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Effects of seam and surface texture on tennis balls aerodynamics

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Abstract

Currently, serving becomes a dominant factor in tennis tournament as the ball travels faster and sometimes the returning player and spectators are unable to follow the track of the ball. As a result, the game becomes boring causing the spectator to lose passion for the game. The reduced speed of the ball can make the game more enjoyable. The understanding of aerodynamic behaviour of tennis balls is important in helping to design and develop a ball that can slow down the game. The complex surface texture of a tennis ball may affect its aerodynamic behaviour as well. As limited information on aerodynamic behaviour of contemporary tennis balls are available, a study was undertaken to investigate the effects of seam and surface texture of a range of commercially manufactured tennis balls. The drag coefficients were analysed and compared. The surface texture and seam orientation showed a noticeable variation in drag coefficients among these balls.

Keywords: Drag; wind tunnel; seam angle; tennis ball; flow visualisation; side force

1. Introduction

Tennis is one of the most popular sports in the world. However, in the game of tennis serving has become the dominant key to winning tennis matches. This creates a problem for both the opposing player and tennis spectators worldwide, as tennis is most enjoyable when the rally length is long. This has caused the governing body in world tennis, the International Tennis Federation (ITF) to introduce larger diameter balls (e.g. Wilson Rally 2). The aerodynamic behavior of a tennis ball plays a central role in the process of slowing down the game. Numerous studies on drag and lift of a typical tennis ball as a function of Reynolds number have been reported in the open literature,

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(e.g. Alam et al. [1, 3, 4], Mehta et al. [2], and Chadwick and Haake [5]). There is a significant variation of aerodynamic drag coefficients in this data and it is not clear whether this variation is due to experimental methods or to other effects such as seam position.

The seam design of a tennis ball plays a significant role in determining how the flow over a tennis ball behaves. The seam structure is not regulated by the ITF, and slightly varies between the manufacturer's specifications. The seam depth and width varies between each of the balls, ranging between 3 to 4mm in width and 1 to 2 mm in depth. Seam width and depth size can play an important role in local flow separation over the ball, affecting the boundary layer transition. Therefore, the primary objectives of this paper were to investigate the effect of seam positions under range of wind from 30 to 130 km/h. Flow visualization with smoke was conducted on a novelty size tennis ball for two different seam positions.

2. Experimental Procedure

A stud for holding the tennis ball was mounted on a 6-component force sensor (type JR3) [6] and computer software in the RMIT industrial wind tunnel was used to record all 3 forces (drag, side and lift) and their respective moments acting on the tennis ball. Figure 1 shows the experimental setup. Figure 2 shows the 6 different ITF approved commercially available balls which were used in the wind tunnel testing; of the six balls tested the two Wilson balls and Tretorn Plus have a diameter of 64.5 mm, the two Slazenger balls have a diameter of 65.5 mm and the Tretorn Micro-X has a diameter of 65 mm. the dimensions of the seam of each of the six balls are as follows: the two Slazenger balls, Tretorn Plus and Wilson Aus Open balls each have a seam width of 2 mm; and the Tretorn Micro-X and Wilson Us Open balls have a seam width of 3mm. A view of the seam angle positions is shown in Figure 3.

