19th Australasian Fluid Mechanics Conference
Melbourne, Australia
8-11 December 2014

Aerodynamic Characteristics of Australian Rules Footballs

J.C. Cavuoto, L.W.J. Earl, T.J. Fahy and R.M. Kelso

School of Mechanical Engineering
University of Adelaide, South Australia 5005, Australia

Abstract

The aerodynamic forces on 15 Australian Rules footballs were measured in a wind tunnel. Three leading manufacturers were represented with 5 varieties of ball tested. A total of 13 ball orientations were tested in order to encompass a ball rotation range of 180° about the transverse axis, as commonly seen in a 'drop punt'. The flow speed was 28.5 m/s, corresponding to a Reynolds number (based on ball diameter) of 3.4×10^5. The drag and lift coefficients were measured for each of these orientations.

The results show similar trends to a previous study of AFL balls reported in the literature, with similar lift coefficients but significantly larger drag coefficients. The difference is attributed to the low free-stream turbulence intensity in the present case, which leads to earlier separation of the boundary layer, hence higher pressure drag. A second observation, absent from previous literature, is the impact of the laces on the flow. The laces trip the boundary layer on one side of the ball, leading to delayed separation and ultimately lower drag and greater lift over a small range of pitch angles. These observations were confirmed through the use of smoke visualisation.

It is found that there are no statistically-significant differences between the lift and drag produced by balls manufactured to Australian Football League (AFL) specifications. However, the balls not manufactured to the AFL regulations produced higher drag and lift coefficients than the standardised balls.

Introduction

The motivation for the current study is a recent initiative of the AFL to standardise the balls used throughout Australia. The aerodynamic analysis of Australian Rules footballs is an area of scarce research, due in part to the geographic localisation of the sport. Understanding the aerodynamic characteristics of the football not only provides a technical insight into one of Australia's national sports, but also delivers quantitative data to aid in the design and manufacture of the football.

A thorough review of the literature was conducted prior to testing. The majority of aerodynamic research into AFL footballs has been conducted by Alam *et al.* [2, 3], while studies of various other prolate sports balls proved useful. Such previous literature includes the study of Rugby balls by Vance *et al.* [8] and Alam and Djamovski [1] as well as the study of American footballs by Watts and Moore [9]. In addition to insights into methodology, the previous studies also showed that for flow velocities over 100 km/h, the lift and drag coefficients are essentially independent of Reynolds number.

The primary objective of this study was to determine the adequacy of the current AFL regulations [6] in producing aerodynamically-consistent footballs. The research also provides an insight into the aerodynamic phenomena associated with a prolate spheroid rotating in the manner of an Australian Rules 'drop punt'.

Footballs

Five different types of football were chosen for the current study as they represent the three major manufacturers as well as encompassing the range of balls used throughout state and senior leagues across Australia. The three manufacturers represented are Burley Sekem, Faulkner and Sherrin.

Ball	Longitudinal Circumference (mm)	Transverse Circumference (mm)
Burley R	727 ± 1	548 ± 1
Burley Y	723 ± 3	553 ± 2
Sherrin R	719 ± 5	551 ± 4
Sherrin Y	727 ± 1	549 ± 4
Faulkner	727 ± 1	539 ± 4

Table 1. Mean circumferential dimensions and variability of the tested footballs. R = red, Y = yellow.

The Burley Premier, shown in figure 1, is manufactured in accordance with current AFL specifications and is used in the South Australian National Football League (SANFL) and the Western Australian Football League (WAFL). The Faulkner Match Ball, shown in figure 1, is used throughout country leagues and was formerly used in the AFL alongside the Sherrin. Faulkner does not hold an AFL license and as a result the balls are not made to the governing body's specifications.

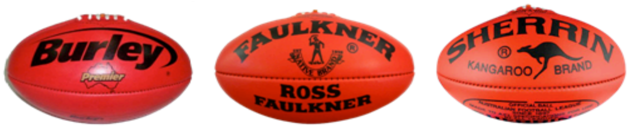

Figure 1: The three footballs chosen for the study. From left to right, Burley Premier, Faulkner Match and Sherrin KB Match balls.

The Sherrin Kangaroo Brand Match ball is the official ball of the AFL. Along with the traditional red leather, the Burley and Sherrin balls are produced in yellow leather styles for night games. These balls were therefore tested in both red and yellow with the red Faulkner completing the set of 5 varieties.

