ICME07-FL-17

AN EXPERIMENTAL STUDY OF CRICKET BALL AERODYNAMICS

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ABSTRACT

Aerodynamic properties of a cricket ball play an important role in cricket games. The external characteristics (seam and surface roughness) of a cricket ball generate asymmetric airflow over it which causes the flight deviation (swing) and the unpredictable flight. The unpredictable flight of the ball makes difficult for the batsman to hit the ball with his bat and guard the stamps. Although some studies on aerodynamic properties of a cricket ball have been conducted, the mechanism of various swings is not well understood. Therefore, the primary objectives of this work as part of a larger project were to understand the aerodynamic properties and swing mechanisms of a cricket ball. The study also included the measurements of aerodynamic forces using a six component force sensor in the wind tunnel. The aerodynamic forces and moments were measured at a range of speeds and seam orientation. The airflow around the cricket ball was visualised and documented with video and still images.
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Keywords: Swing, drag, side force, wind tunnel, flow visualization, seam.

1. INTRODUCTION

The game of cricket is one of the most popular and widely watched games. Over 60 countries of the former British Empire are involved with a potential viewing audience of over 1.5 billion people. Recently China has adopted a plan to participate in the game by 2012. Then, cricket will be the 2nd most viewed game following various forms of football in the world. Cricket's popularity has already moved outside the boundary of the former British colonial countries. In any event making up the game, a bowler bowls a ball to a batsman who attempts to hit the ball and score runs whilst protecting three standing stumps sited at the extremity of a narrow strip of turf. The primary objective of a bowler is to bowl the ball such a way so as to deceive the batsman into making a false stroke resulting in the ball hitting the stumps or forcing the batsman to mis-time his shot and hit the ball on the full to a fielder of the opposing team. In order to deceive the batsman, the bowler has to manipulate the ball's trajectory and landing position on the wicket. As a cricket ball has to be projected through the air as a three dimensional body, the associated aerodynamics play a significant role in the motion of the ball.

A cricket ball is constructed of a several layers of cork tightly wound with string. The ball is covered with a leather skin comprising 4 quarters stitched together to form a major seam in an "equatorial" plane. Moreover the quarter seams on both halves of the ball are internally stitched and juxtaposed by 90 degrees. The seam comprises six rows of stitches with approximately 60 to 80 stretches in each row. A cricket ball with a mass of 156gm and approximate diameter of 70 mm (diameter of a tennis ball is approximately 54 mm) is much heavier than a tennis ball. However, the prominence of the seam and mass can vary from one manufacturer to another. At present, over a dozen firms manufacture cricket balls, under the auspices of the International Cricket Council, overseeing the game at the highest level (Test cricket).

The aerodynamic properties of a cricket ball are affected by the prominence of the seam, the surface roughness of the ball in play and the launch attitude of the ball by the bowler. Asymmetric airflow over the ball then causes the flight deviation (swing). One of the objectives of this research is to understand the aerodynamic properties of the ball and to explain the mechanism of swing and de-mystify the unpredictability of the ball's trajectory. The sideway deviation of the ball during the flight towards the batsman is called swing. There are various types of swing: conventional swing and reverse swing. Conventional swing results in the ball experiencing a sideways force directed away from the shiny half of the ball. Such a force is achieved by maintaining laminar boundary layer of air flowing over the shinny or smooth half with a turbulent boundary layer of air flowing over the rough half. Roughness over one half of the ball is a result of its natural deterioration during play whilst a shiny side is maintained by polishing the ball when the opportunity presents itself to the fielding team.

Conventional swing can be achieved in at least two ways:

(a) By angling the seam to the batsman and with the mean direction of the flight so that one side experiences laminar (smooth) airflow and other side experiences turbulent airflow caused by the angulation of the seam

itself. The points on each side of the ball half where the flow separates is asymmetrical, generating aerodynamic pressure variations with a component transverse to the ball's motion causing eventual trajectory deviations. Generally, the ball is pushed towards the half where the airflow is remains attached.

