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Research Paper

A Review on the Swing of a Cricket Ball

Engineering

KEYWORDS : Boundary Layer Theory, Swing, Seam Angle, Surface Roughness, Backspin, Trajectory

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ABSTRACT

Swing of a cricket ball has been a fascinating subject for generations of cricket fans. Principles of boundary layer separation theory which describes this phenomenon is discussed. Different kinds of swing bowling and the factors affecting them are analyzed. Hence, optimal conditions for swing bowling are evaluated. It is concluded that a speed of 33 m/s at about 150 seam angle generates maximum swing with a new ball. The seam angle increases as the ball gets older. Equations describing the trajectory of a cricket ball are also mentioned. Some of the myths surrounding the game like the effect of humidity on swing, control of late swing and ball tampering are investigated. Finally, some conclusions and further avenues for research are suggested.

1. Introduction

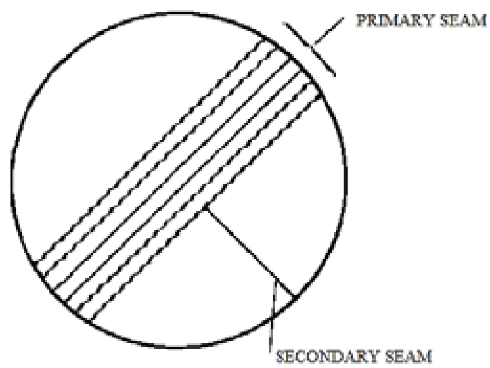
One of the biggest mysteries in the game of cricket has been the lateral deflection of a cricket ball in flight. This deflection (also known as swing, swerve or curve)has always been observed, sometimes understoodbut, rarely controlled.

The point of prime interest is to curve the ball from its initial straight path, a phenomenon that is also common to other sports like baseball, golf and tennis. Pioneers in sports ball aerodynamics were Newton (1672) and Rayleigh (1877). They credited "Magnus Effect" for this lateral deflection. Prandtl in 1904 introduced the boundary layer theory and characteristics of boundary layer were later accredited as the primary factor affecting the aerodynamics of a cricket ball. The first paper published solely on cricket ball aerodynamics was by Cooke[1]in 1955. But, it was not until 1982 when Barton[2] performed comprehensive wind tunnel tests and came up with very interesting results that research in this field really intensified, something that has continued for the past 35 years.

In this review paper, an investigation on cricket ball swing and factors affecting it is performed. First,construction of a cricket ball is describedand development of boundary layer on the cricket ball surface is discussed. Then, different kinds of swings and the factors affecting it are analyzed. A study is made on wind tunnel tests (both stationary and spinning ball) for measuring pressure distribution, side force, lift and drag under different operating conditions of free stream velocity, seam angle, surface roughness and backspin. Thus, optimal conditions for swing bowling is suggested. Trajectory of a cricket ball in flight is also examined along with the age old confusion regarding humidity affecting swing. Conclusions and areas that deserve further research are also suggested.

2. Construction of a Cricket Ball

The unique construction of a cricket ball and its effects on swing bowling were analyzed by Mehta[3]. At the core of a cricket ball is a leather cork which is tightly wound by woolen twines. This is incased in layers of corks twined with wool and at the crust are two leather hemispheres. These leather hemispheres are held together by six rows of 60-80 prominent stitching creating what is known as a "primary seam". The two hemispheres are themselves made by internal stitching of two quarters forming a "secondary seam". The secondary seam adds structural integrity and are at right angles to the primary seam. For our purpose, the internal structure is of little significance. We will be mostly concerned with the primary seam and its effects on the aerodynamics on a cricket ball in flight.



