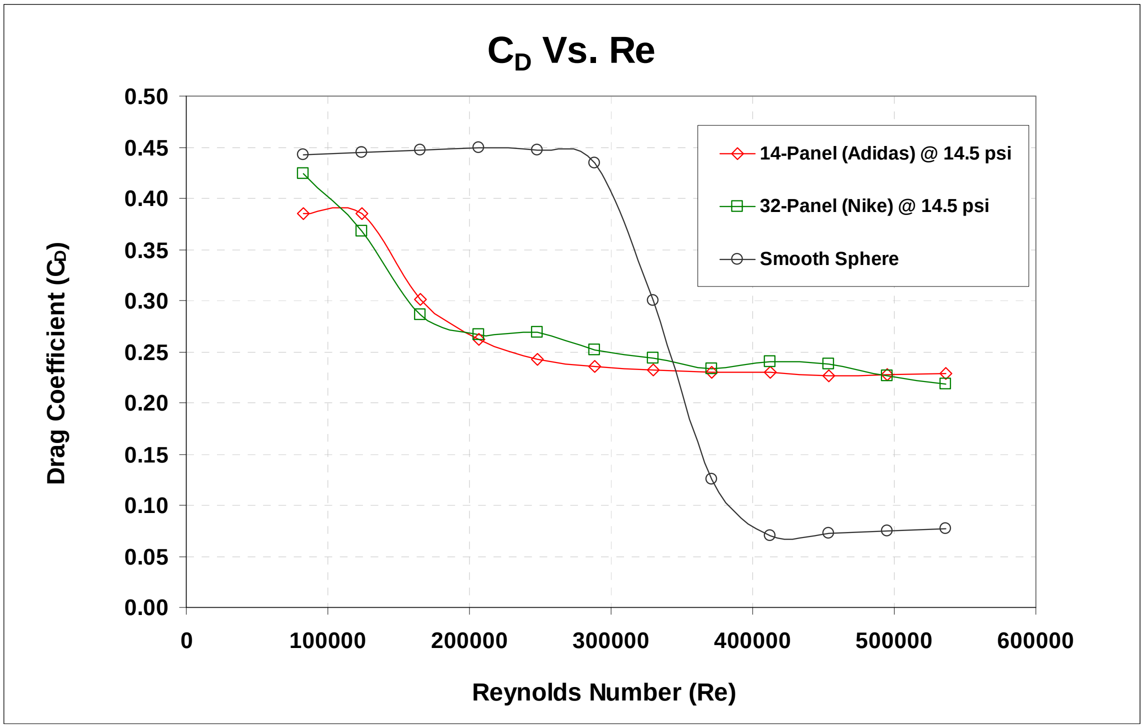

Fig 9. Drag coefficients of balls and a smooth sphere

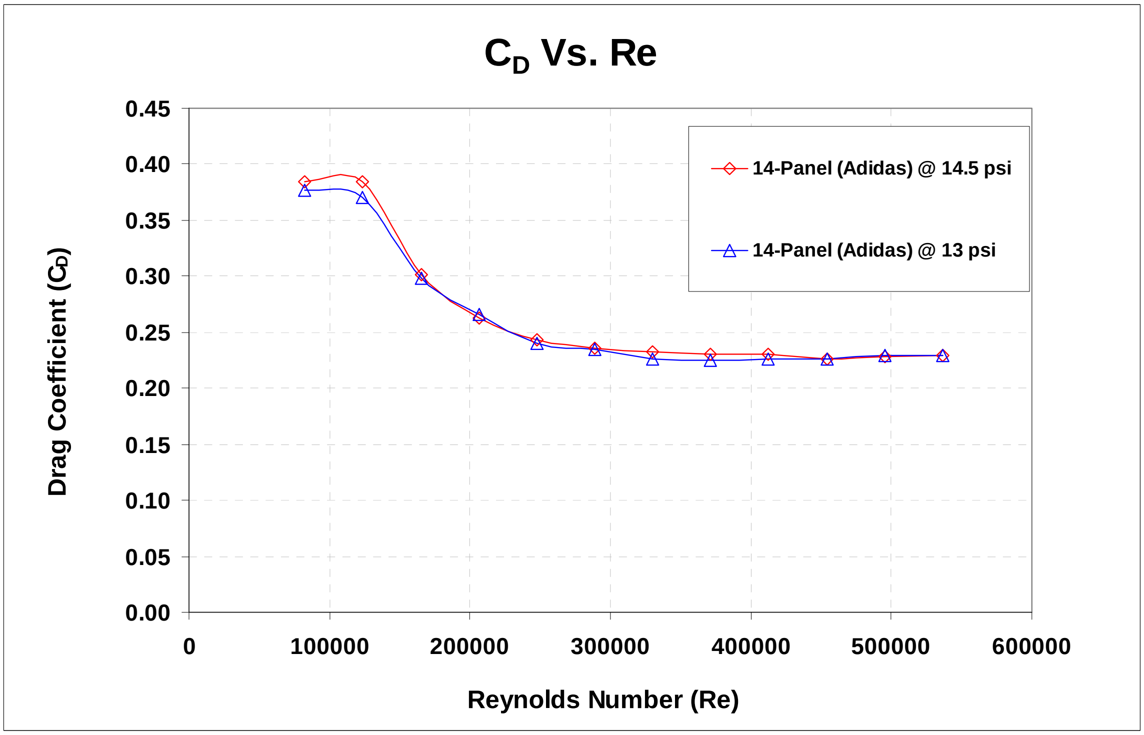

Fig 10. Drag coefficients of 14-panel ball under two different pressures

4. DISCUSSION

The C_D value largely depends on the roughness of the ball exterior surface and the seams can cause additional drag due to the boundary-layer separation. The results indicate that the C_D value for a football is in between a smooth sphere and a golf ball. The golf ball data was not shown here, however for more details, see [6]. As the speeds of football are generally in the range of 90 km/h to 130 km/h during a free kick or long shot, the C_D value of 32 panel or 14 panel balls are expected to be the same. However, the C_D value can be in the transition zone when the ball is kicked for a short pass.

5. CONCLUSION

The following concluding remarks have been made based on the experimental study presented here:

- The drag coefficient of a non-spinning football is approximately 0.40 at low speeds (below 30 km/h) and 0.23 at high speeds (over 60 km/h).
- The 32 panel ball has slightly higher drag at high speeds compared to the 14 panel ball.
- The drag coefficient of the 32 panel ball fluctuates more as it is believed to be less spherical compared to a 14 panel seamless and stitch-less ball.
- A small pump up pressure variation has negligible effect on aerodynamic properties.

6. ACKNOWLEDGMENT

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8. NOMENCLATURE

Symbol	Meaning	Unit
D	Drag Force	(N)
L	Lift Force	(N)
S	Side Force	(N)
C_D	Drag Coefficient	-
C_L	Lift Coefficient	-
C_S	Lateral-Force Coefficient	-
Re	Reynolds Number	-
V	Velocity of Air	m/s
ρ	Density of Air	kg/m^3
A	Projected Area	m^2

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