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AN EXPERIMENTAL AERODYNAMIC STUDY OF A SERIES OF RUGBY BALLS

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ABSTRACT

The aerodynamic properties of oval shaped balls, rugby balls and Australian Rules (AFL) football, exhibit peculiar trends which impacts sharply on the balls flight trajectory; with a kicking efficiency of only 60% amongst elite footballers in AFL and NRL, understanding the physics behind oval shaped balls can be very perplexing. Very little literature has been made available on the aerodynamic characteristics of oval shaped balls, under non-spinning conditions. The rugby and AFL footballs are asymmetric by design, and hence can rotate both laterally and longitudinally, not to mention an offset angle to these axes of rotation. Initial tests of three differing rugby balls, positioned at a zero pitch angle but with a varying yaw angle have been analysed with curious results. Subsequently, a look into the flow around these balls was studied using flow visualisation methods of wool tuft and smoke flow.

Keywords: Drag, Wind Tunnel, Yaw Angle, Rugby Ball, Flow Visualization.

1. INTRODUCTION

The aerodynamic properties of sports balls play an integral role in the way in which a sports ball behaves during flight, affecting the balls' speed and trajectory. Apart from the research conducted by Alam et al. [1-5] and the ever increasing popularity of games such as rugby, there seems to be very little aerodynamic research available in the public domain. A major part of the game of Rugby is the distance kick, be it a set shot or a drop punt during play. So with the ball travelling through the air at high speeds, crosswinds and spin play significantly on the ball's trajectory. Therefore, understanding this concept will improve the game immensely. Searching open literature for studies undertaken on the aerodynamic properties of rugby balls; with the exception of Alam et al.(2008) and Seo et al.[6], with aerodynamic studies of other miscellaneous balls being studied in-depth by Asai et al;. [7] Mehta and Pallis [8], Himeno [9] and Alam et al. [10]. Statistics from the 2007 Rugby World Cup indicates that distance kicking plays an increasingly significant role in the outcome of the game, and it is anticipated that this trend will continue throughout the 2011 Rugby World Cup in New Zealand. Stadium crosswinds and spin has significant effects on the ball's flight trajectory and sideway deviation. Each of the three different rugby balls sued for this study were commercially available to the public; in order to assess the products available to amateur sports people, focusing on improving the game for the wider community. By comparing the three biggest brands in the game of rugby; Gilbert, Summit and Adidas we are able to ascertain a well-rounded set of results for a major cross-section of the rugby ball market. By comparing three distinctly different balls, we will be enabled to also understand what the best design regarding surface geometry and ball dimensions for the game of rugby. Ultimately, the work will be extended to understanding the complexities of spinning a rugby ball, but for the purposes of this work the ball was restricted to non-spinning flight.

The aerodynamic drag and side force are directly related to air velocity, cross sectional area of the ball, air density and air viscosity. Drag and side forces are generally defined in the context of fluid mechanics as:

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

$$S = C_S \frac{1}{2}\rho V^2 A \tag{2}$$

where C_D and C_S are the non-dimensional drag and side force coefficients respectively whereby; ρ is the air density, V is the free stream air velocity and A is the cross sectional area of the ball. The non-dimensional values of C_D and C_S are defined as:

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 A} \tag{3}$$

$$C_S = \frac{S}{\frac{1}{2}\rho V^2 A} \tag{4}$$

The C_D and C_S are related to the non-dimensional parameter, Reynolds number (Re) and are defined as:

$$Re = \frac{\rho V D}{\mu} \quad (5)$$

2. EXPERIMENTAL PROCEDURE

2.1 Experimental Facilities and Equipment

The RMIT Industrial Wind Tunnel used in this study is a low speed recirculating wind tunnel with a six component balance; with a maximum wind velocity of about 150 km/h with a rectangular test section measuring 3 m wide, 2 m high and 9 m long, with turbulence level equal to approximately 1.8%. The wind tunnel is also equipped with a turntable, which enables the ball to be rotated at a desired yaw angle. A plan view of the RMIT Industrial Wind Tunnel is shown in Figure 1. The tunnel was calibrated before conducting the experiments; with the tunnel's airspeeds being measured via a modified NPL ellipsoidal head Pitot-static tube (located at the entry of the test section) which is connected to a MKS Baratron pressure sensor through flexible tubing. The balls in focus are connected to a force sensor via a solid metal sting mount. The JR-3 force sensor is then connected to a computer, which has integrated software with an easy to use interface; allowing for simple data retrieval of all 6 forces and moments acting on the ball (drag, side, and lift forces) and (yaw, pitch and roll moments). The JR-3 force sensor used in this study, allows for a maximum measurement of 200 Newton's force, and is robust enough to carry loading. Due to its high stiffness and integration into the system, the force sensor allows minimal degradation of system dynamics, position accuracy and high resonant frequency; allowing accurate sensor response to rapid force fluctuations.

