THE SWERVE OF A CRICKET BALL

N.G. Barton*

All cricketers and cricket followers know that a medium pace bowler can swing a new or well-preserved cricket ball in flight. In this article, I will explain the physical mechanism that allows cricket balls to swerve transversely in flight, and I will give some experimental details of the magnitude of the transverse forces on various cricket balls at varying speeds. Before proceeding, I must apologise for the minimal mathematical content in what follows, but a mathematical analysis of the airflow around a cricket ball is too complicated to be included. Therefore, I will leave you with a description of the physics of the situation, whilst assuring you that a mathematical analysis could be made (provided you had enough time and access to a large computer).

The swerve of cricket balls has been recognized for about a hundred years; indeed a certain Noah Mann was able to make the ball "curve the whole way" with his left-hand *under-arm* deliveries. Early cricketers were aware that new balls seemed "to favour the peculiar flight", although the mechanisms causing the effect most probably were not explained until the 1920's or even later.

Of course, swerve in flight occurs in many games apart from cricket – golf, tennis, table tennis, soccer and baseball are examples that spring immediately to mind. In each of these cases (and sometimes also in the case of cricket), the swerve is due to spin about a vertical axis imparted to the ball at release or projection. This totally separate phenomenon is called the Magnus effect and, I believe, was known to very early naval gunners who observed the swerve in flight of spherical cannon balls which picked up substantial spins when fired. (You may find an account of this in the book by Daish cited below.)

In cricket, however, swerve occurs even when the ball does not have a significant spin imparted to it. This is possible because a cricket ball is not spherically symmetrical, rather it has a prominent band of stitches (the seam of a 6-stitcher) which join the two hemispheres of the ball. A bowler is able to exploit the band of stitches to produce an asymmetry in the air flowing past the ball, and it is this asymmetry that causes the ball to swerve in flight.

Let us now examine what happens to the air near a rapidly moving cricket ball. The air is not just pushed aside by the ball only to rejoin it at the back in an otherwise undisturbed way. The reason for this is due to a subtle fluid mechanical property that was not analysed until the start of this century by Ludwig Prandtl in Germany. A real fluid such as air possesses viscosity (or inherent

* *Noel Barton is a lecturer in the Department of Theoretical and Applied Mechanics at the University of New South Wales.*

"stickiness") and, at any moving boundary such as the surface of a cricket ball, the air must have the same speed as the boundary. A little way from the ball however, the air would stream past the ball and would hardly be disturbed by the ball's progress. Clearly there must be a region, which turns out to be very thin, in which the air speed must adjust from nearly zero to the high speed of the ball. This thin region is known as a *boundary layer* and the viscosity or stickiness of the air is all important in this region. Boundary layers are mathematically difficult to analyse, although now a whole branch of applied mathematics has been devoted to their understanding. Before we start to look at the boundary layers in the air flowing around a cricket ball, let us first record some of the properties of boundary layers around perfect spheres.

Consider the hypothetical situation illustrated in Figures 1(a) and (b) in which air is blowing around two identical smooth balls.

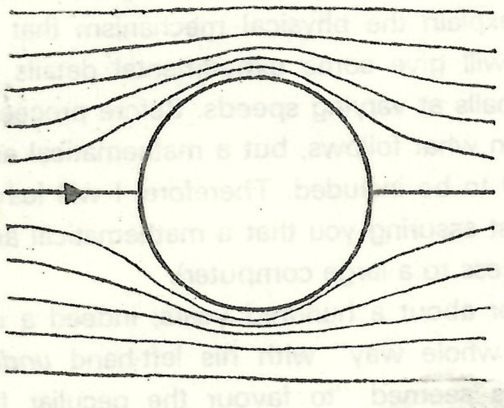

Figure 1(a)

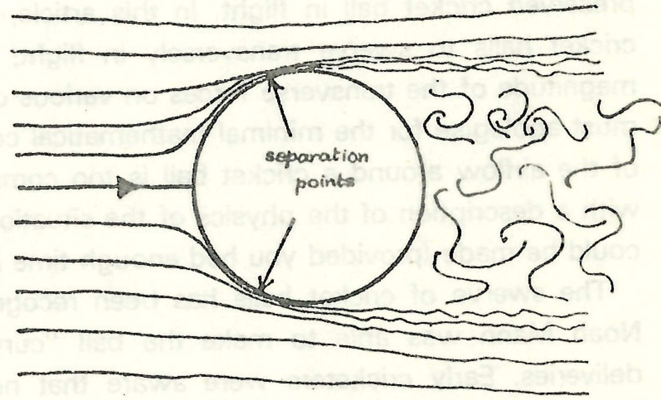

Figure 1(b)