Diameter = 7.19 cmMass = 0.156 kg

Figure 1: Typical dimensions of a cricket ball (Mehta, 1983)

3. Basic Principle of Swing

3.1 Boundary Layer Theory

"Magnus Effect" was initially credited for the swing produced in a cricket ball. Magnus Effect creates a side force which makes the ball swing in air when spin is imparted on the ball. Cooke[1] rightly argued that a fast bowler imparts little or no spin on the ball and thus there must be another factor that controls the swing of a cricket ball. He proposed that the primary seam and surface roughness of the cricket ball causes an asymmetric separation of boundary layer on the two halves of the ball. This generates a side force on the ball, deviating it from a straight line and developing a swerve. He also concluded that a cricket ball cannot be approximated as a sphere while performing aerodynamic analysis. The significance of this inaccuracy was experimentally tested by Sherwin and Sproston[4]. They compared the flow over a cricket ball and a sphere with a 1mm trip wire and found significant variations.

The asymmetric nature of boundary layer separation has been extensively discussed.[1,2,3,5,6,7] Skillful fast bowlers make use of this phenomenon to swing the ball. They release the ball at a small seam angle (angle between primary seam and airflow) and the primary seam along with surface roughness trips the laminar flow on one side to turbulent flow while the other side still remains laminar. The turbulent layer separates at 1200 and the laminar layer at 800. This asymmetric separation of boundary layer generates an asymmetric pressure distribution resulting in a side force responsible for swing.

Figure 2 shows a wind tunnel test in which the ball was held stationary to the air flow at an angle of $40^{0.}$ Smoke was injected into the air flow behind the ball in a separation region.

It can be clearly seen that the lower region has already tripped into turbulent phase while the upper region is still in laminar phase. Furthermore, the upward deflection of the wake confirms that laminar layer on the upper surface separated relatively earlier than turbulent layer on the lower surface. The critical Reynold's Number in this case for transition from laminar to turbulent flow was found to be 0.85 x 105.

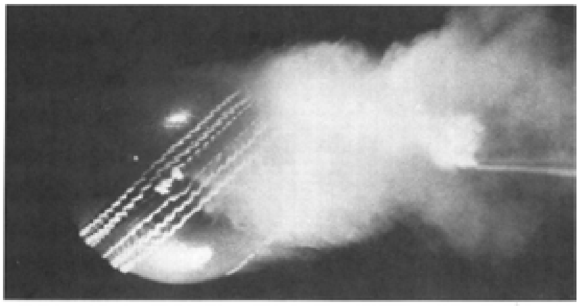


Figure 2: Flow over a cricket ball. Flow is from left to right. (Mehta, 1983)
Seam Angle = 400 Flow speed = 17 m/s

3.2 Conventional Swing

Conventional Swing is achieved when the ball is new and the effect of surface roughness is insignificant. The swing is caused when the side with the seam is tripped into turbulence while the other side still remains laminar. In Figure 3, it can be observed that a net force will act on the ball on the side in which the seam is pointing.

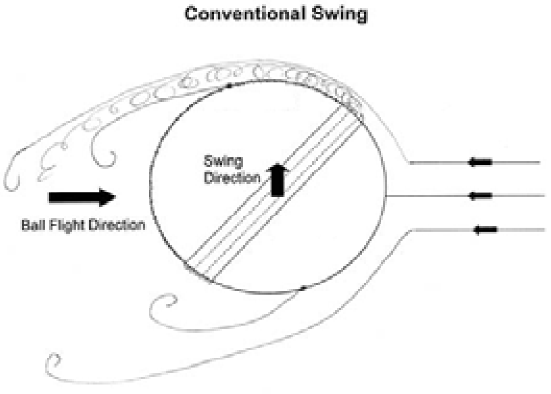


Figure 3: Flow over a cricket ball for conventional swing (Mehta, 2005)

3.3 Reverse Swing
Reverse swing is achieved when the ball gets old and surface roughness factor becomes significant. In this case, the flow on both sides are turbulent. As the Reynold's Number increases, the separation points start moving towards the front of the ball.They are symmetrically located as shown in Figure 4. When flowing through air, the side of the ball that has not encountered the seam (lower side in the figure) has a thicker and consequently, weaker boundary layer. It separates relatively earlier than the boundary layer on the other side. This pressure difference creates a side force, in the direction opposite to the direction in which the seam is pointing.

