The Aerodynamic Forces on a Series of Tennis Balls

F. Alam, S. Watkins and A. Subic

School of Aerospace, Mechanical & Manufacturing Engineering
RMIT University, Melbourne, VIC 3083, AUSTRALIA

Abstract

The aerodynamic properties of typical tennis balls as a function of Reynolds numbers have been reported in the open literature. However, the results are somewhat different as each study indicated differences in drag coefficients. The primary objective of this paper is to study the aerodynamic drag of tennis balls used in major tournaments around the world. Results presented in this paper are at steady conditions (no spin involved).

Introduction

Tennis is one of the most popular games in the world. The International Tennis Federation (ITF) is actively considering how to slow down the speed of tennis balls in order to make the game more attractive to spectators by increasing the diameter of the ball or some other way. The aerodynamic properties of a tennis ball will play a vital role in this process. However, not many studies have been conducted on aerodynamics of tennis balls. Several studies on the aerodynamic drag and lift of a typical tennis ball as a function of Reynolds numbers have been reported in the open literature (Mehta and Pallis [1], Chadwick and Haake [2], Cooke [3], Stepanek [4]). There is a significant variation of aerodynamic drag coefficients and it is not clear if this variation is due to experimental techniques or to other effects such as the relative position of the seam. It is well known that aerodynamic properties are significantly affected by the spin of a ball thus the motion and flight path of the ball. Although several studies on aerodynamic drag, lift and surface (fuzz) effects have been conducted there are still gaps in understanding. Therefore, a project is being undertaken in the School of Aerospace, Mechanical and Manufacturing Engineering of RMIT University to study the effects of spin on aerodynamic properties of a series of tennis balls. As a part of this large project, a separate study on steady state (without spin) aerodynamic forces and moments has been conducted on a series of new tennis balls used in the Australian Open Tennis Championship. The aerodynamic drag coefficients are compared with the published work in order to understand the variation.

Experimental Procedure and Equipment

The aerodynamic forces and their moments were measured for a range of Reynolds numbers based on ball diameters and tunnel air speeds (40 km/h to 140 km/h with an increment of 20 km/h air speeds) as a function of seam orientation. Six tennis balls have been selected for this work as they are officially used in the Australian Open Championship. These balls are: Dunlop 3 Ti, Dunlop 2 Grand Prix, Kennex Pro, Tretorn Micro X, Tretorn Plus and Penn Tennis Master Series. Their average diameters are: 65.5 mm, 65.5 mm, 64.0 mm, 65.0 mm, 64.5 mm and 65.5 mm respectively. The diameter of the ball was determined using an electronic calliper. The width was adjusted so that the ball can slide through the opening with minimum effort. Diameters were measured across several axes and averaged. All balls were brand new. Fuzz structures of these balls are slightly different from each other. A special mounting support device was designed to hold each ball and spin up to 3500 rotations per minute (RPM),

see Figures 2 and 3. The motorised device was mounted on a 6 component force balance (type JR-3).
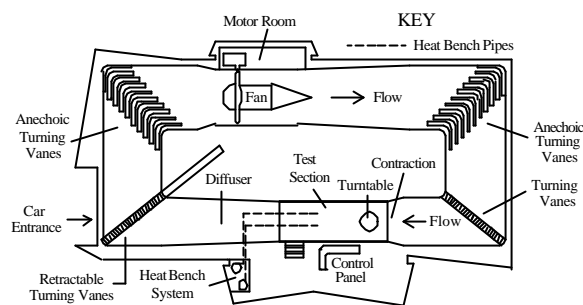

Figure 1: A Plan View of RMIT Industrial Wind Tunnel

Figure 2: Experimental Set Up in Tunnel's Test Section

Figure 3: Motorised Ball Supporting Device mounted on a 6-Component Force Balance

Figure 2 shows the experimental set up in the wind tunnel test section. The distance between the bottom edge of the ball and the tunnel floor was 350 mm, which is well above the tunnel's boundary layer and considered to be out of ground effect. Each ball was tested at 4 seam positions (at 0, 90, 180 and 270 degrees). The seam positions for all 6 balls are shown in Figures

4 to 9. Experiments were performed in RMIT University Industrial Wind Tunnel. A plan view of RMIT Industrial Wind Tunnel is shown in Figure 1. This is a closed test section, closed return circuit wind-tunnel with a maximum speed of 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 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. Purpose made computer software was used to compute all 6 forces and moments (drag, lift, roll, yaw moment, pitch moment and roll moment) and their non-dimensional coefficients. Since the blockage ratio was extremely low no corrections were made.

