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THE CURVE OF THE CRICKET BALL – SWING AND REVERSE SWING

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It is a well known fact in cricket that the new ball when bowled by a fast bowler will often swing in its flight on the way down the pitch to the batsman. This means that the ball does not stay in one vertical plane during its flight but curves to one side or the other. It is part of the skill of the pace bowlers to control this swing as much as they can.

In a previous article in Parabola (Volume 15, Number 3) the swing of the cricket ball was discussed. I will summarise its main points and elaborate on them, but I will also discuss a relatively new discovery by fast bowlers – the phenomenon of reverse swing.

Balls curve in flight in many games, such as golf, soccer, tennis and so on, but this is due to the ball spinning about a vertical axis, which gives rise to what is known as the Magnus Effect. This is entirely different to a cricket ball swinging, and will not be discussed here.

The Boundary Layer

Let us consider what happens to the air close to a smooth ball (unlike a cricket ball) as the ball travels through it. Air has a stickiness called the viscosity, which is due to friction. As a result, as the ball moves through the air, the particles of air in contact with the ball stick to the ball and move along with it. However, not far away from the ball the air is hardly disturbed at all by the ball's flight. Consequently, there is a very thin layer of air near the ball in which the speed of the air changes from that of the ball to virtually zero. This layer is called the *boundary layer*, and is typically only about 0.2 mm thick. The study of boundary layers is a branch of applied mathematics.

The pressure exerted by the boundary layer on the ball varies as the layer travels past the ball. Where the layer is flowing relatively slowly at the front, a high pressure is exerted. As the layer moves around the ball it travels more quickly, and so exerts less pressure. The fastest speed and least pressure is reached halfway around the ball (Figure 1). This relationship is expressed by Bernoulli's law which states that the faster a fluid (such as air) flows across a surface, the less pressure it exerts. This law was first formulated by the famous Swiss mathematician Daniel Bernoulli (1700-1782) and

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is expressed in one simple equation

$$\frac{p}{\rho} + \frac{v^2}{2} + gz = \text{ Constant}$$

where p is the pressure, ρ is the density, V is the velocity, g is the acceleration due to gravity, and z is the height of the streamline. This assumes a steady flow with no viscosity.

For small speeds of the ball (e.g 15 m/s or 54 km/h, as for a slow bowler) the boundary layer clings to the surface of the ball almost around to the rear of the ball, before leaving in a narrow stream. As the speed of the ball increases (e.g 30 m/s or 108 km/h as for the average fast bowler), the separation points where the boundary layer leaves the ball move forward around the ball. There is, however, a limiting position for the separation points, and this occurs at an angle of approximately 80 degrees around from the nose of the ball (Figure 2). This angle can be predicted mathematically.

As stated above the least pressure on the ball is halfway around the ball. Beyond the separation points of the boundary layer the ball is surrounded by air of roughly constant pressure. So if the layer separates before halfway around the ball, the pressure over the region around the halfway mark is higher than if it separates after the midpoint.

Incidently, the region of air immediately behind the moving ball is called the *wake* and the pressure here is lower than on the front part of the ball. The net effect of pressure produces a force on the ball opposing its motion, and this is the main force which slows the ball down in its flight.

