The So-Called Unpredictable Pitch; The Knuckleball

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This experiment explores the motion of a knuckleball during its flight path to home plate. Using a device called a Rapsodo, the flight path was characterized into distinct features including speed, spin rate, true spin, horizontal and vertical break, and the axis that the ball spins on. Using volunteers from the Wooster baseball team and myself, pitches were thrown with the exact same baseball off of a portable mound indoors. Using the same baseball eliminated possible discrepancies from the Magnus force related to seam height and being indoors eliminated wind. Using the data from the Rapsodo, it was found that the break or movement on the pitch is directly related to its spin axis and its vertical and horizontal components of spin. However, the speed of the pitch had no correlation with the break of the pitch.

I. INTRODUCTION

The sport of baseball is known as America's pasttime but has lately been called boring because of its slow pace of play. Although the pace is slow, over the past decade players, coaches, and scouts have been obsessing over speed. Not just speed as a runner, but bat speed through the zone, and most importantly for pitchers, pitch speed. In modern day baseball, the average fastball is thrown at 95 miles per hour and guys like Aroldis Chapman of the New York Yankees have thrown fastballs that reach 105 miles per hour. We call guys like this flamethrowers. Previously pitchers such as Nolan Ryan and Bob Feller were rare because they threw so hard, but today they would be your average everyday pitcher. The obsession with spin rate, or how much the ball rotates before it reaches home plate has taken over the game. Pitchers obsess over spin rate because it increases speed and deception and makes it harder for a hitter to pick up the ball out of the pitcher's hand.

What if I told you that a fastball like this was not the hardest pitch in baseball to hit? You would think I'm crazy saying that hitting something traveling 100 miles per hour over a distance of 60 feet six inches is not the hardest thing to hit. You might guess a curveball or a slider or even maybe a changeup because of the break or change of speeds, but you would still be wrong. All of these pitches have spin which makes the movement of the ball more predictable.

What the average person who does not watch a lot of baseball does not know is that there actually is a pitch out there that has little to no spin and is called the knuckleball. The knuckleball was first brought to baseball in 1908 and cannot be credited to one single person, but most believe Eddie "Knuckles" Cicotte was the first to bring this pitch to the major leagues [1]. The knuckleball is also referred to as the floater because it is thrown much slower than other pitches coming in to a hitter at approximately 60 miles per hour. The ball has little to no rotation and looks like a good hitting pitch and a hitter licks their chops as they see the ball floating to the plate. But a knuckleball moves back and forth and appears to wobble or dance as it makes its way to the plate. The dancing of the pitch makes it different than any other pitch because it appears that the ball will stay straight, but it dances back and forth confusing the hitter and causes the hitters to swing and miss. Sometimes the catcher does not catch the ball because the movement is so drastic. It is thrown differently than other pitches because rather than pulling down on the seams to create spin, the pitcher digs their fingernails or knuckles into the seams [1]. Rather than whipping their arm through to create more speed, a knuckleball ball is almost pushed from the shoulder like a shot put and the fingers are extended off of the ball upon release which leads to relatively no spin on the ball.

If the pitch is so hard to hit and has been around for over a century, then doesn't every pitcher have this pitch in their arsenal? Not only is it hard to hit and catch, but the pitch is hard to throw and even harder to throw for strikes. Major League teams take chances on guys that throw this pitch, and there are few and far between that can throw it accurately. In the last century there have only been a handful of guys who have been able to throw it for strikes; Phil Niekro, Charlie Hough, Tim Wakefield, R.A. Dickey, and Steven Wright are the only notable guys who have lasted in the Major Leagues with the ability to throw the knuckleball. Knuckleball pitchers are an enigma and should not be taken for granted because the rarity of the pitch is what makes baseball such a beautiful game. Sometimes the guy that does not throw the hardest or may not be the best overall athlete might have the best pitch in the game, a pitch that has confused hitters and scientists for decades.