Results and Discussion

In order to obtain aerodynamic forces and moment for each ball, the motorised 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 10 to 13 show the drag coefficient variation with velocities for seam position 1, seam position 2, seam position 3 and seam position 4 for all 6 balls.

The Tretorn Plus ball had the highest average drag coefficient and Dunlop 3 Ti and Penn Master Series had the lowest average drag coefficient at all Reynolds numbers tested (see Figures 5 and 6). All balls have relatively high drag coefficients at 40 km/h. However, Tretorn Micro X had the lowest drag at 40 km/h for seam position 2. At higher speeds, the fuzz becomes more streamlined and reduces the turbulent boundary layer and local flow separation. Drag coefficients reduce with an increase of Reynolds numbers and remain almost constant at higher Reynolds numbers. It is well known that flow separation that exists at lower Reynolds numbers will reduce at higher Reynolds numbers. Seam orientation had no significant effect on drag coefficients at high Reynolds numbers as expected. However, seam orientation has noticeable effects on drag coefficients at lower Reynolds numbers for all balls. The highest effects on drag coefficients by seam orientation have been noted for the Tretorn Plus (seam position 1). The averaged drag coefficients for all four seam positions and Reynolds numbers are shown in Figure 14 and Table 1. Overall drag coefficients (averaged) for all Reynolds numbers and seam positions for Tretorn Plus, Tretorn Micro X, Kennex Pro, Dunlop 2 Grand Prix, Dunlop 3 Ti and Penn Master Series 0.69, 0.62, 0.62, 0.61, 0.59 and 0.59 respectively. However, the averaged drag coefficients for all seam positions and Reynolds numbers (except 40 km/h) are lower and they are: 0.64 (Tretorn Plus), 0.62 (Tretorn Micro X), 0.60 (Kennex Pro), 0.59 (Dunlop 2 Grand Prix), 0.57 (Dunlop 3 Ti) and 0.58 (Penn Master Series).

It may be noted that a separate study conducted by Alam et al. [3, 4] showed the overall drag coefficients for some other balls such as Bartlett, Wilson DC 2, Wilson US Open 3, Wilson Rally 2, Slazenger 1 and Slazenger 4 are 0.71, 0.68, 0.66, 0.60, 0.60 and 0.57 respectively under the same test conditions used in this work (eg., 40 to 140 km/h with an increment of 20 km/h).
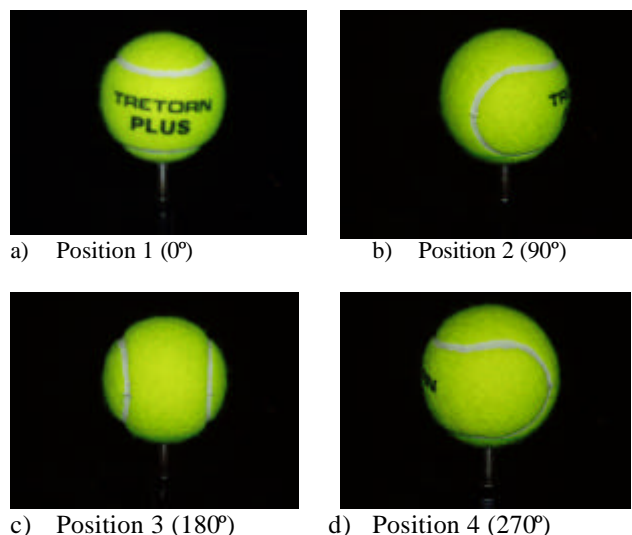

a)   Position 1 (0º)   b)   Position 2 (90º)

c)   Position 3 (180º)   d)   Position 4 (270º)

Figure 4: Orientation of Seam Towards Wind Direction (Tretorn Plus)

a) Position 1(0º)   b) Position 2 (90º)

c) Position 3 (180º)   d) Position 4 (270º)
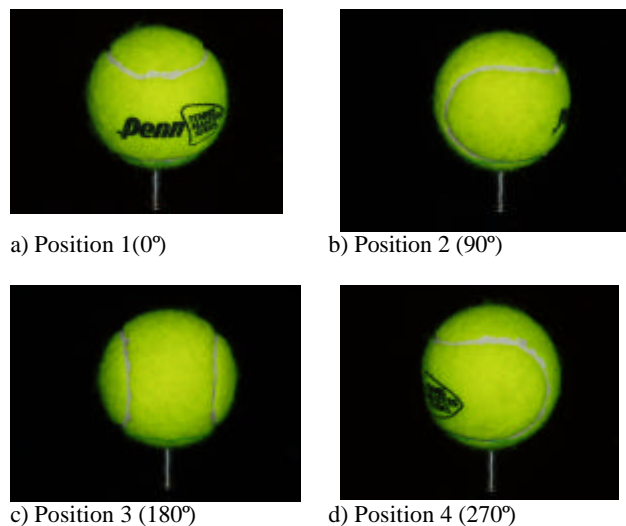
Figure 5: Orientation of Seam Towards Wind Direction (Penn Master Series)

