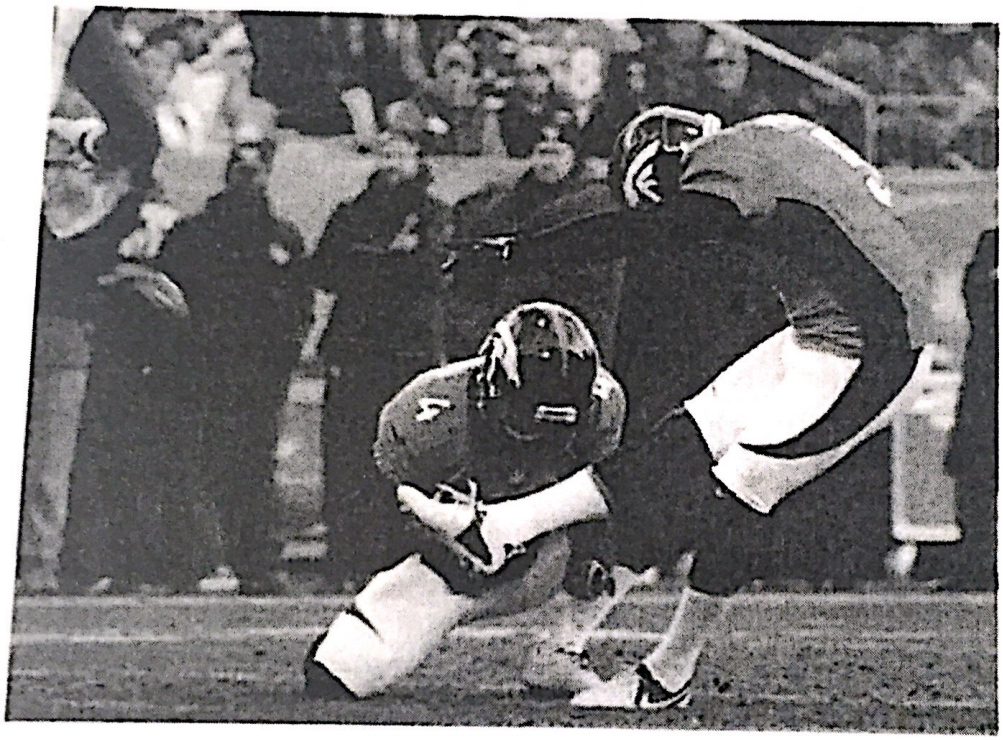
Introduction

On December 8th, 2013, Matt Prater place kicker for the Denver Broncos, kicked the longest field goal in NFL (National Football League) history. He kicked a 64 yard field goal, breaking the previous record of 63 yards set by Tom Dempsey in 1970.

Figure 1: Matt Prater's 64 yard field goal

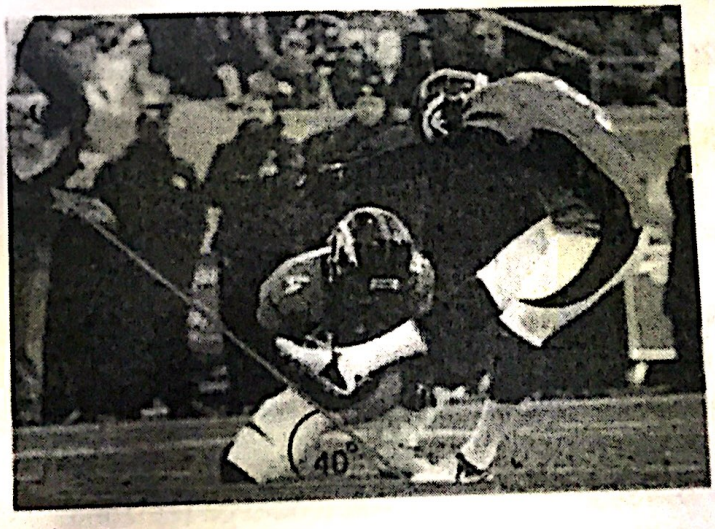


Being a place kicker for my high school football team, I was wondered how he was able to kick the ball so far. When I was learning to kick, I learned that there are many factors that can affect a kick, such as force behind the kick, the path of the ball, the wind, the snap and the hold, and many numerous other factors. However, my instructor stressed that one of the most important