(b) By bowling a deteriorated ball possessing shiny and rough halves to a batsman. However, by aligning the ball's seam under some angles, the bowler can generate different type of swings which will be discussed later.

Generally, if the ball moves in a direction away from the bat, the deviation is called *out* swing. Conversely when the ball moves towards the batsman the resulting sideway deviation is called *inswing*. Figure 1 illustrates a typical swing of a cricket ball to a right-handed batsman.

Reverse swing is generally achieved when the airflow becomes turbulent on both sides of the ball. Here the turbulent airflow at sides separates earlier on one side than the other. The phenomenon usually occurs with a ball that is bowled fast. It is not clear where the limits of velocity exist for this type of swing. A comprehensive study is required to answer this question. In reverse swing, unlike conventional swing, the ball deviates toward the rough side of the ball. Usually, any swing makes difficult for the batsman to hit the ball with his bat and guard the stamps. Traditionally reverse swing occurs when one half of the ball is has been naturally worn significantly. In most cricket matches, the phenomenon of reverse swing occurs after 40 or more overs (one over consists of a set of six bowled balls). The mechanism for a reverse swing is complex and still not fully understood due to the degree of ball's surface roughness and required seam alignment angles with the mean direction of the flight. Although, some studies by Mehta [5, 6, 7], Barrett et al [3], Sayers and Hill [8], Wilkins [9], Barton [4] were conducted to understand the aerodynamics of cricket ball, a comprehensive study to understand the gamut of complex aerodynamic behaviour resulting a wide range of swing under a wide range of wind conditions, relative roughness, seam orientations and seam prominence is yet to be conducted.

Therefore, a large research project has been undertaken in the School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University to understand the overall aerodynamic behaviour of the cricket ball both experimentally as well computationally. The work presented here is a part of this large research project. In order to understand the general behaviour of the airflow around a cricket ball, a large cricket ball (450 mm in diameter) was constructed to visualise airflow using smoke trails. Three new and two old practice cricket balls including a One-Day International ball were used to measure the aerodynamic properties under range of wind and spin conditions at various seam angles (see Figure 7).
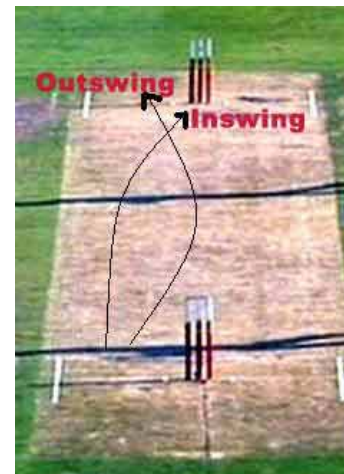

Fig 1: A schematic of outswing & inswing [ref 10]

Fig 2: A typical Test cricket ball

Fig 3: A typical One Day cricket ball

2. EXPERIMENTAL PROCEDURE

The RMIT University Industrial Wind Tunnel was used to visualise the airflow around ball and measure the aerodynamic properties (drag, lift and side force and their corresponding moments) using a six-component force sensor under a range of wind speeds (40 km/h to 140 km/h in increments of 20 km/h). All balls were tested at 0°, 10°, 20°, 30° and 45° seam angles with the mean direction of winds. It is believed that a practical seam angle during bowling is approximately 20 to 30 degree with the mean direction of flight. As mentioned earlier, the large diameter (450 mm) ball with six-rows of artificial seams (shown in Figure 4) was used to visualise the airflow around it. The larger diameter ball was photographed to check flow characteristics and quantify the flow effects with seam orientation angles with wind directions. Smoke was used to see the airflow trail