a)   Position 1 (0º)   b)   Position 2 (90º)

c)   Position 3 (180º)   d)   Position 4 (270º)
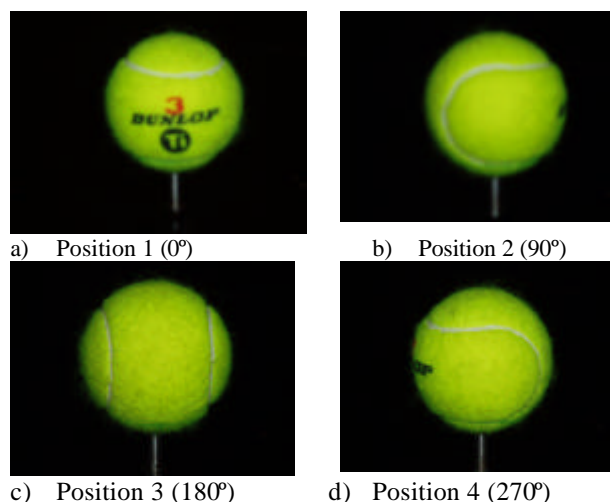
Figure 6: Orientation of Seam Towards Wind Direction (Dunlop 3 Ti)

a)   Position 1 (0º)   b)   Position 2 (90º)

c)   Position 3 (180º)   d)   Position 4 (270º)
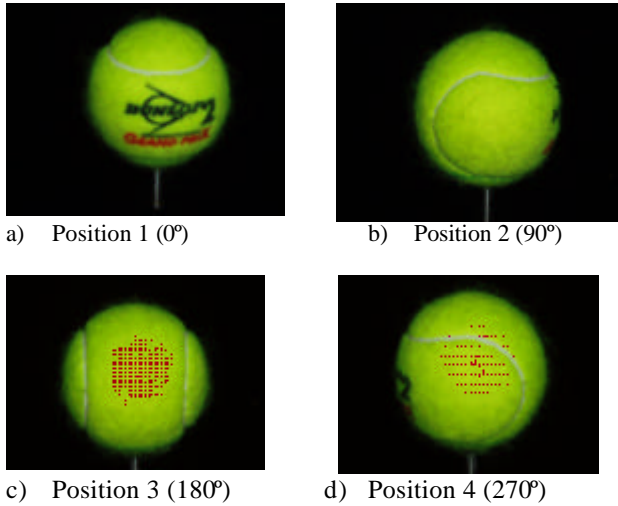
Figure 7: Orientation of Seam Towards Wind Direction (Dunlop 2 Grand Prix)

a)   Position 1 (0º)   b)   Position 2 (90º)

c)   Position 3 (180º)   d)   Position 4 (270º)
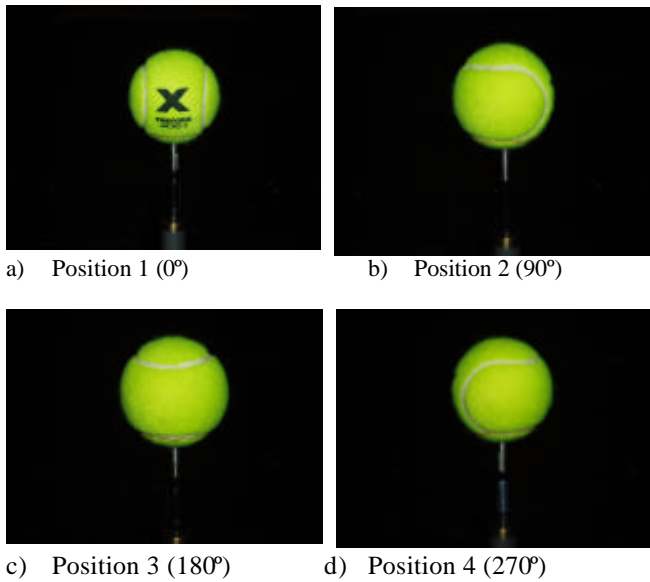
Figure 8: Orientation of Seam Towards Wind Direction (Tretorn Micro X)