3.4 Contrast Swing
In this case, the ball is bowled with upright seam (seam angle = 0). The Reynold's Number responsible for transition from laminar flow to turbulent flow solely depends on the speed of the ball given that the surface roughness remains constant. This creates a certain amount of unpredictability and is a new skill being developed by many professionals.

Figure 5 shows contrast swing at low speeds. Laminar boundary layer on the upper surface separates relatively earlier than the turbulent layer on the lower surface. Turbulence is caused due to surface roughness. The ball swings in the direction of the rough side.

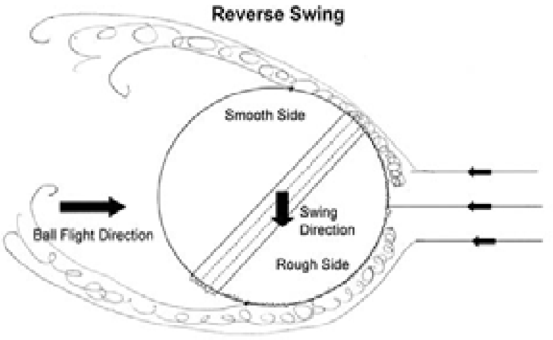


Figure 4: Flow over a cricket ball for reverse swing (Mehta, 2005)

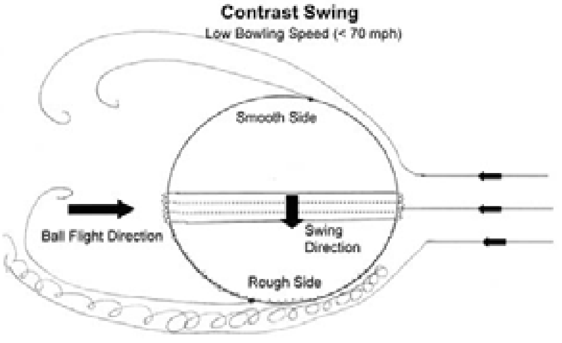


Figure 5: Flow over a cricket ball for contrast swing at low speed (Mehta, 2006)

Figure 6 shows contrast swing at high speeds. Flows on both sides are turbulent but the one on the roughened bottom side is thickened

and separates early. This causes the ball to swing towards the smooth side.

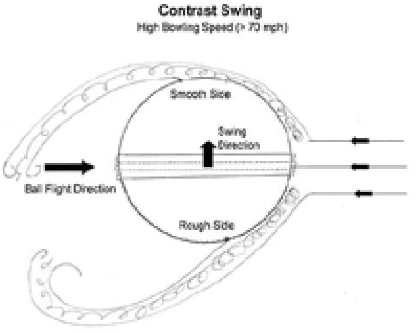


Figure 6: Flow over a cricket ball for contrast swing at high speed (Mehta, 2006)

4. Experimental Tests on Cricket Ball
4.1 Stationary Ball Tests
In this method, a cricket ball is held stationary in a wind tunnel airstream. Normal lift and drag forces acting on the ball are

measured. These measurements can be made indirectly through integration of surface pressure tapings as done by Bentley et al.[10]. He used multiple pressure tapings perpendicular to the seam plane along the equator of the ball as shown in Figure 7. Barton[2] used a compound pendulum system for these measurements where the ball was allowed to swing transversely. Results using both procedures were in good agreement with each other, though the method used by Bentley et al is considered more accurate and was followed in further experiments.[3,4,9,7,11,12]

It was found that at low airstream velocities and zero seam angle, the pressure distribution on both the hemispheres were equal and symmetric. As the flow speeds or the seam angle or the surface roughness was increased, pressure distribution became asymmetric and this resulted in a side force being generated on the ball. The critical Reynold's Number at which transition occurs was found to be a function of seam angle, free stream velocity and surface roughness. Mehta et al.[9] argued that backspin applied on the ball while being released is also a factor. Backspin prevents wobbling of the seam and helps in transition.