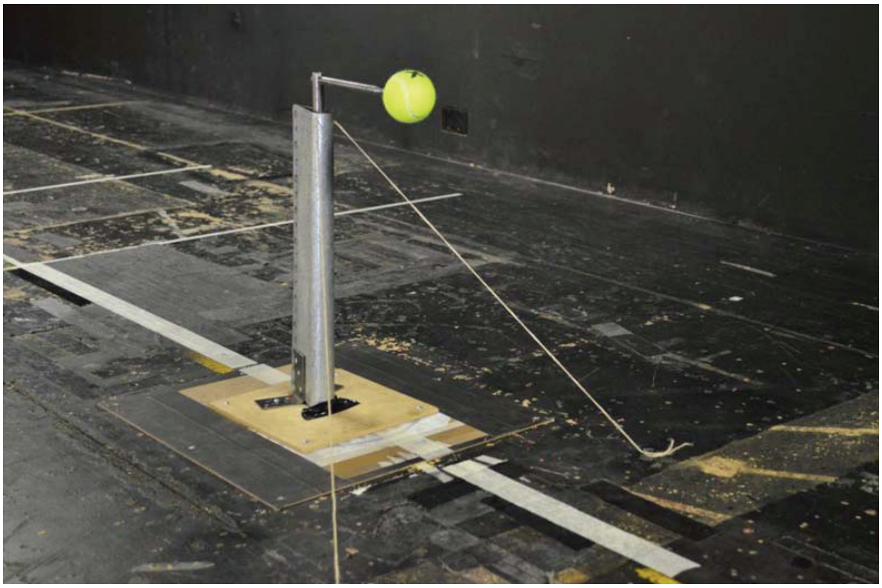

Fig. 1. Side view of horizontal setup of sting and tennis ball

(a) Slazenger HI VIS

(b) Slazenger Ultra VIS

(c) Tretorn Plus

(d) Tretorn Micro-X

(e) Wilson US Open

(d) Wilson Australian Open

Fig. 2. A view of each six different tennis balls used for testing

(a)

(b)

(c)

(d)

Fig. 3. Seam angle positions tested (front view): (a) Position 1 (0º); (b) Position 2 (90º); (c) Position 3 (180º); (d) Position 4 (270º)

3. Flow visualization

Flow visualization tests were also undertaken in the RMIT Industrial Wind Tunnel, on a novelty sized Wilson Australian Open tennis with a diameter of approximately 228.6 mm. Using a larger sized tennis allowed for better analysis and visual observation of the flow around a tennis ball much more accurately, compared to the flow visualization of a regulation size tennis ball. The smoke was directed parallel to the direction of the flow with the free stream velocity set to 10km/h. Tests were conducted on a non-rotating ball, set at a seam angle of 270º shown in

Figures 4 (a) to (f), in order to have two separate sets of seam trip the flow over the top side of the ball. Figure 4(g) shows the ball set to a zero pitch angle with seam angle 0º.

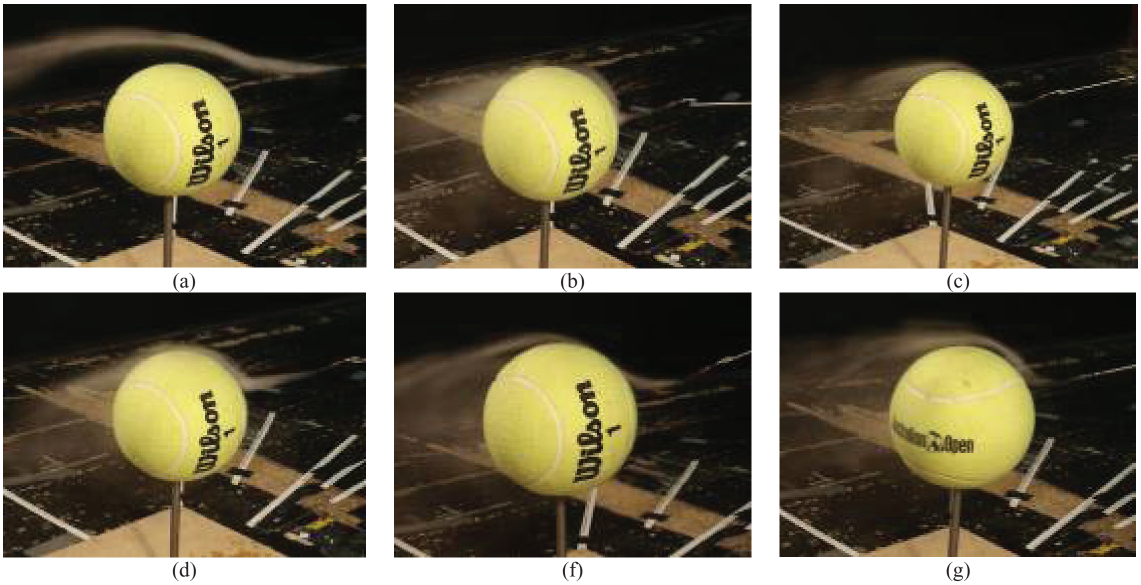

Fig. 4. Flow visualization around different points of a larger diameter (228.6 mm) tennis ball

As shown in Figure 4, the images of the smoke test show the flow development around the tennis ball, especially the drag “wake” region forming behind the tennis ball which is the most crucial section[, stated by Watts and Ferrer [7] and Yun et al.[8]. Flow separation occurs prior reaching the apex of the tennis ball as shown in Figure 4(a). At lower speeds, the flow separation occurs prior to the apex and introduces a “swirl” effect behind the tennis ball that is known as the “wake” region. It is believed that the magnitude of drag is dependent on felt design and wind speed. The felt design can potentially produce more drag due to complex and local flow separation around the individual felt.

