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A Comparative Study of Golf Ball Aerodynamics

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Abstract

The aerodynamic behaviour of the golf ball is primarily dependent on the physical features of complex dimples. The dimples vary in sizes, shapes and depths which generate complex aerodynamic flow pattern around the ball. Although some studies have been conducted on golf ball aerodynamics, the aerodynamic behaviour of dimple characteristics is not fully understood. The primary objective of this research is to experimentally evaluate the aerodynamic properties (drag, lift/down force) of a series of commercially available golf balls. Each of these new balls has different dimple characteristics. These balls were tested under a range of speeds. The aerodynamic properties were analysed. Due to varied dimple geometry, the magnitudes of drag coefficients of these balls were varied significantly. The non-dimensional drag coefficient for each ball was compared. The effects of spin on drag and lift have also been evaluated. However, spin data was not included in this paper.

Introduction

The golf is one of the popular and widely watched sports in many countries of the world. Apart from individual natural skills of the player, the performance is largely depends on the equipment used. Arguably the two most important pieces of the equipment are the golf ball and the club. However, from the aerodynamics point of view, the main centre piece is the dimpled ball. The aerodynamic behaviour of the golf ball is primarily relies on the physical features of the complex dimples. Most commercially manufactured golf balls have dimple numbers ranging from 250 to 500. These dimples vary in sizes, shapes and depths. At present, golf ball manufacturers claim and counter claim about the superior aerodynamic performance of their balls, however there is no independent study confirms their claims. With so many different golf balls in the market with a wide range of prices, the question must be asked: is a more expensive golf ball generally better? Golf balls are made by many different manufacturers and are available in a wide variety of configurations to suit a golfer's style of play and choice. These include the construction of the ball, the number and the shape of the dimples.

The airflow around spherical balls especially golf ball and the oval shaped balls (rugby, Australian rules football, American football etc) are complex [3]. The dimples of the golf ball make the flight trajectory of a golf ball very interesting and complicated. A golf ball usually flies at a high speeds at which the drag of a golf ball is about half of that of a smooth sphere because of dimples on the golf ball surface. Meanwhile, near a golf ball surface, dimples play an important role to trigger the boundary layer transition from laminar to turbulent flow. However, mechanisms of the boundary layer transition by the dimples have not been fully understood [4-5, 7-10]. Several studies conducted by Smits et al. [8-9], Bearman and Harvey [6], Choi et al. [7], Smith et al. [10] and Ting et al. [11] on golf ball aerodynamics under spinning and non spinning conditions and their findings were published widely. However, the effects of dimple characteristics on golf ball aerodynamics remain a mystery. Some studies conducted by the commercial golf ball manufacturers are kept in-house due to the stiff market competition. A very little information is available on the latest development of golf ball in the public domain. Therefore, the primary objective of this research is to evaluate the aerodynamic properties (drag, lift/down force) of a series of commercially available golf balls with varied dimple characteristics and numbers that are widely used in professional as well as amateur golf.

Experimental Procedure

Description of Golf Balls

Eight brand new commercially available golf balls that are widely used in major tournaments around the world were selected for this study. Each of these new balls has different dimple characteristics. A Squash ball was also used in this study. The external surface of the Squash ball is relatively smooth and its diameter is close to the average diameter of the golf ball (see Figure 1). The commercial brand name and their physical characteristics (diameter, mass, price, dimple shapes, etc) are shown in Tables 1 and 2. The pictorial dimple shapes of these balls are shown in Figures 2 and 3.

Table 1: Ball's dimensions and commercial price

	Ball's Name	Measured Diameter (mm)	Measured Mass (g)	Cost (AUD)
1	Callaway Big Bertha	42.67	45.2	3.80
2	PGF Optima TS PLUS+	42.68	45.4	3.80
3	Pinnacle Gold FX Long	42.67	45.8	2.50
4	Srixon AD333	42.67	45.4	4.00
5	Titleist Pro V1	42.67	45.6	7.00
6	TaylorMade TP/Red LDP	42.67	45.6	7.00
7	Top Flite D2 Distance	42.67	45.5	3.00
8	Wilson Staff DX2 Soft Distance	42.68	45.4	3.20
9	Dunlop Progress (Squash Ball)	40.45	24.9	-

Figures 2 and 3 show the dimple configuration of each ball used in this study. The dimple shape and size are quite different from each other as none of these 8 balls that have the same dimple size and configuration. A summary of the dimple configurations of each of these balls is shown in Table 2. The depth ratio (k/D, where k: depth of dimple & D: diameter of the ball) and width ratio (c/D, where c: width of dimple and D: diameter of the ball) of dimple were not determined. However, it will be included in the future study.