II. THEORY

In order to understand the knuckleball, many different factors must be taken into account. During the experiment a device called a Rapsodo, which can be seen in Fig. 1 was used and was able to take data that would be hard to precisely calculate. It was able to analyze a pitch thrown and spit back out information such as spin rate, true spin rate, velocity, horizontal and vertical break, spin efficiency, and spin axis. The spin rate of a pitch

FIG. 1: The Rapsodo 2.0 pitching device. The Rapsodo includes the protective casing as well as a camera and tripod inside of the casing. The camera connects to an internal computer that reads the pitch data from the camera and reports it to an iPad for further analysis. Image found from [2]

is described as the rate at which a ball spins during its flight to home plate. As a baseball travels in its path to home plate the ball can spin in multiple directions. It can spin vertically, diagonally and horizontally and the spin rate measures all of these components into one. The true spin rate is a bit different as it measures the spin directly impacting the movement of a pitch. This spin can also be known as useful spin or rifling and is the spin perpendicular to the flight of the ball. The true spin takes only the spin that actually makes the ball move horizontally or vertically during its path and gives that number back in RPM as well. The true spin value that was given back was not always the same as the spin rate and that's how the spin efficiency of the pitch was determined. The spin efficiency measured the ratio of the true spin to the spin rate and the percentage found from that determined how much of the spin was directly impacting the movement

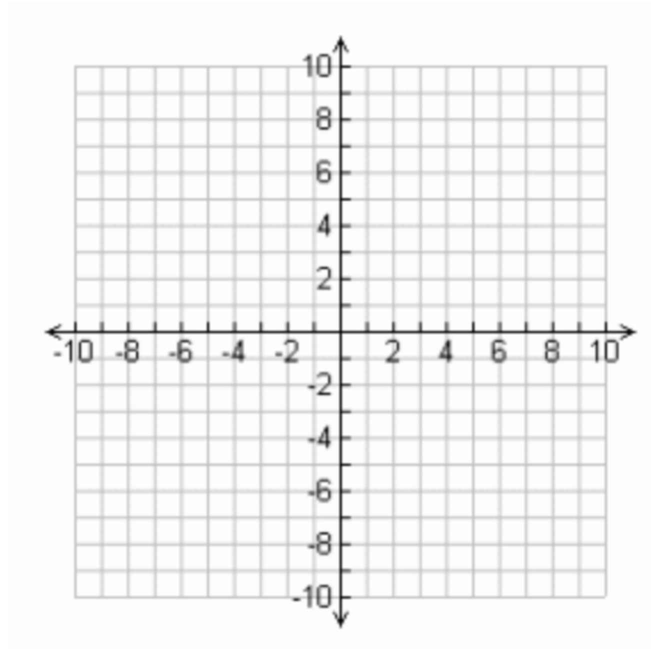

FIG. 2: Orientation for horizontal and vertical break. The figure shows that anything that is to the right or up is positive and anything to the left or down is negative. This is the orientation that was used for the horizontal and vertical breaks and spins. All directions are from the perspective of the pitcher.

of the pitch.

The horizontal and vertical break of the ball is how far the ball moves left or right or up and down during its flight path [2]. However, it is not so simple, the Rapsodo measures this value based on the release position of ball with respect to the pitching rubber. The break in both directions is measured from a reference point that is based on if the ball were to travel completely straight with no spin. For example, if a ball was released three inches from the right side of the rubber at a height of four feet, a ball with no spin would travel the full sixty feet six inches without moving horizontally or vertically besides the effect that gravity has on the ball. So if the same pitch was thrown with spin and moved four inches to the right (from the perspective of the pitcher), and down four inches then the horizontal break would be positive four inches and the vertical break would be negative four inches. Negative horizontal break would stem from the ball breaking to the left from the pitcher's perspective.