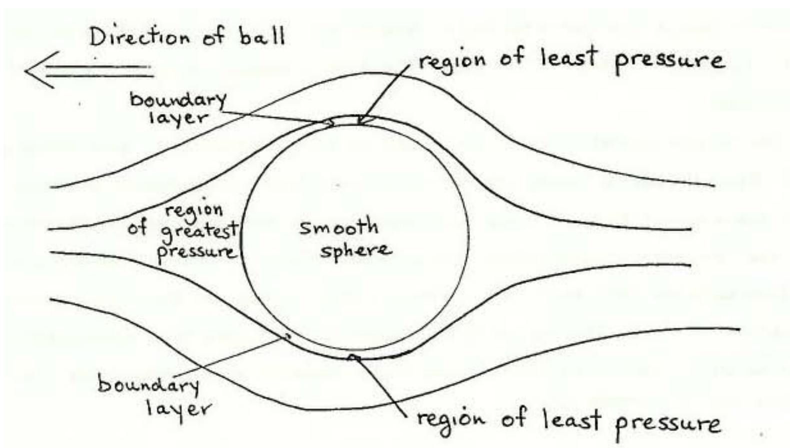

Figure 1

Turbulent Flow

So far we have only considered the flow of air around a smooth ball (this is called a *laminar flow*). The situation is different if the ball is rough. Here, as the speed of the ball increases the boundary layer becomes thinner and thinner so that the rough surface of the ball penetrates into it. This causes the air in the boundary layer to move chaotically

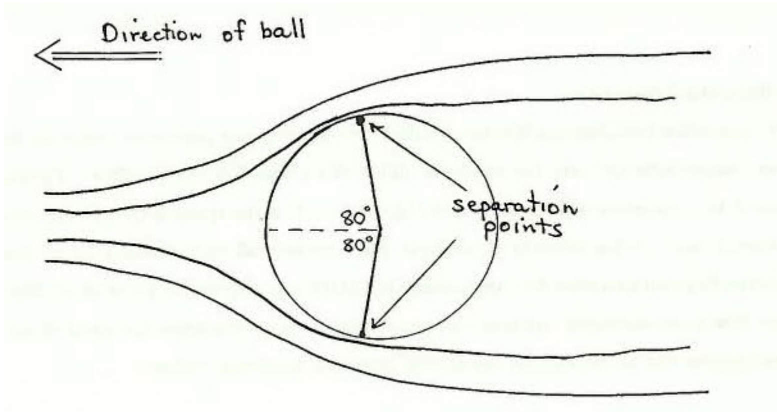

Figure 2

within the layer, producing turbulence, or a *turbulent* boundary layer. It is found experimentally that turbulent boundary layers cling to the surface of the ball longer than laminar boundary layers, and so the separation point from the ball is further towards the back of the ball (Figure 3). The rough surface of the ball is said to "trip" the boundary layer into turbulence. It must be mentioned that even a smooth ball will experience turbulence if travelling fast enough, but the roughness causes turbulence to occur at lower speeds.

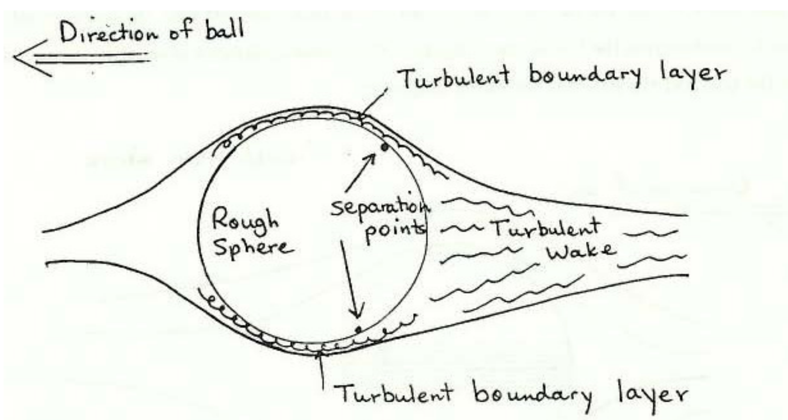

Figure 3

The Reynolds' Number

The transition from laminar flow to turbulent flow depends on a parameter called the *Reynolds' number* (named after Osborne Reynolds who did work on fluid flow in the 1890's). The Reynolds' number R for a sphere is defined to be $R = Ud/\nu$, where U is the speed of the moving sphere, d is its diameter, and ν is the viscosity of the fluid. For a cricket ball with diameter 7.2 cm moving at 30 m/s the Reynold's number R is approximately 140,000. At a critical value of about 200,000 the laminar flow turns turbulent. As noted above, a rough surface encourages the onset of turbulence at lower speeds and so the value of the critical Reynolds' number is reduced.

