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AERODYNAMICS OF A RUGBY BALL AND AUSTRALIAN RULES FOOT BALL

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ABSTRACT

The main objective of this work is to study the aerodynamic drag of a rugby ball and Australian rules foot ball as aerodynamic drag can play an important role in flight trajectory (landing position, altitude etc). Although several studies on aerodynamic properties of some sporting balls have been conducted, there is no or little information about the aerodynamic properties of a rugby ball and Australian rules foot ball found in the open literature. It is believed that knowledge of the aerodynamic properties of these two balls will enhance the outcomes of performance. All three forces (drag, side force and lift) and their moments (yaw, pitch and roll) were measured for a range of speeds (60 km/h to 120 km/h with an increment of 20 km/h) as a function of yaw angles. Flow structures around the balls were visualised with wool tufts and smoke.

Keywords: Drag coefficient, Wind tunnel, Force balance, Yaw angle

1. INTRODUCTION

Air flow around a sporting ball plays a significant role as it influences speed and motion (e.g. position and placement) of the ball. Despite the popularity of games such as Rugby and Australian rules foot balls little or no study was done on the aerodynamic properties. The effects of yaw angles have not been reported in the open literature. Although the external shape of rugby ball and Australian rules foot ball look similar but they are different in terms of geometry (details about the balls will be given later). Rugby is played in more than 100 countries and its membership currently encompasses 94 national unions and five regional associations. Membership has expanded enormously in recent times and encompasses all regions, races and people of the world [1].

Australian rules foot ball originated in mid 1800 in Melbourne, Australia to create a winter diversion game by acquiring knowledge from other ball games (such as International foot ball, rugby ball and American foot ball etc). Australian rules football has enormous influence on the national culture and the use of leisure time. A study conducted by the Australian Football League (AFL) in 1999 [2] showed there were 447,436 Australian rules football players and about 636,000 non-playing members. About 13.9 million spectators watched the game in 1998 including 50.4 per cent attending AFL matches. In 2000, AFL foot ball alone attracted 6.3 million spectators. Currently, Australian rules foot ball is being played in over a dozen countries including USA, Canada, United Kingdom, Germany and Ireland.

It is believed that knowledge in aerodynamic properties of these two balls will enhance performance. Although several studies by Mehta [3], Sherwin and Sproston [4], Stepanek [5], Hoerner [6] on the aerodynamics of ball games have been reported in the open literature, very little knowledge about the aerodynamic properties of a rugby ball or Australian rules foot ball is available in the public domain. Therefore, the primary objective of this study was to investigate the aerodynamic properties such as drag, side force and lift of a rugby ball and an Australian rules foot ball.

2. EXPERIMENTAL PROCEDURE

The aerodynamic forces and their moments were measured for a range of speeds (60 km/h to 120 km/h with an increment of 20 km/h) as a function of yaw angles (±90° with an increment of 10°) using a six component force balance in the RMIT University Industrial Wind Tunnel. It is important to note that axis system is used here (i.e., the force balance and the test ball rotated together). Two balls (rugby and Australian rules made by SUMMIT Australia and SHERRIN Australia) have been selected for this work as they are officially used in various tournaments in Australia. The dimension of the Australian rules foot ball is approximately between 720-730 mm in length and 545-555 mm in width (in the centre) and is inflated of between 62-76 kPa. The ball tested for this work was new and purchased from a local Australian Football League (AFL) shop. It was made of leather and consists of 4 segments (see Figure 5 b & d). The dimension of the rugby ball used for this work is 760-790 mm in length (circumference, end to end) and 580 - 620 mm in width (circumference). The ball was brand new and made by 4 segments of synthetic rubber (see Figure 5 a & c).

A special mounting device was designed to hold each ball, see Figure 5. The mounting device was set up on a 6 component force balance (type JR-3). Figures 1 and 2 show the experimental set up in the wind tunnel test section. The distance between the bottom edge of the ball and the tunnel floor was 420 mm, which is well above the tunnel's boundary layer and considered to be out of ground effect.

