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A STUDY OF BASEBALL AERODYNAMIC DRAG

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ABSTRACT

The baseball is one of the popular games in North and South America, North Asia and some parts of Europe and Africa. It is enjoyed both by participants and spectators. The games centre piece is the spherical ball. The flight trajectory of a baseball largely depends on its aerodynamic characteristics. Despite the popularity of the game, it appears that scant information on the aerodynamic force experienced by a baseball is available in the open literature. Having over 108 curved stitches, complex seams and their orientation, the airflow around the ball is believed to be significantly complex and little understood. The primary objectives of this study were to evaluate aerodynamic performances of a commercially manufactured baseball. The aerodynamic forces and moments were measured experimentally for a range of wind speeds and seam orientations. The aerodynamic forces and their non-dimensional coefficients were analysed. The results indicate that the drag coefficient of a base ball is close to other closely related balls such cricket ball. The findings also indicate that the seam orientation has profound impact on ball's aerodynamic characteristics.

Keywords: Baseball, Drag, Wind Tunnel, Yaw Angle, Flow Visualisation.

1. INTRODUCTION

The flight trajectories of sports balls largely depend on the aerodynamic characteristics. Depending on aerodynamic behaviour, the ball can be deviated significantly from the anticipated flight path resulting in a curved and unpredictable flight trajectory. Lateral deflection in flight, commonly known as swing or knuckle, is well recognized in cricket, football, golf, tennis, baseball and volleyball games. In most of these sports, the lateral deflection is produced by spinning the ball about an axis perpendicular to the line of flight or by other means (e.g. surface features) to make asymmetric airflow around the ball. Therefore, the aerodynamic properties of a sport ball are considered to be the fundamental not only for the players and coaches but also for regulatory bodies, ball designers and spectators. It is no doubt that baseball is widely recognized as the national sport of the United States. The baseball game is very popular at all levels (professional, amateur, and youth) in North America (USA, Canada, Mexico, Cuba), parts of Central and South America and the Caribbean, Japan, South Korea, Australia, New Zealand, and many other countries in Asia, Europe and Africa. Some exciting moments in baseball games are shown in Figure 1.

Unlike sphere, the baseball is not uniformly smooth. The baseball since its inception over 100 years ago has undergone very little design changes in terms of its physical dimensions or materials except the replacement of horsehide made outer surface with the cowhide in early mid 1970s. The outer cover of a professional baseball is generally white and possesses around 108 stitches with over 2,235 mm waxed red strings. The orientation, height and width of the seam vary among the balls. Hence different baseball can behave aerodynamically differently and unpredictable way [3].

Although the aerodynamic behaviour of other sports balls have been well studied by Achenbach [1], Alam et al. [4-7], Asai et al. [10], Mehta [12], and Smits and Ogg [14], scant and reliable experimental data is available to the public domain about the aerodynamic behaviour of baseball except some studies by Adair [2], Alaways [9], Kensrud [11] and Nathan [13]. These studies are neither comprehensive nor conclusive. Moreover, there is no agreed and reliable data on baseball aerodynamics a available in the public domain. Therefore, the primary objective of this work is to experimentally measure the aerodynamic forces such drag, side and lift forces and their corresponding moments of a baseball used in major tournaments in Australia and elsewhere.

a) Pitching and catching

b) Hitting

c) A fully occupied stadium with enthusiastic viewers

Fig 1. An exciting moments in baseball game [15]