However, some challenges arose when trying to compare the break of the pitches with only using spin rate and true spin. The true spin combined both vertical and horizontal spin into one component. To make it easier to compare the data, the spin axis from the Rapsodo data was applied. However, the data was given in terms of time, which sounds weird but in baseball the spin of pitches is usually related to an analog clock face. Most curveballs thrown by pitchers are referred to as 12-

6 curveballs because of the way they break. They start at 12 on the clock and drop straight down to the six on the clock face. However the zero degree mark for this is actually located at the top of the circle so a zero degree spin axis would be located at 12 on the clock rather than the 3 o'clock position it is normally at. To make this value easier to use for plots, the time was recorded in Igor and was converted to degrees using

$$\Theta_{Spin} = \frac{\left(H + \frac{M}{60}\right)}{12} \times 360. \quad (1)$$

H in the equation was the value given for hours and M is minutes and using this value the spin axis, Θ_{Spin} was obtained in degrees. This value becomes very useful in separating the spin obtained horizontally and vertically from the true spin, ω_{true}. Using the newly found spin axis, the value for the horizontal spin ω_{horiz} was obtained by

$$\omega_{horiz} = \sin\left(\Theta Spin \times \frac{\pi}{180}\right) \times \omega_{true}. \quad (2)$$

And similarly, the vertical spin, ω_{vert}, was found using

$$\omega_{vert} = \cos\left(\Theta Spin \times \frac{\pi}{180}\right) \times \omega_{true}. \quad (3)$$

Now the spin is broken down into two components and can be compared with the horizontal component with the horizontal break and the vertical component with the vertical break. The spin axis is kind of tricky to explain without including the magnus force. The magnus force is described as the spin of the ball moving the ball from its original flight path [4]. Let's say that a right handed pitcher throws a slider to a right handed batter. The ball will originally start on its path and appear that it will hit the batter. However, the spin on a slider will cause the ball to move away from the hitter and into the strike zone. Another way to explain the magnus force with respect to picthing is that the ball always follows its nose. If the nose of the ball is spinning to the left the ball will break left. If the nose is spinning with top spin the ball will move downwards and so on.

III. PROCEDURE

An initial group of volunteers, who also happen to be my baseball teammates were brought together in an indoor environment and I initially showed them how I wanted the knuckleball to be thrown. Each knuckleball was thrown across the big four seams of the ball which can be seen in Fig. 3. I played catch with them and personally caught their attempted knuckleballs to see if they could even throw one that had the desired dancing effect. The orientation of the ball used in Fig. 3 was something that was necessary to be controlled so that the values produced by the Rapsodo were consistent and could easily be interpreted. After weeding out the bad knuckleballers,

FIG. 3: Baseball gripped across four seams. This exact grip is used for a four seam fastball and is called a four seam because when the ball is thrown, the ball spins in a way in which four different parts of the ball with seams can be seen. In this experiment the pitchers dug their fingernails into these seams and attempted to throw the ball with relatively no spin [3].

I got approval to use the Rapsodo from one of my teammates who actually owned the device and began setting up the experiment. A portable pitching mound was set up indoors to eliminate any affect that wind would have on the ball. From the front of the pitching rubber on the mound, a measuring tape was taken out to 60 feet six inches and the back of home plate was placed at this distance. This is the distance that high school, collegiate and professional pitchers throw from. The Rapsodo device containing the camera and the internal computer was taken out to 15 and a half feet in front of home plate and placed on the floor directly in line with the pitchers mound. After calibrating the device and syncing the camera and internal computer to an iPad with the Rapsodo pitching application, the device was set to record knuckleballs. Each pitcher used the exact same baseball as well because the height of the seams on a baseball does have an affect on the movement of a pitch [4].The volunteers then began throwing ten knuckleballs at a time before switching to the next volunteer. When the Rapsodo was ready for a pitch to be thrown, a green light would show above the camera indicating to the pitcher that the device was ready for the next pitch. When the pitch was thrown a blue light would appear above the camera indicating that the Rapsodo was analyzing the data from the pitch and all the data would show up on the iPad for immediate feedback on that pitch.

After the session was complete, the data were synced to a cloud and a bullpen report was created and showed all the results in one document. These results included everything measured by the Rapsodo and were sorted by each pitch. The data were then manually entered into Igor pro and different color scale graphs were produced with different axis each time to see if any of the data had correlation. The experiment was repeated with the same mound, ball, and test subjects on a later date and another bullpen report was produced and added more

