Calculating the Optimum Punting Angle to Maximize Net Yardage

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1 Introduction

Using elementary physics, one can easily show that the optimum angle to launch a projectile in order to maximize its range is 45 degrees when air resistance is ignored. Thus when applied to a punt, the kick will travel the most distance when it is kicked at an angle of 45 degrees. However, the analysis is not the same when trying to find the optimum angle to maximize the net yardage of a punt. For instance, if the punt is kicked at a greater angle the punt will be in the air longer and will allow the kicking team to get closer to the punter and thus limit his return. However, kicking at this greater angle will also shorten the kick. I will analytically examine this compromise.

2 Calculation of Optimum Angle

When the kick is made, the kicking team will try to get to the punt returner is fast as possible to make the tackle. The returning team will of course try to block and limit the forward progress of the punting team. However, there will be some average speed that the kicking team will be running at. In this calculation, I will assume that the player on the kicking team that will eventually be making the tackle will be moving at this average speed, which I will call, v_1. Hence, this player's equation of motion is given as:

$$x_1 = v_1 t \tag{1}$$

On the other side, the punt returner will field the ball, try to find his blockers and then start moving up the field. Once again I will use his average speed, v_2, and say that he is moving at constant velocity at this average speed. It will actually be negative because he is moving opposite of the kicking team which I define to be positive. The punt returner's equation of motion is then:

$$x_2 = -v_2 t + C \tag{2}$$

where C is a constant to be used to 'calibrate' the punt returner's equation of motion with the kicking team's equation of motion. This constant, C, will account for the position coordinate of the punt returner and the time delay between the punt returner and punt time.

After the punter kicks the football at angle of θ with respect to the horizontal, the ball will be in the air for a time of $t_{air} = v_0/g\sin(\theta)$ before it is caught, where v_0 is the velocity of the football, and g is the gravitational constant. The distance it will travel before it is caught is $R = {v_0}^2 \sin(\theta)\cos(\theta)/g$. To determine the constant in (2), we say that when $t = t_{air}$, $x_2 = R$, and then solve for C, i.e., we solve the following equation for C:

$$\frac{{v_0}^2}{g}\sin(\theta)\cos(\theta) = -\frac{v_2 v_0}{g}\sin(\theta) + C \tag{3}$$

therefore,

$$C = \frac{v_0\sin(\theta)}{g}(v_2 + v_0\cos(\theta))$$

Plugging this into (2), we now have:

$$x_2 = -v_2 t + \frac{v_0\sin(\theta)}{g}(v_2 + v_0\cos(\theta)) \tag{4}$$

Thus the position of the fielding punt returner, and the delay is naturally incorporated into the above equation.

After the punt returner fields the ball, I will assume he will be governed by (4) and the kicking team will be governed by (1). When they intersect, I will assume for simplicity the tackle is made. Hence, the next step is to find the time until the tackle occurs. We thus set (4) and (1), and solve for t, which I will call t_{tack}:

$$v_1 t_{tack} = -v_2 t_{tack} + \frac{v_0\sin(\theta)}{g}(v_2 + v_0\cos(\theta)) \Rightarrow t_{tack} = \frac{v_0\sin(\theta)}{g(v_1+v_2)}(v_2 + v_0\cos(\theta)) \tag{5}$$

The net distance from the punter to the point of tackle will be (1) with $t = t_{tack}$ since the kick return team has been running from the moment the kick left his foot and stopped when the tackle was made. Thus the net distance is:

$$d_{net} = v_1 t_{tack} = \frac{v_0 v_1\sin(\theta)}{g(v_1+v_2)}(v_2 + v_0\cos(\theta)) \tag{6}$$

To find the maximum of (6) with respect to angle we solve the following equation for θ:

$$\frac{d}{d\theta}d_{net} = 0 \Rightarrow \theta = \arccos\left(\frac{\sqrt{8\,{v_0}^2 + {v_2}^2} - v_2}{4\,v_0}\right) \tag{7}$$

We see that if $v_2 = 0$ and the punt returner does not move, $\theta = \arccos(1/\sqrt{2}) = \pi/4$, or 45 degrees, so (7) is accurate in this check. However, if the punt returner does move, the net distance will depend how fast the returner is moving and thus the optimum angle depends on this also.