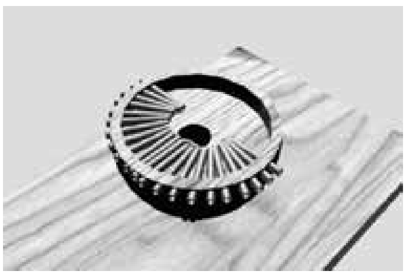


Figure 7: Stationary Ball Test (Uddin et al, 2005)

4.2 Spinning Ball Tests

The method used by Barton[2] and Bentley et al.[10]for spinning ball tests were same. They rolled a ball along a ramp along its seam and projected it into the airflow. Repeatability of such an experiment was low as the balls released did not follow the same path. Sayers et al.[13] mounted a cricket ball spinning about z axis on a shaft with its seam plane lying in the xy plane as shown in Figure 8. It is a trade-off as it gives more accurate results for lift and drag measurements, but side forces due to variation in seam angle cannot be measured.

Experiments were performed by spinning the ball in both forward (top spin) and backward (back spin) directions. Pressure difference was observed only on old balls. It must be due to the fact that they have a significant surface roughness. Highest side force was obtained when one side of the ball was roughened and the other remained smooth at air speed of 30m/s. Drag force varies mainly on air stream velocity and spin is of minor significance.

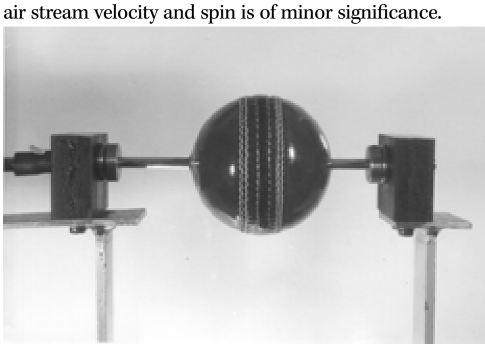


Figure 8: Spinning Ball Test (Sayers, 1997)

5. Optimal Conditions for Swing Bowling

Barton[2] performed the first detailed experiments on the swing of a cricket ball, varying air flow velocity in a wind tunnel. He observed that transition from laminar flow to turbulent flow occurs at 30 m/s. Another important conclusion accidentally noticed was, when repeating experiments at a later time,larger swing was observed. Thus, it can be inferred that surface roughness plays an important part in generating swing, especially at higher velocities. It was also suggested that seam angle and back spin should have some effect on swing. He concluded that ball velocity of 30m/s at a slight seam angle of 100 - 150 with a moderate back spin of 5-8 rev/s should provide maximum swing.

Barton's experiments examined a maximum spin rate of 9.3 rev/s. Bentley[10] analyzed swing for backspins up to 11 rev/s and concluded that 9.3 rev/s is the optimal condition for maximum swing. Mehta et al.[9] did further experiments on optimal conditions for swing. He suggested a ball velocity of 30m/s with a seam angle of 200 and a backspin of 11 rev/s for maximum swing.

These experimental results were still not in agreement with what was actually observed on a cricket ground. This discrepancy was solved by Da Silva et al[12] and Uddin et al[7]. Indirect method of measuring side force was held responsible by Da Silva et al for these inaccuracies. He performed a more detailed analysis and used direct measurement techniques to get maximum swing on a new cricket ball at 35m/s for a seam angle of 100.

This is in good agreement to what is observed on a cricket ground. But, still did not explain the need for a larger seam angle for old balls. Further experiments using direct measurements on old balls at varying speeds were performed by Uddin et al. They concluded that at 33m/s maximum swing is obtained at 150 and at lower speeds of around 30m/s a seam angle of 15-300 is preferable for older balls. It was observed that swing increases as the ball gets old or roughness increases. The increase in swing is limited by the wear and tear resulting in decreasing the hardness of the ball, and thus, making it difficult to swing.