Table 2: Dimple shapes of each ball tested

	Ball's Name	Dimple Shape
1	Callaway Big Bertha	Hexagonal
2	PGF Optima TS PLUS+	Circular
3	Pinnacle Gold FX Long	Circular
4	Srixon AD333	Circular
5	Titleist Pro V1	Circular
6	TaylorMade TP/Red LDP	Circular
7	Top Flite D2 Distance	Circular within Circular
8	Wilson Staff DX2 Soft Distance	Circular

Each of these balls was tested in the wind tunnel using six component force sensor for a range of wind speeds (40 km/h to 140 km/h with an increment of 20 km/h). The effects of spin on drag and lift have also been evaluated. However, spin data was not included in this paper.

Figure 1. Dunlop Progress squash ball (no dimple)

a) Callaway Big Bertha

b) PGF Optima TS PLUS

c) Pinnacle Gold FX Long

d) Srixon AD333

Figure 2. Dimple physical characteristics

a) Titleist Pro V1

b) TaylorMade TP/Red LDP

c) Top Flite D2 Distance

d) Wilson Staff DX2 Distance

Figure 3. Dimple physical characteristics

Experimental Facilities

The study was conducted in RMIT Industrial Wind Tunnel. It is a closed return circuit wind tunnel with a turntable to simulate the cross wind effects. The maximum speed of the tunnel is approximately 150 km/h. The dimension of the tunnel's test section is 3 m wide, 2 m high and 9 m long and the tunnel's cross sectional area is 6 square meter. A plan view of the tunnel is shown in Figure 4. More details about the tunnel can be found in Alam et al. [2]. The tunnel was calibrated before conducting the experiments and tunnel's air speeds were measured via a modified NPL ellipsoidal head Pitot-static tube (located at the entry of the test section) connected to a MKS Baratron pressure sensor through flexible tubing.

A mounting stud was manufactured to hold the ball and was mounted on a six component force sensor (type JR-3) as shown in Figures 5 and 6. Purpose made computer software was used to compute all 6 forces and moments (drag, side, lift forces, and yaw, pitch and roll moments) and their non-dimensional coefficients. The experimental set up in the test section of RMIT Industrial Wind Tunnel is shown in Figures 5 & 6.