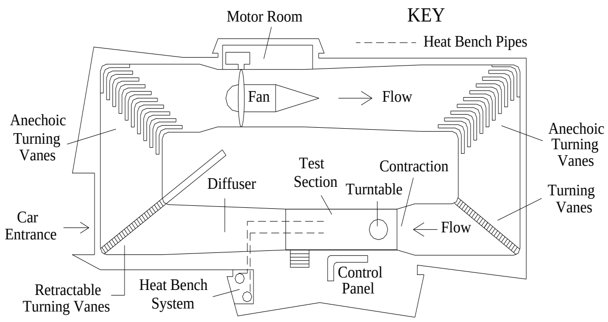

Fig 1. Plan view of RMIT Industrial Wind Tunnel

Fig 2. Orthogonal view of experimental set-up with rugby ball in wind tunnel's test section

2.2 Description of Rugby Balls

A series of three distinguishably different rugby balls were used during the experimental testing phase of this work; a rugby league Gilbert brand rugby ball, Adidas 'All Black' brand and a Summit 'Wallabies brand rugby ball. Each ball is represented in Figures 3, 4 and 5 respectively. Each ball is commercially available to the general public and officially licensed by the manufacturer. Each ball is made of 4 segments of synthetic rubber, stitched together to give a deep seam. The balls were inflated to pressures between 62-76 kPa and the measurements of each ball are as follows; Summit 760-790 mm in length (circumference, end to end) and 580-620 mm in width (circumference), Adidas and Gilbert.

Fig 3. Gilbert brand rugby ball

Fig 4. Adidas ‘AllBlack” rugby ball

Fig 5. Summit ‘Wallabies’ brand rugby ball

The distance between the bottom edge of the ball and the tunnel floor was found to be 240 mm, which is well above the tunnel’s boundary layer and considered to be out of the ground effect. A special aerodynamic mounting device was developed which can be seen in Figure 6, in order to place the rugby balls securely on the 6 component force senor.

Fig 6. Specially designed mounting sting
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3. RESULTS AND DISCUSSION

Each of the balls were tested at 20 to 130 km/h going up by increments of 10 km/h for yaw angle ranging between -90 to +90 degrees, with increments of 15 degrees. Wool tufts and smoke were used to help visualise the flow around the balls at various yaw angles and speeds. The rugby balls were yawed relative to the force sensor’s axis (which was fixed with its resolving axis along the mean flow direction whilst the ball was yawed above it). Having said this, all forces measured were relative to the force balance axis system and are not resolved into wind axis to include the resolved effects of side forces as well as drag forces. Therefore, all drag coefficients are shown here in force balance axis system only. With regard to the flow visualisation by wool tuft, all three rugby balls were utilised; however for the case of the smoke visualisation only the Gilbert brand rugby ball was tested. Figures 7- 10 show comparisons between the two flow visualisation methods of wool tuft and smoke flow for the Gilbert rugby ball are shown in this paper, for 0 and 90 degree yaw angles.