In Figure 1(a), the air is assumed to be blowing very slowly, and the boundary layer which adjusts the air velocity from the free stream speed to zero at the surface of the sphere is thick and stays attached to the surface of the ball almost around to the rear. In Figure 1(b), the air is blowing quite fast and the boundary layer (which in fact is much thinner than illustrated on the figure) is observed to separate or blow off from the surface of the sphere at an angle of about 80° around from the front of the ball. (This angle can be predicted mathematically, but the mathematical techniques are far too complicated to be mentioned here.) Behind the ball in Figure 1(b) is observed a broad *wake* of irregularly moving (or *turbulent*) air. The point of separation of the boundary layer, moves quickly around from the rear of the ball to the 80° position as the air speed increases and, thereafter, the boundary layer continues to separate from the surface at the same position even at higher wind speeds.

A very strange thing now happens if the ball is slightly rough. As the air speed is increased, the boundary layer gets thinner and thinner until the roughness elements on the surface penetrate significantly into the boundary layer. When this occurs, the boundary layer is tripped into a turbulent state wherein the air moves irregularly in the layer in addition to the sweeping flow along the surface. The speed at which the boundary layer becomes turbulent is called the *critical* speed and, experimentally, the critical speed is high for smooth spheres and low for rougher spheres. The effect of transition to turbulence of boundary layers is very marked for it is found that turbulent boundary layers tend to stay attached to curved surfaces longer than the non-turbulent (that is *laminar*) boundary layers we had previously considered. Thus, as the air speed past our hypothetical sphere is increased from zero, the boundary layer at first separates earlier and earlier from the surface until the 80° separation point is reached. Thereafter, the boundary layer separates from this point until the small surface roughness on the sphere is sufficient to trip the boundary layer into turbulence, and the separation point now moves around towards the back of the ball. The situation is sketched in Figure 2 in which the boundary layer is shown to be separating quite late from a rough sphere leaving a relatively thin turbulent wake behind the sphere.

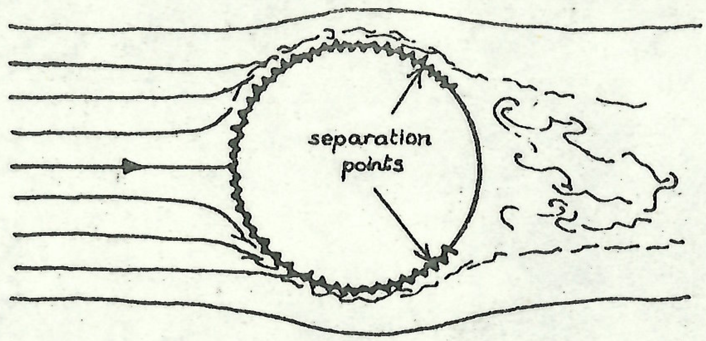

Figure 2

We are now in a position to consider the peculiarities of a cricket ball which enable it to swerve in flight. A cricket ball certainly is not a smooth sphere in view of the prominent band of stitches travelling around the ball. In addition, the surface of the cricket ball is slightly roughened by the internal stitches which hold the two pieces of leather comprising each hemisphere together, and by the trade marks and printing stamped on the surface of the ball. And, of course, the leather surface of the ball becomes scuffed up and roughened in play, although the surface can be smoothed out a little on one side if desired by vigorous polishing of the ball (generally on the trousers of the bowler).