6. Trajectory of a Cricket Ball

The above analysis of swing does not consider the trajectory of a cricket ball in flight. Side force measurements on actual swing trajectories is of practical importance to professionals. Baker et al.[14] investigated the trajectories for new and old ball under no wind and cross wind conditions. In this paper, flight of debris in extreme windstorms were studied to find an approximate solution for swing trajectories. I was concluded that flight of a ball is a function of Tachikawa Number (T) along with side force coefficient (C_D) and drag forcecoefficient (C_S).

$C_D = D/(0.5\rho AQ_2)$
$C_S = S/(0.5\rho AQ_2)$
$T = (\rho AQ^2)/(2mg)$

Where, D and S are the drag and side forces acting on a ball of cross sectional area A, moving with a relative velocity of Q to air of density ρ. Tachikawa Number represents the ratio of inertia force to the weight of the ball. Using these dimensionless parameters, equations predicting the basic trajectory of a cricket ball can be given as

$$\frac{dU}{dt} = -[(U-\bar{U})^2 + (V-\bar{V})^2 + (W-\bar{W})^2]^{0.5} x (U-\bar{U}) C_D T$$

$$\frac{dV}{dt} = -[[(U-\bar{U})^2 + (V-\bar{V})^2 + (W-\bar{W})^2]]^{0.5} x [-C_D T(V-\bar{V}) + C_S T(U-\bar{U})]$$

$$\frac{dW}{dt} = -[(U-\bar{U})^2 + (V-\bar{V})^2 + (W-\bar{W})^2]^{0.5} x [(W-\bar{W}) C_D T - 1]$$

Where, x is along the pitch (direction of flight and opposite to the drag force), y is across the pitch (along the direction of side force) and z is vertical to the pitch. are velocities in x, y and z directions respectively, non-dimensionalized by the initial speed of the ball.

They equations are in good agreement with trajectories experimentally determined by Bentleyet al.[10] and Imbrosciano[16]. In a further publication[15], Baker performed extensive computations to find full solutions to the trajectory equations. He also introduced a new term "Auto-rotational force" and came up with a modified form of equations. The results obtained were similar to approximate solutions and for engineering calculations, it should be approximated as such.

7. Lore vs Logic in Cricket

There are quite a few "popular beliefs" that are present in the game of cricket. Some of them have been there since the advent of the game while others have developed over time. Here we discuss some of the logic (or the lack of it) behind these lores.

7.1 Effect of Humidity on Swing

Cricket players have always believed that a cricket ball swings more on humid days. But, no reliable reason has yet been given for this phenomenon. Bentley et al.[10] performed tests on a cricket ball by dipping it in water. Even under this extreme condition, no variation in natural swing was observed. Mehta[9] placed a cricket ball in a 75%humidity chamber for 48 hours and still observed no difference. It can be reasoned that the swing of a ball depends only on the properties of the air flow and the ball itself. Humidity will affect the density and viscosity of the air around the ball. But, experimental data has suggested that changes in air properties are minimal and do not affect the swing of a cricket ball.

On the other hand, experiments by Binnie[17]at 100% relative humidity suggest the presence of a "condensation shock", which helps in transition from laminar to turbulent flow and thereby inducing swing. These results are in complete contradiction to the results published by Bentley. Sherwin & Sproston[4] and Wilkins[18] followed the experimental method by Bentley and obtained similar results. Whereas, results published by Binnie have not been reproduced and should be considered inaccurate.