Fig 2. A Rawlings made American Baseball

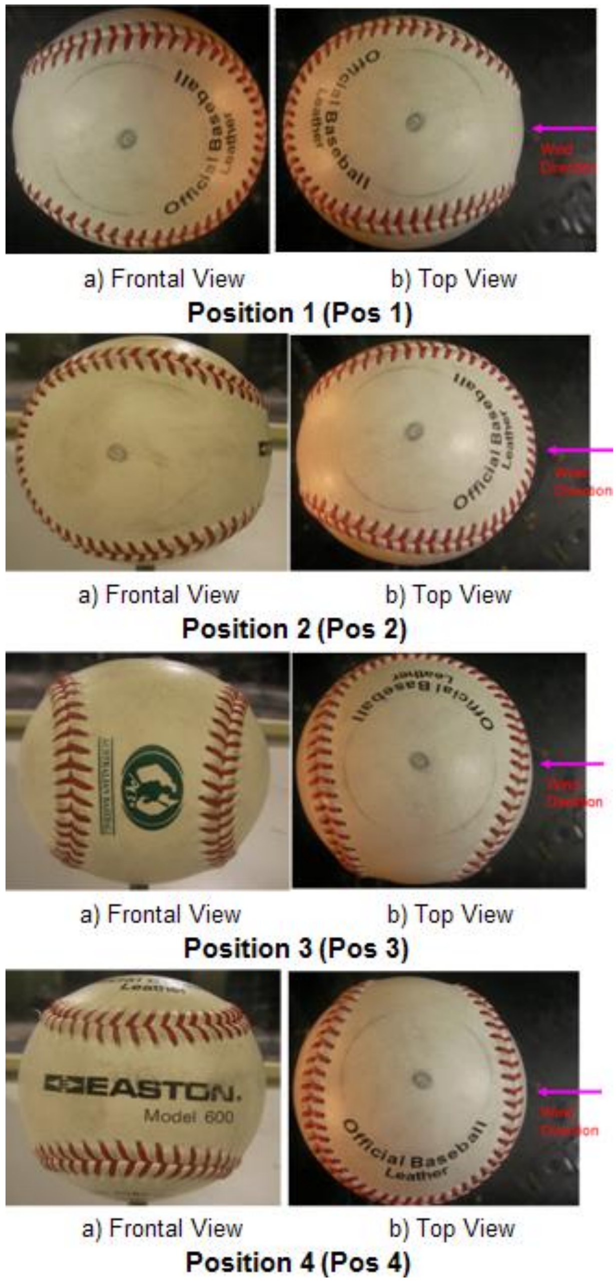


Fig 3. Four seam orientations

2. EXPERIMENTAL PROCEDURE

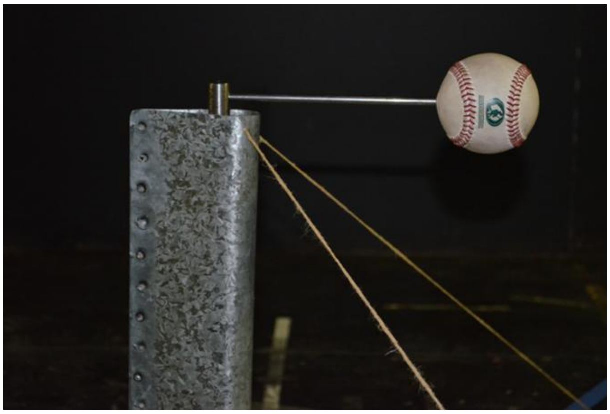
2.1 Description of Balls

A brand new commercially made baseball was selected for this study. The ball was manufactured by Easton approved by Baseball Australia. The ball model is 600. The outer surface of the ball is made of cowhide and the ball diameter is approximately 72 mm. The external shape of typical baseball is shown in Figure 2. Four orientations of a baseball are also shown in Figure 3 as they can generate asymmetric airflow around the ball in flight.

2.2 RMIT Industrial Wind Tunnel

In order to measure the aerodynamic properties of the ball experimentally, the RMIT Industrial Wind Tunnel was used. The tunnel is a closed return circuit with a maximum air speed of approximately 150 km/h. More details about the tunnel can be found in Alam et al. [8]. Two experimental set ups were developed and evaluated. At first, a support system previously developed for tennis and cricket balls was used to hold the baseball on a force sensor in the wind tunnel, and the experimental set up with the support system in the test section of the wind tunnel is shown in Figure 5. However, the measured interference drag using this set up was higher. Therefore, the 2nd experimental shown in Figure 4 has been developed. The measured interference drag was found significantly lower compared to the 1st (vertical) experimental set up. In order to minimise the interference drag further, an aerofoil was used around the support. The aerodynamic effect of the support device was subtracted from the support with the ball. The distance between the bottom edge of the ball and the tunnel floor was 400 mm, which is well above the tunnel boundary layer and considered to be out of ground effect completely. The influence of the support on the ball was checked and found to be negligible. The repeatability of the measured forces was within ±0.01 N and the wind velocity was less than 0.5 km/h.

a) Frontal view



b) Side view

Fig 4. Horizontal experimental set up for the baseball in the wind tunnel

Fig 5. Vertical experimental set up in the wind tunnel

All three forces (drag, lift and side force) and their corresponding moments were measured. Tests were conducted at a range of wind speeds under four orientations (positions) of the ball as shown in Figure 3 to evaluate the effects of seam on aerodynamic properties. As a baseball possesses rough and curved stitches on its surface, the aerodynamic behaviour can differ under different orientations of the ball. Additionally, stitch pattern can also influence the airflow and generate induced drag at different velocities. In order to get insights into potentially different aerodynamic behaviour, as mentioned earlier, the baseball was tested at four seam orientations facing the oncoming wind in the wind tunnel.

