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# AERODYNAMIC STUDY OF ROTATING CRICKET BALL

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## ABSTRACT

*Cricket is a highly popular sport in many parts of the globe enjoyed by participants and spectators both. The flight-trajectory of a rotating cricket ball depends largely on their aerodynamic characteristics. A little information on the aerodynamic force experienced by a cricket ball is available despite the popularity of the game. Having a surface pattern with stitches, seam and their orientation, the airflow around the ball is found to be significantly complex to understand and model. The primary objective of this study was to measure aerodynamic characteristics on a cricket ball having rotation perpendicular to the flow. The aerodynamic characteristics of the ball were measured experimentally for a range of wind-flow and ball orientations. The results show the drag coefficients of a cricket ball did not undergo a distinctive drag crisis as a smooth sphere due to their complex stitches and their orientation. The results also indicate that the stitches had profound impact on aerodynamic characteristics of the ball.*

## I. INTRODUCTION

Since the identification of boundary layers by Prandtl in 1902, there have been numerous attempts to control their behaviour - to increase heat or mass transfer, reduce drag in moving vehicles and so on. In case of drag over moving bodies, like vehicles, boundary layer separation causes unequal pressure distribution causing what is called the ‘form drag’. In case of ideal fluid flow there is no boundary layer and no separation and hence there is no ‘form drag’. Another cause of drag is due to the shear stress at the surface. This ‘skin friction drag’ is however small for cases like vehicular drag.

Form drag can be understood by looking at figure 1(Fox and McDonald). Here pressure distribution over a cylinder, scaled with the dynamic pressure $\frac{1}{2}\rho v^2$ is plotted. In case of an ideal fluid flow (dashed line) the pressure distribution is symmetric about the mid plane, and so no net force due to pressure acts along the flow direction and there is no drag. However in case of real fluids both in case of a laminar or a turbulent flow, the flow separates at some point on the cylinder’s surface because of adverse pressure gradient ( $\frac{dp}{dx} > 0$ ), and the pressure distribution is asymmetric about the mid plane. This asymmetric pressure distribution causes a net force along the direction of the flow. This force is the form drag. In case of turbulent boundary layers, (ie, those that have become turbulent before they can separate) the separation occurs later, as compared to the laminar boundary layers, reducing the asymmetrical region. Thus for turbulent boundary layers, the form drag is less. Note that the skin friction drag is present in both cases, but much smaller compared to form drag beyond moderate values of a Reynolds number characterizing the flow. Stages leading to boundary layer separation over a sphere are briefly described below.

## Stages of boundary layer evolution with the Reynolds number

At very low Reynolds numbers (Re < 1) there is no flow separation from the sphere; the wake is laminar and the drag is predominantly skin friction drag.

As the Reynolds number is increased up to about 1000, the drag coefficient drops continuously. As a result of flow separation, the drag is a combination of friction and pressure drag. The relative contribution of the friction drag decreases with increasing Reynolds number; at Re = 1000, the friction drag is approximately 5 percent of the total drag.

In the range 103 < Re < 3 X 105, the drag – coefficient curve is relatively flat. The drag coefficient undergoes a sharp drop at a critical Reynolds number of approximately 3 X 105. Experiments show that for Re< 3 X 105 the boundary layer on the forward portion of the sphere is laminar. Separation of the boundary layer occurs just upstream of the sphere midsection; a relatively wide turbulent wake is present downstream from the sphere. In the separated region behind the sphere, the pressure is essentially constant and lower than the pressure over the forward portion of the sphere. This pressure difference is the main contributor to the drag.

For the Reynolds number larger than about 3 X 105, transition occurs and the boundary layer on the forward portion of the sphere becomes turbulent. The point of separation then moves downstream from the sphere midsection, and the drag coefficient decreases abruptly. This is known as drag crisis (Frohlich et.al. (1984), see figure 2.).