There have been quite a few speculations on this topic as well. It has been suggested by a few that humid days will have less atmospheric turbulence while others have suggested that it will have more turbulence. Any which way, it should not have any significant effect on swing. Bowen[19] suggested that humidity increases surface roughness and thus increases the amount of swing. This seems a bit farfetched and more evidence is required to believe on this theory. Mehta [9] suggests that sticky conditions on humid days, means that the ball stays in bowler's hand for a longer period of time imparting more backspin and consequently more swing. This seems like a plausible explanation but supporting experiments are needed before it can be validated as an acceptable theory.

Another idea put forward by Baker[14], is that humid days have more cloud cover and the lack of solar radiation should bring changes in boundary layer separation. The effect of solar radiation also seems insignificant. But, James et al.[20] conducted extensive experiments on effect of humidity on cricket ball and concluded that humidity has no significant effect on the air properties around the ball or on the properties of the ball itself. He hypothesized that cloud cover decreases turbulence in air due to lack of solar radiation. The effect of cloud cover still seems insignificant and James agrees that it is a loosely formed idea until more experiments are performed.

7.2 Late Swing

Swing the ball as late as possible in order to deceive the batter is what fast bowlers strive to achieve. Theoretically, it can be achieved by bowling at near critical speeds so that there is turbulent flow on both sides of the ball. When the ball is sufficiently slowed down in flight and reaches its critical speeds it swings according to seam orientation and surface roughness. Mehta[21] observed that speed of the ball reduces by less than 5% during flight. This does not seem significant and anyhow, will be very hard to control in practice. Moreover, Wilkins[18]suggests that even a slight variation in wind direction will have significant effect on this phenomenon. This makes late swing unpredictable along with being uncontrollable.

7.3 Ball Tampering

Conventional swing is obtained with a prominent primary swing whereas reverse swing is achieved with increased surfaceroughness. It is often seen in practice that players try to maintain the shine on the ball by polishing it using sweat and saliva (legally allowed) or Vaseline, Brylcreem etc.(legally not allowed)[21]. Picking the seam on the ball in order to keep the seam prominent is also an "art", not allowed according to the laws of the game. But, in order to get the maximum swing out of the ball, only one side of the ball should be polished while the other side should be allowed to roughen. This will generate maximum conventional swing when the ball is new and maximum reverse swing when it gets old.

8. Conclusions and avenues for Further Research

1. Aficionados of cricket believe that swing of a cricket ball is an unpredictable phenomenon that adds beauty to the game of cricket. A lot of research has been done on this subject, but no one has tried to quantify it yet. It is possible to do it using angle of deviation at the point when the ball starts to deviate from its original path and varying it according it to time till the time it reaches the batter. This will also give us the distance travelled laterally by the ball.

2. Surface roughness is very difficult to measure as it keeps on changing after every delivery bowled. Moreover, roughness is unpredictable and asymmetric. A standard can be developed under ideal conditions relating the surface roughness to the number of deliveries bowled. This should be a good approximation and will help in quantifying and predicting swing.

3. The maximum amount of backspin that can be achieved by a bowler is predicted to be 14 rev/s[9]. This data has been obtained using conventional bowling styles. Different bowlers have different grips and consequently, impart different amounts of backspin. A study on different grips should be made in order find the best grip for providing maximum amount of swing.

4. Trajectory of cricket ball has been determined. But, its effect on swing has not yet been studied. This is an unexplored area and further research will help us understanding actual swing of a cricket ball better.

5. Effect of humidity on swing is an age old question. Recent work by James et al[20] is promising and more experimental data is needed to finally uncover the myth behind this anomaly.

6. Late swing is an unpredictable phenomenon observed in practice. A better understanding of this event and any method to control it should be researched upon. This will add to the arsenal of skills of bowlers and will make the game of cricket even more interesting.

7. We know that swing is a function of seam angle, surface roughness, velocity and backspin. But, a relationship between them does not exist. The final goal of research on cricket ball swing should be to find a quantifiable relationship between

swing and the abovementioned factors. It is also worth finding the effects of trajectory, humidity, wind direction, altitude and other factors that might have significant effect on the swing of a cricket ball.

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