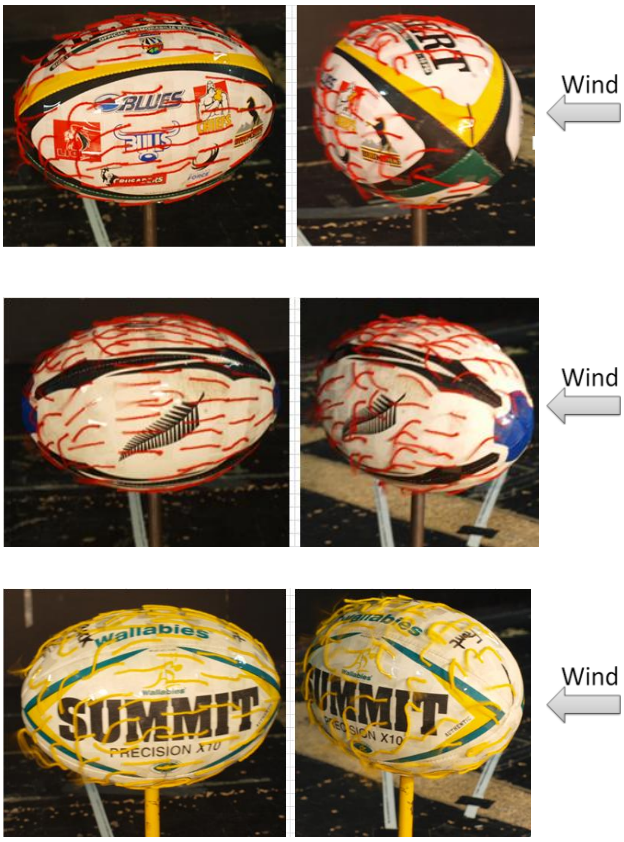

Fig 7. Flow structure (wool tuft) around ball at 0° and 90° yaw angle 80 km/h (Gilbert. Adidas and Summit)

Fig 8. Flow structure (smoke) around ball 0° and 90°

The flow remained relatively laminar up until the middle of the 'G' on the Gilbert logo or around about 75-80 % from of the length of the ball from the leading edge; after which point the flow began to separate and began to chaotically re-circulate at the rear of the ball in the wake region. The averaged drag coefficient of speeds ranging from 60 km/h to 130 km/h at 0^o was experimentally calculated to be 0.19.

Flow visualisation was conducted at speeds of 40 and 80 km/h for the above specified yaw angles, Figures 7 and 8 represent the 80 km/h study. It is clear that for the 90^o case the flow is very complex and 3 dimensional. The flow begins to separate just past the mid-way point of the top panel of the ball, whilst also being time varying. The smoke visualisation technique yielded some interested results, as can be seen in Figure 8. The flow separated began to separate between the L and B of the Gilbert emblem of the top half of the ball. At yaw angle of 90 degrees the flow would travel from one end to the other in a swirling vortex form, and would chaotically detach and re-circulate aft of the back quarter panel of the rugby ball.

In order to obtain aerodynamic forces and moments for each of the three balls, the supporting mounting device was tested separately and then subtracted from the forces and moments of the ball and support assembly. The forces were converted to non-dimensional parameters such as drag and side force coefficients. Figures 9, 10 and 11 show the drag coefficient against yaw angles for all three rugby balls is presented in this paper and side force coefficient against yaw angle for Adidas 'All Black" ball.

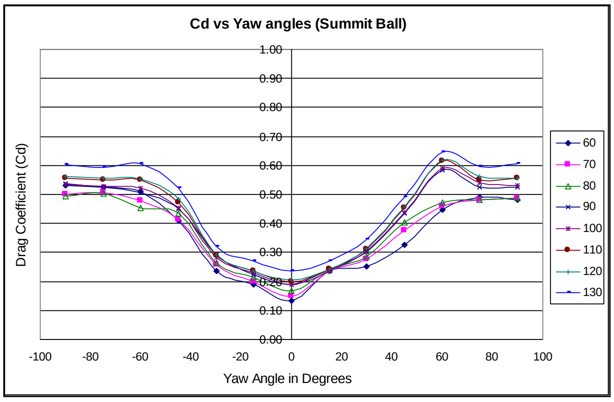

Fig 9. Drag coefficient (C_D) as a function of yaw angle and wind speed Summit ball

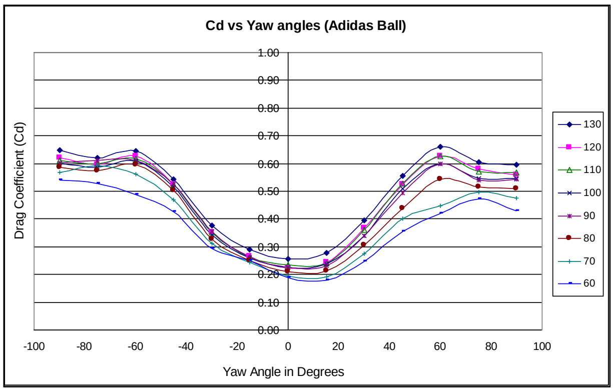

Fig 10. Drag coefficient (C_D) as a function of yaw angle and wind speed Adidas ball

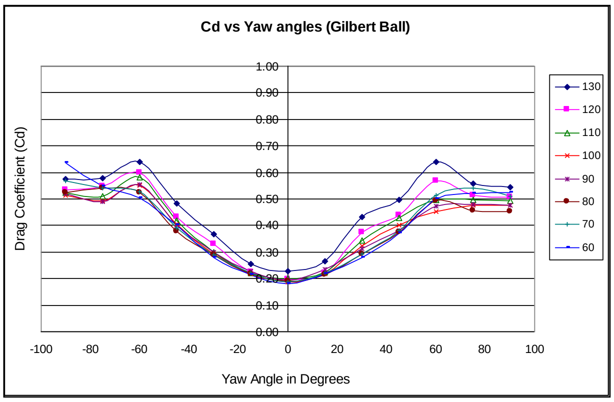

Fig 11. Drag coefficient (C_D) as a function of yaw angle and wind speed Gilbert ball