The aerodynamic forces and moments were measured under a range of wind speeds (40 km/h to 140 km/h with an increment of 20 km/h) under each orientation (position). The non-dimensional parameters such drag coefficient (C_D) and side force coefficient (C_S) were estimated using equations 1 and 2.

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

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

Where D, ρ, V, S, A are the drag, air density, wind velocity, side force, projected frontal area of the ball respectively. The projected frontal area was determined using equation 3.

$$A = \frac{\pi d^2}{4} \qquad (3)$$

Where d is the diameter of the ball measured at the midpoint of the ball with the seam height.

3. RESULTS AND DISCUSSION

In this paper, only drag (D) and its non-dimensional coefficient (C_D) are presented for all four orientations for the entire range of speeds (40 to 140 km/h) tested. The drag force (D) and the C_D values are shown in Figures 6 and 7.

It is clearly evident that there is a significant variation in drag forces at four different orientations. As expected, the drag force increases with an increase of speeds. However, the seam position 1 and seam position 2 which are the mirror image has lower magnitude of drag forces compared to the drag forces of position 3 and position 4. The position 3 and position 4 are also the mirror image and possess no significant drag difference between them. However, a notable variation in drag force is noted between the positions 1& 2 and positions 3 & 4. An average drag force curve of all 4 positions is also shown in Figure 5.

The C_D variations with Reynolds numbers for all four seam positions are shown in Figure 8. The C_D value variations among four positions are evident at low Reynolds number however these variations are minimal at high Reynolds numbers. The minimum variation at high Reynolds number is believed to be due to the elimination and/ or minimization of local flow separations from seams. The average C_D value for all four positions is approximately 0.40 at high Reynolds number. However, the C_D value is over 0.50 at low Reynolds number. The C_D value published by Alam et al. [3] was slightly higher which is believed to be due to the aerodynamic interference of the experimental set up. Therefore, data was obtained here using a new experimental set up (see Section 2.2). The C_D values found in this study agree well with the published data [2]. There is no evidence on the flow transitional effect on the baseball from laminar to turbulent flow under the speed range tested here. The maximum speed used here is 140 km/h however an average speed of a professional pitcher is around 155 km/h which is well beyond the maximum speed limit of RMIT Industrial Wind Tunnel. According to Adair [2], the baseball does not display a notable transitional effect like a smooth sphere due to the presence of its complex seams and stitches. Our data also indicate no transitional effect on baseball. As mentioned earlier, the effects of seam and stitches are evident at all Reynolds numbers as the local flow separation is generated due to seams, stitches and their complex orientation. Nevertheless, these local flow separations become minimal at high Reynolds number thus reducing the effects of seams and stitches. The seam position 4 has the highest effect compared to other seam positions whereas the seam position 1 has the lowest average C_D value in contrast with the C_D value of position 4. The average C_D value is much lower than positions 3 and 4 C_D values whereas the C_D value is higher than positions 1 and 2 C_D values. Further study is underway to visualise the airflow around the baseball and will be reported in the subsequent publications.

As mentioned earlier, the baseball is usually played at speeds greater than 100 km/h. The asymmetric forces can be considerable for baseballs due to the complex seam orientation, stitches and most importantly due to spin. These asymmetric forces can swerve the flight path of the ball so sharply that it is almost impossible to hit and catch. However, the most skilful pitcher has great difficulty in throwing the ball with the precision required to generate a reproducible break. As a result, the behaviour of the ball often surprises players - batter, catcher and pitcher. Therefore, it is utmost important to understand the complex aerodynamics of the base ball under spinning and non-spinning conditions. In this study, as mentioned earlier, only no-spinning condition data is presented. Further study is underway to investigate the spin effects on baseball aerodynamics.

