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S4_4 Roberto Carlos' 'Impossible' Free Kick

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Abstract

In the Tournoi de France 1997, Roberto Carlos scored a free kick in a 1-1 draw between France and Brazil. This goal would go on to make headlines and feature in highlight reels for many years to come. Our calculations show the force applied to the football by Carlos to be 320.2 N at an angle of 9.84 degrees from the initial direction of the ball.

The Significance of the Free Kick

Roberto Carlos' free kick, at the Stade de Gerland, garnered large amounts of media attention; due to the path of the ball having a curl that had not before been witnessed. The strike initially moved around the wall, looking to go well wide of the goal before bending back towards the goal leaving goal keeper Fabian Barthez incapable of stopping the ball.

Method

In order for the ball to bend so aggressively, Carlos had to strike the ball in a way that caused it to rotate perpendicular to the velocity of it with a large enough angular velocity to allow for the Magnus Effect to take control. The Magnus Effect is a force that acts perpendicular to the velocity of an object and in the same plane as its rotation due to the varying air pressures either side of the rotating projectile.

The other impressive aspect of this free kick is its velocity; Carlos always had a reputation for being able to strike the ball with a lot of force, but this was a powerful kick, even for him.

The first task was to calculate the distances travelled using the footage from TF1, 1997[1]. This created the diagram seen in Figure 1 using Pythagoras' Theorem and the sine/cosine rules. Using this diagram, it was then possible to calculate the mean velocity of the ball in its orthogonal components using the reference frame of the initial direction of the ball. Using the mean velocities, total Drag could be calculated using

$$F_d = 0.5\rho V^2 A C_d \tag{1}$$

in which F_d is the drag coefficient, ρ is the density of air calculated using the average temperature of that day being 24 degrees whilst 172m above sea level [2] [3] , V is the mean velocity, A is the cross-sectional area and C_d is the drag coefficient.[4] With a value for the force applied due to drag, it was then possible to calculate the deceleration caused and using SUVAT, calculate the initial and final velocities. By using the plane of the initial trajectory of the ball, it was acceptable to assume that any movement in the perpendicular plane was due to the Magnus effect. With the distance of movement and thus force caused by the Magnus effect known, we could use the Magnus equation to calculate angular velocity. The Magnus equation for a sphere is

$$F_m = (\pi^2 r^3 \rho)\boldsymbol{\omega} \times \boldsymbol{v} \tag{2}$$

in which F_m is Magnus force, r is radius of the ball, ω is angular velocity and v is velocity.[5]

Results

By using a drag coefficient of 0.25 [4]and mass of 0.43 Kg for the football, it was possible to calculate a drag force of 4.793 N which translates to a deceleration of 11.147 ms^{-2}. Using SUVAT and a measured travel time of 1.16 s, an initial velocity of 36.685 ms^{-2} is calculated. Assuming the contact time between the boot and the ball is 0.05 seconds, the force applied to the ball in this direction is 315.49N resulting in an acceleration over this period of 733.7 ms^{-2}.

In order to produce a perpendicular force due to the Magnus effect of 2.039 N over the distance of the kick, the angular velocity is 57.84 rad s^{-1} which is equal to approximately 9.206 Rev s^{-1}. This equates to a tangential velocity of 6.363 ms^{-1} requiring a force of 54.72 N to be applied tangentially to the ball. In order for these orthogonal forces to be applied together, we can use the equations:

$$F_y = F \sin\theta \tag{3}$$

$$F_x = F \cos\theta \tag{4}$$

where θ is the angle from the tangent where the ball is struck on the surface, perpendicular to the initial direction of movement, to the direction of the striking foot through the ball. It is calculated to require a force of 320.2 N at a θ of 80.16 degrees.

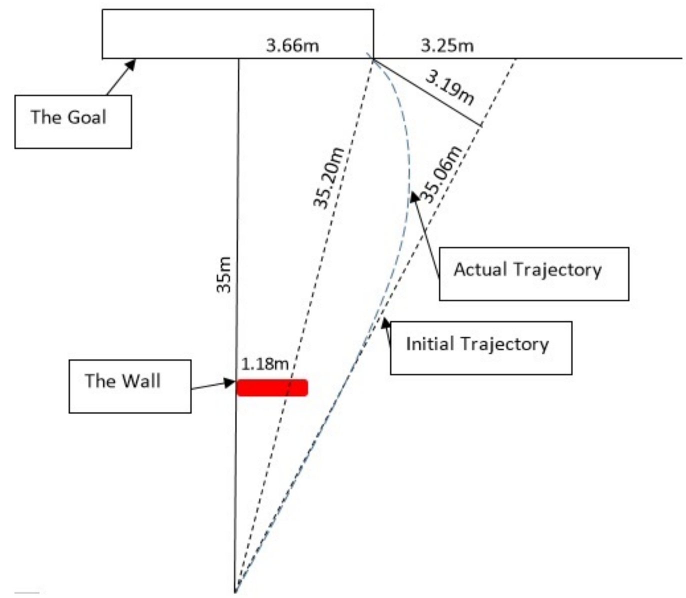

Figure 1: A basic diagram of the trigonometry of the free kick.

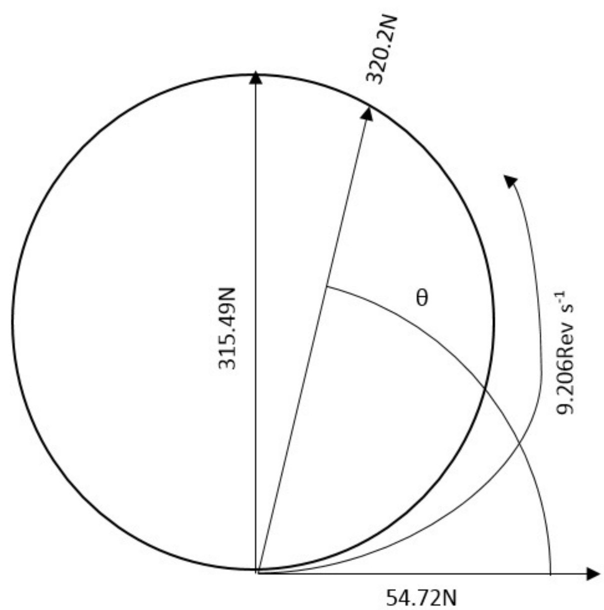

Figure 2: The components of force and the required strike of the ball for it to behave in flight similarly to the free kick.

References

[1] `https://goo.gl/KfTHSE` [Accessed 20 October 2017]

[2] `https://goo.gl/juXQ1i` [Accessed 20 October 2017]

[3] `https://goo.gl/YCdwzM` [Accessed 21 October 2017]

[4] `https://goo.gl/aBZPPU` [Accessed 22 October 2017]

[5] `https://goo.gl/Mm74VF` [Accessed 22 October 2017]