Comparing the three sets of graphs, it is clear that little symmetry with the results evident between the three balls. Slight errors were expected to arise from the slight lack of airflow symmetry, it became clearer that the reason as to why the there was little symmetry with the balls was the surface grip geometry and lack of symmetry between the physical shape of each ball. The Summit rugby ball has an orderly diamond like structure, coarse "pimple" like protuberances' with the greatest height. The Gilbert rugby ball has arbitrarily placed "pimples", which are spaced closer together that are slightly smaller in height but larger in diameter. Lastly, the Adidas ball has the smallest size "pimples" which are arbitrarily positioned with the greatest spacing between them. The surface geometry each rugby ball differs slightly, but it is enough to change the behaviour of the viscous sub layer of the flow around each ball enough to create anomalies in the results. This would mean that the mean velocity would decrease across the ball greater for the Summit rugby ball and the Reynolds number also decreases until the flow becomes turbulent, meaning that for lower speeds the drag is greater.

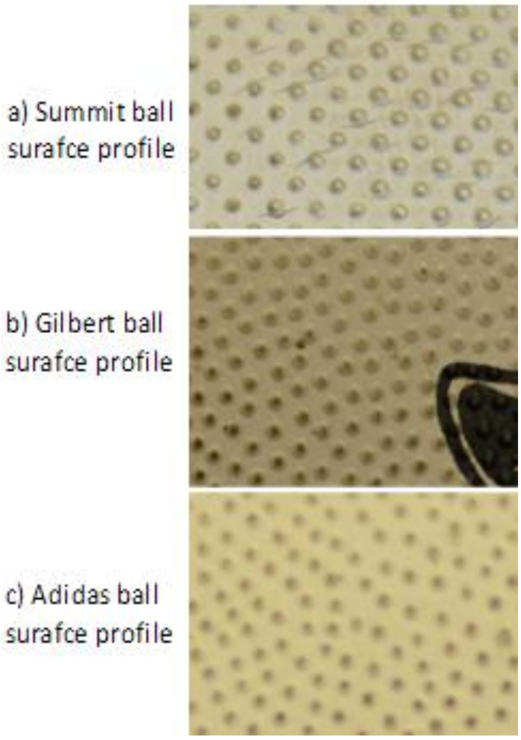

Fig 11. Comparison of surface geometry

The average drag coefficients at zero yaw angles for speeds between 60 to 130 km/h of the Summit, Adidas and Gilbert rugby balls were found to be 0.1, 0.219 and 0.195, respectively (see Figures 9-11). No Reynolds number dependency (effects of speed) was found for zero yaw angles; however a significant variation was evident with the increase of yaw angles. The Reynolds number variation reduces with increasing velocity. As the yaw angle increases beyond approximately 60 degrees, the drag coefficient begins to decrease rapidly, which is the result of very complex flow separation. It should also be noted that as the forces were not resolved into the wind axis, the drag coefficient may not be pure. However, at zero yaw angle the measurement of drag coefficient is believed to be accurate.

The flow remained relatively laminar up until the middle of the 'G' on the Gilbert logo (depicted in Figure 5 with downward arrow) or around about 75-80 % from of the length of the ball from the leading edge; after which point the flow began to separate and began to chaotically re-circulate at the rear of the ball in the wake region. The averaged drag coefficient of speeds ranging from 60 km/h to 130 km/h at 0° was experimentally calculated to be 0.18.

Flow visualisation was conducted at speeds of 40 and 80 km/h for the above specified yaw angles, Figures 7 and 8 represent the 80km/h study. It is clear that for the 90° case the flow is very complex and 3 dimensional. The flow begins to separate just past the mid-way point of the top panel of the ball, whilst also being time varying. The smoke visualisation technique yielded some interested results, as can be seen in Figure 8. The flow separated began to separate between the L and B of the Gilbert emblem of the top half of the ball. At yaw angle of 90° the flow would travel from one end to the other in a swirling vortex form, and would chaotically detach and re-circulate aft of the back quarter panel of the rugby ball.