4. Results and Discussion

As mentioned earlier, the objective of studying six different tennis balls at four different seam angles was to measure the effect of aerodynamic properties, namely drag coefficient. The dimensionless parameter drag coefficient (C_D) was calculated by using the following formula:

$$C_D = D/0.5\rho V^2 A \quad (1)$$

Where, D represents the drag force, ρ is the air density, V is the airflow velocity and A is the area of the tennis ball.

Figure 5 illustrates the C_D variation with wind speeds for each six tennis balls for various seam orientation. The Wilson US Open ball had the highest average drag coefficient and Slazenger Ultra Vis had the lowest average drag coefficient at all wind speeds tested. The balls have a relatively high drag coefficient at the smaller wind speeds tested (30 to 40 km/h) ranging from 0.6 to 0.7, which can be mainly attributed to the felt filament. However, for seam position 1 the Tretorn Micro X had its lowest drag coefficient value at 30 km/h. In tennis ball, there are no clear flow transition phases. However, the flow over the tennis balls can be characterized as transcritical, with a relatively high drag coefficient. For tennis balls, the felt filaments covering the surface not only create a rough surface but also act as small bodies which generate their own form drag and interactions with other fibers on the ball. And with increasing speeds, these fibers tend to bend around the ball, creating a more streamlined ball, which reduces local flow separation. This leads to an overall decrease in the drag coefficient for the tennis ball at high speeds or high Reynolds numbers.

Seam orientation had no significant effect on drag coefficients at high wind speeds as the local flow separation reduces with the speed. However, seam orientation had a noticeable effect on the drag coefficient at lower wind speeds for all balls as the local flow separation occurs around the seam. The largest effects on drag coefficient by seam orientation were observed for the Wilson US Open (seam position 3). This ball has relatively wider and deeper seam compared to all other balls and generates local flow separation.

