Investigating the Range of Flight of a Kicked Football

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Abstract

In 1999 the NFL implemented standards for kicking balls, requiring 12 new footballs, each distinguishable by the marking of a ‘K’. A test for all game kicks. In doing so, the controversy of variable were footballs correlating to different flight ranges became validated. However, the standardization of the weather conditions

Design

The mechanism of the machine dealt with three equations of physics: the transfer of rotational kinetic energy, potential elastic energy, and momentum into the stationary football. The leg mechanism worked as following: an aluminum rod of 1.61 meters was mounted into another rod that ran parallel to the ground. When released from a certain height, the leg swung in a circular motion around the fixed center, thus exhibiting rotational kinetic energy (r, see equation 1). The leg was propelled by a combination of the earth’s gravitational force and the force the two springs provided from the tension of the leg being pulled back. The springs each function according to the equation \( V = \frac{1}{2} k x^2 \).

The spring constant, \( k \), for each of four springs was experimentally measured to be approximately 14000 N/m. When the leg was pulled back to its 1 meter height of release, approximately 1400 J of energy was stored in the springs. Upon release, this energy was transferred to the leg as rotational kinetic energy, ultimately increasing the speed of the leg to its maximum value (0.04 meters/second) at the moment of impact between the foot and the ball. The foot’s mass was measured to be 0.35 kg. The face of the aluminum foot made a 45° angle with the vertical and was covered with protective foam rubber. The increasing velocity of the leg and the mass of the foot carried the initial momentum that was transferred to the football after the trials were run. Finally, the leg was pulled to the height of 1 meter from the ground and then released, kicking the football. Boulevard was placed at the landing spots of each football. After a series of kicks, the ranges were measured using a 50-meter measuring tape.

Procedures

Kicking

Initially, the machine was tested outside, but varying winds and temperatures affected the path of flight of the football. To ensure as consistent as possible the machine was moved into DePauw University’s indoor track and field facility. Before every day’s trials the temperature and humidity were recorded. The machine was stabilized by using metal rings under each roller of the four times; the pressure of each football was standardized using a Tachihara Ball Pressure Gauge with a 0.05 pounds/inch\(^2\) psi resolution; the ball’s temperature was recorded using a Raytek Mini\(^{\circ}\) infrared thermometer.

The test procedure was kept consistent for each day’s trials. Finally, the leg was pulled to the height of 1 meter from the ground and then released, kicking the football. Boulevard was placed at the landing spots of each football. After a series of kicks, the ranges were measured using a 50-meter measuring tape.

Procedures were altered testing multiple variables such as:

- The height of the leg’s release point was varied between 0.5, 0.8, 0.6, 0.4 meters
- The leg speeds and ranges measured at each height
- The football’s air pressure was changed from 26 psi to 5 psi in increments of 3 psi
- The ranges of a football kicked on its seams, panel, and laces
- The position of the tee was altered to find and test the different launch angles and the footballs respective ranges
- By use of a freezer, the footballs’ temperature range to values below -15°C
- We later simulated a half of a football game, the room temperature footballs were rotated between the freezer and being kicked for a period of an hour
- Ranges of a kicked weathered, slightly worn, and brand new football tested.

Restitution

The footballs were dropped from a height of 1.0 meter and were recorded using a video camera to measure the rebound height of the ball. Variables in pressure, temperature were tested. The coefficient of restitution is simply the ratio of rebound height to initial height.

Results

Seams, Panel, Laces

A clear trend was observed: on average the balls kicked on the laces were roughly 1-3 meters shorter than the balls kicked on the panel or seams. No difference was observed between the ranges of the panel and seams kicks.

Height of Leg Release

In hopes of displaying the consistency of the machine, the leg was pulled back to different heights and the ranges and leg speeds were recorded. The results (Figure 1) clearly showed a very low error in the linear correlation between leg speeds. The ranges of the kicks displayed a similar linear correlation.

Launch Angle

The results showed that between the range of 50° and 55° the range was the greatest. The resulted correlation between points was observed to be parabolic in nature (Figure 2). Consequently, the tee was positioned further away from the foot to increase the angle, the results kicks became more inconsistent.

Pressure

The tests of various pressures showed only a slight decrease in range (0.1% per pound/\(^2\)) between the different pressures (Figure 3). Note that the error bars over lay suggesting that there may not be a pressure effect.

Temperature

A linear correlation was observed in both graphs that were produced. (Figures 4 & 5) Because of varying methods to vary the day load discussion on wear below), a control ball was used to normalize as a basis. The normalized value shows that when a football was at the temperature of -17°C, the distance traveled was approximately 10% less than the normalized range at 25°C.

Restitution

When the pressures were varied, the coefficient of restitution was directly proportional to the pressure (Figure 6). The higher pressure football rebounded highest and the lower pressure rebounded the lowest. This was not observed in the kicked football results (see Figure 3). However, when the temperature was varied, the results were similar to the kicked football series. The graph shows a linear relationship for the restitution versus the temperature.

Wear

Testing the wear showed that the NFL needed to standardize the kicking balls used in game play. The new footballs, compared to the old footballs, showed the same effect as a ball being drilled to a temperature of roughly -17°C. Furthermore, the three footballs of the wearing seams, brand new, slightly worn, and weathered, showed different ranges; the greatest being the weathered and the least being the brand new. (Figure 7)