Fig 1. A Front View of Experimental Set Up with Rugby Ball in the Tunnel's Test Section

Fig 2. A Front View of Experimental Set Up with Australian Rules Football in the Tunnel's Test Section

Fig 3. An External View of RMIT Industrial Wind Tunnel

As mentioned earlier, tests were conducted at the RMIT University Industrial Wind Tunnel, which is a closed test section, closed return circuit wind-tunnel and is located at the Department of Mechanical and Manufacturing Engineering (see Figure 4). The maximum speed of the tunnel is 145 km/h. The rectangular test section dimension is 3 m (wide) x 2 m (high) x 9 m (long) with a turntable to yaw suitably sized objects. The tunnel was calibrated before conducting the experiments and tunnel's air speeds were measured via a modified NPL (National Physical Laboratory) ellipsoidal head Pitot-static tube (located at the entry of the test section) connected to a MKS Baratron Pressure sensor through flexible tubing. Purpose made computer software was used to compute all 6 forces and moments (drag, lift, side, yaw moment, pitch moment and roll moment) and their non-dimensional coefficients. Since the blockage ratio was extremely low no corrections were made. A plan and external view of RMIT Industrial Wind Tunnel is shown in Figures 4 and 3. More details about this wind tunnel can be found in Alam [7].

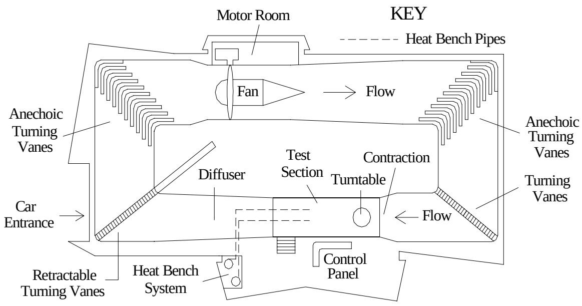

Fig 4. A Bird's Eye View of RMIT Industrial Aeroacoustic Wind Tunnel

a) Rugby Ball (Side View)

b) Australian Rules Football (Side View)

c) Rugby Ball (In-Line View)

d) Australian Rules Football (In-Line View)

Fig 5. Rugby Ball and Australian Rules Foot Ball with Mounting Device on Force Balance

3. RESULTS AND DISCUSSION

Each ball was tested at 60, 80, 100 and 120 km/h speeds under ±90° yaw angles with an increment of 10°. Wool tufts and smoke were used to visualise the flow around the balls at various yaw angles. However, flow visualisation photographs by wool tufts at 0° and 90° yaw angles are shown only in this paper (see Figures 7 and 9). In order to obtain aerodynamic forces and moments for each ball, the supporting device was tested first and then subtracted from the forces and moments of ball and support assembly. The forces and moments were converted to non-dimensional parameters such as drag, lift and side forces coefficients and their respective moment coefficients. Only drag coefficients are presented in this work and they are plotted against the speeds. Figures 6 and 8 show the drag coefficient variation with velocities and yaw angles for the Australian rules foot ball and the rugby ball. All forces are measured in 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.

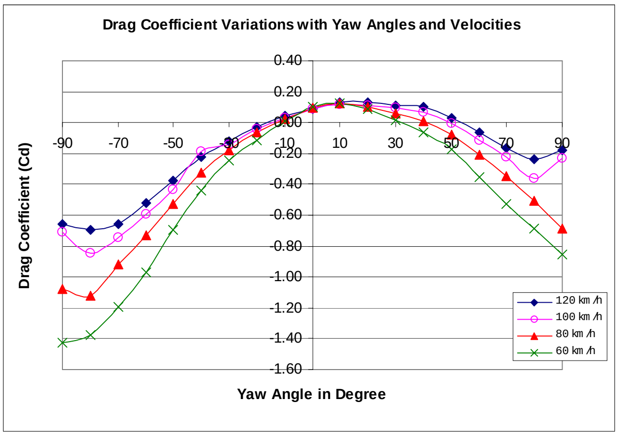

Fig 6. Drag Coefficients as a Function of Yaw Angles and Speeds for the Australian Rules Foot Ball

a) Flow Pattern at 0° Yaw Angle

b) Flow Pattern at 90° Yaw Angle

Fig 7. Flow Pattern around an Australian Rules Foot Ball at 0° and 90° Yaw Angles