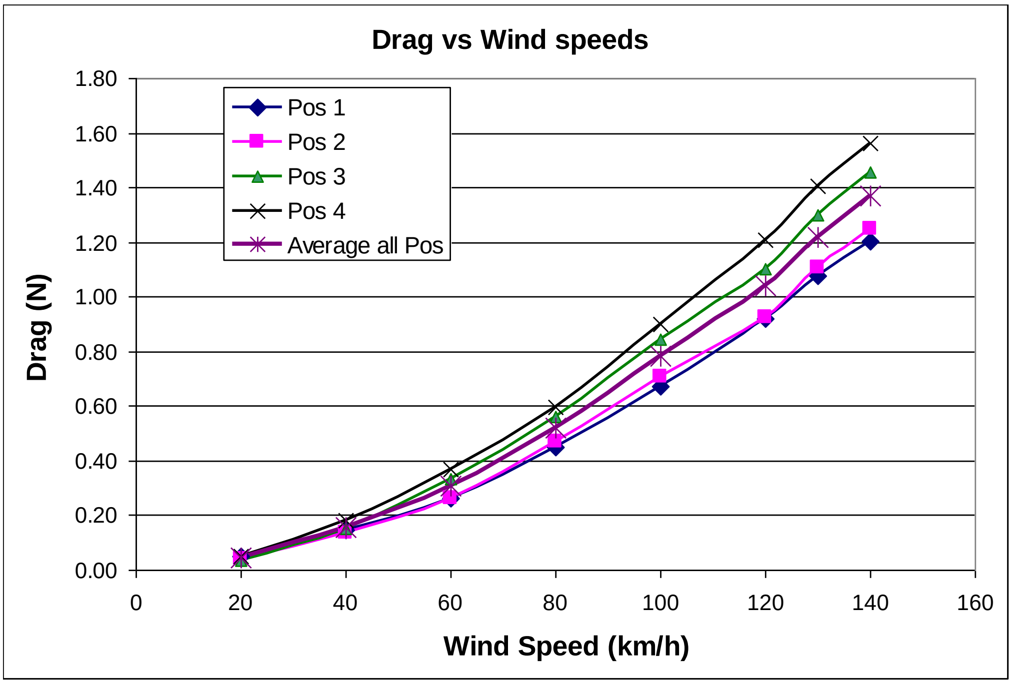


Fig 7. Drag force (D) as a function of wind speeds

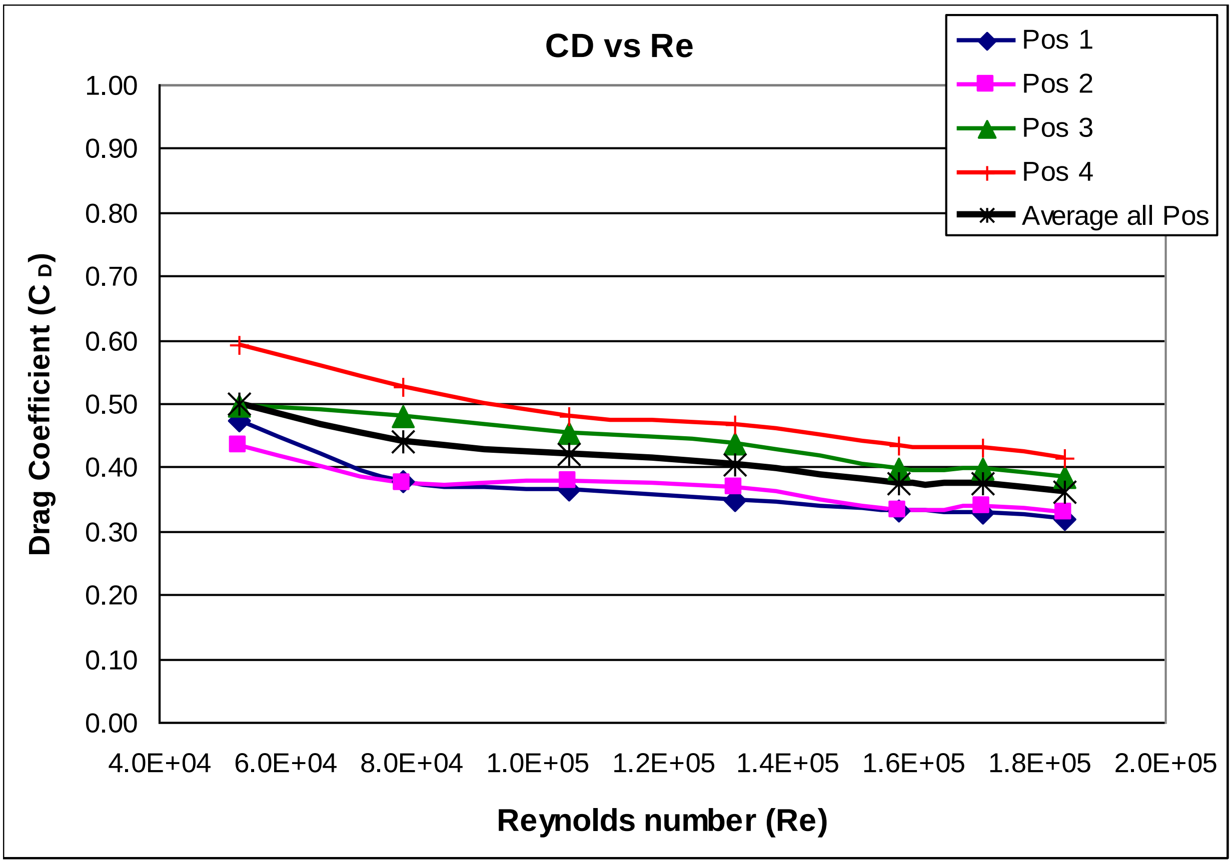


Fig 8. Drag coefficient (C_D) as a function of Reynolds number for all four positions

4. CONCLUSIONS

The following conclusions have been drawn from the experimental study presented here:

The average C_D value for a baseball obtained in this study is around 0.40 at high Reynolds number.

Seam orientation and stitches have significant effects on baseball aerodynamics at low Reynolds numbers however these effects are minimal at high Reynolds numbers.

No significant transitional effect is evident in the baseball C_D value.

The variation of C_D value between sides of a baseball facing the wind can vary be up to 25%.

5. FUTURE WORK

- Measurement of aerodynamic properties of baseballs with varied seam heights and widths;
- Undertaking a comparative aerodynamic analysis of baseball and softball
- Airflow visualization around a base ball to understand the flow dynamics around the ball;
- Measure the effects of spin on aerodynamic properties of baseball.

6. ACKNOWLEDGMENTS

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7. REFERENCES

1. Achenbach, E. (1972), Experiments on the flow past spheres at very high Reynolds numbers. *Journal of Fluid Mechanics*, 54:565–575.
2. Adair, R.K. (1995), The Physics of Baseball. *Physics Today*, 1:26-31.
3. Alam, F., Huy, H., Chowdhury, H. and Subic, A. (2011), Aerodynamics of baseballs, *Procedia Engineering*, 13:207-212, Elsevier
4. Alam, F., Subic, A., Watkins, S., Naser, J. and Rasul, M. G. (2008), An Experimental and Computational Study of Aerodynamic Properties of Rugby Balls, *WSEAS Transactions on Fluid Mechanics*, 3(3): 279-286.