a)   Position 1 (0º)   b)   Position 2 (90º)

c)   Position 3 (180º)   d)   Position 4 (270º)
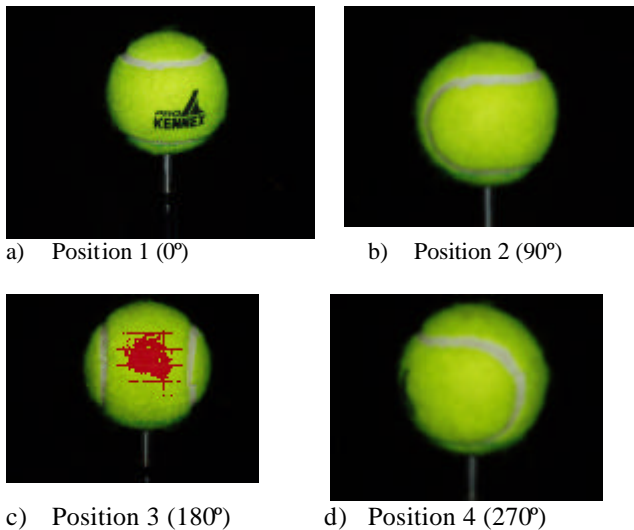
Figure 9: Orientation of Seam towards Wind Direction (Kennex Pro)
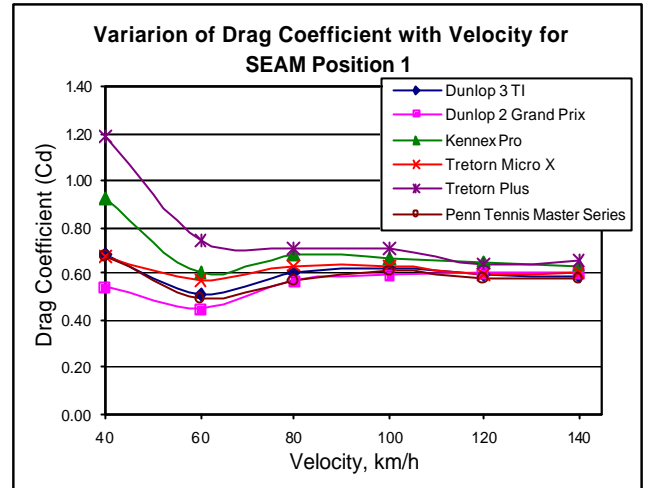

Figure 10:   Drag Coefficient Variation with Velocity, SEAM Position 1
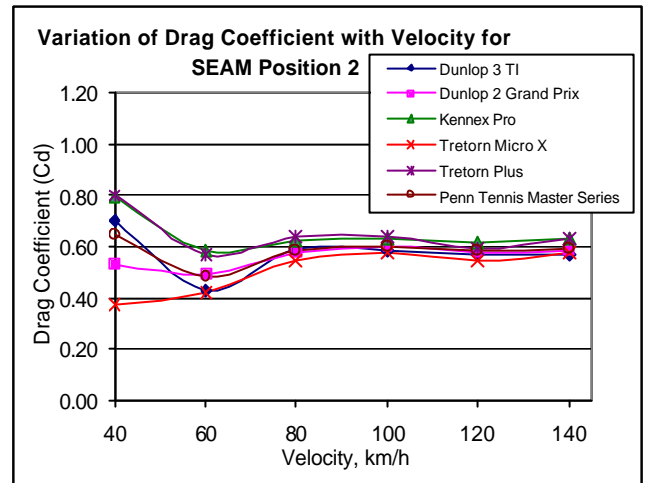

Figure 11:   Drag Coefficient Variation with Velocity, SEAM Position 2
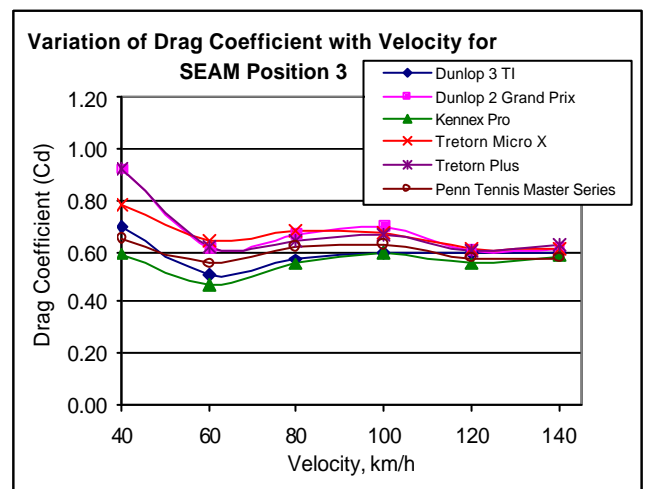