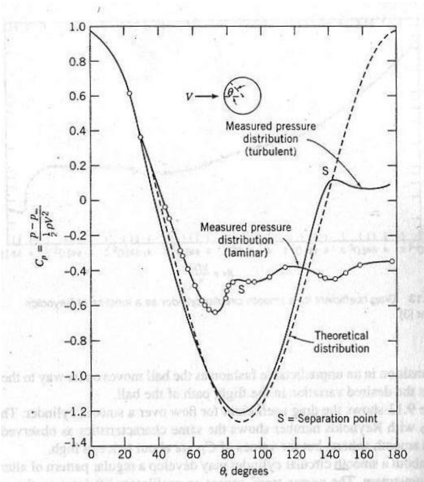


**Figure 1.1 Pressure distribution around a cylinder (from Fox and McDonald)**

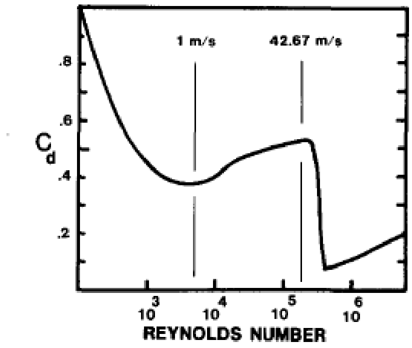


**Figure 1.2 Drag crisis, from Frohlich et al.**

## II. LITERATURE REVIEW

### 2.1. Boundary layer control in sports: Lateral forces

A spherical object moving in a fluid can experience various types of lateral forces. In sports this fact is used to gain the advantage of surprise. For example in sports such as tennis lateral force is achieved due to the spin of the ball. Although the mechanism of this effect is unrelated to the present study, is briefly described for sake of comparison. This effect is also used in sports such as in cricket (dip achieved by a spinner), baseball, and golf (Brigs et.al.(1959)).

Briggs also studied the lateral force on a spinning ball. As pointed out by Briggs, boundary layer separation is apparently delayed on the side of a spinning ball that is moving in the same direction as the free stream flow of the air, while separation occurs prematurely on the side moving against the free stream flow. The wake region of the ball therefore shifted towards the side moving against the free stream flow, deflecting the flow past the ball in that direction. The resulting change in momentum causes a force on the ball in the opposite direction.

A systematic experimental study of the force acting on a spinning baseball was conducted by Briggs. A spinning baseball was dropped across a horizontal wind tunnel in which the velocity of the air was known, and the deflection of the ball's path caused by the spin was measured. The results are shown in fig 3.

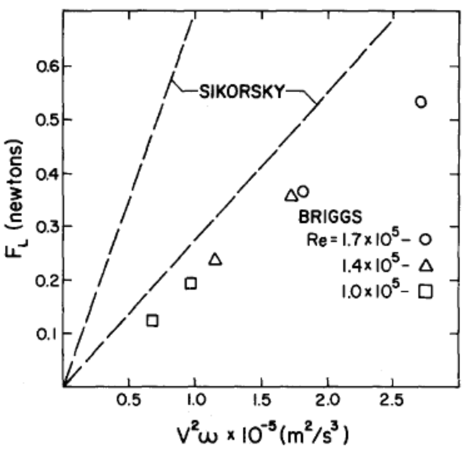


**Figure 2.1 The data of Briggs and Drury's description of the Sikorsky data**

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Briggs reported that the lateral force is proportional to the product of the square of the wind tunnel speed (V) and the rotation rate of the ball (ω) and also showed the strong linear dependence of lift coefficient CL on Reynolds number (Re). According to Joseph F. Drury, Sikorsky et.al.(1987) measured the lateral force on a spinning baseball by placing baseball inside a wind tunnel and found similar result as Briggs .

Bearman and Harvey et.al. (1987) reported that the lift force on a rotating sphere depend on ωV. Data at low Re and low spin rates indicated that under these conditions the lift coefficient is a weak function of Re. However, when Re > 0.6 X 105, CL is largely independent of Re number and a function of πDω / V only. Where (πDω / V) is the ratio of the speed of the surface of the ball relative to its center to the translational speed, πDω / V.

