Magnus Effect – Roberto Carlos Mythical Kick

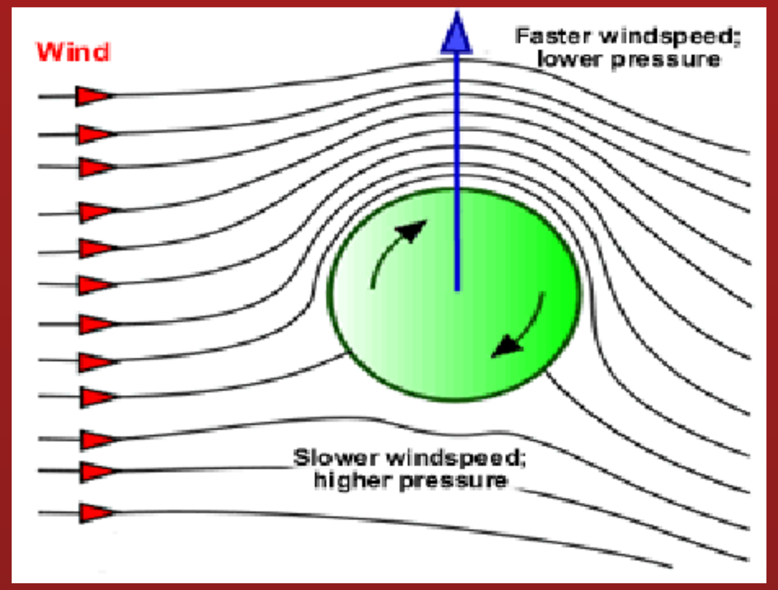
York University
Subbashivani Moorthy
Erick Martinez
Vithurshan Suthakar
Andrew Brkovic

Abstract

Breaking down the iconic Roberto Carlos "Physics defying" curve ball goal into actual physics.

Introduction

Kicking the ball somewhere near the edges will create a spin within its own axis, the ball's angular velocity and the friction generated outside the system will cause a change in air pressure on the plane in which the ball is rotating, the side of the ball in which the air attains greater pressure will generate a sideway force towards the direction of low pressure. This effect is called Magnus Effect



The ball's translational speed slows down abruptly due to the drag coefficient of the medium, having as a result a grater and more predominant bend in the trajectory.

The objective is to calculate the range of possible angles and distance at which the Roberto Carlos impossible goal could be replicated using projectile motion, rotational motion and magnus force.

Methodology

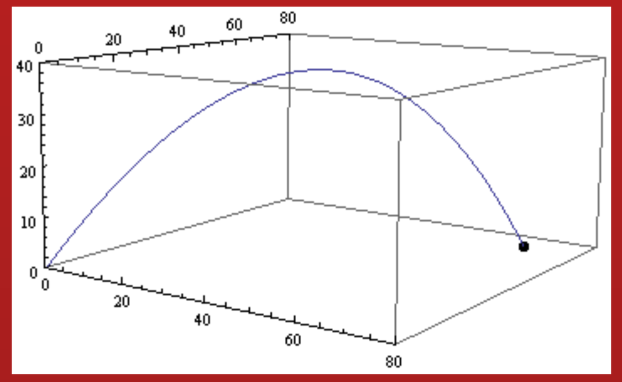
Two different methods were used to optimize the range in which the shot could be made. One neglecting air resistance and change in angular velocity and one using the previous parameters.

- *No drag force*

By neglecting air resistance or drag, it can be said that the angular velocity and not the translational velocity varies within the trajectory, yielding:

$$\vec{F} = \frac{1}{2}\rho A C_M v^2 \hat{F}$$

Where ρ is the density of air, A is surface area, C_M is the Magnus coefficient obtain with $C_M = \frac{2\pi R}{v}$, where R is the radius of the ball.
After solving for $\vec{F}$, the kinematics equations are used to plot trajectory of the ball and optimize the range by changing the initial conditions of the shot.