Why the ball swings

A cricket ball is not smooth. A two-piece ball has a seam where the two hemispheres of leather are joined, and six bands of stitches around it, three on either side of the seam. The balls used in games on turf (i.e. heavily rolled grass) pitches are four-piece balls, and have two extra semi-circles of stitches in the two planes at right angles to the seam. Although most of the surface of a new ball is shiny, it also has trade marks and printing stamped on it, making it slightly rough. In a very short time after play begins the ball becomes roughened up and starts to lose its shine. Fast bowlers try to preserve the shine or smoothness on one side of the ball by rubbing and polishing the ball on their trousers. But they only ever shine the one half of the ball, leaving the other half to be rough.

It is the difference in the position of the separation points of the boundary layer on the sides of the ball which is vital for the swing of the ball. If the ball is bowled with the seam upright and pointing in the direction the ball is travelling, then the boundary layers will separate symmetrically around the ball and the ball will not swing (Figure 4).

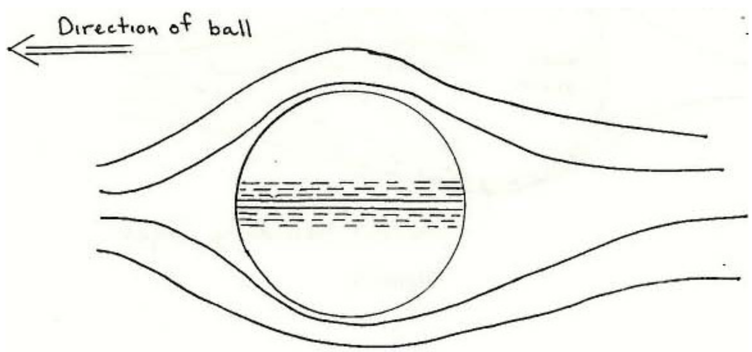

Figure 4: Viewed from above

However, if the ball is bowled fast enough so that the critical Reynolds' number for the rough side is exceeded, and if the seam is upright but at an angle to the ball's direction, with the shiny side forward, then the ball will swing in the direction that the seam is pointing. The reason for this can now be explained. On the polished or smooth side of the ball the laminar boundary layer separates at the 80 degree position. On the other side of the ball the seam and the rough surface trip the boundary layer into becoming turbulent, and so it separates from the ball further to the back of the ball. This causes the air pressure on this side to be *lower* than on the other side of the ball. The higher air pressure on the shiny side results in a force which pushes the ball sideways, producing the swing. Thus the ball swings in the direction the seam is pointing (Figure 5).

The ball will not swing if the seam does not remain upright, which often happens because it spins about an axis not perpendicular to the seam during its flight. To prevent this, fast bowlers impart backspin to the ball as it leaves the hand, and this backspin keeps the seam upright. The control over the backspin is what makes swing bowling so difficult.

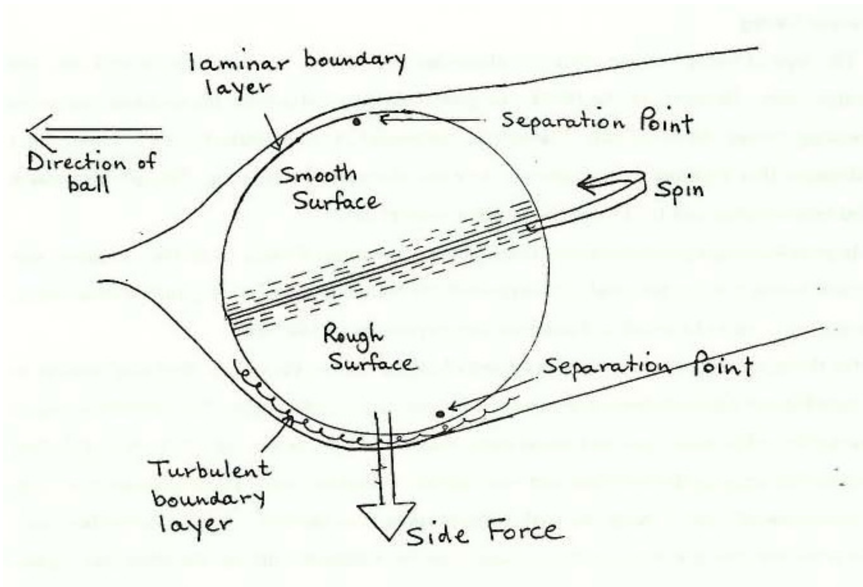

Figure 5: Conventional swing bowling (viewed from above)