Watts and Ferrer et.al. (1987) did experiment in a subsonic wind tunnel at higher value of πDω / V. They found no dependence of lift force on orientation. Also, their data did not show a linear dependence of FL on V2ω. Watts and Ferrer showed that the lift coefficient is a function of πDω / V and the roughness of the sphere and is only a weak function of the free stream Reynolds number. Watts and Ferrer showed that the lift coefficient is a function of πDω / V and the roughness of the sphere and is only a weak function of the free stream Reynolds number.

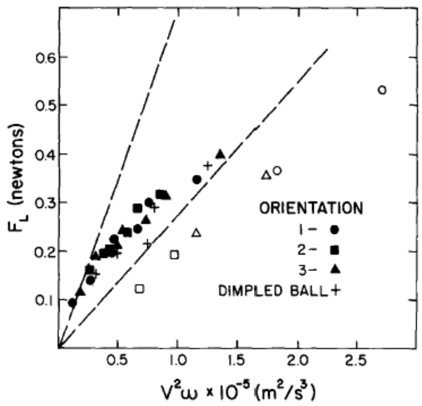


**Figure 2.2 Results of Watts and Ferrier**

However, the spin imparted to a spherical ball is not the only way to generate the lateral force. This brings us to the focus of the present study, where the lateral force is generated by an asymmetrical pressure distribution.

## 2.2. Lateral force due to asymmetric pressure distribution

We will consider a cricket ball, as this is the most relevant in this case. A lateral asymmetry is brought about in the flow conditions on either side of the cricket ball. This asymmetry causes a lateral asymmetry in the distribution of the pressure, resulting in the lateral force responsible for the 'swing' of a cricket ball.

The aerodynamics of a real cricket ball under real conditions depends upon the behavior of the two possible states of the boundary layer, laminar and turbulent. The boundary layer so formed can depend on (a) the angle of the seam to the line of flight, (b) spin of the ball, (c) surface roughness distribution.

When a cricket ball is released into the air flow with the seam at a slight angle, the seam trips the laminar boundary layer into turbulence on one side of the ball. This turbulent boundary layer separates relatively late compared to the laminar boundary layer separation and this results in an asymmetric pressure distribution that produce the lateral force (lift) responsible for the swing (Mehta et.al. (1993)). The 'swing' can be of two types - conventional swing and reverse swing.

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A. T. Sayers et.al. (2000) did experiments on a model cricket ball to study the parameters affecting the reverse swing. From dimensional analysis, for flow over a sphere,

CL = f (Re)

The corresponding velocity and lift force for the cricket ball are measured from the sphere data through the similarity requirement of equivalence of the Reynolds number and the lift coefficient.

Res = Reb

Since, both the model and the actual cricket ball move in air, ν constant, so,

Vb = Vs [Ds / Db ]

Also CLs = CLb

Lb = Ls [Vb / Vs]2 [Db / Ds]2

The swing force ratio (SFR) is the lift of the ball divided by its weight. Specific results are given below.

## 2.3 Smooth sphere with inclined 'O' rings (seam)

At all seam angles other than zero and 900, the sphere experiences some degree of positive or negative net lift force.

The critical Reynolds number at which the lift reversal occurred decreased as the seam angle increased. The maximum side force on the ball is of the order of three times its weight at a seam angle of 150.The rate at which the swing force increases with bowling speed is almost independent of the seam angle (figure 7). The corresponding data derived from figure 7 for an actual cricket ball is in figure 8.