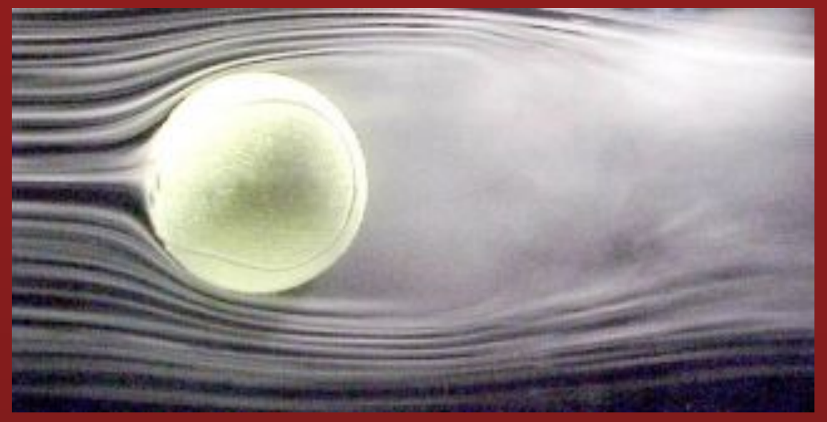


- *Drag force on the Magnus Effect*

By adding an extra drag force term to the initial DE for the motion of the ball, we obtained:

$$\vec{F}_{drag} = \frac{1}{2}\rho A C_{drag} v^2 \hat{F}$$

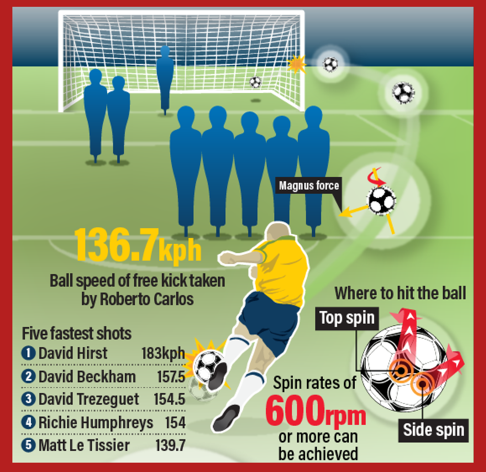
Where C_{drag} is obtained by $C_{drag} = \frac{2\rho v R}{\mu}$ where μ is the dynamic fluid viscosity.
The total drag force is divided into the $\hat{x}$ component, which deaccelerates the translational motion of the trajectory and to the $\hat{y}$ & $\hat{z}$ that resist the total magnus force and the gravitational pull.



Results

- *Expected Results*

If the origin of the coordinate system lays on the ball's position at rest, the distance between the ball and the net is 35 m and the positive span of the net would be 1.83 m. The distance between the defender and the ball is 8.5 m and the span is 0.965 m assuming an average shoulder width.

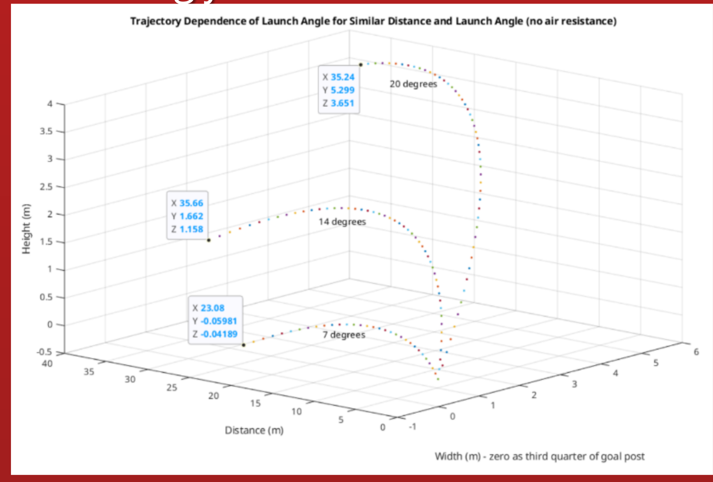


Experimental results analysing and replicating Roberto Carlos shot determined the angular velocity to be 62.8 rad/sec, the initial velocity to be 36.11 m/s and the optimal angle for the shot to be 12 degrees.

- *Result*

Assuming that the maximum velocity at which the ball can be kicked is the initial velocity of Carlo's shot.

