Reverse Swerve – a New Phenomenon in Football

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Abstract

This paper considers the new design of footballs, which have reduced seams and textured roughened surfaces. We propose that at specific forward and rotational (spin) velocities, the balls behave differently, with a tendency to swerve in a direction opposite from that expected. We call this proposed effect reverse swerve, and present an argument based on aerodynamics for it. This argument is developed by first considering the well-known swing and reverse swing effect of the cricket ball, reverse swing being generated because the roughened surface of an old ball triggers a turbulent boundary layer. This argument is then developed for the football. We suggest that the effect is caused by a scenario whereby, at specific forward and rotational velocities, laminar and turbulent boundary layers occur on opposite sides of the ball.

1 Introduction

Newly designed footballs, with reduced seams and textured surfaces, have recently been introduced in professional football. However, such balls have had many critics, particularly during the 2010 World Cup from many high-profile players and coaches. The criticism centred on the difficulty of strikers hitting on target long-range shots, as well as from goalkeepers being unable to catch the ball. Reasons for the ball's unpredictable behaviour have been given as the high altitude of a lot of the sports stadia in South Africa, the ball being fairly lightweight and nearly spherical, the onset of the knuckle effect, and an inability in players' adjustment to the step change in the ball's performance.

However, although most of the stadia were at high altitude, some were not and the ball has also been used in other leagues and tournaments with similar criticisms. So, although high altitude plays a part in making the ball move differently than at sea level, it is likely that it is not the predominant effect causing the unexpected behaviour. The ball being fairly lightweight and near spherical can cause, together with increased elasticity, an increased elastic response on kicking causing the energy being diverted from a player spinning the ball to an elastic mode of vibration. This effect is seen most readily with cheap lightweight perfectly round 'supermarket' balls which do not swerve in an expected way, but although this was a criticism levelled at the ball, it is again not a dominant effect as video footage shows the ball spinning in an expected manner which is undiminished by any perceived elastic response. Furthermore, FIFA have clear guidelines regarding the weight of the ball which must be within 410–450 g [1]. The knuckle effect occurs when the ball is struck straight and without spin. Due to the magnification of asymmetries, the ball will then swerve one way or the other, and this effect has been suggested by NASA scientists to be more prevalent in the new design footballs. Indeed, one player, Forlán, made good use of this at the World Cup, often hitting long-range shots without significant spin in the direction of the middle of the goal. The ball would then swerve unexpectedly one way or the other due to the knuckle effect making it difficult for keepers to save. However, the main criticism by players was by those who try to direct or pinpoint the flight of the ball into the corner of the net, controlling it predominantly by spin rather than kicking the ball flat. With regard to a step change in the ball's performance, although there is a period of adjustment for sportsmen when a new technology is introduced, if it is perceived as a good technology it is welcomed. For example, the changeover in racquet sports from wooden to composite manufacture was a radical step change but at the same time was rapidly adopted. It is therefore the opinion of the authors that there is a fundamental aerodynamic reason for the unexpected behaviour of the newly designed footballs.

Experiments related to the aerodynamics of spheres include the work by Aachenbach [2,3], with the former on smooth spheres, and the latter considering roughness. A comprehensive overview of the aerodynamics of sports balls has been given by Mehta [4]. Experiments investigating the lateral (or lift) coefficient on ball spin [5–9], have been collated, compared and presented by Passmore et al. [10]. These results are presented by plotting the lateral coefficient (normalised to the free stream pressure) against the spin ratio. This means that any sudden change in the flow regime due to the change in spin rather than forward velocity (which requires consideration of the Strouhal number) may not necessarily be picked up by existing experimental results. As well as the Reynolds number and Strouhal number, the third important parameter in the problem is roughness, and the difficulty measuring this is discussed in [11]. Flight trajectories have also been modelled [10, 12]. Furthermore, discussion on the issues related to developing a model for a rough and spinning ball are discussed by Bray [13].