around the ball. Artificial roughness was also created on the ball. Airspeeds ranged from 10 km/h to 40 km/h for the smoke flow visualisation. The study was conducted in RMIT Industrial Wind Tunnel. It is a closed return circuit wind tunnel with a turntable to simulate the cross wind effects. The maximum speed of the tunnel is approximately 150 km/h. The dimension of the tunnel's test section is 3 m wide, 2 m high and 9 m long and the tunnel's cross sectional area is 6 square m. More details about the tunnel can be found in Alam [1]. The test section of RMIT Industrial Wind Tunnel with experimental set up is shown in Figures 5 & 6.
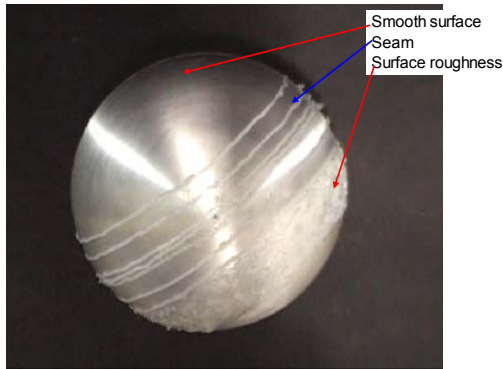

Fig 4: A simplified 450mm diameter cricket ball in the RMIT Industrial Wind Tunnel

Fig 5: Experimental Set-up in RMIT Industrial Wind Tunnel

Fig 6: A Motorised Supporting Device for Cricket Ball mounted on a Six-Component Force Sensor

Five different types of balls (made by Kookaburra, Australia) were tested to measure the drag and side forces. These balls are: Turf white (One Day game ball), Regulation (Test game ball), Club Match (First class game ball), use ball (one side smooth and other side rough), and practice ball (one side white and other side rough & red). These balls except the club match are shown in Figure 7. As mentioned earlier, the side way deviation of a cricket ball in the flight is generally due to the side force variation. However, the variation of side force of a cricket is very small and it is relatively difficult to measure. In this study, only the drag forces for all five balls are presented. The forces acting on the ball were determined by testing ball with the supporting gear and then subtracted from the forces acting on the supporting gear only. A ball with the mounting device on a six component force sensor is shown in Figures 5 & 6. In order to visualise the airflow around the cricket ball, a simplified larger diameter ball (450 mm) made of aluminium was mounted on the side wall of the wind tunnel as shown in Figure 4. Six rows of seam were replicated using a silicone-rubber compound and the surface roughness at one side of the ball was also replicated using the same material.

a) Turf Ball (Test game ball)

b) Regulation Ball (One Day game ball)

c) Used Ball (one half smooth & other half rough)

d) Practice Ball (white half smooth & red half rough)

Fig 7: Various Kookaburra Cricket Balls used for this study

3. RESULTS AND DISCUSSION

3.1 Flow Visualisation

Airflow characteristics under various seam orientation are shown in Figures 8 to 12. Figure 8 shows the flow separation occurring at the ball's apex (90 degrees) whilst the seam remains parallel to the wind direction (zero seam angle with the horizontal axis) reaffirming the classical flow separation point from a sphere. Here, the seam does not play any role in triggering flow separation at all. However, when seam is angled to the flow direction (shown here at

approximately 30 degrees with surface roughness elements located upstream of the seam, the flow no longer separates at the apex (as it was in Figure 8), but accelerates and separates at around 30 degrees past the apex. The surface roughness and the seam then enable turbulence and enhance the delayed flow separation.

When seams are artificially placed at approximately 70 degrees to the flow direction (see Figure 10), the airflow separation is still delayed but not as much as was the case in Figure 9. Here the seams and surface roughness locations are close to the natural trigger of flow separation (see Figure 8). In Figure 11, the seams and surface roughness location trigger the natural flow separation as they are located at the critical zone (apex) and the airflow separates earlier than in the case of Figure 8. The airflow characteristics in Figure 12 show the similar pattern as in Figure 8. In this case, both surface roughness and seams do not play any role in the flow separation at all.