factors behind a good kick is the path the ball takes when it was kicked. This knowledge led me to wonder if there is an ideal path for a football to take to maximize the distance the ball travels, assuming all other factors are constant.

From my previous math knowledge, I know that the path a football takes when it is kicked is a parabola, and is dependent on the initial angle the ball takes when it is kicked and the initial velocity that the ball is kicked at. Also, from my previous knowledge from physics, I know the equation for the distance the ball travels horizontally is $x = V_0 * cos(\Theta) * t$ and the equation for the vertical displacement is $y = 1/2(-9.8) * t^2 + V_0 * sin(\Theta) * t + h_0$ when V_0 = the initial velocity of the ball, t= the time the ball travels, Θ= the angle the ball is kicked with the horizontal, and h_0 = initial height. Also, I know that the ideal angle for the ball to be kicked at is 45 degrees because its when the horizontal and vertical components are equal, which maximizes the height and horizontal distance.

Figure 2: Angle of Matt Prater's 64 yard field goal



Although I already know the distance the ball travels horizontally, I do not know the angle that the ball was kicked at or the initial velocity of the kick. In order to find the angle at which the ball was kicked, I used the picture of Matt Prater kicking the field goal and a protractor to approximate the angle with the horizontal. I found that the approximate angle of the kick was 40 degrees. Also, I used a stopwatch to determine the amount of time between when the ball was kicked and when the ball went through the goal posts, and found the kick took approximately 4 seconds. Then, I plugged this information into the equation $x = V_0 * cos(\Theta) * t$ to find the approximate initial velocity of the kick. First I converted yards into feet to find the initial velocity in feet per second.

$$x = V_0 * cos(\Theta) * t$$

$$192\,ft = V_0 * cos(40) * 4s$$

$$192ft/(cos(40) * 4s) = V_0$$

$$71.97ft/s = V_0$$

$$23.99\,yds/s = V_0$$

With this information I can then find the vertical displacement of the ball.

