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A study of golf ball aerodynamic drag

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Abstract

The aerodynamics of golf balls is considerably more complex than that of many other spherical balls. The surface roughness in the form of dimples intensifies the level of complexity and three-dimensionality of air flow around the golf ball. Prior studies have revealed that golf ball aerodynamics is still not fully understood due to the varied dimple size, shape, depth and pattern. The current study experimentally measured drag coefficients of a range of commercially available golf balls, under a range of wind speeds. It was found that the drag coefficients of these balls varied significantly due to varied dimple geometry.

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1. Introduction

The player's performance can significantly be enhanced if the aerodynamic behavior of the golf ball is understood and the potential benefit exploited intelligently. A wide variety of commercially manufactured golf balls are available to suit individual golfer's style of play. Of particular relevance to this work is the variation in dimple geometry. The flight trajectory is influenced by the aerodynamic forces exerted on the ball, which are significantly dependent on the physical features of the dimples. Most commercially manufactured golf balls have between 250 and 500 dimples, however these dimples vary in size, shape and depth. Golf ball manufacturers often claim superior aerodynamic performance of their balls, however

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there is an absence of detailed aerodynamic data available in the public domain. This hampers verification of claims, and also intelligent selection of balls by players.

A golf ball usually moves at a speed that is sufficiently high to reduce its' drag to about half that of a smooth sphere. This favorable reduction in drag is caused by the dimples on the golf ball surface which trigger the boundary layer to transition from laminar to turbulent flow. Several widely published studies have been 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. Despite this work the mechanisms through which the dimpled surface influence the boundary layer transition have not been fully understood to the extent that accurate force and trajectory prediction would be possible [4-5, 7-10].

Studies conducted by commercial golf ball manufacturers are generally kept “in-house” as confidential information in a highly competitive market, and consequently very little information is available in the public domain on development and the current performance of golf balls. In this context the primary objective of this research is to experimentally evaluate the aerodynamic properties, especially drag, of a series of commercially available golf balls with varied dimple characteristics, which are widely used in professional and amateur/recreational golf.

2. Experimental Procedure

2.1. Description of 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 balls has different dimple characteristics. The average diameter and mass of the golf ball is around 42.7 mm and 45.5 g. The balls' retail prices vary significantly from 2.5 to 7.0 Australian dollars. The commercial brand name and their physical characteristics (diameter, cost and dimple shapes) are shown in Table 1. The pictorial dimple shapes are shown in Figure 1.

Table 1. Balls' dimple types

	Ball Name	Dimple Shape
1	Titleist Pro V1	Circular
2	TaylorMade	Circular
3	Srixon	Circular
4	Callaway	Hexagonal
5	Nike PD2	Circular (smaller and large)
6	Wilson Staff	Circular flat
7	Top Flite	Circular within Circular
8	Maxfli	Circular shallow

Figure 1 shows the dimple configuration of each ball used in this study. The dimple shape and size are quite different from each other; none of these eight balls have the same dimple size and configuration. The dimple shape and size are quite different from each other as none of these 8 balls that have the exactly same dimple size and configuration.

Each of these balls was tested in the RMIT Industrial Wind Tunnel using a six-component force balance over a range of representative wind speeds (40 km/h to 140 km/h in increments of 20 km/h).

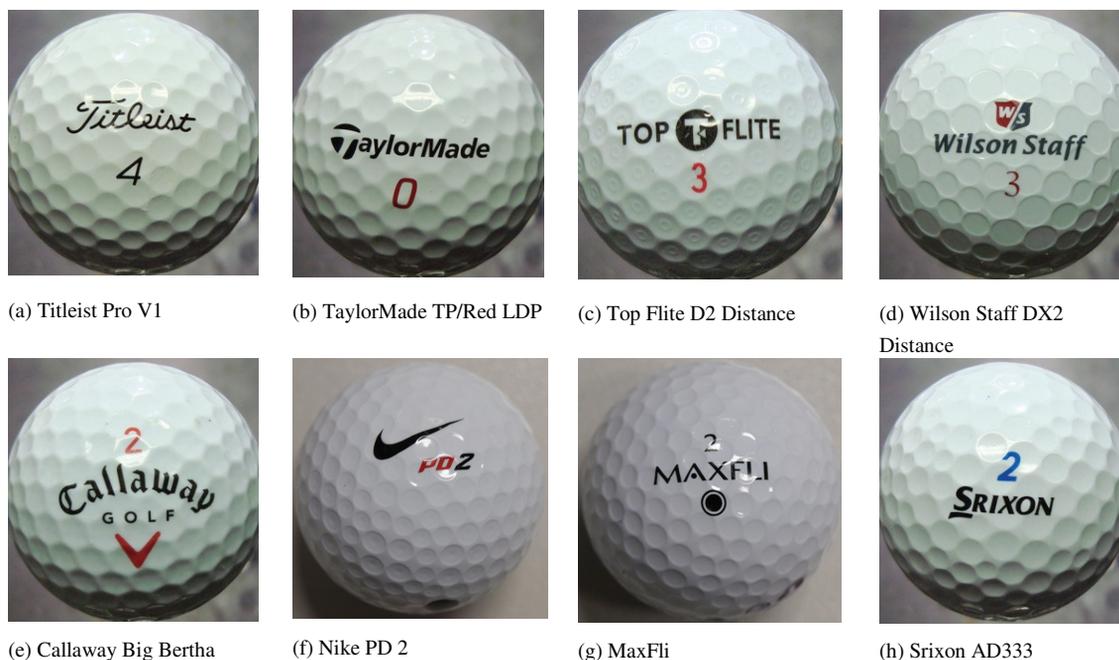


Fig. 1. Range of golf balls used in this study.