The very fast bowlers bowl too fast to swing the ball. This is because the extreme pace of the ball causes the critical value of the Reynolds' number to be exceeded even with the new ball and so the boundary layer on both sides of the ball becomes turbulent, and there is no pressure difference on the sides of the ball (Figure 3). The slow bowlers do not swing the ball because the low speed of the ball gives a Reynolds' number less than the critical value and the boundary layer does not become turbulent.

How far will a cricket ball swing in its flight? Barton (1979) found distances from 47 cm to 65 cm in his experiments with balls in a wind tunnel. Cricketers have long believed that a ball will swing more in a humid atmosphere, but interestingly enough Barton found no effect from atmospheric conditions on the swing of the ball.

Reverse Swing

The type of swing bowling described above has been known by cricketers for well over one hundred years. However, in the 1970's, the great Pakistani fast bowler Imran Khan discovered something strange. He found that, if he bowled fast enough, he could make the *old* ball swing, and furthermore that it swung the *opposite* way to which the seam was pointing. This phenomenon is called *reverse swing* and the Pakistanis gained a mastery of it.

In reverse swing the ball is bowled faster than in conventional swing, with the roughened side forward. In this case, on the rough side of the ball, the boundary layer becomes turbulent as before, clinging to the side of the ball and reducing the air pressure on that side.

On the shiny side, however, the sheer speed of the ball causes the critical Reynolds' number to be exceeded and begins to cause turbulence in the laminar boundary layer. The turbulence begins towards the middle of the ball, and moves forward as the ball increases in speed. In fact, if the ball is bowled fast enough, the boundary layer will trip into turbulence, even *before* it reaches the seam. The seam now acts like a ramp and pushes the air away from the ball. This causes the boundary layer to thicken, and this results in it separating from the ball earlier than on the other side. Again, there is a lower pressure on one side of the ball, but this time it is on the opposite side to which the seam is pointing. So there is a sideways force, and hence reverse swing occurs (Figure 6).

Experiments by Mehta (1993) showed that reverse swing will occur with a new two-piece ball at 180 Km/h (much faster than anyone can bowl); with a new four-piece ball at 130 Km/h and with a roughened old ball at only 110 Km/h (well within the range of medium pacers).

Fast bowlers and medium pace bowlers should be able to learn to use both conventional swing (with the new ball) and reverse swing (with the old ball) and perhaps both types with the ball not too old. Let's hope that Australia's bowlers can develop these skills in the future.

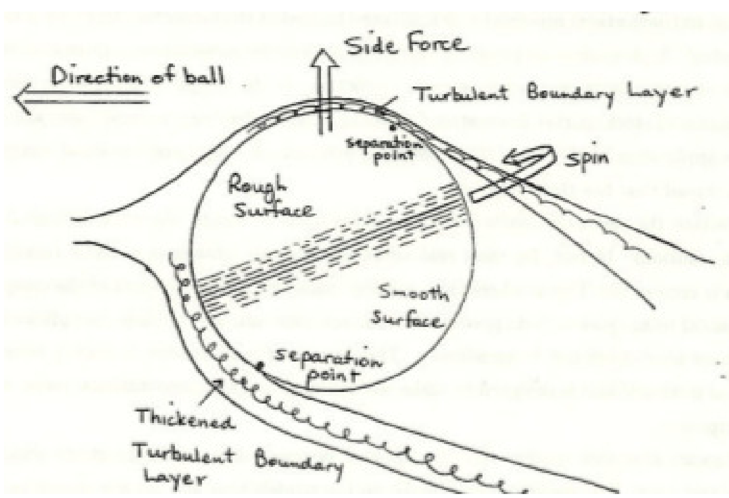

Figure 6: Reverse swing bowling (viewed from above)

Further Reading

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