In the present paper, we propose a new explanation for the ball's unpredictable performance, based on aerodynamic theory and the new design modifications on the football not present on previous footballs. In particular, the new balls appear to fly faster through the air, by means of a textured roughened surface over the ball. As well as making the ball more tactile for players whilst running with the ball and dribbling, this roughness has the aerodynamic effect of generating a fast reduced-thickness turbulent boundary layer, significantly reducing the drag on the ball. The question is, can this

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design feature also have some unintended consequences? To answer this, in the present paper we look at the analogy of cricket ball swing [14] and reverse swing [15]. Cricket ball swing occurs when one side of the ball is shiny, and the other is roughened, creating a difference in the type of boundary layer formed on either side, which results in a pressure difference making the ball swing. However, after many overs play when the ball is old, the shiny side also becomes rough, and an effect called reverse swing occurs where the ball moves in the opposite direction from that expected. So, the change in the type of boundary layer caused by surface roughness significantly changes the swing characteristics of the cricket ball. We propose that a similar effect occurs with the new design footballs in comparison to a standard ball, that this new design with surface roughness also affects in an unexpected way how the ball swerves, and so we shall call this effect reverse swerve. In this paper, we build this argument by first presenting the well-known aerodynamic arguments explaining the swing and reverse swing of a cricket ball, as well as the swerve generated by spinning a football. Then, we propose a new scenario that for a particular forward velocity and spin, the roughness of the ball's surface generates a reverse swerve effect.

2 Cricket ball swing

A cricket ball is made to swing by angling the seam of the cricket ball towards the direction the ball is required to swing, as depicted in Figure 1. In this figure, the ball is moving from left to right, and so the air is flowing over the ball from right to left. The ball is held in flight at this angle by spinning the ball in the direction of the seam's axis. Furthermore, one side of the ball is made shiny which is presented more towards the batsman, and one side of the ball is rough which is more towards the wake.

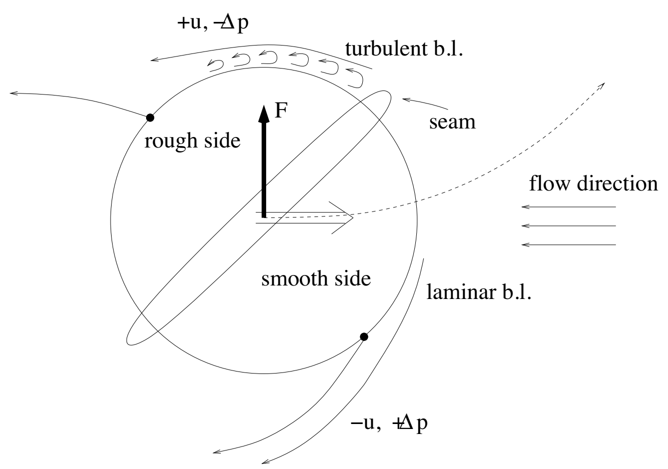

Figure 1: The swing of a cricket ball

A brief account of the reason for swing is presented here, a fuller description is given in [16]. The reason for swing is that one side of the ball (the rough side) generates a predominantly turbulent boundary layer, whereas the other side of the ball generates a predominantly laminar boundary layer (the shiny, smooth side). The seam is also instrumental in this, with the part of the seam presented forward of the ball acting as a vortex generator as air flows over and past the seam's edge. This energises the flow, creating a fast relatively low-thickness turbulent boundary layer on this side. On the other side, the surface is smooth and the flow tends to be more laminar in nature, with the result that the flow is slower and the boundary layer thicker.

This boundary layer difference on either side of the ball affects the flight of the ball by creating faster velocity flow outside the boundary layer on the rough side, and slower velocity flow outside of the boundary layer on the smooth side. Outside of the boundary layer, the flow is nearly inviscid and so Bernoulli's equation applies, see for example [17]. Thus,

$$p + (1/2)\rho u^2 = \text{constant}, \tag{1}$$

where p is the fluid pressure, ρ is the fluid density and u is the fluid velocity. This means that the increase in velocity results in a reduction in pressure, and vice versa, creating a pressure difference called the Magnus effect. This pressure difference results in the ball swinging in the direction towards the rough side and away from the smooth side, as depicted in Figure 1.

3 Cricket ball reverse swing

A brief account of the reason for reverse swing is presented here, comprehensive descriptions are given in [18] and [15]. Reverse swing occurs when the ball is old, that is, has been used for around 40 overs or more. The first proponents of reverse swing were the Pakistani test cricketers, and the technique was particularly honed by the fast bowlers Waqar Younis and Wasim Akram who also played for Lancashire County Cricket Club. In this case, the ball is sufficiently old that both sides have a roughness, producing turbulent boundary layer flow on both sides. However, because of the additional wear and tear of the old ball, the raised seam facing the flow tends to build an increased boundary layer and separate the flow away from the ball sooner than in the case of standard swing bowling; the separation point where the boundary layer separates completely from the ball occurs earlier, see the pictorial depiction in Figure 2. Immediately behind the separation point, the flow is quite still and so the velocity is small producing, when applying Bernoulli's equation (1), a high pressure. In contrast, on the other side the raised seam is to the rear of the ball, and so there is a fast turbulent boundary layer along most of the length with a delayed separation point. So, in comparison to normal swing, overall there now is a higher pressure on the other side of the ball than expected, and so the ball swings in the reverse direction to ordinary swing, hence reverse swing.