Now the seam of a cricket ball sticks out about .5mm above the surface, whereas the laminar boundary layer on a smooth sphere bowled at medium pace is somewhat thinner, perhaps .2mm. Thus the seam is easily sufficient to trip the laminar boundary layer into turbulence, and the bowler merely has to ensure that the boundary layer on only one side of the ball becomes turbulent in order to produce a marked asymmetry in the flow. The bowler achieves this by slightly rotating the seam with respect to the air flowing past the ball as shown in Figure 3. It is then found that the boundary layer on one side of the ball is laminar and separates at the 80° position, whereas the boundary layer on the other side is turbulent and separates much later from the surface. The resulting air flow around the ball is clearly asymmetrical and it is found that there is a marked nett transverse pressure force acting on the ball.

A cricket ball will lose the transverse force acting upon it whenever the projection speed exceeds the critical speed for the smooth hemisphere of the ball. When this occurs, the boundary layers on both sides of the ball become turbulent, the separation points of both boundary layers become symmetrically placed, and the pressure forces balance on both sides of the ball. It is for this reason that an express bowler cannot swing a cricket ball in flight — he bowls above the critical speed for all but the newest balls. And, as the surface of the ball deteriorates during the course of play, the critical speed becomes lower and lower until eventually the effect is available

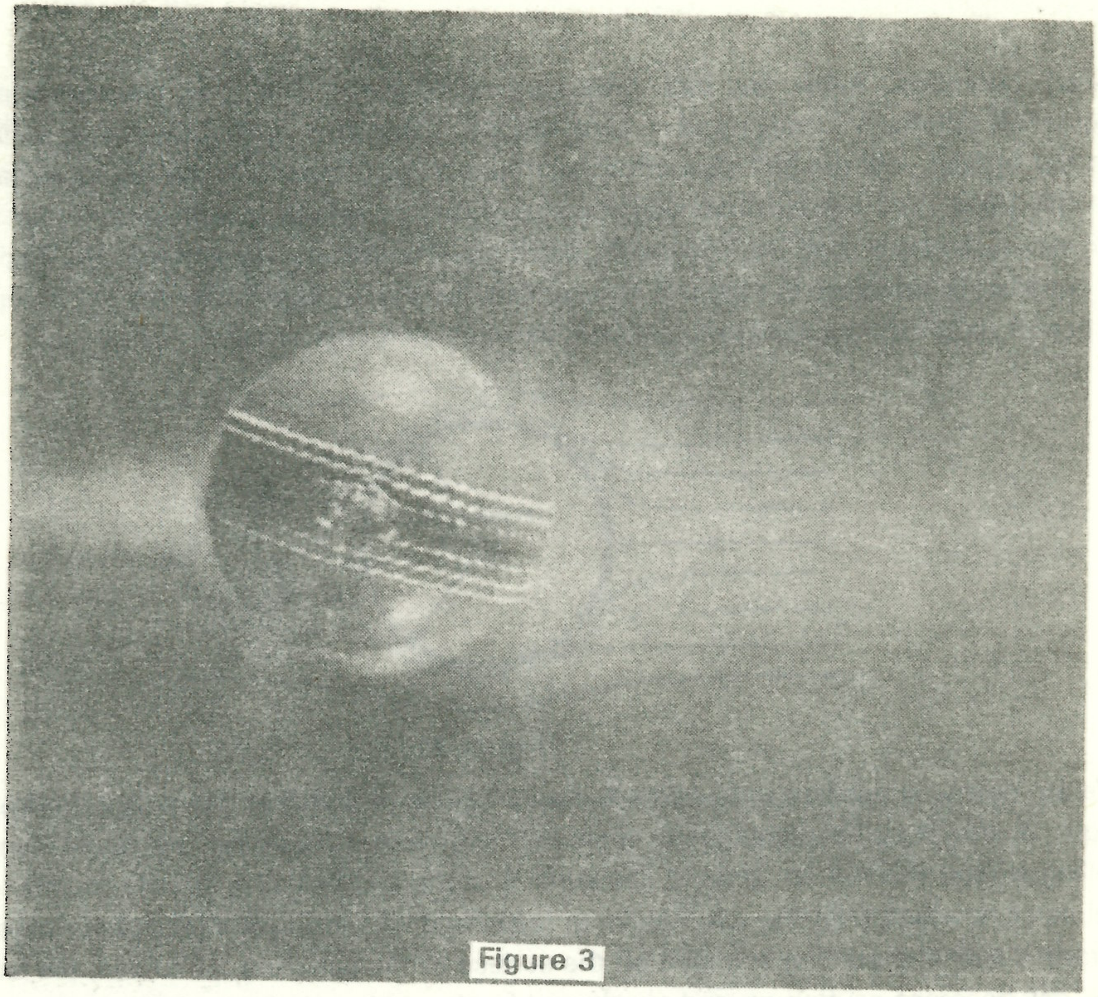

Figure 3

only to those bowling at very gentle speeds. (This may help to explain why Doug Walters, who bowled at a very friendly pace, was able to pick up wickets with very old balls even when bowlers with bigger reputations could not.)