5. Alam, F., Subic, A., Watkins, S. and Smits, A. J.

(2010). Aerodynamics of an Australian Rules Foot Ball and Rugby Ball in Computational Fluid Dynamics for Sport Simulation (edited by M. Peters), ISBN 13: 978-3-642-04465-6, 103-127. Springer

6. Alam, F., Chowdhury, H., Subic, A. and Fuss, F.K. (2010), A Comparative Study of Football Aerodynamics, *Procedia Engineering*, 2(2):2443-2448.
7. Alam, F., Subic, A., Watkins, S., Naser, J., Rasul, M.G. (2008), An experimental and computational study of aerodynamic properties of rugby balls. *WSEAS Transactions on Fluid Mechanics*; 3:279-286.
8. Alam, F., Zimmer, G., Watkins, S. (2003), Mean and time-varying flow measurements on the surface of a family of idealized road vehicles, *Experimental Thermal and Fluid Sciences*; 27:639-654.
9. Alaways, L.W. (1998), Aerodynamics of the curve ball: An investigation of the effects of angular velocity on baseball trajectories. PhD Thesis, University of California Davis, USA
10. Asai, T., Seo, K., Kobayashi, O., Sakashita, R. (2007), Fundamental aerodynamics of the soccer ball, *Sports Engineering*; 10:101-110.
11. Kensrud, J.R. (2010), Determining aerodynamic properties of sports balls in situ, M.Sc Thesis 2010, Washington State University, USA.
12. Mehta, R.D., Alam, F., Subic, A. (2008), Aerodynamics of tennis balls- a review, *Sports Technology*; 1(1):1-10.
13. Nathan, A. (2009), The effect of spin on the flight of a baseball, *American Journal of Physics*; 76:119-124.
14. Smits, A.J and Ogg, S. (2004), Golf ball aerodynamics, *The Engineering of Sport 5*; 1:3-12.

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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