For the purposes of this paper, the plane in which the ball cross-section is approximately circular is defined as the transverse plane and the elliptical cross-section is defined as the longitudinal plane.

Experimental Apparatus & Procedure

The balls were tested in an open-return wind tunnel, shown in figure 2, which had a test section of 0.5m×0.5m, a maximum flow velocity of 28.5 m/s and a turbulence intensity of 0.6%.

Measurements of the aerodynamic forces were acquired through the use of a 6-component, 100 N JR3 load cell which has a nominal accuracy of ±0.25% of full scale and a resolution of 0.013 N. The balls were supported in the core flow on top of a rigid vertical sting of length 170mm and diameter 4mm adjacent to the ball. A thin, dished plate of diameter 35mm was sufficient to provide a stable platform for the balls. Additional support was provided by 0.4mm thickness nylon fishing line. The drag and lift due to the sting were subtracted from all measurements. The overall experimental error was 2.43%, based on the accuracy of the measurement apparatus and an analysis of alignment errors.

The free-stream dynamic pressure was measured using a Pitot-static probe connected to a Fluke 922 manometer with a nominal accuracy of ±1%. The solid blockage of the ball in the air stream varied between 9% and 15%, which was considered to be acceptable due to the blockage tolerance of the open jet wind tunnel [5,7]. Hence, no blockage corrections were deemed necessary.

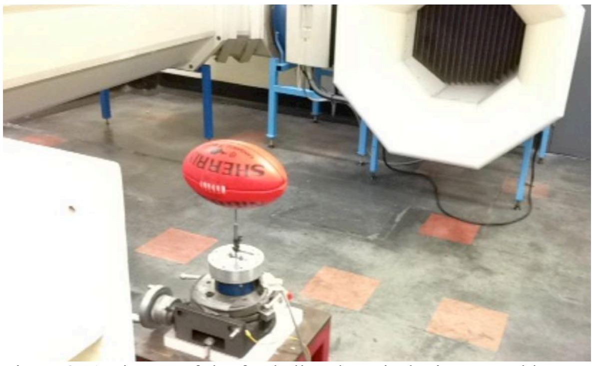

Figure 2: An image of the football and vertical sting assembly at a pitch angle of 90°.

In order to determine the ball velocity experienced during a ‘drop punt’, ball speed measurements were obtained using a high-speed camera operating at 2000 frames per second. A graduated backdrop with increments of 50mm, shown in figure 3, was used in conjunction with the camera to determine ball velocity.

Figure 3: An image taken from the high-speed footage showing the graduated backdrop.

A total of 12 kicks were performed by experienced footballers including a senior player in the SANFL. The kicks were performed over a distance of 20m resulting in an average ball velocity of 30 m/s and a corresponding foot speed of 17 m/s. This result is validated in Ball [4] who found the average foot speed of an AFL player to be 25 m/s for a 50m kick. As the maximum flow speed of the wind tunnel is 28.5 m/s (102 km/h), it was decided that testing would be carried out at this speed, which also matches closely to the middle of the velocity range used by Alam *et al*. [2]. This speed corresponds to a Reynolds number of 3.4 x 10^5, based on the ball diameter, which corresponds to the critical Reynolds number for smooth spheres and cylinders.

Each football was attached to the vertical sting of the test rig and static testing was performed at 13 orientations. The ball orientations, defined at rotation intervals of 15°, encompassed a pitch angle range -90° to 90° as shown in figure 4. In order to minimise the impact of any random errors, each ball was installed and tested 3 times.

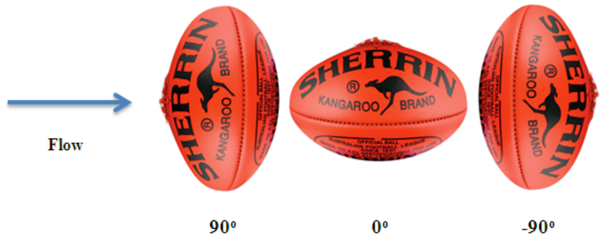

Figure 4: Pitch angle convention based on ball orientation with respect to the oncoming flow.