You may well ask how the bowler maintains the more or less constant orientation of the seam with respect to the airflow. This is achieved by imparting a small back spin along the line of the seam as the ball is released. Good swing bowlers regard this backspin as very important in stabilising the flight of the ball, and the bowler's aim should be to bowl a ball whose seam does not wobble in flight.

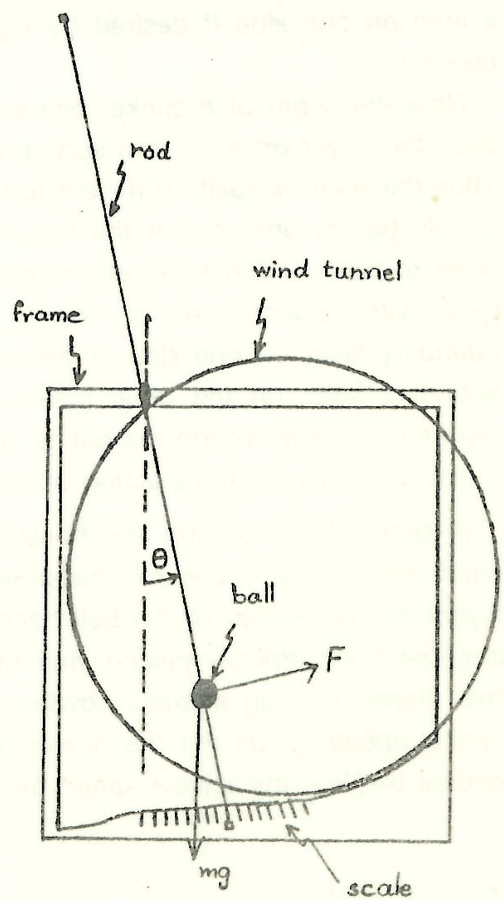

Figure 4

Now let us examine how large the transverse pressure force on a cricket ball can be, and what factors affect the magnitude of this force. Earlier this year, I designed a simple wind tunnel experiment to measure the transverse force on various cricket balls. Each cricket ball was skewered on a long thin metal rod which was pivoted on a frame clamped in front of the wind tunnel and free to swing transversely (see Figure 4). The experimental set up is designed so that the deflecting aerodynamic force is given by $F = mg \sin \theta$, where θ is the angle of deflection from the vertical.

Three balls were used in the experiments; they were a new ball and two balls about 10 and 40 (8 ball) overs old. In Figure 5, I have displayed the transverse force on the three balls as a function of wind speed when the seams were at approximately 30° to the air flow. The results were quite reproducible and they appeared to be independent of the atmospheric conditions. In accord with the experience of cricketers, the transverse force dropped to zero at air speeds greater than 30 m/sec. (respectively 28 m/sec., 26 m/sec.) for the new (respectively 10 over, 40 over) balls. Moreover, the transverse force at any given moderate air speed was the greatest and steadiest for the new ball, and the least and most variable for the oldest ball. The effects of varying the angle of the seams were then considered. Figure 6 shows the mean transverse force on the new ball for seam angles of 15° and 30° to the air flow, and also the mean transverse force on the 10 over ball at seam angles of 0°, 15° and 30°. The most surprising effect was found with the 10 over ball; in this case, the greatest transverse force was obtained with the seam at zero incidence. Clearly, the surface roughness of one side of the ball was sufficient by itself to trip the adjacent boundary layer into turbulence, although I am at a loss to explain why the transverse force should be greatest for this case.