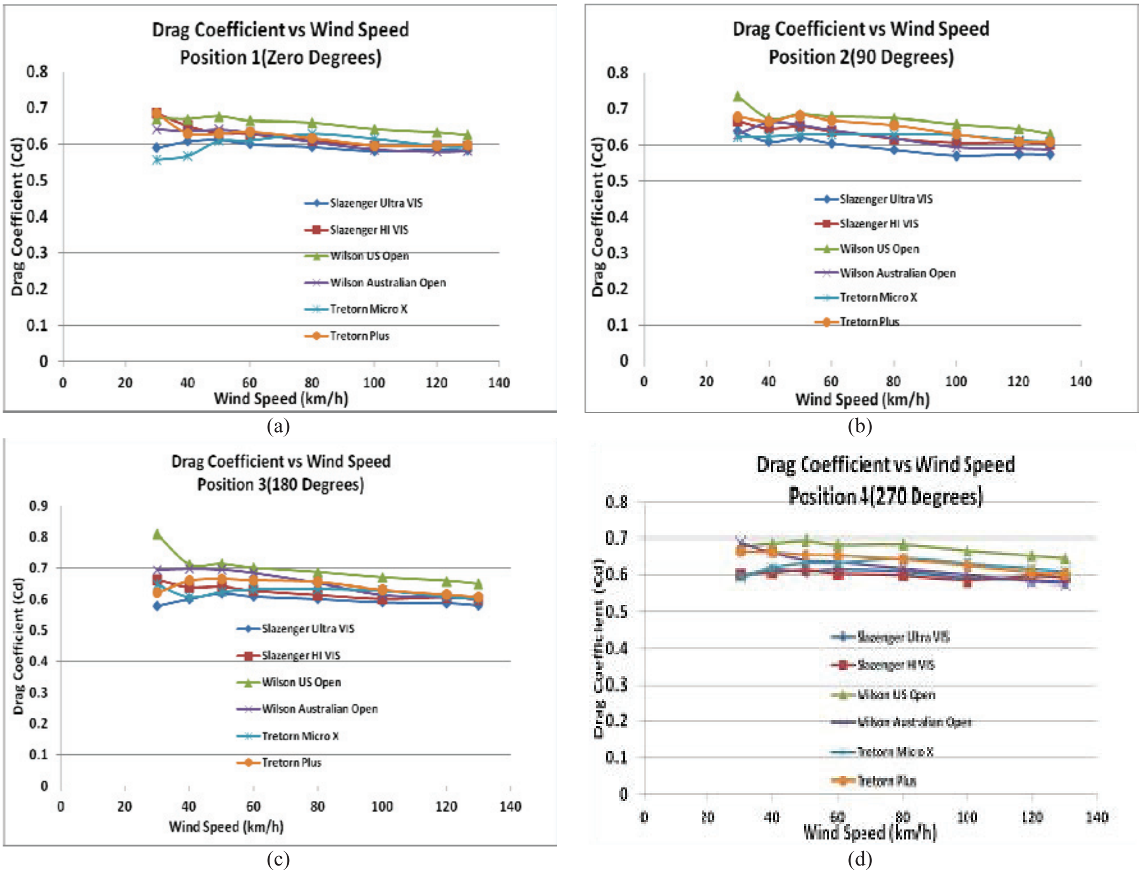

Fig. 5. Dag coefficient as a function of wind speed at: (a) 0º; (b) 90º; (c) 180º; (d) 270º seam orientations

The C_D values found in this study are slightly higher compared to the published data (e.g. Alam et al. [4], Chadwick & Haake [5] and Mehta et al. [9]). There are some minor differences in results however these are mostly due to experimental errors arising from the sensitivity of the force sensor reading, misalignment of the ball, and the turbulence intensity of the airflow. The turbulence intensity at RMIT

Industrial Wind Tunnel is approximately 1.8% which is considered to be close to the atmospheric condition.

5. Conclusion

The aerodynamics and flow around a tennis balls is significantly complex compared to a smooth sphere, due to the felt. The drag coefficient for such a small ball is quiet large, considering its size with an average drag coefficient of 0.6. It can be concluded that the seam orientation relative to the airflow plays no significant part in affecting the aerodynamic characteristics of a tennis ball in flight. The felt covering of the tennis ball has the most influence on the aerodynamic properties of the ball; with increasing speed there is an overall drop in the aerodynamic drag due to the felt covering becoming more streamlined. It is believed that the C_D value will reduce further with the ageing of the ball as the felt and filament will be shortened due to wear.

References

[1] Alam F, Tio W, Watkins S, Subic A and Naser J. Effects of Spin on Tennis Ball Aerodynamics: An Experimental and Computational Study, Proceedings of the 16th Australasian Fluid Mechanics Conference 2007, 324-327.

[2] Mehta RD, Alam F, and Subic A. Aerodynamics of tennis balls- a review. Sports Technology 2008;1(1):1-10.

[3] Alam F, Subic A and Watkins S. Effects of Spin on Aerodynamic Properties of Tennis Balls, Proceedings of The 5th International Conference on Sports Engineering (by ISEA) 2004, 83-89.

[4] Alam F, Watkins S and Subic A. The Aerodynamic Forces on a Series of Tennis Balls, Proceedings of the 15th Australasian Fluid Mechanics Conference, University of Sydney, Sydney; 2004.

[5] Chadwick S G and Haake S J. The drag coefficient of tennis balls. The Engineering of Sport: Research, Development and Innovation, Balckwell Science, 2000:169-176.

[6]] Djamovski V and Alam F. An experimental and computational study of a rugby ball's aerodynamics. In:The Proceedings of the International Conference on Mechanical Engineering and Renewable Energy (ICMERE2011), Bangladesh: CUET; 2011.

[7] Watts R G and Ferrer R. The Lateral Force on a Spinning Sphere. American Journal of Physics 1987;55:40-45.

[8] Yun G, Kim D and Choi H. Vortical Structures behind a Sphere at Subcritical Reynolds Numbers. Physics of Fluids 2006;1:1-18.

[9] Mehta R D and Pallis J M.Sports Ball Aerodynamics: Effects of Velocity, Spin and Surface Roughness. In: Froes S and Haake SJ, Editors. Materials and Science in Sports, 2001, p. 185-197.