4 Football swerve

The swerve of a football is explained by elementary inviscid fluid dynamics, building on the fundamental theoretical developments of Euler, Magnus and Rayleigh given in foundation textbooks. The simplified argument presented here uses the Bernoulli equation.

A football swerves because of the spin applied to it. In Figure 3, a clockwise spin is applied to the ball. In this case, on the side where the ball is spinning into the flow (in Figure 3, this is the top side), the direction of the spinning ball is opposing the motion and so there is a tendency for the velocity of the flow to be reduced. Using Bernoulli's equation (1), this gives a tendency for the pressure to be increased. Conversely, on the side where the ball is spinning with the flow, the direction of the spinning ball is with the motion and so there is a tendency for the velocity of the flow to be increased. Using Bernoulli's equation (1), this gives a tendency for the pressure to be decreased. The difference in pressure on the two sides of the ball makes the ball swerve as depicted in Figure 3.

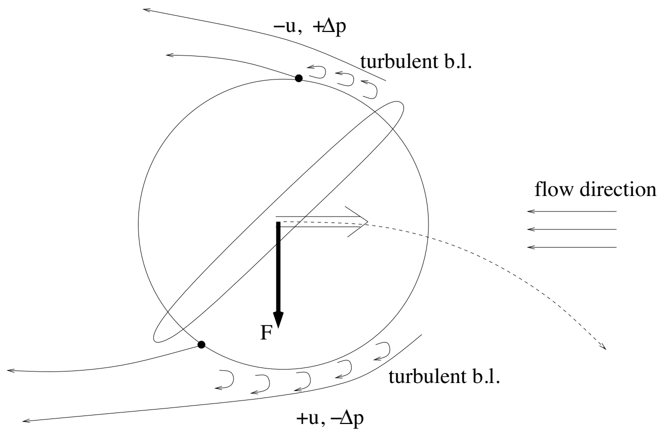

Figure 2: The reverse swing of a cricket ball

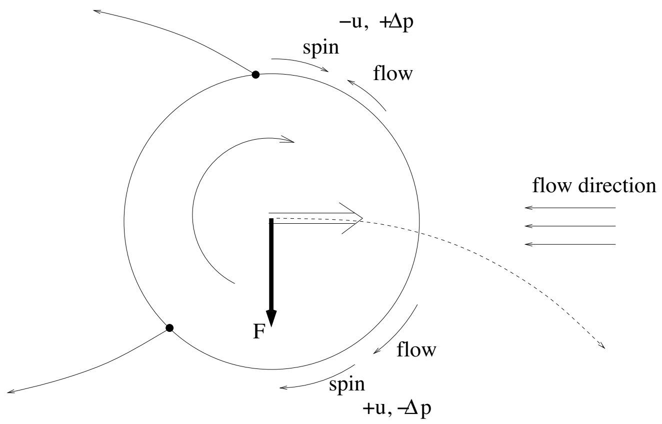

Figure 3: The swerve of a football

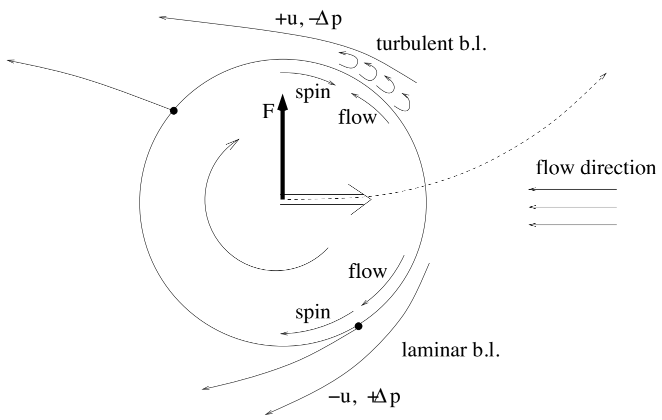

Figure 4: The reverse swerve of the new design footballs

5 Football reverse swerve

In this section, we present an aerodynamic theory suggesting that it is possible for the new design footballs to experience a reverse swerve effect. An old football design has large smooth patches stitched together. However, the new design footballs have a continuous roughened surface. It is known that this surface improves the aerodynamics of the football, in particular the football experiences greatly reduced drag. This indicates that a fast turbulent relatively small-thickness boundary layer is generated over the surface of the ball. However, if a high degree of spin is applied to the ball, generating a spin velocity at the surface of the ball of a size similar to the forward velocity of the ball, then on the side of the ball where the ball is spinning in the same direction as the air flowing past, it is more likely that the flow will be smooth and laminar, see the lower side of the ball in Figure 4. This means that it is feasible that a fast turbulent boundary layer occurs on one side (the upper side in Figure 4) of the ball but a slow laminar boundary layer occurs on the other (the lower side in Figure 4). Applying Bernoulli's equation (1), this will create a pressure difference opposite to that expected (compare with ordinary swerve in Figure 3), and we name this effect reverse swerve.