The drag coefficients were found by normalising the load cell drag measurements using the measured dynamic pressure and the cross-sectional area of each ball, based on its mean diameter, as described in equation (1). Lift and side-force coefficients were calculated in the same fashion using the same reference area. The use of this reference area is standard practice for the presentation of force coefficient data for footballs of prolate spheroid shape.

$$C_D = \frac{D}{qA}, \quad where \quad q = \frac{1}{2}\rho V^2 \qquad (1)$$

A total of 585 tests were conducted in order to accumulate the data set, and each of these tests was performed for a period of 15 seconds with a sampling rate of 100 Hz. The inflation pressure of each ball was maintained within the range of 62–76 kPa specified by both the manufacture and the AFL regulations [6].

Results

The data acquisition process yielded over one million data points which were analysed using MATLAB coding. Figures 5 and 6 summarise the drag and lift measurement for each ball.

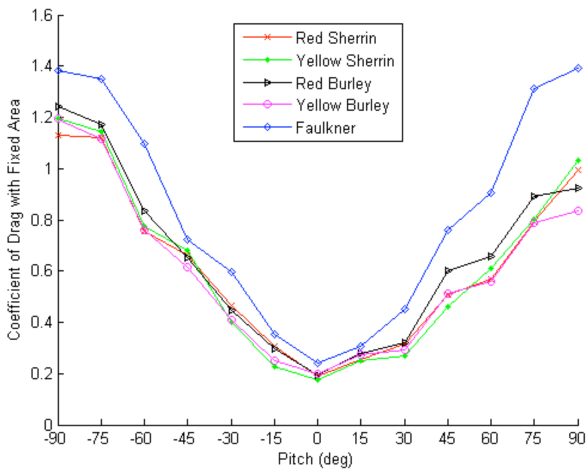

Figure 5: A comparison of the drag coefficients for all 5 ball types.

The overall drag and lift variations with pitch angle are consistent with the results of Alam *et al.* [2,3] with the exception of the magnitudes. Whereas the results of Alam *et al.* show the drag coefficient varying from 0.1 at 0° pitch angle to and 0.7 at 90° pitch, the present results show drag coefficients varying from 0.2 to 1.2 respectively, at the same Reynolds number of 3.4 × 10^5. The significantly different values of turbulence intensity (TI), 1.8% for *Alam et al.* and 0.6% for the present case, may be sufficient to cause these differences. Son *et al.* [10] demonstrate that a change in the turbulence intensity from 0.65% to 2.1% at a

Reynolds number of 3 x 10^5 can decrease the drag on a smooth sphere by 50%. Confirmation of this effect is provided by flow visualization studies, an example of which is presented in figure 7 (TI = 0.6%). Here the boundary layer is seen to separate at the equator of the ball, anchored by the 3mm-deep panel seams. By contrast, the wool tuft visualization of Alam *et al.* [3] (TI = 1.8%) indicates that in this experiment the flow separates downstream of the equator, close to an angle of 120˚ from the flow direction. These observations are consistent with the observed differences in the drag coefficient magnitudes. It is concluded that in the present experiments, the boundary layer approaching the equator is most likely to be laminar or transitional, and the seams promote separation, rather than acting as a turbulence trip. The resulting separation at the equator leads to higher pressure drag compared to separation at an angle of 120˚.

The data in figure 5 indicate that there is no discernible difference in the coefficient of drag between the Burley and Sherrin footballs of either colour. However, a statistically significant difference is evident with the Faulkner balls which have considerably greater drag and lift coefficients. These differences are believed to occur due to both the geometry and the surface roughness of the footballs. Upon consultation with the manufacturers, it was found that the Burley and Sherrin balls are both produced using an identical grade of leather from the same source. By contrast, the Faulkner balls, are produced using hide leather which is harder and rougher than the leather used by Burley and Sherrin. In addition, although the circumferences of the Faulkner balls matched those of the Burley and Sherrin balls in the longitudinal plane, the circumferences of the Faulkner balls averaged 2% smaller in the transverse plane. Together these differences in roughness and shape are consistent with the differences between the Faulkner balls and the others. At zero pitch, the increased drag of the Faulkner balls is most likely due to the increased roughness of these balls, in spite of the ball presenting a more "streamlined" shape due to its slightly larger aspect ratio. At large pitch angles, the increased drag of the Faulkner balls is likely to be due to the larger aspect ratio of the balls and differences in cross-sectional shape due to the increased stiffness of the leather.