2.2. Experimental set up

The study was conducted in the RMIT Industrial Wind Tunnel, which is a closed return circuit wind tunnel with a turntable to enable study of cross wind effects. The maximum speed of the wind tunnel is approximately 150 km/h, with a turbulence intensity of 1.8%. The wind tunnel test section has a rectangular cross-section; dimensions of the test section are 3 m wide, 2 m high and 9 m long. Further details about the tunnel can be found in Alam *et al.* [3]. The wind tunnel was calibrated before conducting the experiments relevant to this present work, and the air speeds were measured via a modified NPL ellipsoidal-head Pitot-static tube located at the same station as the golf ball, 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 balance (type JR-3) as shown in Figure 2. The 1st set up shown in Figure 2(a) was used for the initial measurement however the interference drag was found to be very high compared the drag of the golf ball. The 2nd set up, shown in Figure 2(b), was developed later and found to be more suitable for this study. Computer software developed in-house was used to acquire load data from the force balance, and compute all six forces and moments (drag, side, and lift forces, and yaw, pitch, and roll moments), and then calculate their non-dimensional coefficients.

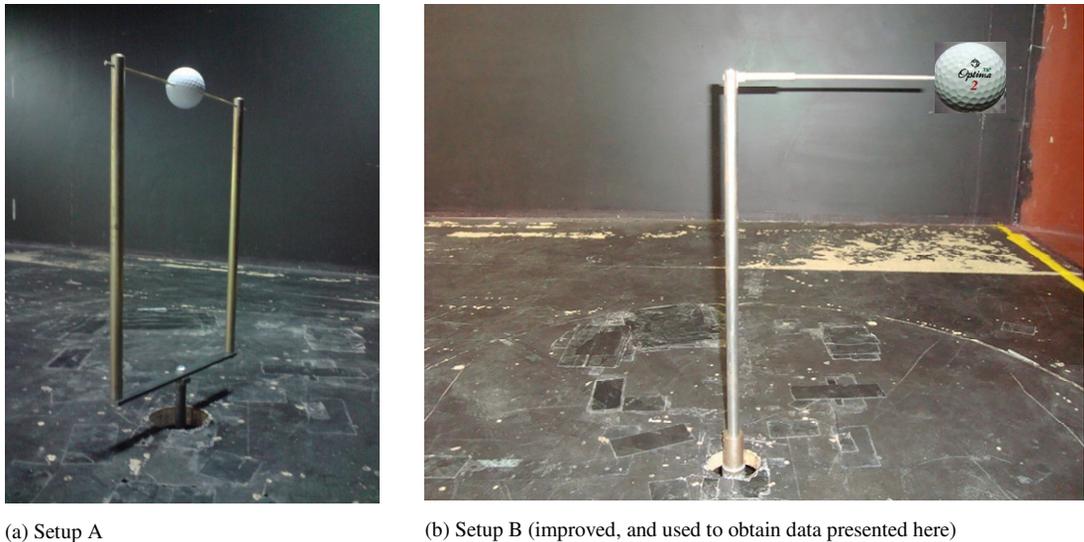


Fig. 2. Two experimental setups that have been used in this study shown here

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 alone were determined by subtracting the forces acting on the supporting gear only (with no ball attached) from the combined force determined for balls attached to the supporting gear (mounting stud).

3. Results and Discussion

The output data from the wind tunnel computer data acquisition system comprised three forces (drag, lift, and side force) and three moments (yaw, pitch, and roll). The drag coefficient (C_D) and Reynolds number (Re) were calculated by using the following formulae: $C_D = \frac{D}{\frac{1}{2}\rho V^2 A}$ and $Re = \frac{\rho V d}{\mu}$; where, D , ρ , V , d , μ and A are respectively the drag force, air density, wind velocity, ball diameter, absolute dynamic viscosity of air, and projected frontal area of the ball.