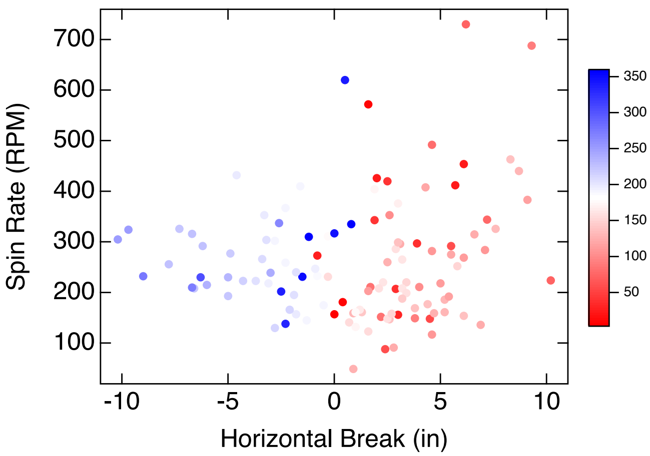

FIG. 4: Graph of spin vs horizontal break. The data points on the graph are all scattered and were set to a color scale function that depends on the spin axis, Eq. 1. The plot shows no correlation between spin and horizontal break and no correlation between the two with respect to the spin axis.

data to be analyzed.

IV. RESULTS AND ANALYSIS

Once all of the bullpen sessions were complete, the data was synced to the cloud and bullpen reports were generated. Over 400 knuckleballs were thrown, but only 124 pitches registered with complete data. The large number of pitches that did not register were due to some of the pitches being so wild that the camera was not able to track the ball throughout the entire course of the flight. The other pitches not registering were due to the pitches not being thrown with enough speed for the Rapsodo to read. For the 124 pitches that did register, the data was manually inputted into Igor and were plotted to find correlation. I was looking for correlation in the spin rate and true spin rate with the horizontal break because I wanted to find out if the spin had any relation to the dancing of the knuckleball.

The spin rate was first plotted against the horizontal break which can be seen in Fig 4. At first I thought the spin rate would contribute the most to the horizontal break because in my personal experience as a pitcher, I have heard that spin rate is the most important aspect to movement. After all, there is more correlation between spin rate and swings and misses by hitters than there is between speed and swings and misses [2]. However, the plot shows that there is almost no correlation as the points are all over the place. Even when set to color scale with the spin axis of the ball, the points are scattered. The color scale function was used for all of the graphs and set to the function of the spin axis. The spin axis was chosen for the spin axis because each of the graphs excluding Fig. 9 were dependent on the orientation of

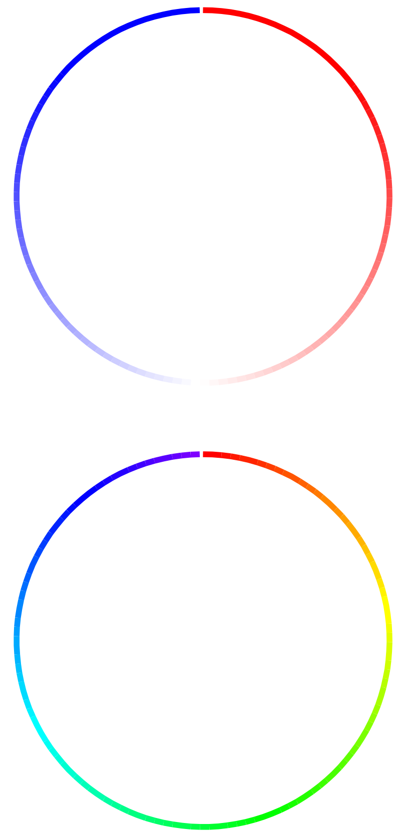

FIG. 5: Color Scale function for spin axis. In the figure 0 and 360 degrees are at the top of the circle and increase in a clockwise fashion. In the top figure the colors for 180 are white and the top figure can be applied for Fig. 7, 8. The multicolored circle can be applied to Fig. 4, 6

spin. Some of the pitches with similar spin axis, such as the light green points on the graph, differ in spin rate from 45 to 400 RPM and the horizontal break has upwards of five inches down to less then one inch of break which can be seen in Fig 4. A useful figure to show how exactly the color scale function was applied can be seen in Fig. 5 where the circles are oriented like a clock face and the spin axis can be understood clearly.