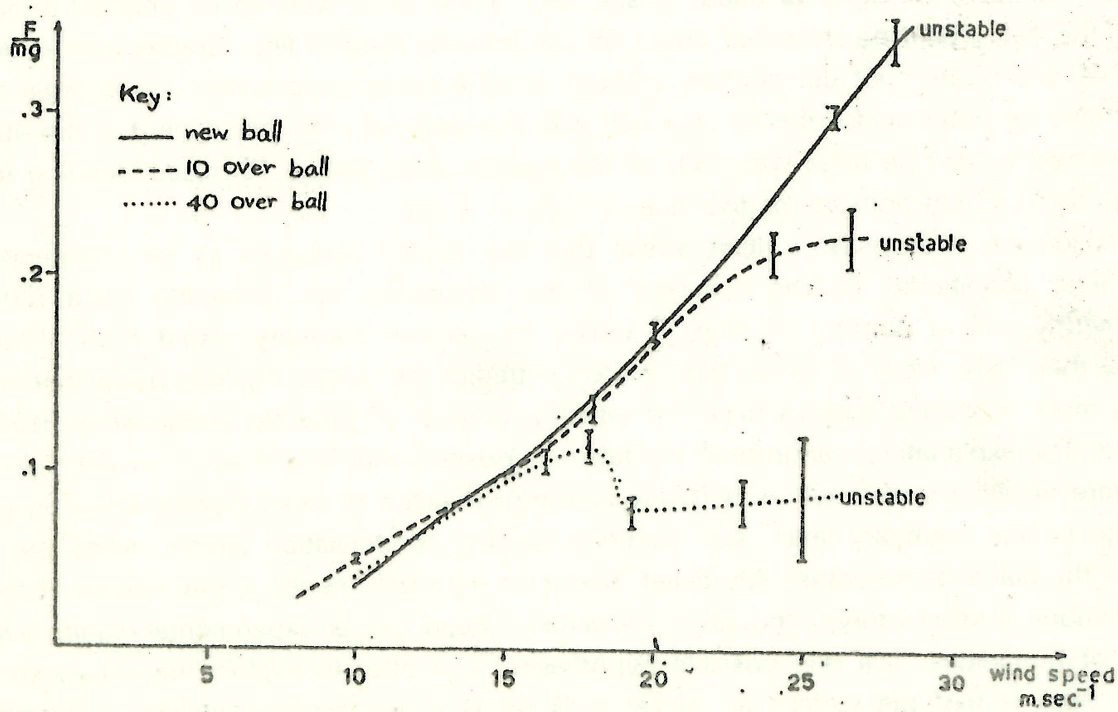

Figure 5: Transverse force as a function of speed. Bars indicate fluctuations. The transverse force became intermittent at the points marked "unstable" and dropped quickly to zero for higher speeds.