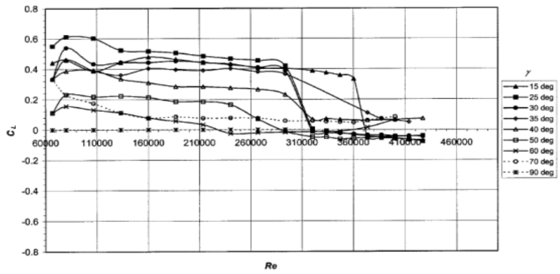

**Figure 2.5 Lift coefficient for the smooth-seamed sphere**

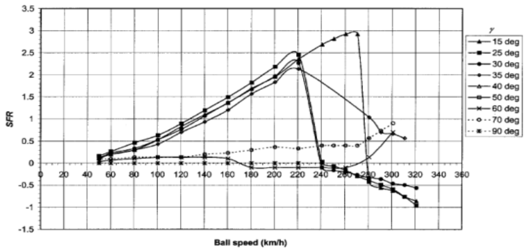

**Figure 2.6 Corresponding force for a new cricket ball as derived from smooth sphere data**

## 2.4 Sand-roughened sphere with 'O'rings

The effect of the sand-roughened surface to reduce the Re numbers at which lift reversal occurs. The magnitude of CL prior to lift reversal is almost independent of the seam angle at a value of approximately 0.3. However, after lift reversal has taken place, CL is highly dependent on the seam angle, but constant with further increase in Re number, and decreases with seam angle for any given Re. By a slight adjustment of the seam angle, between 00 and 250 the reverse swing can be achieved at lower Re number.

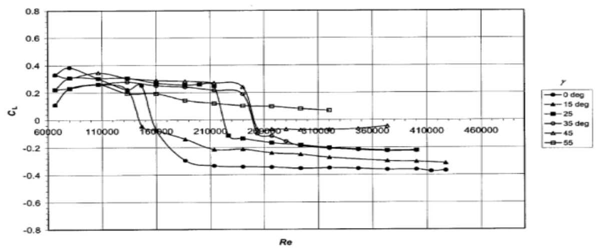


**Figure 2.7 Lift coefficient for the sanded-surface sphere**

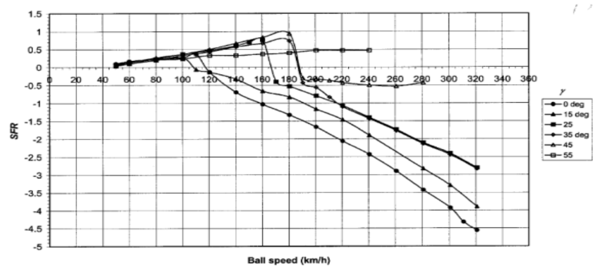


**Figure 2.8 Corresponding force for a used cricket ball as derived from sanded sphere data**

The lowest Reynolds number at which lift reversal takes place is reduced to 1.33 x 105, with a zero seam angle, which from fig 10 is at a corresponding cricket ball speed of 120 km/h or 74 mph at which reverse swing is usually achieved. It is also obvious that the degree of roughness effect strongly to the reverse swing. This is why artificial and scratching of the ball with fingernails, bottle caps or soil seams to make reverse swing easier to generate.

Thus it can be said that the seam angle and the degree of roughness both can affect the reverse swing. Derived data for an actual cricket ball is in figure 10.

### 2.5 Flight-trajectory of a cricket ball

Flight-trajectory of a cricket ball can significantly be deviated because of complex aerodynamic characteristics produced by the outer surface of the ball. Again, lateral deviation in trajectory, i.e. swing, is well recognized in many sports like cricket, football, tennis, etc. In sports like this, lateral deviation is generated by spinning the ball about an axis perpendicular to the line of flight-trajectory or by any means to create asymmetric airflow around the ball. The aerodynamic characteristics of a cricket ball are considered to be the fundamental for the players, coaches and ball manufacturers. Unlike sphere, the cricket ball is not uniformly smooth but is characterized by the seam and stitch pattern. The stitches, seam and their orientations can make the airflow around the ball complex and unpredictable. The aerodynamic nature of balls from various sports have been studied by Alam et al. [8-10], Asai et al. [11], Mehta [12], and Smits and Ogg [13], scant and reliable experimental aerodynamic data is except some studies by Alam et al. [14], Adair [15], Alaways [16]. The objective of the work is to study the aerodynamic characteristics of commercially made cricket ball.