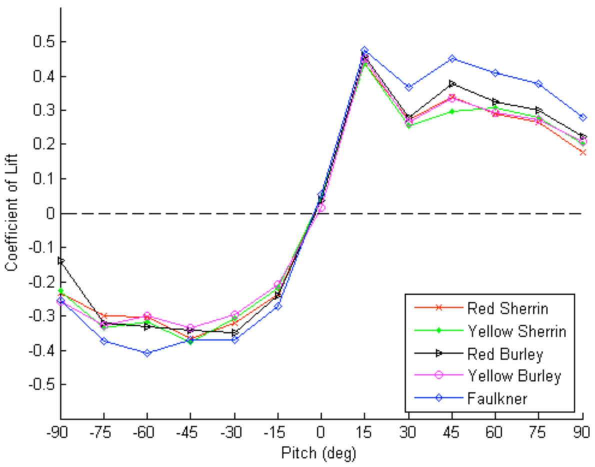

Figure 6: A comparison of the lift coefficient for all 5 ball types.

It is clear from the lift coefficient plot in figure 6 that the Faulkner ball also produced significantly higher lift coefficients across the range of angles. While all balls produced similar lift coefficients between -15° and 15°, outside this range the small differences in geometry and roughness cause a statistically-significant difference in the lift. While the mean lift generated by the ball over an entire 360˚ rotation is approximately zero, assuming quasi-steady flow, these results indicated that there is a clear difference in the aerodynamic properties of balls that do not adhere to AFL specifications and those that do. The above effects aside, the lift coefficient results are broadly consistent with those of Alam *et al.* [2,3].

Figure 5 illustrates that, for pitch angles greater than 30°, the drag coefficient is significantly lower when the laces are on the upstream surface compared to when the laces are located in the wake. Investigation with the aid of smoke visualisation showed that the laces led to a localised delay in the separation of the boundary layer. This in turn led to a smaller, asymmetric wake region causing the lower drag and higher lift. In previous studies by Alam *et al.* [2, 3], the ball was orientated in a different manner to the current study and this phenomenon was absent. The effect of the lace-induced asymmetry in the present flow is most strongly evident at a pitch angle of 15˚. Figure 7 presents a smoke visualisation image of this flow case, showing evidence (in addition to 2000 video frames) of the asymmetric flow separation.

Figure 7: Flow visualisation images of the ball at two orientations. The upper image corresponds to a pitch angle of -90˚ and the lower image corresponds to 15˚ pitch, where the red dots indicate the separation points of the boundary layer.

Aside from the peak at 15°, the lift coefficient maxima occurred at ±45° as expected, suggesting that as the ball is rotated towards this angle from 0 degrees, the distance between the two separation points increases to a maximum distance, and then converges back towards a symmetric alignment when the ball is rotated from ±45° to ±90°. From the data presented in figure 6, no significant difference can be determined between the positive and negative angles, with the exception of 15°. This suggests that at all other angles, the tripping effect of the laces does not affect the flow pattern significantly.

The graph shown in figure 8 represents the side force coefficient acting on the ball. Given that each ball is manufactured symmetrically, it was expected that the side force coefficient would be negligible. The plot was utilised to determine the amount of alignment error incurred due to the attachment of the ball to the vertical sting for each test, plus the influence of the sting itself. The coefficient of side force ranged between 0.01 and 0.1, which demonstrates that the effects were generally small. The largest effects were observed between ±60-90˚, where the interference and boundary layer tripping by the support would be expected to delay the flow separation point to a location downstream of the equator.

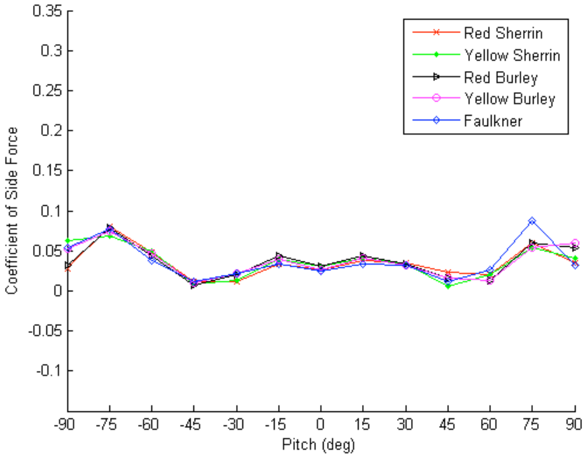

Figure 8: A comparison of the Side force coefficient for all 5 ball types.

The lift-to-drag ratio data are presented below in figure 9, which shows no significant differences in the flow characteristics of all five balls. The graph emphasises the effect that the laces have on the flow around the ball at a pitch angle of 15˚, with a significant increase in the lift-to-drag ratio.