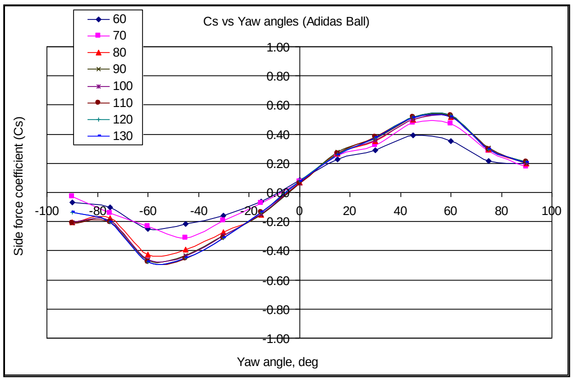

Fig 12. Side force coefficients (C_S) as a function of yaw angle and wind speed (Adidas ball)

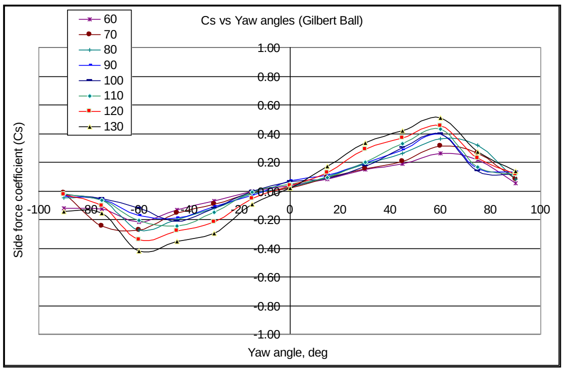

Fig 13. Side force coefficient (C_S) as a function of yaw angle and wind speed (Gilbert ball)

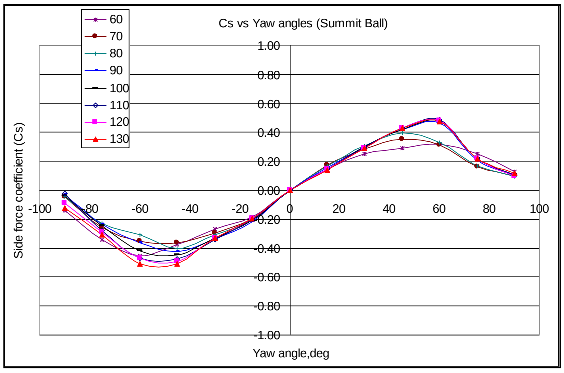

Fig 14. Side force coefficient (C_S) as a function of yaw angle and wind speed (Summit ball)

The side force coefficient has a minor off-set from the 0° yaw angle for the rugby ball which is believed to be attributed to a small mounting error, see Figure 12. A minor variation in Reynolds number was noticed at the lowest Reynolds number speed corresponding to 60 km/h. only a minor variation in positive and negative magnitudes of side force coefficient with changing yaw angle was noted, which again contributes to the claims that both the ball's shape and wind tunnels wind flow are not quiet symmetrical. It can be seen that Figures 12 and 14 are nearly identical. At ±60, notable drag coefficient variation with Reynolds number was noted for all three balls. However, these variations are minimal at high Reynolds number (high speeds).

5. CONCLUSIONS

The following conclusions can be made from the work presented here;

The aerodynamic properties of ellipsoidal shaped balls differ greatly to any other sports ball and have a very complex flow structure, even when the ball is not spinning. The average drag coefficient for the rugby ball at 0° yaw angle are as follows; Summit, Adidas and Gilbert rugby balls were found to be 0.19, 0.219 and 0.195, respectively. Conversely, the average drag coefficient of the rugby balls for the for 90º yaw angles was found to be 0.53 for Summit and Adidas balls and roughly 0.50 for Gilbert rugby ball. It was found that the greater the ratio of length on diameter was for the 'pimple' on the rugby balls surface, the greater the drag at higher Reynolds numbers. The highest positive magnitude of side force coefficient was to be +0.53 noted at yaw angle +60° and the highest negative magnitude of -0.47 at yaw angle -60. Relative symmetry was found in both the drag and side force coefficient plots, showing that the ball is manufactured accordingly. Slight variations in Reynolds number dependency was noted for the three balls, pertaining to specific yaw angles. A major effect on the aerodynamic properties of each ball was found to correlate directly with the surface grip geometry.

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8. NOMENCLATURE

Symbol	Meaning	Unit
C_D	Drag Coefficient	NA
C_S	Side Force Coefficient	NA
ρ	Air Density	kg/m^3
V	Free Stream Velocity	m/s
μ	Viscosity	kg/m.s

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