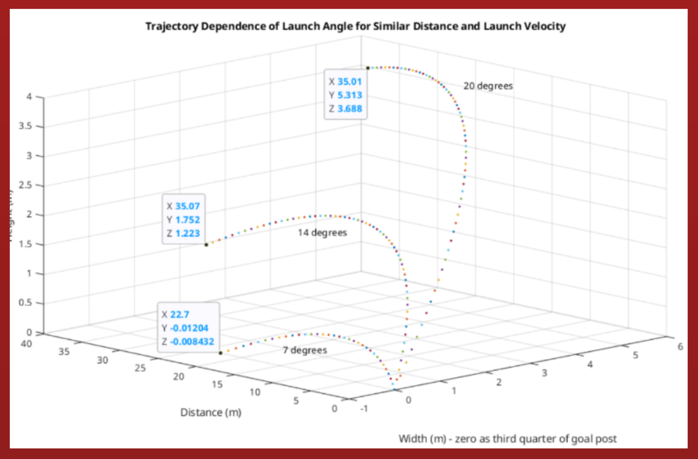
- *No drag force*

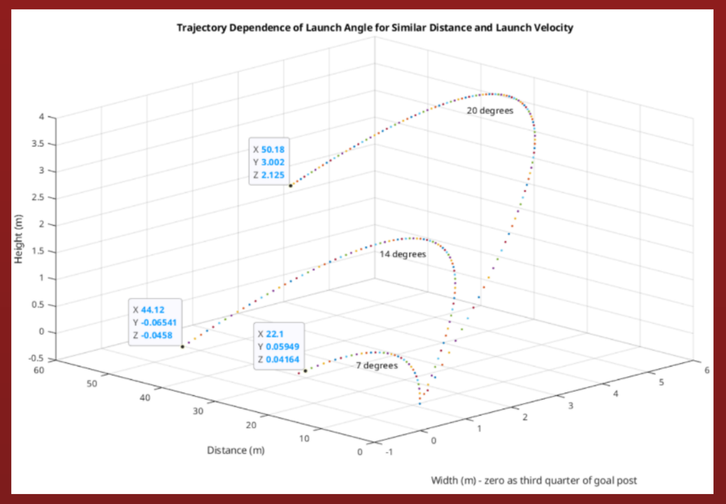


Setting the distance to be 35m, it can be seen that the only shot that made through the net was at an angle of 14 degrees. The shot made it through the net by 0.17m, implying a short range of possible angles.

- *No drag force*

Using the same parameters as before, the shot barely made it through the net by 0.08m, which reassures that the drag force is acting against the magnus force.

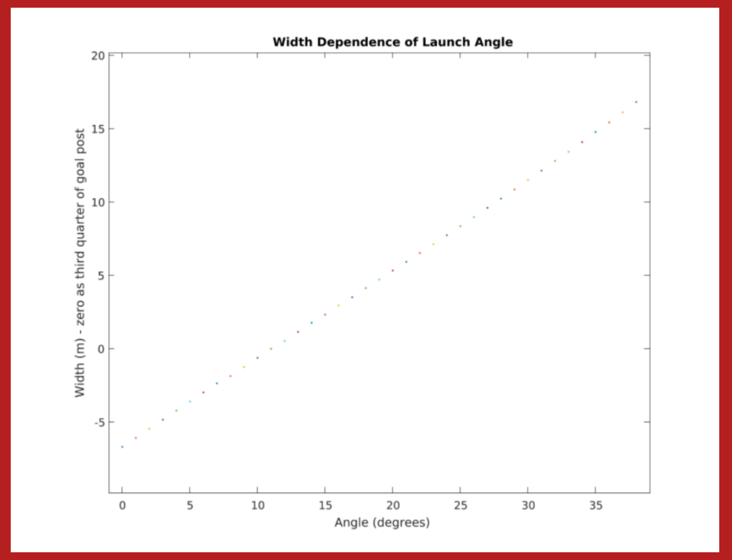




When the distance is set to 50 m, the 14° shot makes it to the goalkeeper's range with a small bounce that reduces its velocity, implying that the shot has to be made at a shorter distance.

Conclusion

By the analysis of our data and the previous results, it can be seen that our drag force model accurately agrees with the data of the complex mathematical analysis of the shot's spatial location by a difference of 2 degrees and can predict the outcomes at different angles and distances.



Note that at first glance, the plot may appear linear, but this is not the case.

Although our model can not describe the ideal magnus effect in denser mediums (I.e. water) due to the lack of particular fluid dynamics terms, it can approximate curvatures in trajectory for cases like football and similar sports with translational motion, gravitational force and rotational motion and It can be concluded that the projectile motion approximation for the magnus effect works for the Roberto Carlos iconic goal.

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