Flow separation location

Fig 8: Seam orientation parallel to flow direction (0 degrees)

Flow separation location
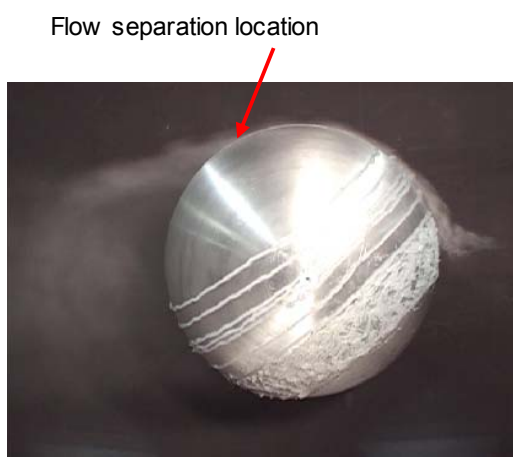
Fig 9: Seam orientation approximately 30 degrees with flow direction

Flow separation location
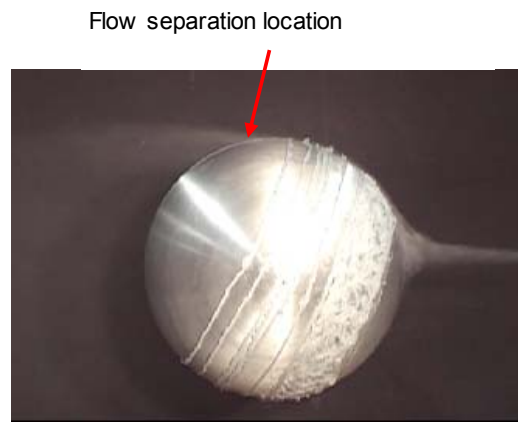
Fig 10: Seam orientation approximately 70 degrees with flow direction

Flow separation location

Fig 11: Seam orientation approximately 90 degrees with flow direction

Flow separation location

Fig 12: Seam orientation parallel to flow direction (30 degrees)

3.2 Effects of Seam on Aerodynamic Forces

All five balls were tested in the wind tunnel at a range of speeds under a range of yaw angles as mentioned earlier. The ball was yawed relative to the force balance (which was fixed with its resolving axis along the mean flow direction whilst a ball was yawed above it) thus the wind axis system was employed. The Regulation and Turf (white) balls are new with no wear and tear. However, the red-red and white-red balls are used balls and one side is of the ball is rougher than other (see

Figure 7). The forces and moments were converted to non-dimensional parameters (Cd, Cs, Cl and their moment coefficients) and tare forces were removed by measuring the forces on the sting (mounting device) in isolation and them removing them from the force of the ball and sting. Only drag force coefficients are presented in this work and they are plotted against Reynolds numbers (varied by the tunnel wind speeds) as a function of yaw angles. These plots are shown in Figures 13 to 16. A comparison of drag coefficients at all speeds and yaw angles for all five cricket balls indicates that there is a slight variation of drag coefficients between new and used balls. The new ball's drag coefficient (Cd) at high Reynolds numbers (above 100 km/h) is approximately 0.5 regardless of seam orientation. The findings agreed well with the published data (see Sayers and Hill [8]). The seam angles have negligible effect on drag coefficients at high speeds on Kookaburra made balls. However, a small variation in drag coefficients was noted for two used balls (see Figures 15 & 16). The used practice ball (half white and half red) shown in Figure 16, possesses slightly higher drag coefficient in all speeds tested. However, the used 'Red-Red' (one side smooth &other side rough) ball has the lowest aerodynamic drag coefficient at higher speeds which approximately equals to 0.45. It is not clear why the old ball displays laser drag coefficient compared to a new ball. A close inspection revealed that Kookaburra made balls possess flat seams compared to other brand balls and they are machine made and have similar pattern of seams.
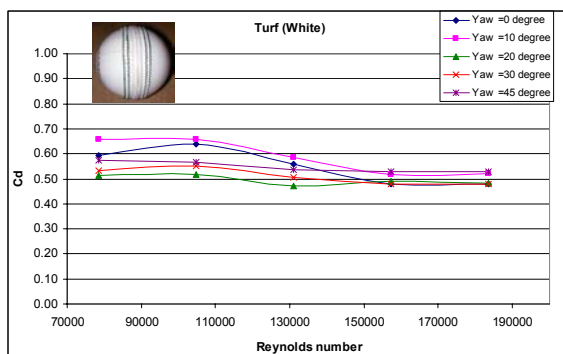