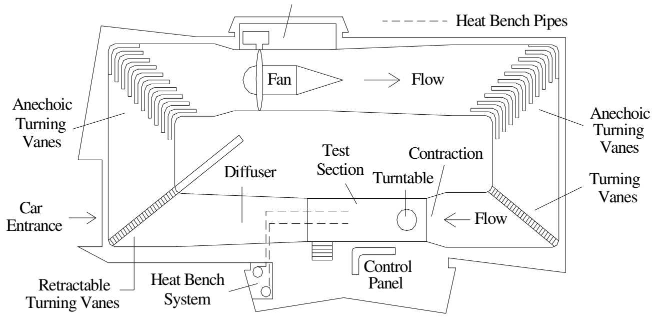

Figure 4. A plan view of RMIT Industrial Wind Tunnel

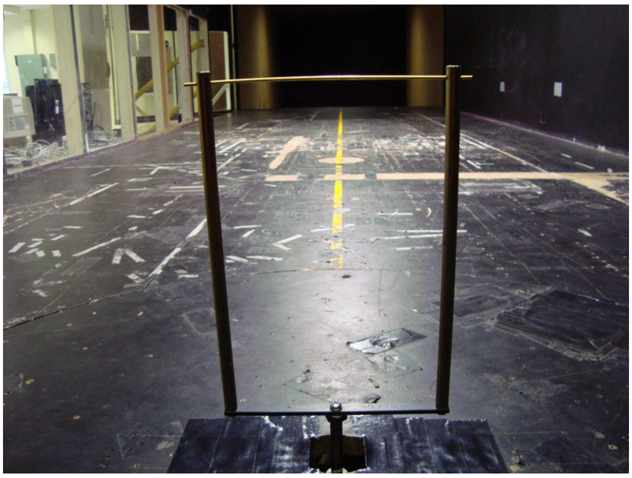

Figure 5. Experimental Set-up in RMIT Industrial Wind Tunnel

The aerodynamic properties (drag, lift and side force and their corresponding moments) were measured at wind speeds of 40 km/h to 140 km/h. The aerodynamic forces acting on the balls were determined by testing balls with the supporting gear (mounting stud) and then subtracted from the forces acting on the supporting gear only. An alternative mounting support to the one used in this study is currently being under construction to minimise the interference of the mounting device on aerodynamic properties.

Figure 6. Mounting device on force sensor

Results and Discussion

The output data from the wind tunnel computer data acquisition systems was the 3 forces (drag, lift and side forces) and 3 moments (yaw, pitch and roll). The drag and side force were converted to their non-dimensional drag coefficient and side force coefficient using the equations 1 and 2.

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 A} \tag{1}$$

$$C_S = \frac{S}{\frac{1}{2}\rho V^2 A} \tag{2}$$

Where, D, ρ, V, S & A are drag, air density, wind velocity, side force and projected frontal area of the ball. The drag (D) and C_D value variations with speeds and Reynolds number ($Re = \frac{\rho V d}{\mu}$) are shown in Figures 7 and 8 for all golf balls and the Squash ball. The drag and C_D variations are significant among the balls. The aerodynamic behaviour of the Squash ball is similar to the smooth sphere as demonstrated by Achenbach [1]. However, the transition from viscous to inertial flow is taken place much earlier compared to the smooth sphere. The C_D of the golf ball varies significantly with Reynolds numbers. The change from the sub critical region to the critical region occurs at approximately $Re = 1.0 \times 10^5$. At this Reynolds number, the C_D decreases suddenly to approximately $C_D = 0.20$. The dimples on the surface of the ball cause the critical region of the golf ball to shift a lower Reynolds number compared to that of the smooth ball.

The average drag coefficient for the golf ball is around 0.2 after the transition. As mentioned earlier, the transition for golf balls occurs at a very low speed. As shown in Figures 7 & 8, some balls golf balls have slightly lower C_D value while some displayed higher C_D values from the average value of the drag coefficient due to varied characteristics of dimple geometry. A significant variation in C_D values was noted at lower speeds. The highest variation of C_D values was found approximately 40% between Taylor made, Callaway and Pinnacle golf balls. The pinnacle and Taylor made balls have circular dimples and the Callaway ball has the hexagonal dimples. The cheapest ball 'Pinnacle' displayed the lowest C_D value compared to the expensive Taylor made ball. The variation is significant. Therefore, further studies are underway to clarify it. It may be noted that the Callaway ball is also a relatively cheaper ball. Figures 9 and 10 clearly show the aerodynamic advantages of the most expensive and cheapest golf balls.