$$y = 1/2(-9.8) * t^2 + V_0 * sin(\Theta) * t + h_0$$

$$y = 1/2(-9.8) * (4s)^2 + 71.97ft/s * sin(40) * (4s) + 0$$

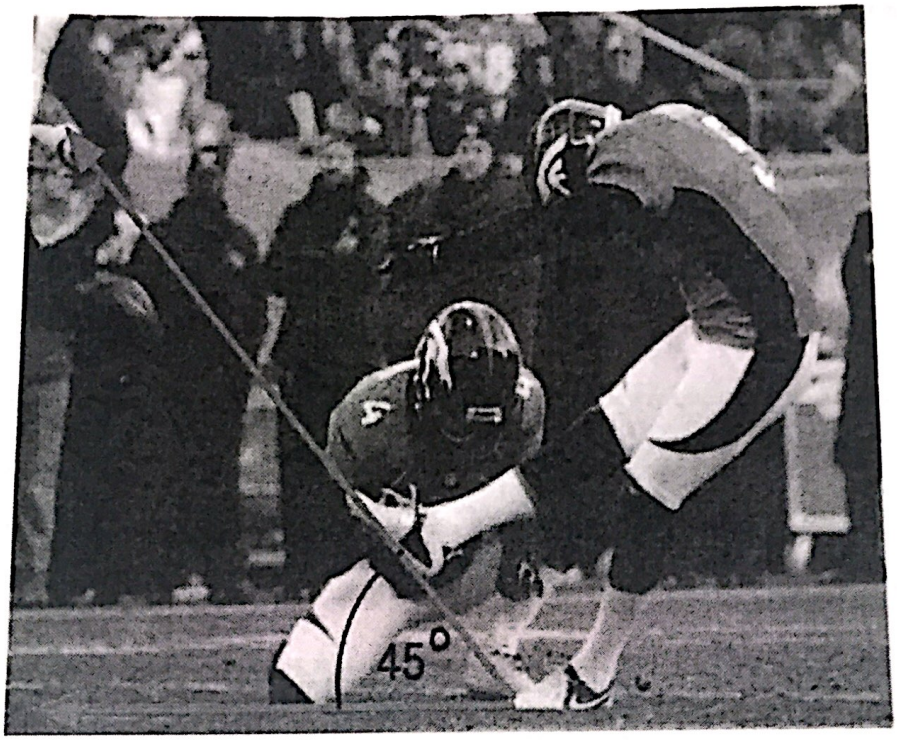
$$y = -78.4 + 214.50 + 0$$

$$y = 136.1\,ft$$

$$y = 45.36\,yds$$

Then, this knowledge lead me to wonder how far the ball would go horizontally is it was kicked at 45 degrees.

Figure 3: Matt Prater's kick at 45 degrees



$$x = V_0 * cos(\Theta) * t$$

$$x = 71.97ft/s * cos(45) * 4s$$

$$x = 151.23ft$$

$$x = 50.41\ yards$$

To find the approximate distance the ball travels horizontally with a angle of 45 degrees with the horizontal I plugged in the initial velocity I found from the initial equation and 45 degrees for Θ and 4 seconds for the time the ball was in the air. Surprisingly, I found that if Matt Prater kicked the ball at a 45 degree angle instead of a 40 degree angle the ball would have travelled 50.41 yards instead of 64 yards, and it would not have made it to the goal posts. This lead me to

wonder, why is the horizontal distance greater at 40 degrees than at 45 degrees? Is it because the 40 degrees is cIs the vertical displacement greater for 45 degrees than for 40 degrees?

$$y = 1/2(-9.8) * t^2 + V_0 * sin(\Theta) * t + h_0$$

$$y = 1/2(-9.8) * (4s)^2 + 71.97ft/s * sin(40) * (4s) + 0$$

$$y = -78.4 + 214.50 + 0$$

$$y = 136.1\,ft$$

$$y = 45.36\,yds$$

$$y = 1/2(-9.8) * t^2 + V_0 * sin(\Theta) * t + h_0$$

$$y = 1/2(-9.8) * (4s)^2 + 71.97ft/s * sin(45) * (4s) + 0$$

$$y = -78.4 + 244.96 + 0$$

$$y = 166.56\,ft$$

$$y = 55.52\,yds$$

The work above shows that when the ball is kicked at a 45 degree angle with the horizontal the ball travels a greater distance than when the ball is kicked at a 40 degree angle with the horizontal. So how much harder would he have to hit the ball in order to hit a 64 yard field goal with an angle of 45 degrees with the horizontal?

$$x = V_0 * cos(\Theta) * t$$

$$192\,ft = V_0 * cos(45) * 4s$$

$$192\,ft/(cos(45) * 4s) = V_0$$

$$91.37\,ft/s = V_0$$

$$23.99\ yds/s = V_0$$

Matt Prater would have to kick the ball with an initial velocity of 19.4 ft/sec faster than the original initial velocity.

Conclusion

So in conclusion, although Matt Prater's record breaking 64 yard field goal wasn't kicked at the ideal angle, he still kicked it with enough initial velocity to maximize the distance the ball travels horizontal. Through this exploration, I have answered many of my questions that I had about the math behind kicking a football. Although I could have furthered my exploration by finding the maximum height of the ball during its flight path, I am satisfied with my exploration and the answers that I found. These mathematical techniques could be applied to other sports and can be used to find the maximum distance a certain ball can travel.