Fig 13: Drag Coefficient variation with Reynolds numbers as a function of seam angle (Turf white)
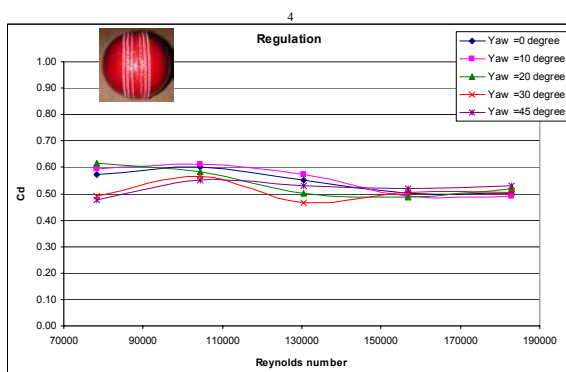

Fig 14: Drag Coefficient variation with Reynolds numbers as a function of seam angle (Regulation)
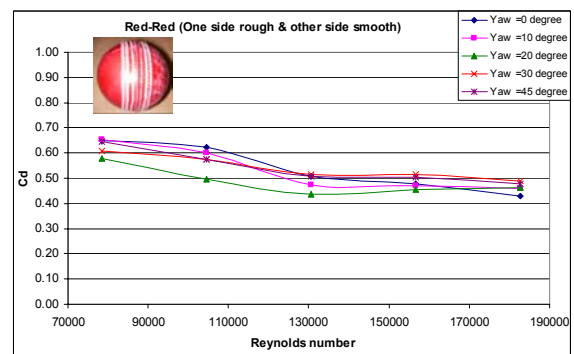

Fig 15: Drag Coefficient variation with Reynolds numbers as a function of seam angle (One side smooth & other side rough)
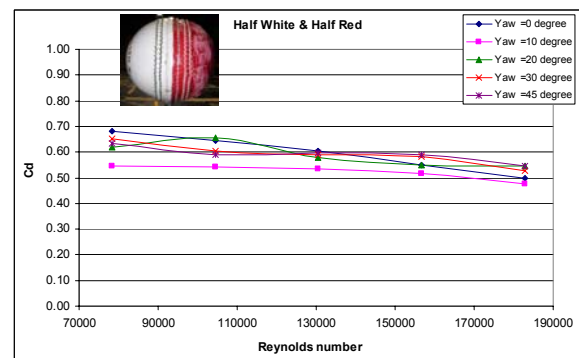

Fig 16: Drag Coefficient variation with Reynolds numbers as a function of seam angle (Half white & half red with roughness)

4. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were made from the work presented here:

- The airflow around a cricket ball is complex due to the surface roughness, seams and spins involved.
- The drag coefficient of a cricket ball is approximately 0.5 at speeds over 100 km/h.
- The side-way deviation (swing) largely depends on the seam geometry (seam height) and orientation to the flow direction.
- There is minimum variation of aerodynamic drag coefficient between new and used balls made by Kookaburra.
- The seam location close to the apex of the ball triggers early flow separation (evidenced by flow visualisation).
- The seam location close to the mean direction of the airflow (horizontal axis) enhances the delayed flow separation (evidenced by flow visualisation).
- Further flow visualisation is required to quantify the exact location using a real cricket ball.
- The quantification of deviating side forces is required.
- The effects of spin on side forces need to be quantified.

5. ACKNOWLEDGEMENT

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7. NOMENCLATURE

Symbol	Meaning	Unit
Cd	Drag coefficient	
Cs	Side Force coefficient	
Re	Reynolds number	-