Still focused on how spin affected the horizontal break, the true spin of the pitch was next to look at. After finding no relationship between spin rate and horizontal break, I figured that true spin must correlate because the true spin of the pitch is the spin that directly impacts the break of the pitch. Using the color scale function, the plot was set to show the dependence on spin axis. Because the spin axis ranges from zero to 360 degrees, the points that are dark red and dark blue are very similar in spin axis. However, the data are still scattered and show no relationship between true spin, horizontal break, and spin axis. After some thought and discussion, I came to the realization that the true spin was actually spin that combined the vertical and horizontal components of

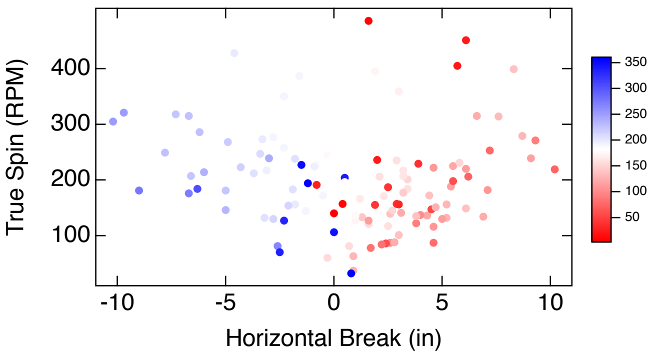

FIG. 6: Graph of true spin vs horizontal break. The graph was set to a color scale function that also depended on the spin axis, but again showed no relationship. The true spin is the spin that directly impacts the movement of the pitch, but the values obtained show a scatter plot that show the break of a pitch with a true spin of 400 RPM can be the same as pitch that has a true spin less than 50 RPM.

true spin. This epiphany lead to splitting the true spin back into its components and plotting those against their respective breaks which can be seen in Fig 7, 8.

The components of the true spin were quite simple to calculate using Igor. The spin axis first had to be calculated from the data produced by Rapsodo. The Rapsodo produced the spin axis in terms of an analog clock face from the pitchers perspective which was converted to degrees using Eq. 1. From the spin axis, Eq. 2, 3 were used to determine the true spin components in radians per second. With these new values, I plotted the horizontal true spin vs the horizontal break which can be seen in Fig. 7.

The data appeared to correlate but just as a check, the vertical components of true spin and break were plotted against each other in the same fashion that the horizontal components. It can be observed in Fig. 8 that the data again correlated with a positive slope. The color of the markers depended on the spin axis where the dark red and dark blue markers were similar due to the angle of the spin axis being close to zero and 360 degrees and also when they are close to 180 degrees the markers are very light in color and almost appear white because the spin axis values are similar. The size of the markers for both Fig. 7, 8 depended on the speed of the ball and show that the speed of the knuckleball has no impact on either the vertical or horizontal break. However, what can be related is the negative values for both horizontal and vertical true spin can be associated with negative break in both directions. And the positive values of the true spin components are directly related with positive break upwards or to the right. To further prove the point that speed has no impact on the break of a knuckleball, the speed was plotted against the horizontal break. Looking at Fig. 9, it can be seen that the horizontal break has no dependence on the speed. On the right side of the graph, two of the light blue points appear to have a small value for horizontal break close to one inch but one of the speeds is under 48 miles per hour while the other is close to 60. The only relationship that can be observed from the graph was when the color scale function was applied with respect to the horizontal true spin, ω_{vert}. The values of ω_{vert} increased from left to right which further show the relationship expressed in Fig. 7 that the horizontal break depends on the horizontal true spin.