## 2.6 Description of balls

Four new commercially made cricket balls are selected for this study. The balls were manufactured by A.P.G. Sports Industries, Jalandhar, India. Both balls are English Cricket Ball (Grade-A), weight 161g and have same approximate diameter of 22.6 cm with their seam characteristics almost the same. Different views and seam orientations of these balls i.e. left side view, right side view and front view of the balls are shown in the figure 1.


**Figure 1**

## III. EXPERIMENTAL SETUP

To determine the aerodynamic properties of the cricket balls experimentally, a Wind Tunnel is maintained with a maximum speed of approximately 150 km/h. The rectangular test section's dimension is 3 m (wide) × 2 m (height) × 9 m (long) and is equipped with a turntable to yaw the ball. The balls were mounted on a six component force sensor (type JR-3) and a computer software was used to digitize and record all three forces i.e. drag, side and lift forces and three moments (yaw, pitch and roll moments) simultaneously. Different support systems for vertical and horizontal setups are used. The variation in results was noted using these two experimental setups. In this study, all results were obtained using horizontal set up. The 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 aerodynamic drag coefficient (CD) is defined as: $C_D = \frac{F_D}{\frac{1}{2}\rho v^2 A}$, where FD, ρ, v & A are drag, air density, wind velocity and projected frontal area of the ball respectively. The drag coefficients are determined and presented in this paper.

**Figure 2 Vertical Set-up**

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**Table 1: Variations in Drag Coefficient $C_D$**

| Wind Speed (km/h) | $C_D$ | | % variation in $C_D$ |
|---|---|---|---|
| | Vertical Seam | Horizontal Seam | |
| 40 | 0.52 | 0.62 | 16.1 |
| 60 | 0.47 | 0.58 | 19.0 |
| 80 | 0.43 | 0.55 | 21.8 |
| 100 | 0.40 | 0.52 | 23.1 |
| 120 | 0.40 | 0.49 | 18.4 |
| 140 | 0.39 | 0.48 | 18.8 |
| | | Average | 19.5 |

## IV. RESULTS AND DISCUSSION

The experiment is carried with the cricket balls at 40, 60, 80, 100, 120 and 140 km/h wind speeds. The aerodynamic force was made nondimensional (drag coefficient, CD). The support effect was found to be negligible. The repeatability of the measured forces was within ±0.01 N and the wind velocity was less than 0.1 km/h. As a cricket ball possesses rough and curved stitches on its surface, the aerodynamic behavior is expected to differ for different orientations of the ball. Additionally, different sectors of the stitching can influence the airflow differently and generate induce drag at different velocities. In order to get some insights into it, the baseballs have been tested at different seam orientations facing the oncoming wind in the wind tunnel. The CD variations with Reynolds numbers for different seam positions are recorded.

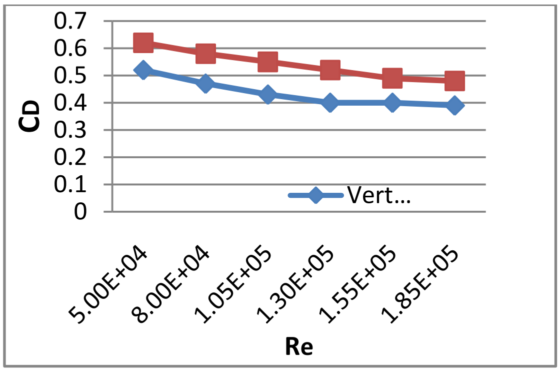


**Figure 3 Variation in Coefficient of Drag**

Unlike a sphere, there is no significant drag crisis due to the flow transition from laminar to turbulent noted for the balls.The average CD value for the cricket ball at high Reynolds number (120 km/h and above) is around 0.40 however at low Reynolds number (40 km/h) could be as high as 0.50 respectively. Seam orientation and stitches have significant effects on the ball aerodynamics. The average variation of CD value can vary up to 19.5%.

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