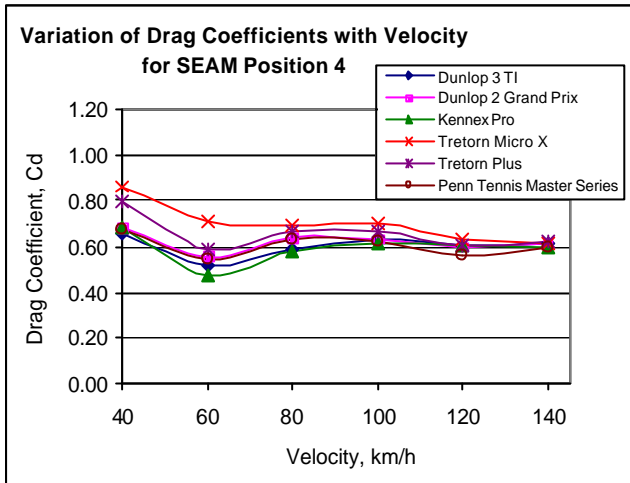Figure 12:   Drag Coefficient Variation with Velocity, SEAM Position 3

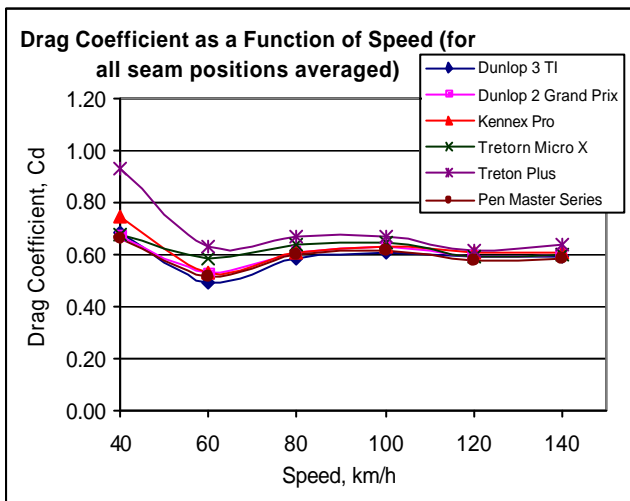Figure 13: Drag Coefficient Variation with Velocity, SEAM Position 4

Figure 14: Averaged Drag Coefficient Variation with Velocity for all 4 SEAM Positions)

Table 1: Averaged Drag Coefficients for all 6 Balls

	Dunlop 3 Ti		Dunlop 2 Grand Prix	
Speed	**Averaged Cd**	**Averaged Cd**	**Averaged Cd**	**Averaged Cd**
km/h	All seam pos.	All seam pos. & speeds	All seam pos.	All seam pos. & speeds
40	0.69		0.67	
60	0.49		0.53	
80	0.58	0.59	0.61	0.61
100	0.61		0.63	
120	0.59		0.59	
140	0.59		0.60	

	Kennex Pro		Penn Master Series	
Speed	**Averaged Cd**	**Averaged Cd**	**Averaged Cd**	**Averaged Cd**
km/h	All seam pos.	All seam pos. & speeds	All seam pos.	All seam pos. & speeds
40	0.75		0.66	
60	0.53		0.52	
80	0.61	0.62	0.60	0.59
100	0.63		0.61	
120	0.61		0.57	
140	0.61		0.59	

	Tretorn Micro X		Tretorn Plus	
Speed	**Averaged Cd**	**Averaged Cd**	**Averaged Cd**	**Averaged Cd**
km/h	All seam pos.	All seam pos. & speeds	All seam pos.	All seam pos. & speeds
40	0.68		0.93	
60	0.59		0.63	
80	0.64	0.62	0.67	0.69
100	0.65		0.67	
120	0.60		0.61	
140	0.60		0.64	

Conclusions

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

- Seam orientation has effects on drag coefficients at a very low Reynolds numbers. The magnitude of drag coefficient variations largely depends on seam and fuzz geometry.
- The "Tretorn Plus" possesses the highest drag coefficient and the "Dunlop 3 Ti and Penn Master Series" has the lowest aerodynamic drag coefficient.
- The averaged drag coefficients of all six new tennis balls (studied in this work) are between 0.59 to 0.69.

Acknowledgments

References

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