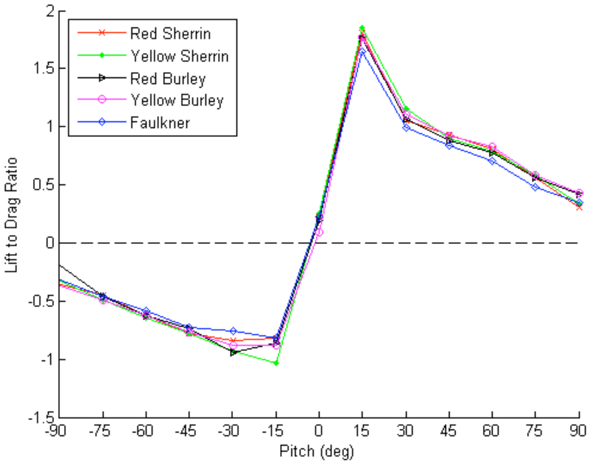

Figure 9: A comparison of the Lift-to-Drag ratio for all 5 ball types.

One objective of the present study was to compare the red and yellow balls to determine if any aerodynamic differences exist. The manufacturing of a yellow football involves a greater extent of chemical treatment to the leather compared to the red balls, potentially affecting the surface finish. The data presented in figures 5 and 6 show that no significant differences are apparent between the red and yellow balls from Burley and Sherrin, with most data falling within a 2% range, compared with an overall experimental error of ±2.43%. The small differences are also likely to be affected by the minor geometrical differences indicated in table 1.

Concluding Statements

The present study is only the second to report the aerodynamic characteristics of Australian Rules footballs. The orientation of the laces differs from the previous studies of Alam *et al.* [2,3] and the free-stream turbulence intensity in the flow is much lower. These differences lead to a significant increase in the drag coefficients and small differences in the lift coefficients, as well as some angle-specific effects due to the boundary layer tripping by the laces.

The research into the aerodynamic characteristics of Australian Rules footballs has shown that the current AFL specifications are sufficient to produce balls which provide consistent aerodynamic performance. Deviations from the approved specifications can lead to significant differences in the aerodynamic characteristics, which is evident from the deviation between the Faulkner footballs and the AFL-approved Burley and Sherrin balls when comparing coefficient of drag and lift individually. Conversely, when combining the two coefficients to form a lift to drag ratio, it is evident that there is no significant difference between the characteristics of the five balls.

References

[1] Alam, F. & Djamovski, V., An Experimental Aerodynamic Study of a Series of Rugby Balls, Proceedings of the International Conference on Mechanical Engineering, 2011.

[2] Alam, F., Djamovski, V., Smith. S., Chowdhury, H., Watkins, S. & Subic, A., Aerodynamics of Oval Shaped Sports Balls, 18th Australasian Fluid Mechanics Conference, Launceston, Australia, 2012.

[3] Alam, F., Subic, A., Watkins, S. & Smits, A.J., Aerodynamics of an Australian Rules Football and Rugby Ball, *Computational Fluid Dynamics for Sport Simulation*, editor M. Peters, Springer, Berlin, 2009, 103-127.

[4] Ball, K., Foot-Ball Interaction During Kicking in Australian Rules Football, In *Science and Football VI*, edited by Reilly, T. and Korcusuz, F., Routledge, London, 2007, 30-34.

[5] Barlow, J.B., Rae, W.H. & Pope, A., *Low-Speed Wind Tunnel Testing*, 3rd edition, John Wiley & Sons, 1999.

[6] Laws of Australian Football, Australian Football League, Melbourne, 2012.

[7] Sayers, A.T. & Bull, D.R., Blockage Corrections for Rectangular Flat Plates Mounted in an Open-Jet Wind Tunnel, Proceedings of the Institution of Mechanical Engineers, Part C, *Journal of Mechanical Engineering Science*, **197**, 1983, 259-263.

[8] Vance, A., Buick, J. & Livesey, J., Aerodynamics of a Rugby Ball, *Journal of Applied Mechanics*, **79** (2), 2012.

[9] Watts, R. & Moore, G., The Drag Force on an American Football, *American Journal of Physics*, **71** (8), 2003, 791-793.

[10] Son, K., Choi, J., Jeon, W-P. & Choi, H., Effect of Free-Stream Turbulence on the Flow Over a Sphere, *Physics of Fluids* **22** (4), 045101, 2010.