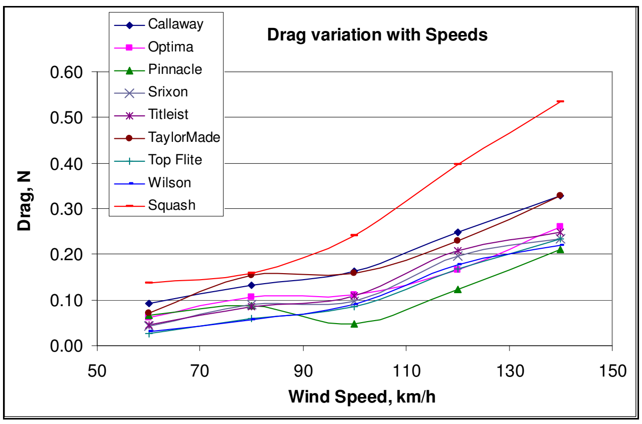

Figure 7. Aerodynamic drag as a function of speeds for all 8 golf balls

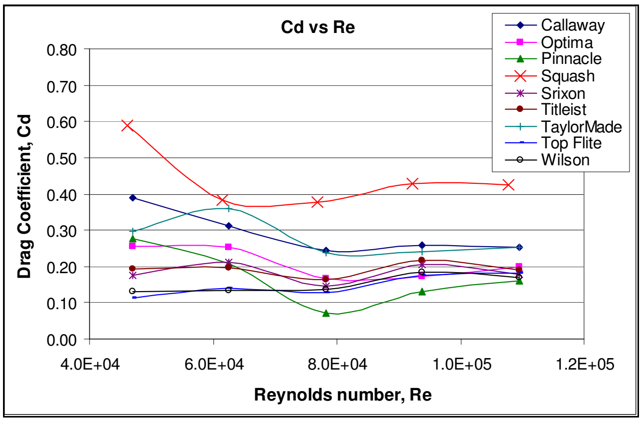

Figure 8. Drag coefficient as a function of Reynolds number for all 8 golf balls

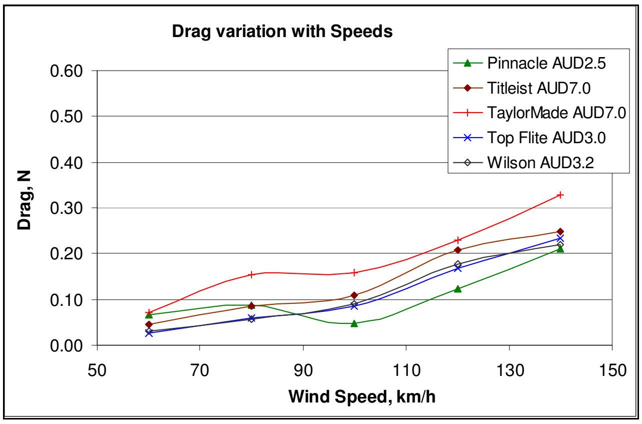

Figure 9. Aerodynamic drag as a function of wind speeds for cheap and expensive golf balls

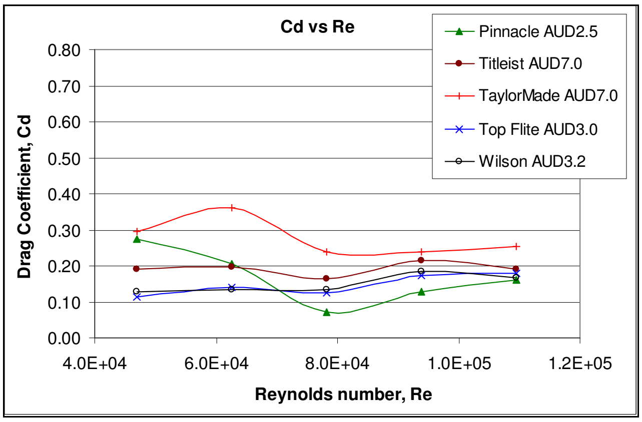

Figure 10. Drag coefficient as a function of Reynolds number for cheap and expensive golf balls

Concluding Remarks

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

- The dimple characteristics have significant effects on aerodynamic properties of the golf ball
- Due to complex dimple geometry, the critical region of a golf ball shifts toward a lower Reynolds number compared to that of a smooth ball. Therefore, the golf ball faces relatively lower drag at low speeds and travels longer distance.
- The cheaper balls are not necessarily bad compared to the expensive balls. It is especially important for the amateur and non-professional golfers.
- The variation of drag coefficient among the current production golf balls has found to be as large as 40% due to dimple characteristics.

Future Work

The work is underway to characterise the dimples and relate them to aerodynamic properties.

The effects of spin on aerodynamic properties especially on drag and lift will be analysed.

A thorough flow visualisation around the golf ball will be made.

A comparative study of CFD and EFD of golf ball aerodynamic properties is currently being undertaken.

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