Of course the speed of the returner and the kicking team matter greatly. Typically these speeds are between 5 to 9 m/s. Also, the speed the football is punted also factors into the equation. If one assume that the average punt is at an angle of 45 degrees travels 45 yards or 41 meters, the speed of the kick is about 38 meters/second. Thus typical speeds are between 35 m/s to 45 m/s. If one looks at Figure 1, it can be seen that the optimum angle is within five degrees of 45 degrees and thus is not appreciably different than 45 degrees.

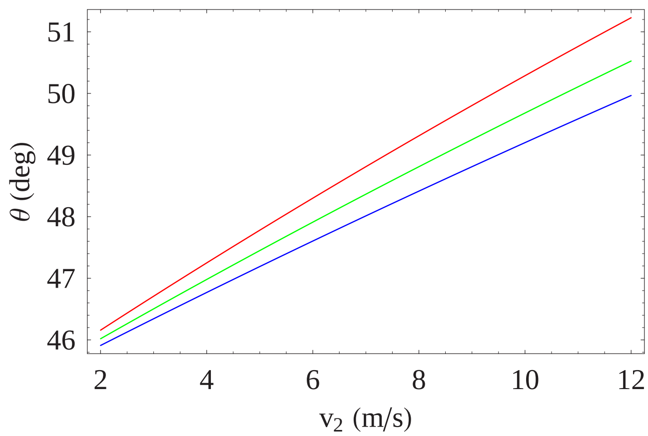

Figure 1: Plot of optimum angle versus punt return speed for different values of v_0. Red is $v_0 = 35$ m/s, green is $v_0 = 40$ m/s, blue is $v_0 = 45$ m/s.

I then looked at the difference, Δd, in return distance between the optimum angle and a 45 degree angle as a function of the return speed and the kicking team speed fixing v_0 to be 40 m/s. As can be seen in Figure 2, under the most extreme conditions, the difference on the order of a fraction of a meter (or yard), so this optimum angle makes little difference.

3 Conclusions

The optimum angle to maximize the net yardage does depend weakly on the average speed of the punt returner and the speed of the football. However, for realistic speeds, the dependence is so weak that it is very close to 45 degrees and a punter does not have tolerance when kicking to distinguish these angles. Not only is the angle extremely close to 45 degrees, if one could actually kick at that angle, the angle has almost negligible affect on the net return. Thus, to maximize net yardage, the analysis is practically the same as the maximal range angle and the punter should punt at an angle close to 45 degrees.

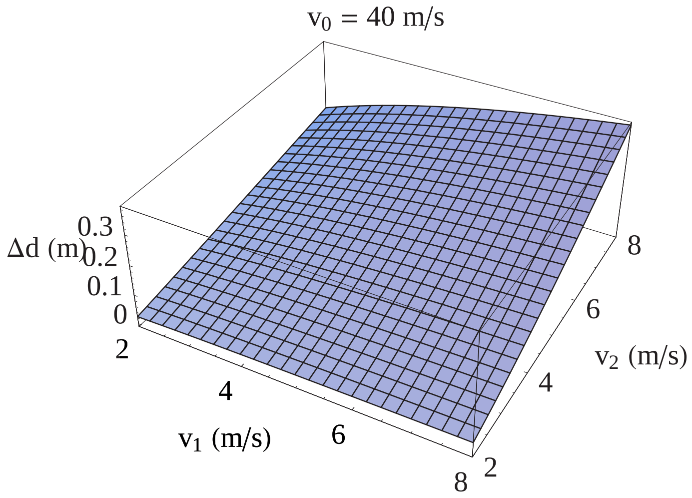

Figure 2: Plot of Δd versus v_1 and v_2 with v_0 fixed at 40 m/s.