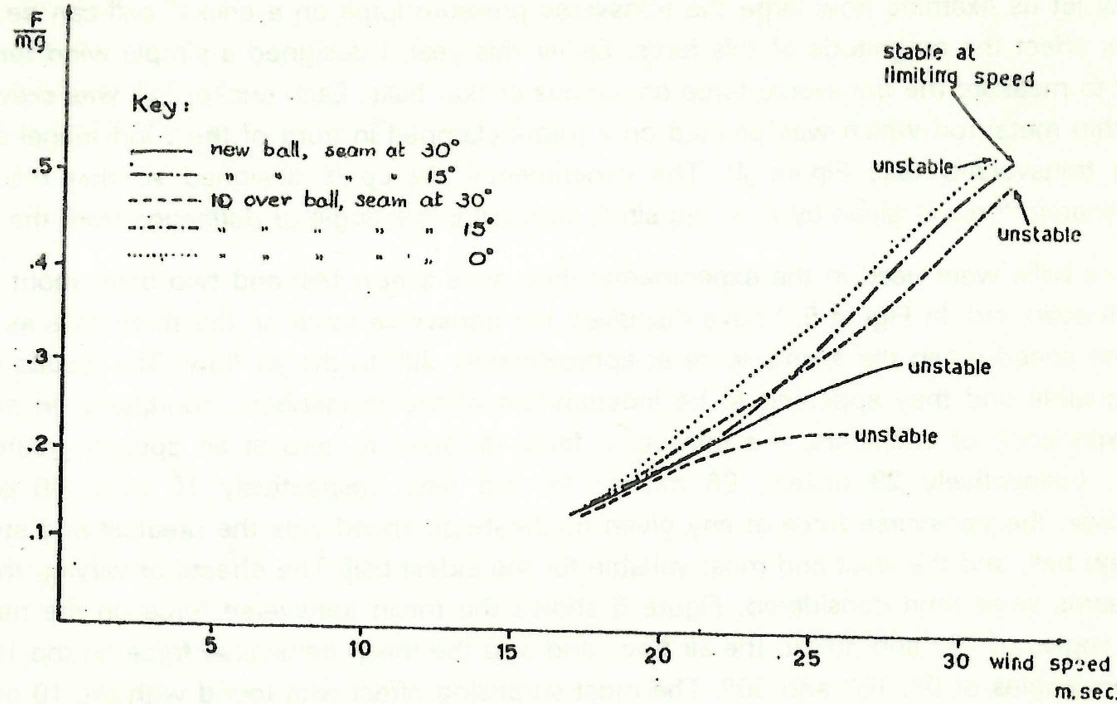

Figure 6: Transverse force as a function of speed for various seam angles.

How much can a cricket ball swerve in flight? The largest transverse force I measured was 53% of the weight of the ball for the new ball with the seam at 15° and at 31.5 m/sec. At this speed, the ball would be in flight for about .5 sec. and, if this force were to be uniform throughout the flight, the ball would be deflected about 65 cm from its original line. Greater deflections may be possible, but I could not detect them without using a better wind tunnel. Deflections of this size could also be obtained for the 10 over ball with the seam at zero incidence. For the 40 over ball, the greatest transverse force was 15% of the weight of the ball at 18 m/sec., leading to a deflection of about 47 cm from the original line of flight in .8 sec.

To conclude this essay, I must stress that the results appeared to be independent of atmospheric conditions. To the accuracy of the apparatus, the deflecting force did not vary significantly over a number of days in which the relative humidity varied from about 50% to greater than 76%. Now this result appears to contradict the commonly held belief that cricket balls swing more on humid days, a belief for which a number of possible explanations have been advanced. The explanations range from the false supposition that humid air is heavier than dry air, to the more plausible ones such as humidity causing the seam to swell thereby ensuring greater turbulence in one boundary layer, and humidity causing condensation which makes the "smooth" side of the ball even smoother. My belief, based on my experiments, is that neither of the last two explanations is satisfactory, although to be certain I need further experimental results over a wider range of humidities. The one possible hypothesis I can offer to explain the enhanced swing on humid days is that the surface of cricket balls tends to get scuffed up less on humid days. A glance at the graphs for the 10-over ball which had one side "rough" and the other "smooth" shows that surface roughness alone can cause very large deflecting forces even with the seam at zero incidence. Thus the surface condition of the ball is very important, and if cricket balls retained their shine longer on humid days, this could go a long way towards explaining the popular belief.

Further Reading

C.B. Daish, "The physics of ball games", English Universities Press, (1972).
R.A. Lyttleton, "The swing of a cricket ball", Discovery 18 (1957), 186-191.
J.C. Macfarlane, "Why a cricket ball swerves in the air", Australian Physicist 10 (1973), 126.

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HOW TO MAKE COMMON MATHEMATICAL ERRORS

Professor Basil Rennie of James Cook University, Townsville, has sent us the following riposte to two recent articles. (Parabola Volume 14, number 2 and Volume 15, number 1.)

An easy way to make an error is to pretend that log $|x|$ is an indefinite integral for x^{-1}. Consider the following:

$$\log 2 = \log |x| \Big|_{-1}^{2} = \int_{-1}^{2} x^{-1}\,dx = \int_{-1}^{0} x^{-1}\,dx + \int_{0}^{2} x^{-1}\,dx.$$

In the first integral, put $x = -t$, giving

$$\int_{-1}^{0} x^{-1}\,dx = -\int_{0}^{1} t^{-1}\,dt.$$

In the second integral, put $x = 2s$, giving

$$\int_{0}^{2} x^{-1}\,dx = \int_{0}^{1} s^{-1}\,ds.$$

Consequently,

$$\log 2 = -\int_{0}^{1} t^{-1}\,dt + \int_{0}^{1} s^{-1}\,ds = 0.$$