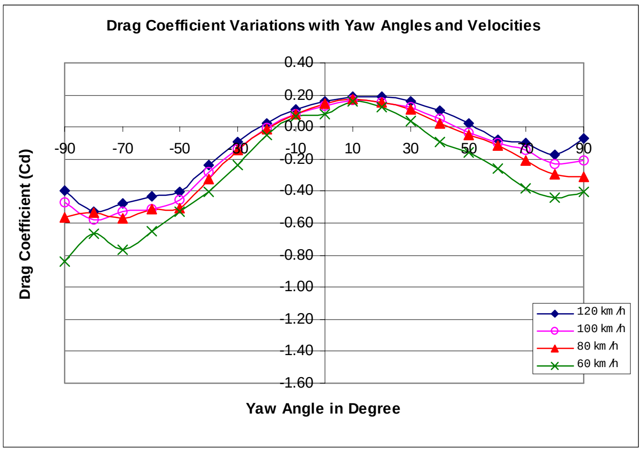

Fig 8. Drag Coefficients as a Function of Yaw Angles and Speeds for the Rugby Ball

a) Flow Pattern at 0° Yaw Angle

b) Flow Pattern at 90° Yaw Angle

Fig 9. Flow Pattern around a Rugby Ball at 0° and 90° Yaw Angles

A comparison of drag coefficients at all speeds and yaw angles for the rugby ball and Australian rules foot ball is shown in Figures 6 and 8 respectively. It is clear for both balls that there is a significant lack of symmetry in the results. Whilst some errors arose from a slight lack of airflow and force balance symmetry, the errors are greater than expected. Examination of the balls indicated that the balls are not symmetrical.

The Rugby ball had the higher drag coefficient (approximately 0.13 at zero yaw angle) and the Australian rules foot ball had a drag coefficient of approximately 0.10 at zero yaw angle (see Figures 6 and 8). No Reynolds number dependency (effects of speeds) was found at zero yaw angles for the Australian rules foot ball. However, a significant variation was evident with the increase of yaw angles (see Figure 6). The Reynolds number variation reduces with the increase of velocities. As yaw angle increases, drag coefficient becomes negative as a result of a very complex flow separation. It may be noted that it is not pure drag as forces were not resolved into the wind axis. However, at zero yaw angle the measurement of drag coefficient is accurate. The higher negative drag is noted at leeward side yaw angles (approximately -20° yaw angles and below) compared to windward side yaw angles (30° and above. The flow visualisation photograph (Figure 7) shows a very complex flow pattern which was formed as yaw angle increases.

A similar trend of aerodynamic drag coefficients for the rugby ball was also noted for all yaw angles tested (see Figure 8). It may be noted that the variation of drag coefficients is lower at higher yaw angles compared to the drag coefficient variations of the Australian rules foot ball (see Figures 6 and 8). Flow structures at ±90° for both balls are complex and have similar trends (Figures 7 and 9). Flow separations start at ¾ length from the front edge at zero yaw angles for both Australian rules foot ball and rugby ball. However, separations are complicated at ±90° yaw angles as a three dimensional reverse flow is formed at the rear of the ball. Further work is needed to understand this effect.

4. CONCLUSIONS

The following conclusions have been made from the work presented here:

- The average drag coefficients for the Australian rules foot ball and rugby ball at zero yaw angles are 0.10 and 0.13 respectively.
- The Reynolds number dependency is evident at higher and lower yaw angles (but not at zero yaw angles)
- The flow structures become very complex with the increase of yaw angles and generate negative drag.

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8. NOMENCLATURE

Symbol	Meaning	Unit
D	Drag	(N)
L	Lift	(N)
Cd	Drag coefficient	-
Cl	Lift coefficient	-
V	Wind velocity	m/s
P	Pressure	(Pa)