The data shows significant variation between balls as far as C_D is concerned, with the greatest variation amongst most balls being evident at lower Reynolds numbers for the range tested. The aerodynamic behaviour of a squash ball (with relatively smooth surface to replicate a smooth sphere) was also measured to compare the findings with the smooth sphere data obtained by Achenbach [1]. The C_D value for the squash ball is also shown in Figure 3 for benchmarking purpose with the published data. The C_D of each golf ball varies significantly with Reynolds numbers, and the drag coefficient for all the balls exhibits similar broad behaviours. The transition from the sub-critical region to the critical region is complete at a Reynolds number of approximately 1×10^5 for all golf balls. At this Reynolds number, the C_D for each ball has decreased to its minimum value. In the data presented in Figure 3, only the Maxfli golf ball has similar drag behaviour to that shown in Bearman and Harvey [7]. After the transition, the Maxfli has a minimum C_D value of approximately 0.25. Although most other golf balls also undergo transition and have minimum values at around, their minimum C_D value is significantly higher (between 25% and nearly 50%) compared to the Maxfli golf ball. The variation in C_D values among the golf balls is believed to be primarily due to the differences in boundary layer separation generated by different dimple

numbers, shapes, sizes, depths and patterns. The significant variation in drag coefficient between balls with superficially similar dimpling suggests that even subtle differences in dimpling can produce substantial changes in flow separations which consequently affect pressure drag.

As shown in Figure 3, although there is significant variation in C_D values one ball, the Maxfli, has drag characteristics that are distinctly different from all the other balls tested. Close examination of the dimple geometry of the Maxfli showed that these dimples were shallow but not flat, and there was a significant angle between the edge of dimples and the outer “spherical envelope”. Other balls appeared to have somewhat smoothed profiles where the dimples merged into the outer “spherical envelope” which reduced the angle in these areas. The data supports a conjecture that this relative “sharpness” opposed to “smoothing” is a critical factor for drag reduction.

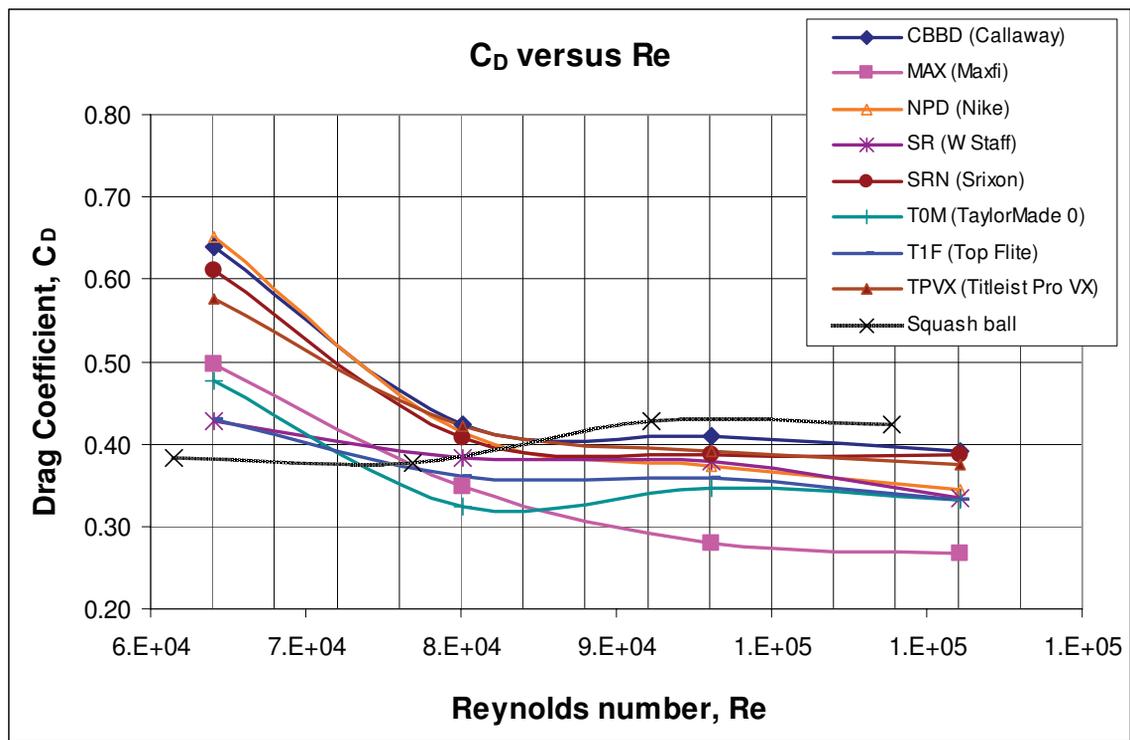


Fig. 3. Drag coefficient as a function of Reynolds Number for balls tested

4. Conclusions

- The following conclusions were made from this work:
- The dimple characteristics have significant effects on aerodynamic drag of golf balls.
 - Price did not correlate with performance for the balls purchased and tested.
 - The variation of drag coefficient among the current production golf balls has found to be as large as 40% due to dimple characteristics.
 - Data obtained supports a conjecture that the profile of the region where the dimple merges into the outer “spherical envelope” has a strong influence on drag.

5. Future Work

- Work is underway to characterize the dimples and relate them to aerodynamic properties. The effects of spin on aerodynamic properties especially on drag and lift will be analysed.
- Thorough flow visualization around a 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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