In contrast, the flow regime is more complicated over an old design football, with a tendency for laminar flow over the smooth patches but also a tendency for vortex generation and flow separation at the seams between patches. It is likely that this mixed flow pattern occurs in relatively equal measure on both sides of the spinning ball, so there is no tendency for any reverse swerve effect with a football made in the standard way.

6 Anecdotal examples that may indicate reverse swerve from the World Cup

6.1 Wayne Rooney's shots

Supposing this effect occurs when the forward velocity of the ball is of a similar size to the surface velocity of the ball due to spin, then this is likely to occur for a long-range shot hit with a lot of spin late in flight. This is because later in flight the forward velocity of the ball reduces significantly but the spin of the ball remains fairly constant and decays slowly. Thus, the ball starts its flight in a regime governed by the aerodynamics of standard swerve and so moves in an expected direction. Later in flight there is the possibility that the reverse swerve effect occurs because the forward velocity of the ball has reduced sufficiently whilst the spin of the ball has not. Evidence of this could be the consistent missing of Wayne Rooney's long-range shots. These are his speciality and it is unusual for him to have been off target. Typically, he moves in from the left wing and fires a low shot towards the far corner of the goal, swerving the ball into this corner (dashed curve of Figure 5). However, all attempts by him saw the ball late in flight appear to straighten out and go wide of the post by several feet (solid curve of Figure 5). This could also be simply due to player adjustment with the ball travelling so much quicker than a standard ball, and so although indicative is not conclusive.

6.2 Robert Green's goalkeeping error

Robert Green, the England goalkeeper, let in a soft goal against the USA in the World Cup competition which directly led to losing his place as first choice goalkeeper. However, this goal is interesting in the fact that the ball had a double bounce. After the first bounce, the ball sprang up with some topspin and also the velocity of the ball was quite low. These are conditions where one would expect reverse swerve to occur. This would manifest itself in the ball's travelling longer than expected through the air before bouncing. The positioning of Robert Green suggests that he was expecting the ball to bounce a few feet in front of him, and to catch the ball. Instead, the ball bounced under his body into the goal. This could be attributed to a simple error of judgement, something that all goalkeepers have experienced sometime in their careers, so although indicative this is inconclusive again, and an experimental test needs to be devised to capture the effect.

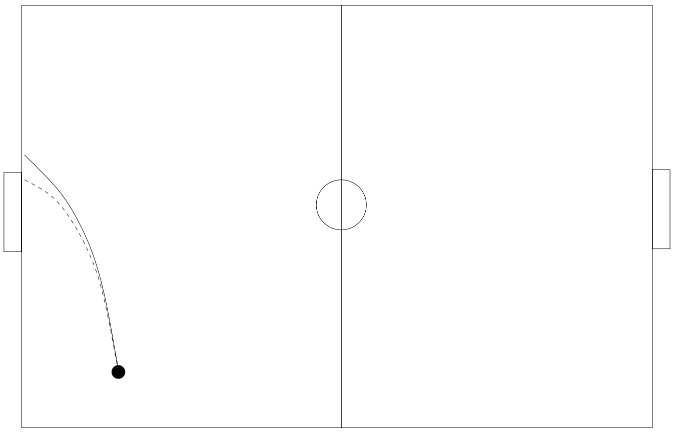

Figure 5: Direction of a Rooney shot in the World Cup

7 Discussion

We have presented an argument to give an explanation based on aerodynamics of why the new design footballs move unexpectedly. This argument is developed by first considering swing and reverse swing of a cricket ball, and then swerve of a football. The new aerodynamic effect is called reverse swerve and occurs if a turbulent boundary layer occurs on one side of the football, whilst a laminar boundary layer occurs on the other. This is likely to occur when the forward velocity of the ball is comparable to the velocity on the surface of the ball generated by its spin. We hope to conduct experiments to test whether this phenomenon genuinely occurs and whether it arises in other contexts. ❑

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