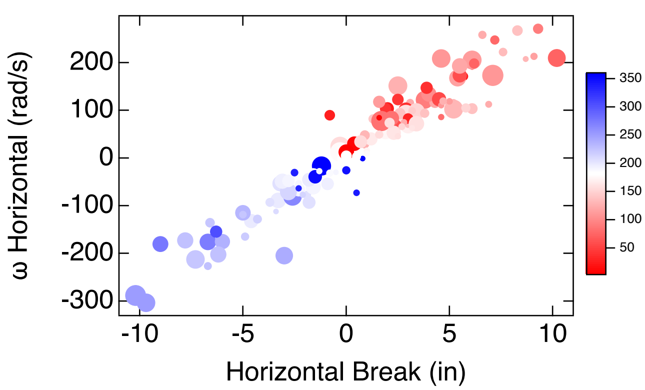

FIG. 7: Graph of horizontal true spin vs horizontal break. A correlation was finally found, as we can observe that the data points appear to have a positive slope. The negative horizontal break relates to a negative horizontal true spin and positive horizontal true spin to positive horizontal break. The color scale function depends on the spin axis where dark red and dark blue are close in value to the spin axis and appear to have small positive and negative values of horizontal break. The size of the markers depends on speed where the bigger dots are a greater value of speed.

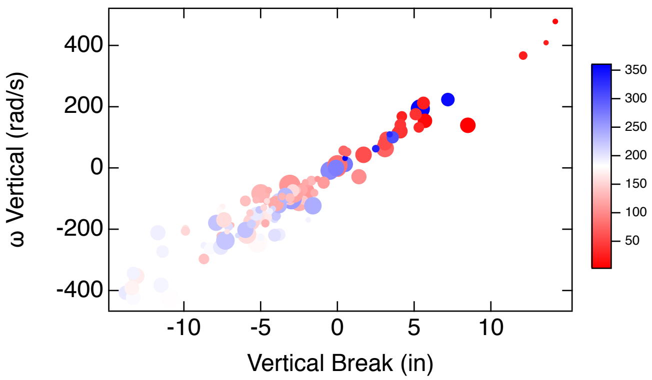

FIG. 8: Graph of vertical true spin vs vertical break. The graph shows the vertical true spin and vertical break and how they depend on each other as well as being dependent on the spin axis via color scale.

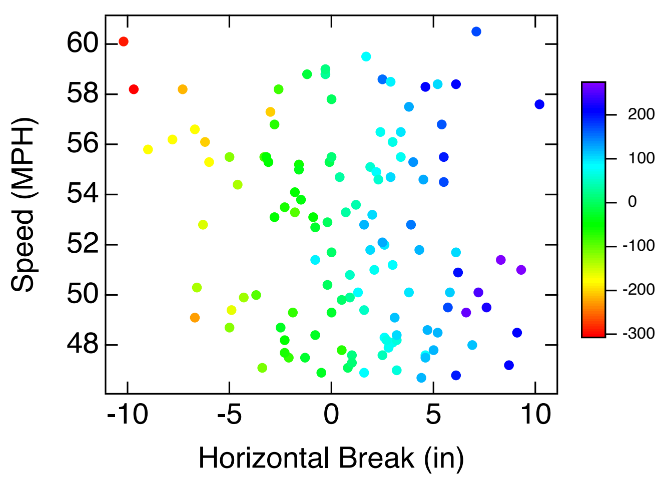

FIG. 9: Graph of speed vs horizontal break. There is no relationship between speed and horizontal break of a knuckleball as we can see from the graph. When the color scale function was applied once again, but this time using the horizontal component of true spin, the relationship between the true spin and horizontal break showed up once again.

V. CONCLUSION

The experiment was set out to find the relationship between the limited spin on a knuckleball and the resulting pitch break that occurs. It was found that any horizontal spin on the ball directly correlated to the horizontal break of the pitch[5]. When the ball was spinning to the left, the ball broke to the left and when spun to the right it broke to the right from the the pitcher's perspective. The same relationship appeared when analyzing the vertical break. When the ball had top spin it broke downward and it moved slightly upwards with backspin. Some things that can affect the break of other pitches such as sliders and curveballs are the speed of the pitch, but for knuckleballs the speed had no direct relationship with the amount of vertical and horizontal break of the pitch. One of the more interesting phenomena of a knuckleball is the dancing effect that occurs on its path. The ball moves both left and right during its path which made it hard to analyze this motion as the Rapsodo was took data for the horizontal break over its entire path and not at each position of the ball while it was in the air. If there was a device out there that could track the motion of the ball at different points in its path while giving the same data feedback that the Rapsodo was able to give, this phenomena could be studied in greater detail. For now we have much more to learn about the knuckleball but the unpredictable pitch became a little more predictable.

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